Chapter 3: Waves

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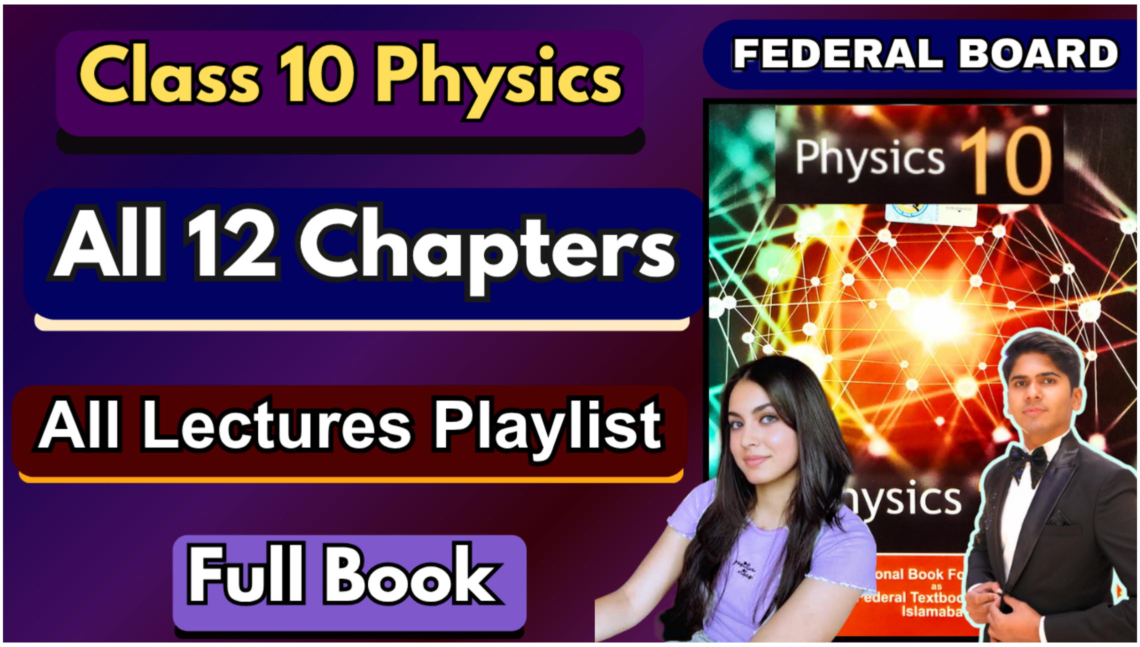

A wave is a repeating disturbance or vibration that moves through a medium (or space), transferring energy from one location to another without the physical transfer of matter. Waves are fundamental to understanding natural phenomena such as sound, light, water motion, and even earthquakes.

12.1 Wave Motion

Wave motion occurs when energy is transmitted from one point to another by the oscillations of particles or fields. Depending on the type of wave, particles of the medium may move perpendicularly or parallel to the direction of propagation.

12.1.1 Water Waves

Water waves are generated when a disturbance, such as dropping a stone into water, creates ripples that travel outward in circular patterns. The particles of water move up and down in place, while energy moves across the surface. This illustrates that waves transfer energy but not matter.

12.1.2 Sound Waves

Sound waves are **longitudinal waves** caused by vibrations of objects like vocal cords. These vibrations cause compressions and rarefactions of air molecules that propagate through the medium. Although air molecules oscillate, they do not travel with the wave; only energy is transferred.

12.1.3 Electromagnetic Waves

Electromagnetic (EM) waves consist of oscillating electric and magnetic fields at right angles to each other and to the direction of wave propagation. They do not require a medium to travel and can travel through a vacuum, such as the space between the sun and the Earth.

12.2 Classification of Waves

Mechanical Waves

- Mechanical waves require a physical medium (solid, liquid, or gas) for their propagation.
- They are caused by the vibration of particles of the medium.
- Examples: Sound waves, Water waves, Seismic waves, Waves in a string.

