National 5 Physics

Waves

Garnock Community Campus

Prefix

Throughout the Course, appropriate attention should be given to units, prefixes and scientific notation.

Prefix	Symbol	Notation	Operation
tera	T	10^{12}	x 1,000,000,000,000
giga	G	10^{9}	x 1,000,000,000
mega	M	10^{6}	x 1,000,000
kilo	k	10^{3}	x 1,000
centi	c	10^{-2}	/100
milli	m	10^{-3}	/1,000
micro	μ	10^{-6}	/1,000,000
nano	n	10^{-9}	/1,000,000,000
pico	p	10^{-12}	/1,000,000,000,000

In this section the prefixes you will use most often are milli (m), micro (μ), kilo (k), mega (M) and giga (G). It is essential that you use these correctly in calculations.

In Physics, the standard unit for time is the **second (s)** and therefore if time is given in milliseconds (ms) or microseconds (μs) it must be converted to seconds.

Example 1

a) A wave takes 40 ms to pass a point. How many seconds is this?

40 ms = 40 milliseconds = 40 x 10^{-3} s = 40/1 000 = 0.040 seconds.

b) A faster wave travels past in a time of 852 μs, how many seconds is this?

852 μs = 852 microseconds = 852 x 10^{-6} s = 852/1 000 000 = 0.000852 seconds.

In Physics, the standard unit for distance is the **metre (m)** and therefore if distance is given in kilometres (km) it must be converted to metres.

Example 2

A wave travels 26.1 km in 0.5 ms. How far in metres has it travelled?

26.1 km = 26.1 kilometres = 26.1 x 10^{3} m = 26.1 x 1 000 = 26 100 metres.

This unit involves calculations which use the term frequency, frequency has units of **hertz** (Hz) although often we meet the terms Megahertz and Gigahertz.

Example 3

A wave has a frequency of 99.5 MHz. How many Hz is this?

99.5 MHz = 99.5 Megahertz = 99.5 x 10^{6} Hz = 99.5 x 1 000 000 = 99 500 000 Hertz.

Significant figures

In physics answers given need to be accurate but answering with lots of decimal places isn't useful if the given data doesn't contain the same. To identify where to round the numbers to require knowledge on significant figures. The rules to identify the number of significant figures are as follows:

- All non-zero numbers ARE significant.

e.g. 642 has three sig figs

- Zeros between two non-zero digits ARE significant.

e.g. 4023 has four sig figs

- Leading zeros are NOT significant.

e.g. 0.0000072 has only two sig figs

- Trailing zeros when a decimal is shown ARE significant.

e.g. 6.00 has three sig figs and 0.050 has two sig figs

- Trailing zeros in a whole number with no decimal shown are NOT significant.

e.g. 400 has one sig fig

- to indicate that trailing zeros are significant a decimal point must be added:

e.g. 400.0 has four sig figs

- For a number in scientific notation: N x 10x, all digits comprising N ARE significant by the first 5 rules; "10" and "x" are NOT significant.

As a general rule your answer should contain the same number of significant figures as the least accurate (least number of sig figs) value given in the question.

Example

A sprinter travels 100.0 metres in 12.6 seconds. Calculate the speed of the sprinter.

d = 100.0m
v = ? ms-1
t = 12.8s

v = d/t
v = 100.0/12.8
v = 7.8125
v = 7.81 ms-1 (to 3 sig figs)

As 100.0m has 4 sig figs and 12.8s has 3 sig figs your final answer should also have 3 sig figs.

