Progressive Waves

An oscillation or vibration that leads to a transfer of ONLY ENERGY.

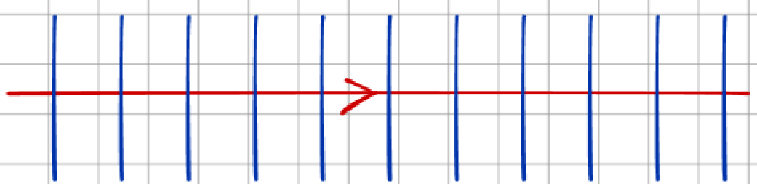
If disturbing a substance then the particles vibrate about fixed positions.

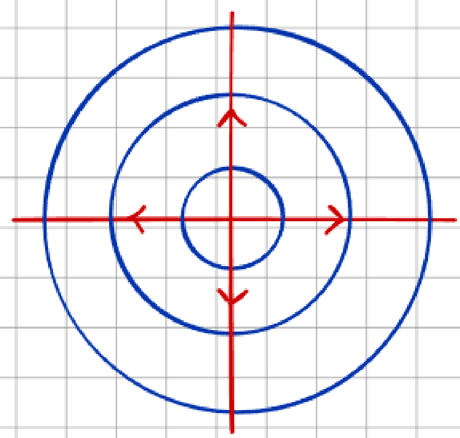
MEDIUM

Representing waves:

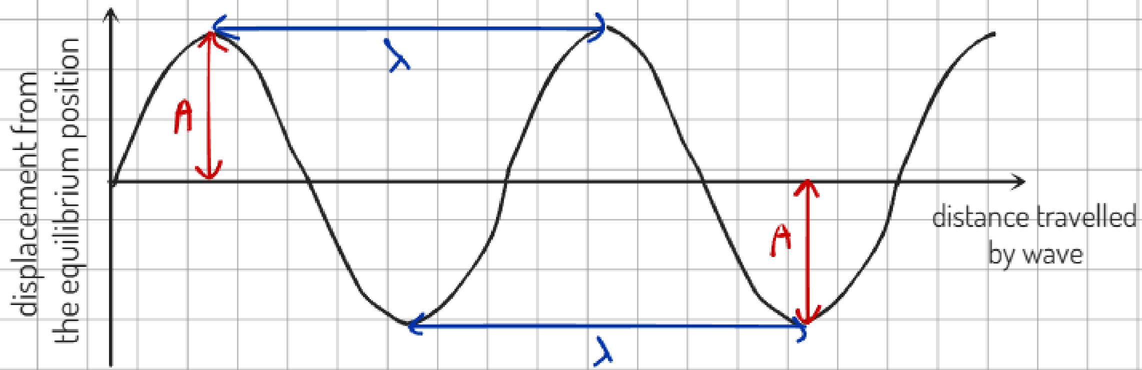
Ray: Imaginary arrow showing the direction of propagation of the waves (the direction in which the energy is being transferred)

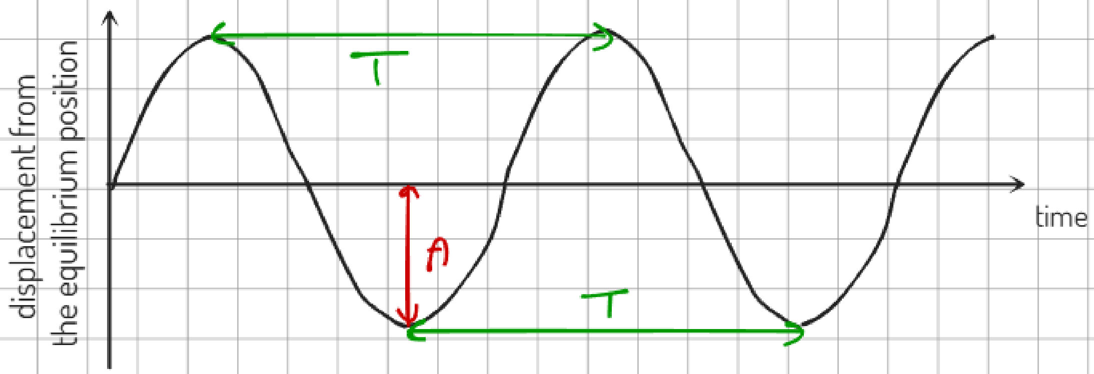
Wavefront: A line which joins points on a wave which are all at the same point within an oscillation cycle.





Movement of particles within a medium:
Choose a point on the wave and model the oscillations.





Amplitude - maximum displacement from the equilibrium position within a cycle

Wavelength - distance between identical points in adjacent cycles (distance travelled by the wave during a single oscillation) [metres]

Period - time taken to complete on full oscillation. [seconds]

Frequency - number of oscillations per second [Hertz]

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

Wavespeed can be calculated from the values:

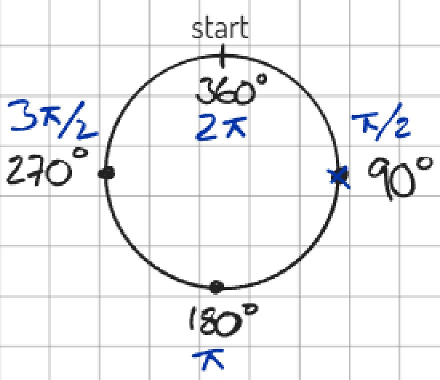
$$\boxed{c = \frac{\lambda}{T}} \quad \text{OR} \quad \boxed{c = f\lambda}$$

Phase

The phase of a wave describes what fraction of an oscillation cycle has been completed compared to the start of the cycle.

Particles moving at the same speed in the same direction are IN PHASE.
Particles at different parts of a cycle are OUT OF PHASE.
Particles moving at the same speed in opposite directions are in ANTIPHASE.

Radians



1 full circle is 360°

1 full circle is $2\pi^c$
(2π radians)

Phase difference

Measured as an angle.

The displacement (Δy) of a particle at any stage of an oscillation depends on the Amplitude and the Phase angle.

