Waves

What is a Wave?

When waves move through a substance, they only move the
the substance backwards and forwards (longitudinal) or side to side (transverse) as the wave passes.
After the wave has gone, the particles of the substance are back where they started but energy has
been carried by the wave from its origin (where it begins) to its destination (where it finishes).

One type of wave (an electromagnetic wave) does not need any substance to get from its origin to its destination. It can travel through a vacuum (nothing). Electromagnetic waves can travel from stars to planets through empty space (space is a vacuum).

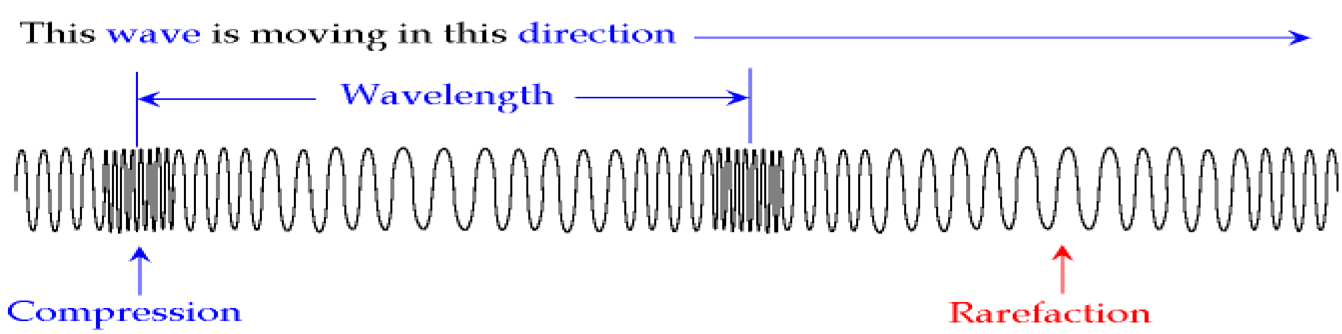
What does a Wave do?

Waves transmit energy without transmitting matter.

This means that waves can move energy (or information) from one place to another without moving any substance (stuff) from one place to another. The amount of energy that a wave has depends on its amplitude.

What is a Longitudinal Wave?

When a longitudinal wave moves through a material, the particles of the material move backwards and forwards along the direction in which the wave is travelling. Below is a picture of a longitudinal wave travelling along a spring.



What is the Wavelength of a Longitudinal Wave?

The wavelength of a longitudinal wave can be measured as the distance between the centre of two compressions.

What is Compression?

Compression is the name given to the region where the coils of the spring are pushed together.

What is Rarefaction?

Rarefaction (pronounced rair - ree - fac - shun) is the name given to the region where the coils of the spring are pulled apart.

It is difficult to show the amplitude and frequency of a longitudinal wave on a picture.

Examples of longitudinal waves are
P waves from earthquakes and sound waves.

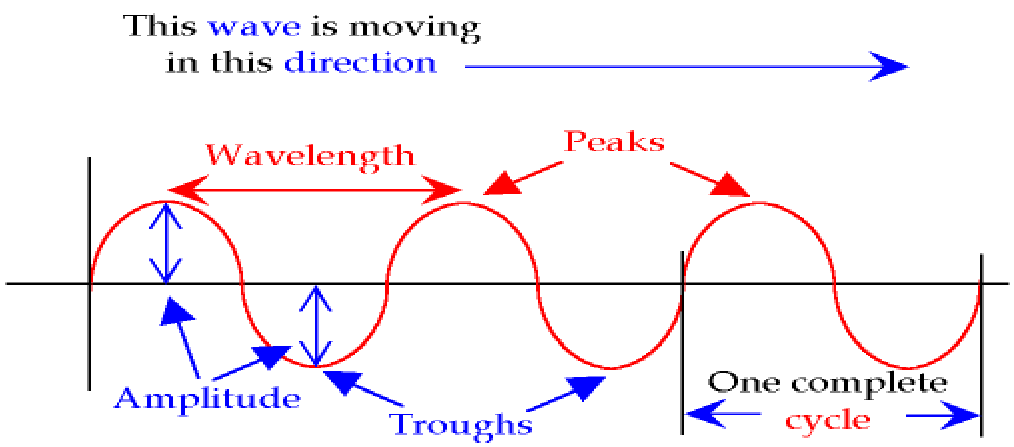
What is a Transverse Wave?

All of the waves that you will meet on your course are transverse except sound waves and P waves from earthquakes.

When a transverse wave travels through a substance, the particles of the substance are moved at right angles to the direction in which the wave is traveling. The particles either move up and down or from side to side as the wave goes past (like waves on the surface of the sea). After the wave has gone, the particles are back where they started.

Electromagnetic waves are transverse waves that do not need a substance to travel through (continued).

Below is a picture of a transverse wave.



What is the Wavelength of a Transverse Wave?

The wavelength of a transverse wave is the distance between two peaks or the distance between two troughs.
Wavelength can be defined as "the distance the wave has traveled during one complete cycle".
Wavelength is given the symbol λ. This is the Greek letter lambda, pronounced lam-der.
Wavelength is measured in metres because it is a distance.

What is the Frequency of a Wave?

Frequency is defined as "the number of complete cycles (complete waves) in one second".
Hertz is the unit of frequency (symbol Hz).
1 Hertz = 1 cycle per second.

What is the Period of a Wave?

The period of a wave is defined as
"the time taken for one complete cycle".

The period = 1 ÷ frequency.

This can be rearranged to give
Frequency = 1 ÷ period.

What is the Amplitude of a Transverse Wave?

The amplitude of a transverse wave is measured from the peak (or trough) to the mid-point.
Amplitude can be defined as "the maximum displacement from the average position".
Amplitude is a measure of how much energy the wave has.

What is the Wave Equation?

The only equation you need for waves is Velocity or Speed = Frequency x Wavelength $v = f \times \lambda$

This equation is important!

The equation can be rearranged to give $f = v \div \lambda$ or $\lambda = v \div f$

See the next page for worked examples.

Q1. A sound wave has a frequency of 3250 Hz and a wavelength of 0·1 m. What is its velocity?

A1. Use $v = f \times \lambda$

$v = 3250 \times 0{\cdot}1$
$= 325$ m/s.

Q2. A sound wave travels with a velocity of 330 m/s and has a frequency of 500 Hz. What is its wavelength?

A2. Use l = v ÷ f

□□□ = 330 ÷ 500
= 0·66 m.

Q3. A wave at sea travels with a velocity of 25 m/s.
If it has a wavelength of 10 m, what is its frequency?

A3. Use f = v ÷ l

$f = 25 \div 10$
$= 2{\cdot}5$ Hz.

Note - always make sure that you give the units for your answer

and that the units are correct.
If the wavelength is given in centimetres, convert it to metres before doing the calculation.

Revision Questions

Longitudinal - Transverse - Amplitude - Wavelength - Frequency

What do Waves do?

Describe the movement of Particles in a Longitudinal Wave.

Give an Example of something which travels as a Longitudinal Wave.

Describe the movement of Particles in a Transverse Wave.

How would you measure the Amplitude of a Transverse Wave?

What does the Amplitude tell you about a Wave?

How would you measure the Wavelength of a Transverse Wave?

What Unit is Wavelength measured in?

Define Frequency.

What Unit is Frequency measured in?

What is the Period of a Wave?

Give the Equation which connects Period and Frequency.

Give the Equation which connects Velocity, Frequency and Wavelength.

What Velocity has a Wave with Frequency 3250 Hz and Wavelength 0·1 m?

What Wavelength has a Wave with Frequency 500 Hz and Velocity 330 m/s?

What Frequency has a Wave with Wavelength 10 m and Velocity 25 m/s?

What is a Sound Wave?

Sound is a longitudinal wave that can travel through gases (air), liquids (under water) or solids (the Earth). Sound cannot travel through a vacuum.

What is the Speed of a Sound Wave?

The speed of a sound wave depends on the density of the medium (substance) through which it is travelling. The more dense the medium, the faster the sound wave will travel. Sound waves travel faster through the Earth than under water, and sound waves travel faster under water than in air.
The speed of sound in air is approximately 330 m/s (see calculations). Sound waves travel much more slowly than light waves.

How are Sound Waves made?

When an object vibrates (moves backwards and forwards) in air it produces sound waves.
The sound waves carry energy which can move other objects, such as the ear drum or a microphone diaphragm.
The sound wave will have the same frequency as the frequency of the vibrating object that made it.
The object may be a column of air (a flute, clarinet or a whistle) or a string (a guitar, violin, double bass or a piano) or a paper cone (loudspeaker) or a firework.

Sound waves can be reflected, refracted or diffracted.

What is the Loudness and Pitch of a Sound Wave?

What is the Loudness of a Sound Wave?

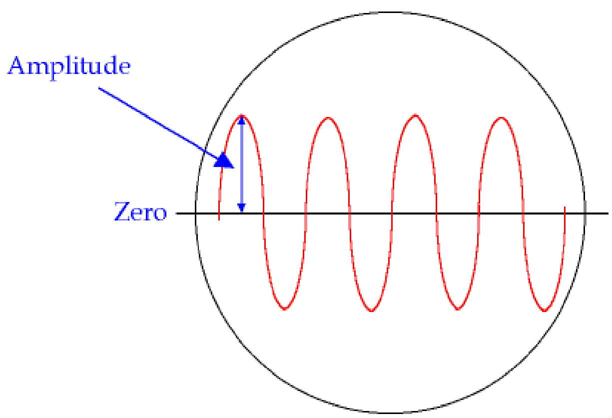
The loudness of a sound depends on the amplitude of the wave. The bigger the amplitude, the louder the sound.

What is the Pitch of a Sound Wave?

The pitch of a sound (how high the note is) depends on the frequency of the wave. The higher the frequency, the higher the pitch.

Sound is a longitudinal wave and so it is difficult to show the amplitude and frequency on a diagram.
A microphone can change the sound wave into an alternating current that can be displayed as a transverse wave on a CRO. This makes it easier to show the affect of amplitude and frequency on loudness and pitch (see the next page)

How do Amplitude and Frequency affect the Loudness and Pitch of a Sound Wave?



What is an Echo?

Sound that has been reflected is called an echo. Sound reflection best occurs from flat, hard surfaces.

The natural echo of a room is called reverberation. Reverberation is a measure of how much the sound is reflected around the room. Materials that are soft and uneven (like curtains, carpets and cushions) absorb sound much more than they reflect it, and decrease reverberation.

Reflected sound (as ultrasound) is used for range and direction finding, scanning and cleaning.

What Sound Frequencies are Heard by Humans?

Sound frequencies between 20 and 20,000 Hz can be heard by people. As people get older the higher frequencies become more difficult to hear.

Hearing can be damaged by being close to very loud sounds over a long period of time. Hearing very loud machinery or music when you are young can result in less sensitive hearing when you are older.

Unwanted sound is sometimes called noise pollution. Noise pollution can cause serious distress. If you live in a noisy environment, for example near an airport or railway, the noise that you hear can be reduced by double glazing. If someone is working with noisy power tools, for example a drill or a saw, they can wear ear defenders. Ear defenders look like headphones or ear muffs.

Infrasound and Ultrasound.

Sound with a frequency lower than 20 Hz is called infrasound. These very low frequency sound waves can be given off by volcanoes and meterorite explosions. Infrasound is used by some large animals for communication. Whales can communicate over hundreds of miles using infrasound.

What is Ultrasound?

Sound with a frequency higher than 20,000 Hz is called ultrasound. Ultrasound echoes are used in Scanning and Range and Direction Finding.

Ultrasound in liquids can be used to clean precious or delicate items because the compressions and rarefactions of the ultrasound will shake dirt and unwanted material free without the risk of damage being caused by handling the item.

What are the Uses of Ultrasound?

Ultrasound is used for scanning, range and direction finding and cleaning.

What is Ultrasound Scanning?

When ultrasound is directed at the human body, the surfaces of different tissues inside the body partly reflect the ultrasound. A detector will receive ultrasound echoes at different times, depending on how deep inside the body the tissue surfaces are.

The detector produces electrical signals that are sent to a computer and then displayed on a screen as a picture. This is a clever way of "seeing" inside a body without causing any damage.

Ultrasound scans can safely be used to see an image of a developing baby inside the uterus of a pregnant mother. This is called "fetal imaging" or "pre-natal scanning" and is useful to show if the baby is healthy.

A similar technique can be used in industry to show cracks or flaws inside metal objects.

What is Range and Direction Finding?

The difference in time between emitted and reflected ultrasound waves can be used to show how far away the reflecting surface is.

A boat on the sea can send a beam of ultrasound down to the sea floor where it is reflected back upwards to a detector on the boat. If both the speed of sound in the water and the time taken for the ultrasound echo to get back to the boat are known, then the depth of the sea water at that place can be calculated since distance = speed x time.

Ultrasound can be used by fishing boats to find fish since a shoal of fish between the boat and the sea floor will return the echo more quickly.

Bats use ultrasound echoes to build up an image of their environment in darkness.
They can locate insects for food in the air and know their speed and direction by analyzing the reflected sound.

Other uses of ultrasound are scanning and cleaning.

What is Light?

Light is a transverse wave.
It is one part (region) of the electromagnetic spectrum.
Light is the visible region, it is the part used by our eyes to see.
Like any electromagnetic wave, light can travel through a vacuum.
Light travels through the vacuum of space from the Sun to the Earth.

What is the Speed of Light?

Light travels very quickly. There is nothing that can travel faster. The speed of light is 300,000,000 m/s in air (that is 300 million metres per second - not easy to imagine!).
The speed of sound in air is approximately 330 m/s, so light is almost one million times as fast.

You can sometimes notice that light is travelling faster than sound. In a storm, the light and the sound are generated at the same time but you see the lightning flash before you hear the sound.
The light has travelled to your eyes more quickly than the sound has travelled to your ears from the same origin.

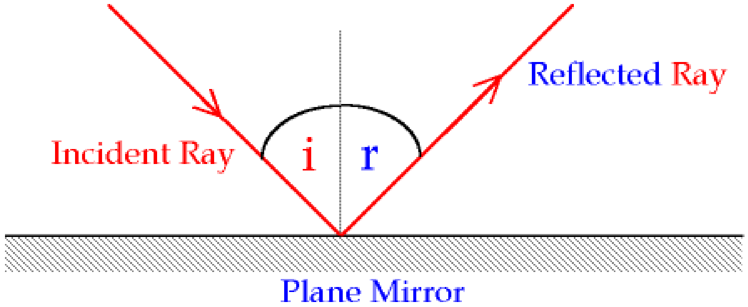
What is a light year?

In one year, light has travelled ten thousand billion kilometres. This very large distance is called a light year and is used by astronomers to measure the vast distances between stars and galaxies.

What is Reflection?

Any type of wave can be reflected. We shall look at the reflection of Sound, Water and Light Waves.
Reflection best occurs from flat, hard surfaces. After reflection, a wave has the same speed, frequency and wavelength, it is only the direction of the wave that has changed.

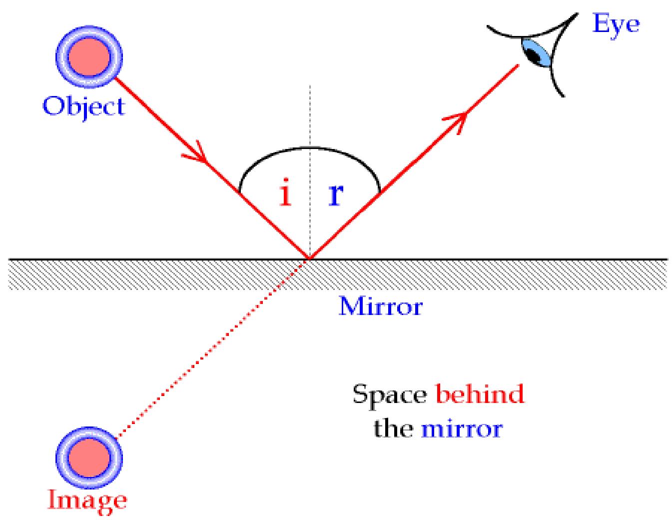
For light (and other electromagnetic radiation) a flat shiny surface, like a plane mirror, is a good reflector.
A plane mirror is one that is straight and not curved.



The light ray that hits the mirror is called the incident ray.
The light ray that bounces off the mirror is called the reflected ray.
The angle of incidence equals the angle of reflection, $i = r$.
This means that whatever angle the light ray hits the mirror, it will be reflected off at the same angle (like snooker balls bouncing off a cushion).

If the surface of the mirror is not smooth but rough or bumpy, then light will be reflected at many different angles.
The image in the mirror will be blurred and unclear.
This is called diffuse reflection (continued).

When you look into a mirror, you see a reflection that is an image of the real object.



The image appears to be the same distance behind the mirror as the real object is in front of it.
This is because the brain thinks that light travels in straight lines without changing direction.

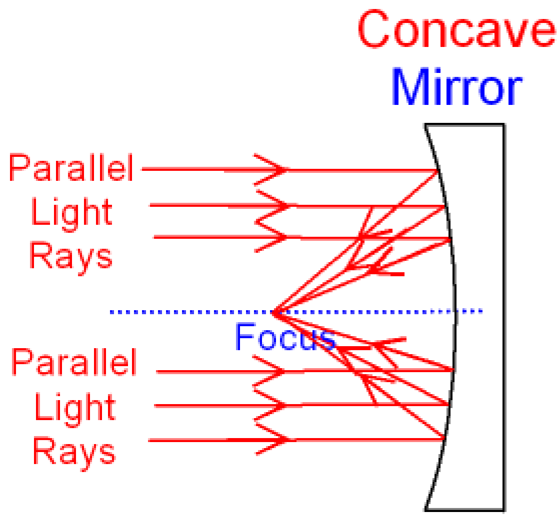
The image is called virtual because the light rays (shown as dotted lines) never really go there (compare this with a real image). The virtual image in a mirror is the same size as the object but with left and right reversed.

Reflection of Light from a Concave Mirror.

When light is a reflected from a curved mirror the light rays change direction in the same way that they do when they pass through a lens.

A convex mirror disperses light like a concave lens and a concave mirror focuses light like a convex lens.

A concave mirror is used in a reflecting telescope.



Parallel rays of light (or other electromagnetic rays) are brought to a focus by the concave mirror to form a real image.

What is Refraction?

Refraction is a change of direction of a wave. Any type of wave can be refracted. We shall look at the refraction of Water Waves, Light Waves and Waves from Earthquakes.

Refraction can occur when the speed of a wave changes, as it moves from one environment (medium) to another. After refraction, the wave has the same but a different speed, wavelength and direction.

When a wave enters a new environment, its change in speed will also change its wavelength (see the definition of wavelength).

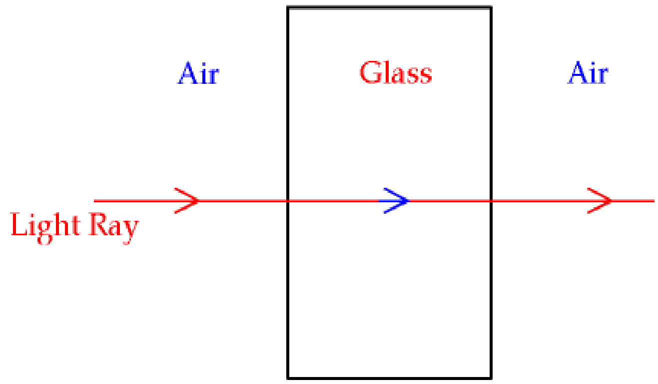
If the wave enters the new environment at any angle other than normal to the boundary, then the change in the wave's speed will also change its direction. This is most easily shown with water waves.

What is Refraction of Light?

A material is transparent if you can see through it. If you can see through it, it means that light can travel through it.
Transparent materials include air, Perspex, glass, and water. Light travels at different speeds in different materials because they have different densities.
The higher the density, the slower light travels. Light travels fastest in space (a vacuum) and a little slower in air.
Light moves noticeably more slowly in glass than in air
because glass is obviously more dense.

Refraction of Light along a Normal.

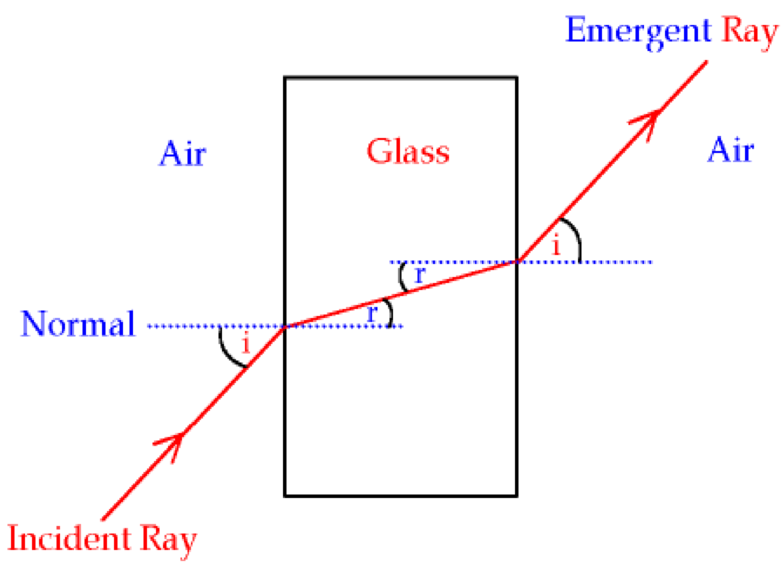
A line drawn at right angles to the boundary between the two media (air and glass) is called a normal.



Light that enters a glass block along a normal does not change direction but it does travel more slowly through the glass and so its wavelength is smaller (continued).

Refraction of Light through a Glass Block.

When a ray of light enters a glass block at an angle other than the normal, it changes speed, wavelength and direction as shown below. This also happens in a Lens.



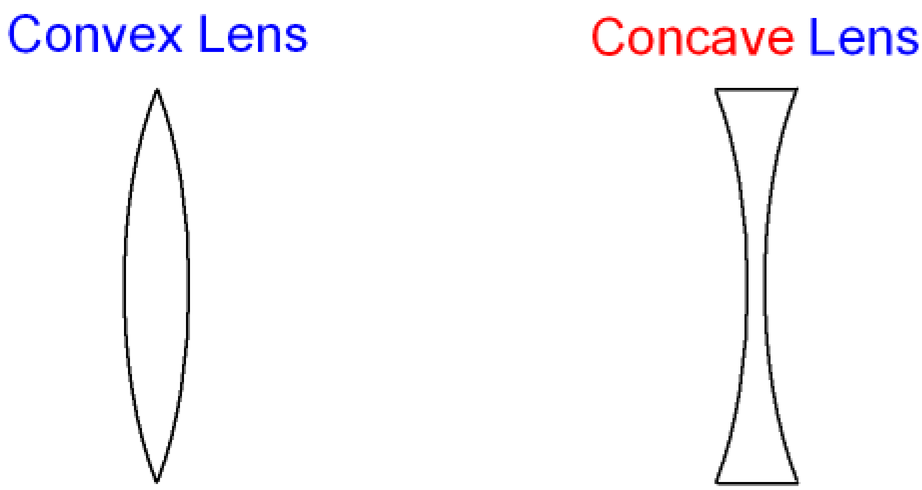
In going from a less dense medium (air) to a more dense medium (glass), light bends towards the normal.
This means that i > r (the angle i is greater than the angle r).
In going from a more dense to a less dense medium (glass to air), light bends away from the normal.
How much the light bends depends on its colour.

The change in angle of the light ray is the same when it enters and leaves the glass.
If the incident ray had continued without changing direction, then the emergent ray would be parallel to it.

What is a Lens?

A lens is a transparent curved device that is used to refract light.

A lens is usually made from glass. There are two different shapes for lenses. They are called convex and concave.



What is a Convex Lens?

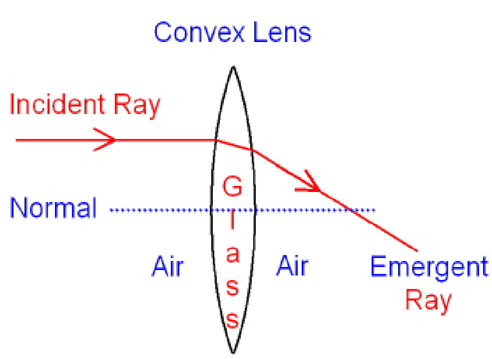
A convex lens is thicker in the middle and thinner at the edges. A convex lens is also called a converging lens. A convex lens will focus light and make an image. The image formed by a convex lens is real and inverted (and can be bigger or smaller than the object) unless it is being used as a magnifying glass when the image will be virtual, upright and bigger than the object.

What is a Concave Lens?

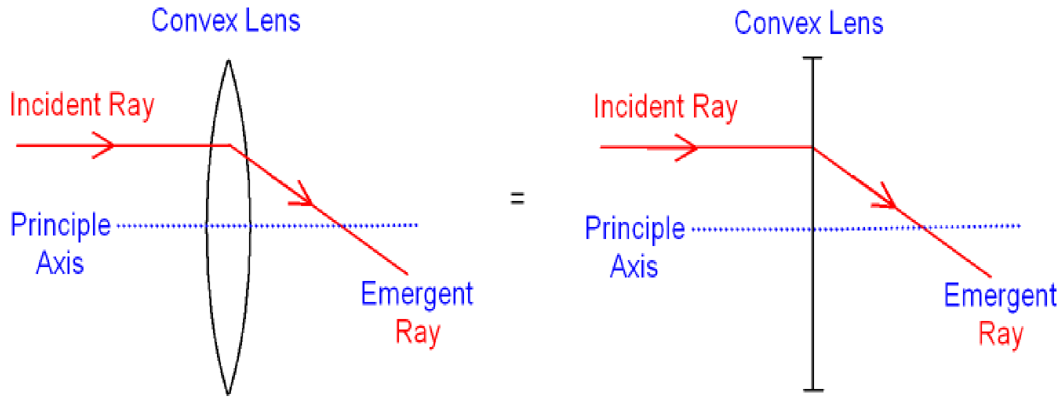
A concave lens is thinner in the middle and thicker at the edges. A concave lens is also called a diverging lens. A concave lens will disperse light and make an image that is always virtual, upright and smaller than the object.

Refraction of Light through a Convex Lens.

When light rays go through a convex lens the rays are refracted. For any ray entering the lens that is not along a normal the light will change direction at both surfaces (see below) where the air meets the glass.
A ray entering along the normal will pass straight through.
The normal for a lens is also called the principle axis.



The light ray is often not shown changing direction at both surfaces of the lens but just changing direction once to give the overall effect. Sometimes the lens is just shown as a thin straight line instead of a curved surface. The picture below gives both ways of showing the same thing. Either way is acceptable.



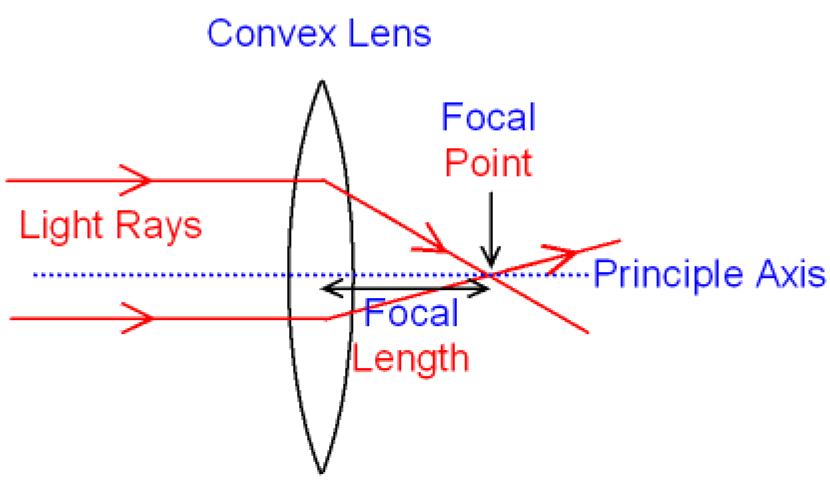
What are Ray Diagrams?

Ray diagrams for a convex lens and a concave lens are different but to draw any ray diagram you only need to know two things.

1. A ray passing through the centre of a lens will go straight through.
2. A ray parallel to the principle axis of a lens will go through the focal point.

What is the Principle Axis and the Focal Point of a Convex Lens?

The principle axis is a horizontal line going through the centre of a lens (shown as the normal on the previous page).



Any light ray parallel to the principle axis will be refracted, change direction and cross the principle axis at the focal point.

What is the Focal Length of a Convex Lens?

The distance from the focal point to the centre of the lens is called the focal length.

