National 5 Physics

Waves

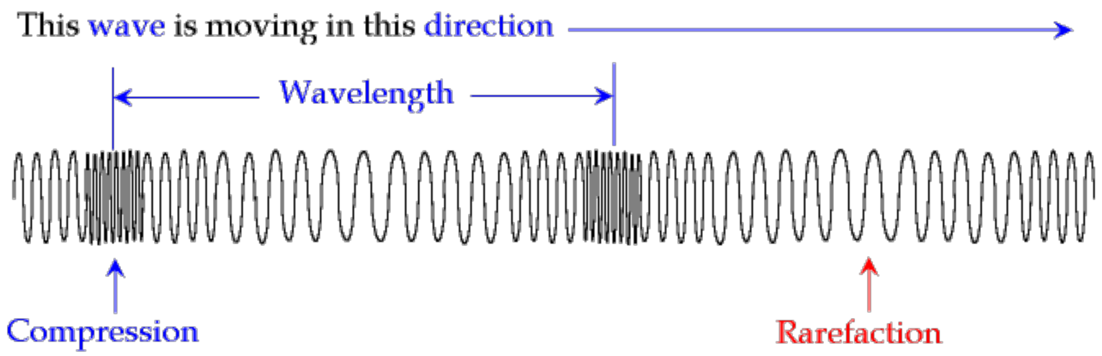
Wave Properties

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

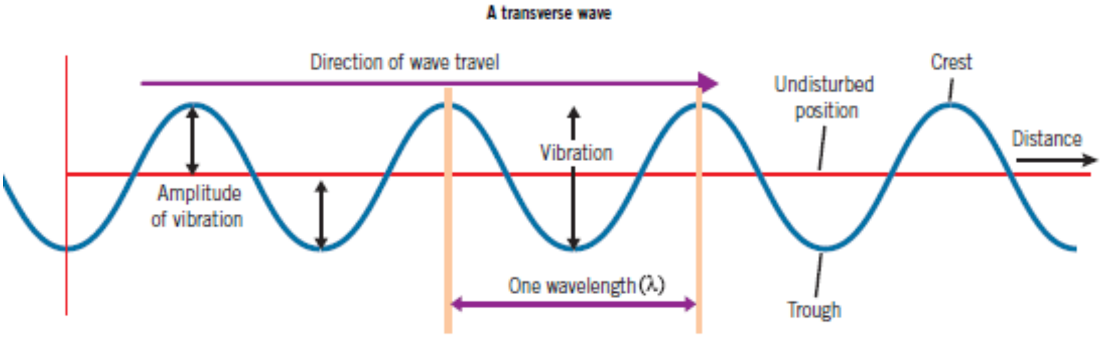
In a longitudinal wave the vibration is in the **same** direction as the direction the wave is travelling in. The oscillations are parallel to the direction of travel.



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

All waves transfer energy.

Transverse waves vibrate at right angles to the direction of travel.

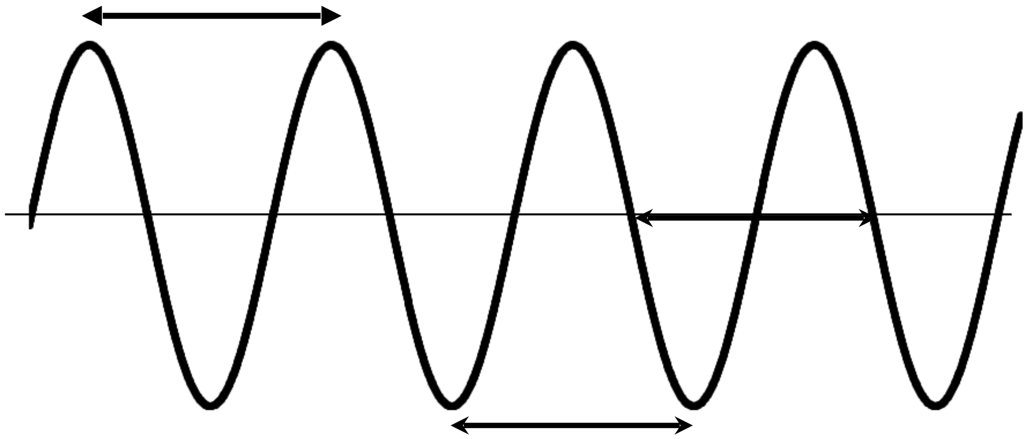
Examples of transverse waves include light, water waves and microwaves.

Longitudinal waves vibrate parallel to the direction of travel.

An example of longitudinal waves are sound waves.