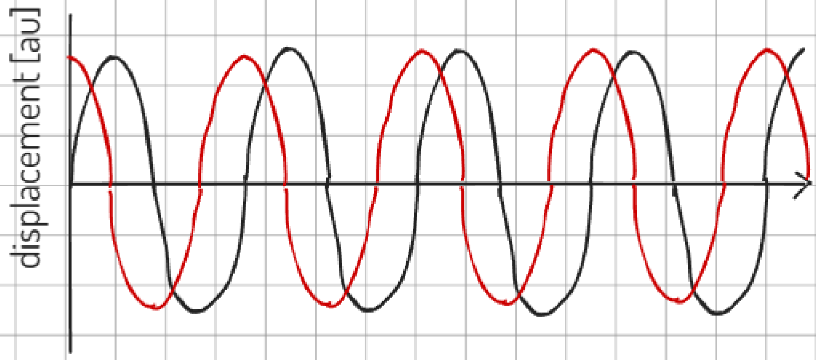
if $t = T$ then the angle is 2π

therefore the phase at any point is

$$\phi = \frac{2\pi t}{T} \quad \text{or} \quad 2\pi f t$$

phase difference

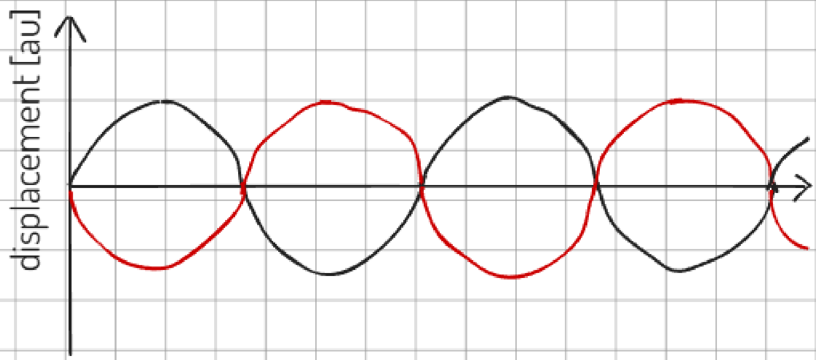
$$\Delta y = A\sin(\phi) \quad \text{or} \quad A\sin(2\pi f t)$$



Amplitude of 3 au
Period of 4 s

OUT OF PHASE

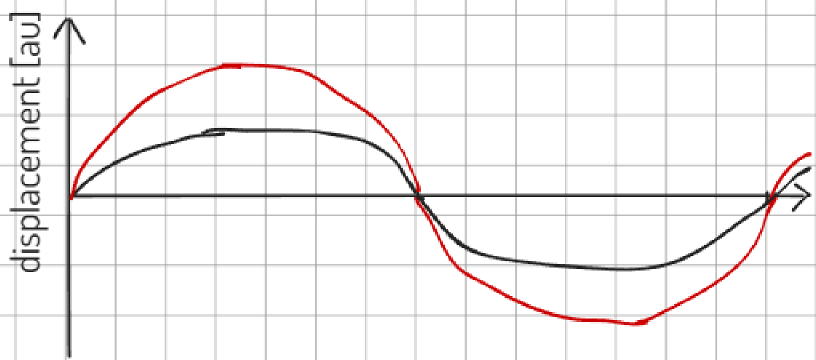
Draw an identical wave
$\frac{3\pi}{2}$ radians OUT OF PHASE



Amplitude 2 au
Period 8 s

IN ANTIPHASE

Amplitude 2 au
π radians out of phase



Amplitude 1.5 au
Period 16 s

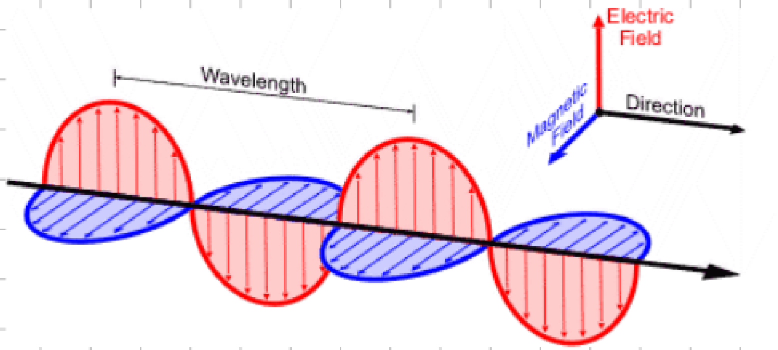
IN PHASE

Amplitude of 3 au
In Phase

Transverse and Longitudinal

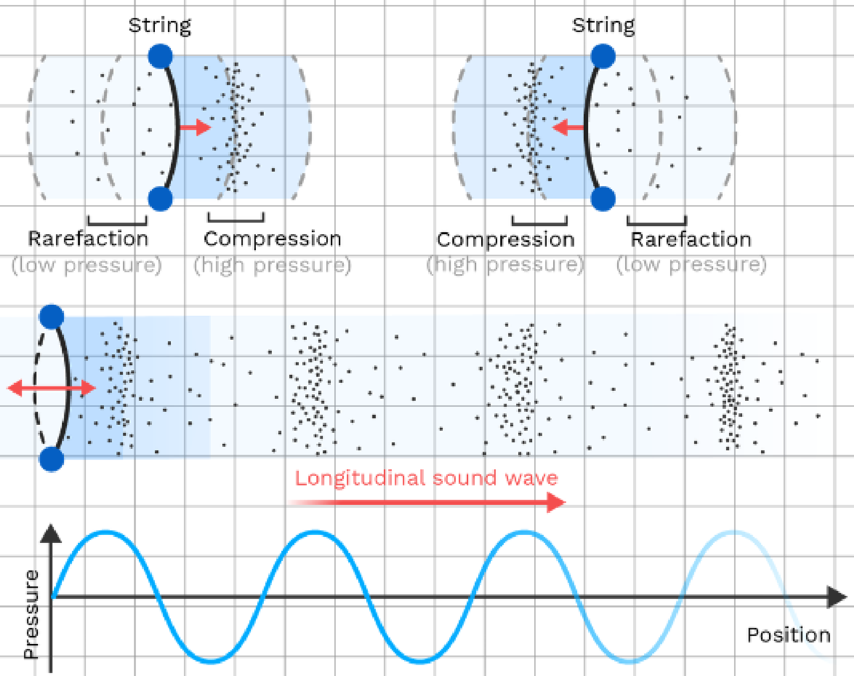
Transverse Waves

Displacement of the particles or field(s) is PERPENDICULAR to the axis of propagation (direction of energy transfer).



