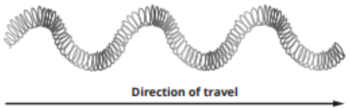
Module 4 Section 2: Waves

Progressive Waves

Progressive waves transfer **energy** without any transfer of matter. They can be transverse or longitudinal.

Transverse:

A transverse wave has **oscillations** at right angles to the direction of travel.



Longitudinal:

A longitudinal wave has **oscillations** parallel to the direction of travel.

Frequency, Speed and Intensity

Frequency and period are linked by this equation:

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

Wavespeed *(v)* can be calculated using this equation:

$$v = f\lambda$$

Speed can also be calculated using this equation:

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

You will need to be able to use both and at times calculate the speed with one equation to use in the other.

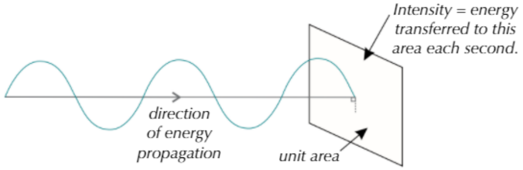


Figure 4: *A diagram demonstrating the intensity of a wave on a unit area.*

You can calculate intensity using the equation:

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

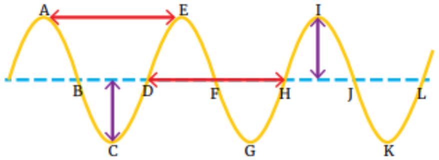
I = intensity in Wm^{-2}

P = power in W

A = area (at right angles to the wave's motion) in m^2

Wave Basics

A complete cycle of a wave is equivalent to 2π or 360°.



On the diagram above;

- Points A and E are **in phase** (phase difference = 2π) as they are at the **same point in their cycle at the same time**. Other pairs in phase include B and F, A and I, G and K…
- Points A and C are in **antiphase** (phase difference = π) as they are at **opposite points in their cycle at the same time**. Other pairs in antiphase include B and D, E and G…

The phase difference is normally expressed as fractions of π. For example, the phase difference between A and I is 4π and between E and F is ½π.

Wavelength (λ); the minimum distance between 2 points oscillating in phase.

Displacement; measured from the equilibrium position.

Amplitude (A); maximum value of displacement.

Frequency (f); the number of cycles per second.

Period (T); the time taken for 1 complete cycle.

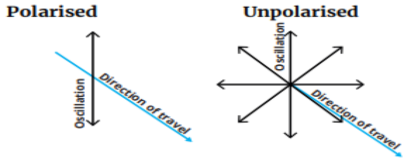
Electromagnetic waves

Type	Approximate Wavelength /m	Penetration	Uses
Radio waves	10^{-1} — 10^{6}	Pass through matter.	Radio transmissions.
Microwaves	10^{-3} — 10^{-1}	Mostly pass through matter, but cause some heating.	Radar. Microwave cooking. TV transmissions.
Infrared (IR)	7×10^{-7} — 10^{-3}	Mostly absorbed by matter, causing it to heat up.	Heat detectors. Night vision cameras. Remote controls. Optical fibres.
Visible light	4×10^{-7} — 7×10^{-7}	Absorbed by matter, causing some heating.	Human sight. Optical fibres.
Ultraviolet (UV)	10^{-8} — 4×10^{-7}	Absorbed by matter. Cause some ionisation.	Sunbeds. Security marks that show up under UV.
X-rays	10^{-13} — 10^{-8}	Mostly pass through matter, but cause ionisation as they pass.	To see damage to bones and teeth. Airport security scanners. To kill cancer cells.
Gamma rays	10^{-16} — 10^{-10}	Mostly pass through matter, but cause ionisation as they pass.	Irradiation of food. Sterilisation of medical instruments. To kill cancer cells.

Polarisation

A polarised wave is a transverse wave where the oscillations are all in the same direction.

A polaroid **allows oscillations in only one direction** to pass through, the other directions are absorbed. The light that has passed through is now polarised and if directed through another, rotating polaroid the intensity that passes through the second would vary between maximum, when the polaroids are parallel, and 0, when the polaroids are perpendicular.



