National 5 Physics

Waves And Radiation

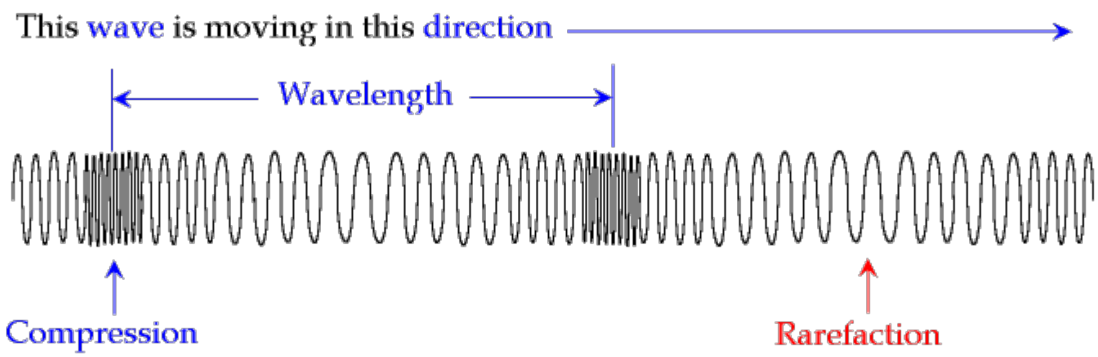
Wave Properties

Waves are everywhere in nature — sound waves, visible light waves, earthquakes, water waves, microwaves…

All waves transfer **energy**. The energy transferred by waves can be considerable! Waves are made up of vibrations or oscillations of particles or fields.

Longitudinal waves

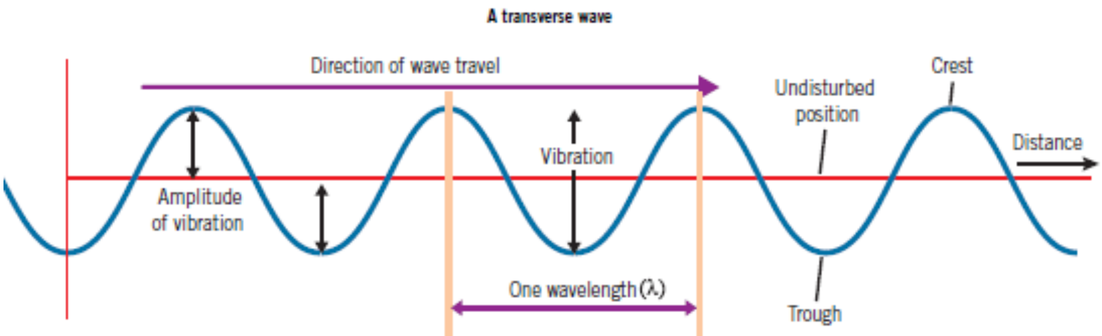
In a longitudinal wave the vibration is in the **same** direction as the direction the wave is travelling in. The oscillations are parallel to the direction of travel.



Sound is the most common example of a longitudinal wave — however there are others, such as seismic P-waves from earthquakes.

Transverse waves

In a transverse wave the vibration is at **right angles** to the direction the wave is travelling in. The oscillations are perpendicular to the direction of travel.



Light and all other electromagnetic waves (such as radio waves) are transverse waves. However many other types of waves are also transverse waves, such as water waves, the waves in a string, mexican waves and seismic S-waves.

Summary

Complete:

All waves transfer ____.

Transverse waves vibrate at _______________ _________________ to the direction of travel.

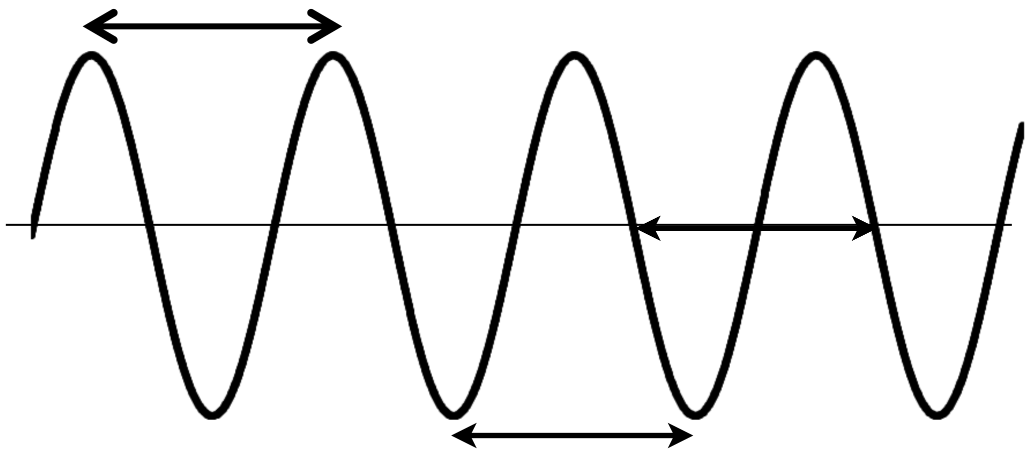
Examples of transverse waves include ____________________, ________________ and microwaves.

Longitudinal waves vibrate _______________________ to the direction of travel.

An example of longitudinal waves are _________________________ waves.

Wavelength

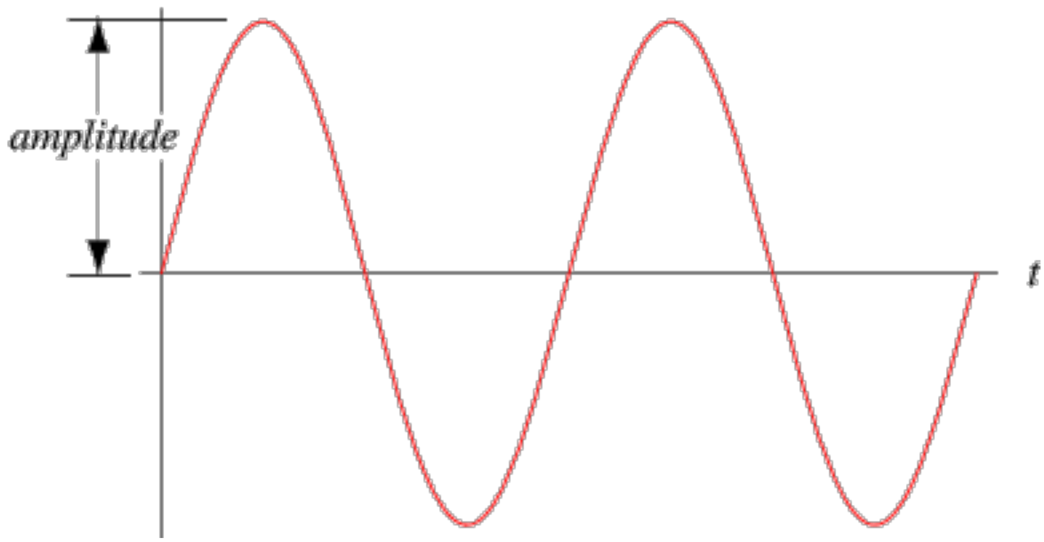
The wavelength of a wave is simply the length of one wave. It can be found by measuring the distance from peak to peak, trough to trough or between corresponding zero crossings (as shown below):



Wavelength is measured in metres (m) and it has the symbol λ (lambda).

Amplitude

The amplitude of the wave is the height of the wave from the middle point of the wave.

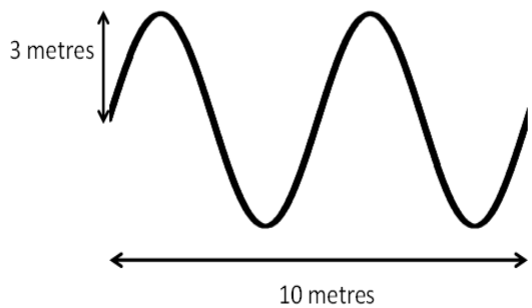


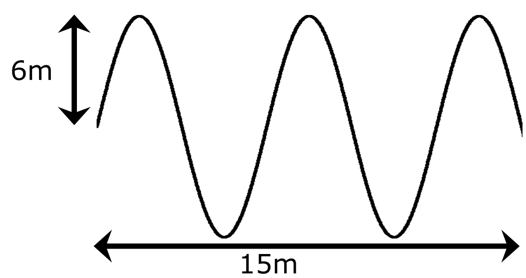
The units of amplitude vary depending on the type of wave. For instance; for water waves the amplitude is measured in metres, for electrical waves the amplitude is measured in volts and for sound waves amplitude is measured in decibels.

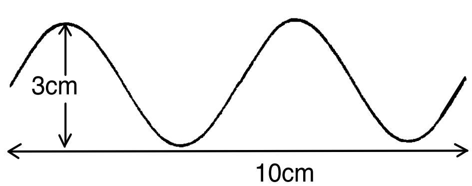
Practice Problems

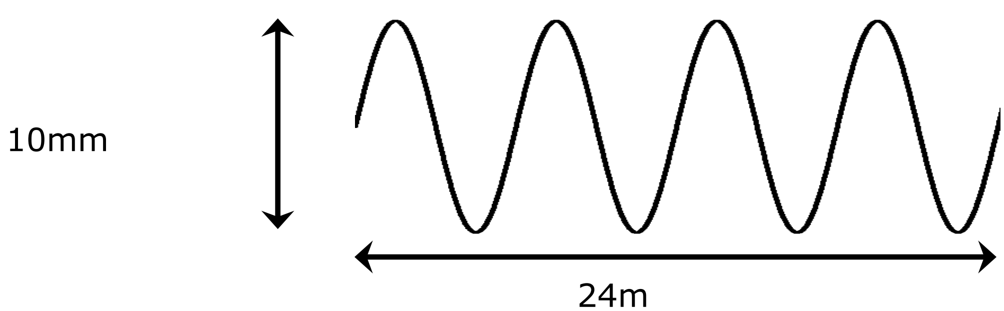
For the following wave traces calculate:

- The number of waves shown
- The wavelength of the wave
- The amplitude of the wave









Frequency

Frequency is a measure of the number of times an event occurs in a period of time. When considering waves in physics, we define frequency as the number of times a wave passes a point every second, or the number of waves per second. The formula for this is **not** on the data sheet but is shown below:

$$f = n \div t$$

Frequency in hertz (Hz)

Number of waves

Time in seconds (s)

The unit of frequency is the hertz (Hz). One hertz is equal to one wave per second.

Period

The period of a wave is the time taken for one wave to pass a particular point. It is also the inverse of the frequency. There is a formula relating period and frequency that does appear on the formula sheet and is given below:

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

The number one

Period in seconds (s)

Frequency in hertz (Hz)

Practice Problems

1. If 10 waves pass a point in 2s, what is the frequency of the waves?

2. A boy counts 24 water waves hitting a beach in 4 minutes. What is the frequency of the waves?

3. A loudspeaker vibrates at a frequency of 256Hz to produce a note called middle C. How many sound waves does it produce every second ?

4. A swimmer at a pool calculates the frequency of waves in the water to be 3Hz. How long did it take for 27 waves to pass him?

