

APPLIED PHYSICS - II

Detailed E-Content & Applied Engineering Study Guide

COURSE OUTCOMES (COS)

- **CO1:** Differentiate between types of waves, their motion, and solve wave propagation problems.
- **CO2:** Illustrate laws of reflection/refraction, optical instrument design, and wave optics principles.
- **CO3:** Demonstrate competency in electrostatics, electric potential, circuits, and electromagnetic fields.
- **CO4:** Characterize band structures, magnetic behaviors, and material properties for technical applications.
- **CO5:** Build a strong foundation in Modern Physics including Lasers, Optical Fibers, and Nanotechnology.

UNIT - I: WAVE MOTION AND ITS APPLICATIONS

1.1 Waves & Types

Definition: A wave is a dynamic disturbance propagating through a physical medium or vacuum, transferring energy and momentum from one point to another without the permanent displacement of matter.

- **Mechanical Waves:** Require an elastic material medium for propagation. Energy is transferred via mechanical oscillations of medium particles.
Examples: Sound waves in air, seismic body waves (P and S waves) during earthquakes, surface ripples on water, vibrations in a guitar string.
- **Electromagnetic (EM) Waves:** Do not require a physical medium; they consist of mutually perpendicular oscillating electric and magnetic fields traveling through free space at the speed of light ($c = 3 \times 10^8 \text{ m/s}$).
Examples: Visible light, Radio signals (Wi-Fi, 4G/5G), X-rays in medical diagnostics, Gamma radiation in cancer therapy.

1.2 Wave Motion Terminology

- **Transverse Waves:** Particle vibration occurs perpendicular to the direction of wave propagation. Consists of alternating *crests* (high points) and *troughs* (low points).
Examples: Electromagnetic waves, plucked guitar string, secondary seismic waves (SS-waves).
- **Longitudinal Waves:** Particle vibration occurs parallel to the direction of wave propagation. Consists of alternating *compressions* (high density) and *rarefactions* (low density).
Examples: Sound waves in air, ultrasound waves in biological tissues, primary seismic waves (PS-waves).

Key Definitions & Parameters:

- **Displacement (y):** The distance of a vibrating particle from its equilibrium/mean position at time t (SI unit: Meter, m).
- **Amplitude (A):** Maximum magnitude of displacement of a particle from its rest position. Determines energy ($E \propto A^2$) and sound volume.
- **Time Period (T):** Time taken by a particle to complete one full cycle of vibration. ($T = 1/f$).
- **Frequency (f or ν):** Number of full vibrations or wave cycles per second (SI unit: Hertz, Hz or s^{-1}).
- **Wavelength (λ):** Distance between two consecutive particles vibrating in the same phase (e.g., crest-to-crest or compression-to-compression).
- **Wave Velocity (v):** Linear distance covered by the wavefront per unit time in a given medium.

$$\text{Fundamental Wave Equation: } v = f \cdot \lambda \quad | \quad v = \lambda / T$$

Worked Example: Wave Velocity & Frequency

Problem: A radio station transmits an EM wave at a frequency of 100 MHz ($100 \times 10^6 \text{ Hz}$). Calculate its wavelength in free space.

Solution: Given $v = c = 3 \times 10^8 \text{ m/s}$ and $f = 10^8 \text{ Hz}$.

$\lambda = v / f = (3 \times 10^8) / (10^8) = 3 \text{ meters}$.

1.3 Simple Harmonic Motion (S.H.M.)

Definition: Simple Harmonic Motion is a special type of periodic oscillatory motion where the acceleration (and restoring force) acting on the particle is directly proportional to its displacement from the mean position and is always directed toward that mean position.

$$\text{Differential Equation of SHM: } d^2x / dt^2 + \omega^2 x = 0$$
$$\text{Restoring Force: } F = -kx \quad | \quad \text{Acceleration: } a = -\omega^2 x$$

Practical Examples of S.H.M.:

- Motion of a simple pendulum swinging through small angular displacements ($\theta < 10^\circ$).
- Oscillation of a mass attached to a helical spring obeying Hooke's Law.
- Vibration of tuning fork prongs generating acoustic tones.
- Oscillations of liquid columns in a U-tube manometer.

1.4 Cantilever

Definition: A structural beam fixed horizontally at one end and loaded/free at the other end. When a load m is placed at the free end, it experiences a vertical depression δ and executes vertical simple harmonic motion when disturbed.

$$\text{Depression } (\delta): \delta = (W \cdot L^3) / (3 \cdot Y \cdot I)$$
$$\text{Time Period of Oscillation } (T): T = 2\pi \sqrt{(\delta / g)} = 2\pi \sqrt{(m / k)}$$

(where L = length, Y = Young's modulus, I = geometrical moment of inertia, k = stiffness constant).

