St Ninian's HS

S3 Physics

Waves and Radiation

Pupil Notes

1.1 Introduction to Waves

All waves transfer **energy** from one place to another. For example, water waves transfer **kinetic energy.** If the water wave is large it can transfer a lot of kinetic energy which can often result in severe damage to objects that they collide with.

The energy of a tsunami can be devastating. Tsunamis can travel at a speed of 100 miles per hour.

Sound and **light** energy are transmitted (sent) by waves.

You can calculate the speed of a wave If you know how long it takes to travel a particular distance:

$$\text{distance travelled (m)} \rightarrow \boxed{s = \underset{\uparrow}{v}\ t} \leftarrow \text{time (s)}$$

speed (ms^{-1})

Example

Water waves travel a distance of 50 m in 10 s. At what speed are the waves travelling ?

v = ?

d = 50 m

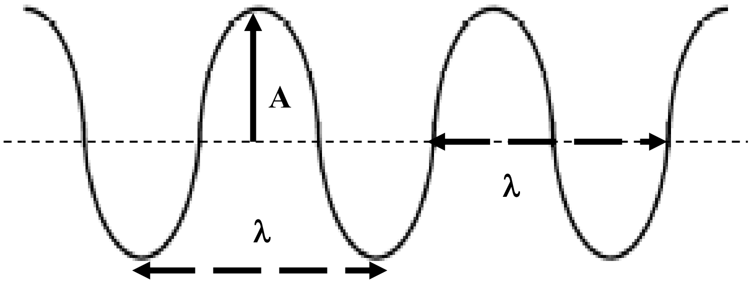
t = 10 s

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

$$v = \frac{50}{10}$$

$$\underline{v = 5ms^{-1}}$$

Wave Characteristics



Wavelength: The distance between any point on one wave and the corresponding point on the next wave. The symbol for wavelength is **λ** (the Greek letter lambda). Wavelength is measured in metres (m).

Speed or velocity: The distance a wave travels in one second. The symbol for speed or velocity is **v**. Speed or velocity is measured in metres per second (m/s or ms^{-1}).

Frequency: The number of waves which pass a point in one second. The symbol for frequency is **f**. Frequency is measured in hertz (Hz).

Amplitude: The height of the wave measured from the centre line to the top of the crest, or bottom of the trough. The amplitude is a measure of the energy the wave possesses. The bigger the amplitude, the more energy the wave carries. The symbol for amplitude is **A**. Amplitude is measured in metres (m).

Period: The period of a wave is the time taken for one complete wave to pass a particular point. The symbol for period is **T.** The unit of period is seconds (s). It can be calculated by taking the inverse of the frequency **(1/frequency).**

Frequency

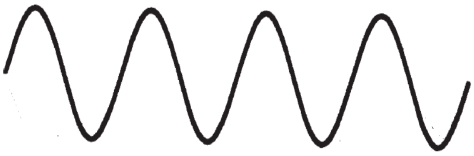
$$\boxed{f = \frac{N}{t}}$$

Number of waves

frequency (Hz)

time (s)

Example



The waves shown in the diagram pass a point in 2s. What is the frequency of the waves?

No of waves = 4
t = 2s

$$f = \frac{N^o}{t}$$

$$= \frac{4}{2}$$

$$\underline{= 2Hz}$$

Period

period (s)

$$\boxed{f = \frac{1}{T}}$$

frequency (Hz)

Example

A wave has a frequency of 50 Hz. Calculate the period of the wave.

f = 50 Hz

T = ?

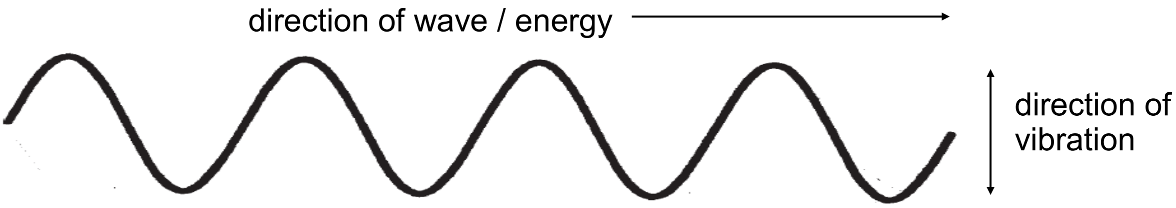
$$f = \frac{1}{T}$$

$$f = \frac{1}{50}$$

$$\underline{f = 0.02\,s}$$

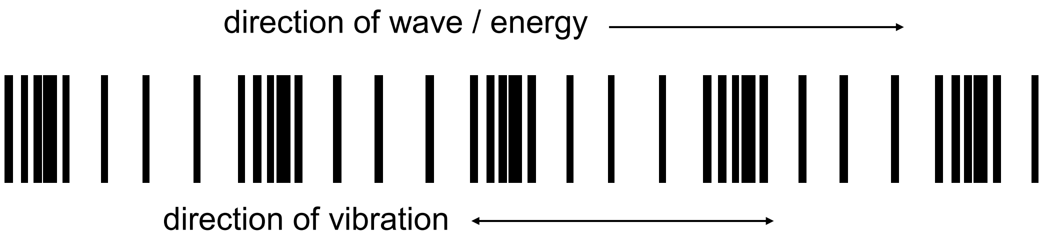
Transverse and Longitudinal Waves

A t***ransverse*** wave is one in which the particles making up the wave vibrate at 90° to the direction of the wave..



Examples of transverse waves are water waves, light, gamma rays, X rays, and all members of the electromagnetic spectrum.

A ***longitudinal*** wave is one which the particles vibrate along the same line as the direction of the wave.

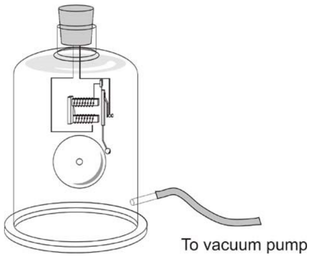


Sound is an example of a longitudinal wave.

Sound

Sound can travel though solids, liquids and gases. The only place that sound waves cannot travel through is a vacuum. A vacuum is an empty space, so there are no particles to pass on the vibrations.

The speed of sound varies. The speed of sound changes from one material to another. The speed of sound in air is of particular interest to ourselves as we communicate because of sound travelling through the air.



The ringing bell can no longer be heard when the air is removed from the jar.

The Speed of Sound in Air

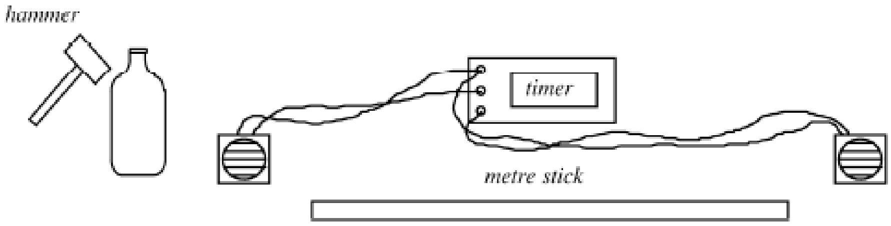
Light travels very much faster than sound. So lightning is seen before thunder is heard, and an athlete sees a puff of smoke from the starter's gun before hearing the bang.

The speed of *sound* in air is about 340 metres per second.

The speed of *ligh*t in air is 300 000 000 metres per second.

Measuring the Speed of Sound in Air

In the laboratory, the apparatus below is used to measure the speed of sound in air.



The bottle is struck to make a sound. This sound passes the first sound sensor to start the timer, covers the distance between the sensors and stops the timer when passing the second sound sensor. The time taken by the sound to pass between the sensors is recorded and the distance between the sensors is measured with the metre stick. The speed of sound is calculated by using the formula :

$$\text{Speed} = \frac{\text{distance between the two microphones}}{\text{time taken to travel between microphones}}$$

Frequency of Sound

Each note or sound has a frequency which is measured in hertz (Hz).

