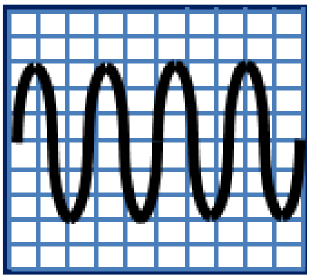
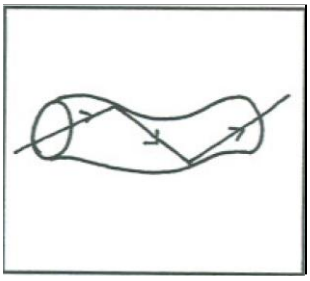
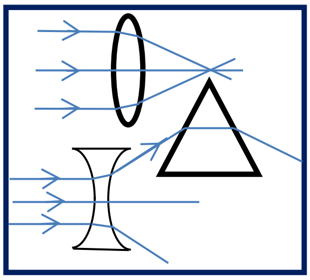
Cumbernauld Academy	Physics	Name

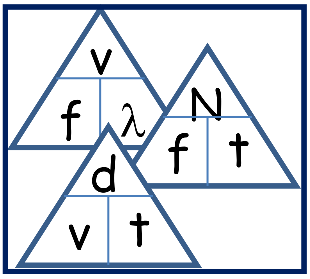
Waves and Radiation Summary

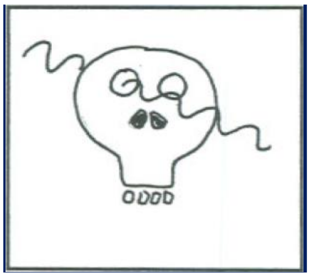
Part 1 Waves











Waves and Radiation

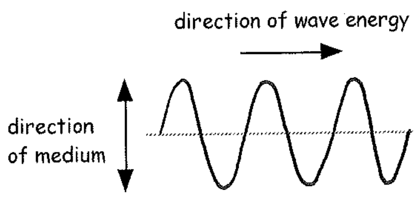
A - Waves

All waves transfer _____energy______________.

Some waves require a medium to travel through including water and others like light can travel through a ___vacuum__________, which has no particles to travel through.

There are __2__ different types of waves, which are __transverse__ waves and a longitudinal waves.

Transverse waves

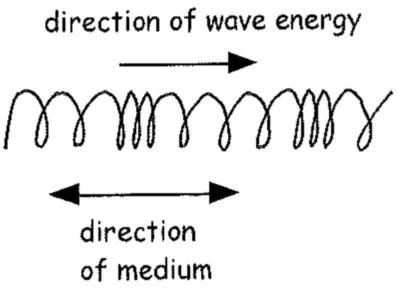


In transverse waves the particles of the medium vibrate at __right__ angles to the direction of the wave energy transfer.

Examples include

tidal waves, _light, water, radio, microwave, ______________

Longitudinal Waves



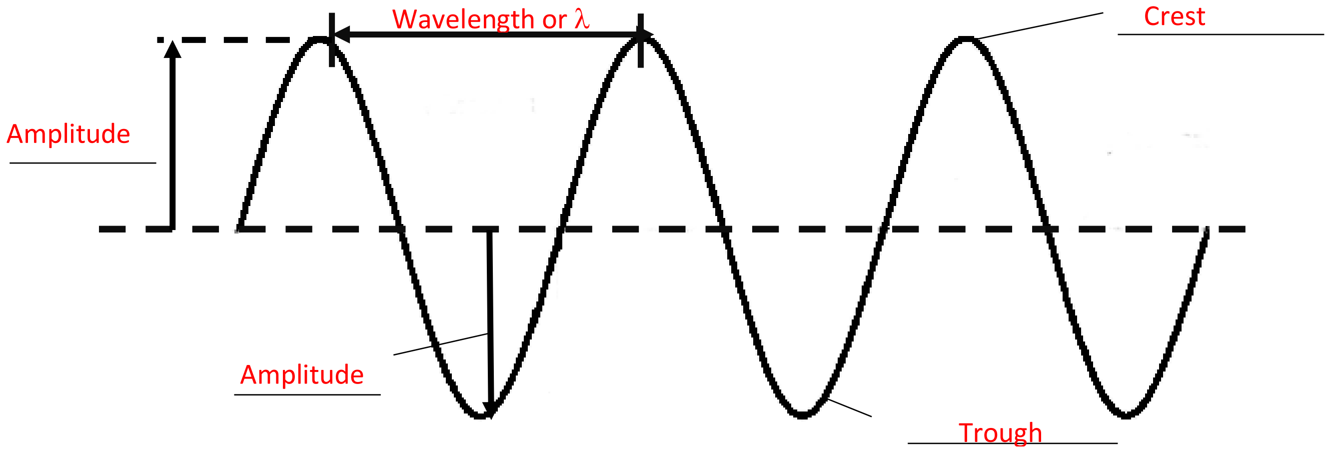
In longitudinal waves the particles of the medium vibrate in the __same____ direction as the wave energy transfer.

An example of a longitudinal waves is __sound__________.

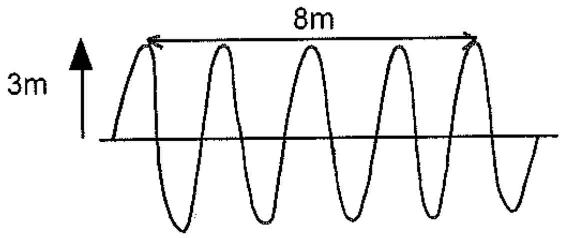
Waves and Radiation Problem Booklet - Page 8 Questions 1-6

Wave Words

Quantity	Quantity Symbol	Definition	Unit	Unit Symbol
crest		Highest point on a wave		
trough		Lowest point on the wave		
frequency	f	Number of waves that pass a point in __one__ second.	Hertz	Hz
period	T	Time for a wave to pass a __point_________.	second	s
wavelength	λ	Distance from one point on a wave to the same __point______ on the next wave.	metre	m
amplitude		Size of maximum disturbance from the zero position.	metres	m
speed	v	Distance travelled by a wave in __one______ second.	metres per second	ms^{-1} or m/s



Example 1 - Below is a diagram representing a water wave.



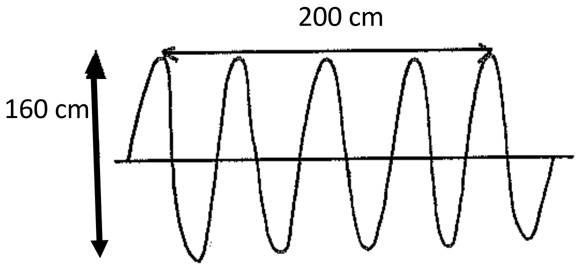
(a) What is the amplitude of the water wave?

Amplitude = 3 m

(b) What is the wavelength of the water wave?

Wavelength = $\frac{8}{4} = 2\,m$

Example 2 - Below is a diagram representing a sound wave.



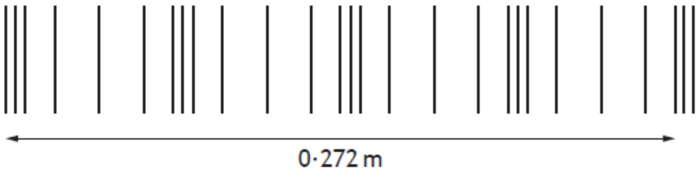
(a) What is the amplitude of the sound wave?

Amplitude = $\frac{160}{2} = 80\,cm$

(b) What is the wavelength of the sound wave?

Wavelength = $\frac{200}{4} = 50\,cm$

Example 3 - Calculate the wavelength this longitudinal wave.



$$\lambda = \frac{0 \cdot 272}{4}$$

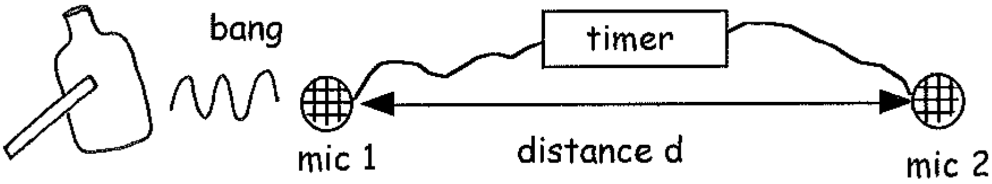
$$\lambda = 0 \cdot 068m$$

Waves and Radiation Problem Booklet - Page 9 Questions 1-10

Speed of Sound in Air

To measure the speed of sound connect 2 microphones to a ___timer_________________.

Measure the distance between the microphones using a ____metre stick_____________.



Make a loud __sound_________.

When the sound gets to microphone 1 the timer __starts______________ and when the sound gets to microphone 2 the timer ____stops___________.

$$\text{Speed of sound} = \frac{distance\ between\ mic\ 1\ and\ \_\_mic\ 2\_\_\_\_\_\_\_\_\_}{time\ to\ travel\ from\ mic\ 1\ to\ \_\_mic\ 2\_\_\_\_\_\_\_\_\_}$$

The speed of sound in air is ___340_________ m s^{-1}.

