# 4 Waves

## 4.1 Waves and Vibrations

- **Mechanical waves** are vibrations which pass through a substance.
- **Electromagnetic waves** are oscillating electric and magnetic fields that progress through space without the need for a substance.
- **Longitudinal waves** are waves in which the direction of vibration of the particles are parallel to the direction in which the wave travels.
  - Sound waves
  - Primary seismic waves
- **Transverse waves** are waves in which the direction of vibration is perpendicular to the direction in which the wave travels.
  - Electromagnetic waves

**Polarisation**

**Plane-polarised waves** are transverse waves which the vibrations stay in one plane only. If the vibrations change from one plane to another, the waves are **unpolarised**.

Longitudinal waves cannot be polarised.

A **polaroid filter** only allow through light which vibrate in a certain direction.

- If unpolarised light is passed through a polaroid filter, the transmitted light is polarised.
- If unpolarised light is passed through **two polaroid filters**, the intensity of transmitted light changes if one polaroid is turned relative to the other.
  - The filters are **cross** when the transmitted intensity is a minimum.
  - Polarised light from the first filter cannot pass through the second filter.

Light is part of the spectrum of **electromagnetic waves**, the plane of polarisation is defined as the plane which the electric field vibrates.

## 4.2 Measuring Waves

- The **displacement** of a vibrating particle is its distance and direction from its **equilibrium position**.
- The **amplitude** of a wave its the **maximum displacement** of a particle.

- The **wavelength** of a wave is the least distance between two adjacent vibrating particles with the same displacement and velocity at the same time.
- One complete **cycle** of a wave is from maximum displacement to the next maximum displacement.
- The **period** of a wave is the time for one complete wave to pass a fixed point.
- The **frequency** of a wave is the number of cycles of vibration of a particle per second. Or the number of complete waves passing a point per second.

$$\text{Time period } T = \frac{1}{f}$$
$$\text{Wave speed } c = f\lambda$$

- The **phase** of a vibrating particle at a certain time is the fraction of a cycle it has completed since the start of the cycle.
- The **phase difference** between two particles vibrating at the same frequency is the fraction of a cycle between the vibrations of the two particles.

$$\text{phase difference} = \frac{2\pi d}{\lambda}$$

## 4.3 Wave Properties 1

A **ripple tank** can be used to study wave properties.

- **Wavefronts** are lines of constant phase.
- The direction in which a wave travels is at right angles to the wavefront.

#### Reflection

When a light ray is directed at a **plane mirror**, the angle between the incident ray and the mirror is equal to the angle between the reflected ray and the mirror.

#### Refraction

When waves pass across a boundary at which the **wave speed changes**, the **wavelength also changes**. If the wavefronts approach at an angle to the boundary, they change direction as well as changing speed.

Refraction of light is observed when a light ray is directed into a glass block at an angle.

### Diffraction

Diffraction occurs when **waves spread out after passing through a gap**.

- The narrower the gap, the more the waves spread out.
- The longer the wavelength, the more the waves spread out.

## 4.4 Wave Properties 2

The **principle of superposition** states that when two waves meet, the total displacement at a point is equal to the sum of the individual displacements at that point.

Where a crest meets a trough of the same amplitude, the **resultant displacement is zero**. If they are not the same amplitude, the resultant is called a **minimum**.

### Water Waves in a Ripple Tank

A **vibrating dipper** on a water surface sends out circular waves. The waves pass trough each continuously.

- **Points of cancellation** are created where a crest from one dipper meets a trough from the other dipper - these points are seen as **gaps in the wavefronts**.
- **Points of reinforcement** are created where a crest from one dipper meets a crest from the other dipper.

### Wave Properties with Microwaves

A microwave transmitter and receiver can be used to demonstrate reflection, refraction, diffraction, interference and polarisation of microwaves.

- Place the receiver in the path of the **microwave beam** and move the receiver gradually away from the transmitter - microwaves **become weaker as they travel** away from the transmitter.
- Place a **metal plate** between the transmitter and the receiver - microwaves **cannot pass through metal**.
- Make a **narrow slit** with two metal plates - **microwaves have been diffracted** as they pass through the slit.
  - If the slit is made wider, less diffraction occurs.
- Make a **pair of slits** with a narrow metal plate and two plates, use the receiver to find **points of cancellation and reinforcement**.

## 4.5 Stationary and Progressive Waves

Stationary waves are formed when two progressive waves pass through each other.

- Use a **string in tension** by fixing both ends.
- Make the middle part vibrate - progressive waves travel towards each end, reflect at the ends, and pass through each other.

The **fundamental mode of vibration** consists of a single loop.

- **Nodes** at either end - point of no displacement.
- **Antinodes** between the nodes - point of maximum amplitude.

$$\text{Distance between adjacent nodes} = \frac{1}{2}\lambda$$

If the frequency is raised, the pattern disappears and a new pattern is observed with **two equal loops** along the rope.

**Stationary waves that vibrate freely do not transfer energy to their surroundings.**

The phase difference between two vibrating particles is

- 0 if to particles are separated by an **even number of nodes**.
- $\pi$ rad if separated by an **odd number of nodes**.

## 4.6 More about Stationary Waves on Strings

- The **first harmonic pattern of vibration** is seen at the lowest possible frequency that gives a pattern. $\lambda_1 = 2L$
- The **second harmonic** has a node in the middle. $\lambda_2 = L$ and $f_2 = 2f_1$
- The **third harmonic** have nodes with distance of $L/3$ from either ends. $\lambda_3 = 2\lambda_1/3$ and $f_3 = 3f_1$.

The progressive wave **reverses its phase** when it reflects at the fixed end and travel back along the string.

- When it reaches the vibrator, it reflects and reverses phase again.
- If this wave is **reinforced by a wave created by the vibrator**, the amplitude of the wave is increased.

The **key condition** for a stationary wave to form is that the time taken for a wave to travel along the string and back should be **equal to the time taken for a whole number of cycles** of the vibrator.

The first harmonic frequency is given by

$$f_1 = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$$

## 4.7 Using an Oscilloscope

The displacement of the spot is proportional to the applied pd.

- The **x-scale** is usually calibrated in **milliseconds per division**.
- The **y-sensitivity** is usually calibrated in **volts per division**.