Wavelength

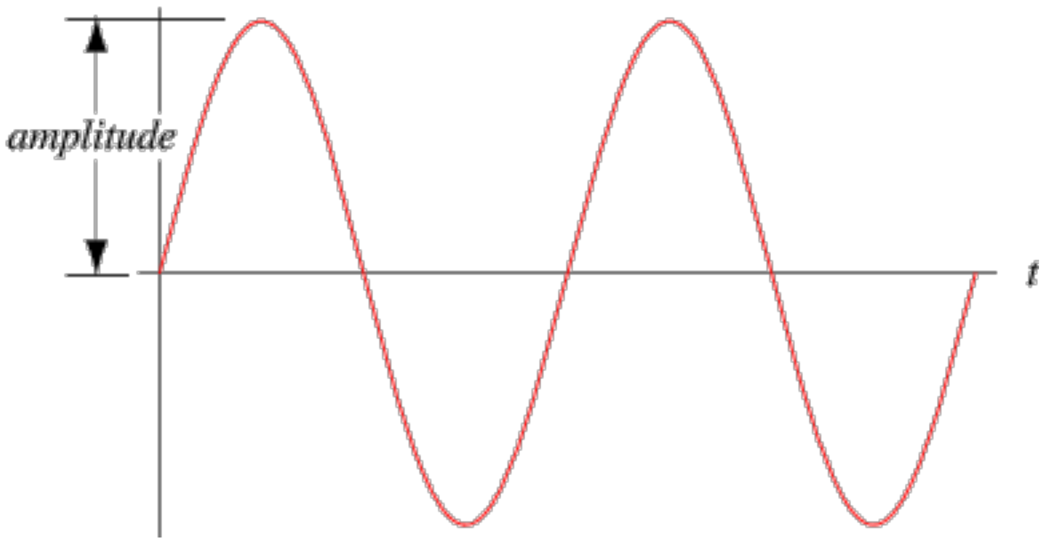
The wavelength of a wave is simply the length of one wave. It can be found by measuring the distance from peak to peak, trough to trough or between corresponding zero crossings (as shown below):



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.

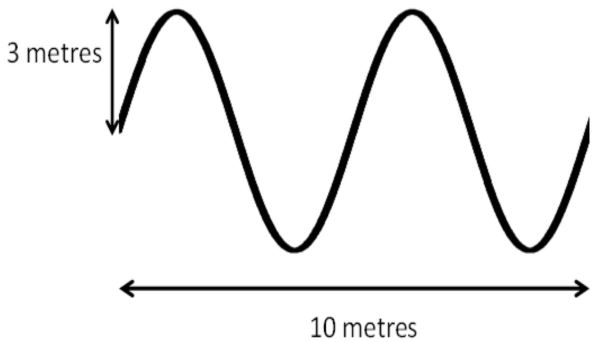


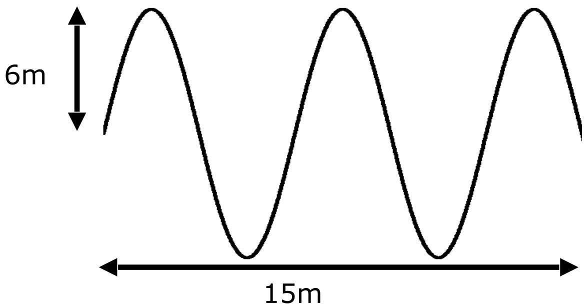
The units of amplitude vary depending on the type of wave. For instance; for water waves the amplitude is measured in metres, for electrical waves the amplitude is measured in volts and for sound waves amplitude is measured in decibels.