Engineering Applications: Aircraft wings, balconies extending from buildings, crane jibs, and atomic force microscope (AFM) cantilever probes.

1.5 Free, Forced, and Resonant Vibrations

- **Free Vibrations:** When a body is displaced from its equilibrium position and released, it vibrates at its natural frequency (f_0) without any ongoing external force. Amplitude gradually decays due to damping (friction).

Example: Plucking a guitar string once, ringing a church bell.

- **Forced Vibrations:** Oscillations driven continuously by an external periodic force operating at an arbitrary driving frequency (f). The body vibrates at the driving frequency rather than its natural frequency.

Example: Vibration of a tabletop caused by a vibrating tuning fork placed on it.

- **Resonant Vibrations (Resonance):** A dramatic phenomenon occurring when the frequency of the external periodic force exactly matches the natural frequency of the vibrating system ($f = f_0$). Energy transfer reaches maximum efficiency, producing a sharp surge in vibration amplitude.

Examples:

- Rupture of glass cups when exposed to a singer's pitch matching the glass's natural acoustic mode.
- Collapse of the Tacoma Narrows Bridge due to wind vortices matching structural resonant frequencies.
- Tuning an LC circuit in a radio receiver to match incoming broadcast carrier frequencies.

1.6 Sound Waves, Noise & Acoustics

• Frequency Classification:

- *Infrasonic Waves*: Frequency $< 20 \text{ Hz}$. Inaudible to humans. Produced by earthquakes, volcanic activity, elephants, and whales.
- *Audible Sound Waves*: Frequency range $20 \text{ Hz} - 20,000 \text{ Hz}$ (20 kHz). Detectable by human ears.
- *Ultrasonic Waves*: Frequency $> 20 \text{ kHz}$. Inaudible to humans. Used in medical ultrasound imaging (SONOGRAPHY), non-destructive material testing (NDT), and bat navigation (echolocation).

- **Noise vs. Music**: Noise consists of irregular, non-periodic waveform combinations causing jarring or unpleasant auditory sensations. Music consists of periodic, harmonically organized waveforms.

- **Coefficient of Absorption (α)**: The fraction of incident sound energy absorbed by a surface relative to total sound incident upon it. Measured in Open Window Units (OWU) or Sabines.

Examples: Acoustic foam ($\alpha \approx 0.85-0.95$), Heavy velvet curtains ($\alpha \approx 0.60$), Concrete wall ($\alpha \approx 0.02$).

- **Echo**: A distinct reflected sound wave reaching the listener after the direct sound. For human perception, the time gap between direct and reflected sound must be at least 0.1 seconds . Taking sound velocity in air as $v = 344 \text{ m/s}$:

$$\text{Minimum Distance for Echo: } d_{\min} = (v \cdot t) / 2 = (344 \cdot 0.1) / 2 = 17.2 \text{ meters}$$

UNIT - II: OPTICS

2.1 Reflection & Refraction of Light

• Laws of Reflection:

1. The incident ray, reflected ray, and normal at the point of incidence lie in the same plane.
2. Angle of incidence (θ_i) equals angle of reflection (θ_r).

- **Refraction & Snell's Law**: Bending of light as it passes across the interface between two optical media with differing refractive indices.

$$\text{Snell's Law: } n_1 \sin(i) = n_2 \sin(r) \Rightarrow \sin(i) / \sin(r) = n_2 / n_1$$

- **Refractive Index (n or μ)**: Ratio of the velocity of light in vacuum (c) to its velocity in the specific medium (v):

$$n = c / v$$

Examples: Vacuum ($n = 1.00$), Air ($n \approx 1.0003$), Water ($n \approx 1.33$), Crown Glass ($n \approx 1.52$), Diamond ($n \approx 2.42$).

2.2 Lens Principles & Power

$$\text{Lens Formula: } 1/f = 1/v - 1/u \quad | \quad \text{Power of Lens: } P = 1/f \text{ (in meters)}$$

Unit of Power: **Diopter (D)** ($1 \text{ D} = 1 \text{ m}^{-1}$). Convex lenses have positive power ($+P$), concave lenses have negative power ($-P$).

Worked Example: Lens Power

Problem: A convex lens has a focal length of $+20 \text{ cm}$. Find its optical power.

Solution: Convert focal length to meters: $f = +0.20 \text{ m}$.

$P = 1/f = 1/0.20 = +5.0 \text{ Diopters (D)}$.