A tuning fork has a frequency engraved on it. The one in the picture opposite has a frequency of 440 Hz. This means the fork will produce 440 vibrations per second, 440 sound waves in one second.

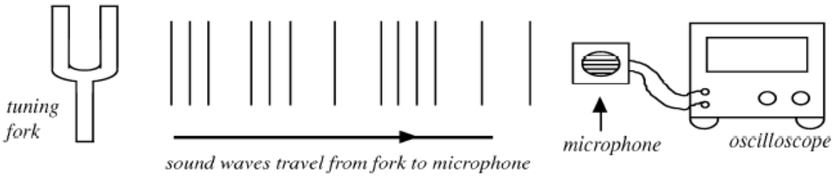
Frequency is the number of waves produced in one second.

Musical instruments produce a range of frequencies. A whistle produces a higher frequency sound than a drum. The whistle has a higher pitch. The higher the pitch means the higher the frequency.

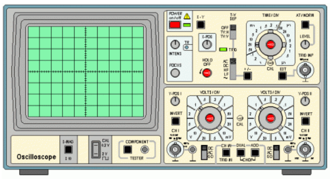
Detecting Sound

Sound can be taken in by a microphone and a trace displayed on an oscilloscope.

Loudness and Frequency



An oscilloscope shows whether a sound wave is loud or quiet, or has a high or low frequency (pitch).

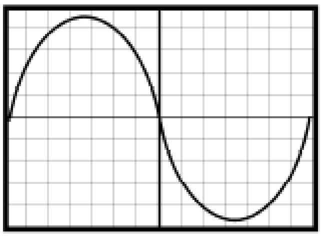


Oscilloscopes are used to display electrical signals, if it is attached to a microphone it will show the sound waves entering the microphone.

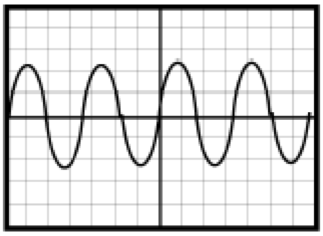
The greater the height of the wave pattern, the louder the sound.

The greater the number of waves, the greater the frequency or pitch.

The oscilloscope patterns below display examples of sound:



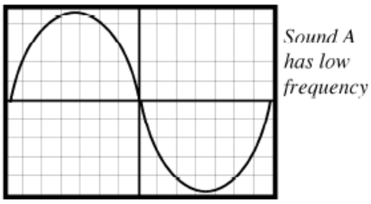
loud, low pitch sound

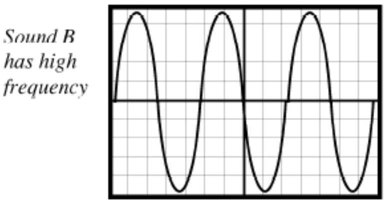


quiet, high pitch sound

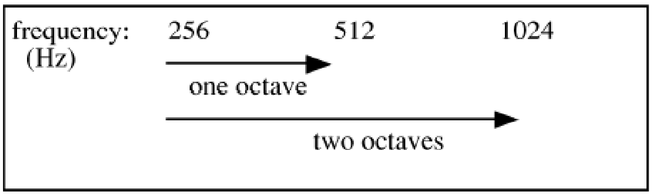
High and Low Frequency

The effect of changing the frequency of a sound can be seen on an oscilloscope screen.
Sound B has a higher frequency than sound A.





If the frequency is doubled, we say the sound is an octave higher.
If the frequency is halved, we say that the sound is an octave lower.



Changing the Note

A musician tunes a guitar by making the string tighter or looser.

While playing the guitar, the note is
changed by altering the length of string which vibrates.

- Short strings produce a higher frequency than long strings
- Tight strings produce a higher frequency than slack strings.

The variety of notes produced by a saxophone depends on the length of the air column which vibrates.

When the upper tone holes are open, much of the sound goes through them. This creates a shorter column of air which produces a note of higher pitch (higher frequency).

When a longer column of air vibrates a note of lower pitch (lower frequency) is produced.

Range of Human Hearing

Humans can hear sounds with a range of frequencies. We can detect sounds that range from **20 to 20 000 Hz**. As we get older the upper limit gradually falls to about 15 000 Hz.

Other animals detect sounds with different frequencies.

Ultrasound

Frequencies beyond the upper level of human hearing (20 000 Hz) are called **ultrasound** or ultrasonic vibrations.

Ultrasound in Medicine

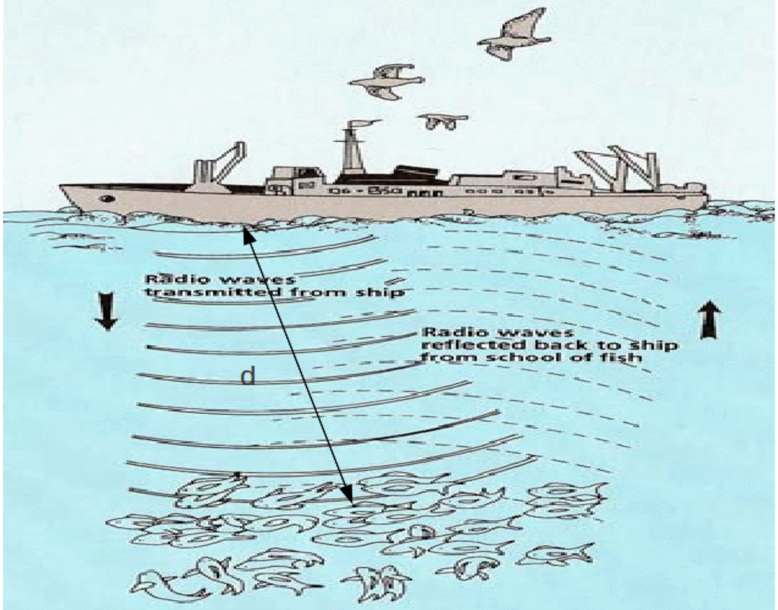
Scanning the body
Ultrasound can be used to image the body. When these high frequency waves are sent out by a transmitter and hit an object, some of the waves will pass through the object while some will be reflected. The reflected waves are picked up by a receiver and processed to provide an image.

A typical scan can check on the progress of a baby in the womb (see the image opposite) or check the functioning of the valves in the heart.

Treating kidney stones
Kidney stones can be shattered by these high frequency sound waves.

Other Uses of Ultrasound

Fishermen use a system called sonar. This involves sending out ultrasound waves towards the sea bed and detecting the echo, the reflected signals. This helps the fishermen to locate shoals of fish.



Sound Levels

The human ear is sensitive and can be damaged by loud sounds. Hence it is important that sound levels are monitored. The sound level varies depending on the source of the sound.

Sound levels are measured in decibels (dB) using a sound level meter.

0dB is the quietest noise a good human ear can hear. The table below contains some common sound level readings.

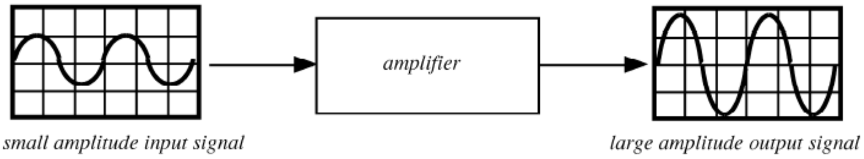
Sound Source	Sound Level
Library	30 dB
Quiet Room	40 dB
Normal conversation at 1m	60-65 dB
City Traffic (inside car)	85 dB
sustained exposure may result in damage (hearing loss)	*90 dB*
Motorcycle	100 dB
Loud Rock Concert	115 dB
Pain begins	*125 - 130 dB*
Jet engine at 30m	140 dB

When sound levels rise to unacceptable levels, the problem is described as **noise pollution**. There are many sources of noise pollution, such as aircraft noise or pneumatic drills. Noise pollution is a term used to describe unwanted environmental sounds.

Exposure to high sound levels over a long period of time can damage our hearing. People exposed to long periods of loud sounds at work should wear ear protection, such as ear muffs or ear plugs, to protect their hearing.