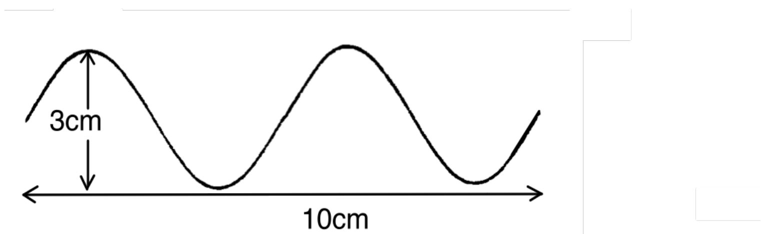
Practice Problems

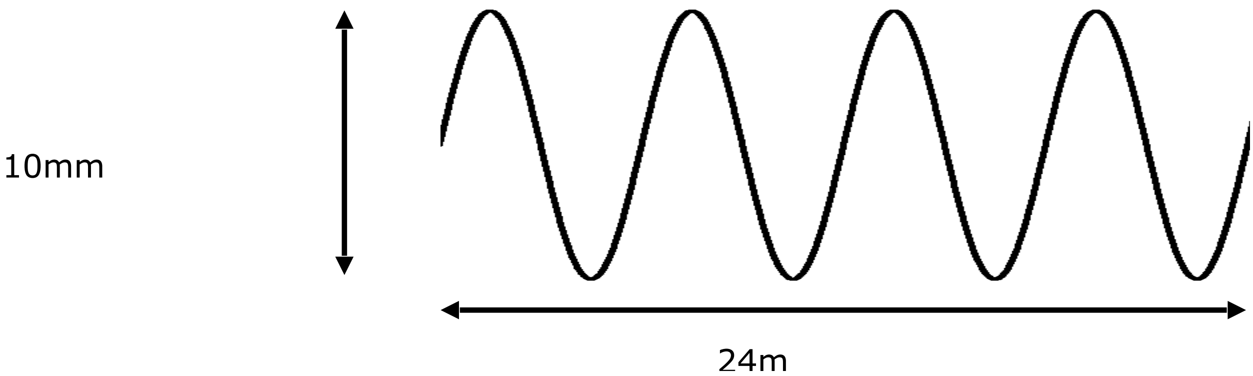
For the following wave traces calculate:

- 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:

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

Number of waves

Frequency in hertz (Hz)

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 measured in seconds (s)

Frequency measured 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 256 Hz 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 3 Hz. How long did it take for 27 waves to pass him?

5. 10 waves pass a fixed point in 50 s. 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:

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

Distance measured in meters (m)

Speed measured in meters per second ($m\,s^{-1}$)

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 0.005 s to travel 1.5 m. 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 2.5 s, what is the speed of light?

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

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

5. When tourists near Edinburgh Castle watch the 1 o'clock gun being fired they see the puff of smoke 5 s before they hear the bang. If the speed of sound is 340 $m\,s^{-1}$, 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:

$$v = f\lambda$$

Speed in meters per second ($m\,s^{-1}$)

Frequency in hertz (Hz)

Wavelength in metres (m)

Example

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

Practice Problems

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

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

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

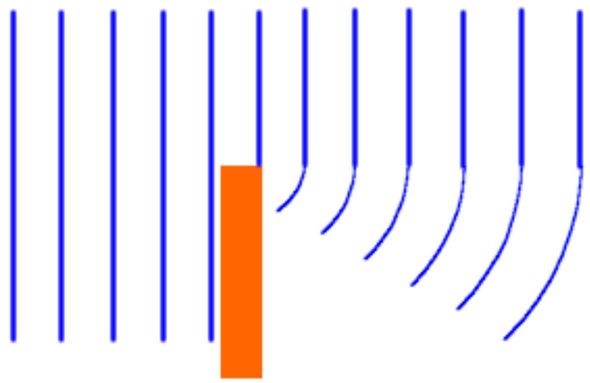
4. Water waves travel towards a lifeboat at a speed of 2.5 $m\,s^{-1}$ with a wavelength of 0.5 m. What is their frequency?

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

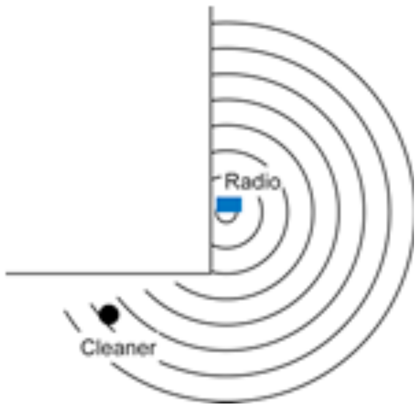
Diffraction

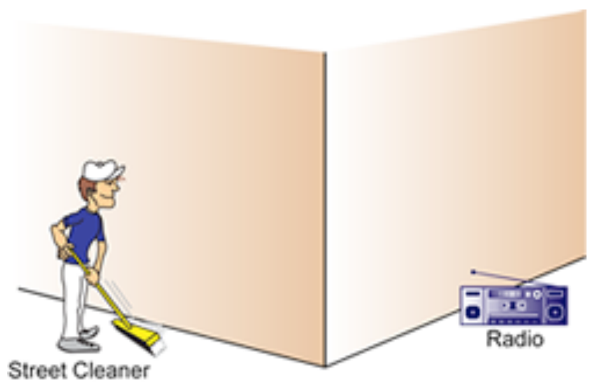
The proper name given to the bending of waves as they pass through a narrow gap or round an object is called diffraction. Diffraction is a property of all waves, it is also a unique property of waves.