Mechanical Transverse waves such as,
Water waves or a wave on a string, require a MEDIUM to propagate through.

Longitudinal Waves

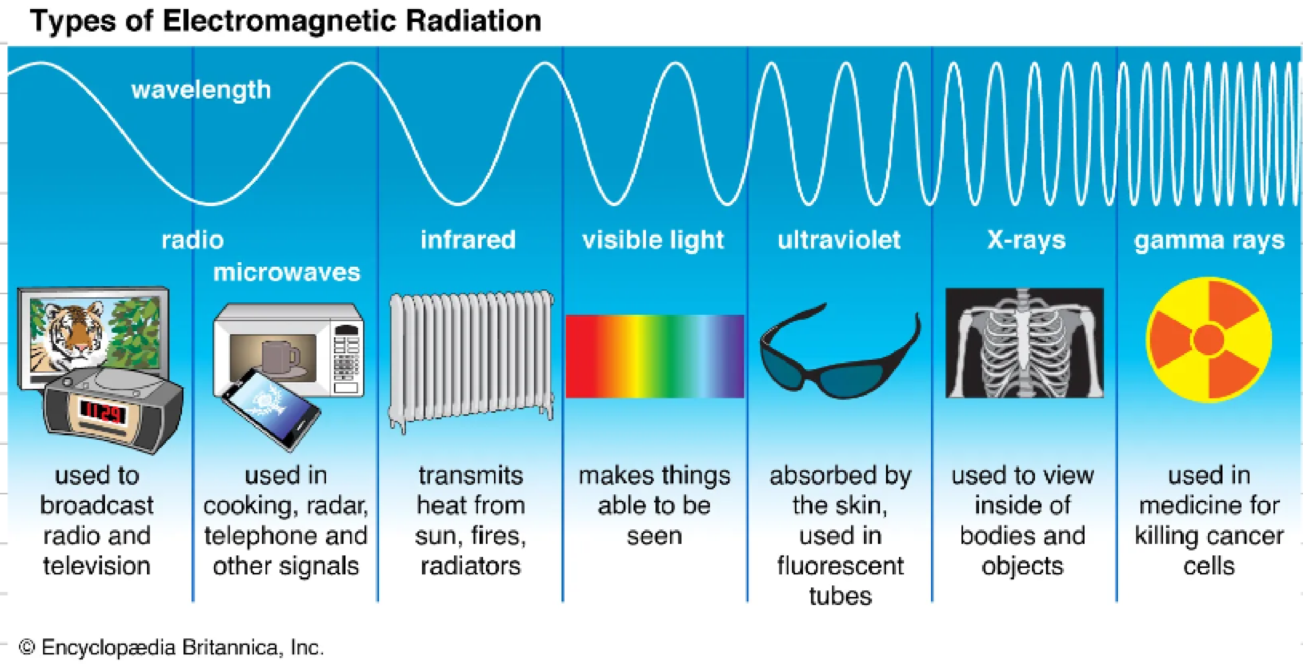


Displacement of the particles or field(s) is PARALLEL to the axis of propagation (direction of energy transfer).

Both forms of wave can be represented as displacement vs time or displacement vs distance graphs and take the SAME FORM.

Sound transfers energy via inter-atomic/inter-molecular bonds. The rate of transfer depends on bond density (so sound travels faster in a solid)

EM Waves

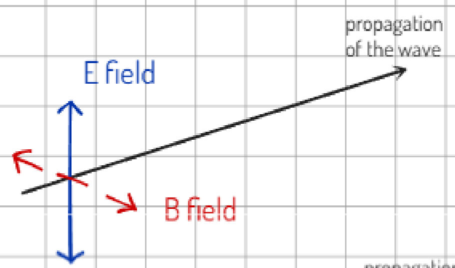


All EM Waves are transverse waves. They consist of an oscillating electric field and an oscillating magnetic field. These fields are perpendicular to each other, and both perpendicular to the direction of propagation.

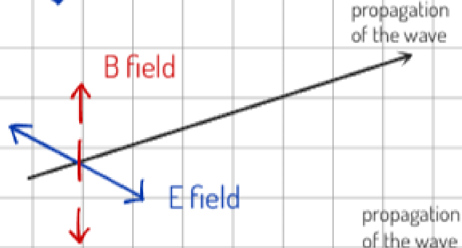
Polarisation

An EM wave can be POLARISED. It is customary to consider ONLY THE ELECTRIC FIELD in this case.

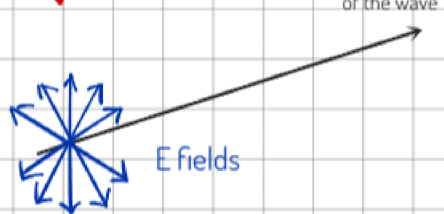
A wave where ALL electric field oscillations are in the vertical plane is said to be VERTICALLY POLARISED.



A wave where ALL electric field oscillations are in the horizontal plane is said to be HORIZONTALLY POLARISED.

