4 Waves

4.1 Waves and Vibrations

Waves that pass through a substance are vibrations that pass through a substance, they are often referred to as **mechanical waves**. When waves progress through a substance, the particles of the substance vibrate in a certain way which makes nearby particles vibrate in the same way and so on.

- Sound waves
- Seismic waves
- Waves on strings

Electromagnetic waves are oscillating electric and magnetic fields that progress through space without the need for a substance - the vibrating **electric field** generates a vibrating **magnetic field**, which generates a vibrating electric field further away, and so on.

- Radio waves
- Microwaves
- Infrared radiation
- Light
- Ultraviolet radiation
- X-rays
- Gamma radiation

Longitudinal waves are waves which the direction of vibration of the particles is parallel to the direction in which the wave travels.

- Sound waves
- Primary seismic waves

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

- Electromagnetic waves
- Secondary seismic waves
- Waves on a string

Polarisation

Transverse waves are **plane-polarised** if the vibrations stay in one plane only. Otherwise if vibrations changes from one plane to another, then the waves are **unpolarised**.

Longitudinal waves cannot be polarised.

- If **unpolarised light** (e.g. light from a filament lamp) passes through a **polaroid filter**, the transmitted light is polarised.
  - The filter only allow through light which vibrate in a certain direction.
  - According to the alignment of its molecules.
- If unpolarised light is passed through **two polaroid filters**, the transmitted **light intensity** changes if one polaroid is turned relative to the other one.
  - The filters are said to be **cross** when the transmitted intensity is a minimum.
  - At this position, the polarised light from the first filter cannot pass through the second filter - as the alignment of the second filter is $90°$ to the first.

The **plane of polarisation** of an electromagnetic wave is defined as the plane in which the electric field oscillates.

Polaroid sunglasses reduces the glare of light reflected by water or glass.

- Light reflected by water or glass is **polarised**.
- The intensity of reflected light is reduced when it passes through the polaroid sunglasses.

4.2 Measuring Waves

- The **displacement** of a vibrating particle is its distance and direction from its **equilibrium position**.
- The **amplitude** of a wave is the **maximum displacement** of a vibrating particle.
  - Height of a wave crest for transverse waves.
- 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 complete waves passing a point per second.
  - Or the **number of cycles of vibration** of a particle 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 <u>fraction of a cycle it has completed</u> since the start of the cycle.
- The **phase difference** between two particles vibrating <u>at the same frequency</u> 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 - a shallow transparent tray of water with **sloping sides**, which prevent waves reflecting off the sides of tank.

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

Reflection

Straight waves directed at a certain angle to a hard surface **reflect off at the same angle** - the angle between the reflected wavefront and the surface is the same as the angle between the incident wavefront and the surface.

Also observed 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 **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.

- Water waves in a ripple tank refracts when they pass across a boundary from deep to shallow water. Because they move more slowly in shallow water therefore changes direction.
- **Refraction of light** is observed when a light ray is directed into a glass block at an angle. The light ray changes direction when it crosses the glass boundary because it travels more slowly in glass than in air.

Diffraction

Diffraction occurs when waves **spread out after passing through a gap** or round an obstacle.

Can be seen in a ripple tank when straight waves are directed at a gap.

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

Consider each point on a wavefront as a **secondary emitter of wavelets**

- The wavelets from the points along a wavefront **travels only in the direction which the wave is travelling**.
- The combine to **form new wavefronts** beyond the gap.

4.4 Wave Properties 2

When two waves meet, they combine for an instant before the move apart, this combining effect is known as **superposition**.

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 a point.

- When two crests meet, the two waves reinforce each other and creates a **supercrest**.
- When two troughs meet, the two waves reinforce each other and creates a **supertrough**.
- When a crest meets a trough of the same amplitude, the **resultant displacement is zero** - the two waves cancel each other out.
  - If they are not the same amplitude, the result is called a **minimum**.

Water Waves in a Ripple Tank

Vibrating dippers on a water surface sends out circular waves, two sets of circular waves passes through each other continuously.

- **Points of cancellation** are created where a crest meets a trough. These points of cancellation are seen as **gaps in the wavefront**.
- **Points of reinforcement** are created where two crests or two troughs meet.

Waves continuously passing through each other at **constant frequency** and at a **constant phase difference** creates **points of cancellation and reinforcement** at fixed positions. This effect is know as **interference**.

- **Coherent** sources of waves produce an interference pattern where they overlap, because they vibrate at the **same frequency** and a **constant phase difference**.