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



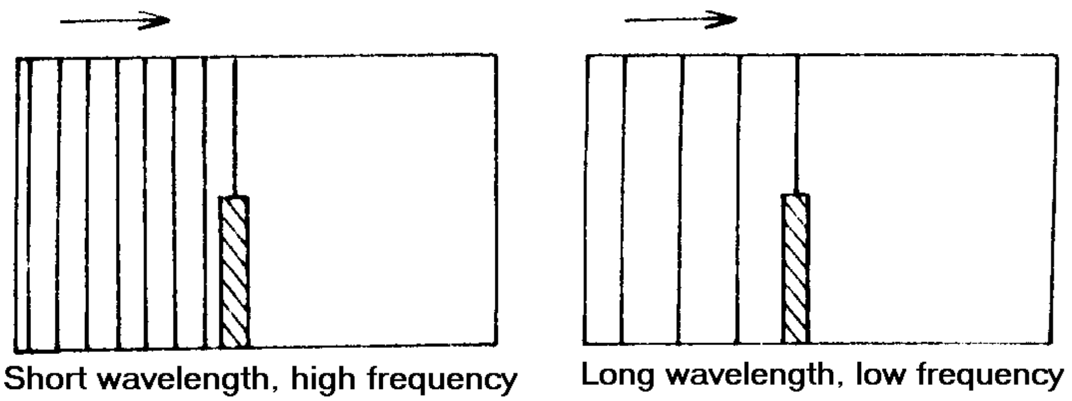
Diffraction of sound waves is why sounds can be heard around a corner.





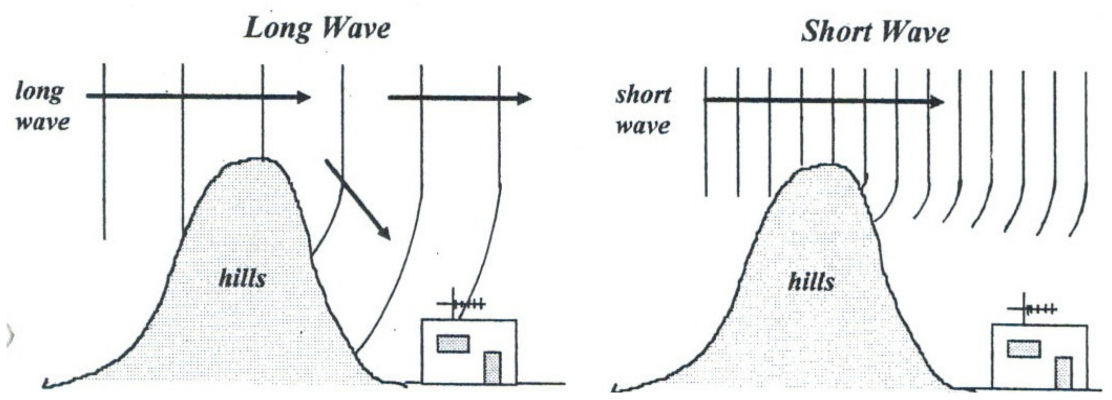
The amount of diffraction depends on wavelength. The **longer the wavelength, the greater the diffraction.**

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



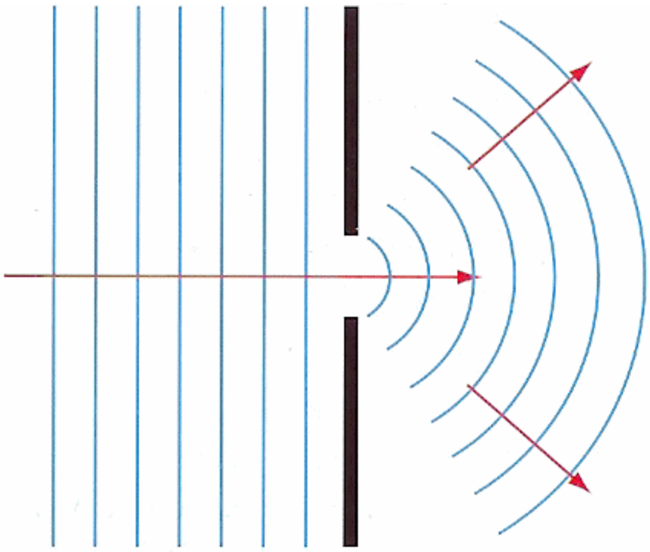
You cannot see around a corner because light waves have a much shorter wavelength than sound waves and so are not diffracted round the corner.