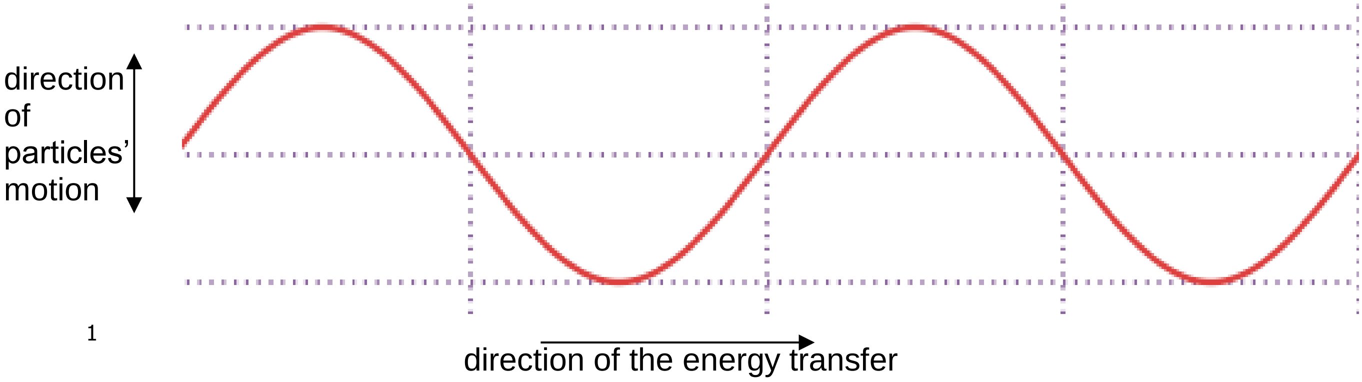
Wave parameters and behaviours

Types of wave

Waves are used to transfer energy. The substance the wave travels through is known as the medium. The particles of the medium oscillate around a fixed position but the energy travels along the wave. For example, consider waves at the beach. Seawater will move up and down as a wave passes through it but as long as the wave does not "break" there is no overall movement of any water.

There are two different types of waves you will meet in this course, transverse waves and longitudinal waves

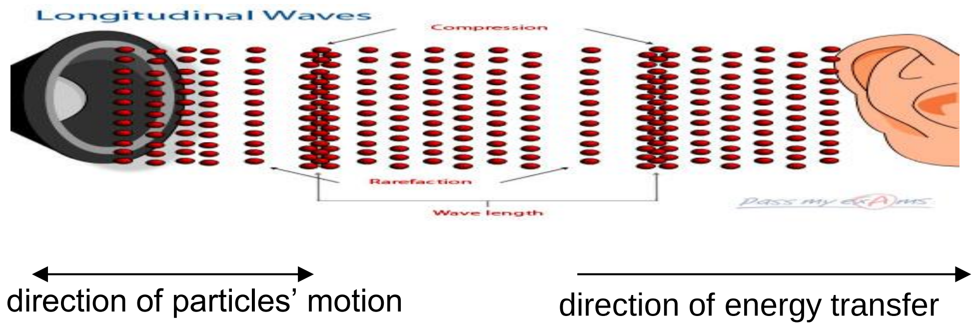
In **transverse** waves the particles oscillate (vibrate) at right angles to the direction of energy transfer



[1]

Examples are water waves, waves in a string, light, gamma rays, X-rays and all the other members of the Electromagnetic Spectrum (see below)

In **longitudinal** waves the particles oscillate in the same direction as the motion of the wave



Sound is an example of a longitudinal wave. Air particles are either squashed together to form a region of increased pressure or they are moved apart to make a region of decreased **pressure.**

[1] http://upload.wikimedia.org/wikipedia/commons/7/77/Waveforms.svg

Examples of Waves

All waves travel through some medium. As the wave travels it disturbs the medium through which it moves.