Almost parallel rays of light come from any object that is [illegible] way (more than 5 metres) from the lens (continued).

Ray Diagrams for Images made by a Convex Lens.

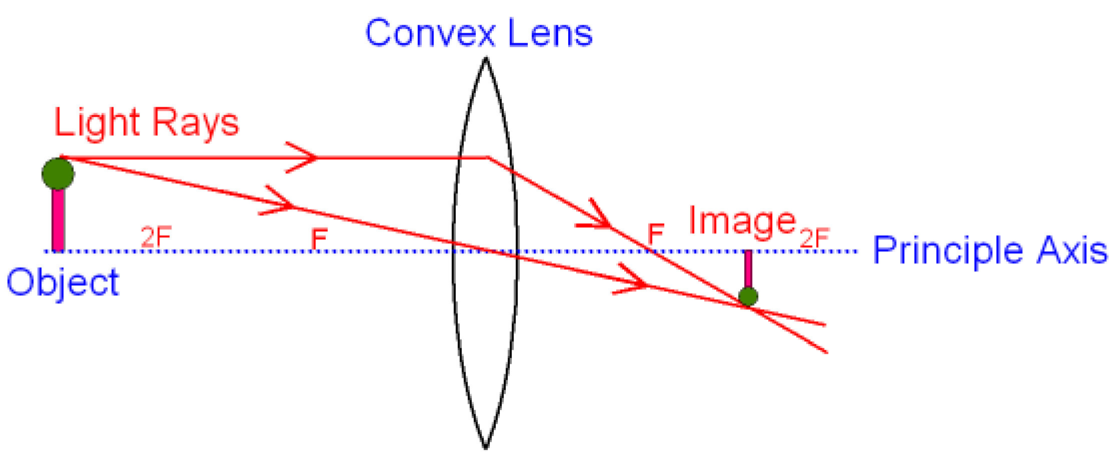
The type of image made by a convex lens depends on how far away the object is.

The first picture below shows how to draw a ray diagram for an object that is further away from the lens than 2F.
Further down the page there is a picture showing a ray diagram for an object that is between F and 2F.
Click here for a ray diagram for an object that is nearer the lens than F.

F is at the focal point of the lens. The distance from F to the centre of the lens is the focal length.
2F is twice the focal length.

Ray diagram for an object that is further away from the lens than 2F.

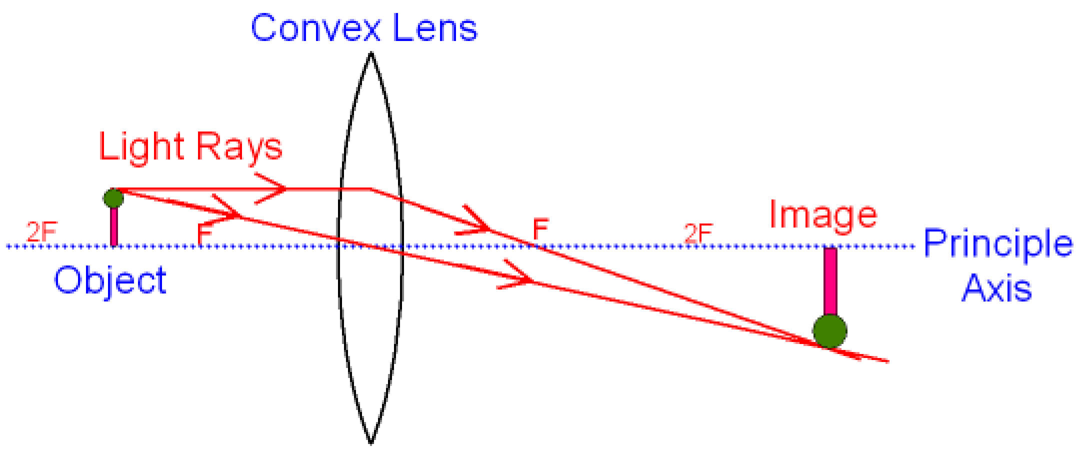
The bottom of the object is placed on the principle axis.
Two rays of light are drawn from the top of the object.
The first ray of light is parallel to the principle axis and therefore passes through the focal point.
The second ray of light goes from the top of the object
and passes straight through the centre of the lens.



The top of the image is formed where the two rays of light cross.
The bottom of the image is still on the principle axis.

You can see that the image is not the same as the object.
The image is smaller than the object.
The image is real meaning that the light rays really go there
(compare this with virtual).
The image is inverted (meaning it is upside down).

The next picture shows a ray diagram
for an object that is between F and 2F.



As above, you can see that the image is not the same as the object. The image is still real and inverted but it is now bigger than the object.

A Convex Lens as a Magnifying Glass.

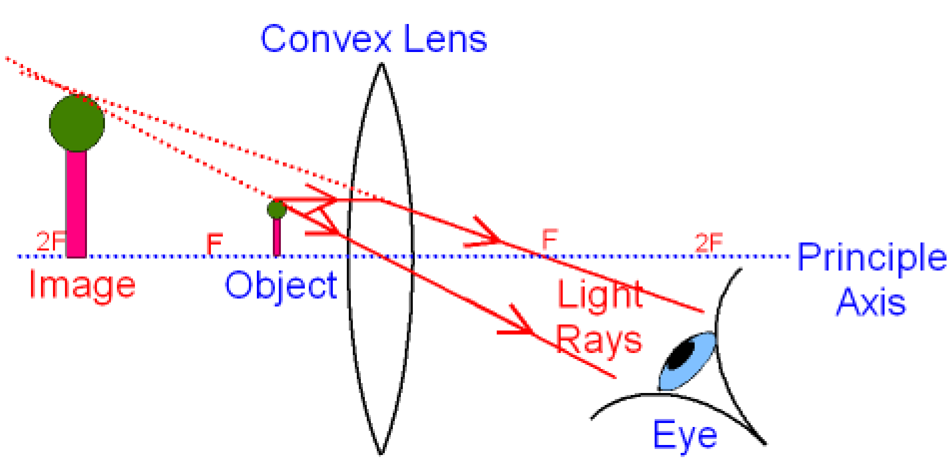
The type of image made by a convex lens depends on how far away the object is.

The picture below shows how to draw a ray diagram for an object that is nearer to the lens than F.
Click here for a ray diagram for an object that is further away than F.

When the object is nearer to the lens than F (less than the focal length) a convex lens acts as a magnifying glass.

What is the Ray Diagram for a Magnifying Glass?

The bottom of the object is placed on the principle axis.
Two rays of light are drawn from the top of the object.
The first ray of light is parallel to the principle axis and therefore passes through the focal point.
The second ray of light goes from the top of the object and passes straight through the centre of the lens.



Unlike the previous page, the rays are diverging (moving apart) on the right side of the lens.
The eye looks back along the rays that seem to have come from a point behind the object where the two rays of light cross.

This is where you draw the top of the image.
The bottom of the image is still on the principle axis.

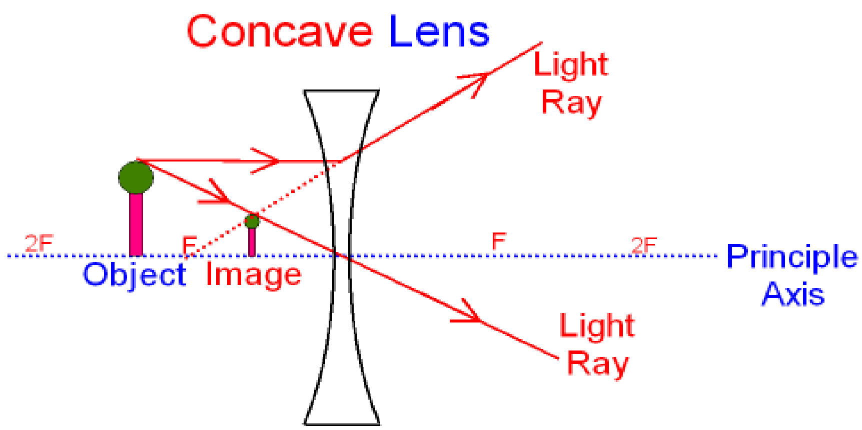
The image made by a magnifying glass is virtual, upright and bigger than the object.

The image is called virtual because the light rays never really go there (compare this with a real image).
The virtual light rays are drawn as dotted lines.
The image is called upright because it is the right way up (compare this with an inverted image).
The image is bigger than the object and on the same side of the lens as the object.

The eyepiece of a telescope is a convex lens used as a magnifying glass.

What is the Ray Diagram for a Concave Lens?

A concave lens is a diverging lens which makes the rays of light disperse and spread further apart.
It does the opposite of a convex lens.



The bottom of the object is placed on the principle axis.
Two rays of light are drawn from the top of the object.

The first ray of light is parallel to the principle axis and bends away from it on the right hand side of the lens.
To find the correct angle for this ray of light you trace it back through the focal point F on the left side.
This part of the ray is virtual and is drawn with a dotted line because the light never really goes there.

The second ray of light goes from the top of the object and passes through the centre of the lens. The second ray of light does not change direction (see ray diagrams).

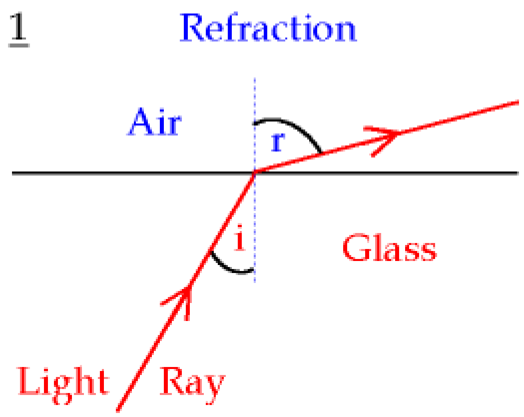
You draw the top of the image where the two rays of light cross. The bottom of the image is still on the principle axis.

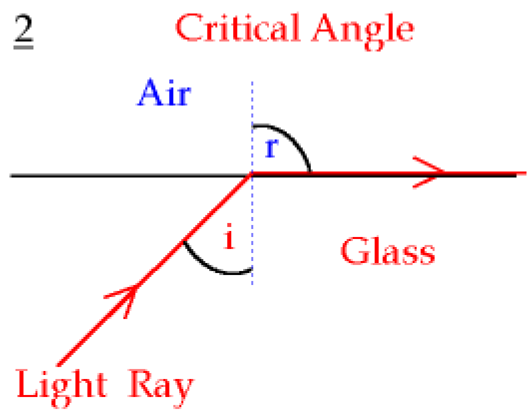
You can see that the image is not the same as the object.
The image is called virtual because the light rays never really cross there (compare this with a real image).
The image is called upright because it is the right way up (compare this with an inverted image).
The image is smaller than the object and on the same side of the lens as the object.

What is the Critical Angle and Total Internal Reflection?

1. When a light ray emerges from glass into air, it is refracted and bends away from the normal, so i < r.

2. As i is made bigger, the refracted ray gets closer and closer to the surface of the glass.
When i equals the critical angle, the refracted ray is just touching the glass surface.



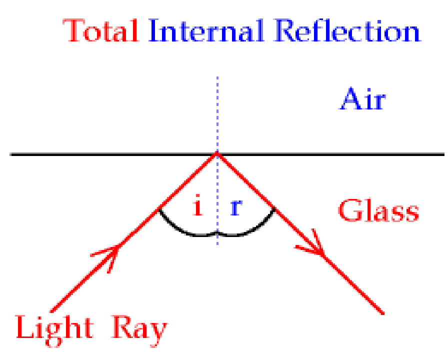


The critical angle is different for different materials. For glass it is about 42 degrees.

Total internal reflection happens when i is bigger than the critical angle (see the next page).

What is the Total Internal Reflection of Light?

When a light ray tries to move from glass to air at an angle greater than the critical angle (see the previous page) the refracted ray cannot escape from the glass.
Refraction cannot happen and all of the light is reflected at the glass / air boundary, as if it had hit a mirror, i = r.



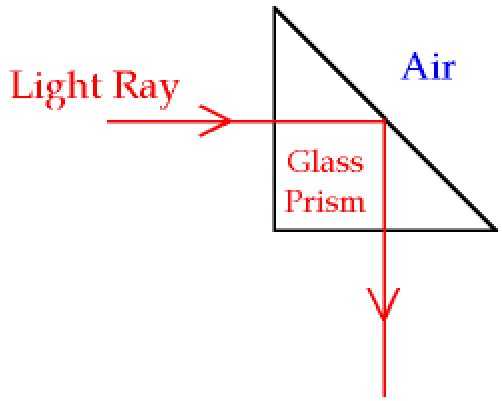
It is called internal reflection because it occurs inside the glass, and it is called because all the light must be reflected.

Total Internal Reflection (TIR) has uses in prisms and optical fibres.
The Total Internal Reflection of Light in Prisms.

A right angle prism can be used to change the direction of a light ray by 90 degrees or 180 degrees.
A prism can also be used to disperse white light into a spectrum.

How is a Right Angle Prism used to Change the Direction of a Light Ray by 90 degrees?

A right angle prism is used to change the direction of light by 90 degrees as shown in the picture below.

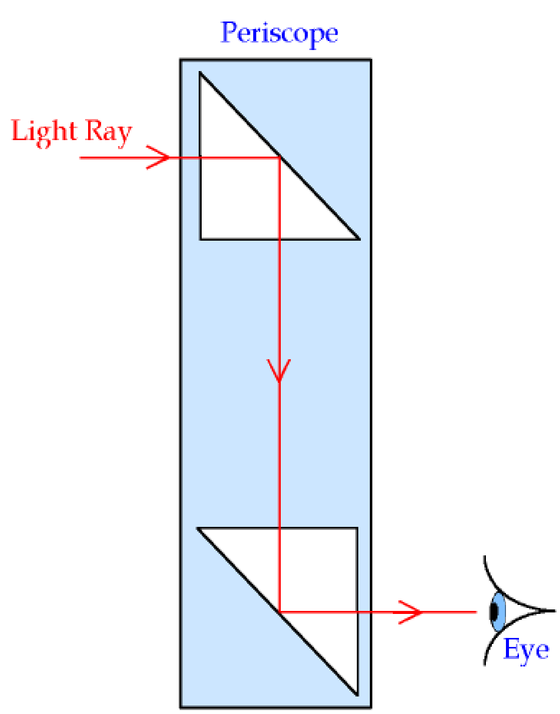


The light ray enters the prism along a normal and continues straight on until it hits the back face of the prism. Total internal reflection occurs here because light strikes the surface at 45 degrees which is greater than the critical angle.
The light ray then emerges from the prism along a normal and so continues through the glass surface.

This type of prism can be used in a periscope.

Using Total Internal Reflection of Light to Make a Periscope.

Two right angle prisms can be used to make a periscope. At the back face of the prisms there is total internal reflection.
Please see the picture below.



What are the Uses of a Periscope?

A periscope may be used by people

1. In a submarine to see above the sea surface.

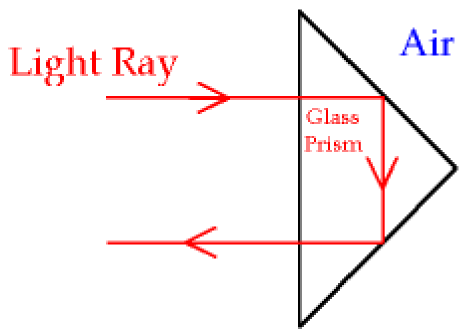
2. To see over the heads of people in a crowd.

The Total Internal Reflection of Light in Prisms.

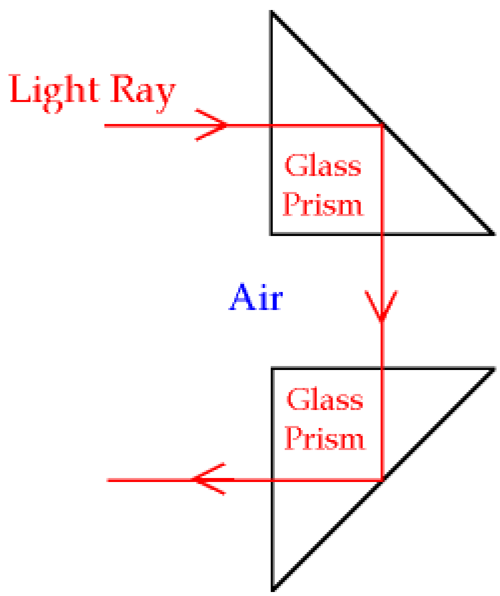
A right angle prism can be used to change the direction of a light ray by 90 degrees or 180 degrees.
A prism can also be used to disperse white light into a spectrum.

How is a Right Angle Prism used to Change the Direction of a Light Ray by 180 degrees?

A right angle prism can be used to change the direction of light by 180 degrees, as shown in the picture below.



The same effect can result from having two right angle prisms arranged as shown in the picture below.

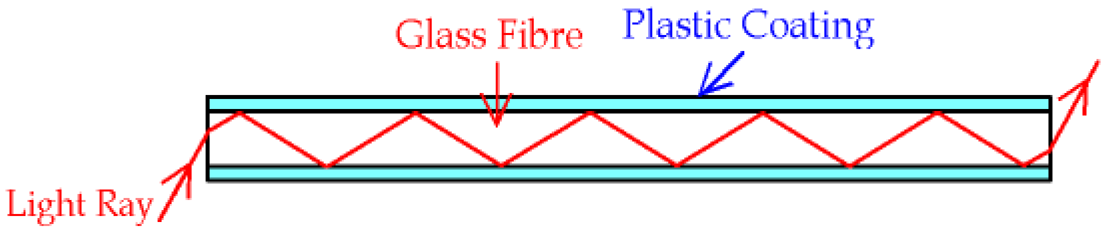


Either of these arrangements may be used to make binoculars or the plastic the rear of cars and bicycles.

The Total Internal Reflection of Light in Optical Fibres.

What is an Optical Fibre?

An optical fibre is a long thin strand of glass that has an outer plastic coating. See the picture below.



How does an Optical Fibre Work?

Light from a laser enters at one end of the fibre, striking the surface of the glass at an angle greater than the critical angle.
Total internal reflection occurs at the glass surface and the light cannot escape until it reaches the other end of the fibre. The plastic coating prevents the glass surface from getting scratched which might allow the light to escape through the side of the fibre.

What are the Uses of Optical Fibres?

Optical fibres are used for telecommunications and to make endoscopes.

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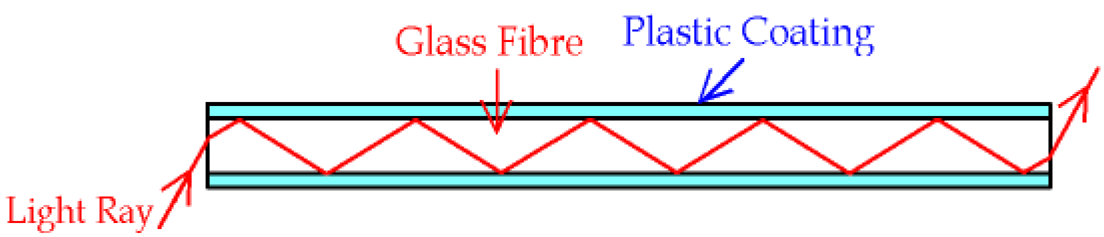

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The use of Optical Fibres in Telecommunications.

What are Telecommunications?

Telecommunications means "the transmission of information over long distances".

Information is transmitted (sent) using electrical signals in copper wires or by using electromagnetic waves including light in optical fibres.

Electromagnetic waves can be used to transmit information as a digital signal or as an analogue signal. A digital signal has a higher quality than an analogue signal. The transmitted information can be used in many ways, including radio, telephone, television, fax and the internet.

How are Optical Fibres used in Telecommunications?

A laser can be made to produce little bits of light (called pulses) which are sent along the optical fibre in the form of a digital signal. The digital signal contains the information.

Many different digital signals can be sent down the same optical fibre at the same time. The optical fibre is said to have a higher capacity than a copper wire of the same thickness (this means that the optical fibre can carry more information).

The Use of Optical Fibres to Make an Endoscope.

What is an Endoscope?

An endoscope is an instrument used by Doctors and Surgeons. An endoscope has a bundle of very thin which are used with lenses to see inside a body. Only a small hole in the skin is necessary to insert the endoscope. This minimizes the trauma and possible damage to the patient.

How does an Endoscope Work?

Some of the optical fibres take light down to the end of the endoscope which shines inside the body. Other optical fibres in the bundle collect the reflected light using lenses. The reflected light is sent along the fibres to a computer which displays the information as a picture on a monitor. It is sometimes possible to perform medical operations inside people by using an endoscope, rather than making a large cut in the skin.

The Refraction of White Light to Produce Colours.

What is a Spectrum?

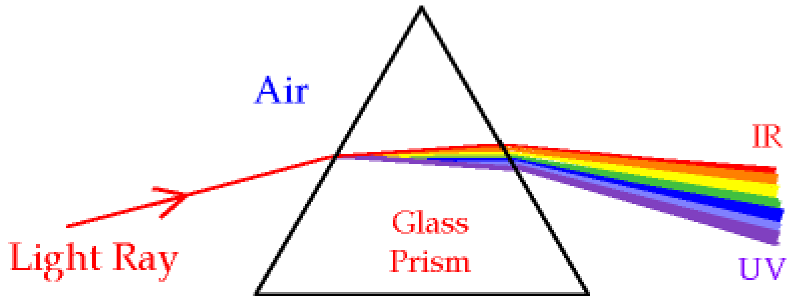
The dispersing of light or other into its component parts produces a spectrum. A glass prism of angle 60 degrees can disperse white light into its different colours. See the picture below.

What are the Colours of the Spectrum of White Light?

The seven colours of light are Red, Orange, Yellow, Green, Blue, Indigo and violet. You can remember the colours and order by remembering Richard of York gave battle in vain.

The different colours of light have each a different frequency and wavelength. The different colours are refracted by different amounts.

Red light has the longest wavelength and is refracted least. Violet light has the shortest wavelength and is refracted most.



The source of light may also emit infra-red and ultraviolet light.

Infra-red is heat radiation with a longer wavelength than red light. A thermometer placed at IR will show a rise in temperature.

Ultraviolet light has a shorter wavelength than violet light.
A fluorescent material will glow when placed at UV.

What type of Waves travel through Water?

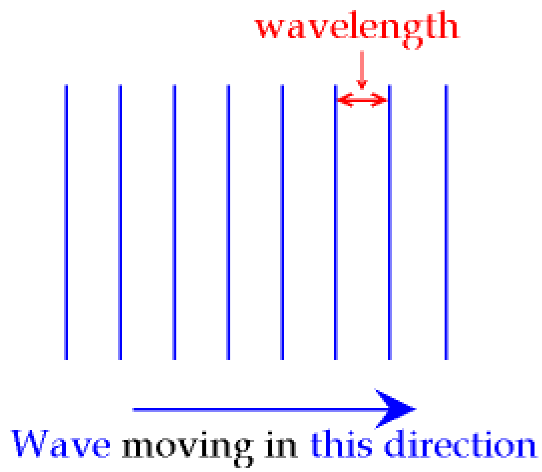
Both longitudinal and transverse waves can travel through water.

How do Longitudinal Waves travel through Water?

Longitudinal waves travel through water underneath the surface. This is under water sound and it can be used by fishing boats for echo location and by sea creatures (for example whales including dolphins) to communicate.

How do Transverse Waves travel through Water?

Transverse waves travel on the water surface and these are the waves which we see as they make the surface go up and down.
Transverse water waves are shown as a series of parallel lines. See the picture below. These parallel lines represent the peaks of the wave, as you are looking down on them from above.

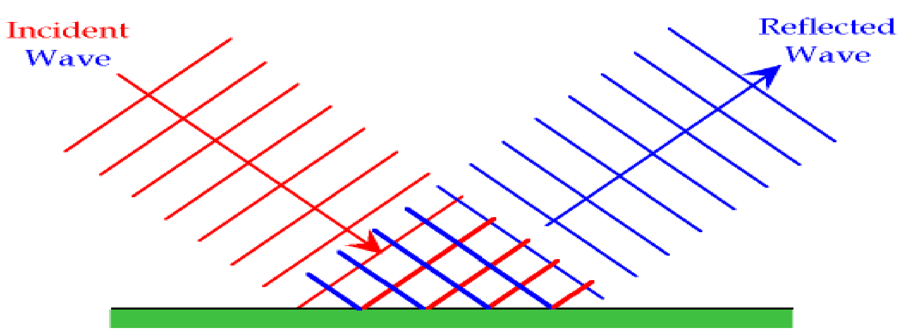


Transverse water waves can be used to show the effects of reflection, refraction and diffraction.

The Reflection of Water Waves.

What Type of Surfaces Best Reflect Water Waves?

Water waves are best reflected from hard flat surfaces as shown in the picture below.



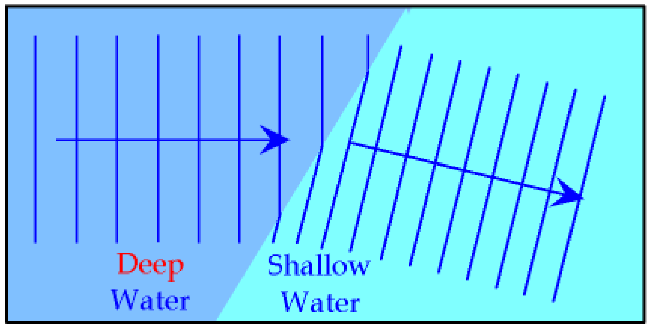
Note that the total length of the line representing the wave peak stays the same where it is being reflected. The red part of the incident wave plus the blue part of the reflected wave is the same length as the original line.

After reflection a wave has the same speed, frequency and wavelength, it is only the direction of the wave that has changed.

The Refraction of Water Waves.

What Causes Water Waves to Refract?

Water waves travel faster on the surface of deep water than they do on shallow water. The change in speed of the wave will cause refraction as shown in the picture below.



As you can see, the change in speed has changed the direction of the wave. The slower wave in the shallow water has a smaller wavelength. The amount of refraction increases as the change in speed of the wave increases.

What is Diffraction?

Any type of wave can be diffracted. A diffracted wave will "spread out".

When does Diffraction happen?

Diffraction occurs when the wavelength of a wave is of a similar size to an obstacle or a gap in a barrier. After diffraction, a wave will have the same speed, frequency and wavelength.

The Diffraction of Sound Waves.

A sound wave with a frequency of 500 Hz has a wavelength of 0·66 m (see calculations).
Sound waves will diffract (spread out) when they pass through a doorway (which is approximately 0·8 m wide) because the wavelength (0·66 m) is of a similar size to the doorway (0·8 m).

The Diffraction of Electromagnetic Waves.

Electromagnetic waves have a huge range of wavelengths.

Radio waves can diffract around hills, mountains or even the whole planet.

Light waves can diffract through tiny slits.

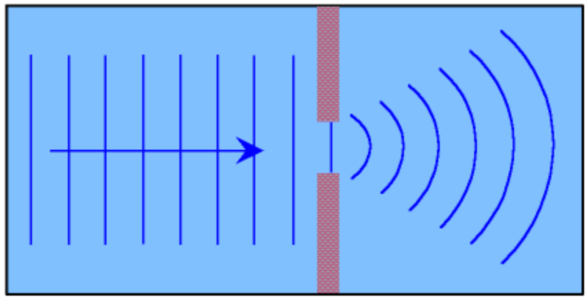
X-rays can diffract around atoms.

The Diffraction of Water Waves.

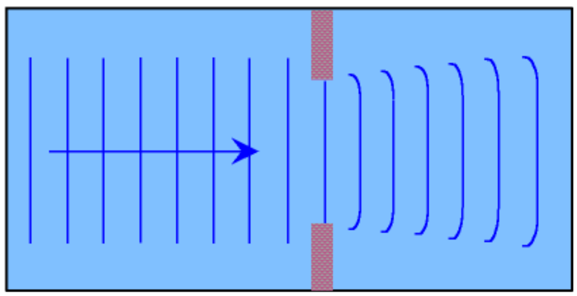
Water waves can diffract when passing through a gap in a harbour wall.

The Diffraction of Water Waves in a Harbour.

The wavelength of water waves may be several metres. If the wavelength is of a similar size to a gap in a harbour wall, then the wave will diffract as shown in the picture below.



If the wavelength does not match the size of the gap, then only a little diffraction will occur at the edge of the wave.
See the picture below.



The part of the wave which hits the wall in the above two pictures is reflected straight back on itself.

What is Electromagnetic Radiation?

All electromagnetic radiation travels at the same speed (in a vacuum). Electromagnetic radiation travels very quickly. There is nothing which can travel faster.
The speed is 300,000,000 m/s in a vacuum (that is 300 million metres per second - not easy to imagine!).