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

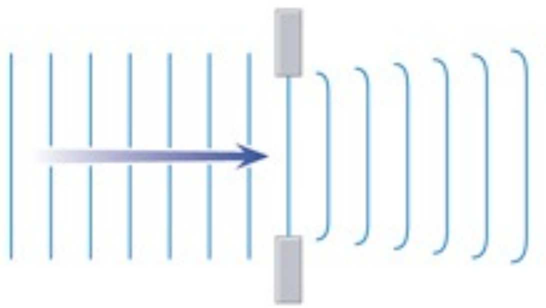


Radio waves have a longer wavelength than TV waves and therefore diffract more. In hilly areas it is much easier to receive radio signals than TV signals because of this. Mobile phones use microwaves which have an even shorter wavelength than TV signals, this is why it is very difficult to get reception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

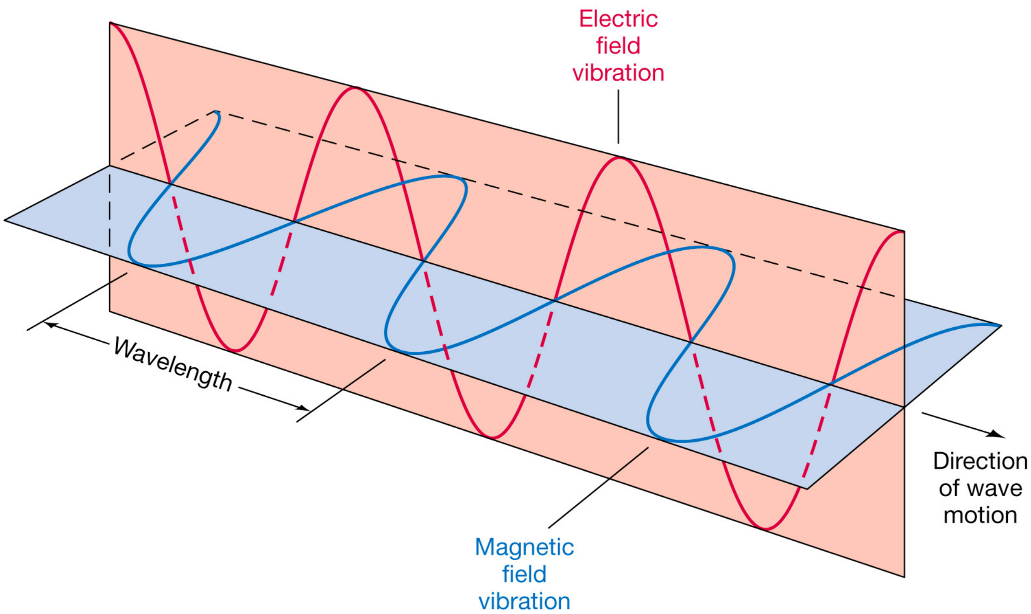
Light is a transverse wave and like all waves it can be described as having peaks, troughs, frequency, wavelength and amplitude. Just like all other waves it transfers energy.

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 400 nm (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.**

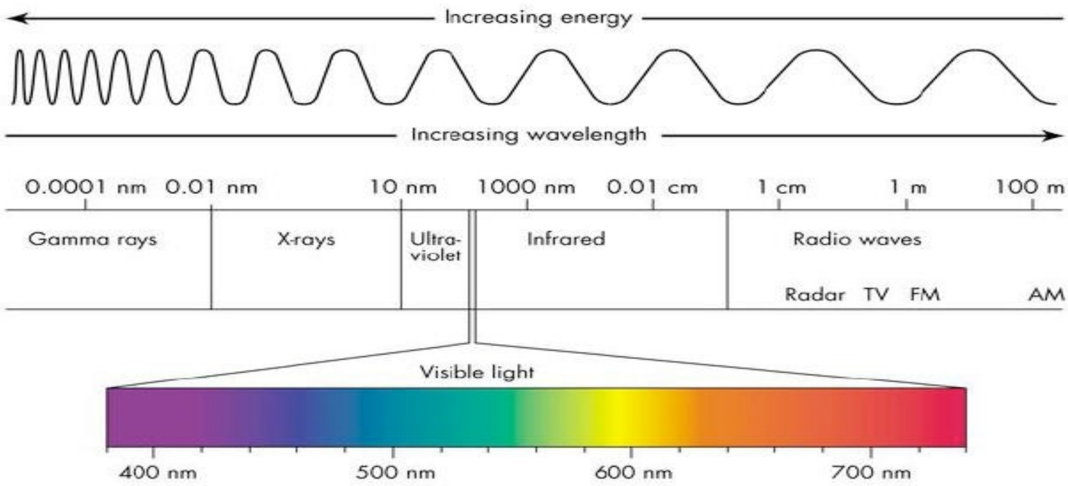
Electromagnetic Waves

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 300,000,000 $m\,s^{-1}$ or 3×10^{8} $m\,s^{-1}$ — 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 700 nm.

