AS Level Physics

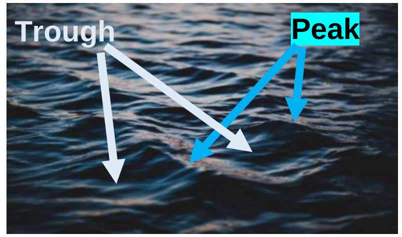
Chapter 10 – Waves

10.1.1 Wave Motion

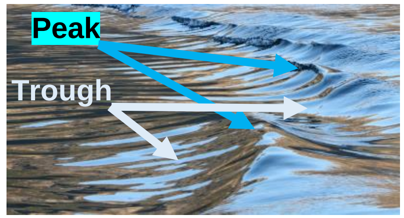
Notes

Progressive Waves

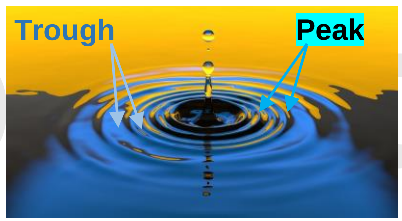
A **progressive** (moving) wave carries energy from one place to another through a material or a vacuum.



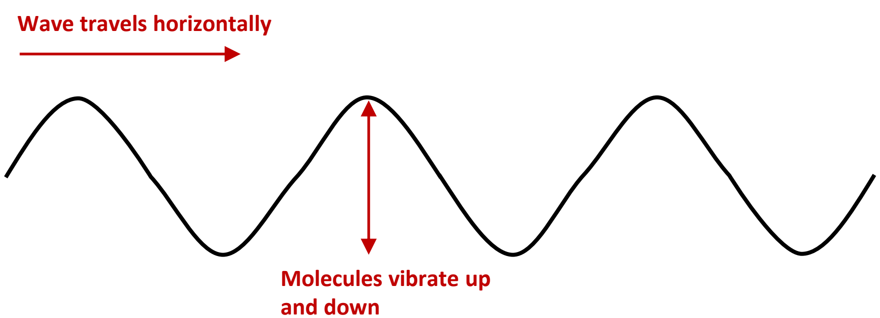
For example, electromagnetic waves cause objects to heat up.



Progressive waves can also be seen on the water's surface and they transmit energy as they travel across it. The wave is formed due to a periodic disturbance causing the water molecules to move up and down.



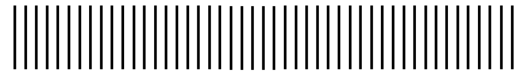
We can observe peaks and bottoms (or troughs) while looking at waves in water, therefore we may represent waves as a sine wave, as shown below:



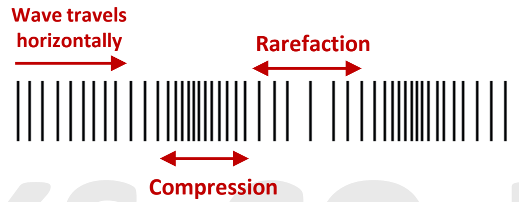
This concept can be applied to a variety of other phenomena such as:

Progressive Waves

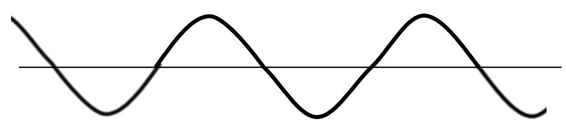
1) Sound waves: travel through air (or any other medium). As the wave moves through the medium, the particles vibrate back and forth, as illustrated below.

(A) 

(A) The wave illustrated when there are no sound waves present.

(B) 

(B) When sound waves are present, a wave is produced travelling horizontally. Particles move back and forth, causing compression and rarefaction to occur. Compression occurs when there is a collection of particles. Whereas rarefaction occurs when the particles are spread out.

(C) 

(C) You can compare the wave produced on (B) to a sine wave where a peak is created by compression, and a trough is created by rarefaction.