Amplified Sound

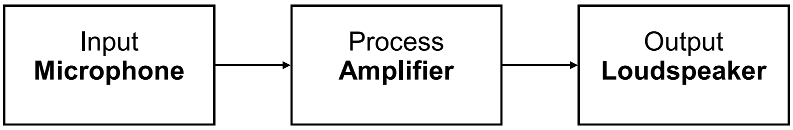
Many electronic devices, such as iPods or phones, contain an amplifier. Amplifiers take an electrical signal of small amplitude and change it into a higher amplitude one.



Only the amplitude of the signal is changed. The frequency does not change.

Amplifiers are used in public announcement systems in airports and stations. This requires sound to be changed into electrical signals, amplified and changed back to sound. A public announcement (PA) system is an electronic system made up of three parts (input, process and output).

The three parts used to amplify the sound are



Part of the System	Function
Microphone	Change sound energy into electrical energy.
Amplifier	Make the electrical signal bigger (stronger).
Loudspeaker	Change electrical energy back into sound energy.

Any device with a loudspeaker has an amplifier.

Speed, Frequency and Wavelength

The relationship between these is

speed (ms^{-1})

$$\boxed{v = f\lambda}$$

wavelength (m)

frequency (Hz)

This is known as the wave equation.

Example

Microwaves have a frequency of 9400 MHz. Calculate their wavelength.

f = 9400 MHz
V = 3x10^8 ms^{-1}

$$v = f\lambda$$

$$3x10^8 = 9400x10^6\ x\,\lambda$$

$$\lambda = \frac{3x10^9}{9400\ x10^6}$$

Convert 9400 Mega Hertz into Hertz using scientific notation.

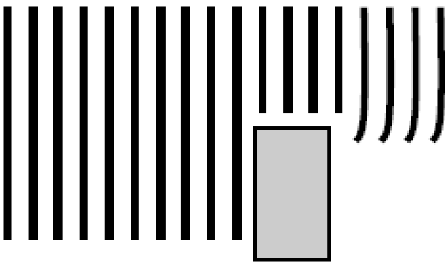
$$\underline{\lambda = 3.2x10^{-2}m}$$

Diffraction

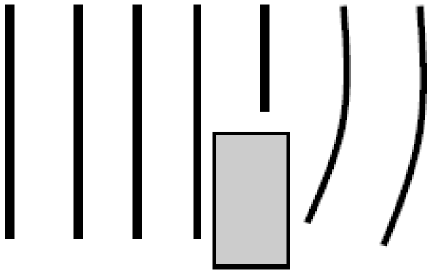
When waves meet the edge of a barrier they bend around it.

This bending of the waves (or spreading out of the waves) is known as **diffraction.** Waves with a longer wavelength diffract more than waves with a short wavelength.

Short wavelength

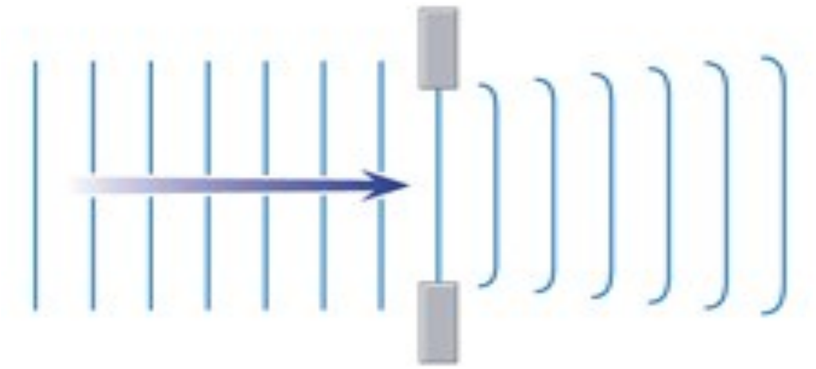


Long wavelength

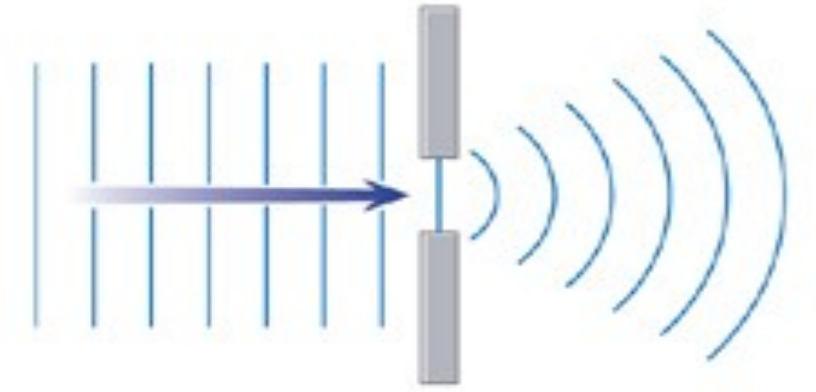


Diffraction (continued)

This also applies to waves that meet a gap in a barrier. They carry on through the gap and spread out to some extent into the area beyond the gap. How much they spread out depends on how the width of the gap compares to the wavelength of the waves. Significant diffraction only happens when the wavelength is of the same order of magnitude as the gap. This is illustrated in the diagrams below.



In the diagram above th gap is much larger than the wavelength and little diffraction takes place



In this diagram the gap is of a similar size to the wavelength so a lot of diffraction takes place.

Diffraction affects radio and television signals. Long wave radio signals are much less affected by buildings, hills, tunnels etc. than those of short wave radio or television signals.

1.2 Electromagnetic Spectrum

Introduction

The electromagnetic spectrum is a range of transverse waves which all travel at 3×10^8 ms^{-1} in a vacuum. Electromagnetic waves **do not carry vibrating particles** but instead carry vibrations in electrical and magnetic fields.

Unlike sound waves, electromagnetic waves can travel in a vacuum (at the speed of light). When electromagnetic waves travel through other materials such as solids and liquids their speed may change.

Members of the Electromagnetic Spectrum

← *Increasing frequency*

Gamma Rays X Rays Ultra Violet Visible Infra Red Microwaves Radio and TV

Increasing wavelength →

As the frequency of the wave **increases,** the waves have **greater energy**. This means that Gamma Rays and X Rays have significantly more energy than radio waves.

Visible light makes up a very small part of the spectrum. The other members cannot be detected using the naked eye as they are invisible.

The visible light spectrum can be separated further into the colours of the rainbow.

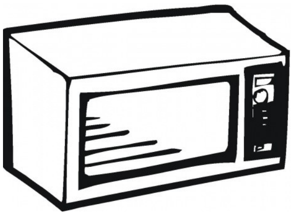
Increasing frequency →

red orange yellow green blue indigo violet

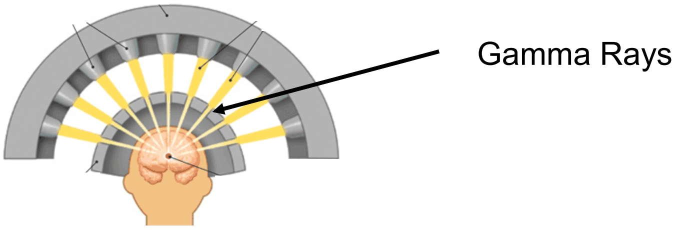
← *Increasing wavelength*

A useful way to remember the order of these colours is **ROYGBIV.**

Applications Using the Spectrum



Type of Wave	Typical Source(s) of Wave	Application(s)	Detector(s)
Radio and TV	electronic circuits	communications	Antenna / Aerial, Radio Telescopes
Microwave	electronic circuits	communications, heating food	Antenna / Aerial, Radio Telescopes
Infra Red	warm objects, the Sun	remote control (TV) treating muscle injuries	Charge-coupled Diodes (CCDs), Thermistors, thermocouple
Visible Light	LEDs, Lamps, the Sun	seeing, photography	Eye, CCDs Photographic Film. LDR, Photodiode
Ultra Violet	gas discharge lamps, the Sun	making vitamin D, treatment for skin conditions	Fluorescent Materials, Photodiode, CCDs
X Rays	very fast electrons striking a metal surface	detecting broken bones, scanner at airport	Photographic Film, CCDs
Gamma Rays	radioactive nuclei decaying	sterilisation, medical / industrial tracers cancer treatment	Photographic Film Geiger-Muller Tube