The speed of light in air is _____300 000 000________________ ms^{-1} or 3×10^8 m s^{-1}

Light is much faster than ____sound__________.

Examples that show the speed of light is faster than the speed of sound include:

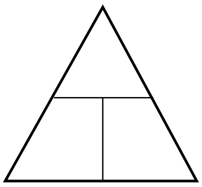
Thunder and lightning - in a thunder storm sound and light are created at exactly the same ___time______. We see the __lightning________ first because the light signal travels _faster________ than the sound, so it gets to us first.

Fireworks, golfer hitting a ball at a distance,

Speed, distance and time.

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

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



Quantity	Quantity Symbol	Unit	Unit Symbol
distance	d	metres	m
time	t	seconds	s
speed	v	metres per second	m/s or m s^{-1}

Example - What distance would a sound wave travel in 0·6s?

d = d t = 0·6s v = 340 m s^{-1}	$d = vt$ $d = 340 \times 0 \cdot 6$ $d = 204\ m$

Waves and Radiation Problem Booklet - Page 2 Q1-5 (4) + Page 3 Questions 1-10 (5)

Scientific Notation

2,300,000 = 2·3 x 10^{6}

300,000,000 = 3 x 10^{8}

0·005 = 5 x 10^{-3}

4,560,000,000 = 4·56 x 10^{9}

806,000 = 8·06 x 10^{5}

0·000 000 047 = 4·7 x 10^{-8}

Prefixes

Using prefixes makes writing big and small numbers much easier.

Prefix	Symbol	Factor	Scientific Notation
nano	n	0·000 000 001	10^{-9}
micro	µ	0·000 001	10^{-6}
milli	m	0·001	10^{-3}
kilo	k	1 000	10^{3}
mega	M	1 000 000	10^{6}
giga	G	1 000 000 000	10^{9}

Another common prefix that is used is cm. To convert from cm to m, divide by 100.

4 km = 4 x 1000 or 4 x10^{3} m

12·6 Mm = 12·6 x 1 000 000 or 12·6 x 10^{6} m

5·23 Gm = 5·23 x 1 000 000 000 or 5·23 x 10^{9} m

5·7 cm = 5·7 ÷ 100 or 5·7 x 10^{-2} m

6·2 ms = 6·2 ÷ 1000 or 6·2 x 10^{-3} s

40 µs = 40 ÷ 1 000 000 or 40 x 10^{-6} s

Example Calculate the time, in microseconds, for light to travel 2·5 km?

t = t
d = 2·5 km = $2{\cdot}5 \times 10^{3}$ m
v = 3×10^{8} m s^{-1}

$$d = vt$$
$$t = \frac{d}{v}$$
$$t = \frac{2 \cdot 5 \text{ x } 10^{3}}{3 \text{ x } 10^{8}}$$

$$t = 0 \cdot 0000083\ s$$
$$t = 8 \cdot 3 \text{ x } 10^{-6} s$$
$$t = 8 \cdot 3\ \mu s$$

Converting time to seconds

Time, quite often, needs to be converted into seconds.

ms = ÷ 1000 or x 10^{-3} s e.g 5·6 x 10^{-3} s

To convert

Minutes to seconds	x No of minutes by 60
Hours to seconds	x No of hours by 60 then by 60
Days to seconds	x No of days by 24 then by 60 then by 60
Years to seconds	x No of years by 365 then by 24 then by 60 then by 60

Example Calculate the distance light would travel in 1·7 minutes?

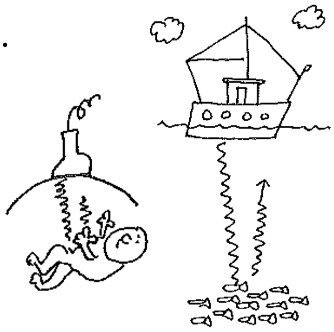
d = d
t = 1·7 mins = 102 s
v = 3×10^{8} m s^{-1}

$$d = vt$$
$$d = 3 \text{ x } 10^{8} \times 102$$
$$\text{d} = 3 \cdot 06 \times 10^{10} \text{ m}$$

Ultrasound

Humans can hear sound waves with frequencies between 20 and __20 000__ Hz.

Sounds with a frequency **above 20 000 Hz** are called __ultrasound__.



Reflections

The reflection of waves, including sound and ultrasound, can be used to:

- detect the ___depth________ of the sea bed
- detect shoals of __fish_______
- detect walls or other obstacles when vehicles are reversing
- detect ___cracks______________ in metal objects like plane wings
- build up pictures of the ____inside_______ of the body e.g. unborn baby

By using the total time between the signal being ___transmitted______________ and received the total distance can be calculated. From this the distance between the object and the transmitter can be calculated by dividing the total distance by __two_____________. The same idea can be applied to echoes from buildings or walls.

Example

The diagram shows a girl standing at a fireworks display.

There is a tall building nearby.

The firework explodes, the girl hears two bangs 0·6s apart.

Calculate the distance between the girl and the building?

d = d
t = 0·6 s
v = 340 m s^{-1}

Total Distance

$d = vt$

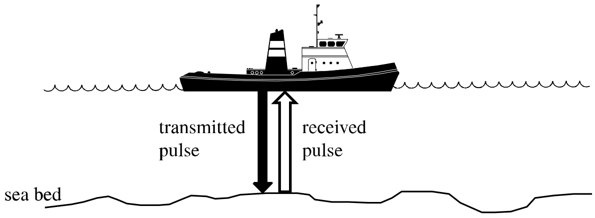
$d = 340 \times 0 \cdot 6$

$\mathrm{d} = 204\ \mathrm{m}$

Distance between the girl and the building

$$d = \frac{204}{2} = 102m$$

Example



The depth of the seabed is measured using pulses of ultrasound. The ultrasound is transmitted by a stationary ship. The ultrasound is reflected from the seabed as shown.

One pulse of ultrasound is received back at the ship 0·3s after being sent out.

(a) (i) Use the data sheet to find the speed of the ultrasound in the water.
1500 m s^{-1}

(ii) Calculate the depth of the sea bed.

d = d
t = 0·3 s
v = 1500 m s^{-1}

Total Distance

$d = vt$

$d = 1500 \times 0 \cdot 3$

$\mathrm{d} = 450\ \mathrm{m}$

Depth of the seabed

$$d = \frac{450}{2} = 225m$$

(b) The ship then sailed into shallower water.
How does the time to transmit and receive a pulse of ultrasound compare to 0·3 s now?

The time has decreased e.g. 0·1 s

Waves and Radiation Problem Booklet - Page 5 Questions 11-18 + Page 16 Questions 1-8

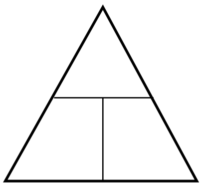
Frequency

Frequency is the number of waves that pass a point in one second.

From this we can write the following equation.

$$frequency = \frac{Number\ of\ waves}{time\ in\ seconds}$$

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



Quantity	Quantity Symbol	Unit	Unit Symbol
frequency	f	Hertz	Hz
Number of Waves	N	waves	waves
time	t	seconds	s

Example 1 600 waves pass a point in 2 minutes. What is the frequency?

N = 600 waves
t = 2 mins = 2 x 60 =120 s
f = f

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

$$f = \frac{600}{120}$$

$$f = 5\ Hz$$

Example 2 The frequency of water waves is 0·5 Hz.

Calculate the number of water waves that pass a point in 1 min 20 seconds.

f = 0·5 Hz
N = N
t = 1 min 20 s = 80 s

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

$$N = ft$$

$$N = 0 \cdot 5\ \times 80$$

$$\mathrm{N} = 40\ \text{waves}$$

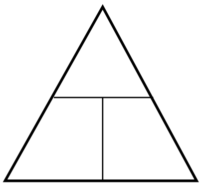
Waves and Radiation Problem Booklet - Page 11 ***Questions 1-12***

Speed, Frequency and Wavelength

The equation that relates speed, frequency and wavelength is

$$speed = frequency \ x \ wavelength$$

$$v = f\,\lambda$$



Quantity	Quantity Symbol	Unit	Unit Symbol
speed	v	metres per second	m/s or m s^{-1}
frequency	f	Hertz	Hz
wavelength	l	metres	m

Example 1 A sound wave has a frequency of 12 kHz.

(a) What is the wavelength of the sound wave?

f = 12 kHz = 12 x 10^3 Hz
v = 340 m s^{-1}
λ = λ metres

$$v = f\lambda$$
$$\lambda = \frac{v}{f}$$
$$\lambda = \frac{340}{12 \text{ x } 10^3}$$
$$\lambda = 0 \cdot 0283 \ m$$

(b) Calculate the time it will take the sound wave to travel 6·8 km?

t = t seconds
v = 340 m s^{-1}
d = 6·8 km = 6·8 x 10^3 m

$$d = vt$$
$$t = \frac{d}{v}$$
$$t = \frac{6 \cdot 8 \text{ x } 10^3}{340}$$
$$t = 20 \ s$$

Waves and Radiation Problem Booklet - Page 17 ***Questions 1-30***

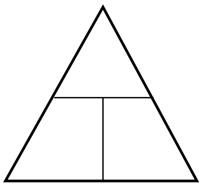
Period of a wave

The period of a wave is the __time______ it takes for one wave to pass a point,(or be produced).

