📘 Chapter 10 – Oscillations and Waves (NEET 2025)

The same tone and structure as before: detailed but readable, formula boxes, examples, and exam focus.

⚙️ 1. Introduction – The World of Repetitive Motion

If you pluck a guitar string, the vibration repeats.
If you watch a clock pendulum, it swings back and forth.
If you listen to sound, it's nothing but a pressure wave repeating again and again.

Such repeating motion is called **periodic motion**, and the simplest among them is **simple harmonic motion (SHM)**.
In this chapter we explore the mathematics of oscillations and how they combine to form **waves** that travel through space and matter.

🎵 2. Periodic and Oscillatory Motion

- **Periodic motion:** motion that repeats itself after equal time intervals (T).
  Examples: Earth's rotation, AC current, revolution of moon.

- **Oscillatory motion:** periodic motion to and fro about a mean position.
  Every oscillation is periodic, but not every periodic motion is oscillatory (e.g., uniform circular motion is periodic but not linear oscillation).

Important terms

Symbol	Quantity	Meaning
T	Time period	Time to complete one oscillation
f	Frequency	Number of oscillations per second ($f = 1/T$)
A	Amplitude	Maximum displacement from mean
φ	Phase	State of motion at given time

⚛️ 3. Simple Harmonic Motion (SHM)

A motion is **simple harmonic** if acceleration is directly proportional to displacement and always directed toward mean position:

$a = -\omega^2 x$

where ω is **angular frequency**.

Integrating gives position and velocity equations:

$x = A\sin(\omega t + \varphi)$ $v = \omega A\cos(\omega t + \varphi)$ $a = -\omega^2 A\sin(\omega t + \varphi)$

Relations

$v_{max} = \omega A, \quad a_{max} = \omega^2 A$

Graphs

- x–t curve → sine wave

- v–t → cosine

- a–t → –sine
  All are **periodic** with period $T = 2\pi/\omega$.

🔢 4. Energy in SHM

- **Kinetic Energy:** $K = \tfrac{1}{2} m v^2 = \tfrac{1}{2} m \omega^2(A^2 - x^2)$

- **Potential Energy:** $U = \tfrac{1}{2} m \omega^2 x^2$

- **Total Energy:** $E = \tfrac{1}{2} m \omega^2 A^2$ (constant)

Hence energy oscillates between kinetic and potential but the total remains constant — a neat physical model of energy conservation.

🪶 5. Mass–Spring System

When a mass m is attached to a spring of force constant k, displacement x from equilibrium produces restoring force $F = -kx$.

Equation of motion:

$$m\frac{d^2x}{dt^2} = -kx \Rightarrow \omega = \sqrt{\frac{k}{m}}$$

Time period:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

This is a **linear SHM**, frequently asked in NEET numericals.

🕰 6. Simple Pendulum

For small angular displacement θ, restoring torque $\tau = -mg\, l \sin\theta \approx -mg\, l\, \theta$.

Equation:

$$\frac{d^2\theta}{dt^2} + \frac{g}{l}\theta = 0 \qquad \omega = \sqrt{\frac{g}{l}}, \quad T = 2\pi\sqrt{\frac{l}{g}}$$

Effect of factors

- $T \propto \sqrt{l} \rightarrow$ longer pendulum, slower swing.

- $T \propto 1/\sqrt{g} \rightarrow$ on Moon (1/6 g), period $\approx \sqrt{6}$ times longer.

- Independent of mass and amplitude (for small θ).

🧩 7. Combination of SHMs

When two SHMs of same frequency act along same line:

$$x = A_1 \sin \omega t + A_2 \sin (\omega t + \varphi)$$

Resultant amplitude:

$$A = \sqrt{A_1^2 + A_2^2 + 2A_1 A_2 \cos\varphi}$$

This explains **interference** in wave motion later.

⏱ 8. Damped and Forced Oscillations

Damped Oscillation

Due to friction or air resistance, amplitude decreases exponentially:

$$A = A_0 e^{-bt/2m}$$

Energy falls as $e^{-bt/m}$.