5. 10 waves pass a fixed point in 50s. What is the frequency of the waves? How long would it take for one wave to pass the fixed point?

Wave Speed

The speed of an object or a wave can be worked out from the following equation:

$$d = v\,t$$

Distance measured in metres (m)

Speed measured in metres per second (ms^{-1})

Time measured in seconds (s)

Example

A gamekeeper fires a gun at the base of a hill. A hillwalker 1500 metres away hears the sound 4.5 seconds later. What is the speed of sound?

Practice Problems

1. During a physics experiment a pupil finds it takes a sound wave 0.005s to travel 1.5m. What value does this give for the speed of sound in air ?

2. If the time taken for light to travel 750 million metres is 2.5s, what is the speed of light?

3. If the speed of sound in air is 340 ms^{-1}, how long will it take for the sound to travel 5.1km?

4. If the speed of sound in water is 1500ms^{-1}, how long will it take sound in water to travel 1.5km?

5. When tourists near Edinburgh Castle watch the 1 o'clock gun being fired they see the puff of smoke 5s before they hear the bang. If the speed of sound is 340ms^{-1}, how far away are they from the castle?

The Wave Equation

There is a second way to calculate the speed of waves. Instead of using the distance, speed, time formula we can instead use the fact that the speed of a wave is equal to the frequency of a wave multiplied by its wavelength. This formula appears on the formula sheet and is given below:

$$v = f\lambda$$

Wave speed in metres per second

Frequency in hertz (Hz)

Wavelength in metres (m)

Example

A sound wave travelling at $340ms^{-1}$ has a frequency of 256Hz. What is its wavelength?

Practice Problems

1. The frequency of sound waves coming from a loudspeaker is 170Hz and their wavelength is 2m. What speed do they travel at?

2. Water waves of frequency 4Hz and wavelength 50cm travel towards a ship. What speed do they travel at?

3. If the speed of sound in air is $340ms^{-1}$, what is the wavelength of sound waves of frequency 512Hz?

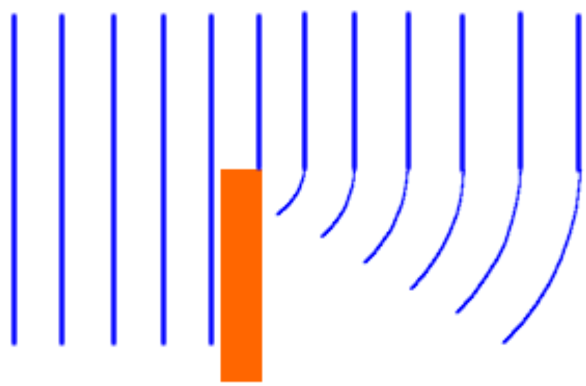
4. Water waves travel towards a lifeboat at a speed of $2.5ms^{-1}$ with a wavelength of 0.5m. What is their frequency?

5. A water wave takes 1.5s to travel 6m. If the frequency of the wave is 2Hz, what is the wavelength of the wave?

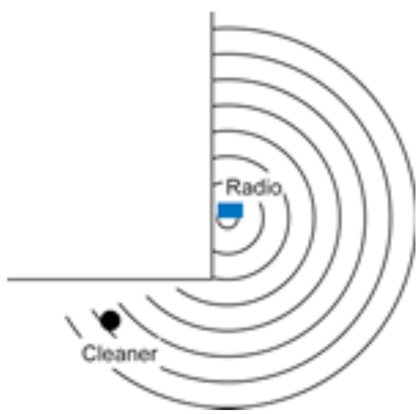
Diffraction

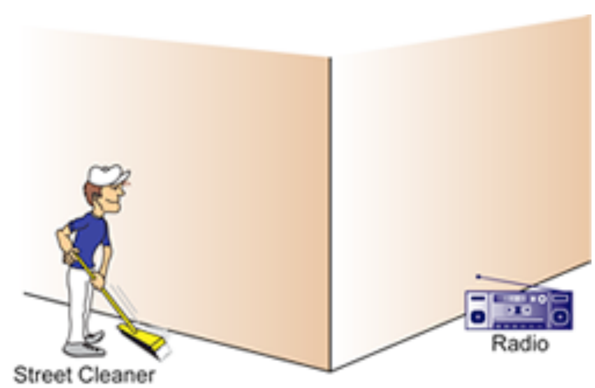
The proper name given to the bending of waves as they pass through a narrow gap or round an object is called diffraction. Diffraction is a property of all waves, it is also a unique property of waves.

An example of this can be seen when water waves pass an obstacle — such as a harbour wall — they bend slightly around it.



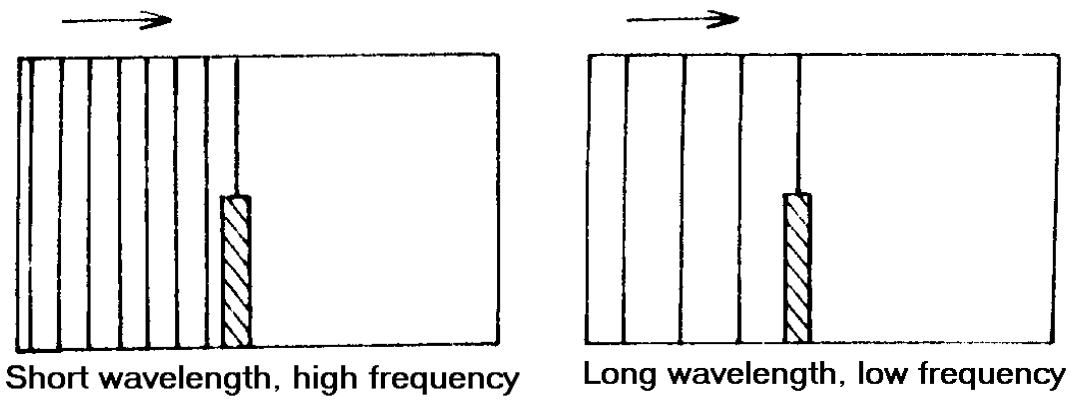
Diffraction of sound waves is why sounds can be heard around a corner.





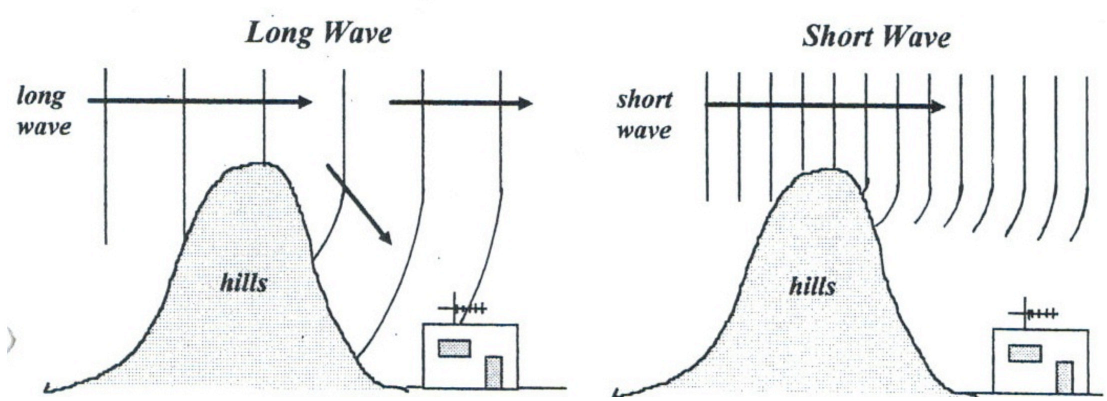
The amount of diffraction depends on wavelength. The **longer the wavelength, the greater the diffraction.**

The amount they diffract (bend) depends on the wavelength of the wave.



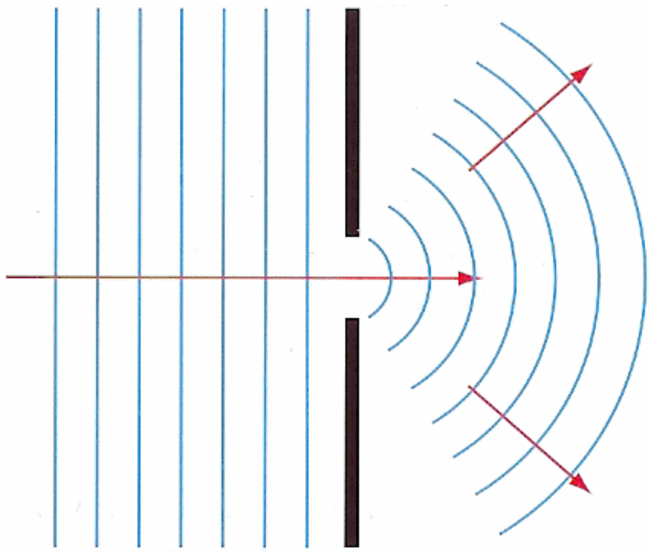
You cannot see around a corner because light waves have a much shorter wavelength than sound waves and so are not diffracted round the corner.

Radio and T.V. waves also diffract around objects. The amount they diffract depends on their wavelength.

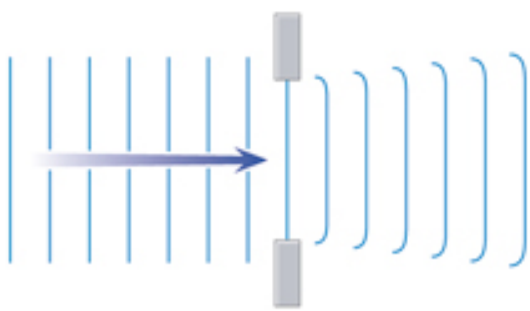


Radio waves have a longer wavelength than TV waves and therefore diffract more. In hilly areas it is much easier to receive radio signals than TV signals because of this. Mobile phones use microwaves which have an even shorter wavelength than TV signals, this is why it is very difficult to get reception in the Highlands!

In the following example the waves travel along until they reach a gap. The width of the gap is similar to the wavelength of the waves.



The waves pass through the gap and spread out due to diffraction. As we know the amount of diffraction depends on how the wavelength compares with the size of the gap. So what happens if the wavelength is much smaller than the width of the gap?



In this case, only the edges of the wavefront diffract.