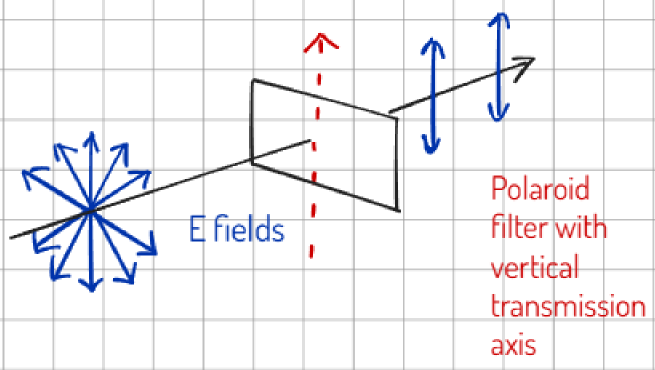


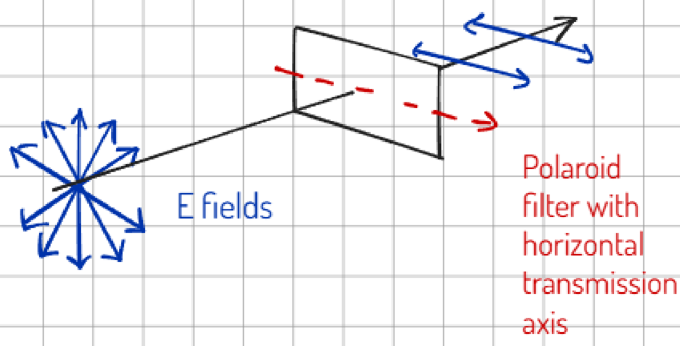
UNPOLARISED waves are an even mixture of all possible directions of oscillation.



Arbitrary directions of polarisation can be RESOLVED into horizontal and vertical polarisations.

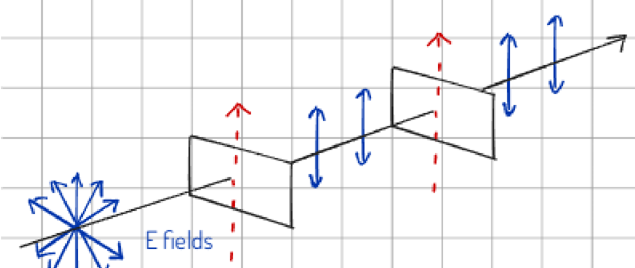
Filters



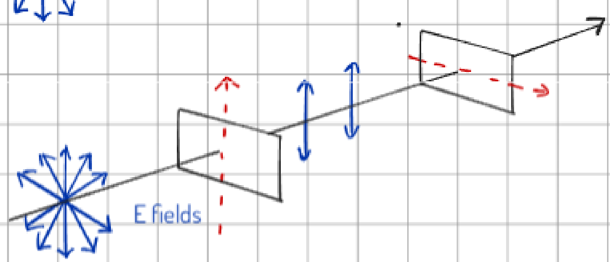


A polaroid filter will:

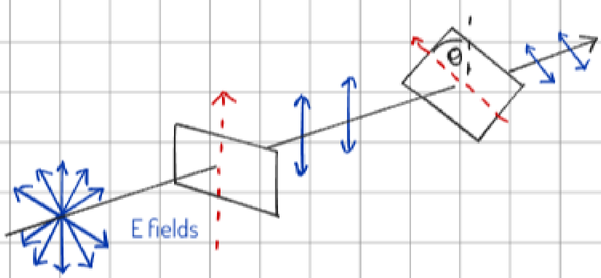
- TRANSMIT COMPONENTS of light which are PARALLEL to the TRANSMISSION AXIS of the filter.
- ABSORB COMPONENTS which are PERPENDICULAR to the TRANSMISSION axis of the filter.



If the plane of polarisation of the second filter is also vertical (x = 0x, 180x)
then the transmitted light will be maximum.

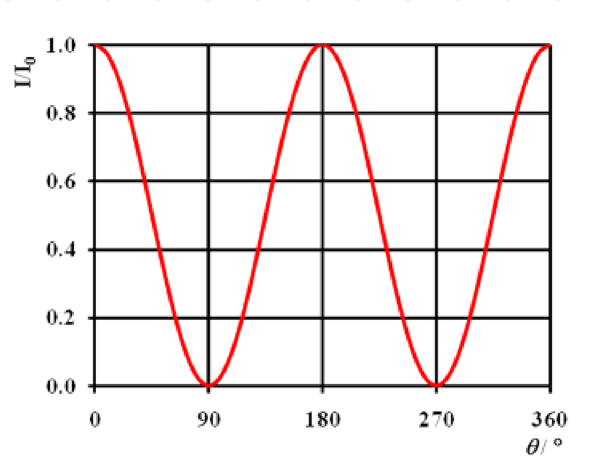


If the plane of polarisation of the second filter is also vertical (x = 90x, 270x)
then the transmitted light will fall to zero.



At intermediate angles some of the light is transmitted, because the vertically polarised light can be resolved so that it has some polarisation component in the direction of the transmission axis of the second filter.

The intensity of the light transmitted varies smoothly between maximum and minimum according to:



$$I = I_0 \cos^2 \theta$$

Where:
I is the intensity of the transmitted light
I_0 is the maximum intensity of the transmitted light
θ is the angle between axes of transmission

Using polarised light

Sunglasses and Cameras

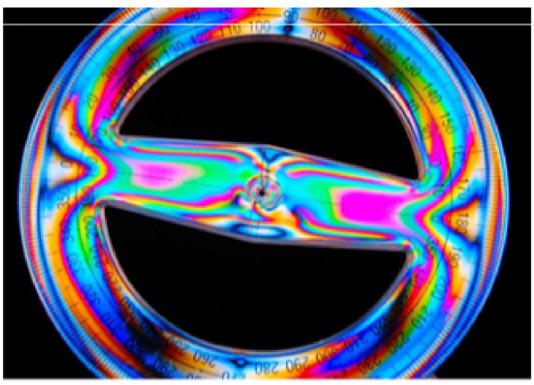
When light is reflected from a surface (such as water) it is partially polarised, with the majority of light in the horizontal polarisation. Polaroid sunglasses and camera filters have a vertical transmission axis to reduce light intensity and glare.