Electromagnetic radiation can be thought of as particles or waves (the word radiation is also used for radioactivity).

Electromagnetic radiation has a wide variety of and frequencies which form the electromagnetic spectrum.

Electromagnetic waves are transverse waves which have both an electric and a magnetic effect.
Electromagnetic waves are unusual because they do not need any substance to get from one place to another. They can travel through a vacuum. Light and infra-red radiation (heat) can reach the Earth from the Sun through the vacuum of space.

When is Electromagnetic Radiation a Particle and when is it a Wave?

It is not true that electromagnetic radiation is sometimes a particle and sometimes a wave. It always has the properties of being both a particle and a wave.
This site will mostly talk about electromagnetic radiation as waves but you need to know a little about it being particles too.

What is a Photon?

When thought of as particles electromagnetic radiation is often called a ray or a beam. A ray or beam of electromagnetic radiation is made from particles called photons. A photon is a packet of energy. Different photons have different amounts of energy.

Three types of electromagnetic radiation (ultraviolet, x-rays and gamma rays) can form ions because the photons have enough energy to remove an electron from an atom or molecule. These three types are called ionising radiation and they can all cause significant damage to living cells.

What is the Electromagnetic Spectrum?

Electromagnetic waves can have wavelengths which range from several thousand metres to less than one million millionth of a metre.
The waves are divided into wavelength ranges according to the wave's effect or uses.

This is called the electromagnetic spectrum.

Radio	Microwave	Infra-red	Visible	Ultraviolet	X-ray	Gamma ray

You need to know the order of the regions shown above and that radio waves have the longest wavelength decreasing down to gamma rays which have the shortest wavelength.

How do the Wavelength, Frequency and Energy Change?

As the wavelength decreases, the frequency increases. Radio waves have the smallest frequency and gamma rays have the largest frequency.

The amount of energy that the wave has increases as the frequency increases (and the energy of each photon increases).
Radio waves have the smallest amount of energy and gamma rays have the largest amount of energy.

What is the Intensity of Electromagnetic Radiation?

The intensity of a beam of electromagnetic radiation is a measure of the amount of energy hitting each square metre of surface every second. The actual amount of energy depends on the energy of each photon as well as the number of photons hitting the surface.

The intensity of electromagnetic radiation decreases the further it travels because it spreads out over a bigger surface area and some electromagnetic radiation is absorbed by the air.

Electromagnetic Waves - What are Radio Waves?

Radio waves are part of the electromagnetic spectrum.
Radio waves are used for broadcasting radio and TV programmes.
The transmitted information may be in the form of an analogue or a digital signal and uses a radio wave as a carrier.

… are Ground Waves, Sky Waves and Space Waves?

Very long wavelength radio waves can travel all the way around the Earth, diffracting around the Earth's surface. These are sometimes called ground waves.

Medium wavelength radio waves are reflected from an electrically charged region of the Earth's atmosphere called the ionosphere. These waves are sometimes called sky waves and they can also be sent from one part of the planet to another.

Shorter wavelength radio waves pass straight through the atmosphere and cannot be used to send information all the way around the Earth's surface. These waves are sometimes called space waves and can be used to send information in a straight line across the Earth's surface.

What is Bluetooth?

Over a short distance, shorter wavelength radio waves can be used for wireless communication between devices.

This is called Bluetooth. An example of Bluetooth is a computer communicating with a wireless printer, mouse or keyboard.

Electromagnetic Waves - What are Microwaves?

Microwaves are part of the electromagnetic spectrum.
Microwaves have wavelengths that are shorter than radio waves.

How are Microwaves Used for Communication?

Microwaves have some wavelengths that pass easily through the atmosphere and they are used to transmit information to satellites. Satellite TV and mobile phone (or smartphone) networks use microwaves.
Some people have concerns that microwaves from mobile phones may be harmful.
However, the intensity of the microwaves emitted from mobile phones is low and the evidence for their safety is not conclusive.

How are Microwaves Used for Cooking?

Some microwaves have wavelengths that are absorbed by water molecules. Microwave cookers use waves which give energy to the water molecules in food, causing the food to get hot.
The cooker has a metal door screen and outer case which absorb or reflect microwaves to protect people who use the cooker.

How can Microwaves cause Harm?

Living cells can absorb microwaves. The cells may be damaged or killed by the heating effect of the waves. Skin cells can be burned.

Electromagnetic Waves - What are Infra-red Waves?

Infra-red Waves are part of the electromagnetic spectrum. Sir William Herschel discovered Infra-red waves in 1800.
This was the first discovery of any electromagnetic waves that were outside the range of the visible spectrum.

Infra-red waves are sometimes also called infra-red radiation or thermal radiation.

How are Infra-red Waves Used for Cooking?

Infra-red waves are easily absorbed by materials. The energy of the wave causes the material to get hot. We usually think of infra-red radiation as heat. Ordinary ovens, grills and toasters use infra-red radiation to cook food (ovens may also cook by convection).

Intense infra-red radiation will damage or kill living cells (such as skin cells) by burning them.

How are Infra-red Waves Used for Communication?

Infra-red waves can transmit information through the air to operate TV's and PVR's by remote control. Information can also be sent through optical fibres.

What is Thermal Imaging?

Infra-red waves are used for thermal imaging. In a thermal imaging device, a detector receives infra-red waves and produces an image where different colours show the intensity of the waves in different places. This gives you a 'heat picture' where hotter objects are orange / red and colder objects are blue / green.
Thermal imaging is used by fire fighters to see where the hottest part of the fire is.

What is a PIR?

A device called a PIR (passive infra-red) is used for security. When a warm object such as a human or animal approaches a house, the PIR can detect it against the colder background and send a signal to switch on an outside light.

Electromagnetic Waves - What are Ultraviolet Waves?

Ultraviolet Waves are part of the electromagnetic spectrum. Ultraviolet waves were discovered by Johann Wilhelm Ritter
when he looked for other waves outside of the visible region after he had heard about the discovery of infra-red waves by Herschel. Ultraviolet waves are often called ultraviolet light or ultraviolet radiation.

Why are Some Materials Fluorescent?

Some materials will absorb (take in) the energy from ultraviolet waves and emit (give out) the energy as visible light.
These materials are called fluorescent and are used for fluorescent lighting and security marking.
Ultraviolet light is used to detect forged (fake) bank notes.

What Effect has Ultraviolet Light from the Sun?

Ultraviolet light from the Sun causes skin to tan. Sunbeds emit ultraviolet light to give an artificial tan.

Intense ultraviolet light in strong sunlight can damage cells which are deep inside skin tissue.
This type of damage can result in skin cancer. Darker skin is more resistant to ultraviolet light than lighter skin. To be safe, avoid strong sunlight or use a skin block (see the page on sunscreens).

Prolonged exposure to ultraviolet light can cause clouding of the transparent lens within the eye.
This condition (known as a cataract) can cause dimming of vision or even complete blindness.
It is important to wear good sunglasses in strong sunlight.

Some ultraviolet light is absorbed by the ozone layer. Very intense ultraviolet light will kill living cells.
Ultraviolet light can be used to disinfect water.
Ultraviolet light can also be used to start chemical reactions.

Electromagnetic Waves - What are X-rays?

Electromagnetic waves with a wavelength shorter than ultraviolet light are called X-rays (not X waves).
X-rays are part of the electromagnetic spectrum.

How are X-rays used for Medical Photographs?

X-rays can pass easily through flesh but not through bone.
X-ray photographs are used to show the image of bones against a black background.
These photographs can show if bones are broken or damaged.

What is a Barium Meal?

X-rays can not pass through barium sulfate. Barium sulfate can be given in a hospital to a patient as a liquid drink called a barium meal.
Information from an x-ray photograph about the stomach and intestines can be used to diagnose illness or disease. Although barium sulfate is toxic, it is safe to use in this way because it is not and can not enter into the blood of the patient.

X-ray diffraction is used in crystallography. It gives information about the arrangement of atoms in materials.

X-ray scanners are used for security at airports and can show the presence of hidden objects in peoples bags or clothing.

How do X-rays cause Harm?

Low intensity X-rays can damage living cells and cause cancer. People who work with X-rays take measures to protect themselves from exposure.
They wear a film badge and stand behind special screens when the X-ray machine is switched on.

High intensity X-rays will kill living cells.

Electromagnetic Waves - What are Gamma rays?

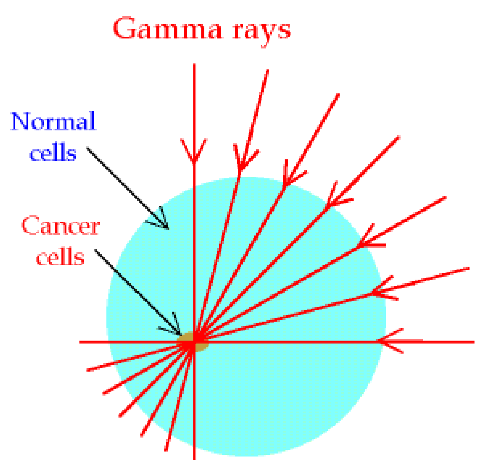
Electromagnetic waves with a wavelength shorter than X-rays
are called gamma rays or gamma radiation (not gamma waves).
Gamma rays are part of the electromagnetic spectrum.
Gamma rays may be emitted from radioactive materials.

Gamma rays have the highest energy of all electromagnetic waves. This means that are dangerous to living cells.

Low intensity gamma radiation can damage living cells and cause cancer.

What is Radiotherapy?

High intensity gamma radiation will kill cells.
It is used in a technique called radiotherapy to treat cancer by targeting the cancer cells with a beam of radiation and then rotating the source of the beam as shown below.



The normal cells receive a lower dose of gamma radiation than the cancer cells, where all the rays meet.
Radiotherapy aims to kill the cancer cells while doing as little damage as possible to healthy normal cells.

Gamma radiation is also used to kill microorganisms. This is called sterilising. Gamma radiation is used to sterilise food and hospital equipment such as surgical instruments.

Electromagnetic Waves - What is Transmission?

Information can be sent over long distances for telecommunications.
The process of sending the information is called transmission.

Different types of electromagnetic wave are used for transmission, including radio waves, microwaves, infra-red and visible light.

Information can be sent in the form of analogue or digital signals.

Electromagnetic Waves - Transmission of Information.

What is the Difference between Analogue and Digital Signals?

Information in the form of images, speech or music can be transmitted as an analogue or digital signal.
An analogue signal will vary continuously. There are no gaps in an analogue signal. A digital signal has gaps in it.

What are Analogue Signals?

An analogue signal will resemble the original speech or music by having the frequency or amplitude of the wave go up and down in the same way as the sound in speech or music goes up and down.
The word "analogue" means "similar" or "corresponding".

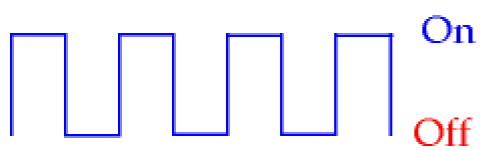
Information in the form of an analogue signal can be added to another electromagnetic wave which is used for transmission. This wave carries the analogue signal and is called the carrier wave.

For much of the last century, information was transmitted in the form of analogue signals. Today information is being increasingly transmitted using digital signals.
Digital signals have advantages over analogue signals.

Electromagnetic Waves - Transmission of Information.

What are Digital Signals?

Information can be transmitted in the form of a digital signal. Unlike an analogue signal, the digital signal uses a code with two states which are called on and off.
The on state is a small pulse of the electromagnetic carrier wave.
The off state is the gap in between the pulses where there is no electromagnetic wave.
The digital signal can be represented by the picture below.



When the digital signal reaches its destination, the series of on and off states must be changed back into the original information.
This process is called decoding.

Digital signals have advantages over analogue signals.

Information today is being increasingly transmitted using digital signals. The amount ofinformation transmitted or stored is measured in bytes.

Bytes are given the symbol B.
1 kilobyte (1KB) = 1,000 bytes.
1 Megabyte (1MB) = 1,000 KB = 1,000,000 bytes.
1 Gigabyte (1GB) = 1,000 MB = 1,000,000 KB
= 1,000,000,000 bytes.
A higher quality transmission requires a larger number of bytes.

What are the Advantages of Digital Signals?

Digital signals have advantages over analogue signals.
The advantages of digital signals are increased capacity, better quality and the signals can be stored and processed by computers.

Increased capacity means that more information can be sent by digital signals than analogue signals in the same time, using the same optical fibre or carrier wave.

Electromagnetic Waves - Transmission of Information.

Digital Signals have a Higher Quality than Analogue Signals.

What is Noise and the Quality of a Signal?

The quality of a signal is a measure of how much the signal has changed during transmission.
A high quality signal has changed very little.
A low quality signal has other information in it which was not there in the original signal.
The additional unwanted information is called noise.

Any noise which is present in an analogue signal reaches the receiver and is processed by the electrical equipment as if it were part of the original signal.

All signals become weaker as they travel and some frequencies in an analogue signal may weaken more quickly than others.
If the signal is amplified during transmission, then the noise is also amplified in the same way.

A digital signal has only two states called on and off.
Since noise is usually of low intensity compared to the signal, noise is interpreted by the decoder as an off state and is not included in the signal processing. A digital signal ignores the noise and therefore has a higher quality than an analogue signal. Digital signals also have increased capacity compared to analogue signals.

What causes Earthquakes?

Earthquakes are caused by tectonic activity.

What type of Waves are made by Earthquakes?

Earthquakes produce waves called seismic waves (pronounced "size-mick waves").
These waves are measured by an instrument called a seismograph or seismometer.

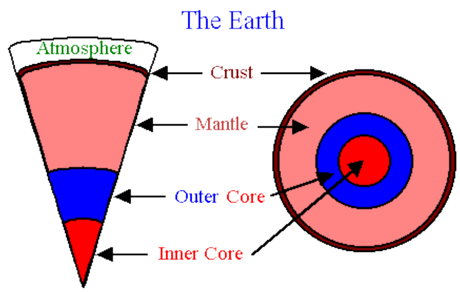
Three types of wave are produced by earthquakes.

One type of wave moves along the surface of the Earth and can cause damage to buildings and pipelines and can result in large numbers of casualties.

Other waves move through the Earth. These are called P waves and S waves. These waves give information about the structure of the inside of the planet.

What is the Structure of the Earth?

The waves from earthquakes which travel through the Earth give information about the structure of the inside of the planet.



The outer crust (called the lithosphere) is made from solid rock.

The mantle is made from hot solid rock which can flow only very very slowly.
The mantle behaves more like a solid than a liquid.
The mantle goes down nearly half way to the Earth's centre.

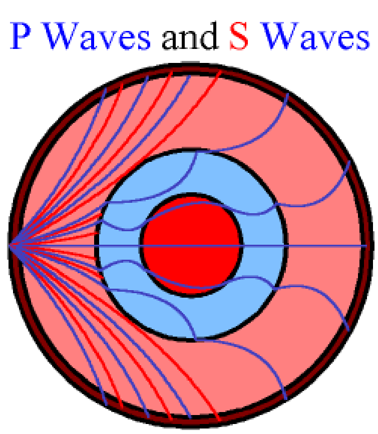
The density of the rocks which are found in the Earth's crust is lower than the density of the planet as a whole. This means that the core of the Earth must be made from a material that is more dense than rock. It is believed that the core is made from a mixture of iron and nickel. The outer core is liquid, the inner core is solid.

Waves which travel through the Earth change direction as they meet the different layers (see the next page).

What are P Waves and S Waves?

The two types of wave which travel through the planet from an earthquake are called P waves and S waves.
S waves are transverse. P waves are longitudinal.
P waves travel faster than S waves.

In the picture below
P waves are shown in blue and S waves are shown in red.
The earthquake has occurred on the left side of the planet,
the waves are moving from left to right.



How do P Waves and S Waves give Information about the Structure of the Earth?

The transverse S waves cannot travel through the liquid outer core.
They can travel through the mantle because the mantle behaves more like a solid than a liquid. The S waves curve as they move through the mantle due to refraction as the density of the mantle changes. There is a large part of the surface of the planet where no S waves are detected. This shows that the outer core is liquid because it blocks S waves. It also shows how big the outer core is.

The longitudinal P waves can travel through the whole planet.
They also curve with the changing density of both the mantle and the core (except the wave passing through the centre, which travels in a straight line, normal to the boundary).
The P waves change direction suddenly at the boundary between the different layers of the Earth. This is due to refraction caused by the different densities of the layers.
The P waves show how big the solid inner core is.

Electrostatic Charge

What is an Electrostatic Charge?

We are familiar with charge flowing through conductors, which we usually just call "electricity".

Charge can also be present on insulators and because these materials do not allow the charge to flow, this is called electrostatic charge (static meaning it "stays still").

Materials which are insulators can be charged by friction.

How can an Insulator get an Electrostatic Charge?

Insulators can transfer charge by friction. When the surface of one insulator rubs against another, electrons can be transferred.

The insulator that gains electrons will get a negative charge, the insulator that loses electrons will get a positive charge.

It is most important to know that it is only the negative electrons which can move. Positive charges (protons) cannot move because they are stuck inside the nuclei of the atoms of the material.

For example, if polythene (a type of plastic) is rubbed with a dry cloth, electrons are transferred from the cloth to the polythene.
The polythene gains electrons and becomes negatively charged, the cloth loses electrons and becomes positively charged.

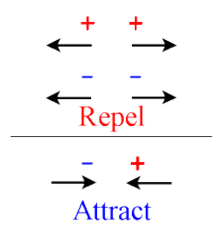
It is not possible to predict in advance which way the electrons will be transferred for a certain material. The same cloth, when rubbed against a different type of plastic called acetate, will gain electrons and become negatively charged, leaving the acetate with a positive charge.

What are Attraction and Repulsion?

Opposite charges attract (pull towards each other).
Like charges repel (push away from each other).

This means that two positively charged things will repel each other and two negatively charged things will repel each other.

One positively charged thing and one negatively charged thing will attract each other.



The further apart the charged things are, the weaker the forces of attraction and repulsion are.

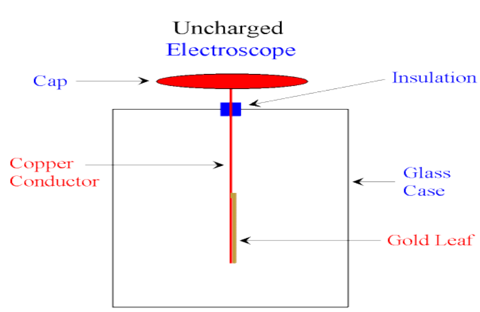
You can show whether something is charged or not by using a gold leaf electroscope.

What is a Gold Leaf Electroscope?

The gold leaf electroscope has a very very thin piece of gold foil (called gold leaf) fixed at the top to a piece of copper.
The copper has a large round top, called the cap.
The whole thing is put inside a glass case, to stop air blowing the delicate gold leaf around.

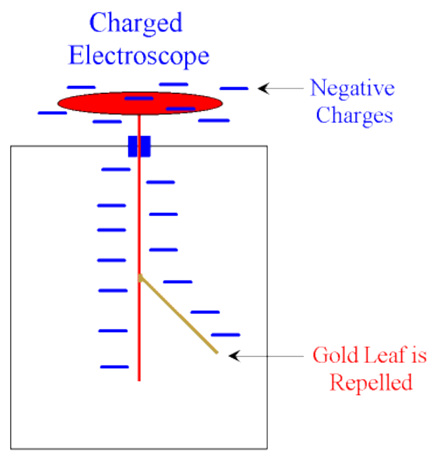
The piece of copper goes through insulation in the top of the glass case, so that any charge on the gold leaf cannot escape.

The picture below shows an uncharged gold leaf electroscope.



Charge can be transferred to the electroscope by wiping the charged object across the cap. The charge flows over the conducting copper and gold, and the gold leaf rises as it becomes repelled by having the same charge as the copper.

The picture below shows a charged gold leaf electroscope.



Neutral Objects.

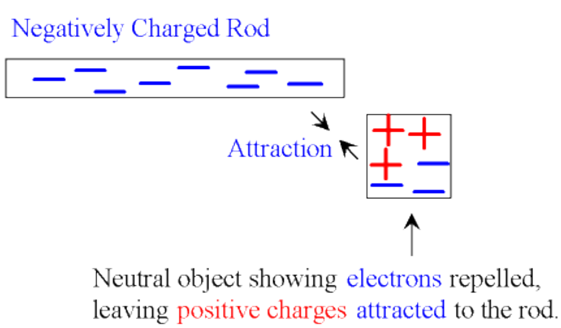
We know that like charges repel and unlike charges attract but what about neutral (uncharged) objects?

Are Neutral Objects Attracted to Charged Objects?

It is found that a charged object, whether positive or negative, may attract uncharged objects. For example a charged plastic comb will pick up small pieces of paper. You can try this yourself. Just charge the comb by combing your hair! Hair is a good insulator.

What is Happening to make the Neutral Object Attract?

It is thought that when a negatively charged object gets close to an uncharged object, electrons in the uncharged object are repelled, leaving the positive charges behind. These positive charges are then attracted to the negatively charged object.
This is shown in the picture below.



If the rod was positively charged, then it would attract electrons in the neutral object and so the two would still attract each other (just reverse the + and - in the picture above).

The small number of charges shown is an oversimplification since in reality are millions and millions of atoms in a tiny piece of paper, each with its own electrons and protons. When we draw the rod with a negative charges, it means that the rod has a few more negative than positive charges.

The fact that charged objects are attracted to neutral objects is used to improve the efficiency of crop spraying.

Electrostatic Shock.

If a high amount of charge builds up on an insulator, it can escape across a small distance through air to a neutral or oppositely charged object.

You may have noticed that pulling off a jumper or other clothing over your head can cause crackling. If the clothing is made from a synthetic fibre (a plastic material which is a good insulator) then charge is transferred as it rubs against your hair (which is also a good insulator).
The crackling is the sound made by the charge jumping through the air between the clothing and your hair.

How can a Car Door or a Radiator give you a Shock?

Touching a car door or a radiator can sometimes give you a shock. If both the car seat and your clothing are made from a synthetic fibre, then one rubs against the other transferring charge as you step out of the car. The charge then jumps the small air gap between your finger and the car as you go to close the car door.

Similarly, if both a carpet and your shoes are made from synthetic materials, then charge is transferred as you walk around. Touching a radiator will cause the charge to jump the small air gap between your finger and the radiator.
The sensation of the charge on your skin feels unpleasant.

If your clothing, carpet, shoes etc. are made from natural fibres then you are much less likely to get a shock. Natural fibres such as wool and cotton attract a small amount of moisture (water) to their surface and this moisture allows the material to conduct a little so the charge escapes before it can build up enough to jump through air. If the air itself is moist, the charge will also escape and no shock will occur.

How can Electrostatic Charge cause a Spark?

In the examples above, when charge jumps across a small air gap it causes a spark which can be dangerous. Lightning is a natural example of a huge charge jumping across a very large air gap between the ground and the sky, and we know how dangerous lightning can be.

What are the Dangers of Electrostatic Charge?

When charge jumps across an air gap it causes a spark. The spark can ignite (set fire to flammable liquids, vapours and powders in pipes.

How can Fuel Flowing through a Pipe cause an Explosion?

Care must be taken to avoid sparks when putting fuel in cars or aircraft. The fuel itself is an insulator (a hydrocarbon) and charge can be transferred as the fuel flows through a pipe if the pipe is also an insulator. The transfer of charge happens because there is friction between the fuel and the pipe. As the nozzle (the end) of the pipe is brought close to the fuel tank, a spark can jump between the two igniting the fuel. This can cause a serious explosion, particularly with aircraft which are filled at a very high speed.

The spark can be avoided if the pipe nozzle is made to conduct by connecting an earthing strap to it and so any charge can be safely conducted away.
An earthing strap connects the pipe to the ground (the Earth). In addition, a cable can connect the pipe to the fuel tank, so that there can be no difference in charge between them.

How can Powder Flowing through a Pipe cause an Explosion?

There is a very similar situation with powders in pipes. If the powder is an insulator then charge is transferred between the pipe and the powder in the same way as fuel in pipes (see above). A spark can ignite a powder just like it can ignite a flammable liquid or vapour.
A powder can burn very quickly because it has a very large surface area and this can cause an explosion.

The way to avoid an explosion is the same as above.
Use an earthing strap between the pipe and the earth and any charge can be safely conducted away.

The Uses of Electrostatic Charge.

What are the Uses of Electrostatic Charge?

Electrostatic charge is used in paint spraying (see below) insecticide spraying, inkjet printers, photocopiers and the removal of pollution from industrial chimneys.

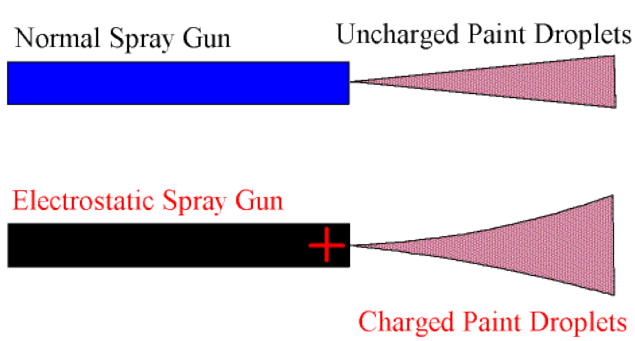
How is Electrostatic Charge used in Paint Spraying?

Millions of cars are made each year and the steel car bodies must all be painted to prevent them from going rusty.
The paint is sprayed onto the car bodies and the process is made more efficient by using electrostatic charge.

The paint spray goes past a high voltage positive needle as it leaves the spray gun and the tiny droplets of paint pick up a positive charge. They do this by losing negative electrons. It is only the electrons which can move.
The car body is then given a high voltage negative charge which attracts the positively charged paint droplets.

This improves efficiency in two ways.

1. The paint droplets spread out more as they leave the gun. This happens because they all get the same positive charge and so they all repel each other. This is better than coming straight out of the gun as the paint will cover a wider area more evenly as shown in the picture below. The same thing happens with insecticide crop spraying.



2. The paint droplets are attracted to the negative metal car body, and so less paint will be wasted by landing on the floor or the walls of the paint shop.

An Inkjet Printer uses Electrostatic Charge.

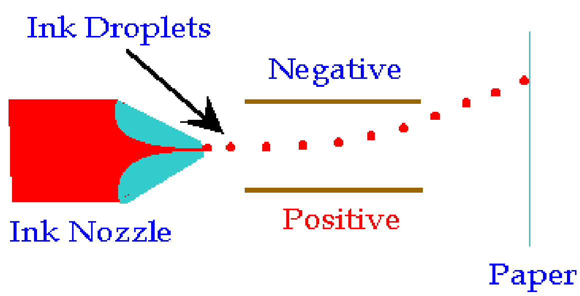
How is Electrostatic Charge used in an Inkjet Printer?

An inkjet printer uses electrostatic charge to direct the tiny ink droplets to the correct place on the page.

Coloured ink is passed through a very small hole called a nozzle which separates the ink into many tiny droplets. The tiny droplets are given an electrostatic charge.

The direction in which the charged ink droplets move can be controlled by electrically charged metal plates. A voltage on the plates means that the charged ink droplets will be attracted to one plate and repelled by the other. This is very similar to a cathode ray oscilloscope where an electron beam is directed to a particular place on a screen.

In the picture below, the ink droplets have a positive charge. The ink droplets are attracted to the negative plate and repelled by the positive plate.



By controlling the voltage on the plates a particular ink drop can be precisely positioned on the paper. There are many nozzles, and the final picture is made up from a very large number of coloured ink drops, each in exactly the right place for the image.

How does a Photocopier work?

How is Electrostatic Charge used in a Photocopier?

A photocopier uses electrostatic charge to produce a copy.

The original (the page you want copied) is placed onto a sheet of glass. An image of this page is projected onto a positively charged drum.

The drum has a coating that conducts electricity when light falls on it. The parts of the drum which are lit by the projected image lose their electrostatic charge when they start to conduct.