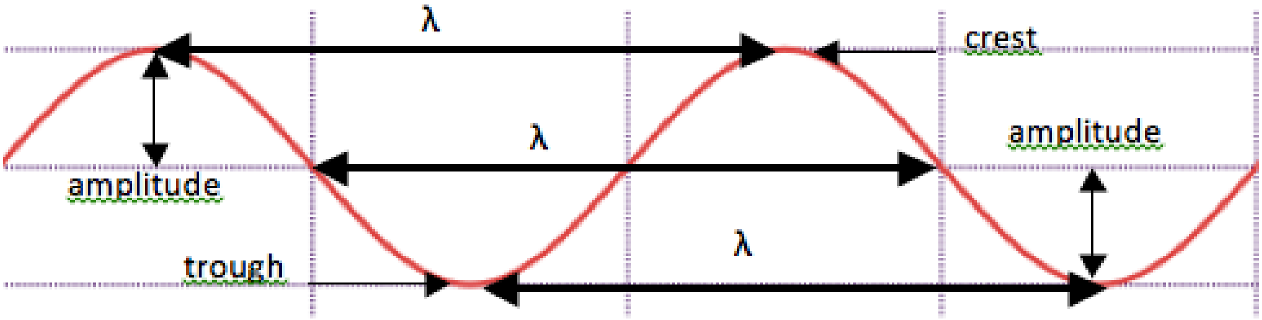
Mechanical Waves

Mechanical waves travel through a medium which is made up from some physical matter with particles (or molecules) in it. For example, when a water wave passes a particular point, some of the water bobs up and then down. For sound travelling through air it is the air particles that vibrate. The typical speed of a sound wave in air is 340 m/s although this varies a bit as the temperature and humidity of the air changes.

Electromagnetic Waves

Electromagnetic waves travel through two media, electric and magnetic fields. These waves cause disturbances in the electric and magnetic fields that can exist in all space. They do not need any particles of matter in order to travel, which is why light can travel through a vacuum. Different examples of electromagnetic waves are gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves, TV waves and radio waves. They all travel at the same speed in a vacuum (3×10^8 m/s). This is usually referred to as the **speed of light** and is given the symbol ***c***. This very fast speed is the fastest that anything can travel.

Properties of waves



Several important features of a wave are shown in the diagram. These are explained in the following table

Wave property	Symbol	Definition	Unit	Unit symbol
Crest		highest point of a wave		
Trough		lowest point of a wave		
Wavelength	λ	horizontal distance between successive crests or troughs	metre	m
Amplitude	A	**half** the vertical distance between crest and trough	metre	m
Wave Speed	v	distance travelled per unit time	metres per second	m/s or ms^{-1}
Period	T	the time it takes one wave to pass a point	seconds	s
Frequency	f	number of waves produced in one second	hertz	Hz

Wave Formulae

Wave Speed

The **distance** travelled by a wave travelling at a **constant speed** can be calculated using:

$$d = v\ t$$

Symbol	Name	Unit	Unit Symbol
d	Distance	metre	m
v	Velocity or Speed	metres per second	ms^{-1} or m/s
t	Time	Seconds	S

Worked Examples

1. The crest of a water wave moves a distance of 4.0 metres in 10 seconds. Calculate the speed of this wave.

$$d = v\ t$$
$$4 = v \times 10$$
$$v = 4 / 10$$
$$v = 0.40\ m/s$$

Wave speeds can vary greatly from a few metres per second up to the speed of light. For example, sound waves travel in air at around 340 m/s. The actual speed of a sound wave will depend on environmental factors like temperature and pressure. Light waves travel in air at 300, 000, 000 m/s (or 3×10^8 m/s). So light travels approximately 1 million times faster than sound in air.

Wave Frequency

The frequency of a wave is defined to be:

$$frequency = \frac{number\ of\ waves}{time\ for\ the\ waves} \qquad f = \frac{N}{t}$$

Symbol	Name	Unit	Unit Symbol
f	Frequency	hertz	Hz
t	Time for waves to pass	second	s
N	Number of waves	-	-

Worked Examples

1. A fisherman counts 5 waves passing the pier in 15 seconds. Calculate the frequency of the waves.

N = 5
T= 15s

f = ?

