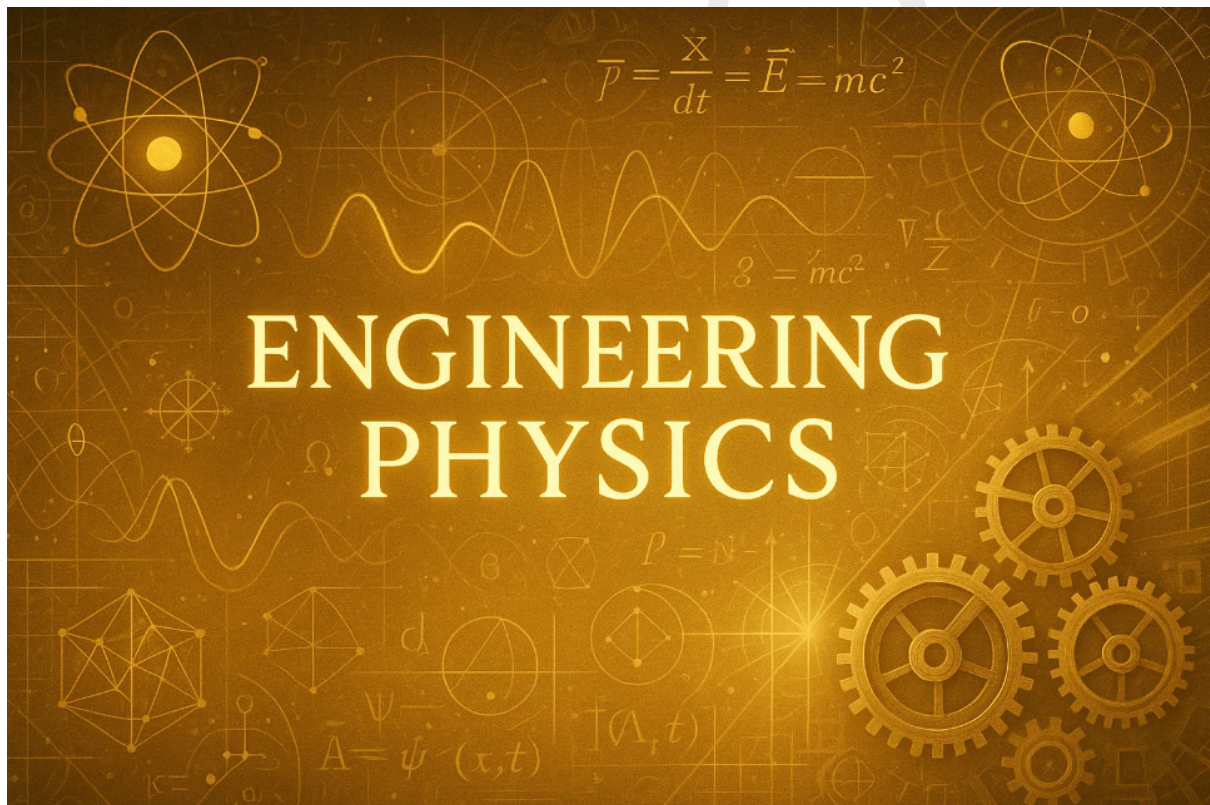


Engineering Physics (25SPH-141)

Compiled by : Subhayu





Course Content

Unit 1 : Quantum Physics and Nanotechnology

Ch 1 : Quantum Physics & Nanotechnology - Quantum Theory (only postulates), Heisenberg's Uncertainty Principle, Wave-Particle Duality, de-Broglie Matter Waves, Wave Packet, Wave Function

Introduction to Nanotechnology, Quantum Confinement Effect, Classification of Nanomaterials, Methods of Synthesis-Top down and Bottom-up Approach: Ball Milling & Sol-Gel Method.

Ch 2 : Recent Inventions -

1. Quantum Computing - Weather Forecasting, Cryptography
2. Edge Computing - IoT, Driverless Cars, and Healthcare
3. Carbon Nanomaterials - Carbon-based Nano Additives
4. Semiconductor Nanodevices - Nanomanipulators, and Nano-transistors
5. Green Nanotechnology - Bioremediation and Biotransformation of soil, Wastewater, Oil Spills, and Other Toxic Pollutants
6. Nanocomposites for Coatings, Additives, Catalysts, and Structural Components
7. Nano-sensors - Enabling Contamination Detection, Environmental Measurements, Remote Sensing, and Communication
8. Nanoencapsulation for Drug Delivery, Bioimaging, Theragnosis, Immunization
9. Nanomaterials for Water Treatment
10. Nanotechnology for Energy Harvesting - Electrodes, and Solar Cells

Unit 2 : Solid State Physics

Ch 3 : Solid State Physics - Classification of Solids, Crystal Structure, Bravais Lattices, SC, BCC, FCC Structures, Atomic packing efficiency, Coordination Number and other parameters. Miller Indices, Interplanar spacing.



