N5 Waves & Radiation

Waves

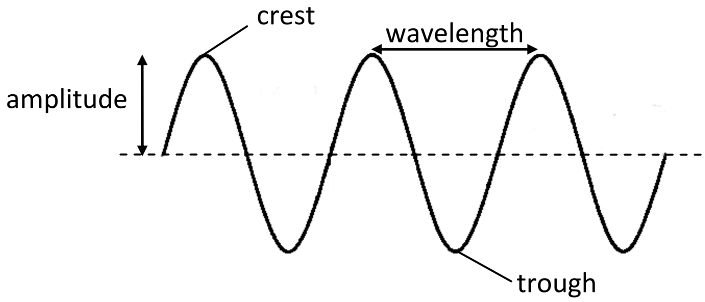
Summary

A wave is a regular disturbance which carries **energy** but has no mass.

Some waves require a medium to travel through (e.g. water waves) others, like light, can travel through a vacuum.

In **transverse** waves the particles of the medium vibrate at right angles to the direction of energy transfer. Water, light, radio and television waves are transverse.

In **longitudinal** waves the particles of the medium vibrate in the same direction as the energy transfer. Sound waves are longitudinal waves.



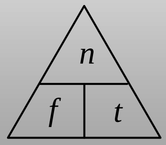
Wave Term	Symbol	Definition	Unit
frequency	f	number of waves passing a point each second	Hz
wavelength	λ	distance from one point on a wave to the same point on the next wave	m
speed	v	distance travelled by a wave in one second	m s^{-1}
amplitude		size of maximum disturbance from the zero position	
period	T	time taken for a wave to pass a point	s

Frequency

Hz

$$frequency = \frac{number\ of\ waves}{time}$$

s



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

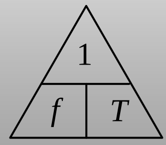
$$t = \frac{n}{f}$$

Frequency and Period

Hz

$$frequency = \frac{1}{period}$$

s



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

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

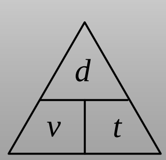
Distance, Speed and Time

m

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

m s^{-1}

s



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

$$d = vt$$

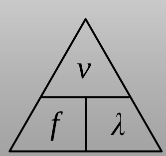
$$t = \frac{d}{v}$$

Speed, Frequency and Wavelength

m s^{-1} m

$$speed = frequency \times wavelength$$

Hz

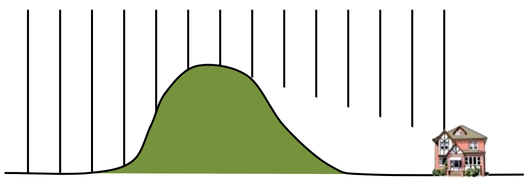


$$v = f\lambda$$

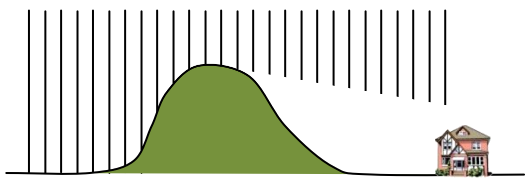
$$f = \frac{v}{\lambda}$$

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

Diffraction is the ability of waves to bend round corners. All waves diffract to some extent, but the longer the wavelength of a wave, the greater the amount of diffraction that takes place.



long wavelengths diffract more
(radio wave reaches house behind hill)



short wavelengths diffract less
(television wave does not reach house behind hill)

The Electromagnetic Spectrum

Summary

Electromagnetic radiation is an oscillation of electrical and magnetic fields that travels through space as a wave and carries energy

The **electromagnetic spectrum** is the range of all possible frequencies of electromagnetic radiation.