From the frequency of a wave the period of a wave can be calculated.

$$Period\ of\ a\ wave = \frac{1}{frequency}$$

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



Quantity	Quantity Symbol	Unit	Unit Symbol
Period of a wave	T	seconds	s
frequency	f	Hertz	Hz

Example 1 A wave is produced in a time of 0·2 s. What is the frequency of the wave?

T = 0·2 s
f = f

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

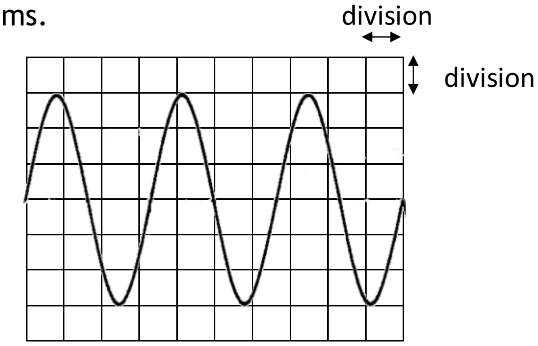
$$f = \frac{1}{T}$$

$$f = \frac{1}{0 \cdot 2}$$

$$f = 5\ Hz$$

Example 2 The diagram below shows a wave on an oscilloscope screen.

Each division is 5·00 ms.



(a) What is the period of the wave?

3 waves = 10 divisions = 10 × 5 ms = 50 ms

$$1\ \text{wave} = \frac{50}{3} = 16 \cdot 7\ ms$$

(b) What is the frequency of the wave?

T = 16·7 ms = 16·7 x 10^{-3} s
f = f

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

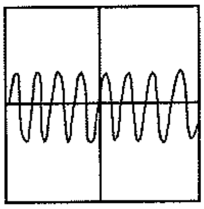
$$f = \frac{1}{T}$$

$$f = \frac{1}{16 \cdot 7 \times 10^{-3}}$$

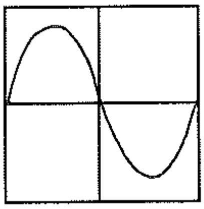
$$f = 59 \cdot 9\ Hz$$

Sound waves on an oscilloscope screen - 4 and 5

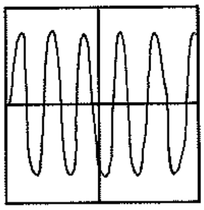
An experiment was set up to investigate sound waves. A signal generator was connected to a loudspeaker. An oscilloscope is now connected across the loudspeaker. The traces obtained by different sounds are shown.



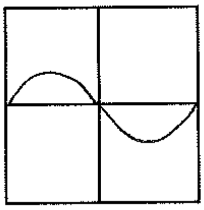
Quiet / loud
High / low
frequency sound



Quiet / loud
High / low
frequency sound



Quiet / loud
High / low
frequency sound



Quiet / loud
High / low
frequency sound

The frequency of the sound affects the __pitch________ of the sound.

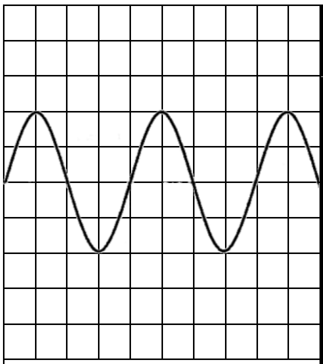
e.g. High pitch =___high_______ frequency, Low pitch = ____low_________ frequency

The loudness of the sound affects the __amplitude____________ of the sound

e.g quiet sound = ___small______ amplitude, Loud sound = ___large______ amplitude

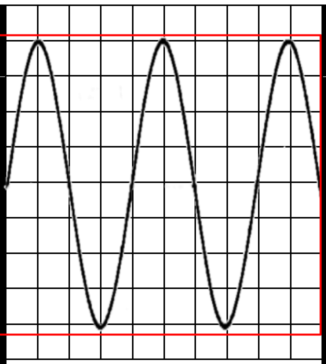
Example A waveform is shown in Figure 1. Complete Figure 2, 3 and 4.

Figure 1



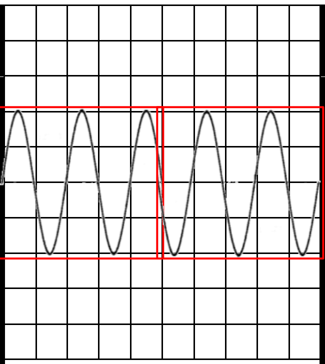
How many waves are in Figure 1 above?

Figure 2



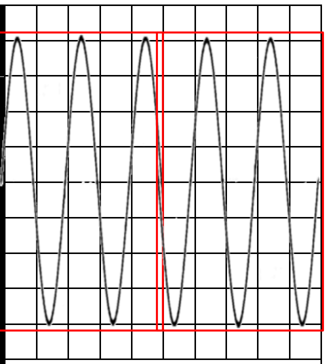
Draw a waveform above that has double the amplitude of Figure 1.

Figure 3



Draw a waveform above that has double the frequency of Figure 1.

Figure 4



Draw a waveform above that has double the frequency **and** amplitude of Figure 1.

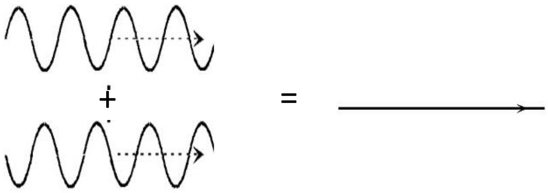
Waves and Radiation Problem Booklet - Page 13 Questions 1-2

Sound Level (Loudness) - 4

The larger the amplitude the ___louder_______ the sound.
Sound level or loudness is measured in units called __decibels___________ or _dB__ for short.
Quiet conversations is __50__ dB. Danger level is _80__ dB.
A loud disco is _110___ dB. Loud sounds can damage your __hearing_____.
Wearing __ear____ protectors will protect your hearing.
Noise __pollution___________ is any sound which can ruin your environment.

Noise Cancellation - 4

Noise cancelling ___headphones___ are being used more and more. These __cancel__ out the sounds from the environment and are used by lots of different people including road workers and __pilots__. This reduces the chances of __damage__ to the persons hearing and a better quality of sound, if listening to music.



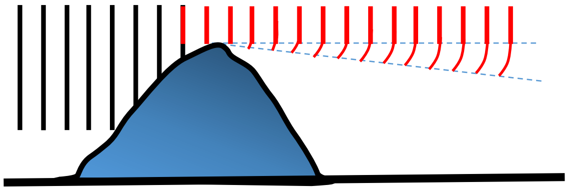
Waves and Radiation Problem Booklet - Page 15 *Questions 1-5*

Diffraction

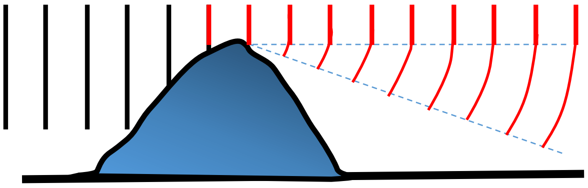
Diffraction is the ability of a wave to bend round corners. All waves will ___diffract _______ to some extent around an obstacle placed in their way.

The **shorter** the wavelength, the less the wave will _diffract________.

The __longer__________ the wavelength, the __more_________ the wave will diffract.



short wavelength



long wavelength

A wave with a wavelength of 4m will diffract __more__ than a wave with a wavelength of 2m.

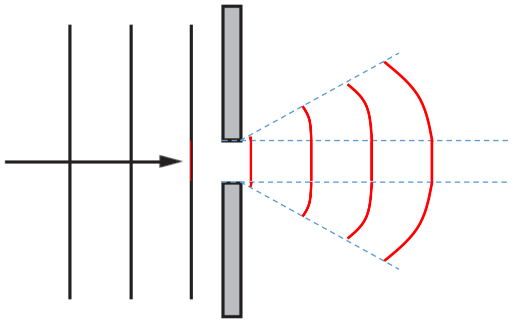
A wave of frequency 1000 Hz will diffract ___less_____ than a wave of frequency 50 Hz.