Superconductors, Critical Temperature, Meissner Effect, Type-I and Type-II Superconductors. Applications of Superconductivity.

Ch 4 : Recent Inventions -

1. High-Performance Solid-State Batteries with Superionic Electrolytes
2. Graphene Superconductivity – Bio Sensors, Foldable Smart Phones
3. Improved Performance of Electronic Devices with Minimum Energy Losses

Unit 3 : Lasers and Fiber Optics

Ch 5 : Lasers - Introduction, Spontaneous and Stimulated Emission of Radiation, Conditions for Amplification, Main Components of Laser, Ruby Laser, Semiconductor Laser, Holography

Ch 6 : Fiber Optics - Principle of Optical Fiber, Basic Structure, Types of Fibers, Acceptance Angle and Cone, Numerical Aperture, Losses in Fibers.

Unit – 1

Quantum Physics and Nanotechnology

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Chapter 1

Quantum Physics & Nanotechnology

1.1 Introduction

Quantum Physics forms the foundation of modern science and technology, explaining the behavior of matter and energy at microscopic scales (atoms and subatomic particles). Classical mechanics fails to describe phenomena like blackbody radiation and the photoelectric effect. To overcome these limitations, Quantum Theory was developed.

Key Idea

Classical physics works well for macroscopic systems, whereas quantum physics governs microscopic phenomena where energy is quantized.

1.2 Postulates of Quantum Theory

Quantum mechanics is built upon a few fundamental postulates that define how physical systems behave at the quantum scale:

1. **State of a System:** The state of a particle is described by a wave function $\psi(x, t)$, which contains all information about the system.
2. **Probability Interpretation:** The probability of finding a particle in a small region around x is proportional to $|\psi(x, t)|^2$.

$$P(x) = |\psi(x, t)|^2$$

3. **Normalization Condition:** Since the particle must exist somewhere,

$$\int_{-\infty}^{+\infty} |\psi(x, t)|^2 dx = 1$$



4. **Observables and Operators:** Physical quantities (like momentum, energy) are represented by operators:

$$\hat{p} = -i\hbar \frac{d}{dx}, \quad \hat{E} = i\hbar \frac{d}{dt}$$

5. **Schrödinger's Equation:** The evolution of the wave function with time is governed by:

$$i\hbar \frac{\partial \psi}{\partial t} = \hat{H} \psi$$

where $\hat{H}$ is the Hamiltonian operator, representing total energy.

Remember

Wave function ψ itself has no physical meaning; only $|\psi|^2$ represents measurable probability density.

1.3 Heisenberg's Uncertainty Principle

Proposed by Werner Heisenberg in 1927, it states that it is impossible to measure both the position and momentum of a particle with absolute accuracy simultaneously.

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

where:

- Δx = uncertainty in position
- Δp = uncertainty in momentum
- h = Planck's constant (6.626×10^{-34} Js)

Physical Meaning

The more precisely we know a particle's position, the less precisely we can know its momentum, and vice versa.

Example Numerical

Q: An electron is confined to a region of width $1 \text{ \AA}$ (10^{-10} m). Find the minimum uncertainty in its momentum. **Solution:**

$$\Delta x = 10^{-10} \text{ m}, \quad \Delta p = \frac{h}{4\pi \Delta x}$$

$$\Delta p = \frac{6.626 \times 10^{-34}}{4\pi \times 10^{-10}} = 5.27 \times 10^{-25} \text{ kg}\cdot\text{m/s}$$



1.4 Wave-Particle Duality

Louis de Broglie proposed that all matter exhibits both particle and wave-like behavior. This duality is expressed by the **de Broglie wavelength**:

$$\lambda = \frac{h}{p}$$

where $p = mv$ is the linear momentum of the particle.

Example

For an electron moving with velocity 2×10^6 m/s,

$$\lambda = \frac{6.626 \times 10^{-34}}{9.1 \times 10^{-31} \times 2 \times 10^6} = 3.64 \times 10^{-10} \text{ m}$$

Thus, the wavelength of the electron is comparable to atomic dimensions.

1.5 de Broglie Matter Waves

1.5.1 Concept

de Broglie hypothesized that a moving particle of mass m and velocity v is associated with a wave of wavelength $\lambda = \frac{h}{mv}$.

1.5.2 Significance

- Explains why electrons in atoms occupy discrete energy levels.
- Led to the development of wave mechanics and quantum theory.

