Chapter 21

Waves

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INTRODUCTION TO WAVES

A wave is a perturbation that travels through space, conveying energy and momentum without the transfer of matter.

Classification of waves

Waves can be categorized depending on the medium's necessity, the particle's motion direction, and the wave's propagation direction as follows:

Based on the requirement of medium:

Based on the medium's necessity for wave propagation, waves are categorized into the following two classes:

Mechanical waves:

Waves that rely on a medium for propagation are termed mechanical waves. The medium must possess elasticity to restore particles to their equilibrium positions and inertia to store and transmit the energy.

Example:

Sound waves are categorized as mechanical waves since they necessitate a medium for propagation. Consequently, they cannot travel through a vacuum.

Non-mechanical waves:

Waves that don't mandatorily need a medium for propagation are termed non-mechanical waves.

Example:

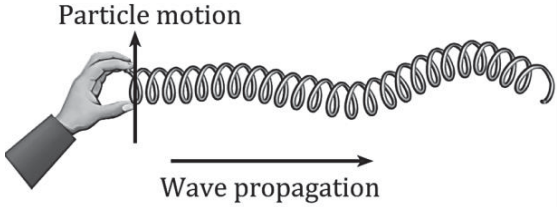
Light waves are considered non-mechanical waves as they can traverse through a vacuum.

Based on the direction of motion of particles:

The subsequent categories are the most significant types of waves, classified based on the direction of particle motion.

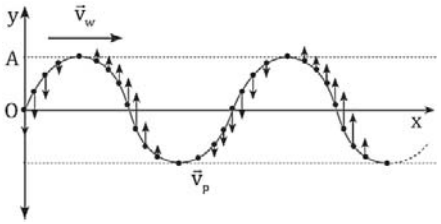
Transverse waves:

When the particles of the medium oscillate in a direction perpendicular to the wave propagation, meaning the displacement is at a right angle to the wave's direction, these waves are referred to as transverse waves.



Examples:

Electromagnetic waves, the Mexican wave which is usually formed by people in a crowd, the waves on a string, the ripples on the surface of water, etc.



Mathematically if $\vec{V}_p$ is the velocity of the particle of the medium and $\vec{V}_w$s the velocity of the wave, then for the case of transverse wave, $\vec{v}_p \perp \vec{v}_w \Rightarrow \vec{v}_p \cdot \vec{v}_w = 0$

Longitudinal waves:

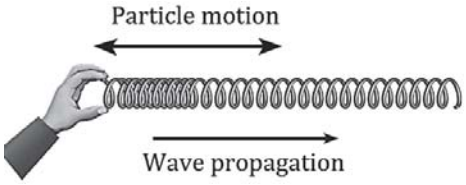
When the particles of a medium oscillate in the same direction as the wave propagation, meaning the displacement is parallel to the wave's direction, these waves are termed longitudinal waves. They propagate as compressions and rarefactions.

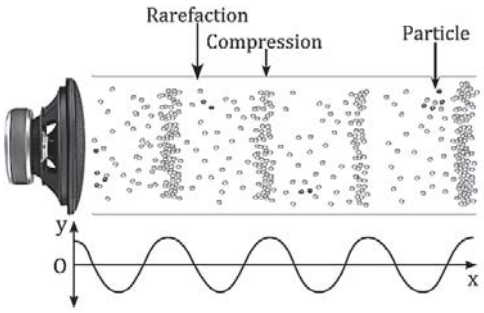
Examples:

Sound wave in air, the vibration in a spring, etc.

Mathematically, if $\vec{v}_p$ is the velocity of the particle of the medium and $\vec{v}_w$ is the velocity of the wave, then for the case of longitudinal wave,

$$\vec{v}_p \parallel \vec{v}_w \Rightarrow \vec{v}_p \times \vec{v}_w = \vec{0}$$





Based on the direction of propagation of waves:

Waves are categorized into three groups based on the direction of their propagation.

1. **One-dimensional waves:**

When waves travel in a single direction, they are referred to as linear waves or one-dimensional waves.

Ex. The waves on a string

2. **Two-dimensional waves:**

When waves spread across a two-dimensional space, they are identified as planar waves, surficial waves, or two-dimensional waves.

Ex. The undulations on the surface of water.

3. **Three-dimensional waves:**

When waves spread throughout space, they are referred to as spatial waves or three-dimensional waves.

Ex. Seismic waves or earthquake waves.

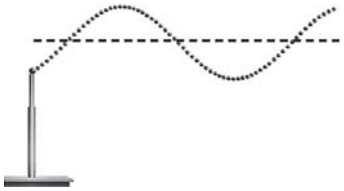
Important Terminologies

1. **Wave pulse:**

A wave pulse is a singular vibration or a non-periodic wave characterized by a solitary major crest.

Ex. Single disturbance in a string.

2. Wave packet:



A consistent wave pulse generated by an external source is termed a wave train or wave packet.

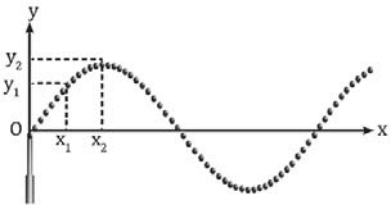
Ex. A persistent disturbance in a string, commonly referred to as waves in practical terms, constitutes these wave packets.

We will focus on the following categories of waves in our area of interest:

1. String waves (One-dimensional, mechanical, and transverse)
2. Sound waves (Three-dimensional, mechanical, and longitudinal)

String Wave

Picture a scenario where an external force consistently generates a wave pulse (upward and downward motion) in a string by holding the free end while the other end remains fixed. This action produces a wave train, and if we capture the scene at a specific moment, it would resemble the figure below:



A wave generated in this manner is termed a string wave, characterized as one-dimensional, mechanical, and transverse in nature. Now, if we align the x-axis horizontally (representing the direction of the string wave's propagation) and the y-axis vertically (representing the vibration direction of the particles in the string), the y-x graph at a particular moment illustrates the position of each particle at that instant. The provided figure captures the scenario at that moment, with origin O representing the end where the vibration originates, and coordinates (x_1, y_1), (x_2, y_2), etc., denote the positions of the individual particles of the string at that particular instant.