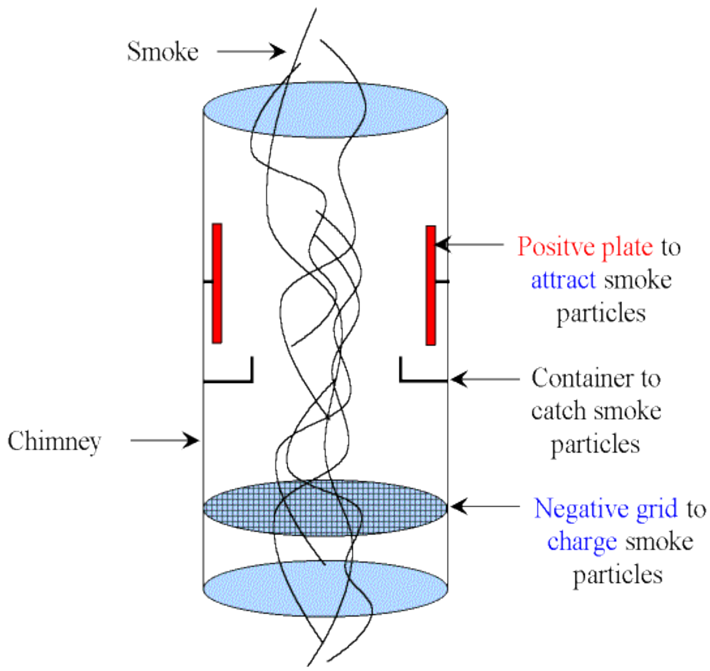
A black powder (called toner) is negatively charged. The toner is attracted to the positively charged parts of the drum.
The drum rotates and rolls against a piece of copier paper. The toner is transferred from the drum to the paper making a black and white image of the original.

Finally, the paper is heated which makes the toner stick to it. This is called "fixing" the image. When you use a photocopier you can feel that the copier paper is still warm.

How can the Pollution from Industrial Chimneys be Reduced?

Pollution from industrial chimneys, for example from a coal burning power station, can be reduced by using electrostatic charge. As well as the waste gases from (carbon dioxide and sulfur dioxide) the chimney contains many small particles of unburnt fuel (mainly carbon).

The chimney has a high voltage negative grid across it and this gives the small particles a negative charge as they go past and gain electrons. Further up the chimney there are positively charged plates which attract the negatively charged particles. The particles of pollution build up on the plates until they are heavy enough to fall down into containers. The containers and the plates are cleaned periodically.



In this way, much of the smoky pollution is removed from the chimney before it can get out into the atmosphere.
Particles in the atmosphere contribute to global dimming.

Using an Electrostatic Charge with an Insecticide Spray.

What is an Insecticide?

An insecticide is a chemical that kills insects.

Why are Crops Sprayed with an Insecticide?

Crops (plants grown for food) are sometimes sprayed from an aircraft with an insecticide to reduce the amount of the crop which gets eaten by insects.

The advantage of spraying crops from an aircraft is that large areas can be sprayed very quickly.

The disadvantage is that it is difficult to control where the spray will fall on the fields. Some parts of the field will receive more insecticide than others. Some insecticide is blown away on the wind and does not fall on the crop at all.

How can an Electrostatic Charge help Crop Spraying?

If the insecticide is given a electrostatic charge as it leaves the aircraft then much more of the spray reaches its target and the spray droplets are spread out more evenly.

This happens because the droplets with an electrostatic charge are attracted to the crop even though the crop is neutral. See the page for neutral objects to explain this.

The insecticide droplets because they all have the same charge and repel each other.

What is Electrostatic Charge?	Answer	
2	How can Insulators be Charged?	Answer
3	Does an Insulator which Gains Electrons get a Negative Charge?	Answer
4	Does an Insulator which Loses Electrons get a Negative Charge?	Answer
5	Can Positive Charges in an Insulator move?	Answer
6	Do Opposite Charges Attract?	Answer
7	Do Opposite Charges Repel?	Answer
8	How does the Force of Attraction depend on the Distance between the Charges?	Answer
9	Why is a Gold Leaf Electroscope enclosed in a Glass Case?	Answer
10	How does the Electroscope show that it is Charged?	Answer
11	How can a Charged Object Attract a Neutral Object?	Answer

The Dangers and Uses of Electrostatic Charge Spray Gun - Inkjet Printer - Photocopier - Chimney		
12	How can you get a Shock by touching a Car Door?	Answer
13	How can Electrostatic Charge be Dangerous when putting Fuel into an Aircraft?	Answer
14	How can the Danger be Avoided?	Answer
15	What is an Earthing Strap?	Answer
16	How can Electrostatic Charge be Useful when Painting Cars?	Answer
17	In an Inkjet Printer, what is a Nozzle?	Answer
18	How are Ink Drops directed to the Correct Place for the Image?	Answer
19	In a Photocopier, what causes parts of the Drum to Lose Electrostatic Charge?	Answer
20	What is the Toner?	Answer
21	How do the Drum and Toner make an Image on the Paper?	Answer

22	How is the Image Fixed on the Paper?	Answer
23	How can Electrostatic Charge Reduce Pollution from a Chimney?	Answer
24	How can Electrostatic Charge improve Crop Spraying?	Answe

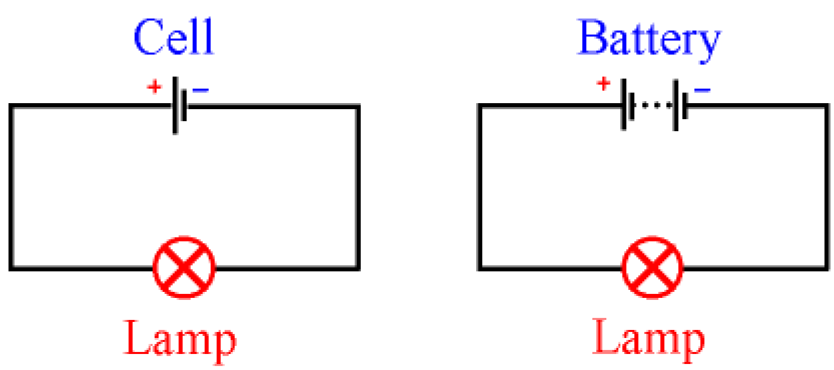
Electricity

What is Electricity?

Electricity is a flow of charged particles. Charged particles can be electrons or ions.

In chemistry, ions which are free to move will conduct electricity during electrolysis.
In physics, we are dealing with electricity as a flow of electrons.
A cell uses chemical reactions to make electricity.

In the circuit below, electricity will flow from the cell (or battery), through the lamp (light bulb) and back to the cell.



There is a difference between a cell and a battery. In every-day life, we use the word "battery".
In physics, one "battery" on its own is called a cell. Two or more cells that are joined together are called a battery.

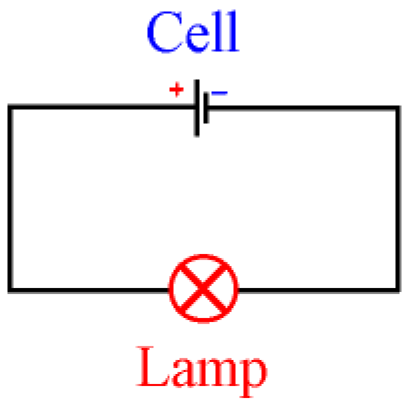
The word "battery" is used to mean "collection". A collection of cells is called a battery of cells.

The cells of a battery are joined together in series. The positive side of one cell touches the negative side of the next cell.

See also what happens to the voltage if cells are in parallel.
What happens to the current if cells are in parallel or in series.

Conventional Current.

A cell is drawn with a long line and a shorter line.
The long line is the positive side (remember plus means more).
The short line is the negative side (remember minus means less).



All electrical circuits are drawn as though electricity flows from positive to negative.
This is called conventional current.

In reality, electricity is a flow of electrons and electrons are negatively charged.
They must therefore flow from negative to positive, since they are repelled from the negative side of the cell and attracted to the positive side. This is called real current.

Why are electric circuits deliberately drawn using conventional current, when we know that this is wrong?
Answer.

Why not real current?

André Ampère (1775 - 1836) was a French physicist and mathematician who made a major contribution to the early work on electricity.
The Amp is named after him.

He realised that electricity flowed from one side of a to the other but this was long before atomic theory had advanced to the level of knowing about electrons and protons.

André guessed that electricity was a flow of positive charge that went from plus to minus. This is called conventional current.
He got it wrong but by the time this was discovered, a large number of electrical circuits had already been drawn and since it makes no practical difference, it was decided to keep the conventional direction of current flow.

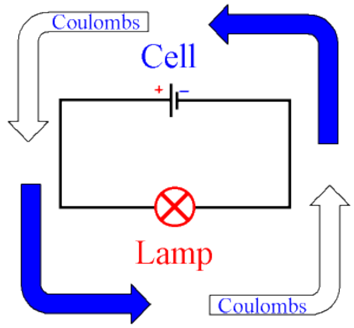
Coulombs

Electrons are very small.
In physics, we take a very very large number of electrons as 1 unit of charge - called a Coulomb.
Charge is given the symbol Q.

1 Coulomb = $6{\cdot}2 \times 10^{18}$ electrons.
(This is 6·2 million million million electrons). Such a large number of electrons can do useful things like light a lamp.

Think of Coulombs as though they are busses, taking a large number of electrons (like passengers) from one side of the cell, through all the in the circuit, and back to the other side of the cell.
The electrons are not used up but keep flowing around the circuit.

This is called direct current.



We need to know the rate of Coulombs flowing around the circuit (how many Coulombs per second) and how much energy each Coulomb has (how many Joules per Coulomb).

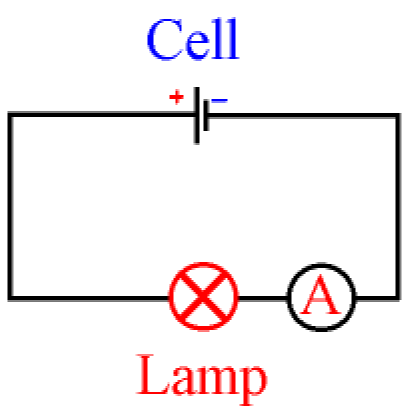
Current – Amps

The "rate of flow of coulombs" (called "current") around an electric circuit is measured in amps.

1 Amp = 1 Coulomb per second.

The word "per" means "divided by",
so current = charge ÷ time.

Current, which is given the symbol I, is shown using an ammeter.



The ammeter, shown as a circle with the letter A inside, is always connected in series with a component.

If the ammeter reads 1 Amp, then the current (I) = 1 Amp at that point in the circuit.
I = 1 Amp = 1 Coulomb per second.

If the ammeter reads 6 Amps, then I = 6 Amps = 6 Coulombs per second.

Charge, which is given the symbol Q, is measured in Coulombs.

So current = charge ÷ time.
$I = Q \div t$

This can be rearranged to give
$Q = I \times t$,
charge = current x time (See equations)

Volts.

Energy is measured in Joules.

The power supply (the cell or battery) gives an amount of energy to each Coulomb going around an electric circuit.
A 6 Volt cell gives 6 Joules of energy to each Coulomb.

1 Volt = 1 Joule per Coulomb.

The word "per" means "divided by", so Voltage = Energy ÷ Charge.

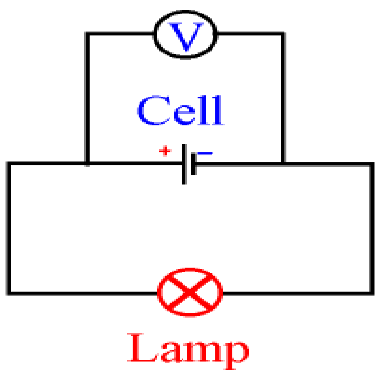
This can be rearranged to give
Energy = Voltage x Charge.   E = V x Q.

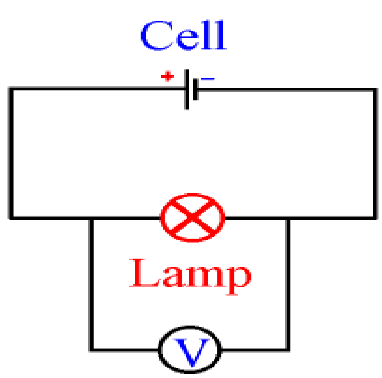
Since Q = I x t, if we write I x t instead of Q in the above equation we get E = V x I x t.
Energy = Voltage x current x time. (see equations).

We can also write Work instead of Energy, so you might see one of the above equations written as Work = Voltage x Charge.   W = V x Q.

Voltage (which is also called potential difference, or p.d.) is an electrical pressure pushing current around a circuit.
Doubling the voltage will double the current.

Voltage is measured using a voltmeter.





The voltmeter, shown as a circle with the letter V inside, is always connected in parallel with the component. (The voltmeter is said to be connected across the component, where the word "across" means "in parallel with").
The circuit on the left would show the voltage of the cell.

The circuit on the right shows the voltmeter connected across a lamp. This will tell you how many Joules of energy are being converted from electrical energy into light energy (+heat) for each Coulomb which passes through it.

A reading of 6 Volts tells you that 6 Joules of energy are being converted for each Coulomb passing through the lamp.

A reading of 10 Volts tells you that 10 Joules of energy are being converted for each Coulomb passing through the lamp.

Watts.

Power is measured in Watts.
Power is an amount of energy supplied in a certain time.

1 Watt = 1 Joule per second.

The word "per" means "divided by",
so Power = energy ÷ time.   P = E ÷ t (see equations).

Since 1 Volt = 1 Joule per Coulomb and 1 Amp = 1 Coulomb per second

then Watts = Volts x Amps,
or Power = Voltage x Current

P = V x I

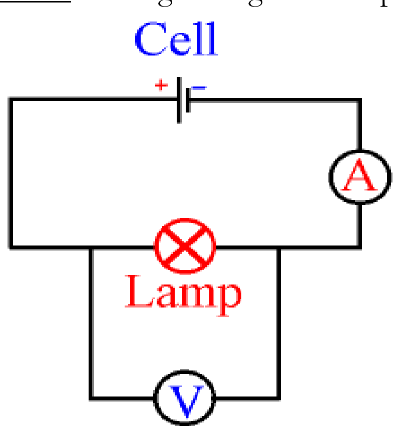
This equation is very important!

On the next page we shall see how to calculate the power of a lamp.

Since from the above, power = energy ÷ time, then   energy = voltage x current x time,
E = V x I x t.

To calculate the power of a lamp.

Firstly, we need to measure the current flowing through the lamp, and the voltage across the lamp.



The circuit above shows where to place an ammeter and a voltmeter. If the ammeter reads 2 A, and the voltmeter reads 6 V,

then   P = V x I
= 6 x 2
= 12 Watts.

The same method can be used to calculate the power of any component.

Resistance.

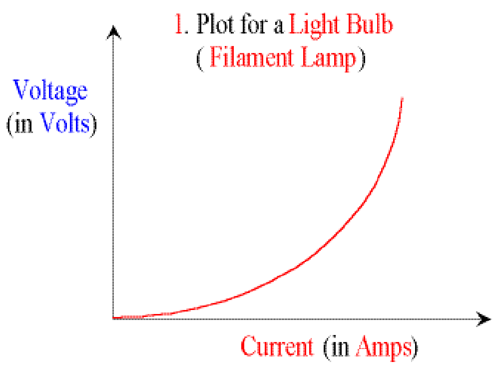
Resistance is measured in Ohms (symbol Ω). Resistance is a measure of how much the current is slowed down. The bigger the resistance, the smaller the current.

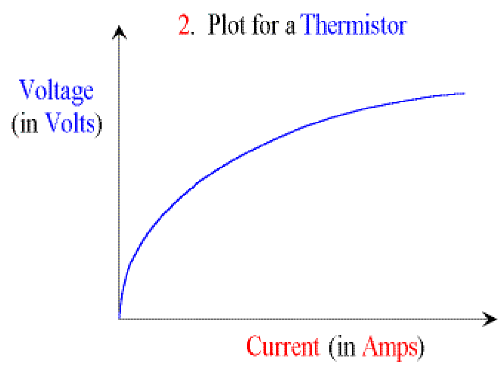
The very important equation

$V = I \times R$ is an expression of Ohm's Law.

If the resistance of a component is constant (stays the same) for different values of V and I, then a plot (graph) of V against I will be a straight line. The gradient (slope) of the line shows how big the resistance is.

This page shows plots for components that don't obey Ohm's Law.



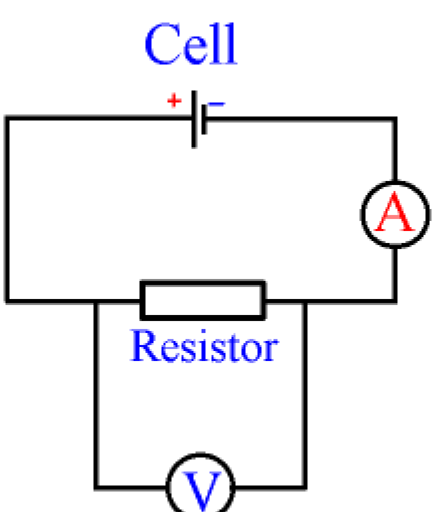


1. The thin wire (filament) inside the light bulb gets very hot when a current flows through it and it glows brightly. This rise in temperature causes an increase in resistance of the filament, and so the gradient (slope) of the plot is seen to increase.

2. A thermistor is a special type of resistor which has been deliberately manufactured so that its resistance decreases as its temperature rises.

To calculate the resistance of a resistor.
A resistor converts electrical energy into heat (see resistance of wires).

Firstly, we need to measure the current flowing through the resistor, and the voltage across the resistor.



The circuit above shows where to place an ammeter and a voltmeter. If the ammeter reads 2 A, and the voltmeter reads 6 V,

then V = I x R

R = V ÷ I
= 6 ÷ 2
= 3 Ohms.

The same method can be used to calculate the resistance of any component.

Test Circuit for a Component.

Anything in an electric circuit (lamp, resistor, motor, diode etc.) is called a component. Each component has its own circuit symbol.

A test circuit can be used to find the characteristics of a component.

A variable resistor
(sometimes called a rheostat when placed in series in a circuit) can change the amount of current flowing through the component, and the voltage across it it.

Values obtained from the voltmeter and ammeter are used to plot the graphs shown on the previous pages. The shape of the graph describes the characteristics of the component

Series and Parallel.

So far we have looked at only one component in a circuit with meters.
When more than one component is used in a circuit, there are two different ways of connecting them and these are called series or parallel.

There are different rules for series and parallel circuits and you must know these rules.

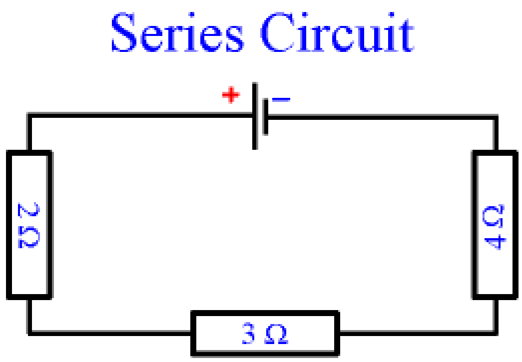
Rules for a series circuit.

Rules for a parallel circuit.

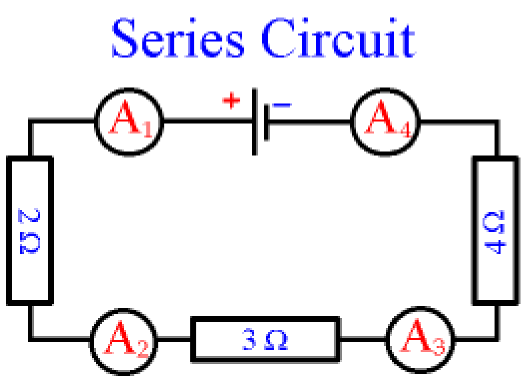
Rules for a Series Circuit.

When components are connected one after another in a ring, the components are said to be in series with each other and the circuit is called a series circuit.

Below is a series circuit shown with three different resistors.



The current in a series circuit is the same everywhere.



An ammeter placed anywhere in a series circuit always gives the same reading.
In the circuit above, $A_1 = A_2 = A_3 = A_4$.

What happens to the current if cells are placed in series?

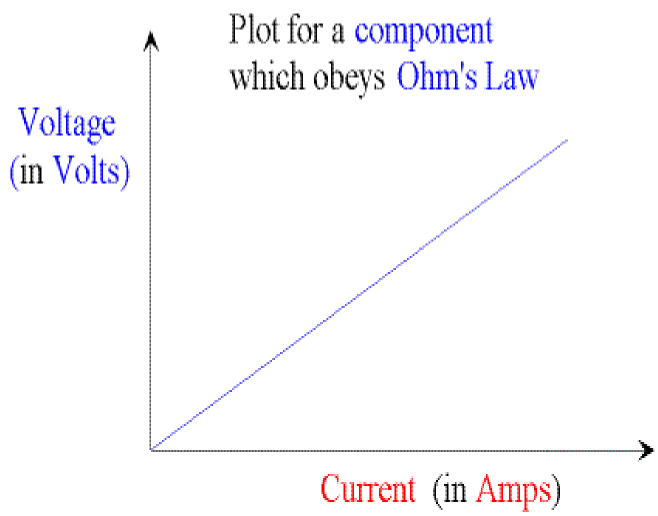
If an identical cell (battery) is placed in series with the original cell the current doubles because the total voltage of the circuit doubles.
However, two cells together provide electricity for only the same amount of time as one cell before they both run out.

See also what happens to the current if cells are in parallel.
What happens to the voltage if cells are in series or in parallel.

1. Current in a series circuit.

2. Voltage in a series circuit.

3. Resistance in a series circuit.



A test circuit is used to find a range of voltages and currents for a component.

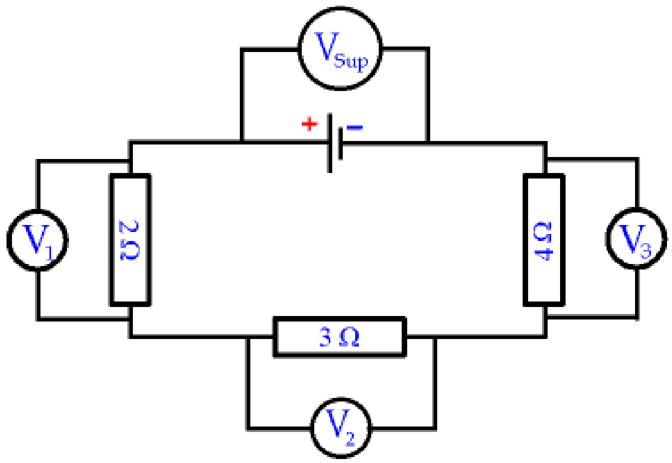
Components which obey Ohm's Law are Wires and Resistors.
A component will only obey Ohm's Law at constant temperature (meaning that the temperature must not change).

In reality, an increase in current through a component will change its temperature (the temperature usually goes up), and so Ohm's Law is only an approximation but it works quite well for many components.
The next page shows plots (graphs) for components which don't obey Ohm's Law.

Voltage in a Series Circuit.

1. The voltage for each component depends on its resistance.

   To calculate the voltages below, we need to know the total resistance of the circuit, and the current flowing through it.



2. The voltage across all of the components adds up to the supply voltage from the cell (or battery). In energy terms, the work done by the cell on each coulomb of charge equals the work done on the components of the circuit.

$V_{sup} = V_1 + V_2 + V_3$.
The supply voltage is divided (shared) between the components. If there is a change in the resistance of one component then the voltage across all of the components will change.

What happens to the voltage if cells are placed in series?

If more cells (batteries) are connected together in series the total voltage is the sum of the individual voltages for each cell
(provided they are connected the right way round, plus to minus).

If an identical cell is placed in series with the original cell in the circuit above, then the voltage doubles. However, two cells together provide electricity for only the same amount of time as one cell before they both run out.

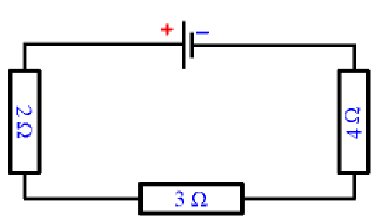
See also what happens to the voltage if cells are in parallel.
What happens to the current if cells are in parallel or in series.

Resistance in a Series Circuit.

You can calculate the total resistance of a series circuit by adding up the resistance of each component.

$R_{total} = R_1 + R_2 + R_3$.

Series Circuit



In the above circuit,

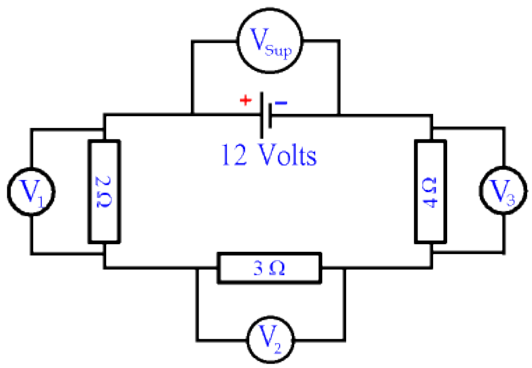
$R_{total} = 2 + 3 + 4$

$= 9$ Ohms.

Calculation of Voltages and Current in a Series Circuit.

If the supply voltage (from the cell) is 12 Volts, what are the voltages across each resistor?

From the previous page, the total resistance of the circuit below is 9 Ohms.



We can use $V = I \times R$ to find the current, which in a series circuit is the same everywhere.

$I = V X R$
$= 12 X 9$
$= 1{\cdot}333$ Amps.

Using the same equation $V = I \times R$ for each resistor in turn
(and rounding up numbers) gives

$V_1 = 1{\cdot}333 \times 2$
$= 2{\cdot}667$ Volts.

$V_2 = 1{\cdot}333 \times 3$
$= 4{\cdot}000$ Volts

$V_3 = 1{\cdot}333 \times 4$
$= 5{\cdot}333$ Volts

You must always say what the units are at the end of the calculation. If you write $V_3 = 5{\cdot}333$ without putting the word "Volts" afterwards, you will lose a mark in the exam.

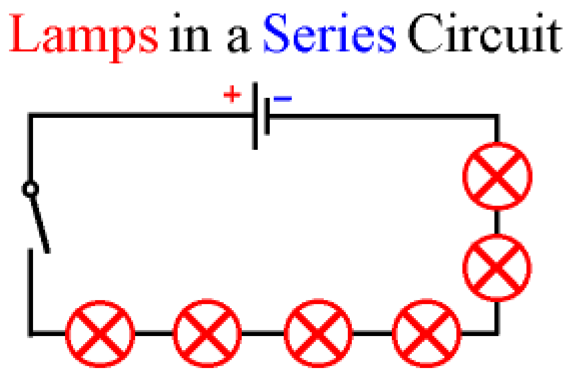
We can see that the largest resistor (4 Ohms) has the largest voltage (5·333 Volts) and the smallest resistor (2 Ohms) has the smallest voltage (2·667 Volts) across it.
In energy terms, the largest amount of work is done by the charge moving through the largest resistance.

Finally, we can check that the voltage for all of the components
adds up to the supply voltage.

$V_1 + V_2 + V_3 = 2{\cdot}667 + 4{\cdot}000 + 5{\cdot}333$
$= 12$ Volts.

Switches and Lamps in Series Circuits

An open switch in a series circuit will turn everything off, because the circuit will be disconnected from the cell.

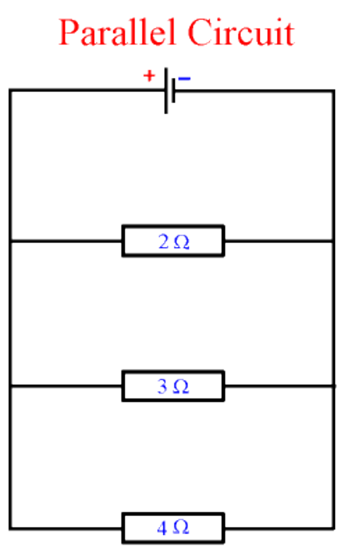


When lamps are connected in series, the more lamps in the circuit the dimmer they get, because the voltage is divided between them.

If one lamp in a series circuit breaks or fails, all the others will go out with it.
For this reason, lamps are always connected in parallel.
The exception is Christmas Tree Lights or Fairy Lights, where the large mains voltage is conveniently divided between the lamps.

Rules for a Parallel Circuit.

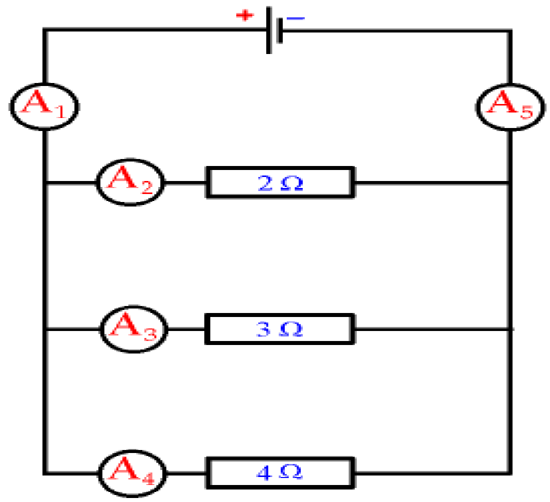
Below is a parallel circuit shown with three different resistors.