2) Light: (and other electromagnetic (EM) waves) do not require a medium. They are a periodic disturbance of the electric and magnetic fields. These fields fluctuate perpendicularly to the direction the wave is travelling in. We will talk more about light and electromagnetic waves later.

Types of Waves

Waves can be divided into two categories:

1) **Mechanical**: waves that require a substance for their transmission.

Sound waves, for example, can travel through air, water, and steel but not through vacuum.

Examples include:

- Water waves
- Sound waves
- Seismic waves
- Waves along a spring coil or rope

2) **Electromagnetic**: waves that do not need a substance for their transmission.

Light waves, for example, travel from stars and galaxies through empty space to reach us on Earth.

Examples include:

- Gamma-rays
- X-rays
- Ultra-violet (UV)
- Visible light
- Infra-red (IR)
- Microwaves
- Radio waves

Longitudinal and Transverse Waves

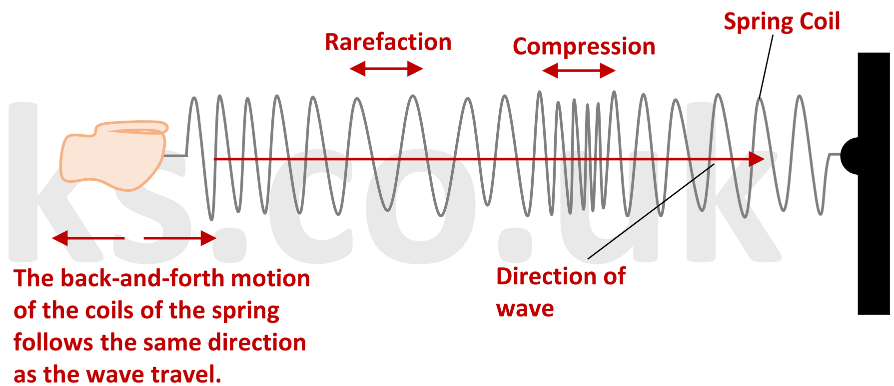
Waves can either can be Longitudinal or Transverse.

Longitudinal Waves

Longitudinal waves are waves whose direction of vibration is parallel to (i.e. along) the direction in which the wave travels.

Examples of longitudinal waves include sound waves, main seismic waves, and compression waves on a slinky.

A spring coil, as shown below, can be used to observe longitudinal wave motion.



Here we will send longitudinal waves through a spring coil.

When one end of the spring coil is moved back-and forth repeatedly, while the other end of the spring coil is fixed, each 'forward' movement causes the coil to push together causing a 'compression'. The coil separates with each 'backward' movement, causing a 'rarefaction' to pass along the spring.

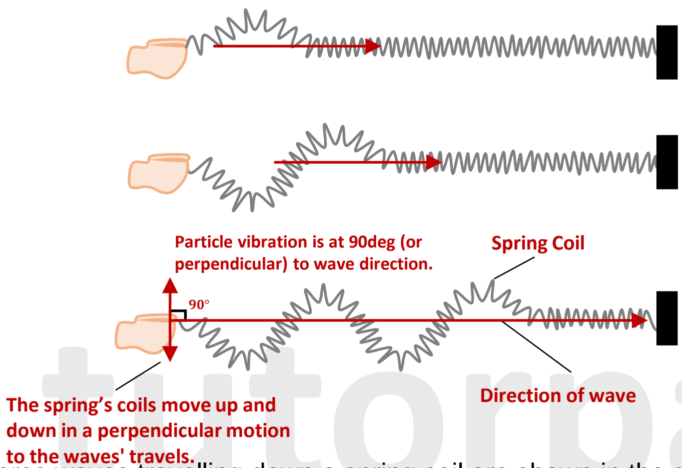
You can see that the vibrations are parallel to the axis of the coil. In other words, the spring coil's back-and-forth motion is in the same direction as the wave travel.

Longitudinal and Transverse Waves

Transverse Waves

Transverse waves are waves in which the direction of vibration is perpendicular to the direction of wave travel.

Transverse waves include electromagnetic waves, secondary seismic waves, and waves on a string or wire.



