AQA Physics A-level

Topic 3: Waves

Key Points

Key Terms

Displacement: The distance and direction of a particle from the equilibrium position.

Amplitude: Maximum displacement of a vibrating particle.

Wavelength: Shortest distance between two particles in phase.

Frequency: Number of wave cycles occurring each second.

Wave speed: Distance travelled by a wave each second.

Phase difference: Measured in degrees or radians, the amount by which one wave lags behind another wave.

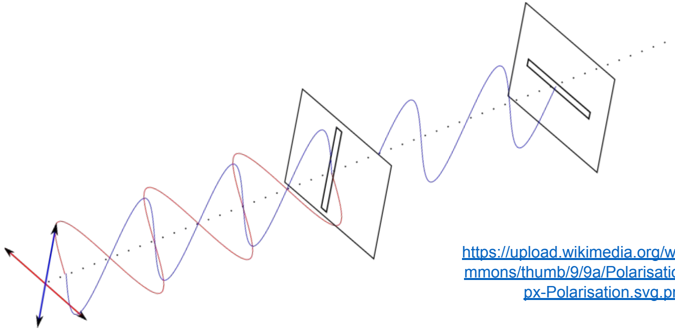
Path difference: Measured in metres, the difference in the lengths of two waves.

Progressive: Waves whose oscillations travel and transfer energy.

Longitudinal and Transverse Waves

Transverse: Waves whose oscillations are perpendicular to the direction of propagation of energy e.g. electromagnetic waves

Longitudinal: Waves whose oscillations are parallel to the direction of propagation of energy. They consist of compressions and rarefactions e.g. sound waves



https://upload.wikimedia.org/wikipedia/commons/thumb/9/9a/Polarisation.svg/800px-Polarisation.svg.png

Only transverse waves can be **polarised**, which means all the waves are oscillating in the same plane. The discovery of polarised light helped prove that light was a transverse wave.

Glare and Cameras

Polarisation can be used in things such as polaroid sunglasses to reduce glare or in a camera to enhance the image.

Radio Signals

TV and radio signals are polarised by the direction of the rods on the transmitting aerial. To receive these signals well, you must ensure the receiving aerial and the waves are in the same plane.

Superposition and Interference

The point where waves meet is called **superposition**. The total **displacement** at a point is equal to the sum of the individual displacements at that point. You should know that waves:

- **Constructively** interfere where they are in phase with each other
- **Destructively** interfere where they are in antiphase with each other (180 degrees out of phase).

This can be explained in terms of **peaks** and **troughs**. When the waves are **in phase**, two peaks or two troughs will **constructively** interfere with each resulting in a 'double' peak or trough being created. When waves are in **antiphase**, a peak will meet a trough and result in **destructive** interference, which is where they **cancel** each other out and produce a minimum point.

Stationary Waves

A **stationary wave** is one that **stores energy** instead of transferring it from one point to another. You need to know the process of a stationary wave being formed on a string that is fixed at both ends:

1. A wave is generated at one end of the string and travels down it
2. At the other end , this wave is **reflected** and travels back in the **opposite** direction
3. The **frequency** of wave generation and the **length** of the string are such that the next wave generated meets this reflected wave and undergoes **superposition**
4. At places where the two waves are **in phase**, they undergo **constructive** interference and form a **maximum** point known as an **antinode**
5. At places where the two waves are in **antiphase**, they undergo **destructive** interference and form a **minimum** point known as an **node**

Waves on a String

The **fundamental** frequency of a wave on a string can be found from the following equation:

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

$$T = mg$$

$$\mu = \frac{M}{l}$$

From the equation, we can tell that raising the tension or shortening the length of a given string increases the **pitch**.

Double Slit Interference

Young's Double Slit Experiment

When two double slits are illuminated, the two slits act as coherent wave sources. Coherence means the waves have the same frequency with a constant phase difference. The light diffracts at the slits and the two waves superpose, forming an interference pattern. This is because a combination of constructive and destructive interference occurs.

Double Slit Formula

$$w = \frac{\lambda D}{s}$$

$$fringe\ spacing = \frac{wavelength \times distance\ from\ the\ screen}{distance\ between\ slits}$$

Evidence for the Wave Nature of EM Radiation

Diffraction and interference are purely wave properties, so this experiment showed that EM radiation has wave properties.

Diffraction

Diffraction is the **spreading** out of waves when they pass through a gap or over an edge. Diffraction depends on the **gap width** and the wavelength of the wave. If the gap is:

- A lot bigger than the wavelength, the diffraction is unnoticeable
- A bit wider than the wavelength, the diffraction is noticeable
- The same size as the wavelength, the diffraction is most noticeable
- Smaller than the wavelength, most of the waves are reflected

One consequence of diffraction is observed when light is shone through a diffraction grating:

- Monochromatic light will display a diffraction pattern.
- White light creates a **spectra** of colours.

Intensity is a measure of the **power** delivered per **unit area**.
Increasing the slit width creates a intense but **narrow** central maximum.
Decreasing the slit width creates a **wider** and less intense central maximum.