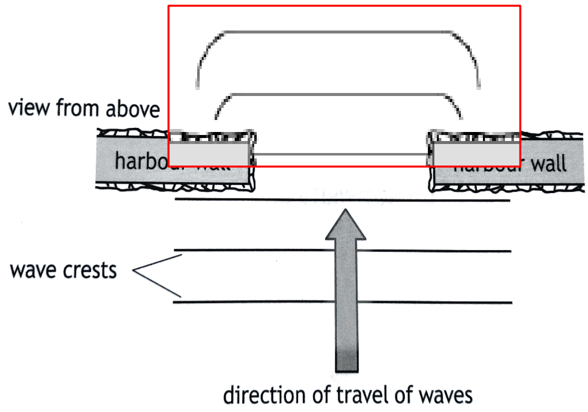
Radio waves diffract __more__ than TV waves, because Radio waves have a longer wavelength.

When water waves meet a gap they also diffract. The smaller the _gap_ the more diffraction there is.

Before and after the barrier there is **no change** to the

- wavelength,
- frequency or
- speed, since $v=f\lambda$.





Waves and Radiation Problem Booklet - Page 14 *Questions 1-5*

B - Electromagnetic Spectrum

Electromagnetic Family

The electromagnetic spectrum describes a range, or family, of waves which

- transfer __energy___________,
- are __transverse_______________ waves,
- travel at __300 000 000________________ ms^{-1}
- all diffract.

The diagram below represents the electromagnetic spectrum.

Radio	TV	Micro waves	Infrared radiation	Visible light	Ultraviolet	X-rays	Gamma radiation

Low f _Long_ λ _Low_ E	R_O_YG_B_IV	_High_ f _Short_ λ _High_ E

Radio waves have the longest __wavelength____________. Gamma rays have the shortest __wavelength_________ and therefore the highest ___frequency_________. Violet light has a shorter __wavelength__________ than red light. As the frequency of the wave increase the wave has more __Energy__________. In the spectrum the waves which diffract the most are ___Radio___________ waves because they have a __longest_______ wavelength.

Example A ray of infrared radiation has a wavelength of 1400 nm. What is its frequency?

λ = 1400 nm = 1400 x 10^{-9} m
v = 3 x 10^{8} m s^{-1}
f = f

$$v = f\lambda$$

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

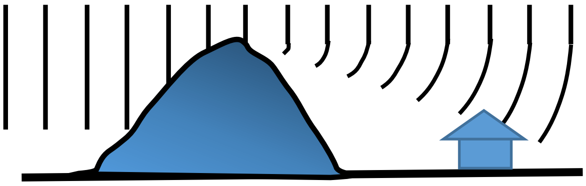
$$f = \frac{3 \text{ x } 10^{8}}{1400 \text{ x } 10^{-9}}$$

$$f = 2 \cdot 14 \times 10^{14}\ Hz$$

Electromagnetic Family -

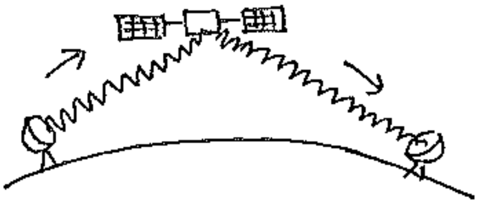
The electromagnetic spectrum is split into several bands, according to its wavelength (or frequency). Different bands of the spectrum require different detectors and have different applications.

Applications - 4 and 5



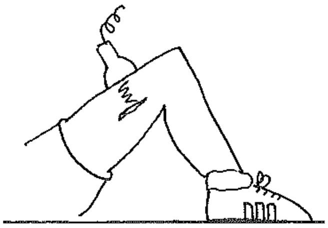
1. **Radio and TV** waves have long ___wavelengths___________ and therefore can __diffract_________ round hills and buildings. This makes them ideal for carrying radio and __TV__ programmes to your house.

   Detector - __aerial____________



2. **Microwaves** are used to carry signals up to a __satellite_______________ in space.

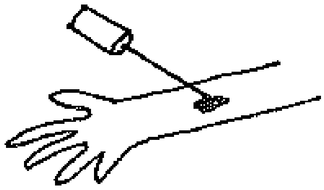
   Detector - __aerial_____________



3. **Infrared** radiation is the scientific name for __heat________. In medicine it can be used in heat treatment to speed up the healing of damaged __muscle___________ tissue.
   In industry it can be used to __dry_____ paint. Rescue service use __thermal____________ imaging cameras to find people in dark or smoky places.

   Detector - **photodiode** or __thermometer__________

4. **Visible Light** is made up of different __colours/wavelengths________. Red has a longer __wavelength___________ than blue light. A concentrated beam of visible light of one colour is called __Laser_________________.
   It can be used to:
   - remove __birth_________ marks,
   - remove __tattoos_________,
   - __kill_______ cancerous tumours.



   Detector - **photodiode**, human _eye____ or photographic film.

Example The frequency of a microwave is 2870 MHz. Calculate its wavelength.

f = 2870 MHz = 2870 x 10^6 m
v = 3 x 10^8 m s^{-1}
λ = λ

$$v = f\lambda$$

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

$$\lambda = \frac{3 \text{ x } 10^8}{2870 \text{ x } 10^6}$$

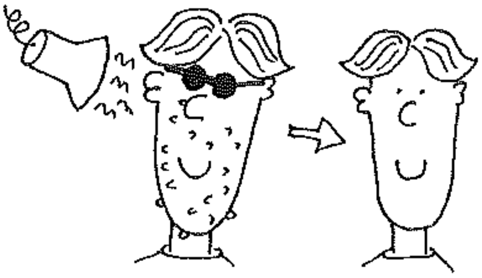
$$\lambda = 0 \cdot 105\ m$$

Example Calculate the time it would take ultraviolet radiation to travel 980 km?

$t = t$
$v = 3 \times 10^{8}\ \text{m s}^{-1}$
$d = 980\ \text{km} = 980 \times 10^{3}\ \text{m}$

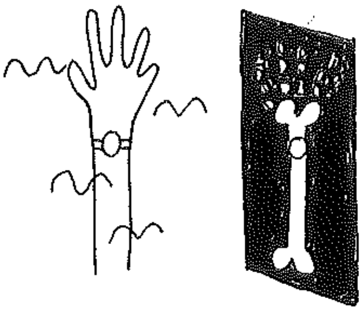
$$d = vt$$
$$t = \frac{d}{v}$$
$$t = \frac{980 \times 10^{3}}{3 \times 10^{8}}$$
$$t = 0 \cdot 00327\ s$$

5. Most of the **ultraviolet** radiation we are exposed to comes from the __Sun_______. It gives us our __tan_____ in summer, but too much can __cause____ the skin or even worse cause skin __cancer_________. UV radiation can be used to treat skin conditions like __acne_______. Special fluorescent __chemicals____ can be painted on important items as __security_____ markings. These markings only show up under __Ultraviolet________________ radiation.

   Detector - **photodiode** or photographic _film______.

6. **X-rays** can be used to **detect** __broken________ bones. X-rays pass through most tissue and cause photographic film to turn __black_____. However X-rays are absorbed by __bones______ in your body. Photographic film behind the bones stay **clear**. This allows X-ray __photos__________ to be taken of your body. Computer Aided Tomography (CAT) or CT scanner allow pictures of __parts________, or sections, of your body to be taken. This allows a more __detailed___________ image to be built up. They can also use the slices to create a _3___D image.

   Detector - photographic _film______,

7. **Gamma Rays** can be used to kill __cancerous _______ cells in your body. Chemicals emitting gamma radiation can be __injected_________ into your blood stream. A gamma camera detects the __gamma_______ radiation being emitted by the chemical and creates an image of __blood_________ flow in your body. This is called a __Tracer_______.

   Detector - Photographic film or _Geiger_______- Müller tube.

Summary

Band	Source	Detector(s)	Applications	decreasing wavelength ↓
Radio	Electronic device	Aerial	Communication (radio broadcast) MRI Scanners	
TV	Electronic device	Aerial	Communication (TV broadcast)	
Microwave	Electronic device, microwave oven, mobile phones	Aerial	Communication (Satellite broadcast/TV) Mobile phone communication Wi-Fi, Radar, GPS	
Infrared	Sun, warm objects	Photodiode	Night vision, thermograms, remote control	
Visible Light	Sun, light bulbs, lasers, LEDs	Photodiode, Photographic film, the eye	Eye sight, photography, lasers e.g surgery	
Ultraviolet	Sun, gas discharge lamps	Photodiode, Photographic film, Fluorescent dye	Security markings (fluorescence), treat skin conditions, sterilization of medical instruments	
X-rays	X-ray tube, very fast electrons hitting a metal	Photographic film	Radiographs (internal images of patients/objects) Radiotherapy (treatment of cancer)	
Gamma	Rocks, radioactive nuclei decaying	Photographic film, Geiger- Muller tube	Treatment of cancer, radioactive tracers	

Waves and Radiation Problem Booklet

- ***Page 23*** ***Questions 1-7 (4) Questions 8-10 (5)***
- ***Page 25*** ***Questions 1-15***

Light

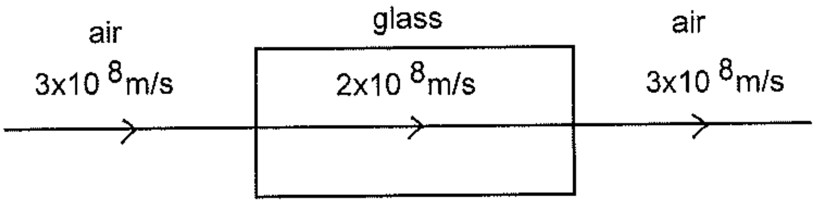
Light is an electromagnetic wave that is visible to the human __eye______.
Light travels in __straight__________ lines.