Forced Oscillation

External periodic force $F = F_0 \sin \omega t$ acts on system.

If driving frequency $\approx$ natural frequency $\rightarrow$ **resonance**, large amplitude.
Examples: breaking of glass by sound, tuning fork resonance.

🌊 9. Wave Motion – Energy on the Move

When oscillations travel through a medium, a **wave** is produced.

Type	Direction of vibration vs propagation	Example
Transverse	⊥	String waves, light

Type	Direction of vibration vs propagation	Example
Longitudinal ∥		Sound in air

Wave transports energy without transporting matter.

🔢 10. Wave Equation

A progressive wave along +x:

$$y(x,t) = A \sin(kx - \omega t + \varphi)$$

where $k = 2\pi/\lambda$ is wave number.

Velocity of wave:

$$v = \frac{\omega}{k} = f\lambda$$

🔶 11. Principle of Superposition

When two or more waves overlap, resultant displacement equals algebraic sum of individual displacements:

$$y = y_1 + y_2$$

Leads to interference, standing waves, beats — foundation of wave physics.

🎶 12. Standing Waves and Resonance

When two identical waves travelling in opposite directions meet:

$$y = 2A \sin(kx) \cos(\omega t)$$

Nodes → zero displacement; antinodes → maximum.

In strings and organ pipes, standing waves form harmonics:

$$\lambda_n = \frac{2L}{n}, f_n = n f_1$$

n = 1, 2, 3…

🔊 13. Sound Waves

Sound = longitudinal mechanical wave of compressions and rarefactions.

Speed of Sound in Gas:

$$v = \sqrt{\frac{\gamma RT}{M}} = \sqrt{\frac{\gamma P}{\rho}}$$

Depends on T, γ, and molecular mass.

Effect of temperature:

$v \propto \sqrt{T} \rightarrow$ increases about 0.6 m/s per °C.

In solids and liquids:

$v = \sqrt{E/\rho}$ (Young's modulus E).

🪐 14. Beats and Interference of Sound

When two waves of slightly different frequencies f_1, f_2 superpose:

$$f_{beats} = |f_1 - f_2|$$

Used to tune musical instruments.

Interference: constructive when path difference = $n\lambda$; destructive = $(2n+1)\lambda/2$.

⚡ 15. Doppler Effect

Apparent change in frequency when source or observer moves:

$$f' = f \left(\frac{v \pm v_o}{v \mp v_s}\right)$$

'+' when moving toward, '–' when away.

Applications: radar, medical imaging, astronomy.

🧠 16. Energy Transmission in Waves

Energy density of wave:

$$u = \tfrac{1}{2} \rho \omega^2 A^2$$

Power transmitted:

$$P = uv = \tfrac{1}{2} \rho v \omega^2 A^2$$

So energy $\propto A^2$. Double amplitude → quadruple energy.

🍀 17. Speed of Transverse Wave on String

$$v = \sqrt{\frac{T}{\mu}}$$

T = tension, μ = mass per length.
Used to design musical instruments and bridges.

☀ 18. Quality and Intensity of Sound

- **Loudness:** related to amplitude.

- **Pitch:** depends on frequency.

- **Quality or Timbre:** distinguishes sources with same pitch/loudness (due to harmonics).

- **Intensity:** $I = P/AI = P/AI = P/A$, measured in $W\ m^{-2}$.

Human ear range: 20 Hz – 20 kHz.

📃 19. Summary

1. SHM: $a = -\omega^2 x$, $x = A \sin(\omega t + \varphi)$.

2. Energy of SHM $= \frac{1}{2} m \omega^2 A^2$.

3. $T = 2\pi\sqrt{(m/k)}$ for spring, $2\pi\sqrt{(l/g)}$ for pendulum.

4. Damping reduces amplitude; resonance gives max amplitude.

5. Wave equation $y = A \sin(kx - \omega t)$.

6. $v = f\lambda$.

7. Standing waves have nodes and antinodes.

8. $v\_sound = \sqrt{(\gamma P/\rho)}$.

9. Doppler effect → apparent frequency shift.

10. Energy $\propto A^2$ in waves.