1.6 Wave Packet

A wave packet represents a localized particle — formed by superimposing many waves of slightly different wavelengths and frequencies.

- **Group velocity** (v_g) represents the particle velocity:

$$v_g = \frac{d\omega}{dk}$$

- **Phase velocity** (v_p) represents the velocity of the individual waves:

$$v_p = \frac{\omega}{k}$$



Relation Between Velocities

For non-relativistic particles:

$$v_g = 2v_p$$

This means the group velocity (of the particle) is twice the phase velocity of the wave.

1.7 Wave Function

The wave function $\psi(x, t)$ is a mathematical representation of the quantum state of a particle.

1.7.1 Properties of Wave Function

1. $\psi(x, t)$ must be finite and single-valued.
2. $\psi(x, t)$ and its derivative $\frac{d\psi}{dx}$ must be continuous.
3. $\psi(x, t)$ must be normalizable:

$$\int_{-\infty}^{+\infty} |\psi(x, t)|^2 dx = 1$$

Important Formula

Expectation value of a physical quantity A :

$$\langle A \rangle = \int_{-\infty}^{+\infty} \psi^* \hat{A} \psi dx$$

where ψ^* is the complex conjugate of ψ .



1.8 Summary of Key Formulae

Concept	Formula / Relation
Uncertainty Principle	$\Delta x \Delta p \geq \frac{h}{4\pi}$
de Broglie Wavelength	$\lambda = \frac{h}{p} = \frac{h}{mv}$
Energy of photon	$E = hf = \frac{hc}{\lambda}$
Group Velocity	$v_g = \frac{d\omega}{dk}$
Phase Velocity	$v_p = \frac{\omega}{k}$
Normalization	$\int \psi ^2 dx = 1$

1.9 Example Numerical

Q: Find the de Broglie wavelength of a proton moving with velocity 1×10^5 m/s. (Proton mass $m = 1.67 \times 10^{-27}$ kg)

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}}{1.67 \times 10^{-27} \times 10^5} = 3.97 \times 10^{-12} \text{ m}$$

Interpretation

This wavelength is much smaller than atomic dimensions; hence, quantum effects for protons are negligible at this speed.

1.10 Introduction to Nanotechnology

1.10.1 Definition and Scope

Nanotechnology is the branch of science and engineering concerned with the design, synthesis, characterization, and application of materials and devices on the nanometer scale (1–100 nm). At this scale, materials often exhibit unique physical, chemical, and electrical properties due to the dominance of quantum mechanical effects and surface phenomena.

Key Concept:

$$1 \text{ nanometer (nm)} = 10^{-9} \text{ meter}$$

1.10.2 Quantum Confinement Effect

When the size of a material becomes comparable to the de Broglie wavelength of electrons (λ_e), the motion of charge carriers is confined, leading to discrete energy levels.

Types of Confinement:

- **Bulk (3D):** Continuous energy bands.



- **Quantum Well (2D):** Confinement in one dimension.
- **Quantum Wire (1D):** Confinement in two dimensions.
- **Quantum Dot (0D):** Confinement in all three dimensions.

Mathematical Expression: For a particle confined in a 1D box of length L :

$$E_n = \frac{n^2 h^2}{8mL^2}$$

where:

- E_n = energy of the n^{th} quantum state
- h = Planck's constant (6.626×10^{-34} Js)
- m = mass of the electron
- L = length of the confinement region

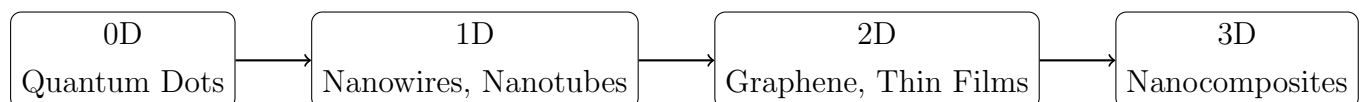
Observation: As L decreases, E_n increases $\rightarrow$ *smaller particles have higher energy separation and altered optical properties.*

1.10.3 Classification of Nanomaterials

Nanomaterials can be classified based on their dimensionality:

1. **Zero-dimensional (0D):** All dimensions are in nanometer range (e.g., quantum dots, nanoparticles).
2. **One-dimensional (1D):** One dimension larger than 100 nm (e.g., nanowires, nanotubes).
3. **Two-dimensional (2D):** Two dimensions extended, one confined (e.g., graphene, nanofilms).
4. **Three-dimensional (3D):** Bulk nanostructures made from nanoscale building blocks (e.g., nanocomposites).

Diagram (Classification Overview):





1.10.4 Methods of Synthesis

Nanomaterials can be synthesized using two main approaches — **Top-Down** and **Bottom-Up**.