Transverse waves travelling down a spring coil are shown in the diagram above. The up and down movements travel along the spring when one end of the spring is continuously moved up and down. The wave's up and down vibrations are perpendicular to the waves direction.

Speed of a transverse wave on a string (Edexcel only)

Assume a string replaces the spring. As you apply the same up and down movement, the string will behave in the same way as the spring above. Using the formula below, you can calculate the speed of this transverse wave on the string:

$$v = \sqrt{\frac{T}{\mu}}$$

Where:

v = the speed in ms^{-1}

T = the tension in the string in Newtons, N

μ = the mass per unit length of the string (this is a constant) in $kg\ m^{-1}$

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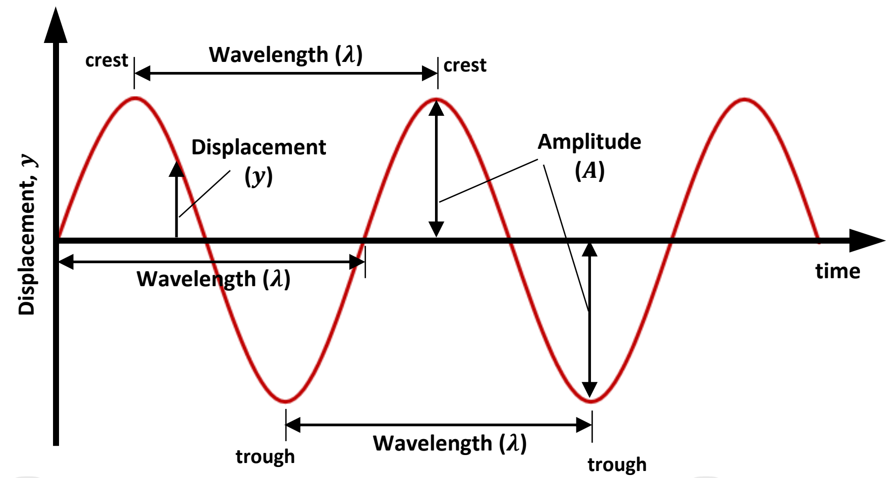
Wave Quantities



- **Displacement (y) / metre (m)**

The distance and direction moved by any vibrating particle from its undisturbed position.

Undisturbed position: its rest position found on the horizontal axis where displacement is zero.

- **Amplitude (A) / metre (m)**

The maximum displacement from its undisturbed position of any particle. The amplitude is the height measured from the horizontal axis to the crest or trough.

- **Wavelength (λ) / metre (m)**

A waves wavelength, λ, is the distance between adjacent crests (or troughs), or the distance between two adjacent points on a wave which are at the same point in the cycle.

The wavelength, in other terms, is the length of a single wave from crest to crest or trough to trough.

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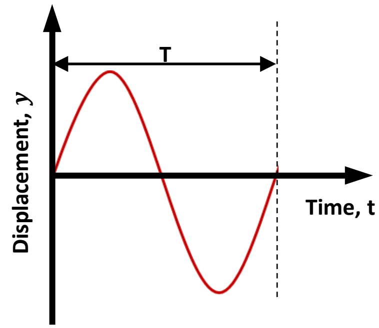
Wave Quantities

- **Period (T) / seconds (s)**

A period (T) is the time taken for a complete wave cycle (or one wavelength) to pass through a fixed point.



Remember time (t) is not the same as period (T).

Time (t) is continuous (like a clock) and never stops, whereas a period (T) has a set value and represents the length of time it takes for one complete cycle to pass a fixed point.

- **Frequency (f) / hertz (Hz)**

Frequency is the number of complete waves passing a fixed point per second.

Frequency can be calculated using the Period (T):

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

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

Frequency is measured in hertz (Hz).

$$\boldsymbol{1Hz = 1\, wave/s = 1s^{-1}}$$

So frequency is the number of waves per second, where as period is the number of seconds per wave.