Refraction of Light

Refraction is the process which occurs when ___light________ passes from one medium into another, which causes a change in

- Wave __speed________
- Wavelength
- __direction____________ (where the angle of incidence is greater than 0°)

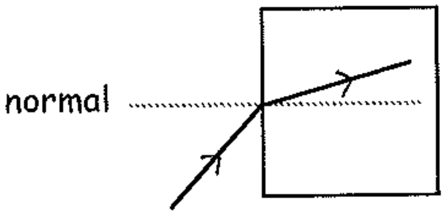
Refraction of light happens when the light passes into a different medium of different density. (e.g air into glass)

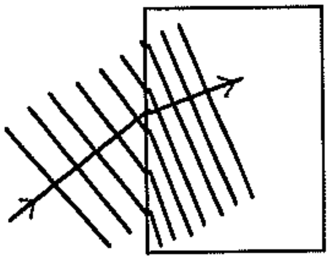


A special line is drawn in ray diagrams called the __Normal__. This line is drawn at right angles, or __90°__, to the block. This line is very important because

- **all** __angles________ are measured **from** the normal **to** the ray of light.

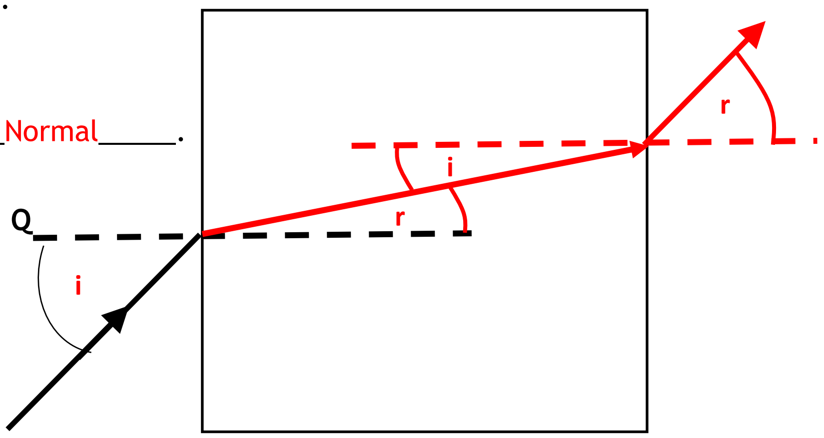
If the light travels at an angle of incidence greater than 0° to the normal, from one medium into another, its __direction________ also changes as shown below.





Below is a diagram that represents a ray of light travelling from air into a glass block then from the glass back into the air.

Line Q is called the __Normal_____.



Label the angle of incidence (**i**) and angle of refraction (**r**) on the diagram above.

When light moves from a

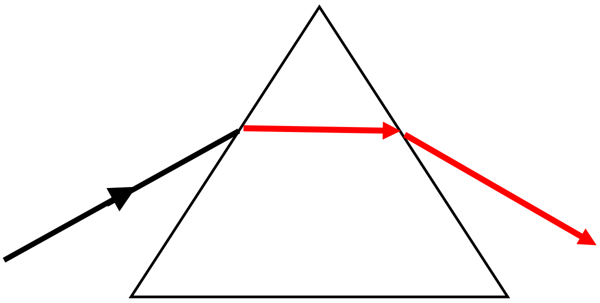
- **less** dense medium in to a __more__ dense medium the light refracts **towards** the normal.
- **more** dense medium in to a __less__ dense medium the light refracts **away** from the normal.

	Air → Glass	Glass → Air
	Less dense → more dense	More dense → less dense
Refraction direction	Towards the normal	Away from the normal
Wavelength	Decreases	Increases
Speed	Decreases	Increases

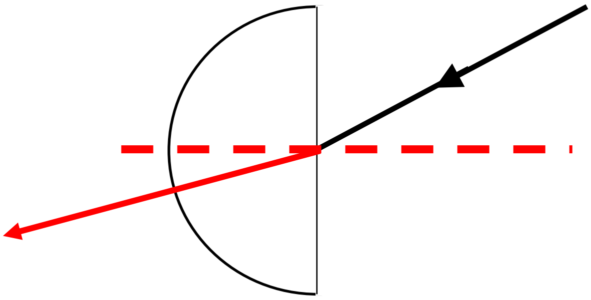
Triangular prism

When light is directed through different shapes and materials the rules above still apply.

When white light is directed into a triangular prism, you get to see all the colours that make up white light.
R_O_Y G _B_ I V
Each __colour_________ of light refracts by a different amount.



Semi-circular glass block

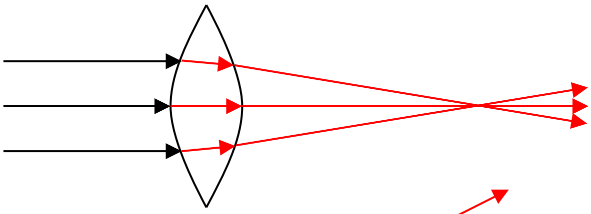


Lenses

Lenses are used in all sorts of things from cameras, to optical telescopes and glasses. There are two lenses that are very helpful:

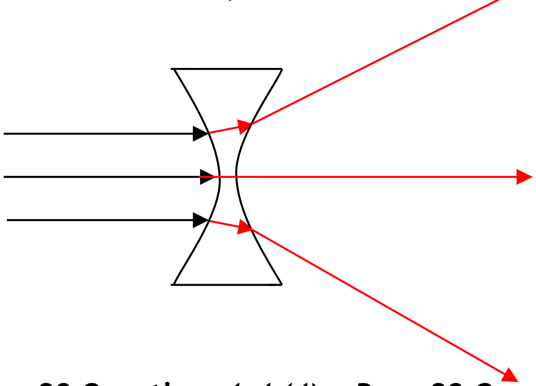
Convex Lens or Converging lens

Without a lens, if the rays of light meet **beyond** the ____retina____, a Convex lens is used to correct __long___ sight.



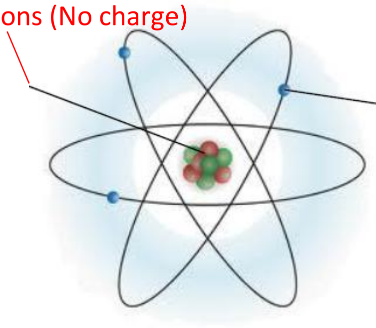
Concave lens or Diverging lens

Without a lens, if the rays of light meet **before** the __retina______, a Concave lens is used to correct __short___ sight.



Waves and Radiation Problem Booklet - Page 28 Questions 1-4 (4) + Page 29 Questions 6-10 (5)

C - Nuclear Radiation



The Atom - Revision

An atom is the basic unit of matter.
An atom has a __nucleus______ made up of positive __protons______ and __Neutrons__________ which have no charge.

The ___Nucleus______________ contains nearly all of the mass of the atom and has an overall positive charge.

Around the nucleus of the atom are orbiting __electrons__________ which have a __negative_______ charge and are much lighter than __protons________ or ___neutrons__________.

As an atom gets bigger it has more protons, neutrons and ___electrons___________.

Most atoms are electrically neutral because they have equal numbers of positive __protons_________ and negative ___electrons_____________.

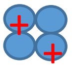
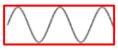
Isotopes are atoms of the same element with different numbers of neutrons in the nucleus.

Some isotopes are stable and some unstable. The nuclei of unstable isotopes undergo radioactive decay and emit **nuclear radiation**.

Waves and Radiation Problem Booklet - Page 31 ***Questions 1***

Nuclear Radiation

Small atoms are stable because they have fairly similar numbers of protons and __neutrons_________. However very big atoms like Uranium have a big imbalance. Uranium-235 has __92_____ protons and __143____ neutrons. To become more stable the nucleus can eject ___3___ types of radiation. We call these 3 types of NUCLEAR radiation, because they come from the __Nucleus________ of the atom.

Radiation	Symbol	Picture	Nature	Nucleus symbol
Alpha	α		2 __protons___ and 2__neutrons_____ or Helium Nucleus	${}^4_2He$
Beta	β	⊖	A fast moving __electron__________.	${}^0_{-1}e$ or ${}^0_{-1}\beta$
Gamma	γ		An __electromagnetic___________ wave.	

If there are no electrons in the nucleus, where does this beta particle come from?
A neutron turns into a __proton__________ and an electron and the electron is released as a __Beta_________ particle.

