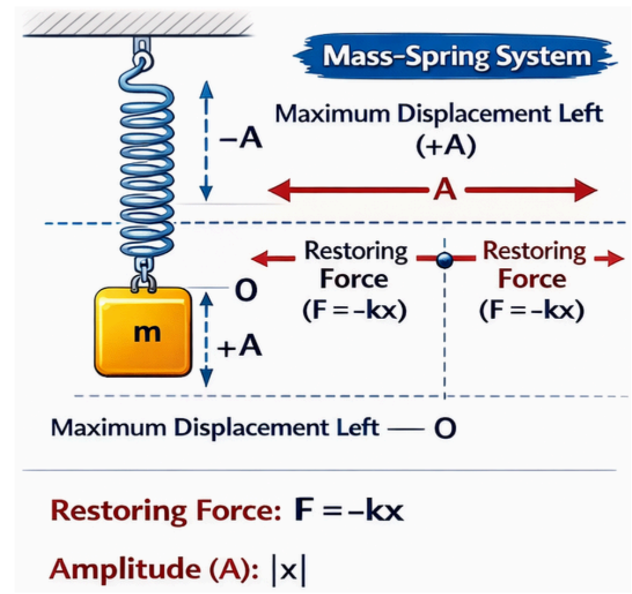
Unit 1: Wave Motion and Its Applications

Subject: Applied Physics II

What is Simple Harmonic Motion?

Simple Harmonic Motion (SHM) is a type of periodic motion in which the restoring force acting on the object is directly proportional to its displacement from the mean position and is always directed towards it. Mathematically, it is given by:

$F=-kx$



where:

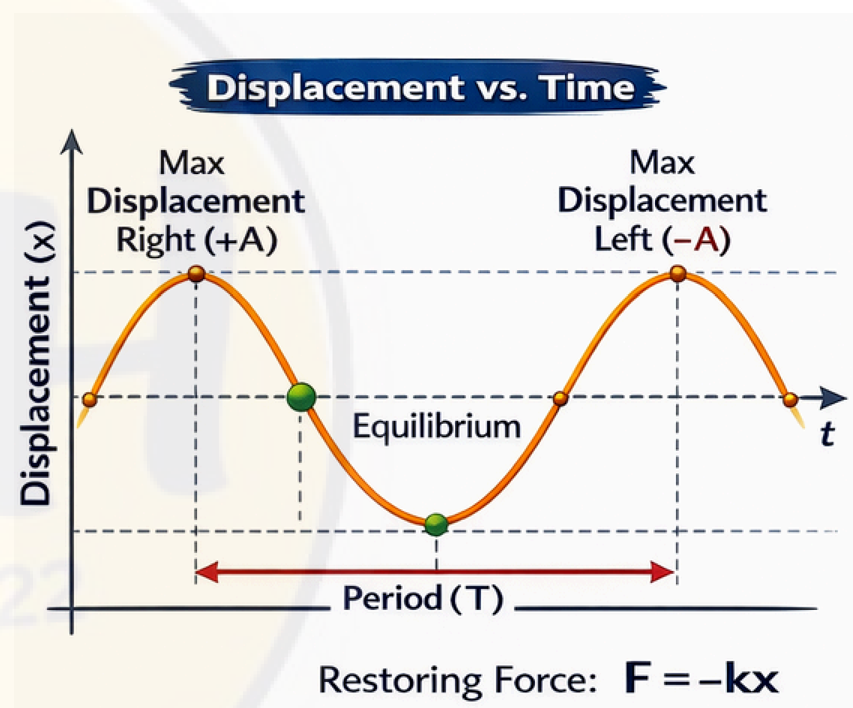
- F = Restoring force
- k = Force constant (stiffness of the system)
- x = Displacement from the mean position

Expression for Displacement, Velocity, and Acceleration

For an object undergoing SHM, the **displacement** at any time ttt is given by:
$x=A\cos(\omega t+\phi)$

where:

- A = Amplitude of motion
- ω = Angular frequency
- ϕ = Phase constant



Velocity:
Velocity is the time derivative of displacement:
$v=dx/dt=-A\omega\sin(\omega t+\phi)$

Acceleration:
Acceleration is the derivative of velocity:

$$a = \frac{dv}{dt} = -A\omega^2 \cos(\omega t + \phi)$$

$$a = -\omega^2 x$$

Time Period and Frequency
The time period (T) and frequency (f) of SHM are given by:

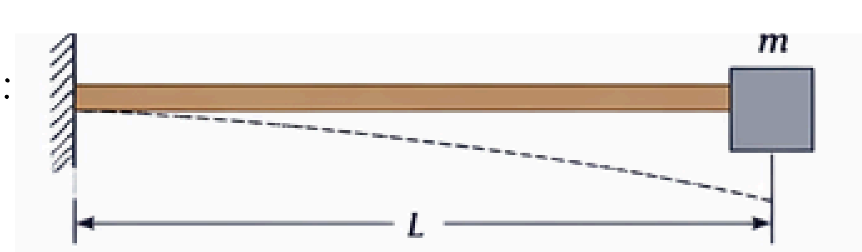
$$T = \frac{2\pi}{\omega}$$

$$f = \frac{1}{T} = \frac{\omega}{2\pi}$$

Study of Vibrations of a Cantilever and Determination of Its Time Period

A cantilever is a beam fixed at one end and free at the other. When displaced and released, it undergoes oscillatory motion.

The time period of a cantilever's vibrations can be determined using:



$$T = 2\pi\sqrt{\frac{l^3}{3EI}}$$

where:

- L = Length of the cantilever
- E = Young's modulus of the material
- I = Moment of inertia of the beam cross-section

Types of Vibration

1. **Free Vibrations:**
   - Occur when a system oscillates on its own without external force after being disturbed.
   - Example: A pendulum swinging freely.
2. **Damped Vibrations:**
   - Occur when the amplitude of oscillation decreases over time due to resistive forces like friction or air resistance.
   - Example: A pendulum swinging in water.
3. **Forced Vibrations:**
   - Occur when an external periodic force is applied to the system.
   - Example: Vibrations of a bridge due to wind or traffic.

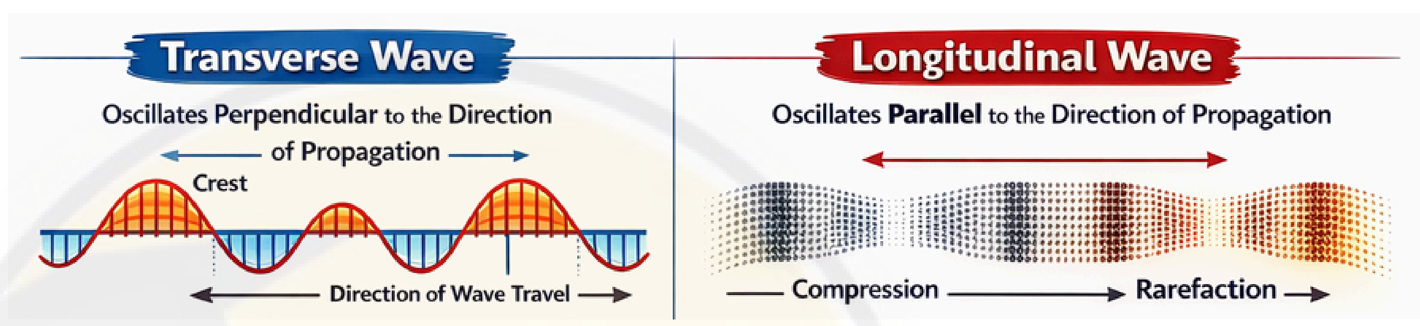
Each of these vibrations plays a crucial role in engineering, mechanical systems, and physics applications.

What is Wave Motion?

Wave motion is the transfer of energy and momentum from one point to another without the actual transport of matter. It occurs due to the oscillations or vibrations of particles in a medium or space.

Types of Wave Motion

There are two types of waves -
1. Transverse Waves
2. Longitudinal Waves



1. **Transverse Waves:** The particles of the medium oscillate perpendicular to the direction of wave propagation. Example: Light Wave, Water Wave, and Wave on String
2. **Longitudinal Waves:** The particles of the medium oscillate parallel to the direction of wave propagation. Example: Sound waves in air, Seismic P-waves

Sound Waves vs Light Waves

Property	Sound Waves (Longitudinal)	Light Waves (Transverse)
Medium	Requires a medium (air, water, solid)	Can travel in a vacuum
Speed	~343 m/s in air	~3×1083 \times 10^83×108 m/s in vacuum
Type	Mechanical wave	Electromagnetic wave
Example	Speech, music	Sunlight, laser beams

Wave Parameters and Their Relationships

1. **Wave Velocity (v):** The speed at which a wave propagates through a medium.
2. **Frequency (f):** The number of wave cycles passing a point per second.
3. **Wavelength (λ):** The distance between two consecutive crests or troughs (transverse) or compressions and rarefactions (longitudinal).