1. The current in a parallel circuit depends on the resistance of the branch.

2. The total current flowing in to the branches is equal to the total current flowing out of the branches.
$A_1 = A_5$

Parallel Circuit



1. The current at A_2 flowing through the 2 Ohm resistor can be found using V = I x R

If the supply voltage is 12 Volts,

I = V X R

= 12 X 2 = 6 Amps.

You would get the same answer for the 2 Ohm resistor, whether or not the other resistors are connected in the circuit.
For parallel circuits, each component behaves as if it is connected independently to the cell, and is unaware of the other components - see Lamps
(continued on the next page).

What happens to the current if cells are placed in parallel?

If an identical cell (battery) is placed in parallel with the original cell, the current stays the same because the total voltage of the circuit is the same.
The two cells together provide electricity for twice as long before they both run out.

See also what happens to the current if cells are in series.
What happens to the voltage if cells are in series or in parallel.

From the previous page, the current A_2 flowing through the 2 Ohm resistor is 6 Amps.

The current A_3 flowing through the 3 Ohm resistor is

I = V X R

= 12 X 3

= 4 Amps.

The current A_4 flowing through the 4 Ohm resistor is

I = V X R

= 12 X 4

= 3 Amps.

Notice that the bigger the resistance, the smaller the current.

The total current A_1 or A_5 is found by adding up the current in each branch.

$A_1 = A_2 + A_3 + A_4$

= 6 + 4 + 3

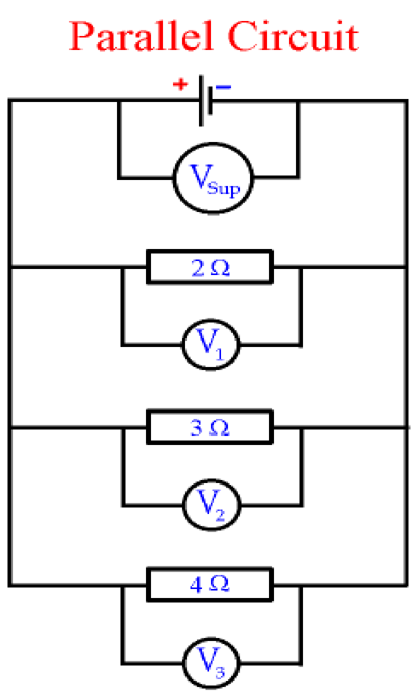
= 13 Amps.

This is much larger than the current of 1·333 Amps which flows through a series circuit with the same resistors and supply voltage.
See also Resistance in parallel circuits.

Voltage in a Parallel Circuit.

1. The voltage in a parallel circuit is the same for all branches.

$V_1 = V_2 = V_3$.



2. The voltage for each branch is the same as the supply voltage.

$V_1 = V_2 = V_3 = V_{sup}$.

What happens to the voltage if cells are placed in parallel?

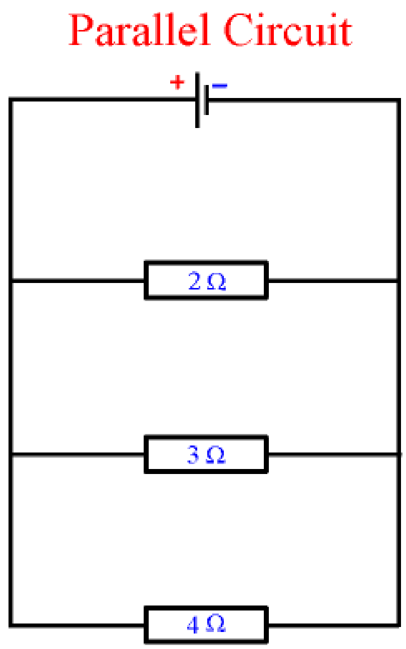
If an identical cell (battery) is placed in parallel with the original cell, the voltage stays the same.
The two cells together provide electricity for twice as long before they run out.

See also what happens to the voltage if cells are in series.
What happens to the current if cells are in parallel or in series.

Resistance in a Parallel Circuit.

The total resistance of a parallel circuit is calculated using the formula

$^1/_R = {}^1/_{R1} + {}^1/_{R2} + {}^1/_{R3} \cdots\cdots$



In the above circuit,

$^1/_R = {}^1/_2 + {}^1/_3 + {}^1/_4$

$= {}^6/_{12} + {}^4/_{12} + {}^3/_{12}$

$= {}^{13}/_{12}$

$R = {}^{12}/_{13}$

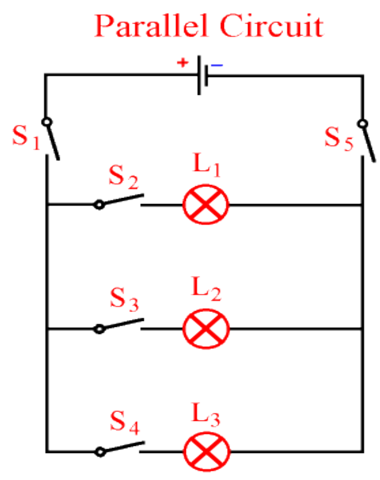
$= 0{\cdot}92$ Ohms.

Notice that this is a much smaller resistance than you get in the series circuit using the same resistors.

It is even smaller than the smallest resistor in the parallel circuit, which is 2 Ohms.
Putting more resistors in the parallel circuit decreases the total resistance because the electricity has additional branches to flow along and so the total current flowing increases.

Switches and Lamps in a Parallel Circuit.

A switch at S_1 or S_5 will switch all the lamps off and on together if all the other switches are "closed" which means "on".



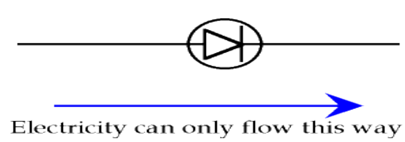
With S_1 and S_5 closed, the switch at S_2 will only light the lamp at L_1. This is very useful because it means that we can switch the lamp off and on independently (without affecting the other lamps).
For this reason lamps are always connected in parallel (except fairy lights for Christmas trees or other occasions).
Also, the brightness of the lamp at L_1 does not change as other lamps in parallel are switched on or off.

Similarly, the switch at S_3 will only operate the lamp at L_2. The switch at S_4 will only operate the lamp at L_3.

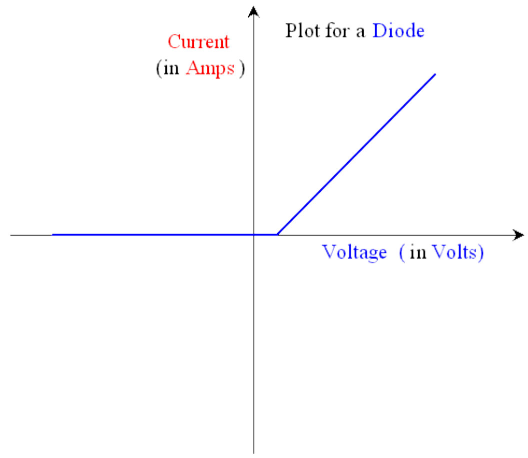
Diode.

A diode will allow electricity to pass through it in one direction only.

The circuit symbol is like an arrow pointing to a bar.
Electricity can only pass in the direction in which the arrow points.
The diode has a very big resistance in the reverse direction.



A graph of the characteristics of the diode are shown below.



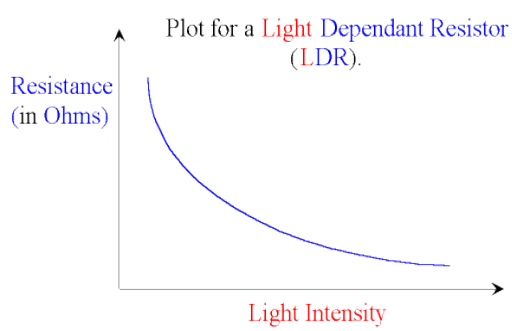
The graph does not go through the origin because a small voltage is needed before the diode starts to conduct electricity and allow a current to flow.

The diode is mainly used in circuits with alternating current.

Light Dependant Resistor.

As the name suggests, a light dependant resistor (LDR) is a component whose resistance changes when the amount of light falling on it (called the light intensity) changes.

All you need to remember is that the resistance goes down as the amount of light goes up.
Resistance decreases as light intensity increases, light is low, dark is high (resistance).



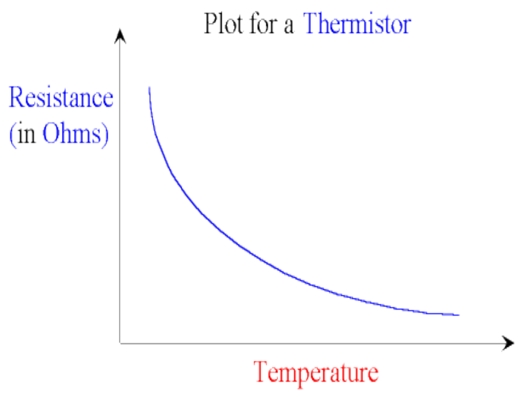
The LDR can be used in a circuit to automatically switch lights on at night (see relay).

Thermistor.

For most components, the resistance rises as the temperature rises.

A thermistor is a special type of resistor which has been deliberately manufactured so that its resistance decreases as its temperature rises.
A plot of its characteristics (a voltage against current graph) has already been shown.

A plot of resistance against temperature is given below.



The thermistor can be used in a circuit that senses a temperature change. A thermistor can be used where a constant temperature is needed, in a commercial freezer for example.
It can trigger an alarm if the temperature gets too high or too low.
A thermistor can also be used to trigger a fire alarm.

What is Mains Electricity?

The electricity that comes into your house through the wall sockets is called mains electricity.
It is different from the electricity that comes from cells in two important ways.

1. It is alternating current (a.c.)

2. It is at a much higher voltage (it can kill you!).

Mains electricity in the UK is supplied at 230 Volts.
In the USA it is 110 Volts.
A cell or battery is typically 1·5 to 12 Volts, which is much less dangerous.

We are familiar with direct current circuits where the electrons flow from one side of the cell, through all the components and return to the other side of the cell.

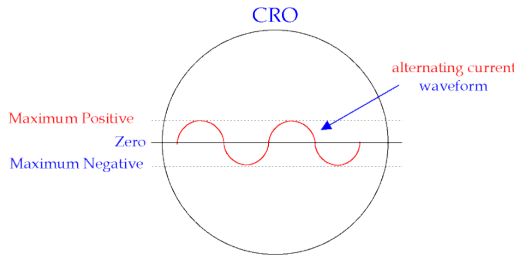
With alternating current (symbol a.c.) the electrons first start to flow in one direction until the current reaches a maximum value, then the current slows down and stops.
The electrons then start to flow in the opposite direction until the current reaches the same maximum value (but it is now given a minus sign to show it is in the opposite direction), then the current again slows down and stops.
This whole cycle then repeats itself over and over again.

The number of cycles in one second (called the frequency) is given in a unit called Hertz (symbol Hz) where 1 Hz = 1 cycle per second.
Mains electricity in the UK is supplied at 50 Hz (50 cycles per second). In the USA it is 60 Hz.

Continued on the next page.

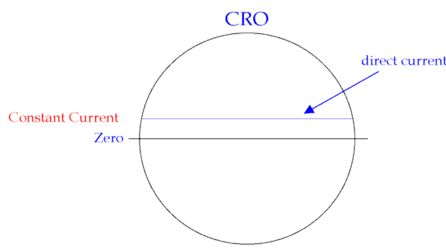
All of the equations which relate to direct current circuits also apply to alternating current circuits, so that voltages, currents, power etc. can be calculated in the same way.

If an alternating current supply is connected to a cathode ray oscilloscope (called a CRO), the display shows a wave as the current changes from maximum positive to maximum negative.



Two complete cycles of the wave are shown on the CRO.
Where the wave goes above the zero line, the current flows forwards.
Where the wave goes below the zero line the current flows backwards.

If a direct current supply is connected to the CRO, the display shows a single straight line which represents a constant current in one direction only.



Mains Electricity - Household Uses.

There are a large number of appliances which use mains electricity. An appliance is a useful arrangement of electrical components. Appliances include cookers, heaters, lighting, TV, computers, DVD, music systems and printers.

The first two, cookers and heaters, can use other types of energy, for example gas.
Lighting today is almost entirely powered by electricity but in the past, gas lamps and candles were used.
The alternating current of mains electricity can be used directly to power cookers, heaters and lighting. They all depend on the heating effect of current passing through a wire.

The last five, TV, computers, DVD, music systems and printers must use direct current electricity.
The alternating current of mains electricity must first be turned into direct current by using an arrangement of diodes, which allow electric current to flow in one direction only.
The voltage is usually stepped down to 12 volts or less by using a suitable transformer.

Mains Electricity - The Three Wires - Do Not Touch.

The UK mains electricity supply has three wires. They are called Live, Neutral and Earth and each wire has its own colour.
Live is Brown, Neutral is Blue, Earth is Green and Yellow stripes.

The Live wire is connected directly to the generators of the electricity supply company.
NEVER touch this wire, it carries 230 Volts and can kill you!!

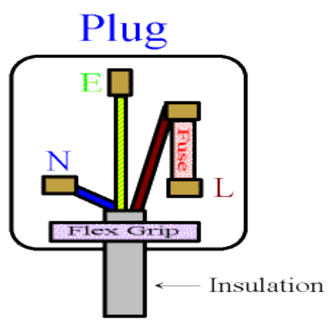
The Neutral wire returns the electricity to the generator after it has passed through the appliance, to complete the circuit.
The Neutral wire is at approximately zero volts but you must NEVER touch this wire either!! If the wiring is faulty it may be carrying the same electricity as the Live wire.

The Earth wire usually carries no electricity, it is there as a safety device.
If something in the appliance goes wrong, or it is wired incorrectly, then the Earth wire may be carrying the same electricity as the Live wire. To be completely safe, NEVER touch this wire either!!

UK Mains Electricity - How to wire a 3-pin Plug.

The three wires are contained in a plastic outer covering (called the flex) which acts as insulation.
The outer covering is held inside the plug by a flex grip.

Each wire has its own coloured insulation, to show if it is Live, Neutral or Earth (see previous page).
The wire inside is made of copper, which is an excellent conductor. The copper wire is held inside the brass pin of the plug by a small screw.



The Live wire is always connected to the Live pin of the plug by a fuse.

Mains Electricity - Insulation.

Insulation means putting something which does not conduct electricity (an insulator) between a live conductor and yourself.

Any metal is a conductor of electricity.
Any non-metal is an insulator, with the exception of graphite which conducts electricity because of its unusual molecular structure.
If you do not know what is a metal and what is a non-metal, see the GCSE Chemistry site at the periodic table.

The wires which we use to conduct electricity are made of a high purity copper metal, which is an excellent conductor.

The insulator which covers the wires is a polymer called PVC (often just called "plastic"). It is an excellent insulator, flexible enough to bend around corners and cheap to make.
Older wires had a rubber material as their insulation but the rubber cracked and split as it got older and so it has been replaced in houses by new PVC covered cable.
This is an example of a new material replacing an older one because the new material has superior properties.

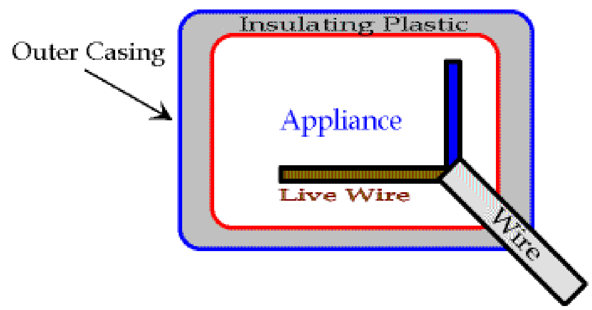
Insulation can become unsafe if it is damaged or if it is wet because impure water will conduct electricity.

Some appliances are double insulated.

Mains Electricity - Double Insulation.

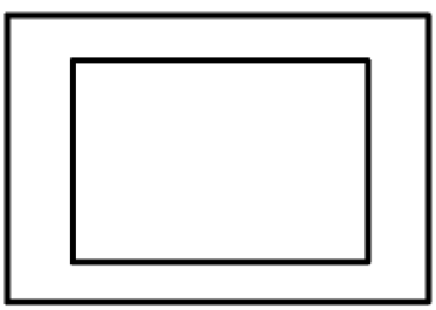
Some appliances are double insulated.
These appliances only need Live and Neutral wires, they do not need an Earth wire.

An appliance which is double insulated has the whole of the inside contained in plastic, underneath an outer casing.
If anything goes wrong with the appliance, no Live conductor can touch the outer casing because of the insulating plastic.



Appliances which are double insulated include electric drills and hairdryers.

The symbol for double insulation is shown below.

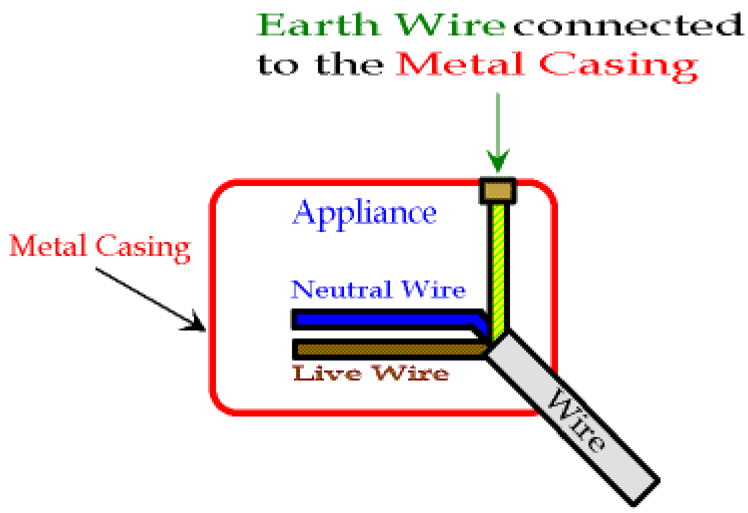


You will see this symbol printed on the appliance which is double insulated.

Mains Electricity - Earthing.

If the outer casing (the outside bit) of an appliance is a conductor (made of metal), then it can be made safe by Earthing.

The Earth wire usually carries no electricity, it is connected to the metal case on the inside of the appliance.



If something goes wrong inside the appliance and the Live wire touches the metal case, then the Earth wire acts like a Neutral wire and completes the circuit for the electricity.
A very large current suddenly flows because the metal case has little resistance.
This large current blows the fuse in the plug and disconnects the appliance from the power supply.

Mains Electricity - What is a Fuse?

A fuse is a safety device which switches off an appliance if too large a current flows through the Live wire (see also MCB). The fuse is connected between the Live pin and the Live wire of a plug.

The fuse has a rating printed on the outside in amps.
If the current going through the fuse rises above its rated value, then the fuse "blows" (it melts) which turns off the appliance.
For example, if the fuse says 5 amps, then a current greater than 5 amps will blow the fuse.

Fuses are given different colours for different ratings.
This is called colour coding.

A 3 amp fuse is red,
5 amp is black (or very dark blue),
13 amp is brown.

A fuse has its own circuit symbol.

To understand how a fuse works in more detail, we must look at the Heating Effect of Current.

The Heating Effect of Current.

When we looked at Ohm's Law, it was mentioned that a component usually gets hotter when a current flows through it.

The wires which link the components of a circuit also get hotter with increasing current.
The more current passing through the wire, the hotter it gets.

A very hot wire might melt or set fire to the insulation that covers it.
e is a thin piece of wire which is manufactured to melt when a certain current (called its rating) passes

through it.
In this way the fuse protects the rest of the circuit from the damage caused by too high a current.

To find the reason why current has a heating effect, we must look at the resistance of the wire itself.

The Resistance of Wires - Theory.

When we see a circuit with its components, we usually assume that the wires which connect the components and complete the circuit have a resistance of zero Ohms.
This is often a good approximation, since the resistance of the wire is much less than the resistance of a lamp or a motor.

However, any wire has at least a small resistance. When electrons move through the wire, some electrons collide with the atoms of the material in the wire. This causes resistance.
Each collision loses some energy to the wire as heat.

When a large current flows there are a larger number of collisions and this causes the wire to get hot.
This is how a lamp and a fuse works.
A wire, like a resistor, turns electrical energy into heat energy.

Resistance also depends on the temperature of the material. As the temperature of the material increases the atoms of the material vibrate more and this increases the number of collisions with electrons moving through the wire.

The Resistance of Wires - Material.

The resistance of a wire depends on the material from which the wire is made.

Nearly all wires are made of metal, since metals are good conductors of electricity.
Some metals are better conductors than others.

Wires are usually made from copper or aluminium which both have a very low resistance.
Wires made from iron or steel have a higher resistance.

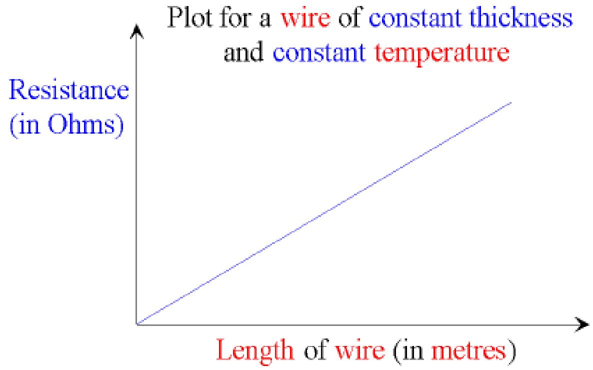
Alloys (metal mixtures) can be made which have a very high resistance. These can be useful for making variable resistors.

The Resistance of Wires - Length.

The resistance of any wire depends on its length. This makes sense if you consider that however hard it is for electricity to flow through 1 metre of the wire, it must be twice as hard to flow through 2 metres and 3 times as hard to flow through 3 metres etc.

As long as everything else about the wire remains the same (material, thickness and temperature) then resistance is directly proportional to the length of wire.
Doubling the length will double the resistance.

If we plot this on a graph, we get a straight line as shown below.



The Resistance of Wires - Thickness.

The resistance of a wire depends on its thickness. The thinner the wire, the higher its resistance. You must use thick wire to carry a large current, or the wire will get too hot and melt.

The relationship between resistance and thickness is not straightforward.
Halving the thickness does not double the resistance (compare this with the relationship to length).
It is the cross-sectional area of the wire, not its thickness, which directly affects its resistance.

The cross-sectional area is what you get if you cut straight through the wire, at right angles to its length, and look at the cut surface.
If the wire is round (most wires are), then the cross-section is a flat circle and the area is pr^2.
Doubling the area will halve the resistance.

The Resistance of Wires - Temperature.

The resistance of a wire increases as its temperature increases.

A small increase in temperature may not give a noticeable change in resistance but the more the temperature rises, the more obvious it becomes that the resistance is also rising.

This can be clearly seen in the Voltage against Current plot for a lamp.
The thin wire inside the lamp (called the filament) becomes white hot, which causes the lamp to shine.
The increase in resistance can be seen by the curved line in the plot.

Mains Electricity - Bills.

If you look at a domestic electricity bill, you will see that there are two meter readings.
One is the present reading and the other is the previous (last) reading. Subtracting the previous reading from the present one gives the number of units used in that 3 Month period.

Electricity is priced in pence per unit. Multiplying the number of units used by the price per unit gives the cost of electricity for that period. Other costs may then be added, such as the standing charge (which must be paid no matter how much electricity you use, for the convenience of being connected), and VAT which is a tax collected by the government.

One unit of electricity is 1kWh (one kilowatt-hour), kilo means thousand, so one kilowatt-hour is the amount of electricity used by a 1000W appliance running for 1 hour.

1 Watt is 1 Joule per second, 1000W = 1000J per s.
1 hour = 60 x 60 seconds, = 3600 seconds.
Therefore, 1kWh = 1000 x 3600 Joules,
= 3,600,000 Joules of energy.

Note that a kWh is a unit of energy, not power.

Radioactivity

What is Radioactivity?

Sometimes the nucleus of an atom is unstable. A change will occur in the nucleus to make it more stable. The change is called a decay. When a nucleus decays it will emit (give out) some particles or waves. Emitting particles or waves from the nucleus is called radioactivity.
Radioactive decay is a random process which gives out heat.

The particles or waves that are emitted (see below) are called radiation. The same word radiation is also used for some electromagnetic waves which have not come from radioactive decay.

What are the Three Types of Radioactivity?

There are three types of radioactivity, called alpha, beta and gamma. A radioactive nucleus will emit either an alpha particle or a beta particle or a gamma ray. After an alpha particle or a beta particle has been emitted from a nucleus, the atomic number of the atom will have changed. The atom will have changed into a different element. An alpha or beta emitter might also emit gamma radiation.

Is Radioactivity Good or Bad?

Radioactivity can be both harmful and useful.

For example, the rate of decay (called the half-life) can be used to find out how old things are.
The energy released from a nucleus during fission can be used to generate electricity.

Radioactivity can cause damage to living cells leading to cancer.

What are Radioactive Nuclei?

What is in the Nucleus of an Atom?

The nucleus of an atom contains protons and neutrons. Protons are all positively charged and repel each other. The protons in the nucleus are held together by a force called the strong nuclear force (or strong interaction).

Protons and neutrons are sometimes called nucleons.
The number of protons is called the atomic number.
The number of protons plus neutrons is called the mass number.
The mass number is sometimes called the nucleon number.
See further information for a more detailed description of an atom.

What are Radioactive Isotopes?

Isotopes of an element can exist where the atoms have different numbers of neutrons.
A stable atom will have a stable number of neutrons.
For small atoms (containing less than 20 protons) a stable atom will have approximately the same number of protons and neutrons. An atom which is very different from this will be unstable.

The unstable nucleus will decay and emit radioactivity.
Radioactive nuclei are also called radioactive isotopes, radioisotopes and radionuclides (they all mean the same thing).
After the decay, the nucleus will have changed into a more stable form. The atomic number will have changed and a new element is formed (see some examples).

The Three Types of Radioactivity.

	Charge	Mass	Penetration	Ionising
Alpha	+ 2	4	Least	Most
Beta	- 1	Tiny	Intermediate	Intermediate
Gamma	0	0	Most	Least

The above table shows a summary of the properties of the three types of radioactivity.

Alpha Particles

What is an Alpha Particle?

An alpha particle (also written as α-particle) consists of 2 protons and 2 neutrons. An alpha particle is the same thing as the nucleus of a helium atom.

It is written ${}^{4}_{2}He$ or ${}^{4}_{2}\alpha$

What are the Properties of an Alpha Particle?

1. An alpha particle has a because the 2 protons have a positive charge.

2. An alpha particle has by far the most mass of the three types of radioactivity. It is the type most likely to collide with other atoms which means that

(i) alpha particles have the least penetrating ability of the three types and are easily absorbed by paper, skin or a few centimetres of air.

(ii) alpha particles are the most ionising of the three types.

Where do Alpha Particles come from?

Alpha particles are most likely to be emitted during the decay of heavy nuclei which have a large number of protons and neutrons.
After an alpha particle has been emitted the atomic number and the mass number changes and a new element is made (see examples).

How can the Direction of an Alpha Particle be Changed?

The positive charge on the alpha particle means that it will be deflected by a magnetic field or an electric field (like the charged droplets in an inkjet printer).
An alpha particle will be deflected less than a because the alpha particle has a bigger mass.
An alpha particle has a positive charge and will be deflected in the opposite direction from a beta particle which has a negative charge

Examples of Radioactive Decay and Nuclear Equations.

Alpha Particles from Radioactivity.

What happens when an Alpha Particle is Emitted from a Nucleus?

After a radioactive nucleus has emitted an alpha particle, the mass number goes down by 4 and the atomic number goes down by 2.
This change in the atomic number produces a different element.

What is a Nuclear Equation?

A nuclear equation shows the change in the mass number and the atomic number during a radioactive decay.

Radium (Ra) becomes radon (Rn) after emitting an alpha particle.

$$^{224}_{88}\mathrm{Ra} \longrightarrow {}^{220}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$$

The nuclear equation is balanced because the mass number on the left of the arrow is equal to the sum of the mass numbers on the right of the arrow, 224 = 220 + 4.
Similarly for the atomic numbers, 88 = 86 + 2.

How to find the New Element in a Nuclear Equation.

Radon (above) is itself radioactive and decays by alpha emission.

$$^{220}_{86}\mathrm{Rn} \longrightarrow {}^{4}_{2}\mathrm{He} + \ ?$$

You can work out what the new element is by balancing the equation.
220 = 4 + 216,   86 = 2 + 84.
The element with atomic number 84 is polonium (Po)
(see the periodic table)

The balanced nuclear equation is

$$^{220}_{86}\mathrm{Rn} \longrightarrow {}^{4}_{2}\mathrm{He} + {}^{216}_{84}\mathrm{Po}$$

If you are given the two elements, you can work out which particle is emitted by balancing the equation.