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

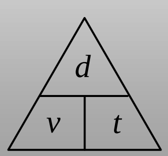
decreasing wavelength

Region	Detector(s)	Applications
Radio	aerial	communication (e.g. broadcast radio) MRI scanners
Microwave	aerial	satellite communication (e.g. satellite TV) mobile phone communication Wifi radar GPS
Infrared	photodiode	night vision thermograms remote controls
Visible light	the eye photodiode photographic film	eyesight photography lasers (e.g. surgery)
Ultraviolet	photodiode photographic film	fluorescence (e.g. security markings) treatment of skin conditions sterilisation of medical instruments excessive exposure causes skin cancer
X-rays	photographic film	radiographs (internal images of objects/people) radiotherapy (treatment of cancer)
Gamma	Geiger-Muller tube photographic film	treatment of cancer radioactive tracers

All waves in the electromagnetic spectrum travel at the same speed (300 000 000 meters per second in a vacuum), but have different wavelengths and frequencies.

Distance, Speed and Time

$$\underbrace{speed}_{m/s} = \frac{\overbrace{distance}^{m}}{\underbrace{time}_{s}}$$



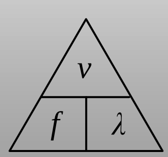
$$v = \frac{d}{t}$$

$$d = vt$$

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

Speed, Frequency and Wavelength

$$\overbrace{speed}^{m/s} = \underbrace{frequency}_{Hz} \times \overbrace{wavelength}^{m}$$



$$v = f\lambda$$

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

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

Since the frequencies of electromagnetic waves are often very large, and their wavelengths can be very small, it is common to use prefixes for their units.

Prefix	*Symbol*	*Factor*
giga	G	1 000 000 000 = 10^{9}
mega	M	1 000 000 = 10^{6}
kilo	k	1 000 = 10^{3}
milli	m	0·001 = 10^{-3}
micro	µ	0·000 001 = 10^{-6}
nano	n	0·000 0000 01 = 10^{-9}

N5 Waves & Radiation

Light

Summary

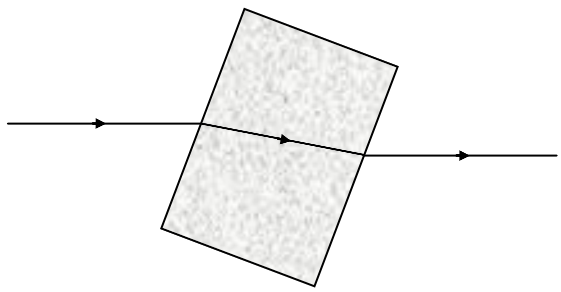
Light is an electromagnetic wave that is visible to the human eye.

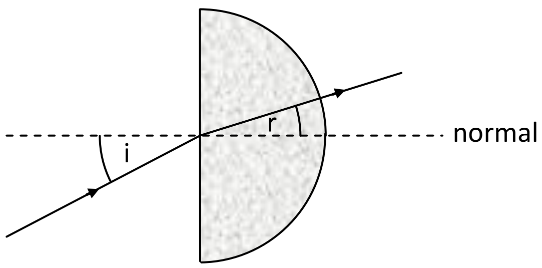
Light travels in straight lines

Refraction

Refraction is the **change in speed** of light as it passes from one material (medium) into another. This can cause a change in direction.

When light passes from a fast medium into a slow medium it bends towards the normal and when it passes from a slow medium into a fast medium it bends away from the normal.





