Waves

Introduction

A **wave** is a disturbance that transfers **energy and momentum** from one point to another without the actual transfer of matter. Waves are found in many forms, such as sound waves, water waves, light waves, and radio waves. This chapter explains the basic properties of waves, types of waves, wave motion, and important terms such as wavelength, frequency, time period, and wave velocity.

Wave Motion

Definition

Wave motion is the propagation of a disturbance through a medium or space. As a wave travels, the particles of the medium oscillate about their mean positions.

A wave transfers **energy**, but the particles of the medium do not travel along with the wave.

Types of Waves

Mechanical Waves

Mechanical waves require a material medium for their propagation.

Examples:

- Sound waves
- Water waves
- Waves on a stretched string

Electromagnetic Waves

Electromagnetic waves do not require a material medium and can travel through vacuum.

Examples:

- Light waves
- Radio waves
- X-rays

Transverse and Longitudinal Waves

Transverse Waves

In a **transverse wave**, particles of the medium vibrate **perpendicular** to the direction of wave propagation.

Examples:

- Waves on a stretched string
- Electromagnetic waves

They have **crests and troughs**.

Longitudinal Waves

In a **longitudinal wave**, particles vibrate **parallel** to the direction of wave propagation.

Examples:

- Sound waves in air

They have **compressions and rarefactions**.

Important Terms

Wavelength

Wavelength (λ) is the distance between two consecutive particles in the same phase of vibration.

For transverse waves, it is the distance between two consecutive crests or troughs.

SI Unit: **metre (m)**

Frequency

Frequency (ν) is the number of complete oscillations made by a particle per second.

SI Unit: **Hertz (Hz)**

Time Period

Time Period (T) is the time taken to complete one oscillation.

$T = 1/\nu$

Amplitude

Amplitude (A) is the maximum displacement of a particle from its mean position.

Greater amplitude means greater energy carried by the wave.

Wave Velocity

Definition

Wave velocity is the speed at which a wave disturbance travels through a medium.

Formula:

$$v = \nu\lambda$$

where:

- **v** = Wave velocity
- **ν** = Frequency
- **λ** = Wavelength

Since **$\nu = 1/T$**:

$$v = \lambda/T$$

The velocity of a wave depends on the properties of the medium.

Principle of Superposition

Statement

The **Principle of Superposition** states that when two or more waves overlap, the resultant displacement at any point is equal to the algebraic or vector sum of the individual displacements.

This principle explains:

- Interference
- Beats
- Standing Waves

Progressive Waves

Definition

A **progressive wave** is a wave that travels continuously from one point to another, transferring energy through the medium.

Characteristics:

- It transfers energy.
- Particles oscillate about their mean positions.
- All particles have the same frequency.
- Particles generally have different phases.

Standing Waves

Definition

A **standing wave** is formed when two identical waves travel in opposite directions and superpose.

It consists of:

- **Nodes** – Points where displacement is always zero.
- **Antinodes** – Points where displacement is maximum.

Standing waves do not transfer energy from one place to another.

Sound Waves

Nature of Sound

Sound is a **mechanical longitudinal wave** that requires a medium for propagation.

Sound cannot travel through vacuum.

The speed of sound depends on the properties of the medium and generally increases from gases to liquids to solids.

Beats

Definition

Beats are periodic variations in sound intensity produced when two sound waves of slightly different frequencies interfere.

Beat frequency:

$\nu beat = |\nu_1 - \nu_2|$

Beats are used to compare frequencies and tune musical instruments.

Doppler Effect

Definition

The **Doppler Effect** is the apparent change in the frequency of a wave due to the relative motion between the source and the observer.

Examples:

- Change in pitch of a passing siren
- Measuring speeds of stars
- Radar speed measurement

Applications of Waves

Importance

Waves are used in:

- Communication
- Radio and Television
- Mobile Networks
- Medical Imaging
- Sonography
- Music
- Radar and Navigation
- Earthquake Detection

Key Points

- Waves transfer energy without transferring matter.
- Mechanical waves require a medium.
- Electromagnetic waves can travel through vacuum.
- Transverse waves have crests and troughs.
- Longitudinal waves have compressions and rarefactions.
- The wave equation is $\mathbf{v = \nu\lambda}$.
- Standing waves contain nodes and antinodes.
- Beats are produced by two waves of slightly different frequencies.
- The Doppler Effect is the apparent change in frequency due to relative motion.

Chapter Summary

This chapter explains wave motion and the different types of waves. It covers mechanical and electromagnetic waves, transverse and longitudinal waves, wavelength, frequency, time period, amplitude, wave velocity, superposition, progressive and standing waves, sound waves, beats, and the

Doppler Effect. Waves play an important role in communication, technology, medicine, music, and many natural phenomena.