Wave Quantities

- **Phase Difference / degrees or radians**

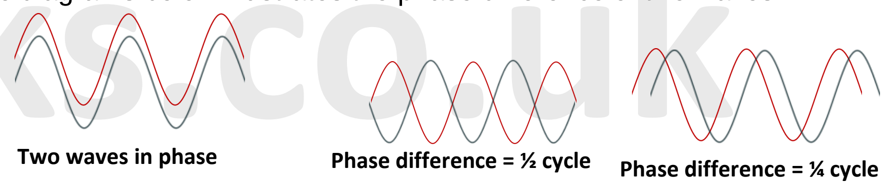
The fraction of a wave (or cycle) between the vibrations of two particles is known as the phase difference.

Phase difference can also mean the amount by which one wave lags behind another wave.

The phase difference is measured in radians (rad) or degrees (°) or expressed as a fraction of a cycle i.e.:

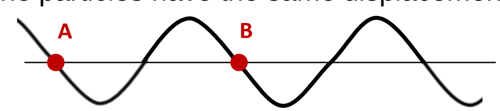
- 1 cycle = 1 complete wave = $2\pi\, rad = 360°$
- ½ cycle = $\pi\, rads = 180°$
- ¼ cycle = $\frac{\pi}{2}\, rad = 90°$

The diagrams below illustrates the phase difference of two waves:

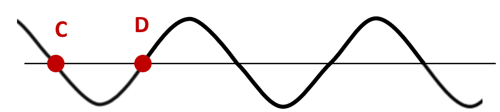


A phase difference between two points on the same wave is illustrated below.

Points A and B are separated by one wavelength and are in phase with each other. At these points the particles have the same displacement and velocity.



Points C and D are separated by half a wavelength and have a phase difference of 180º.



Speed of a Wave

As we know waves can transfer energy from one place to another, but how quickly they accomplish this depends on the speed of the wave.

The wave's speed, v, indicates how quickly it travels i.e. the distance travelled per second by a crest.

Speed, v is calculated using the formula below:

$$\boldsymbol{Speed = frequency \times wavelength}$$

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

Where:
$\boldsymbol{v}$ = speed measured in $\boldsymbol{ms^{-1}}$.
$\boldsymbol{f}$ = frequency measured in **hertz, $\boldsymbol{Hz}$**.
$\boldsymbol{\lambda}$ = wavelength measured in **metres, m**.

Units:

Frequency, f is measured in hertz, Hz and $1\ Hz = 1s^{-1}$.

Wavelength, λ is measured in metres, m.

$$\therefore v = f\lambda = Hz \times m = s^{-1} \times m = ms^{-1}$$

Speed of a Wave

Deriving $\boldsymbol{v = f\lambda}$

Consider a wave with a wavelength (λ), a period (T), a frequency (f) and moving with a speed (v).

The wave will travel a distance (λ) in time (T). Therefore:

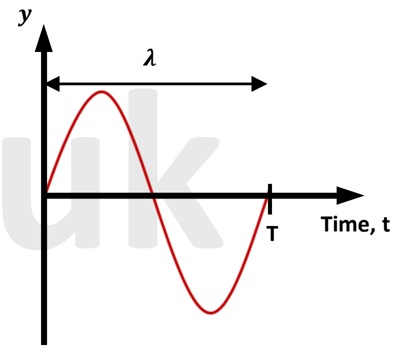
$$\text{Wave speed, } v = \frac{distance\ travelled}{time\ taken} = \frac{\lambda}{T}$$

And since, $T = \frac{1}{f}$, we can substitute this in the above formula to get:

$$v = \frac{\lambda}{1/f}$$

So:

$$v = f\lambda$$



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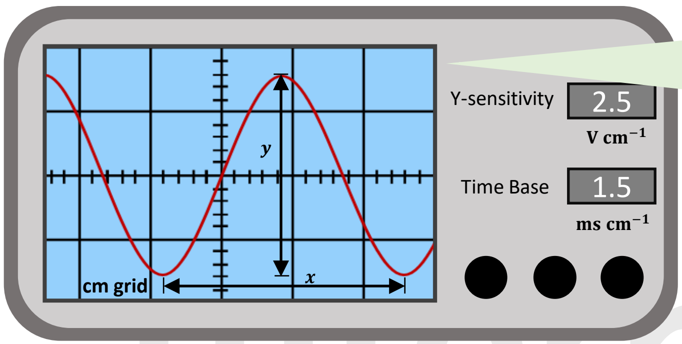
Using an Oscilloscope to Determine Frequency