The Electromagnetic Spectrum

Visible Light

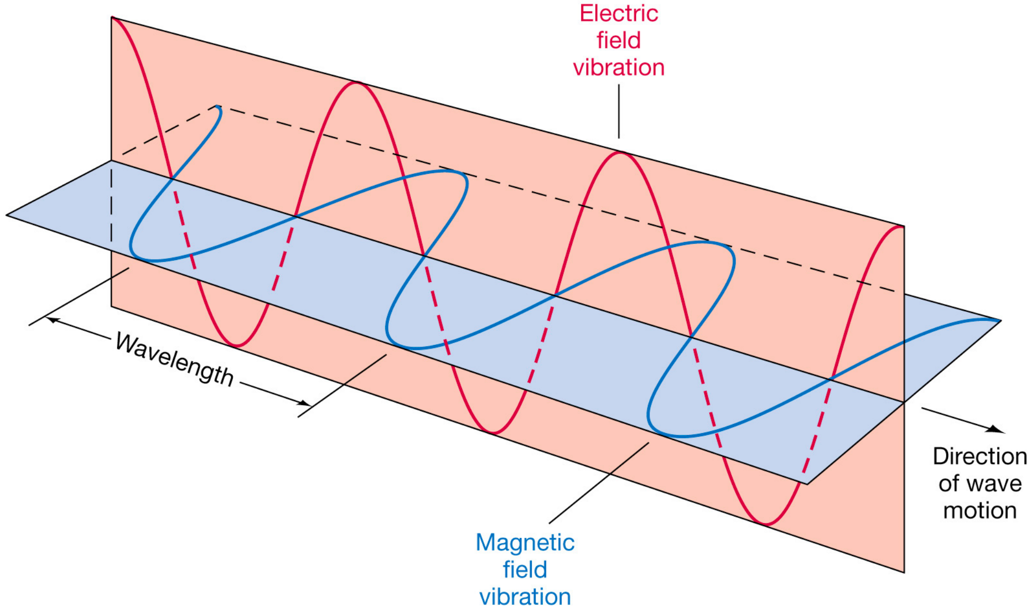
Light is a transverse wave and like all waves it can be described as having peaks, troughs, frequency, wavelength and amplitude. Just like all other waves it transfers energy.

Light waves behave in the same way as other types of waves and therefore the same formulas can be applied to solve problems involving speed, distance, time, frequency, period and wavelength.

Visible light covers a range of wavelengths from 400nm (violet) to 700 nm (red). However light waves can have wavelengths that are invisible to the human eye. We call the whole family of light waves (the ones we can see and the ones we can't) the **Electromagnetic Spectrum** and the waves **Electromagnetic Waves.**

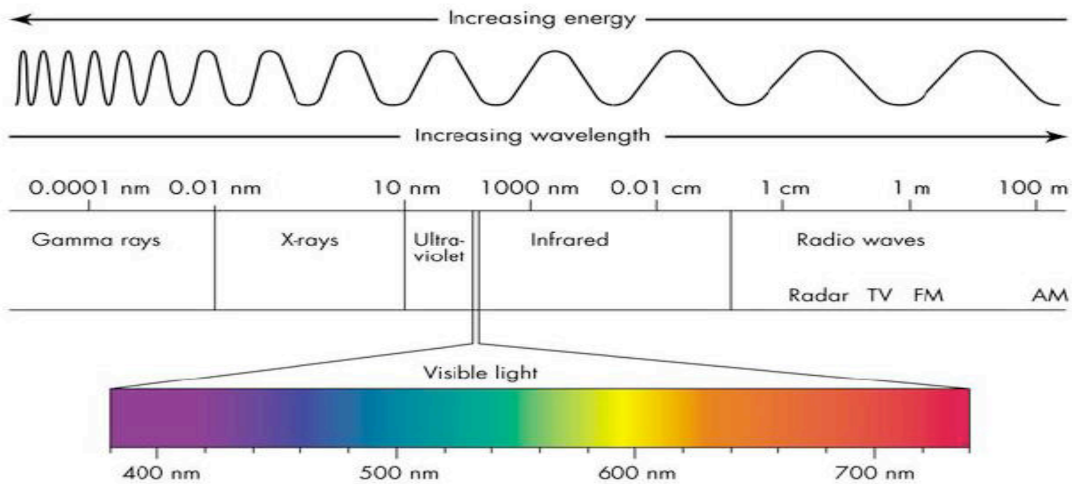
Electromagnetic Waves

All Electromagnetic (EM) waves are transverse waves. Unlike many other types of waves (sound waves for example) they do not need particles to vibrate or to travel through. Instead EM waves oscillate an electrical and a magnetic field perpendicular to their direction of travel (hence the name). This allows EM waves to travel through a vacuum, something that other waves cannot do.



All EM waves (including light) travel at the **same** speed. In a vacuum (or air) this is 300,000,000ms^{-1} or 3×10^8ms^{-1} — roughly 670 million miles per hour.

Parts of the Electromagnetic Spectrum



We can split the Electromagnetic (EM) Spectrum up into parts, or bands, of wavelengths and frequencies that display similar properties. Visible light is just one of these parts of the EM spectrum.

EM Band	Wavelengths	Detectors	Example Use
Gamma rays	< 0.01nm	Geiger–Müller tube	Radiotherapy
X–rays	0.01nm to 10nm	Photographic film	Medical scans
Ultraviolet (UV)	10nm to 400nm	Fluorescent materials	Security marking
Visible	390nm to 750nm	Eyes, CCD’s	Lasers
Infrared (IR)	750nm to 1mm	Thermistor, CCD’s	Remote controls
Microwaves	1mm to 1m	Aerial, water	Mobile phones
Radio waves	> 1m	Aerial	Communications

EM Band	Frequencies	Sources
Gamma rays	> 30EHz (3×10^{19}Hz)	Radioactive substances
X–rays	30EHz to 30PHz (3×10^{16}Hz)	Collision between high energy electrons and a metal target
Ultraviolet (UV)	30PHz to 750THz	The sun and other extremely hot objects
Visible	769THz to 400THz	Very hot objects and LED's
Infrared (IR)	400THz to 300GHz	Hot objects
Microwaves	300GHz to 300MHz	Magnetron
Radio waves	< 300MHz	Wires carrying alternating current, some astronomical objects, lightning

Frequency and Energy

Although the amplitude of an electromagnetic wave is related to the energy of the wave this is not the whole story. In Physics we refer to the amplitude of light as its **intensity**.

However the energy of electromagnetic wave is not only dependant on its intensity. You are probably aware that high frequency EM waves, such as gamma rays, are far more energetic (and dangerous) than low frequency EM waves, such as radio waves, even though they might have the same intensity.

This is because the energy of an electromagnetic wave does not travel as a continuous stream but in 'packets' or 'bundles'. We call these packets of energy **photons**. The energy of a photon is proportional to the frequency of the light.

This means that waves with higher frequencies have higher photon energy.

Waves with lower frequencies have lower photon energy.

Practice Problems

1. If it takes light 8 minutes to travel from the Sun to the Earth, how far away is the Sun from Earth?

2. Calculate the frequency of red light which has a wavelength of 700nm.

3. Calculate the wavelength of green light which has a frequency of 5.8×10^{14}Hz.

4. Northsound 1 broadcasts on 96.9MHz. What is the wavelength of the radio waves that they use?

LIGHT

Reflection

You should remember from S1/S2 the Law of Reflection for light…

Experiment

Aim: To find the relationship between the angle of incidence and the angle of reflection.

Hypothesis: ____

Apparatus: One plane mirror, a protractor, a single slit, a ray box and a power supply

Method:

Ray Diagram:

Results:

Angle of Incidence	Angle of Reflection

Conclusion:

Refraction

The refraction of light is a change in direction of a ray of light when it travels from one medium to another. For example when light travels from glass to air or air to water it will bend and refract. This is because when light enters a more dense material it **slows down**. This means that the speed of light in glass is not $3\times10^{8}ms^{-1}$ (as it is in air). In fact the speed of light in glass is roughly $2\times10^{8}ms^{-1}$.

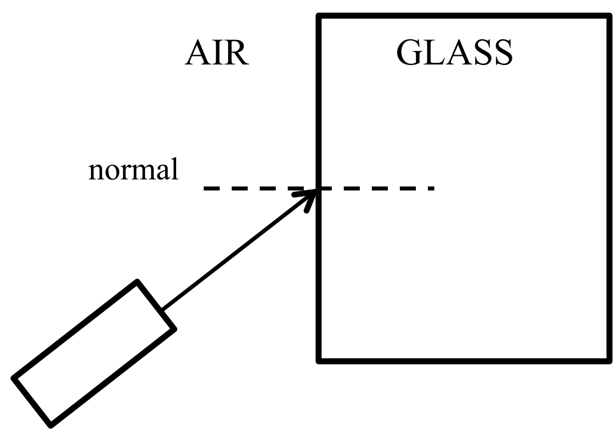
Experiment

Aim: To find the relationship between the angle of incidence and the angle of refraction.

Hypothesis: ____

Apparatus: A protractor, a single slit, a ray box, A3 paper, a glass block and a power supply

Method: Set up the experiment as shown below:



Trace around the glass block onto the A3 paper and mark on the normal. Aim the ray box at the normal and mark on the angles of incidence and refraction. Repeat with different angles of incidence.

N.B. The angle of incidence and the angle of refraction are *always* measured from the normal — *never* the glass block.

Results:

Conclusion:

If the incident ray is passing from air into glass it refracts **towards** the normal.

If the incident ray is passing from glass into air it refracts **away from** the normal.

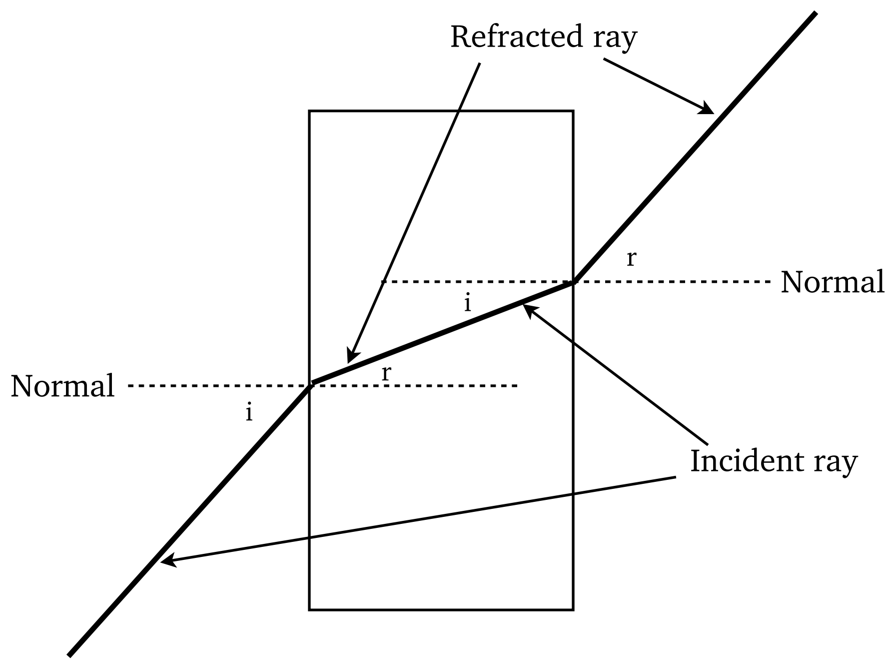
The Law of Refraction

The quantitative Law of Refraction is known as Snell's Law, however at National 5 you only need to remember the following rules:

If the incident ray is passing from a material with a low density/refractive index into another material with a higher density/refractive index the ray will be bent/refracted **towards** the normal.

If the incident ray is passing from a material with a high density/refractive index into another material with a lower density/refractive index the ray will be bent/refracted **away** from the normal.