2.3 Total Internal Reflection (TIR)

Definition: When a light ray traveling in an optically denser medium strikes the boundary of an optically rarer medium at an angle of incidence greater than the critical angle ($\theta_i > \theta_c$), the ray is entirely reflected back into the denser medium.

$$\text{Critical Angle Formula: } \sin(\theta_c) = n_{\text{rarer}} / n_{\text{denser}} = 1/n$$

Conditions & Applications:

- **Mandatory Conditions:** 1. Light must travel from denser to rarer medium. 2. Angle of incidence must exceed critical angle ($\theta_i > \theta_c$).
- **Applications:** Transmission of high-speed data through fiber optic cables, endoscopes in medical diagnostics, brilliant sparkling of cut diamonds ($\theta_c \approx 24.4^\circ$), and desert mirages.

2.4 Wave Optics: Superposition, Interference, Diffraction, Polarization

- **Superposition Principle:** When two or more light waves overlap in space, the resultant displacement at any point is the vector sum of individual displacements: $y = y_1 + y_2 + \dots + y_n$.
- **Interference of Light:** Modification in light intensity distribution caused by the superposition of two or more coherent light sources (constant phase relationship).
Constructive Interference: Path diff = $n\lambda$ (Bright fringe, Max intensity).
Destructive Interference: Path diff = $(2n+1)\lambda/2$ (Dark fringe, Min intensity).
Examples: Iridescent rainbow colors on soap bubbles, thin oil slicks on wet roads.
- **Diffraction of Light:** Bending of light waves around the sharp edges of an obstacle or narrow aperture into the geometrical shadow region.
Examples: Rainbow patterns observed when viewing light reflected from a CD/DVD disk, blurring of telescope images due to circular aperture limits.
- **Polarization of Light:** Process of restricting the transverse electric field vector vibrations of unpolarized light to a single spatial plane.
Applications: Polarized sunglasses to eliminate road glares, 3D movie theater glasses, stress analysis in transparent plastics.

2.5 Optical Instruments

- **Compound Microscope:** Optical system utilizing an objective lens (short focal length) and an eyepiece (larger focal length) to produce highly magnified real/virtual images of microscopic biological and material samples.
- **Telescope:** Optical system designed to observe distant celestial bodies or terrestrial objects by increasing the visual angle subtended at the eye.
Types: Refracting telescopes (using lenses), Reflecting telescopes (using parabolic mirrors, e.g., Hubble Space Telescope).

UNIT - III: ELECTROSTATICS AND ELECTRICITY

3.1 Electric Charge & Conservation

Electric Charge (q): Fundamental intrinsic property of elementary particles (electrons, protons) that gives rise to electrostatic forces and electromagnetic fields. (SI unit: Coulomb, C; $e = 1.6 \times 10^{-19} \text{ C}$).

Law of Conservation of Charge: The net electric charge of an isolated system remains strictly constant over time. Charge cannot be created or destroyed, only transferred from one body to another.

3.2 Coulomb's Law

The electrostatic force of attraction or repulsion between two stationary point charges is directly proportional to the product of their charge magnitudes and inversely proportional to the square of the distance separating them.

$$F = k \cdot (|q_1 q_2| / r^2) = (1 / 4\pi\epsilon_0) \cdot (|q_1 q_2| / r^2)$$

(where $\epsilon_0 = 8.854 \times 10^{-12} \text{ F/m}$, $k \approx 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$).

3.3 Electric Field & Intensity

Electric Field: Space surrounding an electric charge within which another test charge experiences electrostatic forces.

Electric Lines of Force Properties: Continuous curves originating from positive charges and terminating on negative charges. They never cross each other and enter/leave conductor surfaces at right angles (90°).

$$\text{Electric Field Intensity (E): } E = F / q_0 \text{ (SI unit: N/C or V/m)}$$

$$\text{Field due to Point Charge: } E = (1 / 4\pi\epsilon_0) \cdot (q / r^2)$$

3.4 Electric Flux & Gauss's Law

Electric Flux (Φ_E): Total number of electric field lines passing normally through a given closed surface area ($\Phi_E = \int \vec{E} \cdot d\vec{A}$).

$$\text{Gauss's Law Statement: } \Phi_E = \oint \vec{E} \cdot d\vec{A} = Q_{\text{enclosed}} / \epsilon_0$$

Applications of Gauss's Law: Calculating electric fields around infinitely long straight charged wires, uniformly charged thin spherical shells, and infinite flat sheets of charge.