You can connect a microphone to an oscilloscope and use it to find the frequency of a sound wave and display the sound on screen. The waveform of the sound waves produced by a loudspeaker is represented by the trace on the oscilloscope screen. The example below explains how to use the oscilloscope controls to measure the amplitude and frequency of this waveform.



a) Trace height **y** = 3.2cm

Therefore Trace amplitude = $\frac{3.2\ cm}{2}$ = 1.6cm

Given Y-sensitivity = 2.5 $V\ cm^{-1}$

Voltage amplitude = 2.5 $Vcm^{-1} \times 1.6cm = \mathbf{4.0\ volts}$

b) x - distance from peak-to-peak = 3.4cm

Given time base $1.5\ ms\ cm^{-1}$

Time period = $1.5ms\ cm^{-1} \times 3.4cm = 5.1\ ms$

Frequency $f = \frac{1}{Time\ period} = \frac{1}{5.1\times10^{-3}s}$

$5.1ms = 5.1 \times 10^{-3}s$

$$f = 196.1\ Hz$$

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Reflection, Refraction and Diffraction of Waves

Ripple Tank

A ripple tank can be used to observe and study wave properties such as reflection, refraction, and diffraction of water.

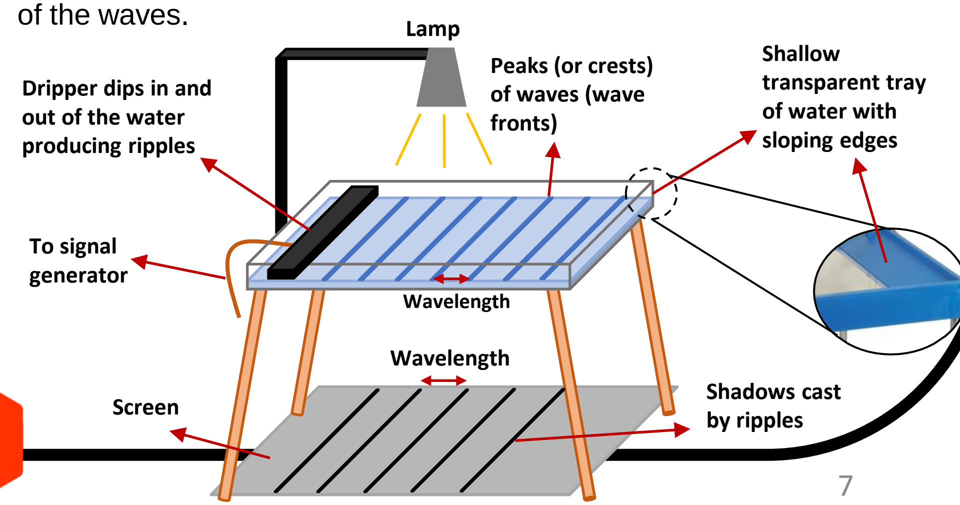
The tank is a shallow transparent tray with sloping edges that holds water. Waves do not reflect off the tank's sides because of the sloping edges. If the waves were to reflect, it would make it difficult to observe the waves.

To create the waves in a ripple tank, a vibrating dripper is used which dips in and out of the water.

The waves observed in a ripple tank are known as 'wave fronts' and we draw the 'wave fronts' as if we are looking down on the ripples from above.