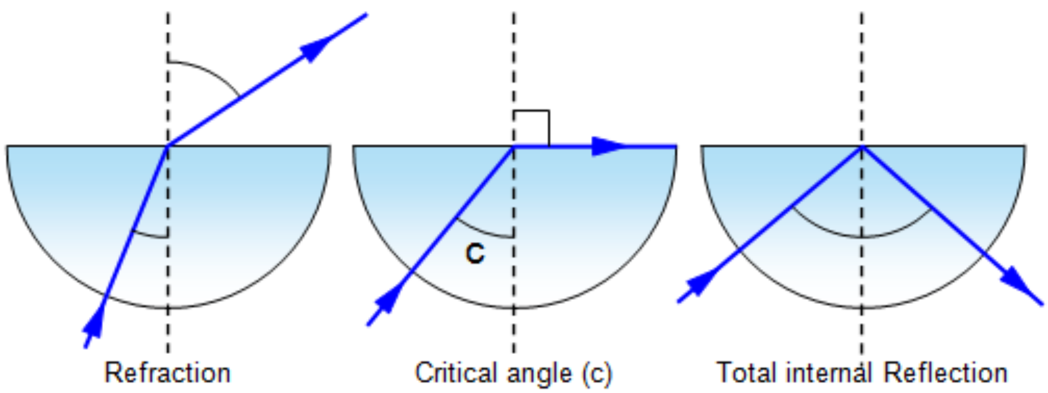
For a glass block **two** refractions occur. Once when the ray enters the block and again when the ray leaves the block.



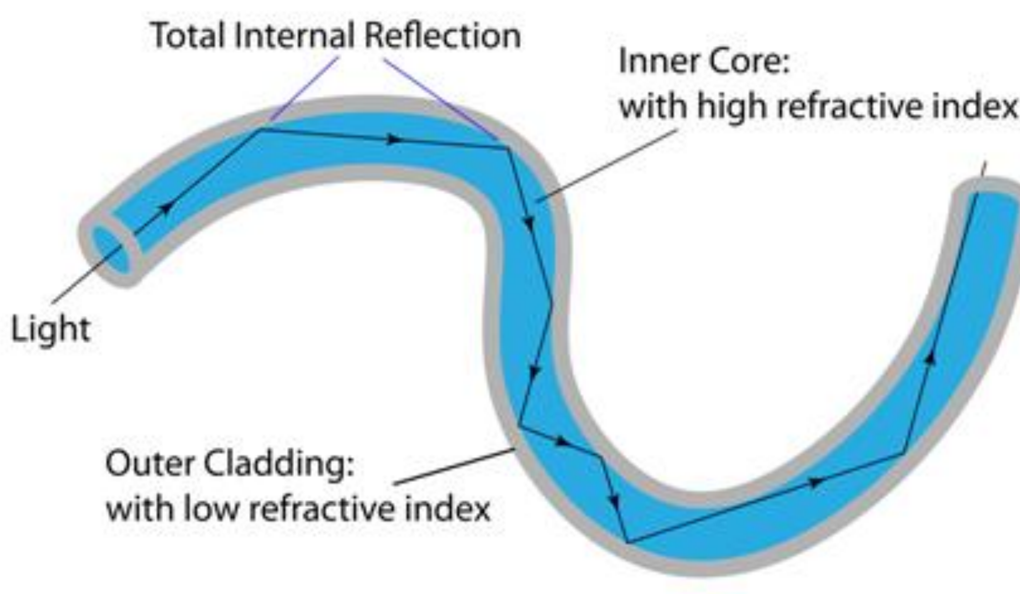
Note that the same result would be observed if the ray was sent through the block in the opposite direction.

Total Internal Reflection

Total internal reflection occurs when the angle of refraction is so large the refracted ray would not leave the material it was in. When this happens the ray reflects instead. This occurs at the **critical angle**. If the angle of incidence is less than the critical angle the ray will refract. If the angle of incidence is at or above the critical angle the ray will reflect. The value of the critical angle depends on the refractive index of a material — the higher the refractive index the smaller the critical angle. This is why diamonds (which have a very high refractive index) appear to be so sparkly — they are 'trapping' light through total internal reflection.



Total internal reflection is an extremely useful property of light and it is used to allow light to travel through a fibre optic cable:



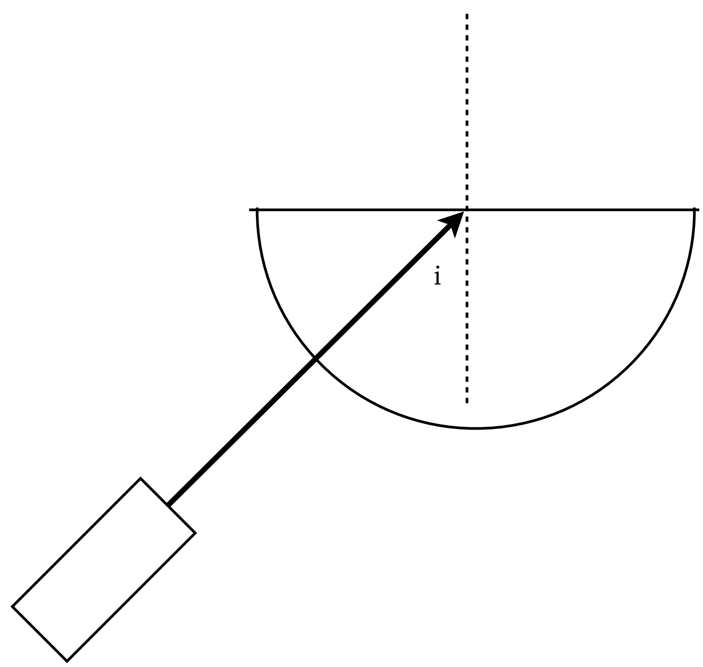
Experiment

Aim: To measure the critical angle for a semi–circular glass block.

Hypothesis: ____

Apparatus: A protractor, a single slit, a ray box, A3 paper, a semi–circular glass block and a power supply

Method: Set up the experiment as shown below:



Vary the angle of incidence until the ray **just** starts to totally internally reflect. Measure the angle of incidence **from the normal** — this is the angle of incidence.

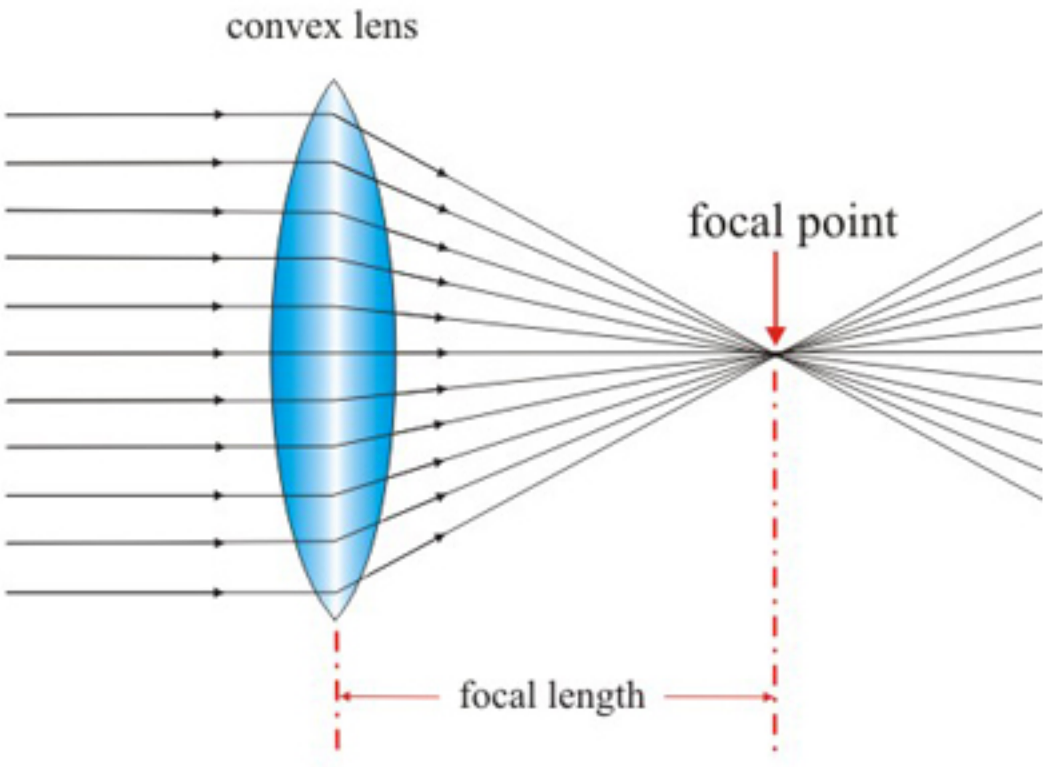
Results:

Critical Angle =

Lenses

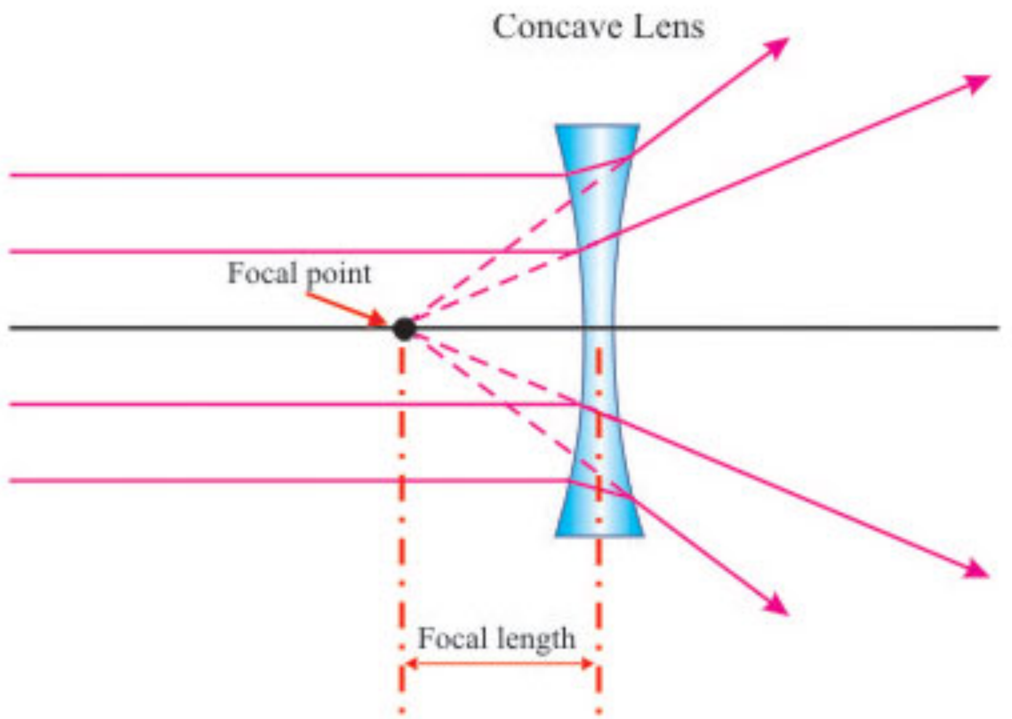
There are two basic types of lenses

Convex/Converging Lenses



A convex lens **focusses** light down to a single point — the focal point. They are used in many devices, such as cameras, because they will create a focussed image.