Polarimeters

Certain crystals and fluids, such as glucose solution, rotate the plane of polarisation of light. This is known as OPTICAL ACTIVITY. The angle of rotation α depends on the length of the sample and concentration of solution.

This means conversely, by measuring α, we can determine the concentration of a polarimeter solution.

Stress analysis



Some plastics, under stress produce colour fringes when illuminated by polarised light.

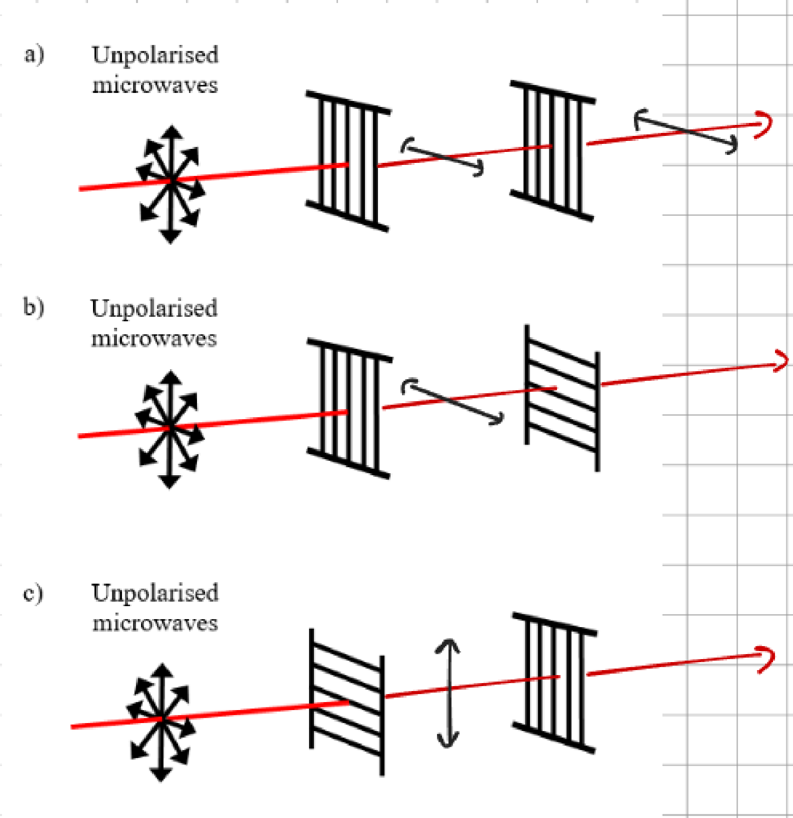
This can be used to model structures and look at areas of high stress.

Other EM waves

Polaroid filters are for visible light, but other regions of the EM spectrum can be polarised.

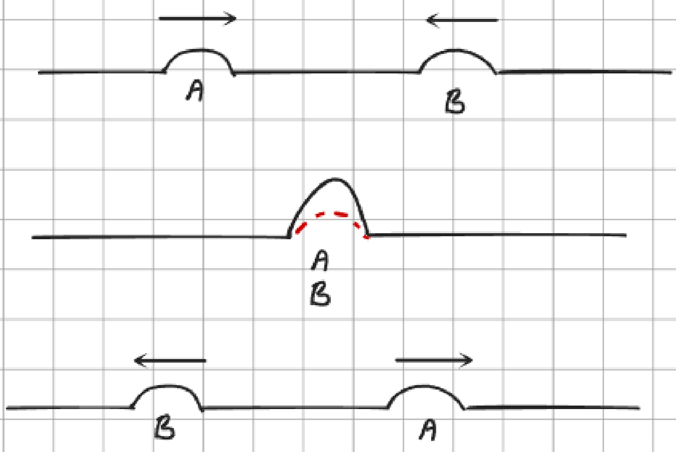
For microwaves, we can use a grid of metal wires, the wave is polarised PERPENDICULAR to the plan of the grid (as the grid absorbs parallel waves)

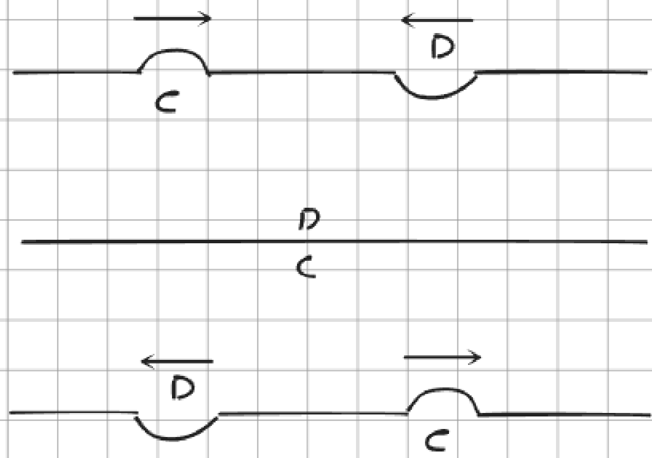
Radio waves are also typically polarised. To receive radio signals, the aerial must be in the same orientation as the polarised radio waves.



Superposition of Waves

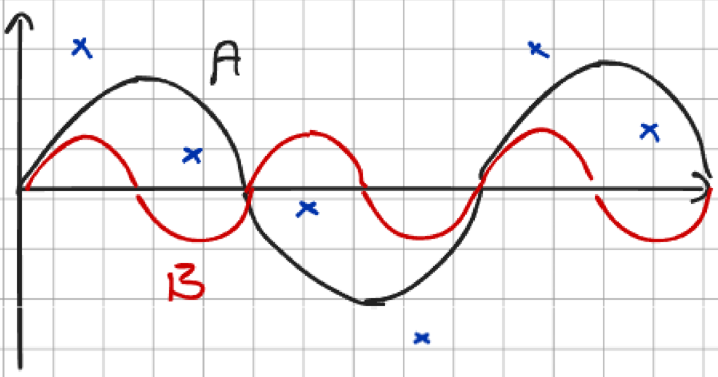
The PRINCIPLE OF SUPERPOSITION OF WAVES states that when two waves meet, the total displacement is equal to the VECTOR SUM of the displacements of each wave.