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

$$f = \frac{5}{15}$$

f = 0.33Hz

Now consider the case for just one wave. The number of waves is one and the time taken is the Period(time for 1 wave to pass). Hence,

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

Using symbols, this becomes

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

Symbol	Name	Unit	Unit Symbol
f	Frequency	hertz	Hz
T	Period	second	s

Worked Examples

2. A certain breed of bat emits ultrasounds with a period of 23 μs. Calculate the frequency of the ultrasound.

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

$T = 23 \times 10^{-6}$ s

$f = ?$

$$f = \frac{1}{23 \times 10^{-6}}$$

$$f = 43.5 \text{ kHz}$$

3. Given that a wave has a frequency of 50 Hz, calculate its period.

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

$T = ?$

$f = 50$ Hz

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

$$T = 0.02 \text{ s}$$

The Wave Equation

The other main formula related to waves is derived from the relationship between distance, speed and time.

distance = speed x time

For just one wave, the distance becomes one wavelength and time becomes one period.

wavelength = speed x period

But period = $\frac{1}{f}$

Therefore, wavelength = speed x $\frac{1}{f}$ or $\lambda = \frac{v}{f}$

this can be rearranged to give an equation called the **wave equation**.

$$v = f\lambda$$

Symbol	Name	Unit	Unit Symbol
v	Velocity or Speed	metres per second	m/s
f	Frequency	hertz	Hz
λ	Wavelength	metre	m

Worked Example

Microwaves have a frequency of 9.4 GHz. Calculate their wavelength.

$v = 3 \times 10^8$ m/s
$f = 9.4 \times 10^9$ Hz
$\lambda = ?$

$v = f\lambda$

$3 \times 10^8 = 9.4 \times 10^9\ \lambda$

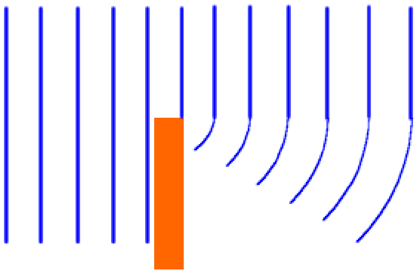
$\lambda = 3 \times 10^8 / 9.4 \times 10^9$

$\lambda = 0.032$ m

Diffraction

Waves can 'spread' in a rather unusual way when they reach a gap in a barrier or the edge of an object placed in the path of the wave - this is called **diffraction**.

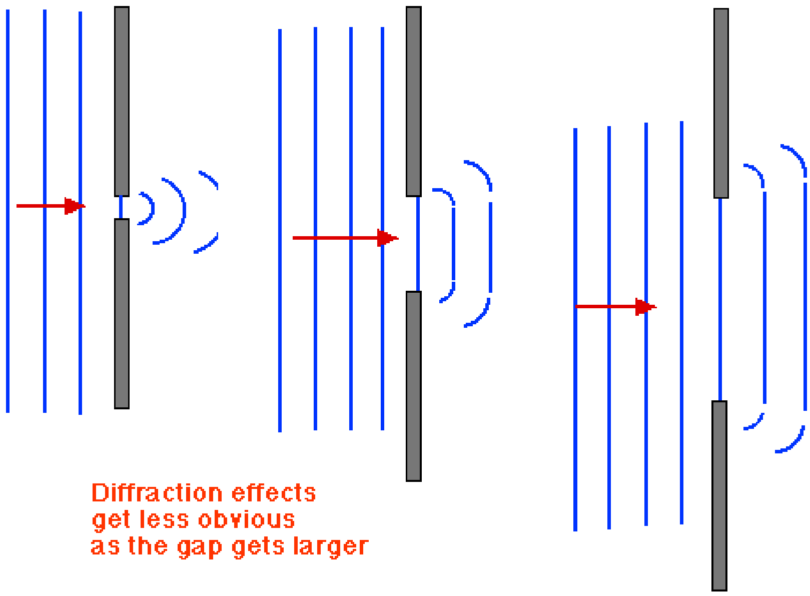
Diffraction can be clearly observed with water waves as shown in the image to the right. Notice that the parallel crests of the water waves become circular as they spread out on passing through the gap between the two harbour walls.