Concave/Diverging Lenses

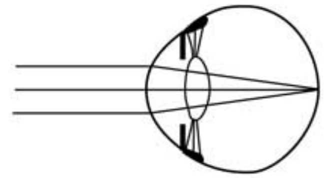


Concave lenses spread light out. Because they do not produce a real image they are usually used in conjunction with convex lenses in various optical systems. One use of the convex lens is in the 'spy holes' fitted to many from doors.

Eye Defects

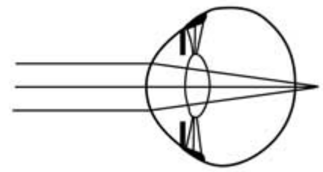
The most common use of lenses is in glasses and contact lenses to correct sight defects. The two most common eye defects that can be treated with glasses are:

Long Sightedness (Hyperopia) — Long sightedness is caused when the eyeball is too short or a person's lens is too weak. This means that the light is focussed **behind** their retina, making everything appear blurry. It is particularly hard to focus on objects that are very close to a person with long sightedness. Long sightedness can be corrected by wearing a **convex** lens.

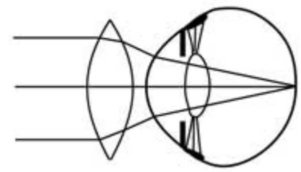


Normal eye

Hypermetropia

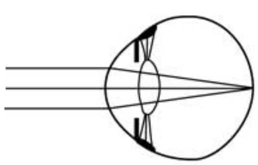


Light focused behind the retina



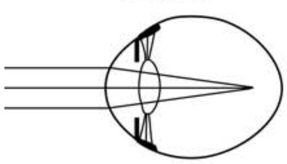
Corrected with convex lens

Short Sightedness (Myopia) — This is caused when the eyeball is too long or the lens too powerful. This means that light is focussed **inside** the eyeball and not on the retina, making everything appear blurry. It is particularly hard to focus on objects that are very far away from a person with short sightedness. Short sightedness can be corrected with a **concave** lens.

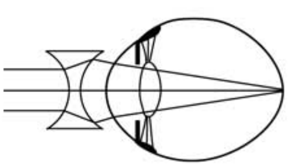


Normal eye

Myopia



Light focused in front of retina

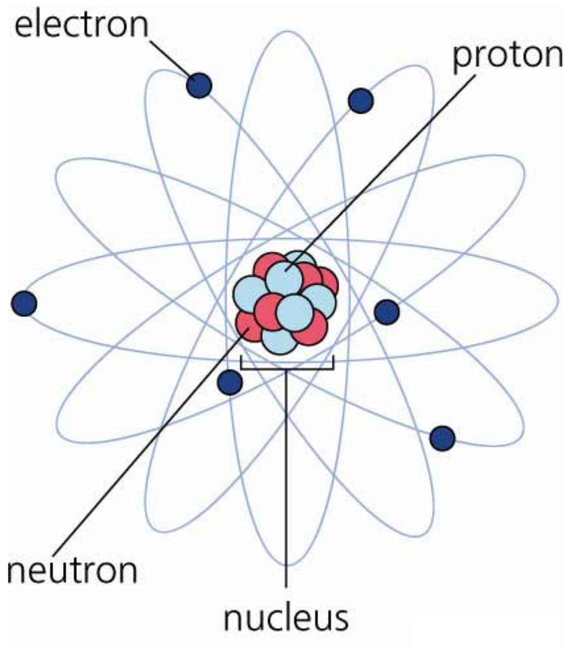


Corrected with concave lens

NUCLEAR RADIATION

The Atom

All matter consists of atoms, however atoms themselves are made up of several different particles. In the middle of an atom is a very small, very dense object called the **nucleus**. The nucleus is made up of positively charged **protons** and electrically neutral **neutrons**. The nucleus is surrounded by negative **electrons**.



A single atom is about 0.1nm across. A nucleus is only a few femto meters ($\times 10^{-15}$m) across. If you imagine a football pitch representing an atom the nucleus would be the size of a pea on the centre spot.

Name	Mass	Charge
Proton	1	+1
Neutron	1	0
Electron	0	–1

Ionisation

Ionisation is what we call the **addition** or **removal** of an electron from an atom. This will turn a neutrally charged atom into a positively (removing electrons)or negatively (adding electrons) charged **ion**. Atoms can be ionised in many ways but we are only going to study one — **ionising radiation**.

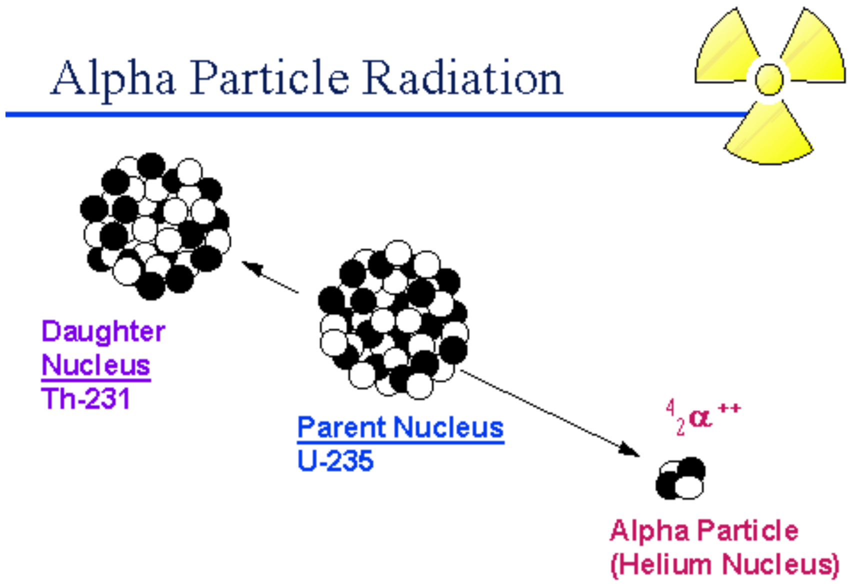
Ionising Radiation

A radiation is considered ionising if it is capable of ionising most atoms. There are three main types:

- Alpha (α)
- Beta (β)
- Gamma (γ)

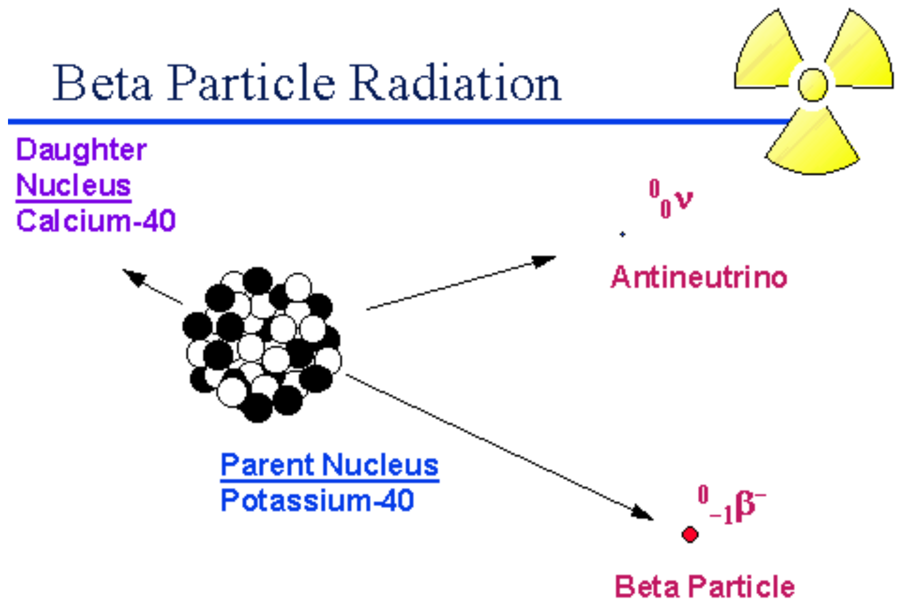
Alpha Particles

Alpha particles are made up of two protons and two neutrons. This means that they are the same as a Helium nucleus (or a He^{+2} ion) — just travelling very quickly. Compared to beta particles and gamma rays, alpha particles are very slow and heavy. Because they are so highly charged, alpha particles are extremely ionising. This means that they will be absorbed very easily — a single sheet of paper or a few centimetres of air is sufficient to absorb nearly all alpha particles. Humans are protected from alpha radiation in the environment by their outer layer of skin, however ingesting or inhaling alpha sources is highly dangerous as the alpha particles are absorbed by organs and tissue.



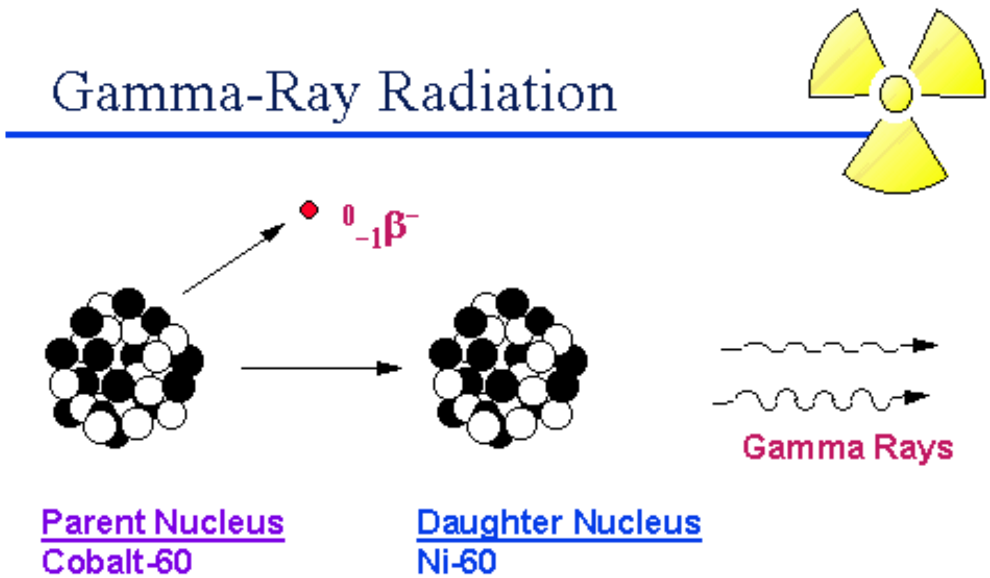
Beta Particles

Beta particles are made up of an electron travelling at high speed. They are much smaller and faster than alpha particles. Beta particles are produced when a neutron decays into a proton. Because beta particles are electrons they are negatively charged. Beta particles are highly ionising — though not as much as alpha particles. Beta particles will be absorbed by a few metres of air or a millimetres of Aluminium.