What is a Decay Series?

Polonium (see the 2 equations above) is also radioactive and decays to form other radioactive nuclei.
One element turning into another which turns into another which turns into another etc. is called a decay series.
Eventually a stable nucleus is formed and the decay series stops.
The stable nucleus is often often lead (atomic number 82, mass number 206, 207 or 208).

Beta Particles.

What is a Beta Particle?

A beta particle (also written as β-particle) is the same as an electron. It is often called a high energy electron because it is very fast moving.
A beta particle comes from the nucleus of an atom! It has a charge of -1 and very little mass (only 1 ÷ 1840 as big as a proton).

It is written $^{0}_{-1}e$ or $^{0}_{-1}\beta$

The e shows that the particle is an electron.
A beta particle is given a mass number of zero because the mass is very small compared to a proton or a neutron.

What are the Properties of a Beta Particle?

1. A beta particle has a negative charge because it is an electron.

2. A beta particle has less mass than an alpha particle but more mass than a gamma ray. See the three types of radioactivity.
This means that

(i) beta particles have more penetrating ability than alpha particles but less penetrating ability than gamma rays.

(ii) beta particles are less ionising than alpha particles but more ionising than gamma rays.

Where do Beta Particles come from?

Beta particles may be emitted from the nucleus during the decay of either big or small nuclei. See some examples.

How can the Direction of a Beta Particle be Changed?

The negative charge on the beta particle means that it will be deflected by a magnetic field or an electric field (like the charged droplets in an inkjet printer). A beta particle will be deflected more than an alpha particle (because of its smaller mass) and in the opposite direction (because of its negative charge).

Beta Particles from Radioactivity.

What happens when a Beta Particle is Emitted from a Nucleus?

After a radioactive nucleus has emitted a beta particle, the mass number stays the same and the atomic number goes up by 1.

A neutron in the nucleus has changed into a proton plus an electron.
The proton stays inside the nucleus but the electron is emitted as a beta particle.
The change in the atomic number produces a different element.

Nuclear Equations for Beta Particle Emitters.

In the nuclear equation below, carbon-14 becomes nitrogen-14 by emitting a beta particle.

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

The nuclear equation is balanced because the mass number on the left of the arrow is equal to the sum of the mass numbers on the right of the arrow, 14 = 14 + 0.
Similarly for the atomic numbers, 6 = 7 - 1.

Using a Nuclear Equation to find which Particle is Emitted.

Some nuclei can decay by emitting either an alpha particle or a beta particle. An example is bismuth where $^1/_3$ of the atoms emit an alpha particle and $^2/_3$ of the atoms emit a beta particle.

You can work out which particle is emitted by balancing the equation.

$$^{212}_{83}Bi \longrightarrow {}^{208}_{81}Tl + ?$$

In the nuclear equation above, the mass number of the unknown particle is 212 - 208 = 4.
The atomic number of the unknown particle is 83 - 81 = 2.
The particle that has a mass number 4 and atomic number 2 is an alpha particle.

What Element would be formed if Bismuth emitted a Beta Particle?

Answer - it would have a mass number 212 and atomic number 84. This element is polonium.

$$^{212}_{83}Bi \longrightarrow {}^{0}_{-1}e + {}^{212}_{84}Po$$

This form of polonium and the form shown on page 6 are isotopes.

Gamma rays.

What is a Gamma Ray?

A gamma ray (also written as □ -ray) is an electromagnetic wave. It is at the small wavelength end of the electromagnetic spectrum.
A gamma ray has no mass and no charge.

It is written ${}^{0}_{0}\gamma$

Emitting a gamma ray makes no difference to the mass number or the atomic number but will make the nucleus more stable.

What are the Properties of a Gamma Ray?

1. A gamma ray has no charge (see above).

2. A gamma ray has no mass. Of the three types of radioactivity a gamma ray the least likely to collide with other atoms which means that

(i) gamma rays have the most penetrating ability and are not easily absorbed. Many centimetres of lead or a few metres of concrete will absorb most gamma rays but some will still get through.

(ii) gamma rays are the least ionising radiation.

Where do Gamma Rays come from?

Gamma rays are likely to be emitted at the same time as alpha particles or beta particles but some isotopes only emit gamma rays (see some examples).

How can the Direction of a Gamma Ray be Changed?

Unlike an alpha particle or a beta particle, a gamma ray is not deflected by a magnetic or electric field because it has no charge.

Gamma Rays from Radioactivity.

What happens when a Gamma Ray is Emitted from a Nucleus?

When a radioactive nucleus emits an alpha particle or a beta particle, the protons and neutrons in the new nucleus may not be in their most stable arrangement. The protons and neutrons can rearrange themselves to become more stable and in this process energy is emitted in the form of gamma rays.

Nuclear Equations for Gamma Ray Emitters.

Below are examples of nuclear equations where both alpha and beta emitters give off gamma rays.

$$ {}^{238}_{92}\mathrm{U} \longrightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He} + {}^{0}_{0}\gamma $$

$$ {}^{90}_{38}\mathrm{Sr} \longrightarrow {}^{90}_{39}\mathrm{Y} + {}^{0}_{-1}\mathrm{e} + {}^{0}_{0}\gamma $$

The nuclear equations above are balanced.

One form of protactinium-234 (chemical symbol Pa) is an example of a radioactive nucleus which only emits gamma rays.

$$ {}^{234}_{91}\mathrm{Pa} \longrightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{0}\gamma $$

The gamma rays do not change the mass number or atomic number.

Penetrating Ability.

What is Penetrating Ability?

The ability of radioactivity to pass through materials is called its penetrating ability. Penetrating ability depends on the size of the radioactive particle. The table of the shows that alpha particles are the biggest, beta particles are very much smaller and gamma rays have no mass.

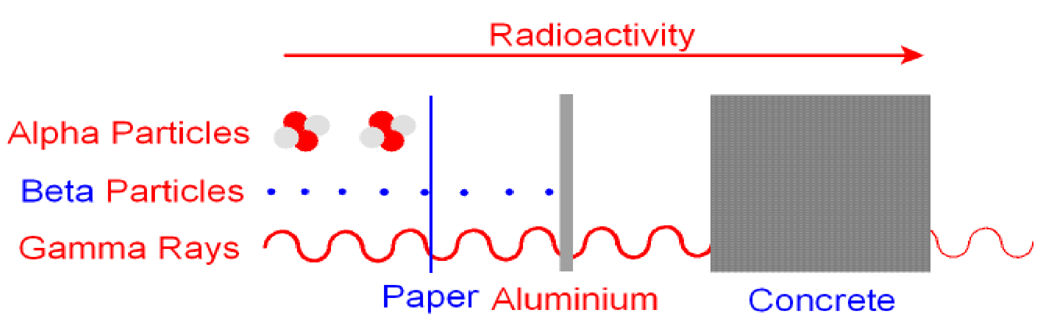
The bigger the particle, the more likely it is to have a collision with the atoms of the material.
The collision will stop the particle going through the material.

Alpha particles are the biggest and are least able to penetrate a material. Paper or smoke particles will stop them. Even in air, alpha particles can only travel for a few centimeters before they are stopped by collisions with the air molecules.

Beta particles are stopped by a few millimetres of aluminium but some beta particles will penetrate thin aluminium foil or paper.

Gamma rays are the most able to penetrate and will even find their way through metres of concrete.

The picture below shows the relative penetrating ability of the three types of radioactivity.



When the particle or ray collides with the material it can knock an electron off the atom and form an ion.
Ionising ability is related to penetrating ability.
As penetrating ability increases, ionising ability decreases.

Ionising Ability.

What is Ionising Ability?

Ionising ability is the ease with which radioactivity forms ions. Radioactivity is called "ionising radiation".

How does Radioactivity form Ions?

When alpha particles, beta particles or gamma rays collide with a material they can knock an electron off an atom and form an ion. An ion is any atom that has lost or gained electrons.
An ion always has a charge. An ion has a positive charge if it has lost electrons and a negative charge if it has gained electrons.
Click here for further information on atoms, electrons and ions.

The ability of radioactivity to form ions depends on its mass. Ionising ability is related to penetrating ability. Alpha particles are the most ionising because they have the most mass.
Gamma rays are the least ionising because they have no mass.

What are the Uses of Ionising Radiation?

1. Radioactivity can be detected because it forms ions.

2. A smoke detector works because ions are formed in the air around a radioactive source.

Detecting Radioactivity using a Film Badge.

How can Radioactivity be Detected?

Radioactivity causes ionisation. The ions formed can be detected using a photographic film badge or a Geiger-Müller tube.

What is a Film Badge?

A film badge is a thin plastic container which opens at a hinge. Inside there is a piece of film behind some windows (see below).

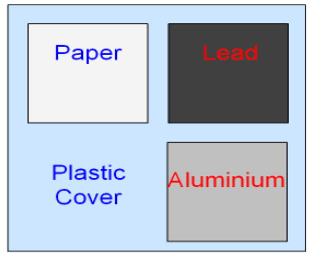
People who work with radioactivity (or X-rays) wear a film badge to monitor their exposure. Radiation will make photographic film darken in the same way that exposure to light and X-rays do.
The greater the amount of radiation that the film is exposed to, the darker the film becomes.

What is the Meaning in Physics of the word Window?

People who do physics use the word "window" for any substance which allows a wave or particle to pass through it. The glass windows in your house allow light to pass through them. An aluminium window would allow gamma rays to pass through.

A film badge has spaces in the plastic in front of the film containing thin windows of paper, aluminium and lead.

Below is a picture of a film badge.



When the film is developed it gives an indication of the exposure to the type and amount of radiation the film badge has received.
You can work out what type of radioactivity will reach the film behind the different materials by looking at the penetrating ability.

The film badge is a cheap and convenient method of monitoring exposure to radiation. A Geiger-Müller tube is a more precise method of measuring radiation.

Detecting Radioactivity using a Geiger-Müller Tube.

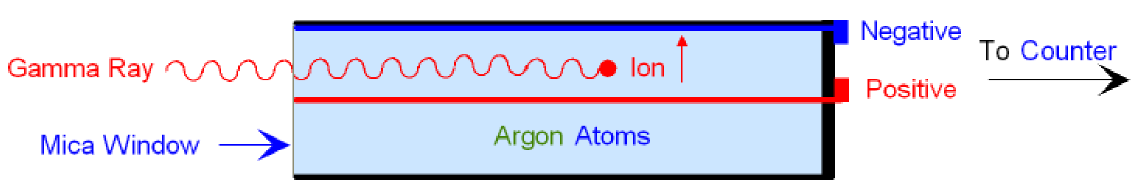
How is Radioactivity Measured?

Radioactivity is measured in Becquerels, symbol Bq.
1 Bq = 1 decay per second.
A Geiger-Müller tube displays the amount of radioactivity in Bq.

What is a Geiger-Müller Tube?

A Geiger-Müller tube detects the ions which are formed by radioactivity. The tube is filled with argon gas and has a very thin piece of mica at the end. It is called a mica window, and it lets all types of radioactivity penetrate through it, even alpha particles.

Below is a picture of a Geiger-Müller tube.



The tube is filled with argon gas. When an electron is knocked off an argon atom, a positive ion is formed. The ion is attracted to the negative inside lining of the tube. When the ion collides with the tube it collects an electron and becomes an argon atom again.

The electron that was knocked off is attracted to the central positive wire. When the electron collides with the positive wire, the tiny amount of electricity causes a click from the loudspeaker of the counter.

The counter has a digital display of the number of clicks per second. This is the same as the number of radioactive waves or particles that have entered the tube and made ions in one second.

The Geiger-Müller tube and the counter together are often called a Geiger counter. The count rate (reading) obtained from a Geiger counter depends on the distance of the tube from the radioactive source.
The closer the tube is to the source, the more radioactivity will enter it and the higher the reading will be.
The reading is also affected by the background count.

Background Radiation

What is Background Radiation?

Radioactive nuclei (the source of radioactivity) are all around us. Radioactive nuclei come from both natural and man made sources.

Natural radioactivity is found in the air, the ground and the sea. Everything living is radioactive and food is also radioactive.
Radioactivity comes from rocks, particularly granite (see below).
Radiation also comes from space. Some comes from the Sun.
Some comes from other galaxies in space as gamma ray bursts.
These bursts may come from a distant star during a supernova.

Some man made radioactivity in the environment comes from nuclear weapons testing and accidents at nuclear power stations.

All of this radioactivity is called the background radiation.
The level of this radiation (called the background count) is low. If you switch on a Geiger counter it will detect this background radiation and give a reading in Becquerels (Bq) for the level.

Radioactive Decay is a Random Process.

The background count is not constant but keeps going up and down. This is because radioactive decay is a random process. Remember the phrase, radioactive decay is a random process.
It will be useful in the exams. A random process means that you don't know when the decay will happen.

On average, the background count might be 0·4 Bq. At any one time, the background count might be 0, 1, 2 or 3 Bq.
To get an accurate reading for the background count (or other radioactive source) you need to calculate the average value of a large number of readings which have been taken over a long period of time.

The background count is different in different parts of the country.
It is affected by the release of radioactive radon from rocks (granite).

When a Bq value for a radioactive material is given, the background count is subtracted first.
The background count is subtracted because otherwise the value would represent the radioactive source plus the background count. This is particularly important if the source is a weak emitter of radioactivity, where the background count is a significant amount of the total reading.

Half-life.

What is Half-life?

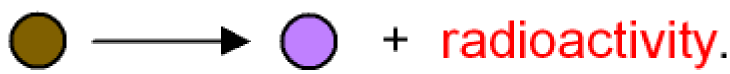
1. Half-life is the time taken for half of the radioactive nuclei to decay.

2. Half-life is the time taken for the count rate to fall to half of its original reading.

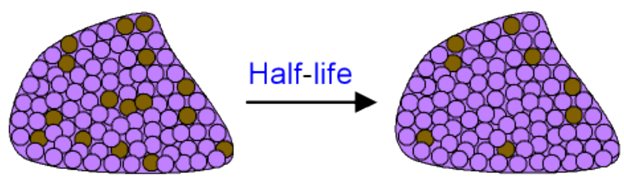
There are a number of ways to define half-life. Remember one of the above definitions, it may be useful in the exams.

An Explanation of Half-life.

A radioactive material will have some nuclei that are stable and some that are unstable. The stable nuclei don't change, that is what stable means. In the picture below, the unstable nuclei (shown as brown balls) will change into stable nuclei (shown as purple balls) and emit radioactivity.



Half-life is a measure of the time taken for the unstable nuclei to change into stable nuclei.

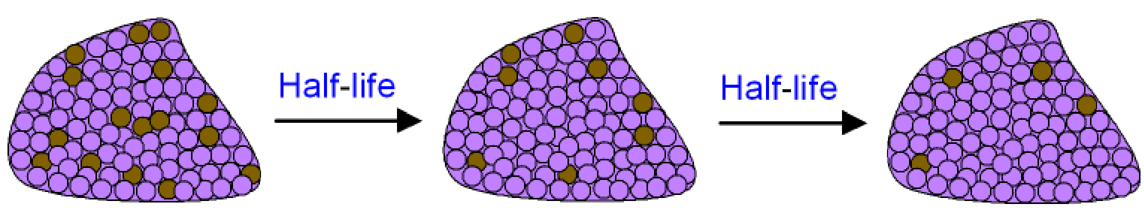


Different substances do this at different rates.

Some do it very quickly and half of the unstable nuclei decay in less than one second. For example, lithium-8 has a half-life of only 0·85 seconds.

Some do it very slowly and half of the unstable nuclei take billions of years to decay.
For example, uranium-238 has a half-life of 4·51 billion years.

Remember that half-life is an amount of time. In the same amount of time, the picture on the right above will lose half of the remaining unstable nuclei.



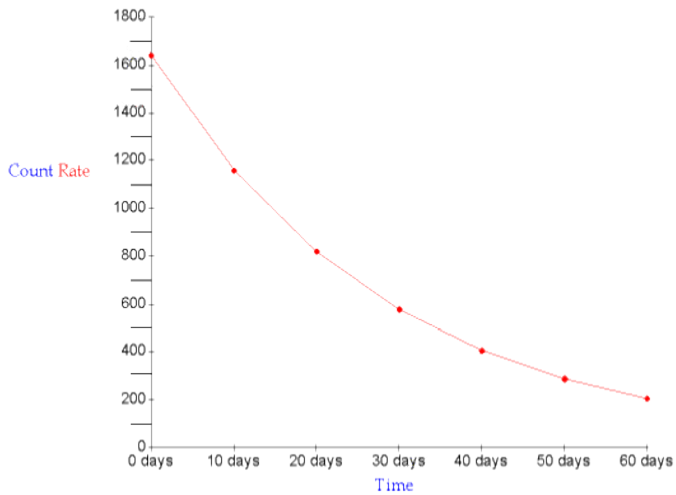
Continued on the next page.

Measuring Half-life from a Graph.

How can Half-life be Measured from a Graph?

A graph showing how the count rate decreases as time goes by will have a curve like the one shown in the picture below.

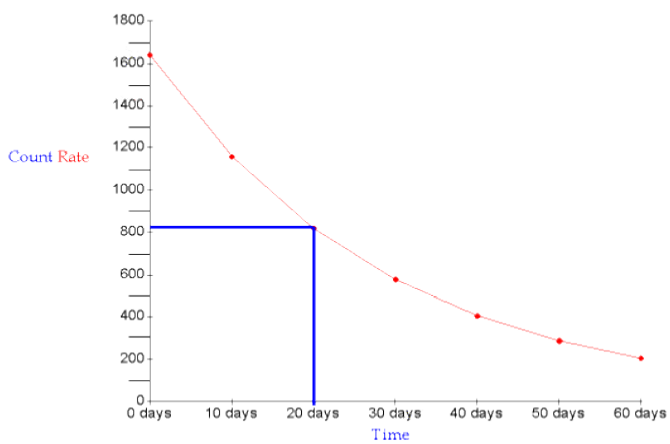
For any particular radioisotope the count rate and time will be different but the shape of the curve will be the same.



The easiest way to measure the half-life from the graph is to

1. Read the original count rate at zero days. On our graph the reading is 1640 counts.

2. Go down to half the original count rate (820 counts) and draw a horizontal line to the curve.
Then draw a vertical line down from the curve. You can read off the half-life where the line crosses the time axis.



On our graph the half-life is 20 days.

Using Half-life to Calculate the Count Rate.

Calculations using Half-life.

There are two types of calculation using half-life.

1. If you are given two count rates and you know how long it takes to get from one to the other, then you can calculate the half-life of the material.
The method for this is shown on the next page.

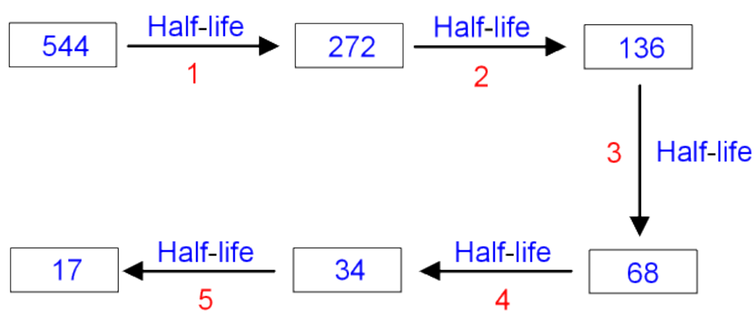
2. If you know the half-life of a material, you can calculate what the count rate will be at some time in the future. The method for this is shown below.

How Half-life can be used to Calculate the Count Rate.

Question.
The half-life of a material is 3 hours. If the initial count rate is 544 Bq, what will the count rate be after 15 hours?

Answer.
Put the count rate in boxes and use arrows to represent the half-life.

We are told that the half-life of the material is 3 hours. In 15 hours there are 15 ÷ 3 half-lives = 5 half-lives.
After each half-life the count rate is halved.



After five half-lives the count rate is 17 Bq.

How to Calculate the Half-life from the Count Rate

Calculations using Half-life.

There are two types of calculation using half-life.

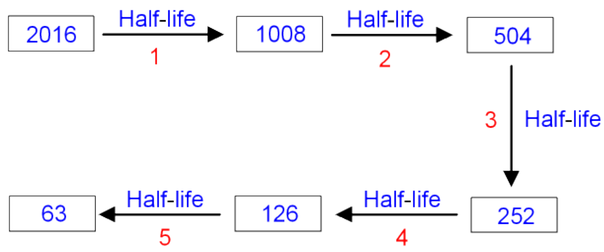
1. If you know the half-life of a material, you can calculate what the count rate will be at some time in the future. The method for this is shown on the previous page.

2. If you are given two count rates and you know how long it takes to get from one to the other, then you can calculate the half-life of the material.
The method for this is shown below.

How the Half-life can be Calculated from the Count Rate.

Question.
The count rate of a material is 2016 Bq. After 35 days it has fallen to 63. What is the half-life?

Answer.
Put the count rate in boxes and use arrows to represent the half-life.
After each half-life the count rate is halved.



In going from 2016 to 63 there are 5 half-lives.
If 5 half-lives take 35 days, each half-life is
35 ÷ 5 = 7 days.
The half-life of the material is 7 days.

Radiodating.

What is Radiodating?

The half-life of a radioisotope can be used to measure the age of things. The method is called radiodating.

Radiodating can be used to measure the age of rocks (see below) and carbon dating can be used to date archaeological specimens.

Using Uranium-238 to Date Rock.

Some rocks contain uranium-238 which is radioactive and follows a decay series until it produces a stable isotope of lead.
The amount of uranium in the rock is compared to the amount of lead and then the age of the rock can be calculated.

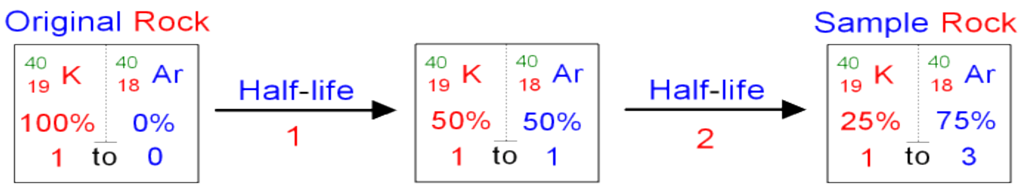
For example, it is found that there are equal amounts of uranium and lead in a rock.
The half-life of uranium-238 is 4·5 billion years.
After 4·5 billion years, half of the uranium originally present in the rock would have decayed and become lead.
The proportion of uranium to lead would be 1 to 1 (equal amounts). The rock could therefore be dated as 4·5 billion years old.

You can only use the ratio of uranium-238 to lead to date rock if you are sure that there was no lead originally present in the rock and that all the lead in the rock has come from the decay of uranium.

Using Potassium-40 to Date Rock.

Some rocks contain the radioisotope potassium-40 which decays to form argon-40. Argon-40 is a stable isotope.
If the argon gas is unable to escape from the rock, then the proportions of potassium-40 to argon-40 can be used to date the rock.

For example, it is found that there is three times as much argon-40 as potassium-40 in a rock.



After 2 half-lives there is three times as much argon-40 as potassium-40 in the rock (see the boxes above).
The half-life of potassium-40 is 1·3 billion years.
The rock could therefore be dated as 2 x 1·3 billion years = 2·6 billion years old.

Carbon Dating?

What is Carbon Dating?

The age of archaeological specimens can be calculated by looking at the amount of carbon-14 in a sample. The method is a form of radiodating called carbon dating. Radiodating can also be used to date rocks.

How is Carbon-14 formed?

The isotope carbon-14 is created at a constant rate in the upper atmosphere by cosmic rays acting on nitrogen.
The carbon-14 which is formed is radioactive and decays to produce nitrogen again.
There is therefore a fixed amount of carbon-14 in the environment which is a balance between the rate at which it is formed in the atmosphere and the rate at which it decays back to nitrogen.

How does Carbon Dating work?

All living things take in carbon from the environment.

Plants take in carbon during photosynthesis. Animals take in carbon when they eat food because food contains carbon.

All living things therefore have carbon-14 in them at the same amount which is present in the environment. This amount is small. Only one in 850 billion carbon atoms are the isotope carbon-14. The others are not radioactive.
They are carbon-12 (about 99%) and carbon-13 (about 1%).

When a living thing dies, it stops taking in carbon from its environment. The amount of carbon-14 in it will start to decrease as the carbon-14 slowly decays. The further back in time that something died, the less carbon-14 will be present in it today.
The half-life of carbon-14 is 5,730 years. Measuring the amount of carbon-14 in a sample today can tell you how long ago the thing died and therefore the age of the sample.

Carbon dating is very useful but also has its limitations.

Carbon Dating and Archaeological Specimens.

What are Archaeological Specimens?

Archaeological specimens are things which belonged to people in the past and have been dug up from the ground.
Archaeological is pronounced ar-key-o-logical.

Why are Archaeological Specimens Important?

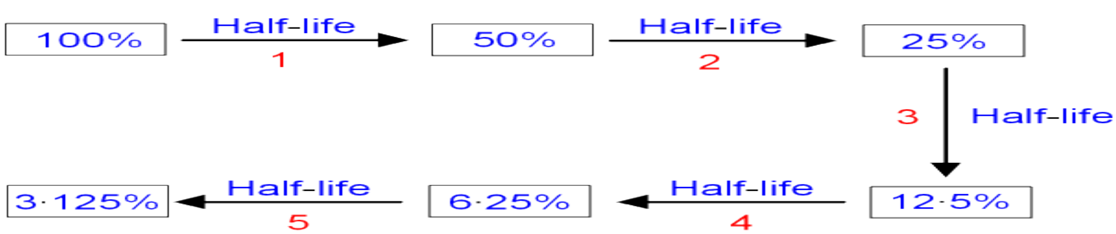
The study of archaeological specimens can tell you a lot about how people in the past lived. One of the most important things to know is the age of the object. This tells you how long ago the thing was used or how long ago the thing was living.

How is Carbon Dating used to Date Archaeological Specimens?

The half-life of carbon-14 is 5,730 years. The half-life can be used to calculate the age of a sample containing carbon-14.
Carbon dating is very useful but also has its limitations.

Question.
If a specimen sample had an amount of carbon-14 which was 25% of the amount in today's environment, how old would the sample be?

Answer.
Find how many half-lives would be needed to reduce the amount of carbon-14 to 25%.



After 2 half-lives the amount of carbon-14 is reduced to 25%.

The sample is 2 x 5,730 years old
= 11,460 years old.

If the amount of carbon-14 in the sample was only 6·25%, then the sample would be 4 half-lives old.
4 half-lives are 4 x 5,730 years = 22,920 years old.

The Uses and Limitations of Carbon Dating.

What are the Uses of Carbon Dating?

Carbon dating can be used on anything which used to be alive.

Examples are

1. Animal (or human) remains, including skin, fur and bone.

2. Plant remains, including wood, natural fibres (cotton, silk, wool, cloth, rope), seeds and pollen grains.

3. Some fossils can be dated this way if they still contain some of the original carbon of the plant or animal.

What are the Limitations of Carbon Dating?

1. Carbon dating cannot be used on things which have never lived because they do not take in carbon from the environment.
   Brick, rock and metal are examples of things which have never lived.

2. The amount of carbon-14 in samples is very small. After 9 or 10 half-lives the amount of radioactivity which is emitted by the sample is too tiny for an accurate count rate to be measured.
Therefore carbon dating cannot be used to date samples which are more than 50,000 to 60,000 years old.

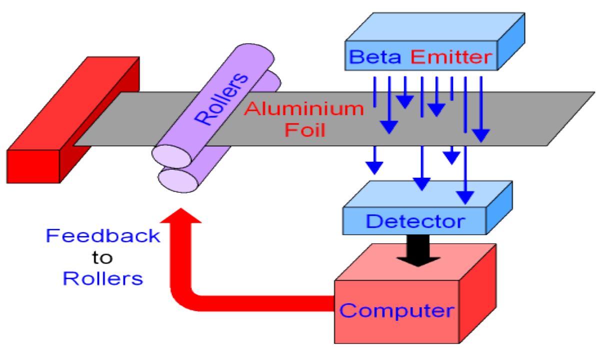
3. The method of carbon dating uses an assumption that the amount of carbon-14 present in the past is the same as that present in the environment today. If this assumption is not correct then the age of samples measured by carbon dating is also not correct.

Thickness Control.

How can Radioactivity be used to Control the Thickness of a Material?

The amount of radiation which passes through a material can be detected and used to control the thickness of the material.

The manufacture of aluminium foil (for cooking) is a good example. A radioactive source is placed above the foil and a detector below it.