3.5 Capacitors & Capacitance

A capacitor is a passive electronic component consisting of two conducting plates separated by a dielectric medium, used to store electric charge and electrostatic energy.

$$\text{Capacitance Formula: } C = Q / V \text{ (SI unit: Farad, F)}$$

$$\text{Parallel Plate Capacitor: } C = (\epsilon_r \epsilon_0 A) / d$$

3.6 Electric Current, DC & AC

Electric Current (I): Time rate of flow of electric charge through a conductor cross-section ($I = Q / t$, SI unit: Ampere, A).

- **Direct Current (DC):** Unidirectional current flow with constant magnitude over time.
Sources: Chemical batteries, solar PV cells, DC generators.

- **Alternating Current (AC):** Current that periodically reverses direction and continuously varies in magnitude over time.

Sources: Thermal/hydroelectric AC generators, wall outlets (230 V, 50 Hz) in India).

3.7 Resistance, Conductance & Combinations

Resistance (R): Opposition offered by a material to the flow of electric current ($R = \rho L / A$, SI unit: Ohm, Ω).

Conductance (G): Ease with which charge flows ($G = 1 / R$, SI unit: Siemens, S or Ω^{-1}).

Series Combination: $R_{eq} = R_1 + R_2 + R_3$ (Current remains same, Voltage divides)

Parallel Combination: $1 / R_{eq} = 1/R_1 + 1/R_2 + 1/R_3$ (Voltage remains same, Current divides)

3.8 Ohm's Law

Statement: Current passing through a conductor between two points is directly proportional to the potential difference across the two points, provided physical conditions (temperature, pressure) remain constant.

$$V = I \cdot R$$

Worked Example: Ohm's Law & Power

Problem: An electric heater element of resistance 46Ω is connected to a 230 V AC supply. Calculate current drawn and power consumed.

Solution: $I = V / R = 230 / 46 = 5.0 \text{ Amperes (A)}$.

Power $P = V \cdot I = 230 \times 5 = 1150 \text{ Watts (1.15 kW)}$.

UNIT - IV: CLASSIFICATION OF MATERIALS AND THEIR PROPERTIES

4.1 Energy Band Theory & Material Classification

In crystalline solids, isolated atomic energy levels broaden into continuous **Energy Bands** due to interatomic wave-function overlap. The highest occupied band is the **Valence Band (VB)** and the next higher empty/partially filled band is the **Conduction Band (CB)**. The energy gap between them is the **Forbidden Energy Gap (E_g)**.

Classification	Band Gap (E_g)	Electrical Conductivity	Examples
Conductor	Overlapping bands ($E_g = 0 \text{ eV}$)	Extremely High ($10^6 - 10^8 \text{ S/m}$)	Copper (Cu), Aluminum (Al), Silver (Ag)
Insulator	Very Large ($E_g > 3 \text{ eV}$)	Extremely Low ($10^{-18} - 10^{-10} \text{ S/m}$)	Glass, Quartz, Rubber, Wood
Semiconductor	Small ($E_g \approx 1 \text{ eV}$)	Intermediate ($10^{-4} - 10^2 \text{ S/m}$)	Silicon (1.1 eV), Germanium (0.67 eV)
Dielectric	Large ($E_g > 4 \text{ eV}$)	Zero DC conductivity; stores electrical polarization	Mica, Ceramics, Pure Water, Transformer Oil

4.2 Intrinsic & Extrinsic Semiconductors

- **Intrinsic Semiconductor:** Pure semiconductor material without impurities. Charge carriers (electrons in CB and holes in VB) are created solely by thermal excitation ($n_e = n_i = p$). Very low conductivity at room temperature.
- **Extrinsic Semiconductor:** Formed by adding controlled trace amounts of impurity atoms (**Doping**) to boost conductivity:
 - *N-Type Semiconductor:* Doped with **Pentavalent** impurity atoms (e.g., Phosphorus, Arsenic, Antimony). Donates extra free electrons. Majority carriers = Electrons; Minority carriers = Holes.
 - *P-Type Semiconductor:* Doped with **Trivalent** impurity atoms (e.g., Boron, Aluminum, Gallium). Creates electron voids (holes). Majority carriers = Holes; Minority carriers = Electrons.

4.3 Magnetism & Magnetic Materials

- **Diamagnetic Materials:** Weakly repelled by magnetic fields. Magnetic susceptibility (χ) is small and negative.
Examples: Bismuth (Bi), Copper (Cu), Gold (Au), Water (H_2O).
- **Paramagnetic Materials:** Weakly attracted by magnetic fields. Magnetic susceptibility (χ) is small and positive.
Examples: Aluminum (Al), Platinum (Pt), Oxygen (O_2).
- **Ferromagnetic Materials:** Strongly attracted by magnetic fields; form permanent magnetic domains. Magnetic susceptibility (χ) is very high and positive.
Examples: Iron (Fe), Cobalt (Ni), Nickel (Co), Ferrites.