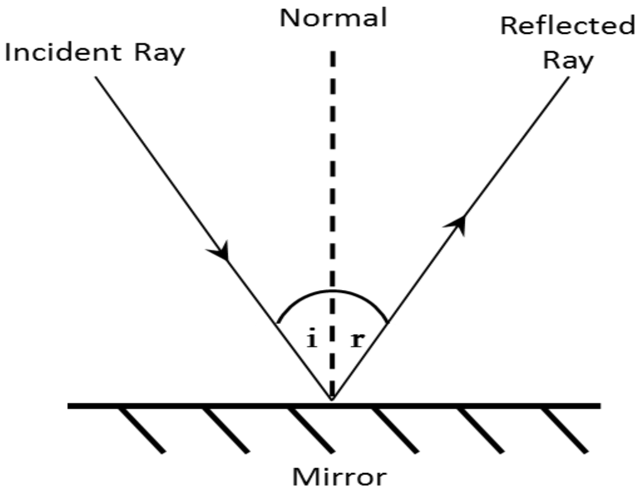


1.3 Light

Reflection

Light travels in straight lines called rays. When light hits certain materials it will reflect.

If a ray of light is shone onto a mirror as shown below, the angle of incidence is the angle between the ray and the normal. The angle of reflection is measured from the normal to the reflected ray. By changing the angle of incidence and measure the corresponding angle of reflection it is found that they are always equal. This is the law of reflection.



Note: The normal is a line at right angles to the surface of the material.

i = angle of incidence
r = angle of reflection

Law of Reflection

The law of reflection states that, the angle of incidence (i) is equal to the angle of reflection, (r).

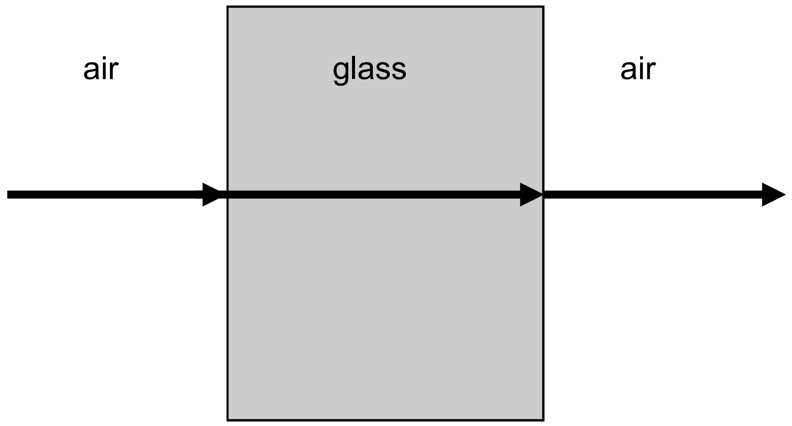
$$\boxed{i = r}$$

Refraction

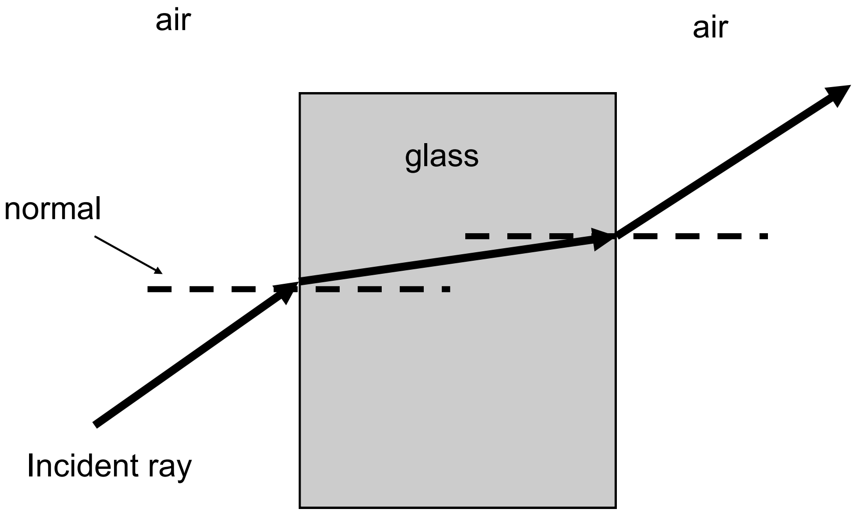
When light passes from one material to another material with a different density its speed will change. This change of speed is known as **refraction.**

Refraction (continued)

If the light travels along the normal (a line at 90° to the surface), the ray will pass straight through the material. Refraction still occurs in this case as the light is changing speed.

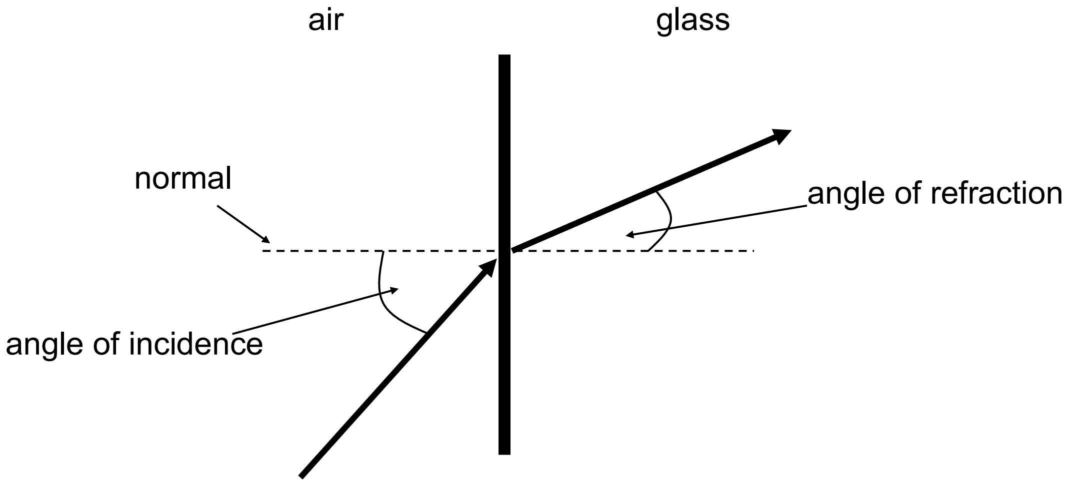


If light strikes the surface of the material at an angle the light will change speed resulting in a change of direction:



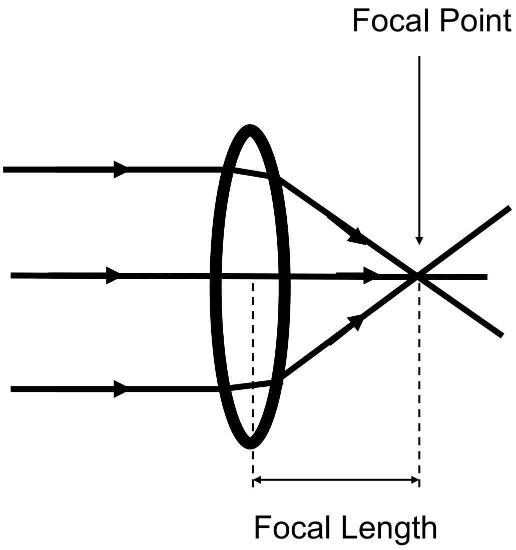
As light enters the glass the ray bends towards the normal and as the ray leaves the glass it will bend away from the normal.

It is important to remember that **all angles are measured to the normal**.