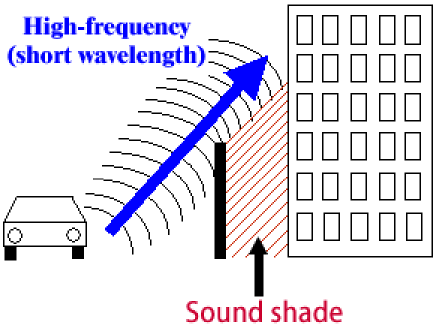
Sea waves incident on a breakwater are found to spread into the region behind the wall where we would expect the sea to be flat calm. This is an example of diffraction at an edge.

Diffraction will only be significant if the size of the gap or object is matched to the size of the wavelength of the waves.

- When the size of the gap or object is **much larger than the wavelength of the waves,** the waves are only **slightly** diffracted.
- When the size of the gap or object is **nearly the same as the wavelength of the waves,** the diffraction effect is **greatest**

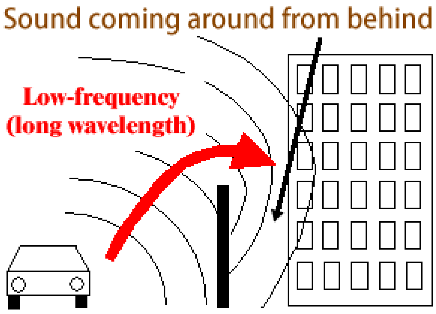


Waves other than water are also affected by diffraction



Sound

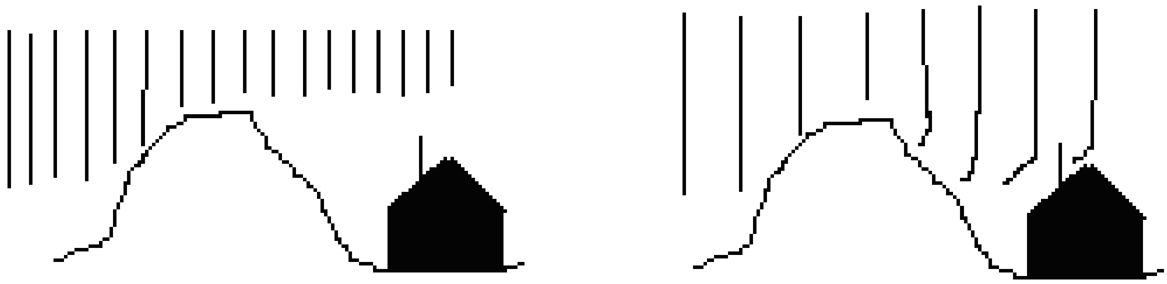
Sound can diffract through a doorway or around buildings. Lower pitched sounds travel better than high-pitched sounds. This is because low-pitched sounds have a long wavelength compared with the width of the gap, so they spread out more.



Ultrasound

Ultrasound is sound with a high frequency. It has a very short wavelength compared with most structures in the body, so there is very little spreading. This makes sharp focusing of ultrasound easier, which is good for medical scanning.

Diffraction of waves round a hill



Long wavelengths diffract (bend) more than short wavelengths

This is why long wave radio stations can be detected in remote hilly areas where as short wavelength radio stations cannot.

Light

Light has a very short wavelength compared with most everyday gaps such as windows and doors. There is little obvious diffraction, so it produces sharp shadows.

Electromagnetic spectrum

Frequency and Wavelengths

Electromagnetic waves travel through two media, electric and magnetic fields. These waves cause disturbances in the electric and magnetic fields that can exist in all space. They do not need any particles of matter in order to travel, which is why they can travel through a vacuum. Electromagnetic waves travel at a very high speed. In a vacuum this speed is three hundred million metres per second – i.e. **300 000 000 m/s or 3 x 10^8 m/s**. This is usually referred to as the speed of light and is given the symbol ***c***. This is a universal speed limit – nothing can travel faster than c.