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

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

Refraction

All waves will refract, but the phenomenon is most commonly seen with visible light. The refraction of light is a change in speed, and sometimes 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 $3\times10^{8}\,\mathrm{m\,s^{-1}}$ (as it is in air). In fact the speed of light in glass is roughly $2\times10^{8}\,\mathrm{m\,s^{-1}}$.

The wavelength of the light is also changed when the light is refracted. However frequency (which is related to energy) does not change when light is refracted. This means that when light slows down as it enters a material the wavelength of the light becomes **shorter**.

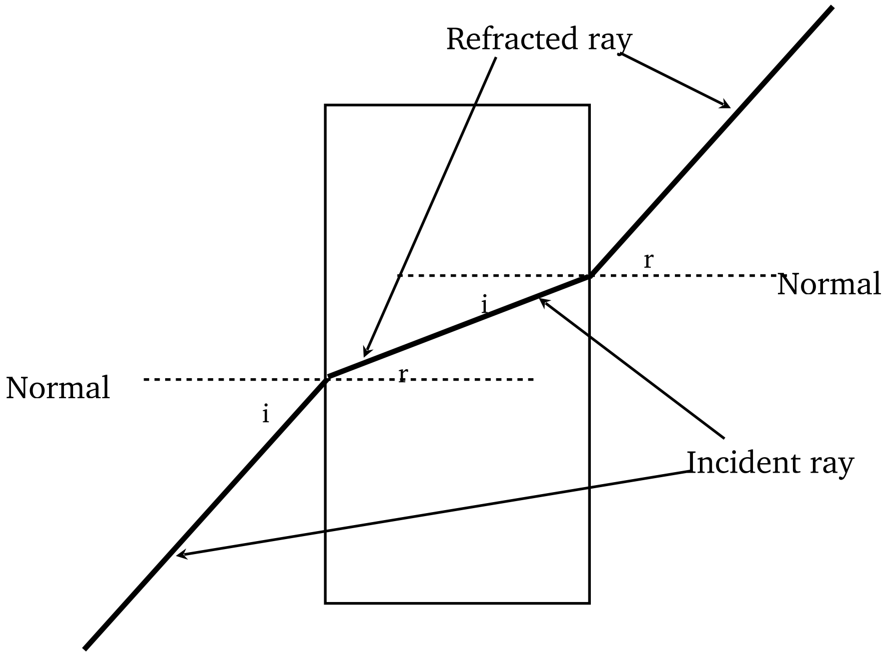
The Law of Refraction

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.

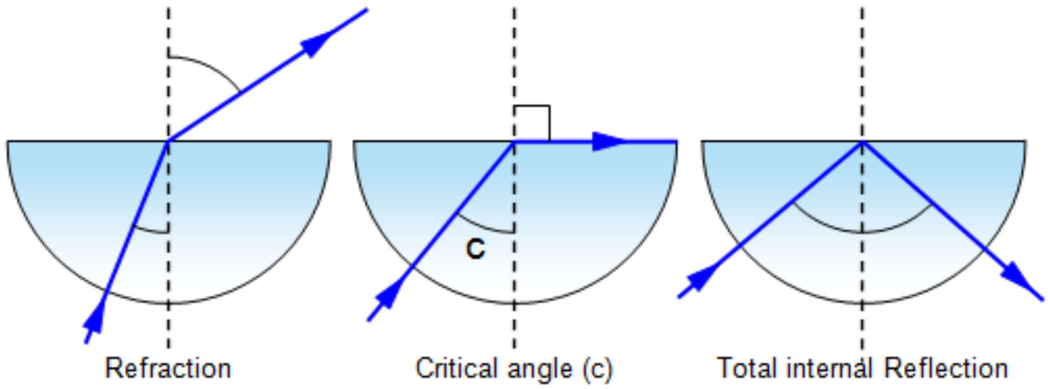
For a glass block **two** refractions occur. Once when the ray enters the block and again when the ray leaves the block.