4.4 Magnetic Fields & Electromagnetic Induction

- **Magnetic Flux (Φ_B):** Total number of magnetic field lines passing normally through a surface area ($\Phi_B = \int \vec{B} \cdot \vec{A} = B A \cos \theta$, SI unit: Weber, **Wb**).
- **Electromagnetic Induction:** Generation of an induced electromotive force (emf) across an electrical conductor when it experiences a changing magnetic flux.

$$\text{Faraday's Law \& Lenz's Law: } \mathcal{E} = -N \cdot (d\Phi_B / dt)$$

Applications: Electric power generators, transformers, induction cooktops, metal detectors.

UNIT - V: MODERN PHYSICS

5.1 Laser Physics Principles

LASER: Acronym for *Light Amplification by Stimulated Emission of Radiation*. Produces highly monochromatic, directional, coherent, and intense light beams.

Fundamental Processes:

- **Stimulated Absorption:** An atom in ground state energy level E_1 absorbs an incoming photon of frequency $h\nu = E_2 - E_1$ and jumps to excited state E_2 .
- **Spontaneous Emission:** An excited atom at level E_2 naturally returns to ground state E_1 after its lifetime ($\sim 10^{-8}$ s), emitting a photon of frequency ν in a random direction and phase.

- **Stimulated Emission:** An incoming triggering photon of energy $h\nu = E_2 - E_1$ interacts with an already excited atom at E_2 , causing it to immediately drop to E_1 and emit a second photon that is identical in energy, phase, direction, and polarization to the triggering photon.
- **Population Inversion:** A non-equilibrium thermodynamic state where the population of atoms in a higher energy state (N_2) exceeds the population of atoms in lower energy state (N_1) ($N_2 > N_1$). Achieved via external **Pumping** (optical, electrical, or chemical).

Engineering & Medical Applications of Lasers:

- **Industrial:** Precision laser cutting, high-energy welding of thick alloys, micro-drilling.
- **Medical:** LASIK vision correction surgery, non-invasive tumor removal, laser dermatology.
- **Technology:** Barcode scanners, LIDAR sensors in autonomous vehicles, optical disc read/write heads.

5.2 Optical Fibres

Definition & Principle: Flexible, hair-thin glass or plastic waveguides designed to transmit optical signals over long distances with minimal attenuation using **Total Internal Reflection (TIR)**.

Structural Components:

- **Core:** Central inner cylindrical glass rod with high refractive index (n_1). Light travels within this region.
- **Cladding:** Outer concentric glass layer surrounding the core with a slightly lower refractive index ($n_2 < n_1$) to enforce TIR.
- **Buffer Coating:** Protective outer plastic jacket safeguarding the optical fiber against mechanical moisture and abrasion.

Classification by Mode & Index Profile:

- **Mono-Mode (Single-Mode) Fiber:** Ultra-narrow core diameter ($\sim 8\text{--}10\ \mu\text{m}$). Supports only a single light propagation path (mode). Eliminates modal dispersion; ideal for long-distance telecommunications (undersea cables, internet backbones).
- **Multi-Mode Fiber:** Larger core diameter ($\sim 50\text{--}100\ \mu\text{m}$). Allows multiple light rays to propagate simultaneously along different paths. Prone to intermodal dispersion; used for short-distance LAN networks and medical endoscopes.

5.3 Nanotechnology & Nanomaterials

Definition: Science, engineering, and technology conducted at the nanoscale ($1\ \text{nm} = 10^{-9}\ \text{m}$), typically involving structures sized between $1\ \text{nm}$ and $100\ \text{nm}$.

Nanomaterial Types: Carbon Nanotubes (CNTs), Graphene single-atom sheets, Quantum Dots, Metallic Nanoparticles (e.g., Nano-Gold, Nano-Silver).

Unique Properties at Nanoscale:

- **High Surface Area to Volume Ratio:** Exponentially increases chemical reactivity and catalytic efficiency.
- **Quantum Confinement Effects:** Energy bands split into discrete levels; shifts optical absorption/emission wavelengths and electrical properties.
- **Super Mechanical Strength:** Carbon Nanotubes possess tensile strengths over 100 times greater than structural steel at a fraction of the weight.

Applications of Nanotechnology:

- **Medicine:** Targeted drug delivery systems targeting cancer tumors directly without harming healthy tissue.
- **Energy:** Next-generation high-efficiency solar cells, high-density lithium-sulfur nano-batteries.
- **Consumer & Materials:** Stain-resistant fabrics, scratch-proof ceramic coatings, self-cleaning glass.