Remember that the wave equation states

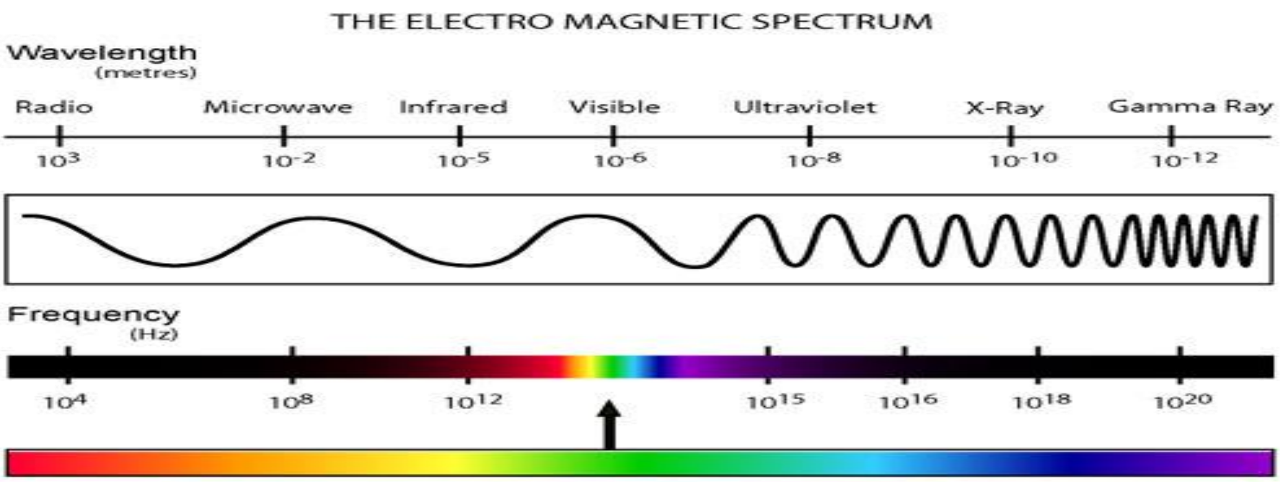
$$v = f\lambda$$

So if v is fixed, it is possible to have a whole family of electromagnetic waves whose frequencies are different but are always related by this equation, e.g. as f doubles, so λ halves such that the equation

$$c = f\lambda$$

is always true.

This family of waves is known as the electromagnetic spectrum and consists of Radio Waves, Microwaves, Infrared, Visible Light, Ultraviolet, X-Rays and Gamma Rays. The image below shows the spectrum arranged in order of increasing frequency (i.e. decreasing wavelength).



Notice how small the section is for visible light compared to the width of the whole spectrum. The colour order of the visible spectrum is expanded in the lowest section of the image and is shown in the decreasing wavelength or increasing frequency order

Red – **O**range – **Y**ellow – **G**reen - **B**lue – **I**ndigo - **V**iolet (**ROY G BIV**)

Uses and sources of electromagnetic radiation

Each member of the electromagnetic spectrum transfers energy from source to receiver/detector and as such may be called electromagnetic radiation. radiation and a typical use for each of them.

Type	Source	Typical use	Detectors
Gamma Radiation	Nuclear decay, Cosmic Rays & some Stars	Killing cancer cells	photographic film, GM tube
X-Rays	Man-made sources & some Stars	Medical images of bones	Photographic film
Ultraviolet Radiation	Ultra-Hot objects, Electrical discharges/sparks, Starlight	Sunbeds/ Sterilisation, plant growth	fluorescence (glowing) in some objects,
Visible Light	Very-Hot objects (lamps), Electrical discharges/sparks, Starlight	Seeing	Photographic film, light dependent resistor (LDR)
Infrared Radiation	All hot objects, Starlight	Optical fibre communication, Remote controls, "Night" vision	Heat sensitive paper, thermometer, black bulb
Microwaves	Electrical circuits, some Stars	Cooking, Mobile Phone signals	aerials
Radio Waves	Electrical circuits, some Stars	Television signals, communications	aerials

Frequency and Energy

All waves transfer energy. Gamma rays with the shortest wavelength transfer more energy than radio waves with the longest wavelength. The amount of energy a wave transfers increases as the frequency increases. This is why gamma rays are more hazardous than radio waves!