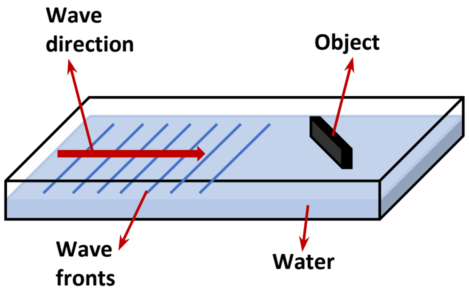
These 'wave fronts' can be observed on a screen (placed below the tank) by shining a lamp over the ripple tank. The 'wave fronts' are then projected as shadows on the screen below. Each line represents the crest (or peak) of the wave. These are lines of constant phase (e.g. crests) and the wavelength is given by measuring the separation between two parallel 'wave fronts'.

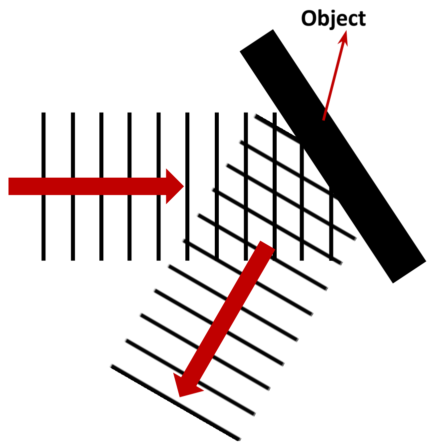
To see what effects are produced, obstacles are placed in the path of the waves.



Reflection, Refraction and Diffraction of Waves

Reflection





Reflection occurs when a wave collides with a solid flat surface, and some or all of the wave bounces of it.

The angle formed by the incident wave front and the surface is equal to the angle formed by the reflected wave front and the surface.

In other words:

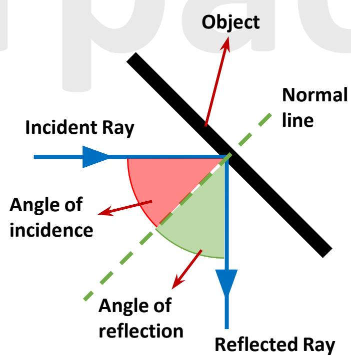
$$angle\ of\ incidence = angle\ of\ reflection$$

A water wave hitting a solid flat surface at 32°, for example, will be reflected at 32°.

The angle of incidence and reflection is measured between the wave and the normal (an imaginary line that passes through the solid surface at a 90º angle).

The diagram above shows a water wave being reflected at a solid flat surface, however this can alternatively represent a light ray being reflected at a flat mirror.

Sound waves are also reflected in the same way. Echoes are produced due to the reflection of sound.

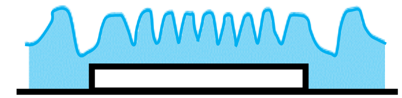


Reflection, Refraction and Diffraction of Waves

Refraction

Refraction occurs when a **wave changes direction** when travelling from one medium to another and there is a **change in speed**.

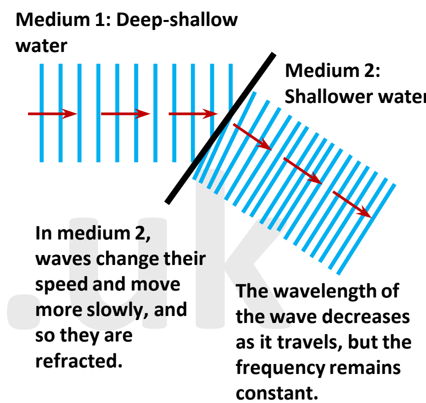
Refraction of Water



By placing a flat, rectangular piece of Perspex in the tray, will cause the water to become shallower, slowing the waves down as they pass over it (i.e. there is a change in speed).

When water waves are incident at an angle, with the DEEP-SHALLOW boundary, they change direction and their wavelength (λ) decreases. As there is a change in direction and speed, refraction occurs.