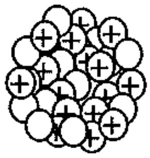
$$ {}^1_0n \rightarrow {}^1_1p + {}^0_{-1}e $$

Nuclear Decay

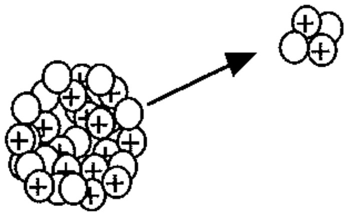
A material that contains radioactive atoms is called a __source___.

When a source has emitted radiation we say that it has __decayed________________.

This diagram shows a radioactive nucleus decaying by emitting an __alpha____________ particle.



radioactive atom



radioactive atom decaying

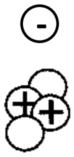
Gamma emission can also happen when either beta or gamma radiation has been emitted.

Ionisation

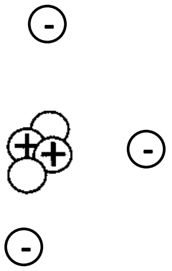
Ionisation is when an atom loses or gains an electron.

When ionisation takes place on a neutral atom the atom becomes charged.

Neutral atom
2 +ve protons
And
2 -ve electrons
Overall charge - 0



__Positive______ ion
2 +ve protons
and
1 -ve electron
Overall charge - _+1___



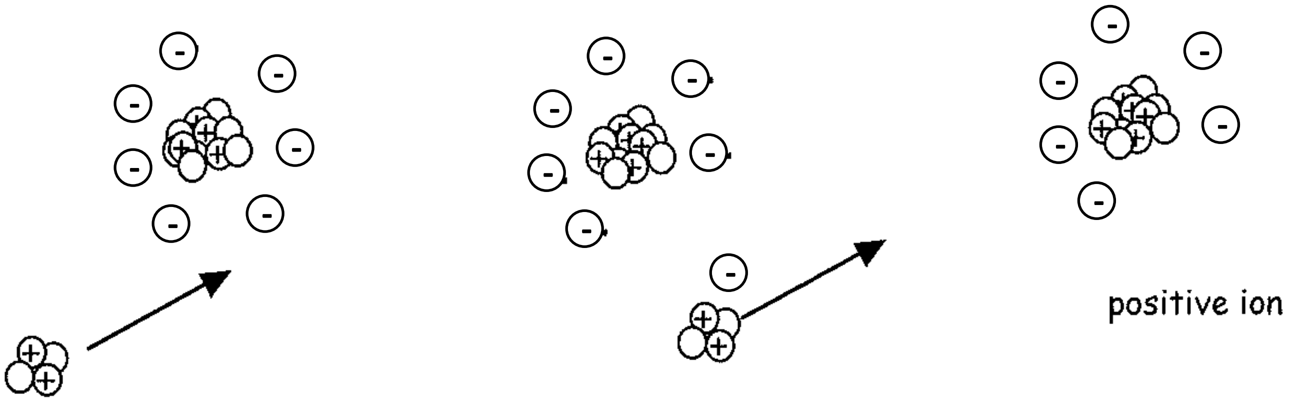
__Negative______ ion
2 +ve protons
and
3 -ve electrons
Overall charge - ___-1__

Alpha, __Beta_______ and gamma radiation all cause ionisation. They all cause different amounts of Ionisation.

__Alpha__________ particles **cause the most ionisation** because they are the biggest of the three nuclear radiations. Alpha has a positive charge and it can attract the __electrons__________ from an atom without actually colliding with it.

Beta and Gamma cause much less ionisation.

The diagram below shows a neutral atom being ionised by an __Alpha______ particle.



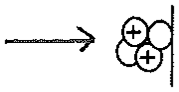
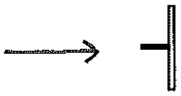
Radiation is dangerous to humans because it can damage healthy cells by __Ionising__________ the atoms which make up the cells. A group of damaged cells is called a __tumour_____________.

It is important to measure the exposure to radiation. Detectors of radiation rely on ionisation to detect the radiation including __Geiger_________-Müller tubes, photographic __film______ badges, spark counters, scintillation counters and cloud chambers.

Radiation causes photographic film to turn __black_________.

Absorption

When a material stops a radioactive particle or wave moving we say it has ___absorbed____________ the radiation. The table below shows what the limits of penetration are for alpha, beta and gamma radiation.

Type	*Range in air*	*Absorbed by*	*Diagram*
Alpha Particles	a __2____ cm	thin sheet of paper	
Beta Particles	a __2____ metres	2-3 mm of Aluminium	
Gamma radiation	infinity	thick _lead______ or thick concrete	

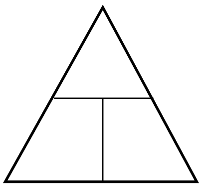
Activity

Activity is the number of nuclear disintegrations (decays) per second.

Activity is measured in Becquerels or __Bq_______ for short.

One Becquerel is one decay per __second__.

$$Activity = \frac{No.\ of\ disintegrations\ (decays)}{time\ in\ seconds}$$



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

Quantity	Quantity Symbol	Unit	Unit Symbol
Activity	A	Becquerels	Bq
Number of decays	N	decays	decays
time	t	seconds	s

Example A radioactive source emits 2400 alpha particles in 3 minutes. What is its activity?

N = 2400
t = 3 minutes = 3 x 60 = 180 s
A = A

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

$$A = \frac{2400}{180}$$

$$A = 13 \cdot 3\ Bq$$

Waves and Radiation Problem Booklet - Page 33 Questions 1-5

Background Radiation

Background radiation is the radiation which is __around_____________ us all the time.

Background radiation can come from ___natural____________ sources or artificial sources.

Source	*Natural*	*Artificial*
Cosmic rays	✓	
Rocks and soil	✓	
Human body	✓	
Medical use e.g X-rays		✓
Fallout from weapons testing		✓
Nuclear waste		✓
Nuclear accidents e.g Chernobyl, Fukushima		✓

Background count can be measured using ___Geiger - Müller__________________ tube and a counter.

When measuring the activity of an unshielded source it is important that the __background_________ count is measured. The background count must then be subtracted from all readings taken.

Half-Life

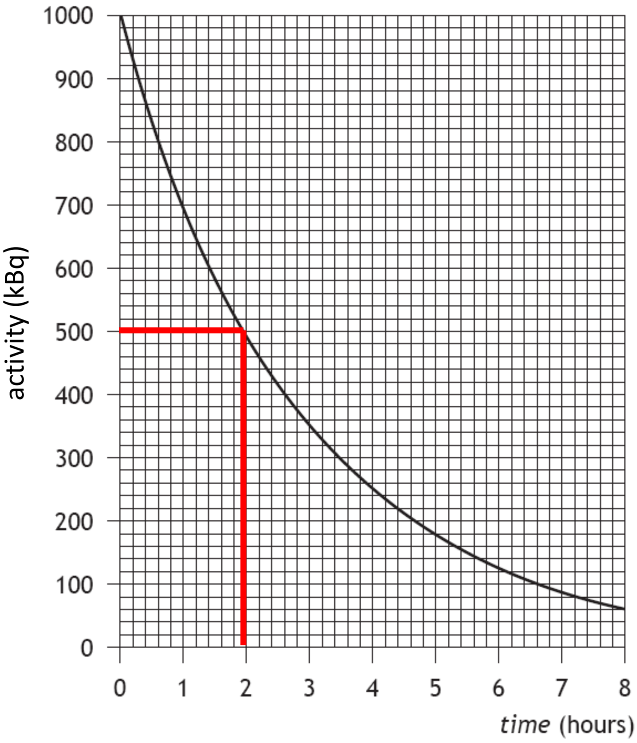
Half-life is the time for the activity to half.

The activity of a source __decreases________________ with time.

Half Life - Experiment Description.

The half-life of a radioactive material can be determined experimentally as follows:

- Connect a Geiger-Müller tube to a counter and measure the count rate.
- Measure the background count rate
- Measure the count rate due to the source at regular intervals
- Subtract the background count from each of these values to determine the corrected count rate
- Draw a graph of corrected count rate against time.
- Determine the time taken for the corrected count rate to half.



The graph shows how the activity of a radioactive material varies with time.

Determine the half-life of this radioactive source.

_________2 hours_________________

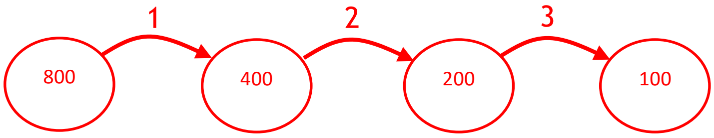
Example The activity of a source is 800 kBq and its haf-life is 2 days.

What is the activity after 6 days?

A = 800 kBq

half-life = 2 days

Number of half-lives = $\frac{Total\ Time}{1\ half\ life} = \frac{6}{2} = 3$



$\underline{A_{6\ days} = 100\ kBq}$

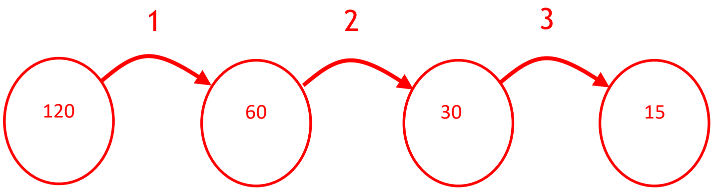
Example - The activity of a source is 120 MBq. 12 years later the activity is 15 MBq.