Refraction

Refraction is when a wave changes **speed** when it crosses into a new medium:

- If the medium is **more** optically dense, the wave will **slow down** and bend towards the normal

$$\theta_i > \theta_r$$

- If the medium is **less** optically dense, the wave will **speed up** and bend away from the normal

$$\theta_i < \theta_r$$

A measure of how optically dense a medium is, is the material's **refractive index**:

The **absolute refractive index** of a material measures how much it slows down light. It is a ratio.

$$n = \frac{c}{c_1}$$

The **relative refractive index** at the boundary between two materials is a ratio of the speed of light in the two materials.

$${}_1n_2 = \frac{c_1}{c_2}$$

Snell's Law

It is possible to calculate the **refractive index** from the **angles of incidence** and **refraction**, or to predict the angles of refraction for a given angle of incidence, using Snell's law.

Snell's law states that:

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

This can then be used to form the equation used to calculate the **critical angle** for a given material. The critical angle is the angle for which the refracted ray just passes along the boundary line and beyond which all of the wave will be reflected.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$
$$n_1 \sin \theta_1 = n_2 \sin 90$$
$$n_1 \sin \theta_1 = n_2 \times 1$$

$$\sin \theta_1 = \frac{n_2}{n_1}$$

Total Internal Reflection

Light entering a less dense material refracts away from the normal. The greater the angle of incidence, the greater the angle of refraction. Eventually it will increase to such an angle that it refracts along the boundary, called the critical angle. At this point the angle of refraction is 90°.

However if the angle of incidence is greater than the critical angle, then it is reflected back inside.

For TIR to occur:
The light must travel from a more optically dense to a less optically dense medium.
The angle of incidence of the light ray must exceed the critical angle of the interface.

Derivation of the Critical Angle:

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

$$n_1 \sin \theta_1 = n_2 \sin 90$$

$$n_1 \sin \theta_1 = n_2 \times 1$$

$$\sin \theta_1 = \frac{n_2}{n_1}$$

Optical Fibres

Optical fibres make use of total internal reflection to **transfer signals**. They are used for several purposes including:

- High-speed internet cables
- Medical imaging as endoscopes
- Engineering inspections to view hard to reach areas

The type of optical fibre you need to know about are **step-index optical fibres.** These consist of two main parts:

1. A **core** made of a **high-refractive index** material
2. **Cladding** made of a **low-refractive index** material

The difference in refractive indexes is due to the fact that TIR can **only** occur when a wave passes from a high-refractive index into a lower one.

Cladding

The cladding of an optical fibre serves a number of purposes that you must be aware of:

- It provides **tensile strength** to the optical fibre so that it doesn't break when twisted
- It prevents information from **transferring** between different cores in a bundle
- Prevents the core from being **damaged**, for example by getting scratched

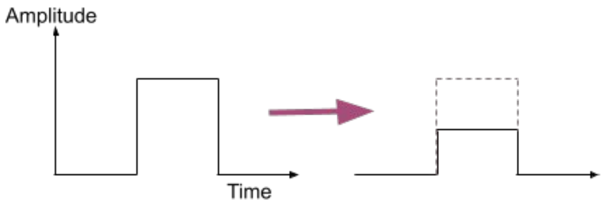
There are two main reasons that you should know as to why the core must be protected from **scratches**:

1. **Water** can get into the scratch, which will increase the refractive index to a level that may be higher than the core, and therefore prevent TIR from occurring - instead the signal will exit the core
2. The scratch may alter the angle at which the signal interacts with the core's boundary such that the **angle** is lowered below the **critical angle** - this once again will prevent TIR occuring and cause **signal loss** outside of the fibre

Absorption

Signal transfer through optical fibre is susceptible to two pulse changing phenomenon, the first being absorption.

Absorption is where **energy** is lost as the signal is transferred. It results in a **loss of amplitude** for the signal, but doesn't affect the **frequency**.

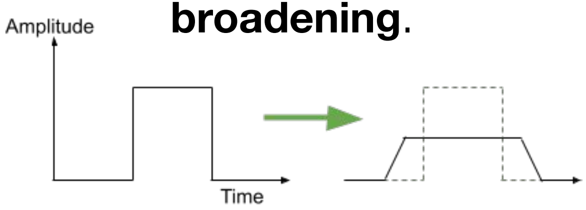


The effects of absorption can be reduced by using an **optical fibre repeater** to boost the signal at periodic positions along the fibre.

Dispersion

The second pulse changing phenomenon that can occur in optical fibre signal transfer is dispersion. **Dispersion** comes in two main types:

1. **Modal dispersion** is a consequence of the beams entering the fibre at **different angles**, which results in each beam undergoing TIR a different number of times and so means that each beam reaches the end at a slightly different time. This results in **pulse broadening**.



2. **Material dispersion** is a consequence of the signal containing several **different wavelengths**, each of which travels at slightly different speeds in the core. This again results in pulse broadening.