Light

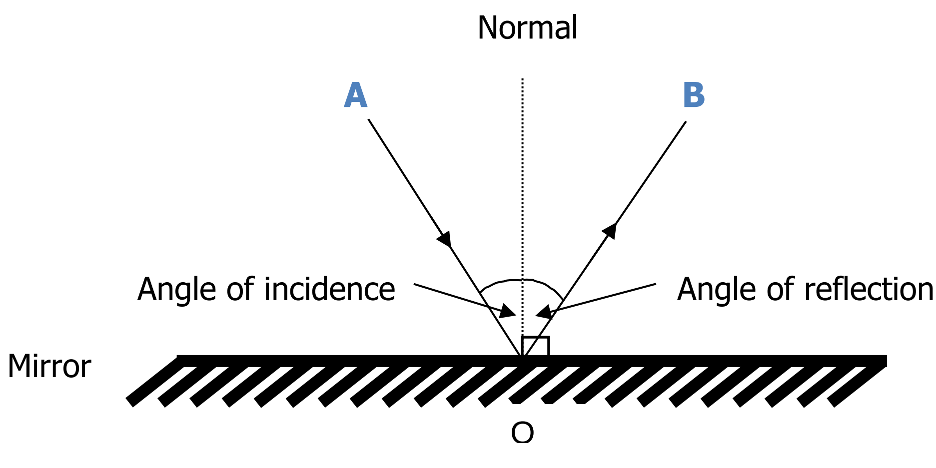
Wave behaviours

It has already been shown that waves **diffract**, or spread out, when they meet a gap or edge of an object. In addition, waves can be shown to **reflect and refract**. The next two topics of this unit cover reflection and refraction. It is particularly useful to study the reflection and refraction of visible light waves, though any waves can exhibit these phenomena.

Reflection

The diagram below shows the path of a ray of light when reflected off a mirror.
Some simple rules:

- A **ray** is a line with an arrow to show the wave direction.
- The **normal is a dotted line drawn at 90º to the mirror** at the point where the ray of light hits the mirror.
- All angles are measured **between the ray and the normal.**
- The incoming ray is called the **incident ray** and this makes the **angle of incidence** with the normal.
- The outgoing ray is called the **reflected ray** which travels at the **angle of reflection** to the normal.



It is very important to **always put arrows** on any diagram that contains rays of light. Otherwise you would not be able to tell in which direction the light was travelling.

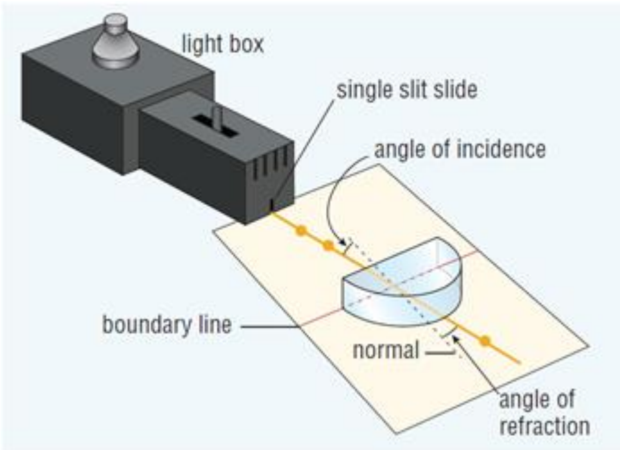
Law of Reflection:

The angle of incidence **equals** the angle of reflection

Refraction

The wave speed depends on the medium in which the wave travels. When a wave changes medium it's changes speed. This change of speed is called **refraction**.