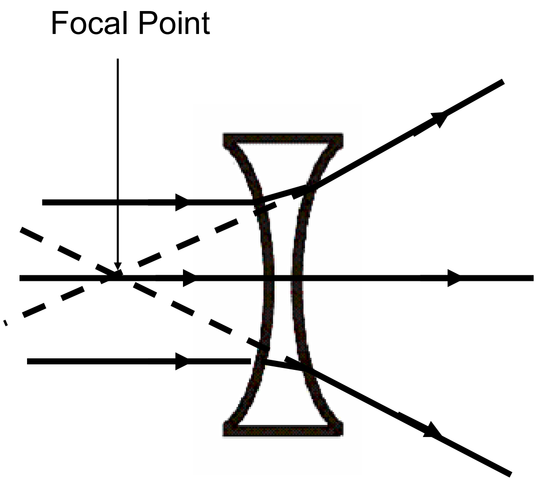


Lenses

The ray diagrams below show the effect of converging (convex) and diverging (concave) lenses on parallel rays of light. The lenses cause the rays of light to refract but with different results.



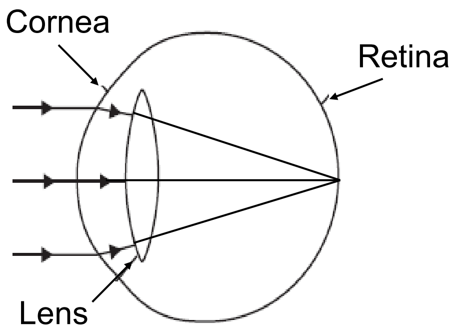
Converging / Convex Lens



Diverging / Concave Lens

Sight

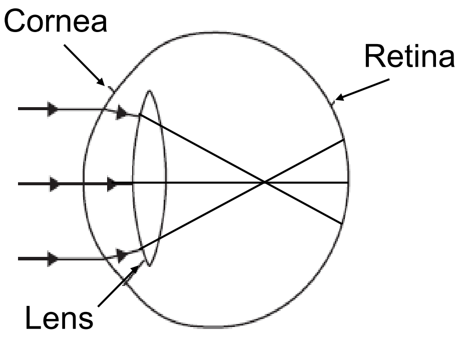
Objects can be seen because they either **emit** light or **reflect** light. The rays of light travel through the eye lens and cornea and are focussed on the retina. People who see close and distant objects clearly without the aid of glasses are said to have “normal sight”. The image is formed on the retina.



Normal Sight

Short Sight

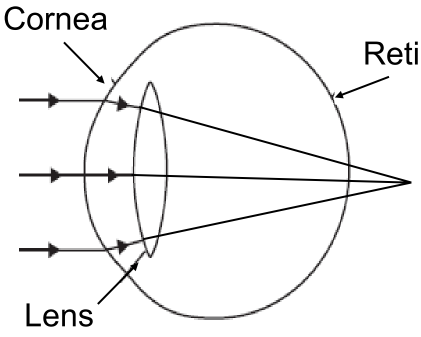
A person is said to have ‘short sight’ if they can see close objects clearly but distant objects appear blurred. The image is formed short of the retina.



Short Sight

Long Sight

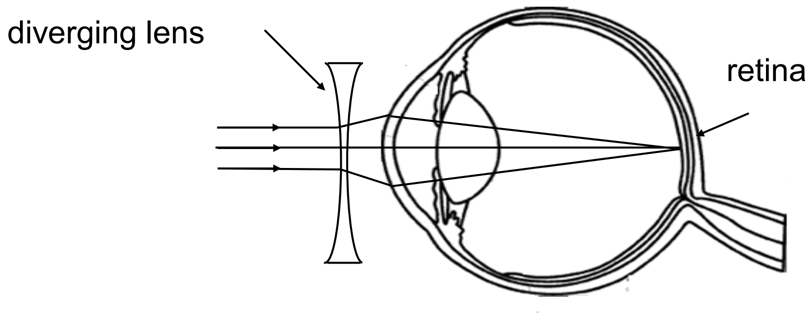
A person is said to have ‘long sight’ if they can see distant objects clearly but close objects appear blurred. The image is formed beyond the retina.



Long Sight

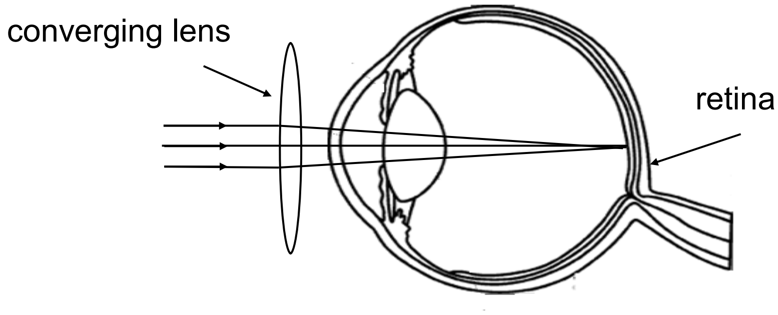
Rectifying Short Sight

Short sight can be rectified using a diverging lens in glasses.



Rectifying Long Sight

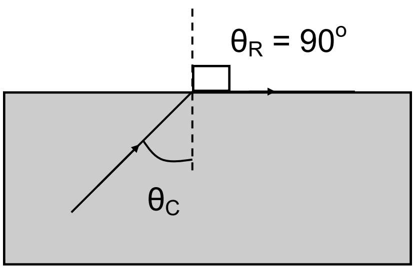
Long sight can be rectified using a converging lens in glasses.



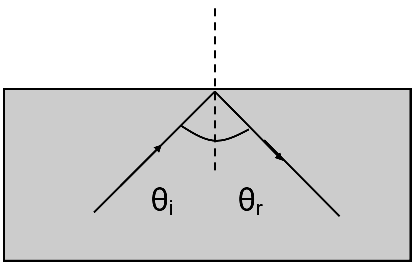
Critical Angle & Total Internal Reflection

When the angle of incidence is greater than θ_C there will be **total internal reflection.**

The **critical angle θ_C,** is the angle of incidence in a material that gives an angle of refraction of 90° in air.



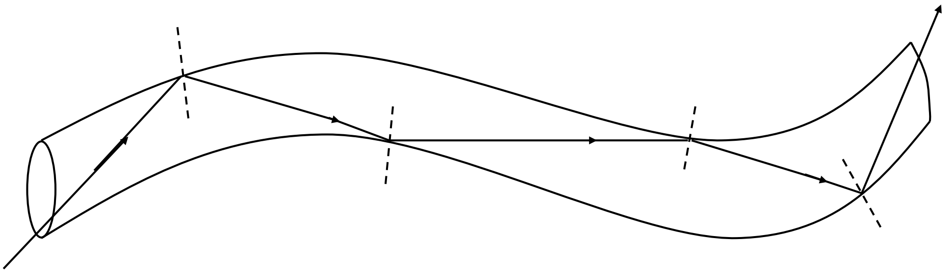
Ray shone at critical angle



Total Internal Reflection
$\theta_{incidence} = \theta_{reflection}$

Optical Fibres

One application which uses total internal reflection is the optical fibre. A optical fibre is a long, thin strand of glass. The principle of total internal reflection is used to transmit light rays through the optical fibre.



Optical fibres have had a significant impact on society:

Medical Applications

Optical fibres are used in endoscopes. In an endoscope there are two bundles of optical fibres; one bundle supplies light into the patient's body and a second bundle transmits the image back to a computer .An endoscope enables doctors to see inside the patient's body without having to perform open surgery, this reduces the risk of patients' being subject to infection and longer term discomfort.

As well as the endoscope camera, some surgical instruments can be place on the end of the endoscope. The light from the optical fibres as well as the instruments enables the doctor to perform "Key hole" surgery operations inside the body without having to open up any wounds. This decreases the risk of infection that could be caused by having to carry out an "open" surgery.

Industrial Applications

Optical fibres are replacing copper cables in our communication systems. This is because they are cheaper and lighter. An optical fibre can carry many more signals at the one time compared to a copper cable.

One disadvantage of optical fibres over copper cables is that optical fibres are harder to join together. This is because the join has to be seamless to ensure total internal reflection takes place. If any of the light is refracted out of the glass fibre information may be lost.