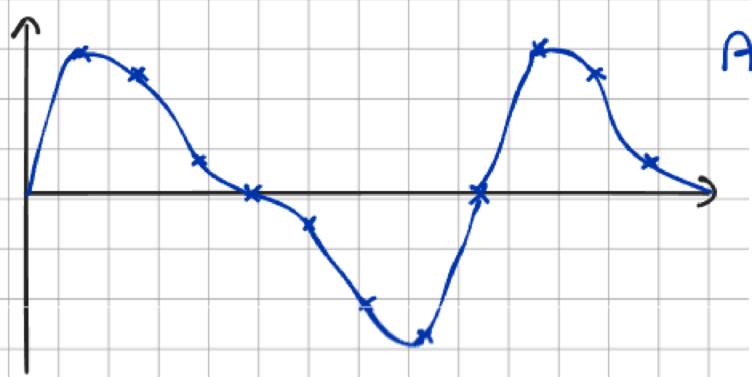




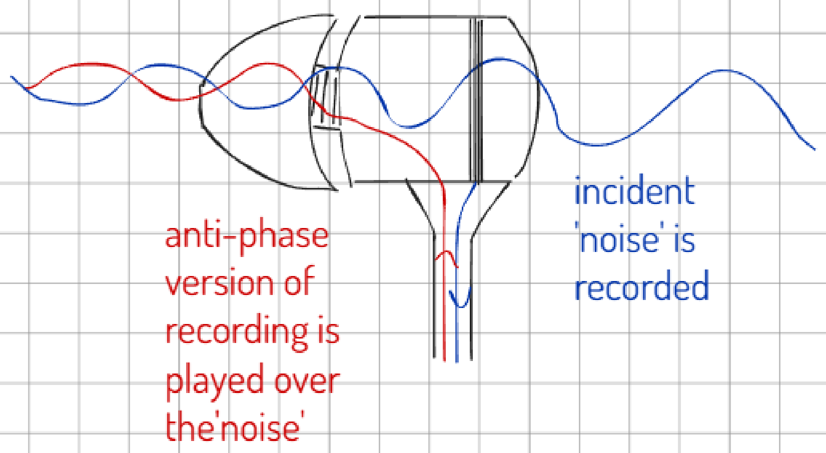
When the crests of two waves of EQUAL WAVELENGTH meet, the waves are said to be IN PHASE. If the waves have the same amplitude, the waves combine CONSTRUCTIVELY leading to a single crest with twice the amplitude.

When the crest of a wave meets the trough of another wave, they are in anti-phase (phase difference of 180° or π and combine DESTRUCTIVELY leading to a total amplitude of zero.





Superposition can only occur between two waves of the same type. (i.e. light and sound cannot superpose)

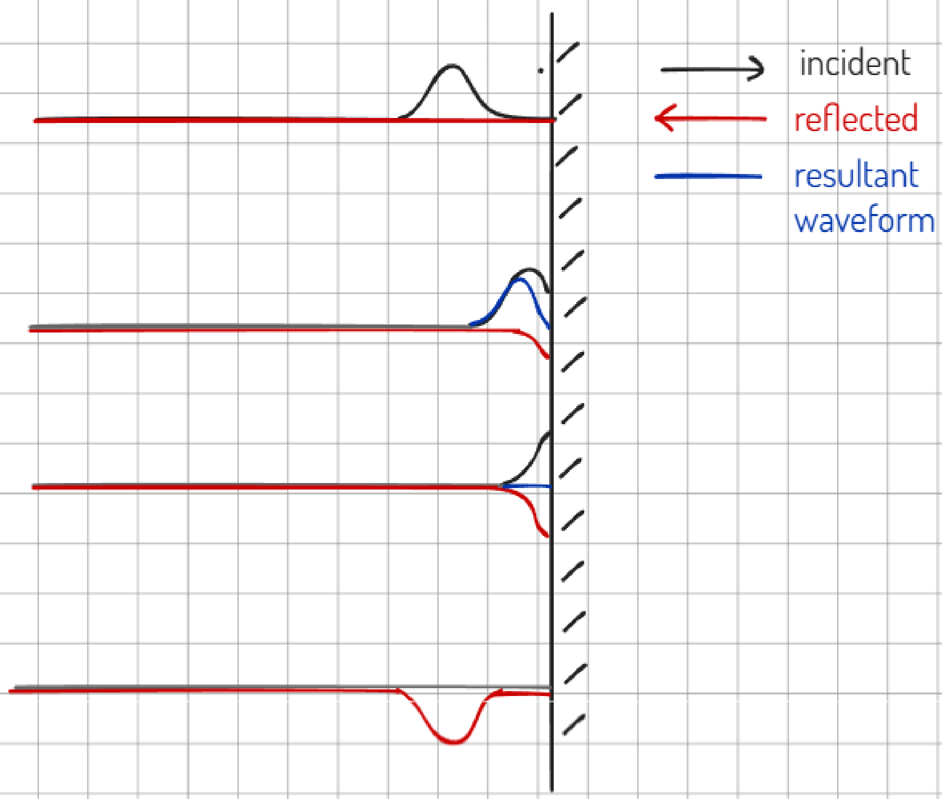


Active noise-cancellation can use the principle of superposition to minimise persistent background noise from your environment.

Reflection from a boundary

The point of the wave which is at the barrier does not move, so can have no resultant displacement.