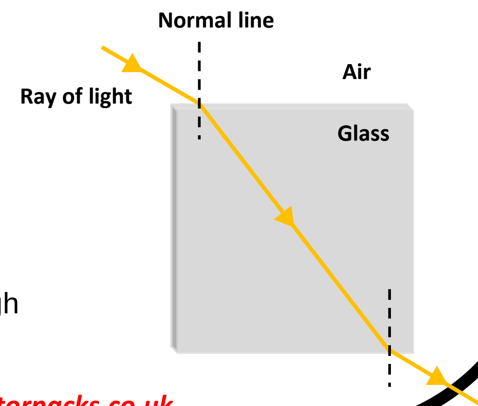
This wavelength decreases due to the fact that $v = f\lambda$ and since v decreases and f stays the same, λ must decrease.



Refraction of Light

When a light ray is directed at an angle into a glass block, it changes direction at the glass boundary, causing it to refract.

This occurs because light waves travel slower in glass than through air causing a change in speed.

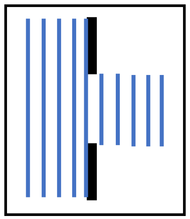


Reflection, Refraction and Diffraction of Waves

Diffraction

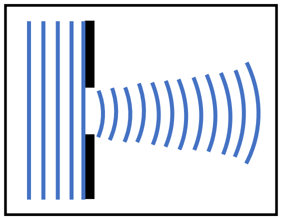
Diffraction occurs when waves spread out after passing through a gap, or around an obstacle.

A ripple tank can be used to demonstrate the effect when straight waves are directed at a gap, as shown below:



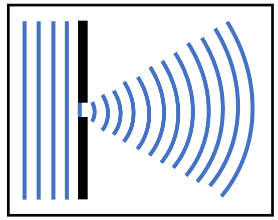
Wide gap = small diffraction effect

Diffraction is unnoticeable when the gap is much larger than the wavelength.



Slightly narrower gap = some diffraction effect

A gap several wavelengths wide, you get noticeable diffraction.



Narrower gap = large diffraction effect

When **gap size is approx. equal to the wavelength** you get a large diffraction effect.

Note: The wavelength (and frequency) of the diffracted wave remains constant.

Also, the waves are mostly reflected back if the gap size is smaller than the wavelength.

Reflection, Refraction and Diffraction of Waves

Diffraction

Sound waves:

When sound travels through a doorway, the gap size and the wavelength of the sound are usually close to being equal, resulting in a lot of diffraction.

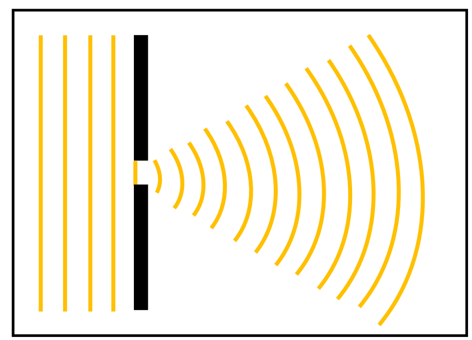
That's why, even though a person might be out of sight, you can hear them through an open door into the next room.

Light waves:

In normal circumstances, light wave diffraction is rarely observable. This is due to the fact that visible light wavelength (approx. 400–700 nm) are extremely small in comparison to the gaps and objects we normally encounter.

However, diffraction in light can be demonstrated experimentally by shining a laser light through a very narrow slit onto a screen. The width of the slit can be changed to alter the amount of diffraction.

Light and sound waves diffract as shown on the diagram below.

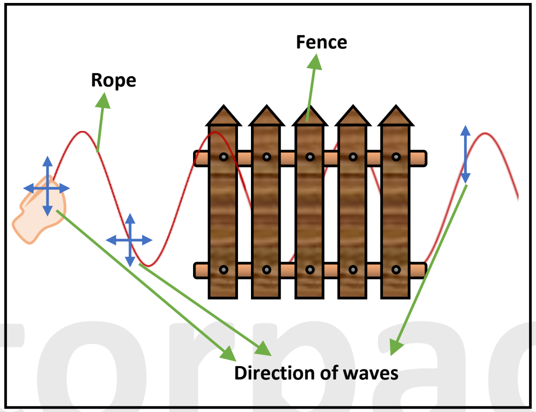


Reflection, Refraction and Diffraction of Waves

Polarisation of a Wave

When you shake a rope to form a wave, you can move your hand up and down, side to side, or in a combination of directions, and the wave will still be transverse.