Some of the radiation is absorbed by the foil and some radiation passes through to the detector.
The thicker the foil, the less radiation passes through to the detector. The amount of radiation arriving at the detector is monitored by the computer. The computer sends a signal (called feedback) to control the gap between the rollers. The gap between the rollers controls the thickness of the foil.

How does the Feedback Control the Thickness of the Material?

If the foil is too thick, less radiation arrives at the detector. The computer sees that the level of radiation is too low and sends a signal to the rollers to make the gap smaller.
The smaller gap makes the aluminium foil thinner until the amount of radiation at the detector increases to its normal level.

If the foil is too thin, more radiation arrives at the detector. The computer sees that the level of radiation is too high and sends a signal to the rollers to make the gap bigger. The bigger gap makes the aluminium foil thicker until the amount of radiation at the detector falls back to its normal level.

The thickness of paper can be controlled in the same way.

What Radioactive Source is used for Thickness Control?

The radioactive source is a beta emitter. This has the right amount of penetration to be useful for thickness control of aluminium foil.

A beta emitter with a half-life of many years would be used so that

1. The count rate would stay almost constant each day.

2. The radioactive source would not have to be replaced very often.

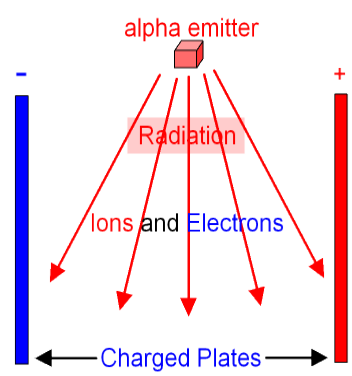
If an alpha emitter was used, all of the alpha particles would be stopped by the foil and none would reach the detector. The computer would not be able to control the foil's thickness.

If a gamma emitter was used, all of the gamma rays would pass through the foil and reach the detector. The computer would not be able to tell if the foil was too thick or too thin.

How does a Smoke Detector Work?

How is Radioactivity used in a Smoke Detector?

The radioactive source in a smoke detector is americium-241. Americium-241 is an alpha emitter. The alpha particles ionise the molecules of the air forming ions and electrons which are attracted to a pair of charged plates as shown in the picture below. When the ions and electrons hit the plates they provide a small amount of electricity (a small current). This current stays constant and is monitored by the smoke alarm.



What happens when Smoke Enters the Smoke Detector?

When smoke enters the smoke detector, the smoke particles near to the radioactive source absorb many of the alpha particles before they can ionise the air between the charged plates.
The number of ions and electrons between the charged plates therefore decreases and so the current which is

passed between the charged plates also decreases. The smoke detector notices the decrease in current and sets off the alarm.

What is a Radioactive Tracer?

A tracer is a radioactive material which is put into a liquid (or gas). Radioactive tracers can be used in both medicine and industry.

How are Radioactive Tracers used in Industry?

A leak in an underground industrial pipe can be found by adding a radioactive tracer to the liquid in the pipe. A detector is moved along the ground above where the pipe is buried. The count rate will be found to increase where the pipe is leaking as a larger amount of liquid containing the radioactive tracer will collect there. In the picture below, the red arrows represent radioactivity emitted from the pipe.

What type of Radioactive Tracer is used to Detect Leaks?

The radioactive tracer would need to be a gamma emitter. Gamma rays can penetrate through the ground (and metal pipe) and be detected at the surface. Alpha and beta radiation would not penetrate through to the surface and could not be detected.

How are Radioactive Tracers used in Medicine?

The gamma emitter tracer would have a short half-life to minimize the danger to living organisms near to the pipe.
A short half-life means that the amount of radioactivity being emitted from the tracer in the pipe would decrease quickly.

How can Internal Bleeding be Detected?

A radioisotope can be injected into someone's blood to detect internal bleeding. Internal bleeding can occur inside the body when blood is being lost from a damaged vein although it may not be obvious where the bleeding is happening.

The method used to detect the bleeding is the same as that used in industry to find a leak from an underground pipe.

How can the Thyroid Gland be Monitored?

Radioactive iodine-131 can be used to see if the thyroid gland in the neck is working properly. Iodine is present in small amounts in the body and up to ¼ of the total amount of iodine can be stored in the thyroid gland.
The amount of iodine entering the gland can be seen by detecting the radioactivity emitted from the radioactive iodine.

Which Radioisotopes can be used as Medical Tracers?

A radioisotope which is used inside the body must be a beta emitter or a gamma emitter because both of these can penetrate body tissue and be detected outside of the body.

A medical tracer must have a short half-life because this will minimize the harm done to the cells of the body. For example, iodine-131 (above) is a beta emitter with a half-life of 8 days.

An alpha emitter cannot be used because the alpha particles cannot penetrate the body tissue and would not be detected.

Radioactivity used for Sterilisation.

How is Radioactivity used for Sterilisation?

Exposure to high intensity gamma rays will kill living cells.

What is Sterilisation?

Sterilisation means killing the cells of pathogenic microorganisms. Pathogenic means that the microorganisms cause harm (for example, they may cause disease or infection). The technique is used in the sterilisation of food and surgical instruments.

How are Surgical Instruments and Food Sterilised?

Gamma rays can be used to sterilise both surgical instruments and food at room temperature. Food such as vegetables and fresh fruit can be made safe to eat without heating them. Heating the food would cause damage and change the food's flavour.
The food will stay fresh for a longer time because microorganisms (fungi and bacteria) are involved in the decay process. Killing the microorganisms slows down the decay of the food.

Surgical instruments in hospitals such as scalpels and clamps can be made safe after use in operations.

High intensity gamma rays are also used to kill cancer cells in a technique called radiotherapy.

Radioactivity can cause Damage to Living Cells.

Ionising radiation can cause damage to the DNA in cells.
Ultraviolet waves and x-rays also cause the same kind of damage.
DNA is the name given to the long molecules in the nucleus.
DNA is a double helix and contains the genes and chromosomes.

The word nucleus is used in biology, chemistry and physics.
In biology the nucleus is the middle part of cells containing DNA.
In chemistry and physics the nucleus is the centre of an atom.

How does Radioactivity Damage Living Cells?

Radiation of a high intensity and long exposure will cause so much damage to a living cell that it will die. This is used for the technique of sterilisation. Intensity means the amount of radiation in an area. Exposure means the length of time that the radiation that is present.

Low intensity radiation can cause small changes to the DNA which may alter the cell without killing it.
A change in the DNA of a cell is called a mutation. Some mutations are harmless and make no difference to the organism, some may be beneficial (good), and some may be harmful.

How does Radioactivity cause Cancer?

A harmful mutation will increase in number when the cell copies itself by mitosis. The cells with the harmful mutation will continue to grow in an uncontrolled way and may then spread to other parts of the body. This is what is called cancer. The chance of radiation causing cancer increases as the exposure and intensity increases. Cancer can be treated using radiotherapy.

Which Type of Radioactivity is the Most Harmful?

The three types of radioactivity cause different amounts of damage depending on whether they are inside or outside of the body.

Damage to Living Cells from External Radiation.

What is External Radiation?

Radiation that has come from radioactive sources outside of the body is called external radiation. All three types of radioactivity are harmful and safety precautions must always be taken.

What is the Most Harmful Type of External Radiation?

Of the three types of radioactivity, alpha particles are the least harmful form of external radiation.
Alpha particles can not penetrate through the skin and so will not cause damage to the cells of internal organs of the body.
This does not mean that alpha particles are safe. Alpha particles can cause cancer of the skin and in some cases this can be fatal.

Both beta particles and gamma rays will penetrate through all of the tissues in a body and can cause damage to the cells of any internal organs. Beta particles are more ionising than gamma rays and will cause more damage for the same exposure and intensity.

People who work with radioactivity must follow special safety precautions and wear a film badge.

Damage to Living Cells from Internal Radiation.

What is Internal Radiation?

Radiation which has come from radioactive sources inside of the body is called internal radiation. All three types of radioactivity are harmful and safety precautions must always be taken.

What is the Most Harmful Type of Internal Radiation?

Of the three types of radioactivity, alpha particles are the most harmful form of internal radiation. Alpha particles can not penetrate through body tissue and so will be absorbed by the cells which are near to the radioactive source. This can cause damage and lead to cancer of the internal organs of the body.

For example, granite rock contains radium-224 which to form the gas radon-220. Radon-220 is an alpha emitter and can be present in some buildings which have been built on granite.
People who live in the buildings can breath in radioactive radon-220 which than continues to emit alpha particles from inside the lungs. This increases the risk of getting lung cancer.

Both beta particles and gamma rays will penetrate through all body tissues and are less likely to cause damage than alpha particles.
Beta particles are more ionising than gamma rays and will cause more damage for the same exposure and intensity. Gamma rays are the least harmful form of internal radiation. Gamma emitters with a short half-life are the most suitable for use as medical tracers.

Safety Precautions.

People who work with must always take the necessary safety precautions.

What Safety Precautions are Needed when Working with Radioactivity?

Safety Precautions in School.

Radioactive sources that are used in school are usually very weak.
They can only be used in the presence of an authorized teacher.
They are kept in a sealed container except when they are being used in an experiment or demonstration. They are immediately returned to the container when the experiment or demonstration is finished.

When using the radioactive source it should be

1. Handled with tongs or forceps, never with bare hands.

2. Kept at arms length, pointing away from the body.

3. Always kept as far as possible from the eyes.

Hands must be washed after the experiment and definitely before eating.

Safety Precautions in Industry.

Radioactive sources that are used in industry may be very strong and additional precautions must be followed. Fully sealed protective suits can be used which prevent any direct contact with radioactive materials. The suit can be lead lined to prevent any penetration by alpha particles or beta particles.

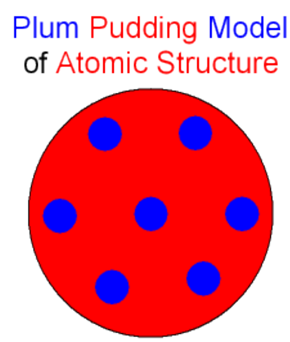
Robots that are operated by remote control can be used to deal with very contaminated areas or high intensity gamma emitters.

People who work with radioactive sources wear a film badge.

Rutherford and Marsden's Scattering Experiment.

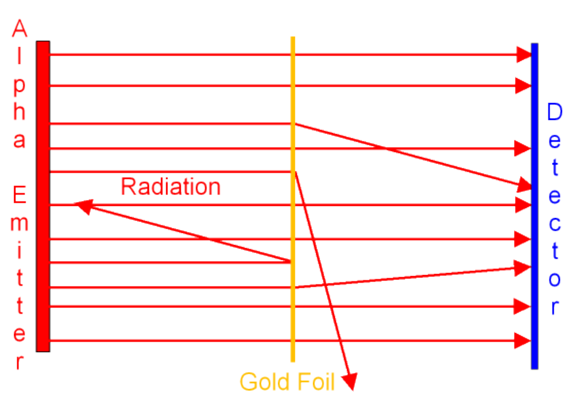
What is the Structure of an Atom?

In the past it was suggested that an atom was a large area of positive charge with negative electrons stuck in it. This was called the plum pudding model where the electrons (shown in the picture below as blue balls) were like plums stuck in a positive pudding (the big red ball).



Rutherford and Marsden fired very fast into a very thin piece of gold sheet (called gold foil).
The foil was only a few atoms thick and most of the alpha particles went straight through it to the detector.

When the detector was moved around the foil they were surprised to find that a small number of alpha particles seemed to have been scattered in all directions.
Some of the alpha particles even came back towards the emitter.



Rutherford and Marsden suggested a structure for the atom which would account for the scattering of these alpha particles.

Continued on the next page.

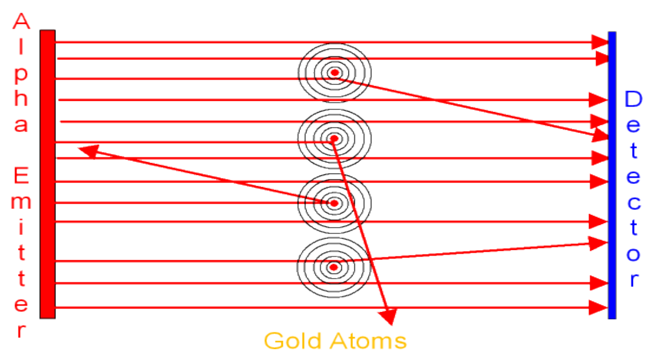
What were the Conclusions from Rutherford and Marsden's Scattering Experiment?

From the results of the scattering experiment on gold foil (see below) Rutherford and Marsden drew the following conclusions.

1. Since most of the alpha particles went straight through the foil most of the space taken up by the atoms must be empty.

2. Since some of the positively charged alpha particles were scattered back towards the emitter, they must have been repelled by a positive part of the atom (the nucleus).

3. Since the alpha particles were very fast moving, they have a relatively large momentum.
The positive nucleus of the gold atom must have a large mass to be able to stop some of the alpha particles from moving forward and then repel them back again.



In the above picture, the black circles represent the electron shells. The alpha particles travel straight through the electron shells without changing direction.

The red circles represent the positive nucleus.
If the alpha particle gets close to the positive nucleus it is repelled and changes its direction.
The closer the alpha particle gets to the positive nucleus the more it changes its direction.

If the alpha particle goes straight towards the positive nucleus it is repelled back towards the emitter. This accounts for the scattering of the alpha particles from the gold foil.

Rutherford and Marsden's model of the structure of the atom has a small positively charged nucleus which contains nearly all of the mass and electrons in shells which have almost no mass but take up most of the space. This is the model of atomic structure which we use today.

Generating Electricity using Nuclear Power.

What is Fission?

Nuclear power stations get their energy from a type of nuclear reaction called fission.
Fission means the splitting of a big nucleus into smaller nuclei.

Fission is not the same as fusion.
Using nuclear power to has advantages and disadvantages.

Why is Energy Released when a Nucleus is Split?

A large amount of energy is released when the nucleus is split, much larger than the amount of energy in a chemical bond.
If you add up the mass of the nuclei before and after fission, you find that some mass has gone missing.
The process of fission destroys a little bit of mass.
This little bit of mass turns into a large amount of energy.
The amount of energy can be calculated using Einstein's equation
$E = mc^2$
where E is energy, m is mass and c is the speed of light.
The energy released is used to generate electricity.

What is the Fuel for Nuclear Power Stations?

Nuclear power stations use either uranium-235 or plutonium-239.
Most nuclear power stations use uranium as their fuel but the process of fission described below is the same for both.

Uranium-235 can capture a neutron and become uranium-236.
Uranium-236 is unstable and splits to form 2 smaller nuclei (called daughter nuclei) plus an additional 2 or 3 neutrons.
These additional neutrons can be captured by other atoms of uranium-235 and so the process continues.

What is a Chain Reaction?

The type of process where one atom splits to release neutrons which then cause other atoms to split which release more neutrons which cause other atoms to split and so on is called a chain reaction.
A moderator and control rods in the reactor core are used to control the speed of the chain reaction.

The smaller nuclei produced by fission are themselves radioactive and contribute to an ever increasing amount of radioactive waste.

Nuclear Power. The Moderator and Control Rods.

Fission causes a chain reaction in the core of a nuclear reactor.

The speed of the chain reaction must be controlled because the ever increasing numbers of splitting nuclei will very quickly release a large amount of heat energy and this would cause the nuclear reactor to explode.

The moderator and control rods together control the rate of reaction in the core of the nuclear reactor.

What is the Moderator in a Nuclear Reactor?

The moderator is a material which slows down the speed of the neutrons. The moderator is usually made from water but some reactors use graphite.

Neutrons released from the chain reaction must be moving at the right speed for other atoms of uranium to capture them.
If the neutrons are moving too fast then they do not get captured by the nucleus of another uranium atom and the chain reaction stops. The moderator slows the neutrons down so that they can be captured and keep the chain reaction going.

What are the Control Rods in a Nuclear Reactor?

The control rods prevent the chain reaction happening too quickly.
Some control rods are made from an alloy of silver and cadmium.
Some are made from boron mixed with iron or carbon. The control rods are very good at absorbing neutrons.
They reduce the number of neutrons available to continue the chain reaction.

The control rods can be moved up and down inside the reactor core.
As they are lifted up and out of the reactor, the less neutrons they absorb, the faster the chain reaction happens and the reactor gets hotter.
The heat is then used to generate electricity. The further down the control rods go the more neutrons they absorb, the slower the chain reaction happens and the reactor gets colder.
The control rods can used to shut the reactor down completely.

1	What is a Decay?
2	During Radioactive Decay, what can a Nucleus Emit?
3	Is Radioactive Decay a Random Process?
4	What are the Three Types of Radioactivity called?
5	What does the Nucleus of an Atom contain?
6	What is the Atomic Number?
7	What is the Mass Number?
8	What is an Isotope?
9	How can a Nucleus be Unstable?
10	How can an Unstable Nucleus change into a More Stable form?
11	What is a Radioactive Isotope?
12	What is a Radionuclide?

13	What does an Alpha Particle consist of?
14	How is an Alpha Particle written?
15	Does an Alpha Particle have More Mass than a Beta Particle?
16	Does an Alpha Particle have More Penetrating Ability than a Beta Particle?
17	Is an Alpha Particle More Ionising than a Gamma Ray?
18	What happens to the Mass Number when an Alpha Particle is emitted?

19	What happens to the Atomic Number when an Alpha Particle is emitted?
20	What is a Decay Series?

21	What is a Beta Particle?
22	Where does a Beta Particle come from?
23	What is the Charge on a Beta Particle?
24	How is a Beta Particle written?
25	Does a Beta Particle have More Mass than an Alpha Particle?
26	Does a Beta Particle have More Penetrating Ability than an Alpha Particle?
27	Is a Beta Particle More Ionising than a Gamma Ray?
28	What happens to the Mass Number when a Beta Particle is emitted?
29	What happens to the Atomic Number when a Beta Particle is emitted?
30	What does a Neutron in the Nucleus become when a Beta Particle is emitted?

31	What is a Gamma Ray?
32	What is the Charge on a Gamma Ray?
33	How is a Gamma Ray written?
34	Does a Gamma Ray have More Mass than an Alpha Particle?
35	Does a Gamma Ray have More Penetrating Ability than an Alpha Particle?
36	Is a Gamma Ray More Ionising than a Beta Particle?
37	What happens to the Mass Number when a Gamma Ray is emitted?
38	What happens to the Atomic Number when a Gamma Ray is emitted?
39	What happens to the Nucleus when a Gamma Ray is emitted?

40	What is Penetrating Ability?
41	What does Penetrating Ability depend on?
42	What type of Radioactivity will be Stopped by Paper?
43	What type of Radioactivity will be Stopped by Air?
44	What type of Radioactivity will be Stopped by Aluminium?
45	What types of Radioactivity are called Ionising Radiation?
46	How can Radioactivity form Ions?
47	What does the Ability of Radioactivity to form Ions depend on?
48	What does Radioactivity do to Photographic Film?
49	What is a Film Badge?

50	What Windows are used in a Film Badge?
51	What does a Geiger-Muller Tube Detect?
52	What Gas is used to fill a Geiger-Muller Tube?
53	What is a Becquerel?
54	What is Background Radiation?
55	Name two Places where Background Radiation comes from.
56	Why is the Background Count not Constant?
57	How can you get an Accurate Reading for the Background Count?

58	What is a Definition of Half-life?
59	What does it mean if Nuclei are Stable?
60	Can a Half-life be Less than one Second?
61	Can a Half-life be More than one Billion Years?
62	How can Half-life be measured from a Graph of Count Rate against Time?
63	If a Count Rate is 544 Bq now, what is it after 15 Hrs if the Half-life is 3 Hrs?
64	If a Count Rate is 2016 Bq now, and 63 after 35 Days, what is the Half-life?
65	What is Radiodating?
66	How old is a Rock with 1 K-40 (Half-life 1·3 Billion Years) to 3 Ar-40?
67	What is Carbon Dating?
68	Where does Carbon-14 in the Environment come from?
69	What are Archaeological Specimens?
70	Name two Things which can be Dated using Carbon Dating.
71	Name one Thing which can not be Dated using Carbon Dating.

72	What type of Radioactivity would be used in the making of Aluminium Foil?
73	Would the Radioactivity used to make Aluminium Foil have a Long Half-life?
74	What type of Radioactivity would be used in a Smoke Detector?
75	How does the presence of Smoke make the Detector set off the Alarm?
76	What is a Radioactive Tracer?
77	What type of Radioactivity could Detect a Leak in an Underground Pipe?
78	Would the Radioactivity used to Detect a Leak have a Long Half-life?
79	What type of Radioactivity could be Injected into Blood?
80	Would the Radioactivity Injected into Blood have a Long Half-life?

81	What is Sterilisation?
82	What type of Radioactivity would be used in Sterilisation?
83	Give one Example of the use of Radioactivity for Sterilisation.
84	What is a Mutation?
85	How can a Mutation lead to Cancer?
86	What does Exposure mean?
87	What does Intensity mean?
88	What is External Radiation?
89	Are all forms of External Radiation Harmful?
90	Which form of External Radiation is Least Harmful?
91	What is Internal Radiation?
92	Are all forms of Internal Radiation Harmful?
93	Which form of Internal Radiation is Least Harmful?
94	Give two Safety Precautions used when handling a Radioactive Source.

95	What was the Plum Pudding Model?
96	What did Rutherford and Marsden fire Alpha Particles at?
97	Did some of the Alpha Particles go straight through?
98	Did some of the Alpha Particles change direction?
99	Did some of the Alpha Particles bounce back towards the Source?
100	What takes up Most of the Space of an Atom?
101	Where is Most of the Mass of an Atom?
102	What is Fission?
103	Does Fission of a Nucleus release a Large Amount of Energy?
104	Where does this Energy come from?
105	What is this Energy used for in a Nuclear Power Station?
106	What is a Chain Reaction?
107	How is the Speed of a Chain Reaction controlled?
108	Give two Advantages of Nuclear Power.
109	Give two Disadvantages of Nuclear Power.

Magnetism

What are Magnets and Magnetic Fields?

A magnet has two poles, called North and South. A magnetic field is a region around the magnet where magnetic materials experience a force.

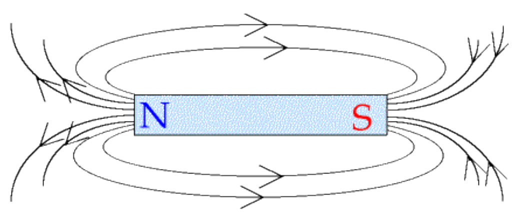
There are only three magnetic elements. They are iron, nickel and cobalt. In practice you will only use iron, or steel which is an alloy of Iron.

What is the Shape and Direction of a Magnetic Field?

The shape of the magnetic field around the magnet is shown by lines. Arrows the lines point away from North and towards South to show the direction of the magnetic field.

Notice that the lines of magnetic force do not cross each other. The closer together the lines are, the stronger the field is. You need to know the shape of the magnetic field for a bar magnet (see below) poles which attract and poles which repel.

Bar Magnet



The magnetic field can be seen by placing the magnet under a piece of paper with small iron filings on top. The filings line up in the shape of the field, as shown above.

The direction of the arrows can be seen by placing a compass in the field. The compass points in the direction of the arrows, away from North and towards South.

Note - this means that when a compass points to the Earth's North Pole, there must be a magnetic South Pole up there (bet that confuses the penguins!).

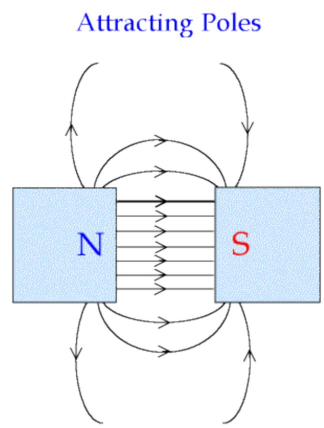
What are the Forces between Magnetic Poles?

The forces between North and South magnetic poles are similar to the forces between electrostatic charges.

Unlike poles attract (pull towards each other), Like poles repel (push away from each other).

This means that two North poles will repel each other
and two South poles will repel each other.
One North pole and one South pole will attract each other.
The further apart the poles are,
the weaker are the forces between them.

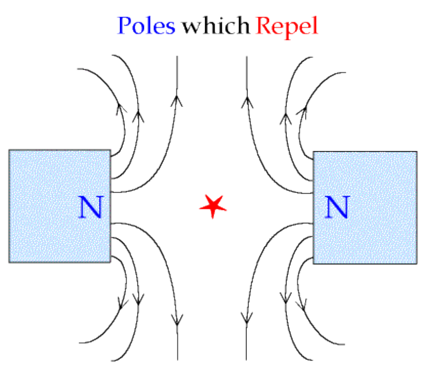
You need to know the shape of the magnetic field for
a bar magnet, poles which attract and poles which repel.



Notice that the lines of magnetic force between the poles are parallel.

Which Magnetic Poles Repel?

Two like poles will repel each other. These may be two North poles or two South poles, they will both have the same magnetic field shape.



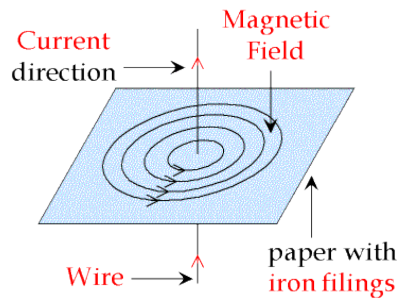
The region in the centre of the poles shown by the red star has no magnetic field, as the two opposing fields cancel each other out.

See also the magnetic field shape for a bar magnet and poles which attract.

Electromagnetism

When a current flows through a conductor, it produces a magnetic field. The shape of the magnetic field depends on the shape of the conductor.
You need to know the shape of the magnetic field for a straight wire (shown below) and a coil.

What is the Shape of a Magnetic Field around a Straight Wire?



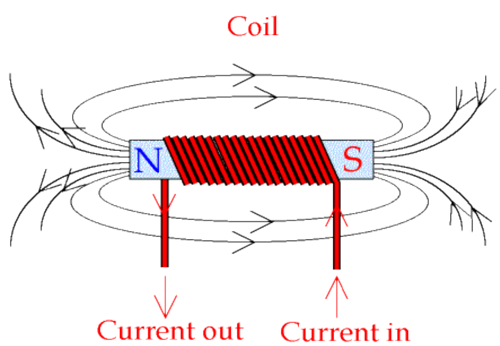
Iron filings on a piece of paper will line up with the magnetic field. The magnetic field around a straight wire is circular, at right angles to the wire.

You can work out the direction of the field using your right clenched fist. Point your thumb upwards in the same direction as the current. The direction of the field is the same direction in which your fingers curl.

Reversing the direction of the current will reverse the magnetic field direction.

Electromagnetic Coil.

The magnetic field around a straight wire is not very strong. A strong field can be made by coiling the wire around a piece of soft iron. This electromagnet is sometimes called a solenoid.
The shape of the magnetic field is the same as a bar magnet.



The soft iron inside the coil makes the magnetic field stronger because it becomes a magnet itself when the current is flowing. Soft iron is used because it loses its magnetism as soon as the current stops flowing. Soft iron is said to form a temporary magnet. In this way, the electromagnet can be switched on and off by turning the electricity on and off.

Steel forms a permanent magnet. If steel was used inside the coil, it would continue as a magnet after the electricity was switched off. It would not be useful as an electromagnet.
Permanent magnets are needed for electric motors, generators, loudspeakers and microphones.

The strength of the magnetic field around the coil can be increased by

1. Using a soft iron core (core means middle bit).

2. Using more turns of wire on the coil.

3. Using a bigger current.

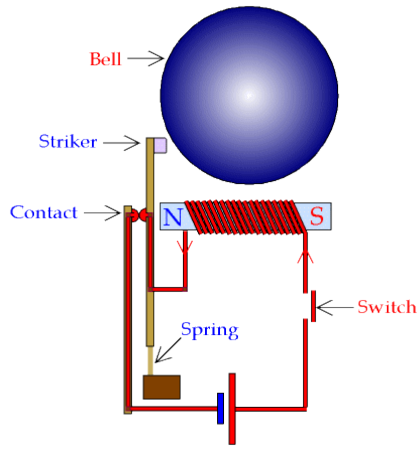
Reversing the direction of the current will reverse the magnetic field direction. Alternating current produces a constantly changing magnetic field.

An electromagnet is used in the electric bell, relay, circuit breaker, loudspeaker and microphone.

How does an Electric Bell Work?

When the switch is pushed closed the circuit is completed and current flows through the electromagnetic coil.