Types of Mechanical Waves:

1. **Longitudinal Waves**
2. **Transverse Waves**

Electromagnetic Waves (EM Waves)

- EM waves do not require any material medium for their transmission and can travel through a vacuum.
- They are produced by the vibration of electric and magnetic fields.
- Examples: Radio waves, Microwaves, Infrared, Visible light, Ultraviolet, X-rays, Gamma rays.

12.3 Transverse and Longitudinal Waves

Transverse Waves

In a transverse wave, the particles of the medium vibrate or oscillate **perpendicular** (at a 90° angle) to the direction of wave propagation.

- **Crest:** The highest point of a transverse wave.
- **Trough:** The lowest point of a transverse wave.
- **Amplitude:** The maximum displacement from the equilibrium position.
- **Wavelength (λ):** The distance between two consecutive crests or troughs.

Examples: Water waves, Waves in a string, Electromagnetic waves.

Longitudinal Waves

In a longitudinal wave, the particles of the medium vibrate or oscillate **parallel** to the direction of wave propagation. They travel as a series of compressions and rarefactions.

- **Compression:** A region where the particles are crowded together, resulting in high density and pressure.
- **Rarefaction:** A region where the particles are spread apart, resulting in low density and pressure.
- **Wavelength (λ):** The distance between two consecutive compressions or rarefactions.

Example: Sound waves.

12.4 Wave Characteristics

- **Amplitude (A):** The maximum displacement of a vibrating particle from its equilibrium or mean position. The energy of the wave is proportional to the square of its amplitude (Energy $\propto A^2$).
- **Wavelength (λ):** The shortest distance between two points in a wave that are in phase (e.g., two consecutive crests, troughs, or compressions).
- **Frequency (f):** The number of complete waves or cycles that pass a given point in one second. Formula: $f = \frac{1}{T}$ SI Unit: Hertz (Hz), where 1 Hz $= 1$ cycle/second.
- **Time Period (T):** The time required for one complete cycle or wave to pass a given point. It is the reciprocal of the frequency. Formula: $T = \frac{1}{f}$ SI Unit: Second (s).
- **Wave Speed (v):** The distance covered by a wave in unit time. Formula: $v = f\lambda$

12.5 The Ripple Tank

Purpose: To study the properties of water waves like reflection, refraction, and diffraction.

- **Experiment:** A shallow tank filled with water. A vibrator creates ripples, and a lamp shines through the water onto a screen below, where the wave patterns are observed.
- **Observation:** Crests appear as bright lines, and troughs appear as dark lines on the screen.

12.6 Properties of Waves

1. **Reflection:** The bouncing back of a wave when it hits an obstacle. *Example:* Echo (sound wave reflection).

2. **Refraction:** The change in the direction and speed of a wave as it passes from one medium to another. *Example:* The apparent bending of a spoon in a glass of water (light wave refraction).

3. **Diffraction:** The spreading of a wave as it passes through an opening or around the edges of an obstacle. *Example:* Hearing sound around a corner.

12.7 Reflection of Waves

When waves strike a barrier or boundary, they bounce back into the original medium.

- **Angle of incidence** (i) is the angle between the incident ray and the normal.
- **Angle of reflection** (r) is the angle between the reflected ray and the normal.

Law of Reflection:

- The angle of incidence is equal to the angle of reflection ($\angle i = \angle r$).
- The incident ray, the reflected ray, and the normal to the surface at the point of incidence all lie in the same plane.

12.8 Refraction of Waves

Refraction occurs when waves enter a different medium at an angle.

- **Speed Change:** When waves move from a **deeper** to a **shallower** region, they slow down and bend **towards** the normal. When they move from **shallower** to **deeper**, they speed up and bend **away** from the normal.
- **Wavelength Change:** The wavelength of the wave also changes. $\lambda_{\text{deep}} > \lambda_{\text{shallow}}$.
- **Frequency:** The frequency of the wave **does not change** during refraction as it depends only on the source.