1.4 Introduction to Nuclear Radiation

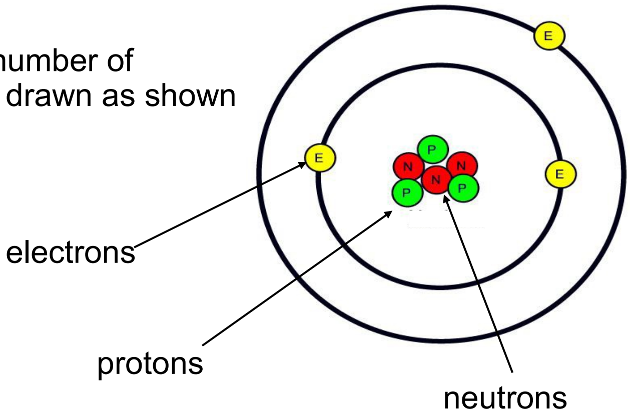
Atoms

Every substance is made up of atoms. Each element is made up of the one kind of atom, sometimes these atoms are combined together to form molecules.
Inside each atom there is a central part called the nucleus. The nucleus contains two particles:

Protons: these have a positive charge
Neutrons: these have no charge.

Surrounding the nucleus are negatively charged **electrons.**

An uncharged atom will have an equal number of protons and electrons. An atom can be drawn as shown opposite.



Ionising Radiations

Some atoms have an unstable nucleus. In order to become stable the atoms eject particles and energy from their nucleus. The ejected materials are **radioactive.** These materials can go on and cause ionisation in other atoms. These are called **ionising radiations.**

This unit will focus on three types of ionising radiation - Alpha, Beta and Gamma.

Ionisation

Atoms are normally electrically neutral but it is possible to add electrons to an atom or take them away. When an electron is added to an atom a negative ion is formed; when an electron is removed a positive ion is formed.
It is important to remember that the nucleus remains unchanged during this time.

The addition or removal of an electron or electrons from an atom is called ionisation.

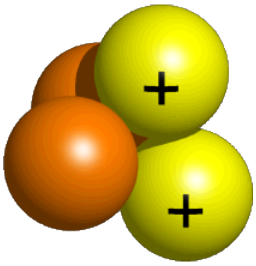
The amount of ionisation produced in a certain volume is called the **ionisation density.**

The Ionising Radiations

Alpha Particles

An alpha particle consists of 2 neutrons and 2 protons. It can be described as a **helium nucleus.** An alpha particle is positively charged.

Symbol: $^{4}_{2}\alpha$

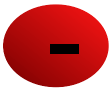


Beta Particles

In order for the nucleus to become more stable it is possible for a neutron to change into a positively charged proton. In order to do this the nucleus must eject a fast moving negatively charged electron. This is called a **beta particle.**

Symbol:

$^{0}_{-1}\beta$



Gamma Rays

Gamma Rays are caused by energy changes in the nuclei. Often the gamma rays are sent out at the same time as alpha and beta particles. Gamma rays have **no mass or charge**. They carry energy from the nucleus which leaves the nucleus in a more stable energy state.

Symbol:

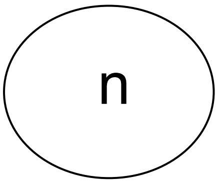
γ

Neutrons

Neutrons have **zero electrical charge**. They are usually categorised as fast or slow moving. A neutron can be absorbed by a nucleus and cause it become unstable and cause it to emit alpha, beta or gamma radiation. Slow neutrons are essential for **Nuclear Fission.** In the nuclear reactor the moderator slows fast neutrons to make them slow (they can also be called thermal neutrons).

Symbol:

n^{0}



Properties of Radiation

Alpha particles will travel about 5 cm through the air before they are fully absorbed. They will be stopped by a sheet of paper. Alpha particles produce **much greater ionisation density** than beta particles or gamma rays. They move much more slowly than beta or gamma radiation.

Beta particles can travel several metres through air and will be stopped by a sheet of aluminium a few millimetres thick. They have a **lower** ionisation density than alpha particles.

Gamma rays can only be stopped by a very thick piece of lead. They travel at the speed of light and have a **very low** ionisation density.

Background Radiation

Background radiation is always present and everyone is exposed to it. This radiation comes from both natural and man-made radioactive sources. Some examples of include:

Natural Sources

- Rocks and soil which contain radon and other radioactive particles
- Buildings can also contain Radon and other radioactive materials
- Cosmic rays from the sun and outer space emit lots of protons which cause ionisation in our atmosphere
- Foods contain radioactive materials
- The human body contains radioactive potassium and carbon

Artificial Sources

- Medical sources such as X-Rays
- Fall out from weapons testing
- Nuclear Power stations
- Radioactive waste

Natural Radiation is by far the greatest influence on our exposure to background Radiation. This is clearly shown in the table below.

Natural Source	Annual Dose (mSv)	Man Made	Annual Dose (mSv)
From Earth	0.4	Medical	0.25
Cosmic	0.3	Weapons (fall out)	0.01
Food	0.37	Occupational	0.01
Buildings	0.8	Nuclear Discharges	0.002
Total	**1.87**	**Total**	**0.272**

Note: You do not need to memorise these individual values but do be aware that the annual equivalent dose is around **2 mSv.**

1.5 Activity and Half-life

Activity

The activity , A, of a radioactive source is the number of decays, N, per second.
It is measured in bequerels, Bq.

$$\boxed{A = \frac{N}{t}}$$

1 Bq = 1 decay per second

Example

A radioactive source decays 4000 times in 2 minutes. Find the activity of this source.

A = ?

N = 4000

t = 2 minutes

$$A = \frac{N}{t}$$

$$A = \frac{4000}{120}$$

Convert 2 minutes into seconds

$$\underline{A = 33\ Bq}$$

It is important to note that the activity of a radioactive source will **decrease with time.**

Half-life

Radioactive decay is a random process. This means that for a radioactive source, it can never be predicted when an atom is about to decay. In any radioactive source, the activity decreases with time because the number of unstable atoms gradually decreases leaving fewer atoms to decay.

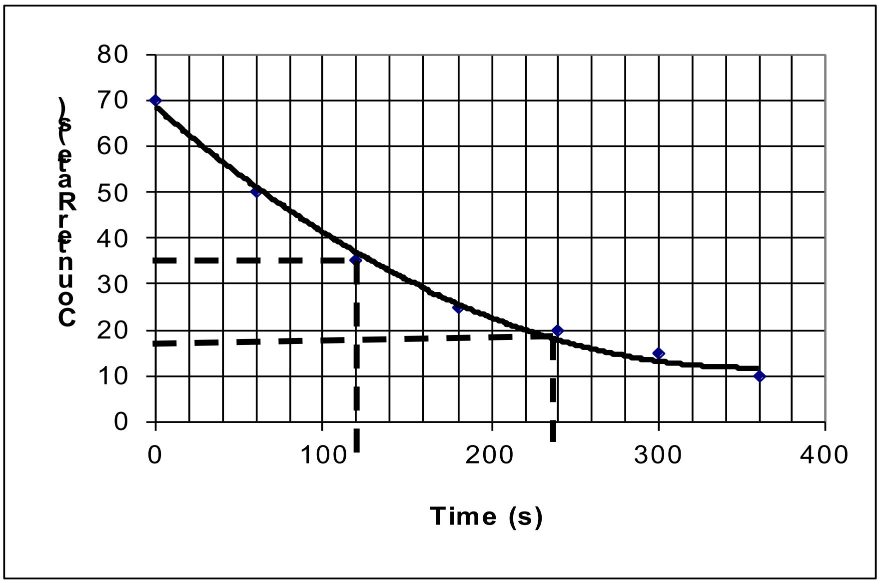
The **half-life** of a radioactive source is the time for the activity to fall to half its original value.

When measuring half-life it is important to take into account background radiation. In order to do this you should measure the background radiation and take this value away from the measured count rate to obtain a corrected count rate.