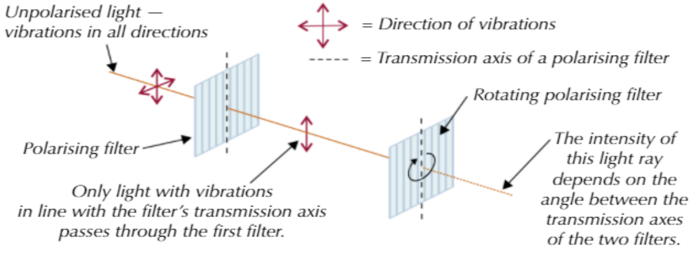


Figure 3: *An unpolarised light wave passing through two polarising filters.*

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Reflection

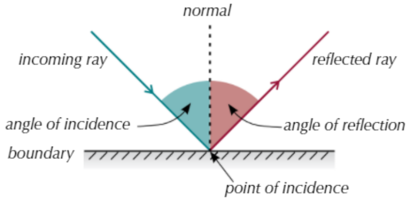


Figure 1: *A ray diagram to show the reflection of a wave at a boundary.*

A reflected wave always bounces off a boundary at the same angle to the normal as it hit the boundary. This is the law of reflection:

angle of incidence = angle of reflection

Reflection

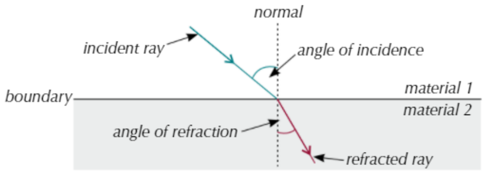


Figure 4: *A ray diagram showing the refraction of a wave as it moves from one material into another.*

You can tell if the wave is speeding up or slowing down by the way it bends towards or away from the normal.

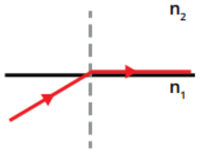
- If the ray bends towards the normal — it is slowing down.
- If the ray bends away from the normal — the wave is speeding up.

Critical Angle

When light travels **towards a medium with a lower refractive index** the ray bends away from the normal.

If the angle of incidence is increased to the point that the ray bends along the boundary, **angle of refraction = 90°**, it is known as the critical angle.

It can be calculated using this equation;



$$n_1 sin\theta_C = n_2$$

Refractive Index and Snell's Law

When waves travel from one medium to another its speed changes. The speed in one medium compared to the speed in a vacuum can be calculated using the **refractive index, n**.

$$n = \frac{c}{v}$$

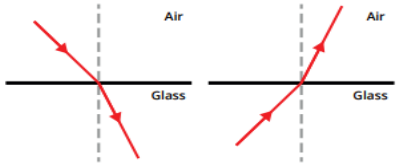
As c, is constant we can compare one medium with another to calculate the speed when light travels across a boundary.

$$n_1 v_1 = n_2 v_2$$

Remember, the refractive index of the initial medium n_1 and the n_2 is the medium it travels into.

Snell's law:

If the wave hits the boundary at an angle, this change in speed will cause a change in direction of the wave.

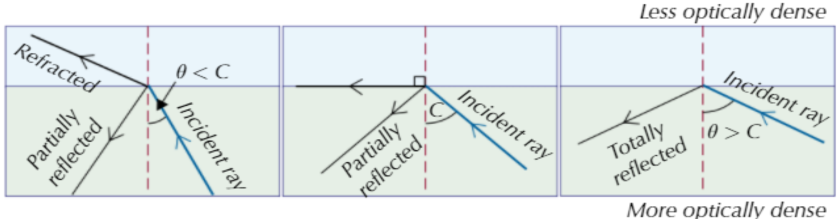


The angle of refraction can be calculated using **Snell's law**;

$$n_1 sin\theta_1 = n_2 sin\theta_2$$

Total Internal Reflection

At angles of incidence greater than the critical angle, refraction can't happen. That means all the light is reflected back into the material. This effect is called **total internal reflection** (**TIR**) — see Figures 6 and 7.



Superposition and Interference

Superposition occurs when two waves meet. If this happens then the total displacement is the vector sum of their individual displacements at that point.

Constructive interference (wave A and B in phase)

If wave A and B occupy the same space, superposition will cause constructive interference and will create a wave with the amplitude of A+B.

Destructive interference (wave A and B in antiphase)

If wave A and B occupy the same space, superposition will cause destructive interference and will cause the amplitude to be 0.