What is the half-life of the source?

$A_{beginning}$ = 120 MBq

t = 12 years

A_{end} = 15 MBq



3 half lives = 12 years

1 half life = $\frac{12}{3} \underline{= 4\ years}$

Fractional Activity

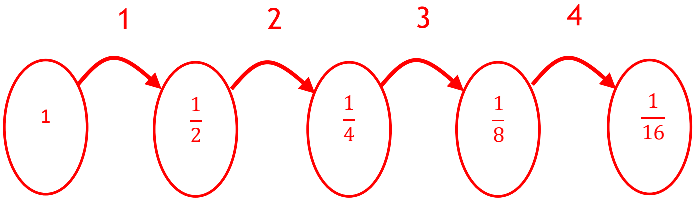
Sometimes instead of talking about the actual activity after a period of time we can describe the source as having a certain fraction of its activity left.

- After 1 half-life the original activity will have decreased to __half_____.
- After 2 half-lives the original activity will have decreased to a __quarter_______.
- After 3 half-lives the original activity would have decreased to an _eighth________ and so on.

Example The half-life of a source is 1 month.

What fraction of the activity is left after 4 months?

Half-life = 1 month
Total time = 4 months
Number of half-lives = $\frac{Total\ Time}{1\ half\ life} = \frac{4}{1} = 4$



$$A_{4\ months} = \frac{1}{16}$$

Waves and Radiation Problem Booklet - Page 37 ***Questions 1-25***

Biological Effect of Radiation

Radiation can __kill____ or __damage___ living things. As a result it is important to measure the exposure to __radiation______.

The biological effect of radiation depends on three factors, the:

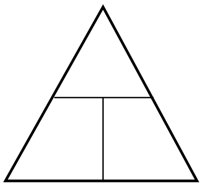
- absorbed __dose_______
- type of __radiation__________
- type of tissue __absorbing_________ the radiation.

Absorbed Dose - D

Absorbed dose is the energy absorbed by __1____kg of mass absorbing material.

Absorbed dose is measured in Grays or __Gy_____ for short.

$$Absorbed\ dose = \frac{Energy\ Absorbed}{mass\ of\ tissue}$$



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

Quantity	Quantity Symbol	Unit	Unit Symbol
Absorbed dose	D	Grays	Gy
Energy absorbed	E	Joules	J
mass	m	kilogrammes	kg

Example A 75 kg scientist absorbs 0·41J of radiation. What is the absorbed dose?

m = 75 kg
E = 0·41J
D = D

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

$$D = \frac{0 \cdot 41}{75}$$

$$D = 0 \cdot 0055\ Gy$$

$$D = 5 \cdot 5 \times 10^{-3}\ Gy$$

Equivalent dose - H

The equivalent dose is a measure of the biological harm that the radiation has on a tissue.

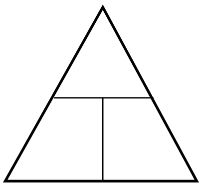
The equivalent dose is measured in __Sieverts______________ or __Sv____ for short.

The equivalent dose takes into account the __absorbed_______ dose and the __type_____ of radiation the tissue has been exposed to.

To calculate the equivalent dose a radiation weighting factor, w_R, is used. Each type of radiation causes a different amount of ionisation and therefore has a different __weighting______ factor.

$$Equivalent\ dose = Absorbed\ dose\ \times weighting\ factor$$

$$H = D\ w_r$$



Quantity	Quantity Symbol	Unit	Unit Symbol
Absorbed dose	D	Grays	Gy
Equivalent dose	H	Sieverts	Sv
Weighting factor	w_r	--	--

The only way to compare biological harm is to work out the total equivalent dose.

A list of weighting factors can be found on the data sheet for different types of radiation.

Example A tissue receives an absorbed dose of 0·15 mGy of alpha particles.

Calculate the equivalent dose the tissue receives?

$D = 0 \cdot 15\ mGy = 0 \cdot 15 \times 10^{-3}\ Gy$
$w_r = 20$
H = H

$$H = Dw_r$$

$$H = 0 \cdot 15 \times 10^{-3}\ \times 20$$

$$H = 0 \cdot 003\ Sv$$

Example A sample of body tissue is irradiated by 2 different types of radiation X and Y.

The radiation weighting factor and the absorbed dose for each radiation is shown.

Type of radiation	*Radiation weighting factor*	*Absorbed dose (μGy)*
X	10	5
Y	5	2

What is the total equivalent dose received by the tissue?

$w_r = 10$
$D = 5\ \mu Gy$
H = H

$$H = Dw_r$$

$$H = 5\ \times 10$$

$$H = 50\ \mu Sv$$

$w_r = 5$
$D = 2\ \mu Gy$
H = H

$$H = Dw_r$$

$$H = 5\ \times 2$$

$$H = 10\ \mu Sv$$

$$H_{total} = 50\ \mu Sv + 10\ \mu Sv = 60\ \mu Sv$$

Waves and Radiation Problem Booklet - Page 34 Questions 6-18

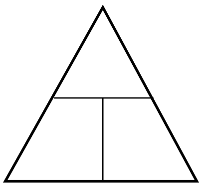
Equivalent Dose Rate - $\dot{H}$

The equivalent dose rate, $\dot{H}$, is the rate at which the equivalent dose is received by the tissue.

Equivalent dose rate is usually measured in mSv y^{-1} or Sv h^{-1}.

$$\textit{Equivalent dose rate} = \frac{\textit{Equivalent dose}}{\textit{time}}$$

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



Example When working with a radioactive source a technician is exposed to an equivalent dose rate of $2{\cdot}5 \times 10^{-6}$ Sv h^{-1}.

The technician works with the source for 1900 hours over a year.

What is the Equivalent dose the technician is exposed to?

$\dot{H} = 2 \cdot 5 \times 10^{-6}\ Sv\ h^{-1}$
t = 1900 hours
H = H

$$\dot{H} = \frac{H}{t}$$
$$H = \dot{H} \times t$$
$$H = 2 \cdot 5 \times 10^{-6} \times 1900$$
$$H = 4 \cdot 75 \times 10^{-3}\ Sv$$

Comparing Risk

By calculating the equivalent dose the biological harm can be found for different types of radiation. The table below shows the equivalent dose an average person receives each year from different sources.

Source	*Natural/Artificial*	*annual equivalent dose (μSv)*
Rocks and soil	N	800
Carbon and Potassium in the body	N	370
Cosmic rays from space	N	300
Medical - X rays , CT scans,..	A	250
Fallout from weapons testing	A	10
Nuclear waste	A	2

The total equivalent dose is still very small and will cause very little harm to the average person.

However from the table above, humans are at a greater biological risk from __natural____________ sources than from __artificial________________ sources.

Nuclear Safety precautions

When using radioactive sources it is necessary to observe certain safety precautions.
For example:

- limit the __time__________ of exposure
- use shielding e.g. store sources in a labelled __lead________ lined container
- increase the __distance__________ between you and the source e.g. use tongs or ___forceps___
- point sources __away___________ from the body (especially the eyes)
- __wash_____________ hands after use

Nuclear Safety Limits

There are safety limits for the public and for those that work in the radiation industries in terms of the annual effective equivalent dose.

• Average annual background radiation in the UK	2·2 mSv
• Average effective __safety_______ limit for a member of the public	1 mSv
• Average effective __safety_______ limit for a radiation worker	20 mSv

Applications

Radiation is used in medicine:

- as a tracer. A __gamma______________ source can be injected into your body and used as a radioactive tracer to study the flow of __blood___________ around the body.
- to __kill__________ cancer cells. High energy gamma rays can be directed at the tumour, or an alpha source can be placed next to the tumour, to kill the cancerous cells.
- to __sterilise___________ medical equipment. Radiation can be used to kill bacteria on medical equipment.

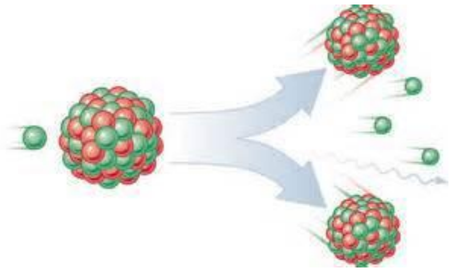
Radiation can also be used in other applications including:

- to generate __electricity________________ in power stations.
- in a __smoke__________ detector. __Alpha_____________ radiation is used to detect if there are smoke particles in the room or not.
- to __sterilise_______________ food. Gamma radiation can be used to kill bacteria on the food and increase its shelf life.
- to detect the __thickness_________________ of paper and foil. Beta radiation can be used to ensure the paper or foil is the right thickness.
- to detect flow rate of liquids in pipes.