However, if you pass the waves in the rope through a vertical fence, the wave will only pass through if the vibrations are vertical. All other vibrations are filtered out by the fence. This is referred to as polarising the wave.



Therefore polarisation means to only let one direction of vibrations through.

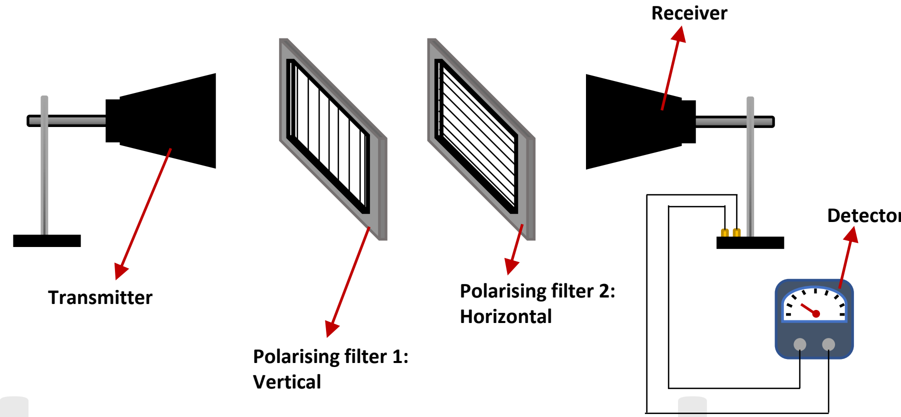
Ordinary light waves are made up of a variety of vibrations in different directions. However, a polarising filter is designed to only let one direction of vibration through. When light passes through a polarising filter its intensity decreases and the light seems dimmer.

No light will pass through if two polarising filters are placed at right angles to each other.

Only transverse waves can become polarised.

Reflection, Refraction and Diffraction of Waves

Polarisation of Microwaves - Experiment



Knowing that only transverse waves can be polarised we can use this information as a test to determine whether a wave is transverse or not.

To test if visible light is transverse we can use two polarising filters.

To test if microwaves are transverse we use 1cm metal grids.

Set up by positioning two polarising filters facing each other between the transmitter and receiver.

Begin by aligning both filters parallel to each other (i.e., both polarising filters 1 and 2 are vertical), which allows microwaves/visible light to pass freely and gives you a reading on the detector.

Then start to rotate the second polarising filter through 90 degrees (so that the first filter is vertical and the second filter is horizontal) and watch the reading on the detector drop until it reaches 0.

This indicates that microwaves/visible light must be polarised by the first filter; otherwise, the detector reading would have been consistent throughout the rotation.

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Intensity and Amplitude

When you say "brightness" for light or "loudness" for sound, you're really talking about how much light or sound energy reaches your eyes or ears every second.

Remember: Rate of flow of energy is just a longer way of saying power

Intensity is the scientific term for this.

Intensity is defined as the rate of flow of energy per unit area at right angles (perpendicular) to the direction of travel of the wave.

To calculate Intensity, use the formula below:

$$Intensity = \frac{Power}{Area}$$

$$I = \frac{P}{a}$$

Intensity is measured in Watts per metre squared (Wm^{-2}).

The greater a wave's amplitude (A), the greater its intensity:

$$I \propto A^2$$

This is because intensity is related to energy, and the energy of a wave is proportional to its amplitude squared.

From this, we can conclude that if wave 1 has twice the amplitude of wave 2, wave 1 will have four times the intensity of wave 2. (i.e. wave 1 is carrying energy at four times the rate). If this were a sound wave, a change in amplitude would correspond to a change in loudness.

Intensity and Amplitude

Also keep in mind that the intensity of a wave reduces as it travels further because its energy is spread out across a larger area and some of it is absorbed.

Please see '10.1.2 Wave Motion worked examples' pack for exam style questions.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.

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