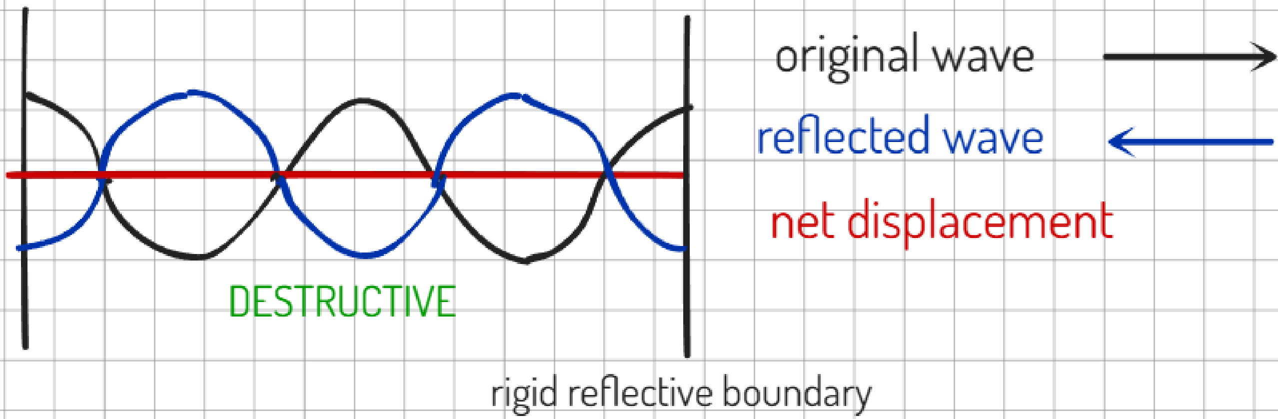
The reflected pulse must create an equal and opposite displacement, so that there is no resultant.



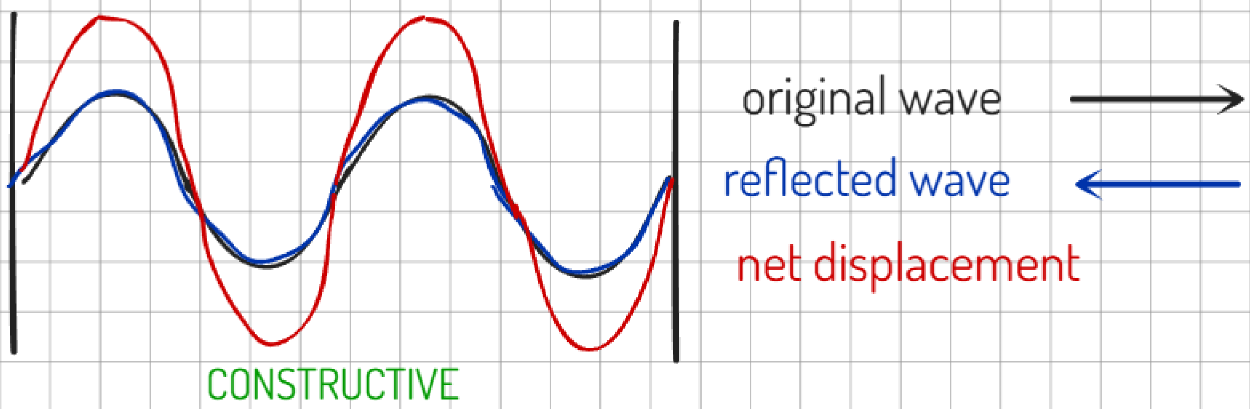
This leads to the reflected pulse being in anti-phase with the incident pulse.

Stationary Waves

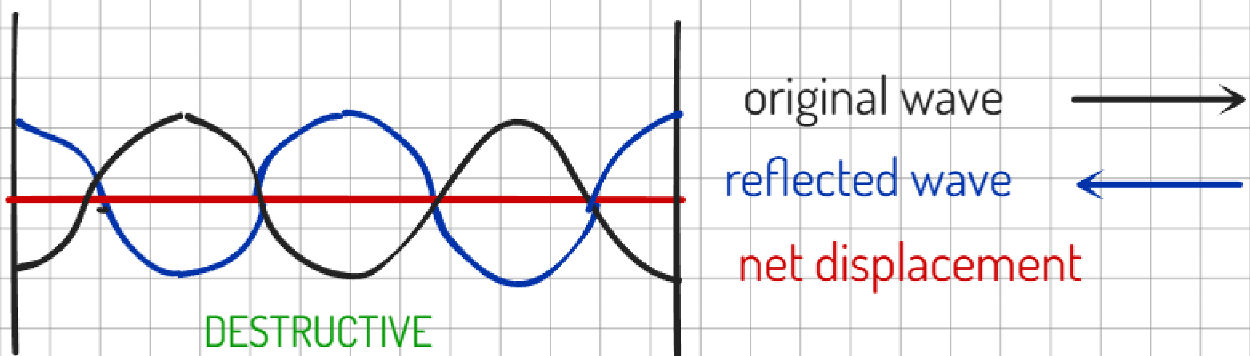
start of a cycle



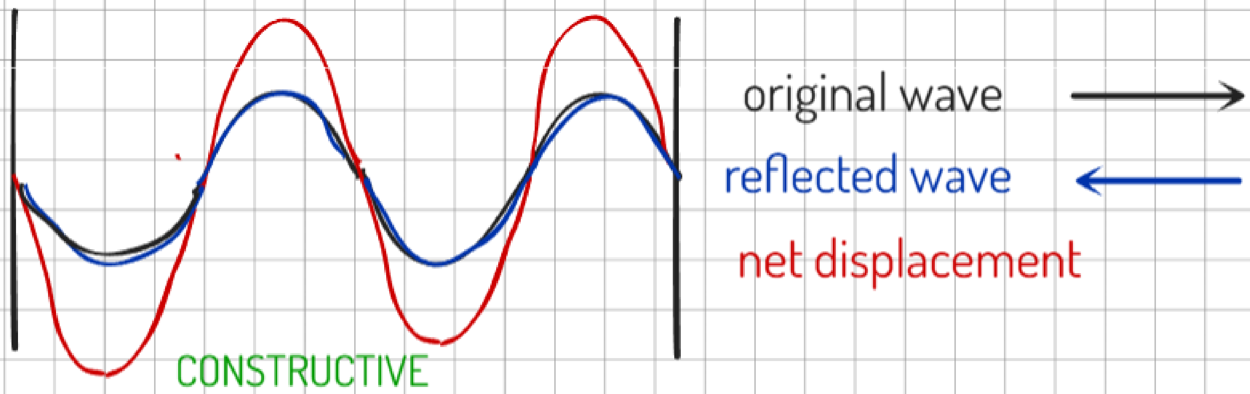
1/4 cycle later $\left(90^\circ, \frac{\pi}{2}\right)$