Gamma Rays

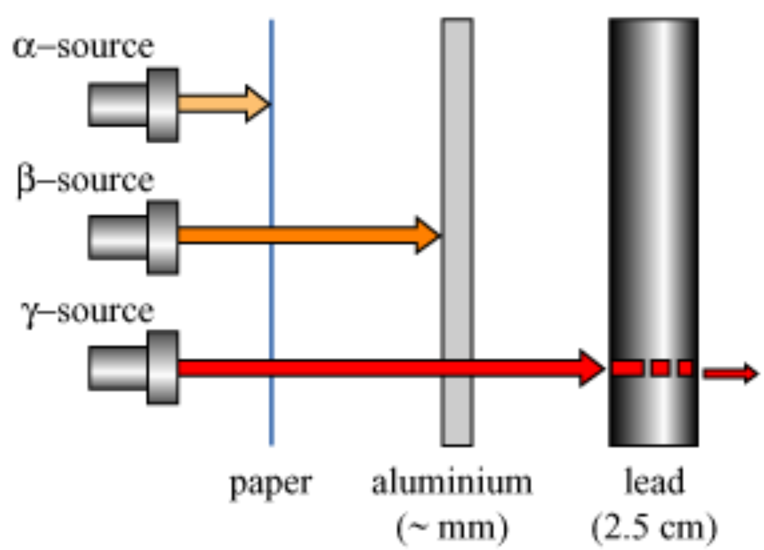
Gamma rays the highest energy, shortest wavelength and highest frequency band of the EM spectrum. Like all kinds of light, gamma rays travel at the speed of light. Gamma rays have no mass or electrical charge so they are only very weakly ionising. Gamma rays are very hard to absorb — you need lots of atoms! Because of this, to absorb gamma rays, a few centimetres of lead or several metres of concrete walls are required.



Summary — Properties of Radiation

Name	Mass	Charge	Made of
Alpha	4	+2	2 protons and 2 neutrons/He nucleus/He^{+2} ion
Beta	almost 0	–1	electrons
Gamma	0	0	EM waves/photons

Summary — Absorption of Radiation



Practice Questions

1. What particles are found in the nucleus of an atom?

2. What particle is found orbiting and atom?

3. What is the electrical charge on an electron?

4. What is the electrical charge on a neutron?

5. What is the electrical charge on a proton?

6. What is the electrical charge on an alpha particle?

7. What is the electrical charge on a beta particle?

8. What is the electrical charge on a gamma ray?

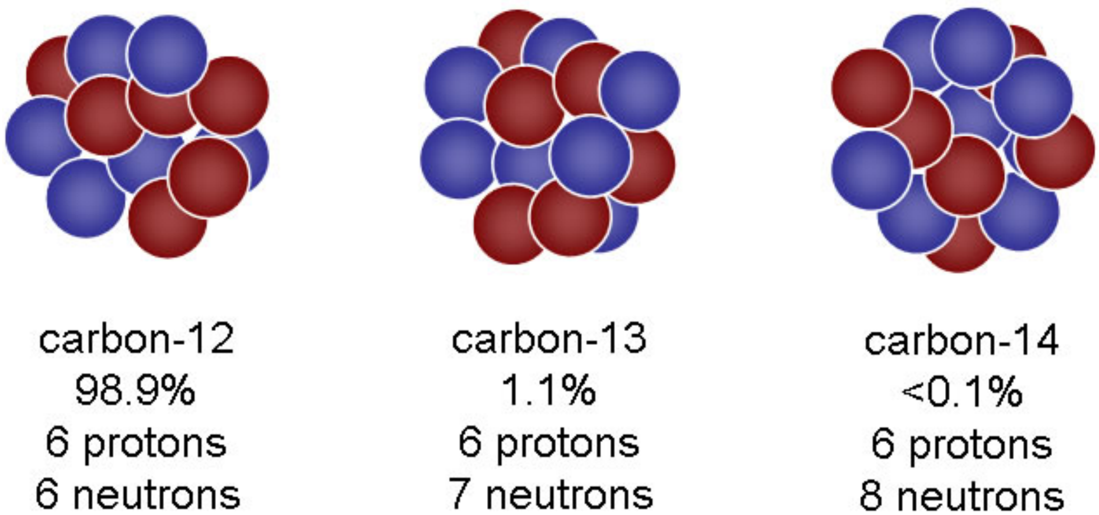
9. Radiation is detected passing through paper but not aluminium or lead. What type of radiation was detected?

10. Another type of radiation is detected passing through paper and aluminium but not lead. What type of radiation was detected?

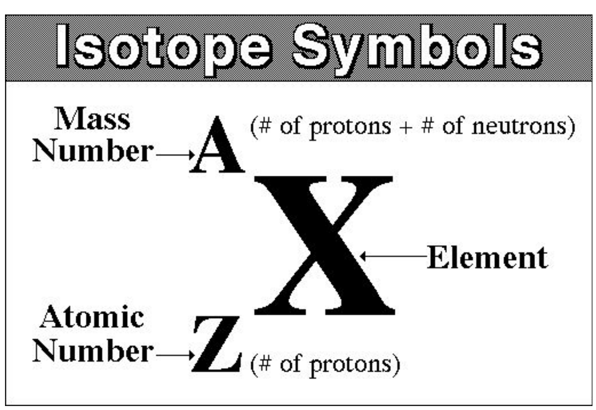
Isotopes

Most radioactivity is caused by an unstable nucleus trying to become stable, releasing radiation in the process. You are familiar with the periodic table of elements (there is a copy in your planner) however this does not tell the whole story. Each element can have variations in the number of neutrons that are in its nucleus — we call these variants **isotopes**.

Below are some of the isotopes of Carbon

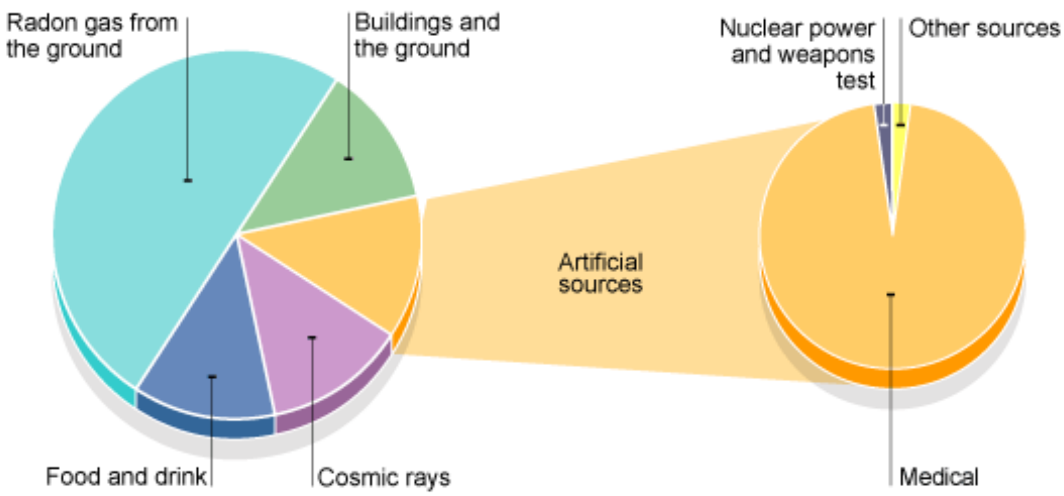


All three have the same number of protons — 6 — but different numbers of neutrons. Isotopes are typically named as their element followed by their atomic mass number (the number of protons and neutrons combined). For instance Carbon–14, Cobalt–60 or Uranium–235. There are a few exceptions, most notably Hydrogen–2, which is known as deuterium, and Hydrogen–3, which is known as tritium.



Background Radiation

There is a small amount of radiation (comprised of all three types) that is emitted all the time. This is known as **background radiation**. It is due to the radioactive decay of various substances all around us. Some of these are natural sources and some are artificial — some are even inside a human body!



Background Radiation Demonstration

Using a Geiger–Müller tube take 3 readings of the background radiation in the lab.

Reading 1: ______________________________

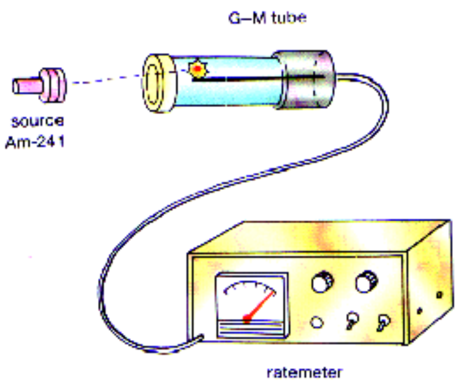
Reading 2: ______________________________

Reading 3: ______________________________

Average background radiation level = ____________________ counts per minute

Detecting of Ionising Radiation

All forms of ionising radiation will turn a **photographic plate or film** dark. Radiation workers wear a film badge. This measures their exposure to radiation by the amount of darkening of the photographic film. Absorbers such as aluminium, lead and plastic in the windows of the badge enable exposure to the different types of radiation to be measured.



A **Geiger–Müller tube** can be used to detect radiation. The tube contains a gas and has two electrodes at either end with a voltage across them. Radiation causes ions to form in the gas and these form a small pulse of current which is amplified and counted. The greater the amount of radiation, the greater the count rate.

Scintillation detectors work by the radiation striking a suitable material and producing a tiny flash of light. This is amplified by a photomultiplier tube, which results in a burst of electrons large enough to be detected. They can recognise the difference between alpha, beta and gamma radiation.

Effects of Ionising Radiation on Living Tissue

Ionising radiation can be extremely hazardous to living cells. Ionisation of the atoms inside a DNA molecule can cause the DNA to malfunction — causing mutations, such as cancer. Extremely high levels radiation can kill off cells completely leading to severe illness and even death. The following safety procedures should always be considered when working with radioactive sources:

- Limit the time exposed to radiation
- Never touch radioactive sources — use tongs instead
- Never point a radioactive source at someone
- Wash your hands after using a radioactive source
- Maintain a safe distance from the source
- Wear protective clothing (i.e. gloves)
- Stand behind a protective screen or radiation shield

Medical Applications of Radiation

Although radiation is potentially very harmful to a healthy person the ability of radiation to kill living cells is used in a variety of ways in medicine — as well as other properties of radiation.

Radiotherapy — This is a treatment for some forms of cancer where the cancer is irradiated (typically with gamma rays). The intense radiation kills the cancer cells However many healthy cells are also damaged, causing patients to feel extremely ill during treatment.

Sterilisation — Medical instruments need to be extremely clean and completely free of any living cells (bacteria) or viruses. Failure to do this can cause patients to become infected, which is potentially fatal. Instruments are exposed to a high intensity gamma source (typically Cobalt–60) that kills all living material on the instrument.