12.9 Diffraction of Waves

Diffraction is the phenomenon where waves spread out after passing through a narrow aperture or around the edge of an obstacle. Diffraction is more pronounced when the wavelength is comparable to or larger than the gap size.

Relation between Diffraction and Wavelength

Diffraction becomes more significant when the **wavelength is large** compared to the size of the gap. Longer wavelength waves (like sound) diffract more easily than shorter wavelength waves (like light).

Relation between Diffraction and Gap Size

- If the **gap size is much larger than the wavelength**, diffraction is minimal (waves mostly pass straight through).
- If the **gap size is similar to or smaller than the wavelength**, diffraction is pronounced, and waves spread widely.

12.9 Tsunamis

Tsunamis are destructive waves caused mainly by underwater earthquakes, volcanic eruptions, or landslides. In deep oceans, they travel rapidly with low amplitude, but near shorelines their height increases dramatically.

12.9.1 Tsunami Generation Process

Tsunamis are a series of enormous ocean waves caused by earthquakes, underwater landslides, volcanic eruptions or asteroids. Usually, tsunamis are generated when the ocean floor is suddenly displaced due to tectonic activity, causing a massive movement of water. The energy spreads outward as long, powerful waves.

12.9.2 Characteristics of Tsunami

- Travel at speeds of 500800 km/h in deep water.
- Appear small in open oceans but rise to enormous heights near coasts.
- Can cause massive flooding, destruction, and loss of life.


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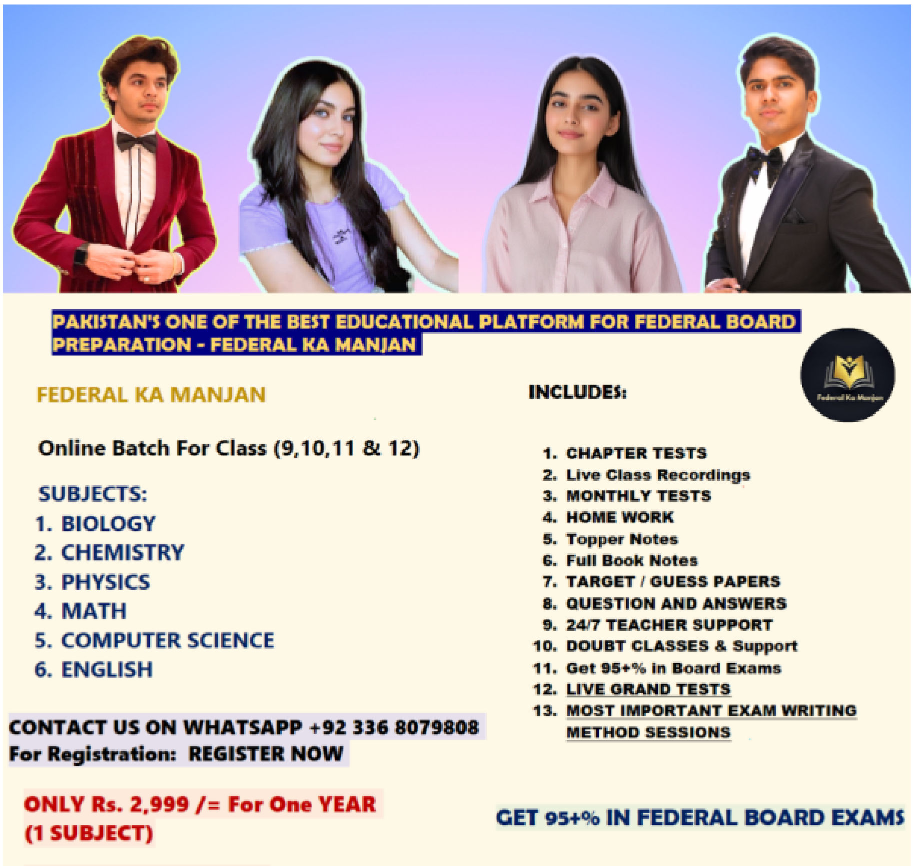
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