1/2 cycle later $(180^\circ, \pi)$



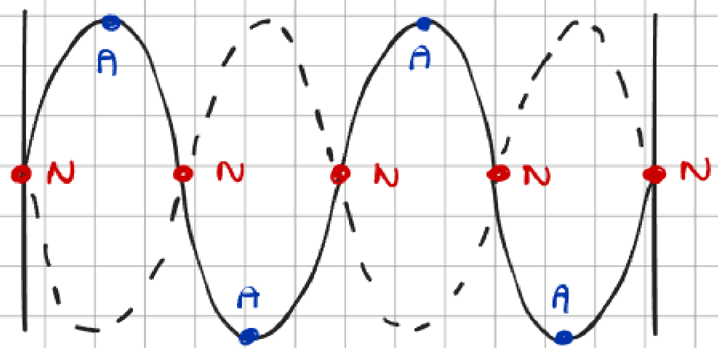
3/4 cycle later $\left(270^\circ, \frac{3\pi}{2}\right)$



A stationary (or standing) wave consists of a pattern of crests, which look like a wave, but the crests do not appear to travel. There is NO TRANSFER OF ENERGY.

The formation of a perfect stationary wave requires:
- Two travelling waves to be meet whilst moving in opposite directions. (This can be a single wave and its reflection)
- Those waves must have EQUAL SPEED, FREQUENCY and AMPLITUDE.

2 mark definition



Each point on a stationary wave alternates between the solid line and the dashed line, so neighbouring points have different amplitudes.

Points which always have ZERO amplitude are called NODES. The displacement at these points is always zero.

The ends of the stationary wave are ALWAYS NODES.

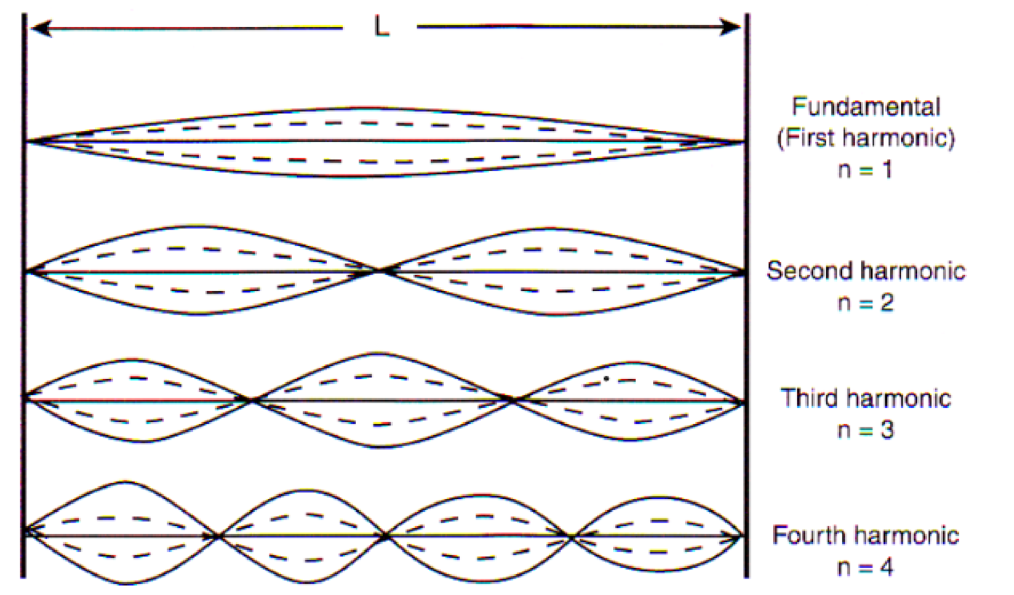
Points of MAXIMUM displacement are called ANTI-NODES.

Stationary vs Progressive

Stationary	Progressive
Points on a stationary wave oscillate: - with the same frequency - with different amplitude Points which lie between one node and the next have the SAME PHASE Points either side of a node are in ANTI-PHASE.	Points on a progressive wave oscillate: - with the same frequency - with the same amplitude - all neighbouring points have different phases Points separated by one wavelength have the SAME PHASE.

Harmonics

The end points of a stationary wave must both oscillate with zero displacement (i.e. they are nodes). As such, there are only CERTAIN WAVELENGTHS which can cause a stationary wave to form between two points which are a fixed distance apart.



Wavelength and frequency of harmonics.

For the simplest stationary wave (n=1) the wavelength, λ, and the length between the two end nodes, L, are related by:

$$L = \frac{\lambda}{2} \quad \text{OR} \quad \lambda = 2L$$

For the next wave (n=2): $L = \lambda$ OR $\lambda = \frac{2L}{2}$

And the next (n=3): $L = \frac{3}{2}\lambda$ OR $\lambda = \frac{2L}{3}$

And for the nth harmonic: $L = \frac{n}{2}\lambda$ OR $\lambda = \frac{2L}{n}$

made with ZITEBOARD

The frequency can be calculated using the wave equation:

$$c = f\lambda$$

Where c is the speed of the wave.

$$f = \frac{c}{\lambda} \qquad f_n = \frac{c}{\left(\frac{2L}{n}\right)} \qquad f_n = \frac{nc}{2L}$$

Given that: $f_1 = \frac{c}{2L}$ $\qquad f_n = nf_1$

Material Waves

The speed of a transverse wave on a string is given by: $c = \left(\frac{T}{\mu}\right)^{1/2}$

Where T is the tension in the string, and
μ is the mass per unit length of the string.

For the fundamental harmonic:

$$\lambda f = c$$

$$2Lf = \left(\frac{T}{\mu}\right)^{1/2}$$

$$\boxed{f = \frac{1}{2L}\left(\frac{T}{\mu}\right)^{1/2}}$$