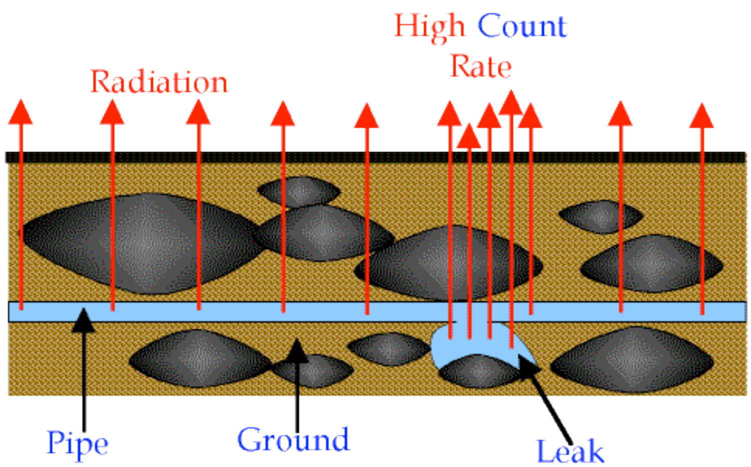
Research it — Find out more about how cancer cells can be destroyed using radiation. Write a short note which should include:

- Why a certain type of radiation is used.
- Why multiple angles of radiation are used.

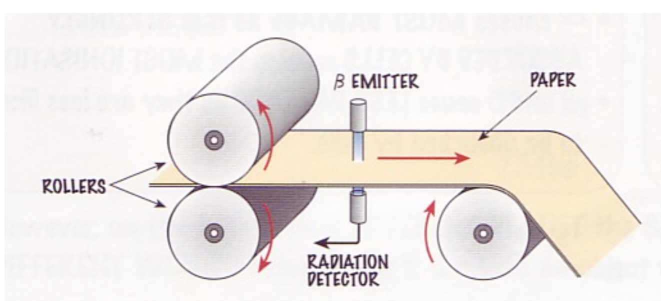
Radioactive Tracers — Radiation can also be used in diagnosis. Radioactive tracers help doctors examine the insides of our bodies. For example:
Iodine 131 (a beta source) is used to check if our thyroid glands are working properly. This gland controls the rate at which our body functions. The gland absorbs iodine, so a dose of radioactive iodine (the tracer) is given to the patient. Doctors can then detect the radioactivity of the patient's throat to see how well their thyroid is working.

Industrial Applications of Radiation

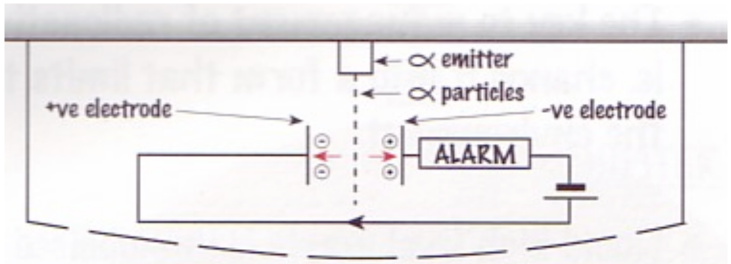
Pipeline Leak Checking — Many long pipelines are used in Scotland to transport oil and gas. A leak in these pipelines would be very costly for businesses in terms of wasted products and environmental clean-up. To make sure that all pipes are sealed or to find a possible leak, a gamma ray source can be put into the oil or gas. If there is a leak, the radioactive source producing gamma rays would leak and be detected by Geiger–Müller tubes in the environment. The type of radiation used has a short lifespan so that the damage to the environment is very small.



Controlling the thickness of sheet materials — Radiation can be used to monitor the thickness of paper as it is being made in a paper mill. Radiation is emitted by an emitter above the sheet. It is detected by a detector on the other side of the sheet. If the thickness of the sheet increases the amount of radiation detected decreases (and vice versa).



Smoke detectors — Most smoke alarms contain a (mildly) radioactive source. The emitted radiation causes ionisation of the air particles and the ions formed are attracted to the oppositely charged electrodes — so a current flows in the circuit.



When smoke enters the space between the two electrodes less ionisation takes place because the radiation is absorbed by the smoke particles. A smaller current than normal flows, and the alarm is designed to sound when this happens.

Practice Questions

1. Why is alpha radiation not used to sterilise medical instruments?

2. How could a radioactive source be used to find a blockage in a kidney?

3. Why are gamma rays used to find leaks in pipelines and not alpha or beta radiation?

4. Why is a beta source used to check the thickness of sheet materials?

Dosimetry

Dosimetry is the measurement of the amount of radiation. We will be looking at three different ways of measuring radioactivity:

- Activity
- Absorbed Dose
- Equivalent Done

Activity

The activity of a radioactive source is defined as the number of nuclei decaying per second in a radioactive source. It is measured in becquerels (Bq). One becquerel is equal to one decay (or count) per second. There is a formula for activity and it appears on the formula sheet. It is given below:

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

Number of decays

Activity in becquerels

Time in seconds (s)

Absorbed Dose

Not all of the emissions from a radioactive source will be absorbed by a body. Much of the activity from a radioactive source will miss the body and some will pass straight through without being absorbed. It is possible to measure the energy that is absorbed. The amount which is absorbed per 1kg of material is called the **absorbed dose**. The unit of absorbed dose is the gray (Gy). One gray is equal to one joule per kilogram. There is a formula for absorbed dose, it appears on the formula sheet, and is shown below:

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

Energy in joules (J)

Absorbed Dose in grays (Gy)

Mass in kilograms (kg)

Practice Questions

1. A radioactive source gives off 300 radioactive emissions in 2 minutes. What is the activity of the source in Becquerels?

2. If 50J of energy are absorbed by 2kg of tissue what is the absorbed dose?

3. Calculate the absorbed dose if 20mJ of energy is absorbed by 400 g of body tissue.

4. A patient of mass 70 kg receives radiotherapy. During the treatment, a tumour of mass 250 g receives 20 J of energy. Calculate the absorbed dose.

Equivalent Dose

The risk to biological tissue from radiation is not just dependant on the amount of energy absorbed and the absorbed dose. The type of radiation is also an important factor. Each type of radiation is assigned a **weighting factor** relating to how dangerous it is. The higher the weighting factor the more dangerous. Some weighting factors are given below:

Radiation	Weighting Factor
Gamma	1
Beta	1
Alpha	20
Protons	2
Neutrons	Varies

The equivalent dose is a measure of how harmful a dose of radiation is. It is found by multiplying the absorbed dose by the correct weighting factor. Equivalent dose is measured in sieverts (Sv). The formula is on the formula sheet and is given below:

$$H = Dw_R$$

Equivalent Dose
in sieverts (Sv)

Absorbed Dose
in grays (Gy)

Weighting factor

Example Equivalent Doses

Equivalent Dose	Source/Effect
0.1μSv	Eating a banana
1μSv	Using a CRT monitor for a year
10μSv	Normal daily dose from background radiation
20μSv	Chest X–Ray
2mSv	Head CT scan
4mSv	Normal yearly dose from background radiation
6mSv	Spending one hour at the Chernobyl plant (roughly) in 2010
50mSv	Maximum yearly dose for radiation workers
100mSv	Minimum dose linked to cancer
400mSv	Minimum dose to cause radiation poisoning
2Sv	Severe radiation poisoning
4Sv	Extreme radiation poisoning — usually fatal
8Sv	Fatal dose even with treatment
50Sv	10 minutes next to the Chernobyl reactor after meltdown on 26 April 1986

Practice Questions

1. A radiographer has an absorbed dose of 30mGy of alpha particles. What is his equivalent dose?

2. A worker in the nuclear industry receives an absorbed dose of 400μGy from alpha particles and an absorbed dose of 2 mGy from gamma radiation. Calculate the total equivalent dose received.

3. In the course of his work an industrial worker receives a dose equivalent of 200μSv. Determine the absorbed dose if he is exposed to alpha particles.

Half–Life

As we already know the nuclei of radioactive atoms are unstable. They break down, emitting radiation and change into a completely different type of atom.

It is not possible to predict when an individual atom might decay as radioactive decay is a random process. In any radioactive source, the activity decreases with time because the number of unstable atoms gradually decreases leaving fewer and fewer atoms to decay.

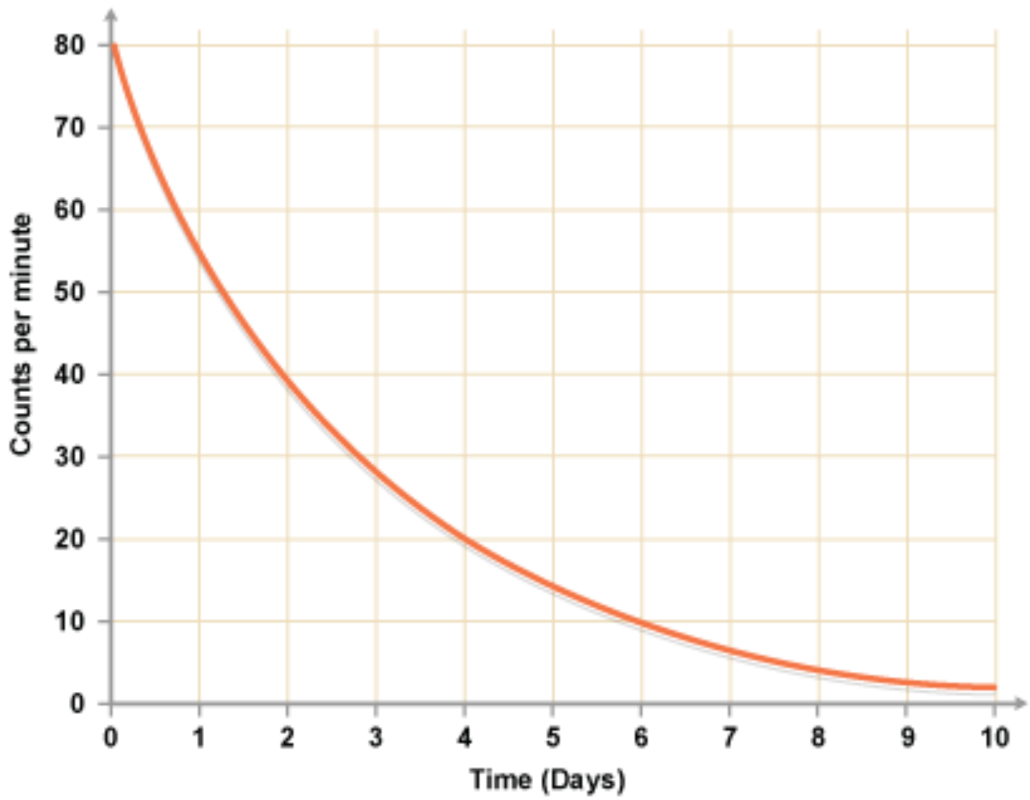
It is possible to measure how long it takes for half the nuclei of a piece of radioactive material to decay. This is called the **half–life** of the radioactive isotope.

Half–life is defined as:

- The time it takes for the number of nuclei in a sample to halve.
- The time it takes for the count rate from a sample containing the isotope to fall to half its starting level.
- The time taken for the activity to fall to half its original value.

Different radioactive isotopes have different half–lives. For example, the half–life of carbon–14 is 5,715 years, but the half-life of francium–223 is just 20 minutes.

It is possible to find out the half–life of a radioactive substance from a graph of the count rate against time. The graph below shows the decay curve for a radioactive substance.



The count rate drops from 80 to 40 counts a minute in two days, so the half-life is two days.

In the next two days, it drops from 40 to 20 — it halves.

In the two days after that, it drops from 20 to 10 — it halves again (and so on).