Wave Properties with Microwaves

A microwave receiver and transmitter can be used to demonstrate wave properties.

1. Place the receiver in the path of the microwave beam from the transmitter, and move the receiver gradually away from the transmitter.
   - The **receiver signal decreases with distance** from the transmitter.
   - This shows the microwaves **become weaker** as they travel away from the transmitter.
2. Place a **metal plate** between the transmitter and the receiver.
   - This shows that microwaves cannot pass through metal.
3. Use two metal plates to make a **narrow slit**.
   - It can be shown that if the slit is made wider, less diffraction occurs.
4. Use a narrow metal plate and two additional plates to make **a pair of slits**.
   - Use the receiver to find **points of cancellation and reinforcement** where the microwaves from the two slits overlap.

4.5 Stationary and Progressive Waves

A stationary wave is formed when **two progressive waves pass through each other**.

- This can be achieved on a string **in tension** by **fixing both ends** and making the middle part vibrate.
- Progressive waves travel towards each other - reflected at the ends, then **pass through each other**.

A string's **fundamental mode of vibration**, or **first harmonic** is the simplest stationary wave pattern on a string.

- Consists of a **single loop**.
- Has a **node** at either end (points of no displacement)
- Has an **antinode** midway between the nodes (point of maximum displacement)

For this pattern to occur

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

If the frequency of the waves sent along the rope is raised, the first harmonic pattern disappears and a **new pattern with two equal loops** is observed on the rope.

Stationary waves that vibrate freely **do not transfer energy** to their surroundings, because the **amplitude of vibration is zero** at the nodes, so there is no energy at the nodes.

- The amplitude of vibration is a maximum at the antinodes, so there is maximum energy at the antinodes.
- Because the nodes and antinodes are at <u>fixed positions</u>, no energy is transferred in a freely vibrating stationary wave pattern.

Explanation of Stationary Waves

- When two progressive waves in opposite directions are **in phase**, they **reinforce each other** to produce a large wave.
- A quarter of a cycle later, the two waves moved one-quarter wavelength in opposite directions, they are now in **antiphase** so they cancel each other.
- After a further quarter cycle, they are back in phase, the resultant is again a large wave.

In general, in any stationary wave pattern.

- Amplitude of a vibrating partial in a stationary wave pattern **varies with position** from zero at a node to **maximum amplitude** at an antinode.
- Phase difference between two particles.
  - Zero if separated by an even number of nodes.
  - 180° if separated by an odd number of nodes.

Examples of Stationary Waves

Sound resonances at certain frequencies in an **air-filled pipe** closed at one end. These **resonance frequencies** occur when there is an antinode at an open end and a node at the other end.

Microwaves from a transmitter are directed normally at a metal plate, which reflects the microwaves back to wards the transmitter. The reflected waves and the waves from the transmitter forms a stationary waves.

4.6 More about Stationary Waves on Strings

The **controlled arrangement for producing stationary waves** consist of

- A string tired at one end to a **mechanical vibrator**.
- The other end **passes over a pulley** and **supports a weight**, which keeps the tension in the string constant.

1. The **first harmonic wavelength** is given by $\lambda_1 = 2L$, the **first harmonic frequency** is given by $f_1 = c/2L$
2. The **second harmonic** has a wavelength given by $\lambda_2 = L$, the **frequency** is given by $f_2 = 2f_1$
3. The **third harmonic** has a wavelength given by $\lambda_3 = 2L/3$, and **frequency** is given by $f_3 = 3f_1$.

Explanation of Stationary Wave Pattern on a String

1. When a **progressive wave** is sent out by the vibrator, the crest **reverses its phase** when it reflects at the **fixed end** and travel back along the string as a **trough**.
2. When it reaches the vibrator, it reflects and **reverses phase again**, travelling away from the vibrator as a crest.

If this crest is reinforced by a crest created by the vibrator, the **amplitude of the wave is increased** and a stationary wave is formed.

The **key condition** 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. Which is

$$\frac{2L}{c} = \frac{m}{f} \qquad \text{where } m \text{ is a whole number}$$

Pitch

The pitch of a note corresponds to frequency - the pitch of a node from a **stretched string** can be altered by

- Raising the **tension** or shortening its **length** to increase the pitch.
- Lowering the **tension** or increasing the **length** to lower the pitch.

A vibrating string can be tuned to be the same pitch as a tuning fork. With difference

- Sound from a vibrating stings **includes all harmonic frequencies**
- Whereas a tuning for vibrates only at a **single frequency**.

The **first harmonic frequency** is given by

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