Examples

1. A Geiger-Muller tube and ratemeter were used to measure the half-life of radioactive caesium-140. The activity of the source was noted every 60 s. The results are shown in the table. By plotting a suitable graph, fin the half-life of caesium-140.

Time (s)	0	60	120	180	240	300	360
Count Rate (counts/ s) Corrected for Background	70	50	35	25	20	15	10



From graph, time taken to fall from 70 to 35 counts per second = 120 s
time taken to fall from 35 to 17.5 counts per second = 120 s

Therefore, half life of the caesium-140 is 120 s.

Example 2

A source falls from 80 MBq to 5 MBq in 8 days. Calculate its half-life.

80 → 40 → 20 → 10 → 5

This takes 4 half-lives (count the arrows) = 8 days

One half life = 2 days.

Example 3

The half life of Cobalt-60 is 5 years. If the source, 20 years ago, had an activity of 500 kBq, what would be the activity now?

20 years would be 4 half-lives.

500KBq → 250 KBq → 125 KBq → 62.5 KBq → 31.25 KBq

After 20 years, activity would be 31.2 KBq

1.6 Dosimetry

Absorbed Dose

When radiation (alpha, beta, gamma or other types) strikes the human body, the energy of the radiation is absorbed by the body.

The **absorbed dose** (D) is the energy absorbed (E) per unit mass (m) of material.

Absorbed dose is measured in grays (Gy)

$$\boxed{D = \frac{E}{m}}$$

Example

What is the absorbed dose if a 300g sample receives 2.7J of energy?

D = ?

E = 2.7 J

m = 300 g

$$D = \frac{E}{m}$$

$$D = \frac{2.7}{0.3}$$

Convert grams into kilograms

$$D = 9Gy$$

The Biological Effects of Radiation

All ionising radiation can cause damage to the body. There is no minimum amount of radiation which is safe. The risk of biological harm from an exposure to radiation depends on:

- the absorbed dose.
- the kind of radiation
- the body organs or tissue exposed.

Equivalent Dose

The body tissue or organs may receive the same absorbed dose from alpha or gamma radiation, but the biological effects will be different. To solve this problem a weighting factor, w_R, is used. This is simply a number given to each kind of radiation as a measure of its biological effect. **The weighting factor for specific ionising radiations will be given in your data sheet inside the front cover of assessments.**

When scientists try to work out the effect on our bodies of a dose of radiation they prefer to talk in terms of equivalent dose. The equivalent dose, H, is the absorbed dose multiplied by the weighting factor.

$$\boxed{H = D\,w_R}$$

Equivalent dose is measured in Sieverts (Sv)

Example

A worker in the nuclear industry receives the following absorbed doses in a year:

30 mGy from gamma radiation, $w_r = 1$
300 mGy from fast neutrons, $w_r = 10$

Calculate the total equivalent dose for the year. **You must calculate equivalent dose for each separately and then add together.**

Gamma Radiation:
$H = Dw_R$
$H = 3\text{x}10^{-3}\text{ x }1$
$H = 30\text{x}10^{-3}\text{ Sv}$

Fast Neutrons:
$H = Dw_R$
$H = 300\text{x}10^{-6}\text{ x }10$
$H = 3.0\text{x}10^{-3}\text{ Sv}$

Total Equivalent Dose: $H = 30\text{x}10^{-3} + 3.0\text{x}10^{-3}$

$H = 33\text{x}10^{-3}\text{ Sv}$

Equivalent Dose Rate

This is given the symbol $\dot{H}$ and can be calculated using the equation:

$$\boxed{\dot{H} = \frac{H}{t}}$$

The units of equivalent dose rate can be: mSv h^{-1}, mSv yr^{-1}, etc.

Example

In a year a worker receives the following exposures to radiation; 30 mGy of γ radiation and 400 μGy of fast neutrons. What is her equivalent dose rate for the year?

Use equation $H=Dw_r$ to calculate total equivalent dose.

Gamma: $H = Dw_r = 30 \times 10^{-3} \times 1 = 30 \times 10^{-3}$

Fast Neutrons: $H = Dw_r = 400 \times 10^{-6} \times 10 = 4 \times 10^{-3}$

Total equivalent dose: $30 \times 10^{-3} + 4 \times 10^{-3} = 34$ mSv

$$\dot{H} = \frac{H}{t}$$

$$\dot{H} = \frac{34}{1}$$

$$\dot{H} = 34\,mSvyr^{-1}$$

The **equivalent dose rate** takes into account the relative risks arising from exposure of different organs of the body. It is the equivalent dose rate that is used to indicate the risk of health from exposure to ionising radiations.

1.7 Applications of Nuclear Radiation

Effects of Radiation on Living Things

All living things are made of cells. Ionising radiation can kill or change the nature of healthy cells. This can lead to different types of cancer.

Medical Applications of Radiation

Radiation can be used in the treatment of cancer. The radioactive source, cobalt-60 kills malignant cancer cells. The source is rotated around the body centred on the cancerous tissue. This ensures that the cancerous cells receive the radiation at all times but the healthy tissue only receives a limited dose. The healthy tissue therefore is not damaged during the treatment.

Radiation treating a tumour in the Brain

Radioactive tracers help doctors to examine the insides of our bodies. Iodine-131 is used to see if our thyroid glands are working properly. The thyroid gland controls the rate at which our body functions. The thyroid gland absorbs iodine, so a dose of radioactive iodine (the tracer) is given to the patient. Doctors can then detect the

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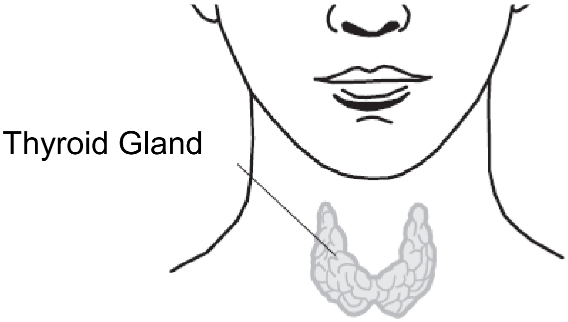
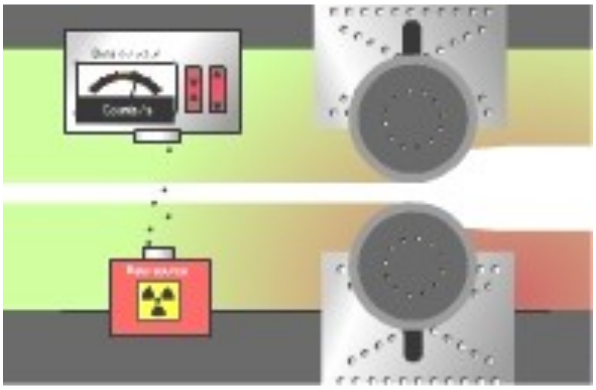


Industrial Applications of Radiation

A beta emitting source is used in the manufacturing process of paper. In order to control the thickness of the paper, a beta source is placed on one side of the rollers and a counter on the other. The beta particles that pass through the paper are detected by counter. The manufacturer is able to monitor the thickness of the paper by monitoring the reading the counter; if the reading increases the paper is too thin and if the reading decreases the paper is too thick.



Radioactive tracers can be used in industry as well as in medicine. A radioactive source can be injected into an underground pipeline and a detector can follow the pipeline above the ground. Any large increases in the meter reading indicates that a leak may be present. This allows the engineers to accurately dig up the correct section on land.