Relationship
$v = f\lambda$

where:
v = Wave velocity
f = Frequency
λ = Wavelength

Equation of a Plane Progressive Wave

A progressive wave moving along the positive x-axis is given by:
$y(x,t)=A\sin(kx-\omega t+\phi)$

where:
A = Amplitude
k = Wave number
ω = Angular frequency
ϕ = Initial phase

Principle of Superposition of Waves

When two or more waves overlap in the same medium, the resultant displacement at any point is the vector sum of the displacements due to individual waves.

Mathematically, if y1 and y2 are two wave functions, the resultant wave is:
$y = y_1 + y_2$

Example:
- Interference of sound waves
- Formation of standing waves in strings

Beat Formation

Beats occur when two waves of nearly equal frequencies interfere, producing periodic variations in intensity.

The beat frequency is given by:
$f = |f_1 - f_2|$

Where;
f1 and f2 are the frequencies of the two waves.

Example:
- Musical tuning (tuning fork experiment)
- AM radio tuning (heterodyne principle)

Reverberation

Reverberation is the persistence of sound in an enclosed space due to multiple reflections from walls, ceilings, and other surfaces. It occurs when sound waves bounce off surfaces before fading away.

Reverberation Time

Reverberation time (RT) is the time required for sound to decay by 60 dB after the source stops. It depends on the room size and the materials used in the interior. The Sabine's formula for reverberation time is:

$$RT = \frac{0.16V}{A}$$

where:
V = Volume of the room (m^3)
A = Total absorption in the room (m^2 Sabine)

Methods to Control Reverberation Time

To achieve the desired acoustic environment, reverberation time must be controlled using the following methods:
1. Using Sound-Absorbing Materials – Installing materials like acoustic panels, carpets, and curtains to absorb sound.
2. Furniture and Upholstery – Sofas, bookshelves, and rugs help in absorbing sound and reducing echoes.
3. Perforated Ceilings and Walls – Panels with perforations help trap and dissipate sound energy.
4. Acoustic Tiles and Foam – Used in theaters, auditoriums, and studios to enhance sound quality.
5. Proper Room Shape and Design – Avoiding parallel walls and using curved surfaces to minimize unwanted reflections.

Noise

Noise is unwanted or unpleasant sound that causes disturbance. It can be classified as:

- Airborne Noise – Travels through air (e.g., conversations, music, vehicle horns).
- Structure-Borne Noise – Travels through solid materials (e.g., vibrations from machinery, footsteps on the floor).
- Impact Noise – Caused by objects striking surfaces (e.g., doors slamming).

Coefficient of Absorption of Sound

The coefficient of absorption (α) measures how much sound a material absorbs. It is given by:

$$\alpha = \frac{\text{Sound energy absorbed}}{\text{Total incident sound energy}}$$

- $0 \leq \alpha \leq 1$
- A value of 0 means total reflection (no absorption).
- A value of 1 means total absorption (no reflection).

Definition of Ultrasonic Waves

Ultrasonic waves are sound waves with frequencies higher than 20 kHz, which are beyond the audible range of human hearing. These waves have short wavelengths, high energy, and are used in various engineering and medical applications, such as imaging, diagnostics, and non-destructive testing.

Properties of Ultrasonic Waves

- **High Frequency** – Greater than 20 kHz.
- **Short Wavelength** – Helps in precision applications.
- **High Energy** – Can penetrate solid objects.
- **Directional Propagation** – Travels in a straight line.
- **Reflection and Refraction** – Used in imaging and flaw detection.

Engineering Applications of Ultrasonic Waves

- **Non-Destructive Testing (NDT)** – Detects internal cracks in metals and structures.
- **SONAR (Sound Navigation and Ranging)** – Used in submarines for underwater mapping and object detection.
- **Cleaning** – Ultrasonic cleaning removes dirt from delicate objects like jewelry and medical instruments.
- **Material Processing** – Used in welding and cutting of metals and plastics.

Medical Applications of Ultrasonic Waves

- **Ultrasonography (Ultrasound Imaging)** – Used to visualize internal body structures like organs and fetuses.
- **Lithotripsy** – Breaks kidney stones into small fragments using ultrasound waves.
- **Cancer Treatment** – Focused ultrasound waves help in destroying tumors.
- **Blood Flow Measurement** – Doppler ultrasound detects blood flow and heart conditions.