i = angle of incidence
r = angle of refraction

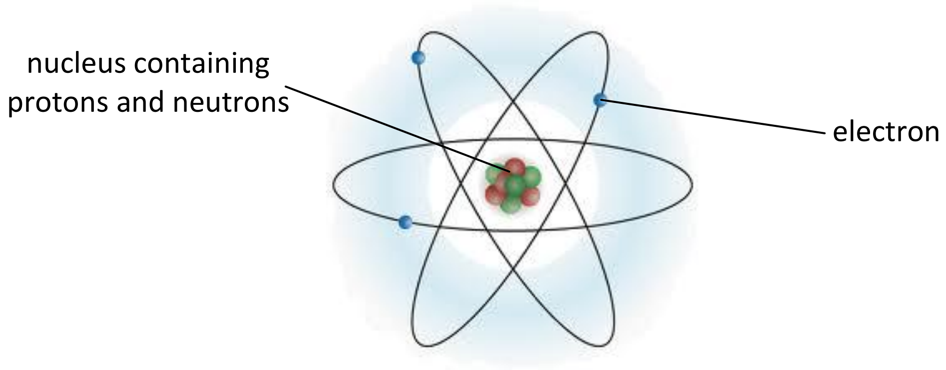
N5 Waves & Radiation

Nuclear Radiation

Summary

The Atom

An atom is the basic unit of matter. An atom is made up of a central nucleus with orbiting electrons.



The **nucleus** contains positively charged **protons** and uncharged (“neutral”) **neutrons**.

The nucleus contains nearly all the mass of the atom and contains all the positive charge

The **electrons** orbit the nucleus at high speed. Electrons are negatively charged and much lighter than neutrons or protons.

An atom is normally electrically neutral as it has the same number of negative electrons orbiting the nucleus as positive protons in the nucleus.

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**. The three main types of nuclear radiation are alpha, beta and gamma.

Type	Description	Range in air	Absorbed by
alpha α	helium nucleus	a few centimetres	sheet of paper
beta β	fast moving electron	a few metres	2-3 mm aluminium
gamma γ	electromagnetic radiation	infinite	5-6 cm lead (not completely)

Ionisation is the addition or removal of an electron from an uncharged atom. All three types of radiation cause ionisation, but alpha is the most strongly ionising.

Detectors of radiation rely on ionisation to detect the radiation and include Geiger-Muller tubes, film badges, spark counters, scintillation counters and cloud chambers.

Activity

The **activity** of a radioactive source is the number of nuclei that decay each second.

The activity of a radioactive source is measured in becquerels, Bq.

The activity of a radioactive source decreases with time.

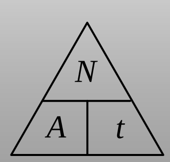
It is difficul to measure the activity of a source directly but it can be estimated from the count rate detected from the source.

Activity and Time

Bq

$$\textit{activity} = \frac{\textit{number of decays}}{\textit{time}}$$

s



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

$$N = At$$

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

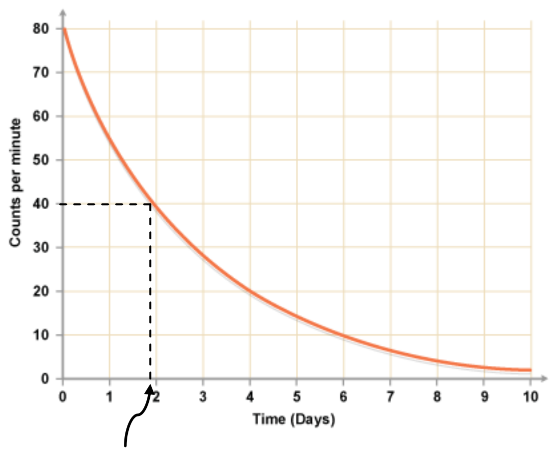
Half life

The **half-life** of a radioactive source is the time taken for half the nuclei in the source to decay.

Each isotope has a particular half-life (e.g. the half life of strontium-90 is 28·8 years)

The half life of a radioactive source can be determined experimentally using the following procedure:

- use a Geiger Muller tube connected to a counter to measure count rate
- measure the background count rate
- measure the count rate due to the source at regular time 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



half-life = 1·9 days

Biological Effect of Radiation

Radiation can kill or damage living cells.

The biological effect of radiation depends on three factors:

- the absorbed dose
- The type of radiation
- The type of tissue absorbing the radiation

The **absorbed dose**, D, is the energy absorbed per unit mass of the absorbing material and is measured in grays, Gy. (1 Gy = 1 J/kg)

A **radiation weighting factor**, w_R, is given to each kind of radiation as a measure of its relative biological effect. Radiation weighting factor has no units.