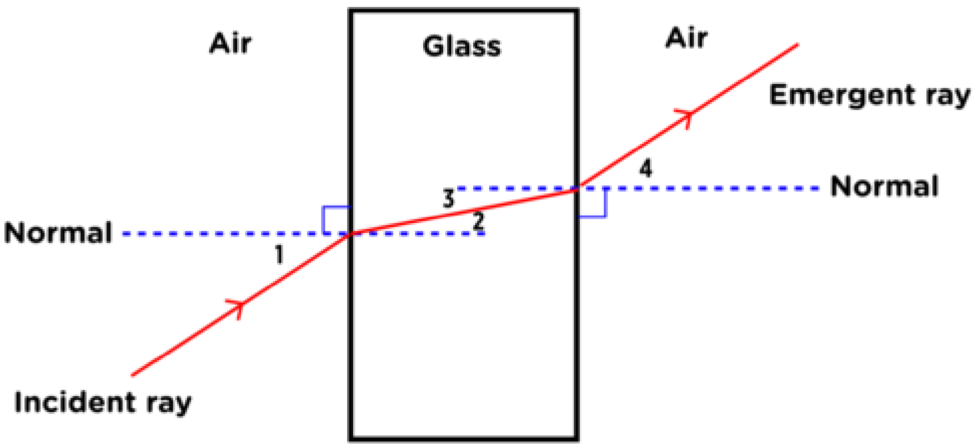
In the diagram below the incident light is shown passing from air into a semicircular glass block.



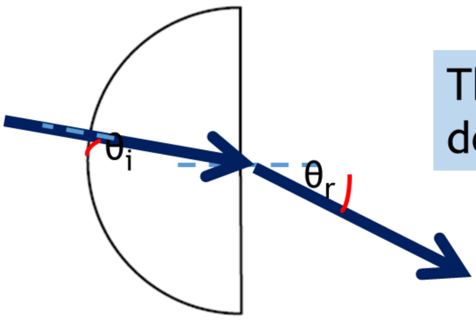
In addition to changing speed the wave **usually** changes direction inside the glass block. This change of direction only happens when the angle of incidence is non-zero, i.e. the incident ray is **not** along the normal. Both these changes are due to refraction.

Remember that the speed of light in a vacuum is the fastest speed possible. The speed of light in air is almost the same as in vacuum. The **light slows down as it enters the glass** and speeds up again as it leaves (think of it as a higher optical density makes it harder to pass through so it slows down).

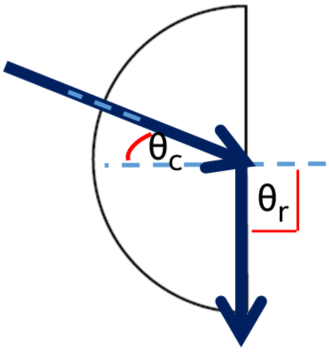
bends towards the normal   bends away from the normal



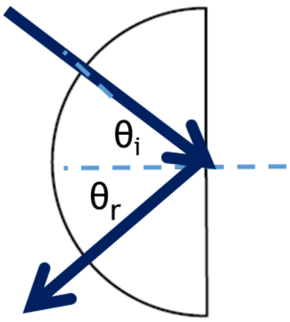
1 – angle of incidence (air to glass)
2 – angle of refraction (air to glass)
3 – angle of incidence (glass to air)
4 – angle of refraction (glass to air)



The light ray is travelling from more dense to less dense material, so $\theta_i < \theta_r$.



At the critical angle, the light ray no longer refracts out of the prism, and instead reflects along the edge.
Here $\theta_r = 90^\circ$



Greater than the critical angle, the light ray no longer refracts out of the prism, but reflects back into it.(Total Internal Reflection)