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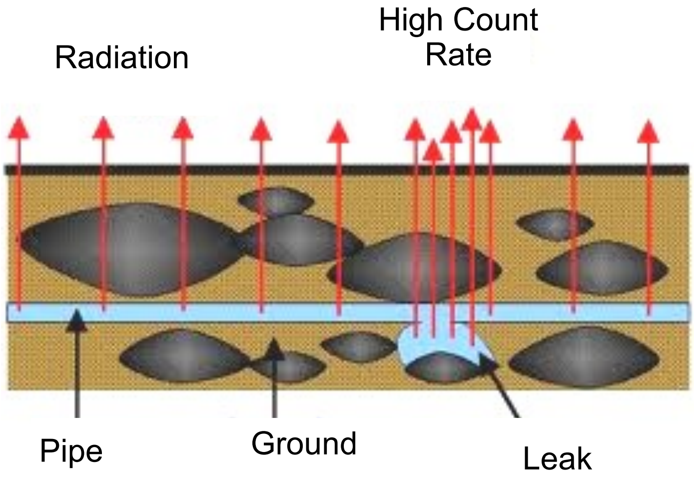


Safety

As radioactive ions can damage living cells it is important to follow safety procedures:

- Always use forceps or a lifting tool to remove a source.
- Always direct radiation away from the body.
- Never leave a source unattended.
- After an experiment, wash hands thoroughly.
- In the U.K students under 16 may not handle radioactive sources.

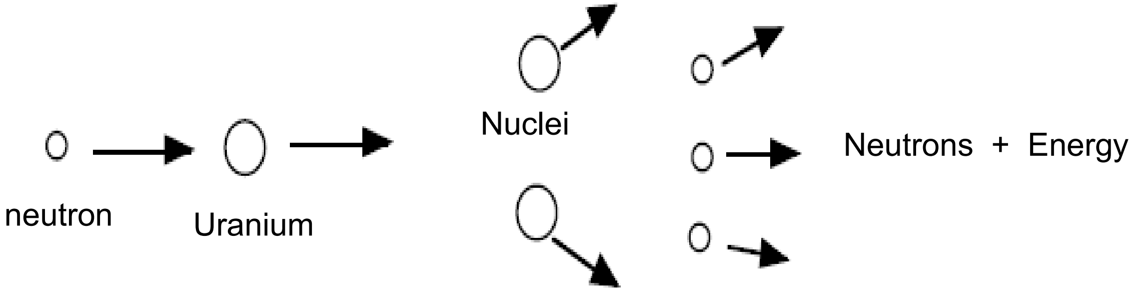
The following can be done to reduce the equivalent dose.

- Use shielding, keep radioactive materials in sealed lead containers. Wear protective lead aprons.
- Keep as far away from a radioactive source as possible.
- Limit the exposure time.

The radioactive hazard warning sign shown opposite should be displayed where radioactive materials are stored and also locations where radioactive materials are used.

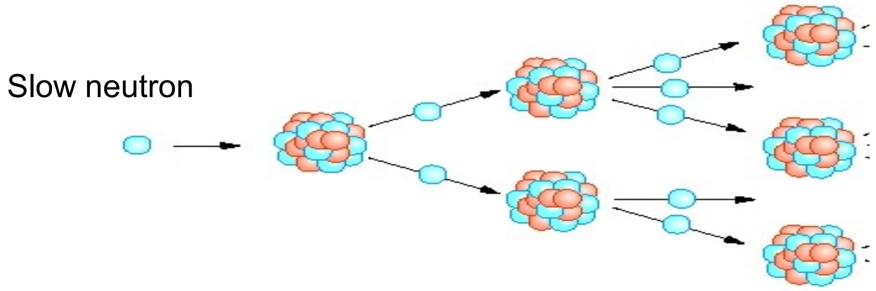
Nuclear Fission

An atom of uranium can be split by a neutron. This can provide two new nuclei plus the emission of neutrons and the release of **energy**. Once nucleus has divided by fission, the neutrons that are emitted can go on a strike further uranium nuclei causing them to split and release energy. This results in what is called a **chain reaction.**



Chain Reaction

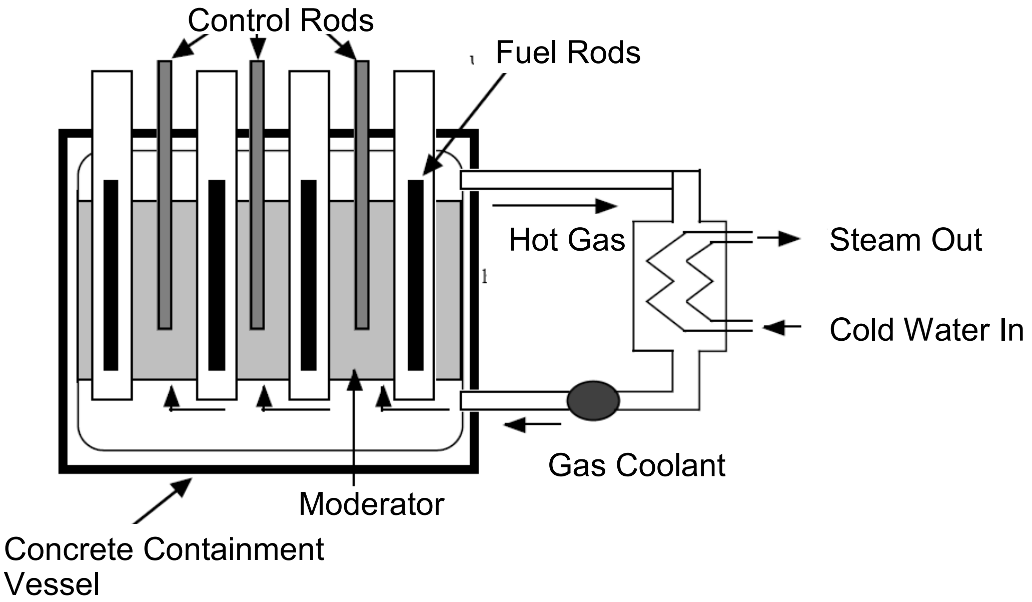
Once a nucleus has divided by fission, the neutrons that are emitted can strike other neighbouring nuclei and cause them to split, releasing energy each time. This results in what is called a chain reaction as shown below.



In a controlled chain reaction, on average only one neutron from each fission will strike another nucleus and cause it to divide. This is what happens in a nuclear power station. In an uncontrolled chain reaction all the neutrons from each fission strike other nuclei producing a large sum of energy. This occurs in atomic bombs.

The Nuclear Reactor

There are five main parts of a reactor as shown in the diagram below:



- The fuel rods are made of Uranium-238 enriched with Uranium-235 which produce energy by fission.
- The moderator, normally made of graphite, has the fuel rods embedded in it. **The moderator slows the neutrons** to ensure nuclear fission can occur.
- The control rods are normally made of boron. **The controls rods absorb neutrons.** This means that the reaction can be slowed, or completely stopped, when necessary.
- The coolant **transfers heat energy to the boilers.**
- The containment vessel acts as a shield to absorb neutrons and other radiations.

Nuclear Power

The advantages of using nuclear power to produce electricity are:

- Fossil fuels are running out, so nuclear power provides a convenient way of producing electricity.
- A nuclear power station needs very little fuel compared with a coal or oil-fired power station. A tonne of uranium gives as much energy as 25000 tonnes of coal.
- Unlike fossil fuels, nuclear fuel does not release large quantities of carbon dioxide and sulphur dioxide into the atmosphere, which are a cause of acid rain.

The disadvantages of using nuclear power to produce electricity are:

- A serious accident in a nuclear power station is a major disaster. British nuclear reactors cannot blow up like a nuclear bomb but even a conventional explosion can possibly release tonnes of radioactive materials into the atmosphere. (The Chernobyl disaster was an example of a serious accident.)
- Nuclear power stations produce radioactive waste, some of which is very difficult to deal with.
- After a few decades nuclear power stations themselves will have to be disposed of.

Nuclear Fusion

Fusion occurs when two light nuclei combine to form a nucleus of larger mass number, e.g. the fusion of two deuterium nuclei (an isotope of hydrogen) to form helium.

During fusion a lot of energy is released from a small amount of mass. All of the energy from the Sun and stars are produced due to nuclear fusion. Nuclear fusion requires an extremely high temperature (such as that of the Sun) in order to occur. However, scientists on Earth are continually developing methods of “cold fusion” in order to try and use the reaction to power our everyday lives.

To date, there has no been no efficient way (the reaction requires more energy than it produces) of producing nuclear fusion for electricity production.