Measuring Half–Life Experiment

Aim: To determine the half life of a radioactive source

Method :

Results and graph:

Conclusion :

Example Question

The activity of a source falls from 80MBq to 5MBq in 8 days. Calculate its half-life.

- It takes 4 half–lives to decay to 5MBq.
- Therefore 4 half–lives = 8 days
- So 1 half–life = 2 days

Practice Questions

1. The initial activity of a radioactive isotope is 400Bq. The sample has a half–life of 2 minutes and is allowed to decay for 8 minutes. Calculate the final activity of the isotope.

2. Radioactive rocks emit radiation, which can be harmful, if exposure to them is not controlled. Some rocks have an activity of 160Bq and emit radiation over a 3 day period. What is the final activity of these rocks given that their half–life is 12 hours.

3. A sample of radioactive uranium has an initial activity of 600kBq. After 10 days its activity has dropped to 150kBq. Use this information to calculate the half–life of the source.

4. Calculate the half–life of a radium spray source, which emits alpha radiation, given that it takes 45 minutes for the activity to drop from 2400 counts per minute to 75 counts per minute.

5. Calculate the initial activity of a radioactive source whose activity falls to 20kBq in 16 minutes given that it has a half–life of 2 minutes.

6. A radioactive source has a half life of 2 days. What fraction of the sample is left after: 2 days, 6 days and 20 days?

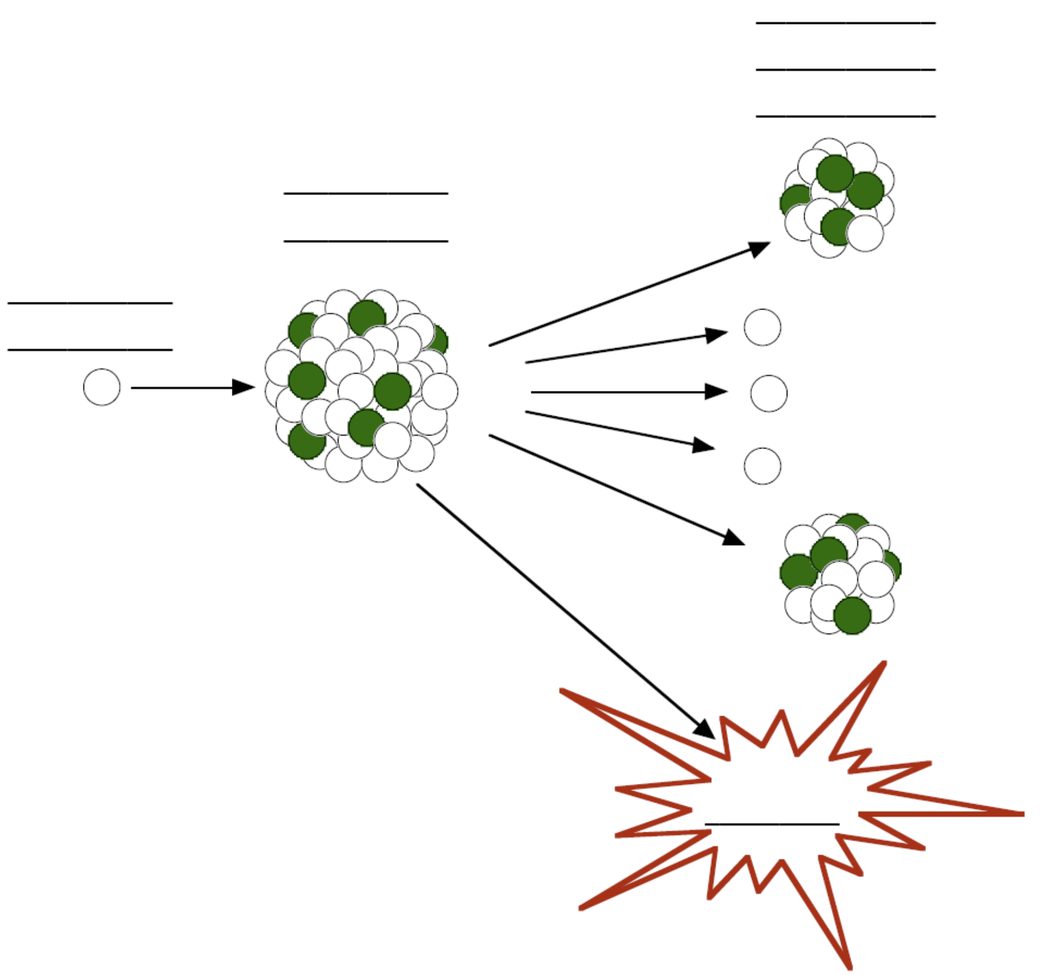
7. The activity of an isotope varies with time as shown below. The count rate is uncorrected for background radiation.

Count rate (per minute)	230	190	160	130	110	95	80	70
Time (hours)	0	1	2	3	4	5	6	7

The background count is 30 counts per minute. Plot a corrected graph of activity against time for the isotope and from it calculate the half–life of the isotope.

Nuclear Fission

Nuclear fission happens when the nucleus of an atom is split in two. This splitting creates two new smaller nuclei, neutrons, and a very large amount of energy. Because fission is caused by neutrons hitting the nucleus, the release of extra neutrons from a fission will in turn cause more fissions in other nuclei. This is known as a **chain reaction**.



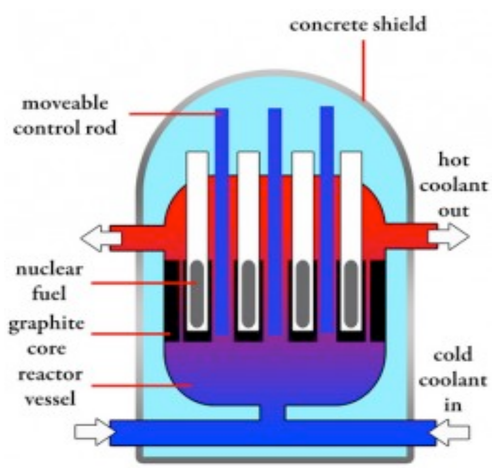
Generating Electricity Using Nuclear Fission

Fission reactions take place in nuclear reactors. The fuel rods are made of uranium-238. The neutrons released are fast moving. A moderator, e.g. graphite, is used to slow them down and increase the chance of further fissions occurring.

These slow (thermal) neutrons cause a chain reaction so that more fissions occur. Control rods, e.g. boron are lowered into the reactor to absorb some of the slow neutrons and keep the chain reaction under control. In the event of an emergency they are pushed right into the reactor core to stop the chain reaction immediately.

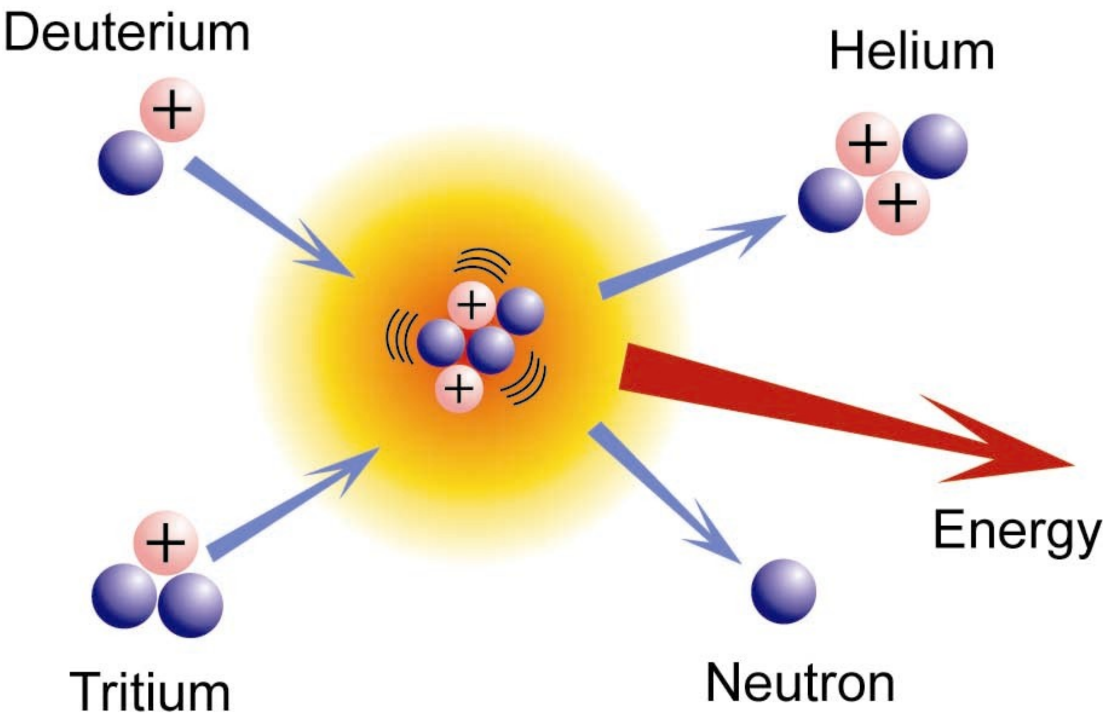
A cooling system is needed to cool the reactor and to transfer heat to the boilers in order to generate electricity. The containment vessel is made of thick concrete which acts as a shield to absorb neutrons and other radiations.

The massive amount of heat generated by the reactor is passed through a heat exchanger to produce steam — which then passes through a turbine — thus generating electricity.



Nuclear Fusion

Nuclear fusion occurs at the extremely high temperatures found inside a star. It is the process of joining two light nuclei (typically hydrogen isotopes) together. This releases very large amounts of energy — as is easily observed by looking at our own Sun.



There is a lot of effort being made to see if the process of nuclear fusion could be replicated under controlled conditions on Earth for the generation of electricity. Nuclear fusion theoretically offers substantial improvements over conventional fission nuclear power plants:

- Improved operational safety
- Far less harmful waste
- Far easier to acquire fuel
- No ability to create materials for nuclear weapons

Waves and Radiation

You need to know:

	✓ ? ✘
The simple model of the atom (protons, neutrons, electrons)	
What alpha particles, beta particles and gamma rays are	
That radiation can be absorbed by the material it is travelling through	
How easily absorbed each type of radiation is and what materials will absorb most/all of each type of radiation	
What ionisation is	
Which types of radiation are the most and least ionising	
A way to detect radiation	
That radiation can kill living cells or change their nature	
What absorbed dose is and what it is measured in	
How to use the $D = E/m$ formula	
What the radiation weighting factor is	
What equivalent dose is and what it is measured in	
How to use the $H = Dw_r$ formula	
That is risk of biological harm depends on absorbed dose, type of radiation and the part of the body exposed	
What causes background radiation	
What safety precautions should be taken when handling radioactive sources	
What the radioactive hazard sign looks like	

	✓ ? ✘
How to reduce the exposure to radiation (by using shielding, limiting time exposed and increasing the distance from the source)	
That radiation can be used to sterilise medical equipment	
A use of radiation (other than sterilisation)	
What is meant by the activity of a source	
What half life is	
How to do half life calculations	
What nuclear fission and fusion are and how they can be used	