The **equivalent dose**, H, is a measure of the biological risk caused by radiation. The equivalent dose is the product of the absorbed dose and the radiation weighting factor. Equivalent dose is measured in sieverts, Sv.

The **equivalent dose rate**, $\dot{H}$ ("H-dot") is the rate at which the equivalent dose is received.

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

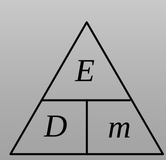
Absorbed dose, Energy and Mass

J

$$absorbed\ dose = \frac{energy}{mass}$$

Gy kg

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



$$E = Dm$$

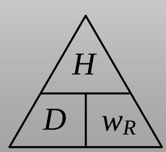
$$m = \frac{E}{D}$$

Equivalent dose, Absorbed dose and Radiation weighting factor

$$equivalent\ dose = absorbed\ dose \times radiation\ weighting\ factor$$

Sv Gy

$$H = Dw_R$$



$$D = \frac{H}{w_R}$$

$$w_R = \frac{H}{D}$$

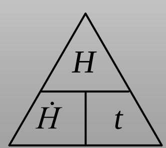
Equivalent dose rate, Equivalent dose and Time

Sv h^{-1} or Sv y^{-1} Sv

$$equivalent\ dose\ rate = \frac{equivalent\ dose}{time}$$

h or y

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



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

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

Background Radiation

Radiation is always present in the environment from a variety of natural and artificial sources.

Natural sources of radiation include: radon and thoron gas from rocks and soil, gamma rays from the ground, carbon and potassium in the body and cosmic rays.

Artificial sources include: medical uses (e.g. X-rays), fallout from weapons testing, nuclear accidents (e.g. Chernobyl) and nuclear waste.

The average equivalent dose rate from background sources for an individual in the UK is 2 mSv y^{-1}.

Safety precautions

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

- limit the time of exposure
- store sources in lead lined containers
- point sources away from body (especially eyes)
- handle with tongs
- wash hands after use

Uses of radiation

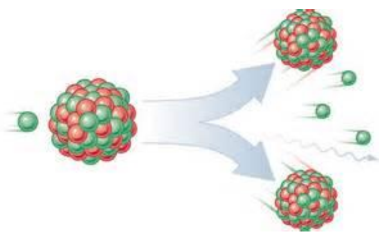
Radiation is used in medicine:

- gamma sources known as radioactive 'tracers' can be introduced into the body and their movement round the body monitored with a gamma camera
- high energy gamma rays can be directed at a tumour to kill cancerous cells
- an alpha source can be placed next to a tumour to kill cancerous cells

Alpha sources are used in smoke detectors and beta sources are used to monitor and control thickness in the manufacture of paper

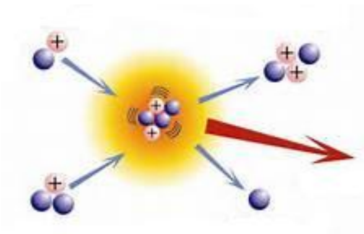
Nuclear radiation is also used in power generation:

Nuclear fission



In nuclear **fission** large nuclei (e.g. uranium-235) are split by a neutron into two smaller nuclei with the release of energy and more neutrons. These neutrons can then split further nuclei in a **chain reaction**. Nuclear fission generates a huge amount of energy from a small amount of fuel, but the waste products are radioactive. Nuclear power stations use nuclear fission.

Nuclear fusion



In nuclear **fusion** small nuclei (e.g. isotopes of hydrogen) are joined together to make larger nuclei (e.g. helium) with the release of energy. Nuclear fusion generates a vast amount of energy from a small amount of fuel and does not produce radioactive waste. Nuclear fusion is the process by which the sun produces energy. Nuclear fusion is extremely difficult to control.