1. The iron striker is attracted to the electromagnet and strikes the bell.



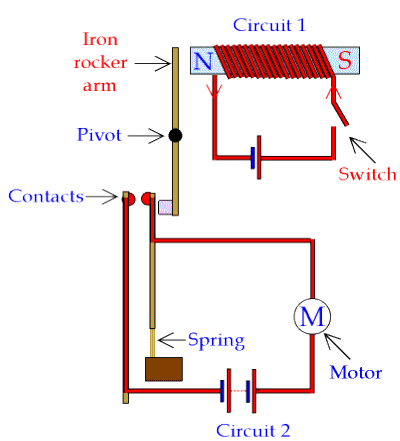
2. As the striker moves towards the bell, the contact is broken. Electricity stops flowing through the coil which loses its magnetism.

3. The spring returns the striker to its original position which makes a new contact and so electricity flows again.

Back to number 1 and the cycle repeats itself. The bell will continue to ring as long as the switch is held closed.

How does a Relay Work?

The relay consists of two circuits. Circuit 1 is a simple electromagnet which requires only a small current. When the switch is closed, current flows and the iron rocker arm is attracted to the electromagnet. The arm rotates about the central pivot and pushes the contacts together. Circuit 2 is now switched on.



t 2 may have a large current flowing through it, to operate a powerful motor or very bright lights.

When the switch is opened the electromagnet releases the rocker arm and the spring moves the contacts apart. Circuit 2 is now switched off.

Why is a Relay Used?

The advantage of using a relay is that a small current (circuit 1) can be used to switch on and off a circuit with a large current (circuit 2).

This is useful for two reasons.
1. The low current circuit (circuit 1) may contain a component such as an LDR, which only uses small currents.

2. Only the high current circuit (circuit 2) needs to be made from thick wire.

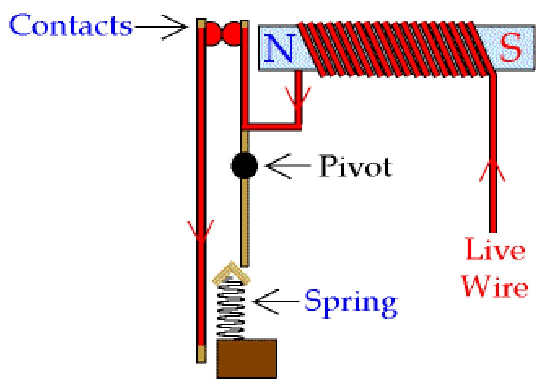
A relay is used to operate the starter motor in cars and the heating circuit in diesel engines.

How does a Circuit Breaker Work?

This page describes a simple circuit breaker. See the next page for the residual current circuit breaker.

The circuit breaker acts as a safety device in the same way as a fuse. Circuit breakers that are used at the distribution board in houses are called MCBs (minature circuit breakers).
The distribution board is also called the consumer unit. The MCBs disconnect the supply if too large a current flows.

Circuit Breaker



When the live wire carries the usual operating current, the electromagnet is not strong enough to separate the contacts.
If something goes wrong with the appliance and a large current flows, the electromagnet will pull hard enough to separate the contacts and break the circuit. The spring then keeps the contacts apart.

After the fault is repaired, the contacts can be pushed back together by lifting a switch on the outside of the circuit breaker.

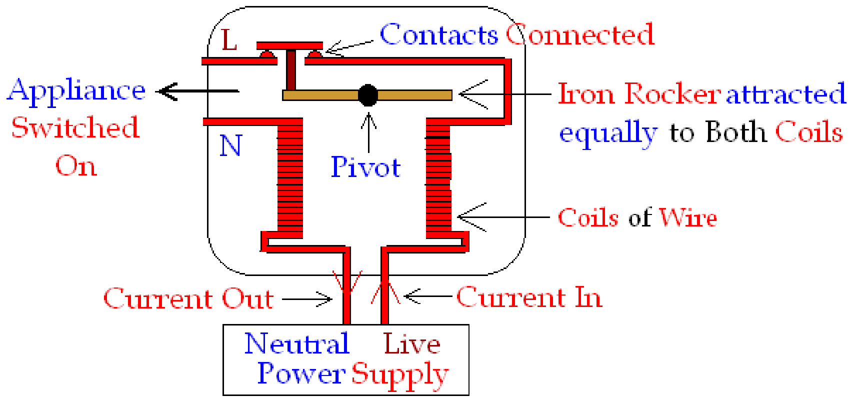
Residual Current Circuit Breaker - RCCB.

An RCCB is also called an RCD (Residual Current Device).

How does a Residual Current Circuit Breaker Work?

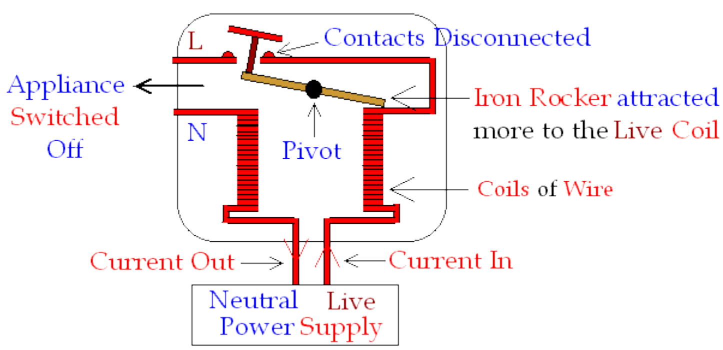
This type of circuit breaker works by comparing the current going in to an appliance with the current coming out.

When an appliance is working correctly all of the current entering the appliance through the live wire is returned to the power supply through the neutral wire. In the picture below the strength of the magnetic field is the same in both coils because they both have the same current.



If something goes wrong with the appliance some of the electric current will flow through the earth wire. The amount of current flowing through the neutral wire decreases and now there is a difference between the current entering the appliance through the live wire and the current returned to the power supply through the neutral wire.
This difference is called the residual current.

The coil connected to the neutral wire now has a weaker magnetic field than the coil connected to the live wire. The iron rocker turns about the pivot and the contacts are disconnected which switches off the appliance and makes it safe. See the picture below.



The RCCB acts to switch off the electricity much faster than a fuse or MCB.

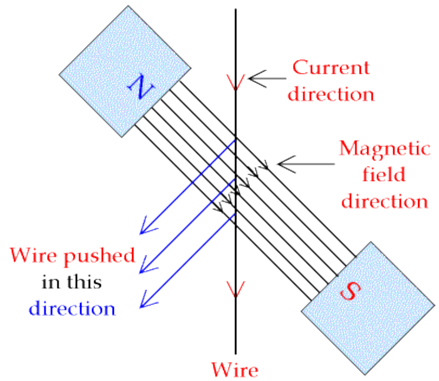
What is the Catapult Effect (also called the Motor Effect)?

The catapult effect shows the force on a wire in a magnetic field when current flows through the wire.

If you put two magnets near to each other, their magnetic fields will interact.
Interact means that the magnets will feel forces on them as like poles will repel and unlike poles attract.

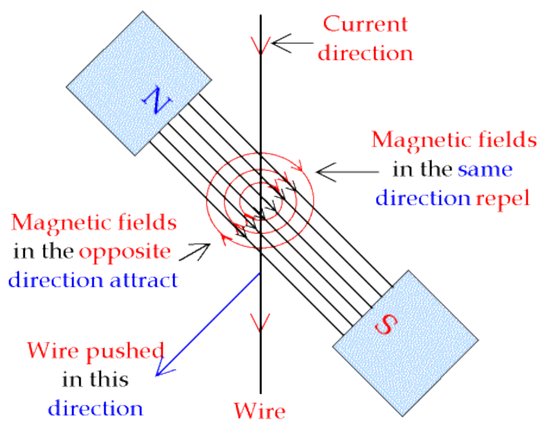
It follows then that a wire in a field from a permanent magnet will feel a force when current flows through it. The magnetic field generated around the wire by the current will interact with the field around the magnet
e two fields will push or pull on each other.

The magnetic field around a straight wire is circular.
The magnetic field between two attracting poles is straight.
When the two interact, the wire is pushed away from the field between the attracting poles at right angles (90°) both to the straight field lines and to the direction of current flow.



How is the direction of the Catapult Effect (or Motor Effect) predicted by Fleming's Left Hand Rule?

If we show the two magnetic fields from the wire and the permanent magnet (see the previous page), we can see that on one side of the wire the fields have the same direction and repel the wire.
On the other side of the wire the fields have opposite directions and attract the wire.
The wire is pushed at 90° to the direction of the magnetic field from the permanent magnets. This is called the catapult effect (or motor effect) and is used to make a simple electric motor spin round..



What is Fleming's Left Hand Rule?

You can predict which way the wire will move by using Fleming's Left Hand Rule.

The thumb, first finger and second finger of the left hand are all pointing at 90° to each other.

1. The thumb points in the direction of motion of the wire.
2. The first finger points in the direction of the field (from the permanent magnet)
3. The second finger points in the direction of the current through the wire.

This works well in theory but in practice it may be difficult to get your thumb and fingers all pointing in the right direction.

What is an Electric Motor?

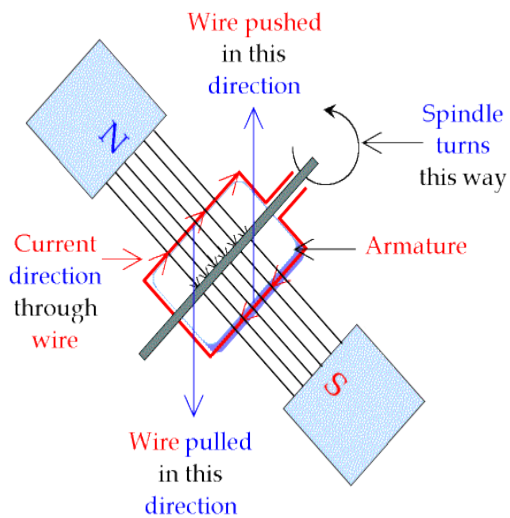
An electric motor is a device that transfers electrical energy into rotational energy.
Something that spins round has rotational energy. Rotational energy is a form of kinetic energy.

Electric motors have a wide variety of uses.

How does a Simple Electric Motor Work?

The catapult effect (motor effect) is used to make a simple electric motor spin round.
The wire is pushed in the opposite direction if the direction of the current through it is reversed.

In a motor, the wire is wound around a central block called an armature. A spindle through the armature allows it to rotate.
The current flows in opposite directions on each side of the armature, so one side is pushed while the other is pulled. This makes the armature rotate.

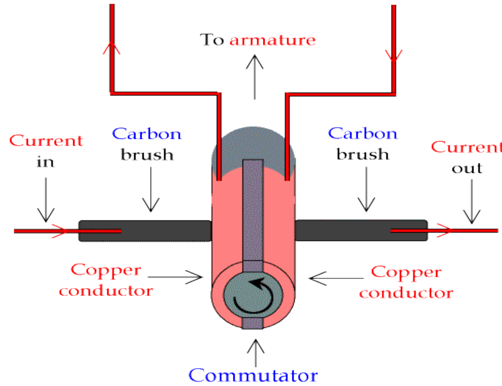


After the armature has rotated through half a turn (180°), then the side of the armature being pushed upwards in the above picture is now on the left and the side being pulled down on the right. The armature would be trying to turn in the opposite direction.

For the armature to continue to spin in the same direction, the direction of the current flowing through the wire must be reversed every half turn. This is achieved using a split - ring commutator (see the next page).

Electric Motor. What is a Split - Ring Commutator?

A split - ring commutator (sometimes just called a commutator) is a simple device for reversing the current direction through an armature every half turn (see the previous page).



The commutator is made from two round pieces of copper, one on each side of the spindle. A piece of carbon (graphite) is lightly pushed against the copper to conduct the electricity to the armature. The carbon brushes against the copper when the commutator spins.

As the motor rotates, first one piece of copper, then the next connects with the brush every half turn. The wire on the left side of the armature always has current flowing in the same direction, and so the armature will keep turning in the same direction (see the previous page).

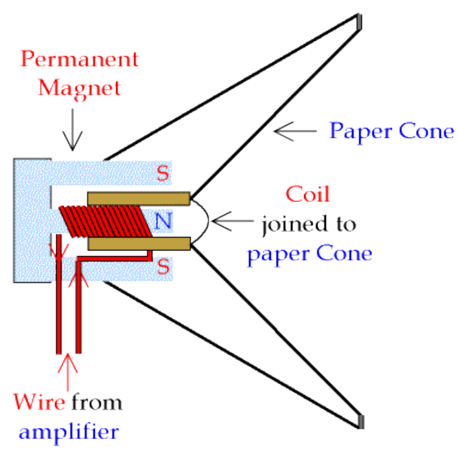
The pieces of copper are held apart in the centre and do not touch each other. They look like a ring of copper which is split down the middle
This is why it is called a split - ring commutator.

What is a Loudspeaker?

A loudspeaker is a device that transfers electrical energy into sound.

How does a Loudspeaker Work?

The loudspeaker uses a coil which can slide backwards and forwards over the central pole of a circular permanent magnet. The coil is joined by the brown bars to a paper cone, shown below.



The wire from the amplifier carries an alternating current which makes the coil (and the paper cone) move backwards and forwards at the same frequency as the changing current. The paper cone then moves the air backwards and forwards which creates the sound.

What is Induced Current or Induced Voltage?

Just as a current flowing through a wire will produce a magnetic field, so a wire moving through a magnetic field will have a current flowing through it. This is called electromagnetic induction and the current in the wire is called induced current.

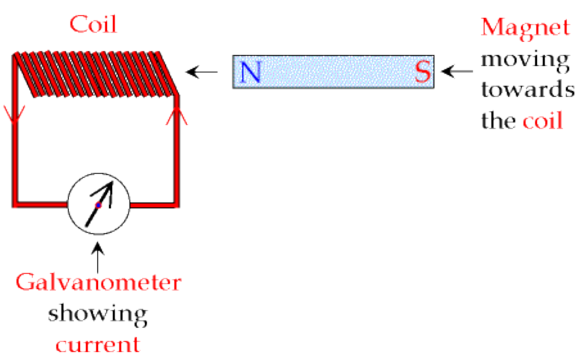
A stationary wire in the presence of a changing magnetic field also has an induced current. A changing magnetic field can be produced either by moving a magnet near to the stationary wire or by using alternating current.
A stationary wire in a magnetic field which is not changing will have no current induced in it.

You will sometimes see this effect described as induced voltage. Strictly speaking, you will only get an induced current in the wire if it is part of a complete circuit.
A wire which is unconnected at both ends will have a difference in voltage between the ends (a potential difference) but current can only flow when the wire is in a circuit.

Induced current is used in electricity generation and transformers.

How is Current Induced in a Coil of Wire?

When a magnet is moved towards (or inside) a coil of wire, a current is induced inside the wire.
This can be shown by connecting the coil to a very sensitive ammeter called a galvanometer.



The size of the induced current can be made bigger by

1. Using a stronger magnet.

2. Moving the magnet at a faster speed.

3. Using more turns of wire on the coil.

These all result in the pointer on the galvanometer moving further to the right.
The direction of the current can be reversed by

1. Moving the magnet in the opposite direction.

2. Using a magnet facing the opposite way round (with North becoming South).

These both result in the pointer on the galvanometer moving to the left.

If the magnet stops moving, even though it may still be inside the coil of wire, no current is induced in the wire.

Induced Current in a Generator

The effect of inducing a current in a coil by moving a magnet inside it is used for the large scale generation of electricity in power stations.

There are two types of generator or dynamo. Both turn rotational energy into electrical energy.

1. One type involves rotating a coil inside a magnet.

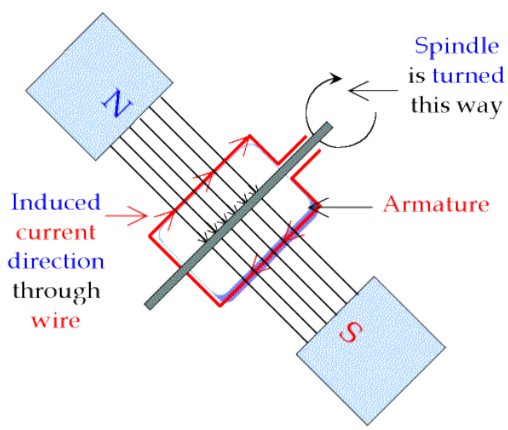
2. The other type involves rotating a magnet inside a coil (like a dynamo found on a bicycle).

Both types produce alternating current.

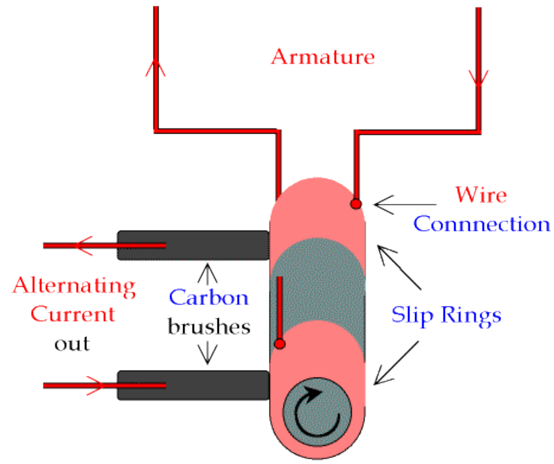
It is possible to make a generator without a permanent magnet. The generator used on cars (called an alternator) uses an inner set of coils to make an electromagnet which turns inside an outer set of coils.

What is a Generator?

A simple generator is similar to an electric motor. With a motor, we put electrical energy in and get rotational energy out. With a generator we put rotational energy in and get electrical energy out.



As with the motor, the current direction changes with each half turn of the generator.
The generator produces alternating current because slip rings are used in place of a split - ring commutator.

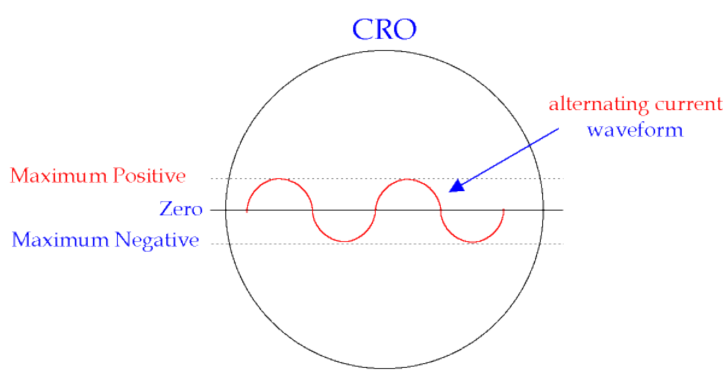


The slip rings keep a continuous connection with the wire around the armature (continued).

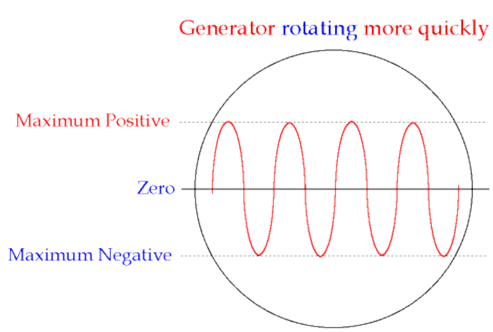
If a simple electric motor with a split - ring commutator is used to generate electricity, you do not get alternating current. A different type of electrical output is produced.

What happens to the Output of a Generator when it Rotates Faster?

The alternating current from a generator is shown below on a CRO (cathode ray oscilloscope).



If the generator is turned faster, both the frequency and the amplitude of the wave increase.

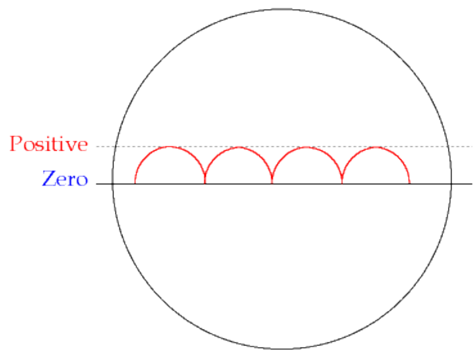


The frequency increases (there are more waves in the same time) because the generator completes more rotations in the same time. One complete turn of the generator produces one complete wave.

The amplitude increases (the waves go further up and down from the zero line) showing that a higher voltage is induced in the coil around the armature.
This happens because the coil is moving through the field from the permanent magnet more quickly.

Using a Simple Motor as a Generator.

if a simple motor is turned to produce electricity, the split - ring commutator will change the current direction every half turn. Instead of generating alternating current (see the previous page) the current is kept positive giving the output shown below.



Compare this with the output shown for direct current and you will see that the two are different.
Direct current from a cell shows a smooth unchanging output.
The output shown above is similar to direct current because the current only flows in one direction.
It looks similar to alternating current because the current rises from zero to maximum and back again to zero but it is not alternating current because the current does not go backwards.

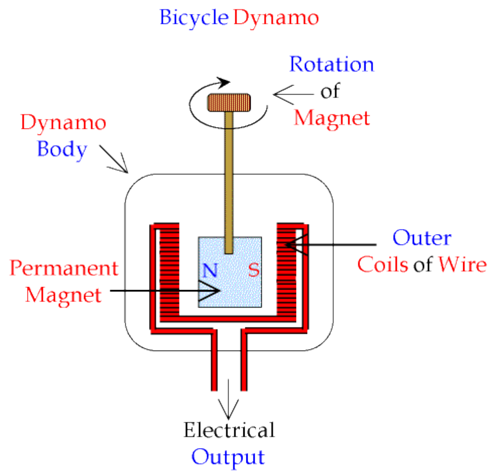
This type of output can be made more like ordinary direct current by using a capacitor to "smooth out the humps".

What is a Bicycle Dynamo?

A small generator is sometimes fitted to a bicycle to provide electricity for the lights at night.
The generator is called a bicycle dynamo.

How does a Bicycle Dynamo Work?

Inside the dynamo a permanent magnet is rotated in the middle of some coils of wire.
Rotating the magnet instead of the coils has the advantage that slip rings are not needed.
The rotating magnet produces a changing magnetic field
and this generates electricity in the coils of wire.



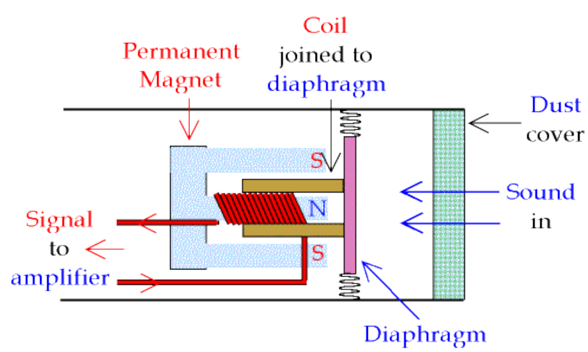
The top of the dynamo is touched against the rim of the tyre which rotates when the bicycle is moving.

What is a Microphone?

A microphone is a device which generates electricity from sound waves.

How does a Microphone Work?

The microphone works by producing a small in a coil of wire when sound waves hit a diaphragm.
It is very similar to a loudspeaker in reverse with a diaphragm instead of a paper cone.
This type of microphone is called a moving coil microphone.



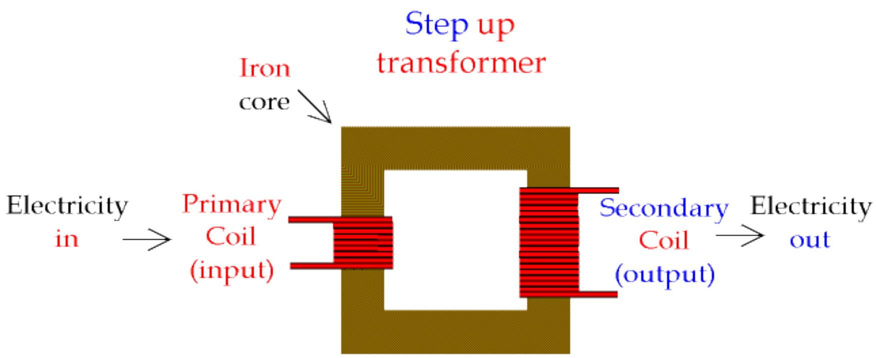
The sound waves strike the diaphragm and move it backwards and forwards at the same frequency as the sound (like the way the ear drum is moved inside the ear). The moving diaphragm moves the coil backwards and forwards which induces a changing current at the same frequency as the sound.
This changing current (called the signal) can be used for recording or the signal can be sent to an amplifier which makes the signal big enough to drive loudspeakers.

The loudspeaker converts the signal back into the original sound.

What is a Transformer?

A transformer is made from two coils, one on each side of a soft iron core. It can decrease the voltage (called a step down transformer) or increase the voltage (called a step up transformer, shown below).

How does a Step Up Transformer Work?



Alternating current is passed through the primary coil (the input) which creates a changing magnetic field in the iron core.
The changing magnetic field then induces alternating current of the same frequency in the secondary coil (the output).

A step up transformer has more turns of wire on the secondary coil, which makes a larger induced voltage in the secondary coil.
It is called a step up transformer because the output voltage is larger than the input voltage. If the secondary coil has twice as many turns of wire then the output voltage will be twice the input voltage. See the transformer equation.

The Transformer Equation.

This equation is important!

The transformer equation relates the number of turns of wire to the difference in voltage between the primary and secondary coils.

$$V_p / V_s = N_p / N_s$$

Where Vp is the voltage in the primary coil.
V_s is the voltage in the secondary coil.
N_p is the number of turns of wire on the primary coil.
N_s is the number of turns of wire on the secondary coil.

There are two points to remember.

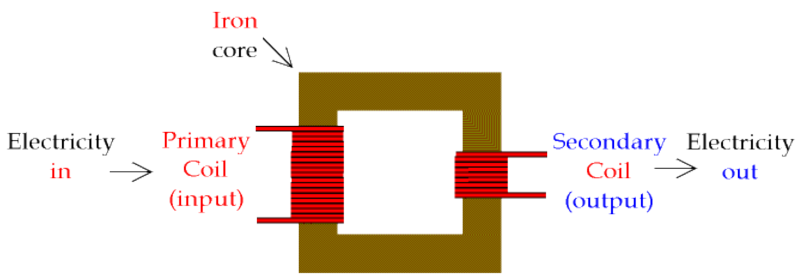
1. Transformers only work with alternating current. Using direct current will create a magnetic field in the core but it will not be a changing magnetic field and so no voltage will be induced in the secondary coil.

2. Using a step up transformer to increase the voltage does not give you something for nothing. As the voltage goes up, the current goes down by the same proportion.
The power equation shows that the overall power remains the same, $P = V \times I$ Power = Voltage x Current.

In reality, the output power is always less than the input power because the changing magnetic field in the core creates currents (called eddy currents) which heat the core.
This heat is then lost to the environment, it is wasted energy.

What is a Step Down Transformer?

A step down transformer has more turns of wire on the primary coil and less turns of wire on the secondary coil. This makes a smaller induced voltage in the secondary coil.
Compare this with a step up transformer.



It is called a step down transformer because the output voltage is smaller than the input voltage. If the secondary coil
has half as many turns of wire then the output voltage will be half the input voltage. See the transformer equation.

Decreasing the voltage does not decrease the power. As the voltage goes down, the current goes up.

Transmission of Electricity.

Electricity is generated on a large scale at power stations and then transmitted through a network of cables (called the National Grid) to factories and homes.

What is the National Grid?

Copper cables carrying the electricity are buried in the ground or aluminium cables are suspended from pylons. Aluminium is used because it has a low density and can safely be suspended from inexpensive thin pylons (see also the uses of aluminium). Pylons have the disadvantage that they look ugly on the landscape but have the advantage of easy access to the cables for maintenance and repair. Electricity Transmission using pylons is cheaper than burying cables underground.

Transformers are used to produce a very high voltage for the transmission of electricity, to minimize energy loss.

Transmission of Electricity and Energy Loss.

A generator at a power station might produce electricity with a voltage of 25,000 V and a current of 8,000 A.

Such a large current would cause the cables of the National Grid to get hot due to the heating effect of current. Energy would then be lost as heat to the atmosphere and by the time that the electricity had traveled from the power station through the cables to the towns and factories, much of the original energy would be lost.

To reduce the energy loss, a step up transformer at the power station is used to raise the voltage to 400,000 V. This is 16 times the input voltage of 25,000 V.

The power equation tells us that if the voltage has gone up by 16 times, then the current must be reduced by 16 times.

The original current of 8,000 A is reduced to 8000 ÷ 16 = 500 A.
This current is still high but the thickness of the cables means that the heating effect is minimal.

At factories, a step down transformer reduces the voltage to 33,000 V. For houses, a step down transformer reduces the voltage to 230 V.

The electricity produced by power stations is in the form of alternating current because

1. It is easy to generate alternating current.

2. Transformers will not work with direct current.