WAVES & OSCILLATIONS

📖 Definition:

Oscillation is the repetitive back-and-forth motion of a particle or body about a fixed point of equilibrium.

🔹 Types of Oscillations

- **Free Oscillations**:
  Definition: Oscillations without external force or energy loss.
  Example: Ideal pendulum in vacuum.
  Note: Rare in nature.
- **Damped Oscillations**:
  Definition: Oscillations whose amplitude decreases over time due to energy dissipation (e.g., friction).
  Example: Swing slowing down.
  UPSC Use: Found in car suspension systems.
- **Forced Oscillations**:
  Definition: Oscillations under continuous external periodic force.
  Example: Children being pushed on a swing.
- **Resonance**:
  Definition: Phenomenon where the frequency of external force matches natural frequency, leading to large amplitude.
  Example: Breaking of glass by singer's voice.

🔹 Simple Harmonic Motion (SHM)

- *Definition:* A type of periodic motion where restoring force is directly proportional to displacement and opposite in direction:
  F=−kx
- *Key Features:*
  - Displacement follows sine/cosine function.
  - Velocity and acceleration vary with time.
  - Energy continuously shifts between kinetic and potential.

📐 Equations in SHM

- Displacement: $x(t) = A\sin(\omega t + \phi)$
- Velocity: $v(t) = A\omega\cos(\omega t + \phi)$
- Acceleration: $a(t) = -A\omega^2\sin(\omega t + \phi)$
- Energy in SHM:
  - **Total Energy (E)**: $\frac{1}{2}kA^2$
  - **Kinetic Energy**: $\frac{1}{2}mv^2$
  - **Potential Energy**: $\frac{1}{2}kx^2$
  - Energy remains constant, just transforms between KE and PE.

🌊 WAVES

📖 Definition:

A **wave** is a disturbance that travels through space or a medium, transferring energy from one point to another without the transport of matter.

🔹 Classification of Waves

A. Mechanical Waves

- *Definition:* Require a material medium to propagate.
- *Examples:* Sound waves, water waves, seismic waves.
- *Important:* Cannot travel through vacuum.

B. Electromagnetic Waves

- *Definition:* Oscillations of electric and magnetic fields that travel through vacuum and media.
- *Examples:* Light, X-rays, radio waves.
- *Key Point:* Do not require a medium.

C. Matter Waves (Quantum Physics)

- *Definition:* Waves associated with particles (as per de Broglie hypothesis).
- *Example:* Electron wave in an atom.
- *Note:* Important in quantum theory, not classical waves.

🔹 Wave Properties – Key Terms

- **Wavelength (λ)**: Distance between two consecutive points in phase.
- **Frequency (f)**: Number of oscillations per second.
- **Amplitude (A)**: Maximum displacement from equilibrium.
- **Time Period (T)**: Time to complete one oscillation.
- **Wave Speed (v)**: v=fλv = f \lambdav=fλ
- **Phase**: Describes the stage of oscillation at a point.

🧩 Important Wave Phenomena

- **Reflection**: Bouncing back of waves.
- **Refraction**: Bending of waves at interface between two media.
- **Diffraction**: Bending of waves around corners.
- **Interference**: Superposition of two waves.
- **Polarization**: Restricting vibration to one direction (only for transverse waves).
- **Doppler Effect**: Change in observed frequency due to motion of source or observer.

💡 Key Examples for UPSC Context

- **Tacoma Bridge Collapse (1940)**: Classic example of resonance.
- **Earthquake Seismology**: Use of P and S waves to understand Earth's interior.
- **Optical Fiber Communication**: Uses total internal reflection – a wave-based principle.
- **Doppler Radar**: Used in weather forecasting, military surveillance.
- **Microwave Ovens**: Use resonance of water molecule