Types of Nuclear Reaction

There are __two________ different types of nuclear reaction, **Nuclear Fission** and **Nuclear Fusion**.

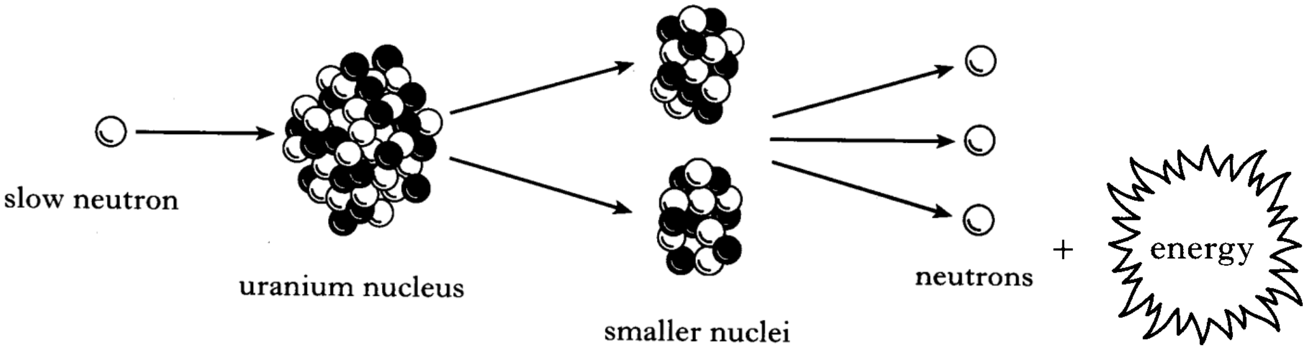
Nuclear Fission



In Nuclear Fission, a nucleus of large mass number is split into nuclei of smaller mass number with the release of energy and __two_______ or three neutrons.

The neutrons that are produced can split further nuclei and cause a __chain___________ reaction.

Importantly the total mass of the particles after the reaction is __less______ than the mass of the particles before the reaction. This lost mass is turned into __heat_______ energy.

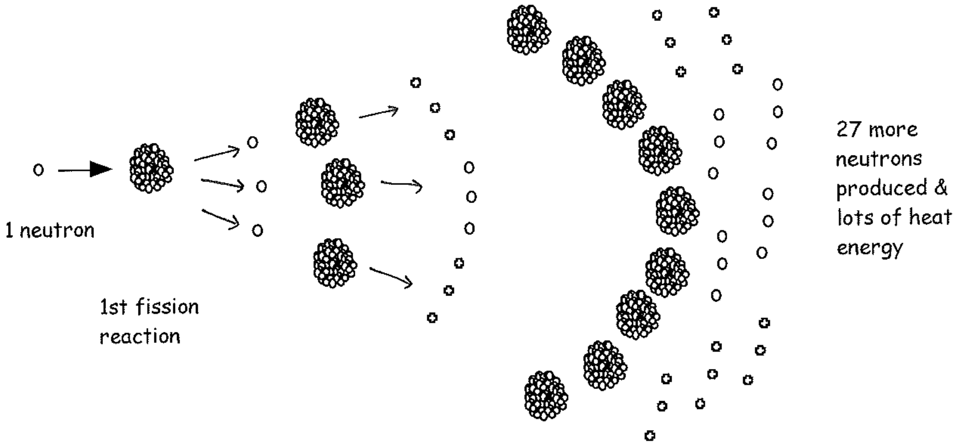


The smaller nuclei in this example are called daughter products or fission __fragments_________.

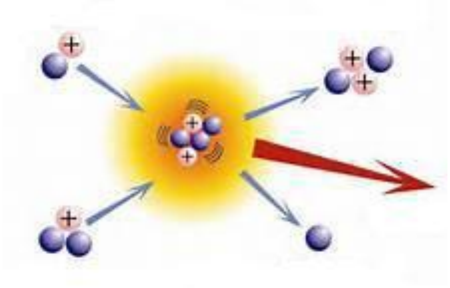
Chain Reaction

The 3 neutrons which are released above cause 3 more __Fission_________ reactions which produce __9______ more neutrons which causes ____9____ more fission reactions. This is called a __chain____ reaction and as a result a huge amount of __kinetic________ energy is created in a short period of time. The kinetic energy is changed into heat.

In a nuclear power station a neutron is introduced to start the chain reaction.



Nuclear Fusion



In Nuclear Fusion nuclei of smaller mass number join/recombine to form a nucleus of larger mass number with the release of energy.

As in a Nuclear fission reaction, the mass of the particles after the reaction is __less_________ than the mass of the particles before the reaction. This lost __mass______ is turned into energy.

Development of this technology has resulted in magnetic fields being used to keep the hot fusion fuel in the form of a plasma. As a result, there has been a lot of research on how to keep the plasma contained. The issue is the plasma has to have a temperature of several tens of millions of degrees which makes containment very difficult. The first generating fusion power plant is scheduled to begin operation in 2035 in France.

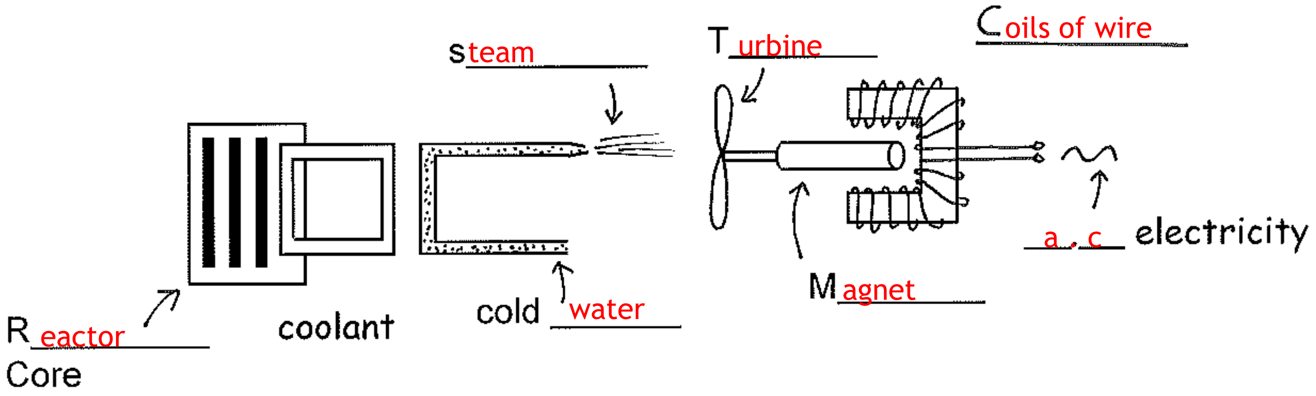
Nuclear fusion generates a vast amount of energy from a small amount of fuel and does not produce __nuclear__________ waste. Nuclear fusion is the process by which the sun produces energy. Nuclear fusion is extremely difficult to control.

Nuclear Power stations

In Nuclear power stations today, Nuclear __Fission____________ is used to generate electricity.

During Nuclear Fission the heat energy produced is used to produce electricity in the following way:

1. A fluid called __coolant__________ flows through the ___reactor_____________ core and absorbs the __heat_______ energy. The coolant then becomes warm.
2. The coolant then passes near pipes containing ___cold_________ water.
3. The cold water absorbs the __heat__ energy from the coolant and is turned into super-heated steam. The steam turns the ___turbine________ blades.
4. The turbine blades turn a __magnet____________ inside a coil of wire.
5. The moving magnet causes, or induces, and electric __current________ in the coil.



Nuclear Fission - Advantages

1. The fission process produces no __greenhouse____________ gases which are partly responsible for global warming.
2. The supply of electricity is very __reliable______________.
3. A small amount of fuel creates a __large_________________ amount of electricity.

Nuclear Fission - Disadvantages

1. The fission reaction produces nuclear waste which remains dangerous for __hundreds______ of years. This is very __dangerous____________________.
2. Nuclear waste has to be stored safely for a __long ______ time.
3. Although normally very safe, catastrophic failure due to earthquakes, tsunamis or terrorism could cause dangerous emissions of __radiation_______ into the atmosphere and water supply.
4. Nuclear power stations are expensive to build and expensive to __decommission_____________ once they have come to the end of their working lives.

Nuclear Fusion - Advantages

1. The fusion reaction is a very clean process. It does not produce __greenhouse____________ or __radioactive______________ waste.
2. The fuel is a type of hydrogen atom which is in plentiful in sea __water________.

Nuclear Fusion - Disadvantages

1. The fusion process requires temperatures similar to the core of the __Sun_______ to fuse the nuclei together. Creating temperatures this high is very __difficult________ and expensive.

If scientists can get fusion working at __lower______ temperatures then we will have clean, cheap and a renewable source of energy.

Waves and Radiation Problem Booklet - Page 31 Questions 1-5 (4) + Page 32 Questions 1-10 (5)