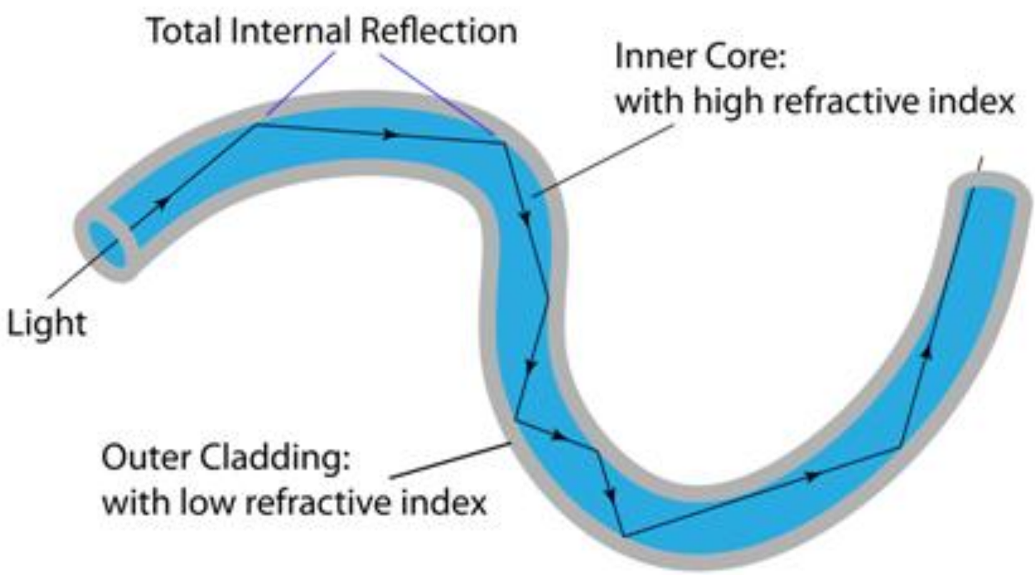
Note that the same result would be observed if the ray was sent through the block in the opposite direction.

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.



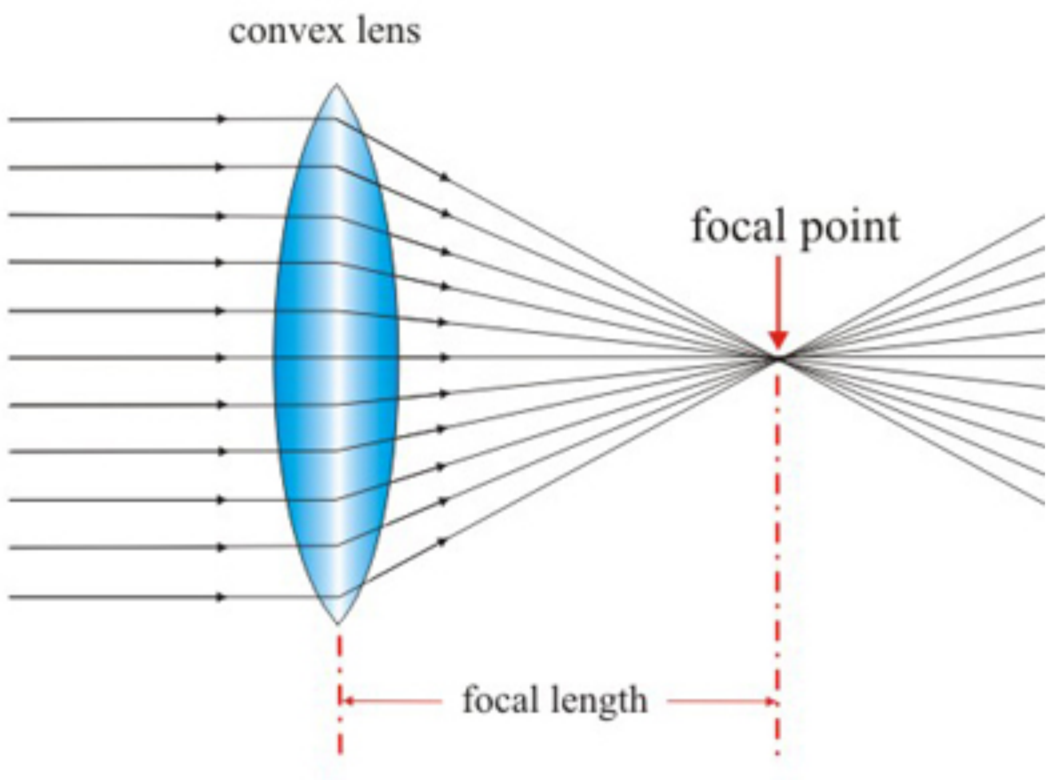
Total internal reflection is an extremely useful property of light and it is used to allow light to travel through a fibre optic cable:



Lenses

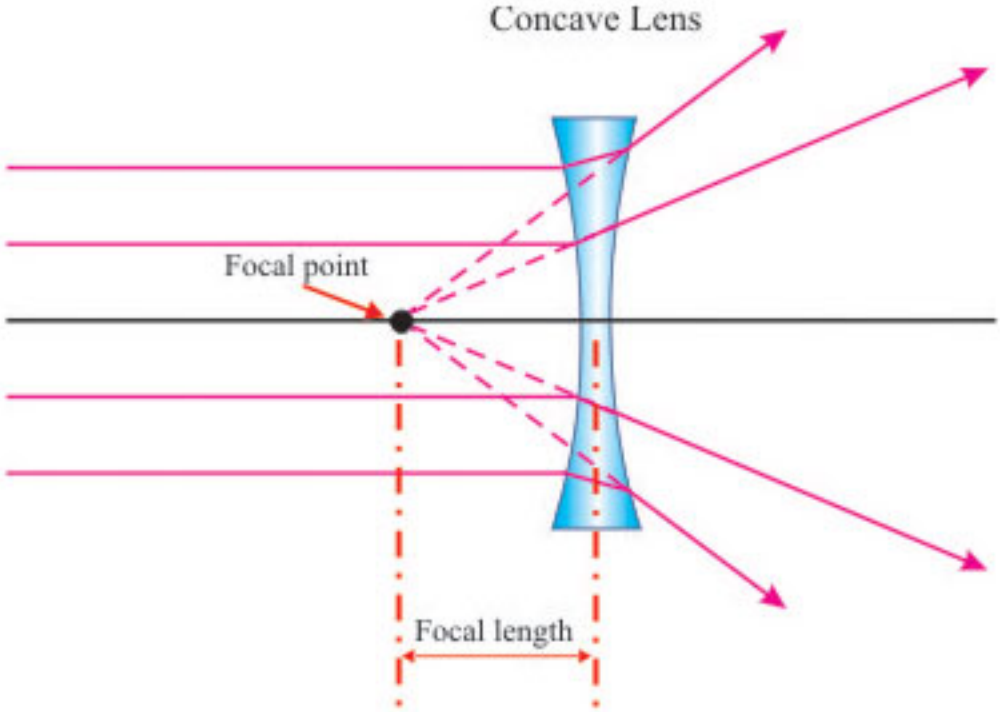
There are two basic types of lenses

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

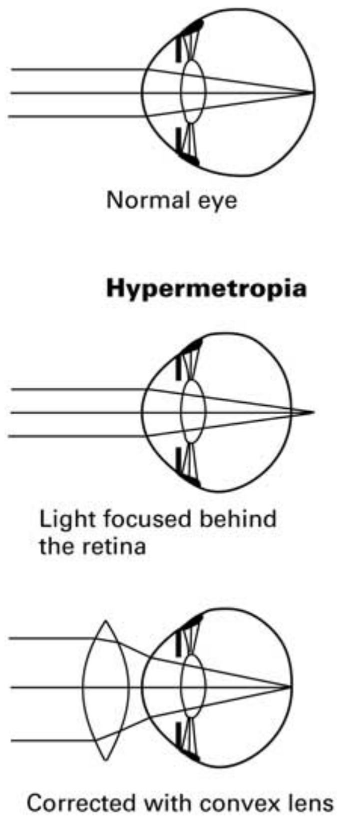


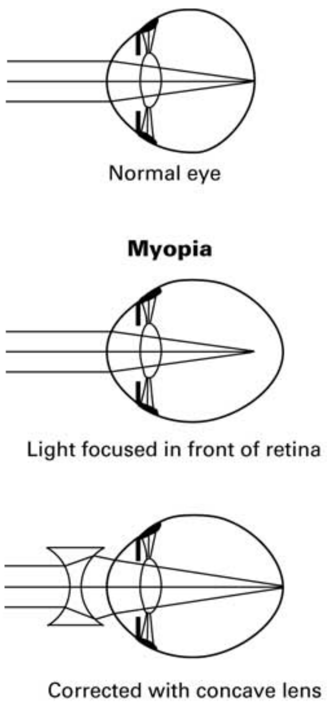
Concave lenses spread light out. Because they do not produce a real image they are usually used in conjunction with convex lenses in various optical systems. One use of the convex lens is in the ‘spy holes’ fitted to many from doors.

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.





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.

WAVES

You need to know:

	✓ ? ✘
Waves transfer energy	
How to calculate frequency, period, wavelength or amplitude of a wave from a trace of the wave	
How to use the v=d/t formula for waves	
How to use the $v=f\lambda$ formula	
How to use the T=1/f formula	
What diffraction is	
The parts of the EM spectrum (in order) and a source, detector and application of each	
The energy of EM radiation increases as frequency increases	
All types of EM radiation travel at the speed of light	
The speed of light in air/vacuum = $3\times10^8\ ms^{-1}$	
What longitudinal and transverse waves are and examples of each	
What the law of refraction is	
Explain refraction in terms of wave speed, wavelength, direction and frequency	
What the normal, angle of incidence and angle of refraction are	