1. Top-Down Approach

This method starts with bulk material and breaks it down into nanosized particles.

Example: Ball Milling

- Bulk material is ground using high-energy balls in a rotating chamber.
- Particle size is reduced by mechanical impact.
- **Advantages:** Simple, cost-effective.
- **Disadvantages:** Contamination risk, poor size control.

Energy Relation:

$$E_k = \frac{1}{2}mv^2$$

where E_k is the kinetic energy of the milling balls, which determines the reduction efficiency.

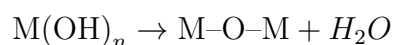
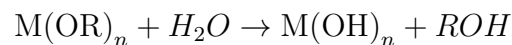
2. Bottom-Up Approach

This method builds nanostructures atom-by-atom or molecule-by-molecule.

Example: Sol-Gel Method

1. A solution (sol) of metal alkoxides or salts is prepared.
2. Hydrolysis and condensation lead to formation of a gel.
3. Gel is dried and calcined to obtain nanoparticles.

Chemical Reactions:



Advantages:

- High purity and uniform particle size.
- Control over composition and microstructure.

Disadvantages:



- Expensive precursors.
- Shrinkage and cracking during drying.

1.10.5 Applications of Nanotechnology

- **Electronics:** Quantum dots, nanoscale transistors.
- **Medicine:** Targeted drug delivery, diagnostic imaging.
- **Energy:** Solar cells, fuel cells, supercapacitors.
- **Environment:** Water purification, pollutant detection.

1.10.6 Numerical Example

Example: Calculate the first energy level (E_1) of an electron in a quantum dot of size $L = 2 \times 10^{-9}$ m.

$$E_1 = \frac{h^2}{8mL^2}$$

Substituting:

$$E_1 = \frac{(6.626 \times 10^{-34})^2}{8(9.11 \times 10^{-31})(2 \times 10^{-9})^2} = 1.51 \times 10^{-19} \text{ J} \approx 0.94 \text{ eV}$$

Result: The first energy level is approximately 0.94 eV.

1.10.7 Summary

- Nanotechnology manipulates matter at the atomic level (1–100 nm).
- Quantum confinement leads to discrete energy levels and size-dependent properties.
- Top-down and bottom-up methods are the two main synthesis approaches.
- Nanomaterials have vast applications in electronics, medicine, and energy.

Chapter 2

Recent Inventions

Nanotechnology and quantum physics together have triggered an unprecedented scientific revolution. This chapter highlights the remarkable recent inventions that have redefined modern science, technology, medicine, and environmental management. Each section elaborates the underlying principle, structure, operation, and practical applications of these innovations in real-world contexts.

2.1 Quantum Computing

Quantum computing exploits the principles of quantum mechanics such as superposition and entanglement to perform computations far beyond the reach of classical systems.

2.1.1 Principle of Operation

Classical computers use bits that can be either 0 or 1. In contrast, a quantum bit or **qubit** can exist in a linear superposition of both states simultaneously:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle, \quad \text{where } |\alpha|^2 + |\beta|^2 = 1$$

The probability of measuring each state depends on the coefficients α and β . This enables massive parallelism in computation.

Another fundamental phenomenon is **entanglement**, where two qubits become correlated such that the state of one instantaneously influences the other, regardless of distance. This is the key enabler of quantum communication and teleportation.

2.1.2 Applications

- **Weather Forecasting:** Quantum algorithms simulate atmospheric particle interactions at molecular scales, leading to highly accurate forecasts.



- **Cryptography:** Quantum Key Distribution (QKD) protocols like BB84 ensure unbreakable encryption by exploiting the no-cloning theorem of quantum mechanics.

Did You Know?

The first 127-qubit quantum processor, named *Eagle*, was unveiled by IBM in 2021, paving the way toward quantum advantage in practical applications.

2.2 Edge Computing

Edge computing decentralizes computation by bringing data processing closer to the data source rather than relying solely on cloud servers.

2.2.1 Working Concept

Instead of transmitting all raw data to centralized data centers, local “edge nodes” (routers, IoT gateways, or on-device chips) preprocess information and send only essential insights to the cloud. This reduces latency, increases reliability, and conserves bandwidth.

2.2.2 Applications

- **Internet of Things (IoT):** Smart home devices perform local data analysis for automation.
- **Driverless Cars:** Real-time edge-based image recognition helps avoid accidents.
- **Healthcare:** Wearable devices like smartwatches monitor health metrics locally, ensuring immediate responses to anomalies.

Key Point

Edge computing complements cloud computing by enhancing speed, reliability, and privacy for mission-critical applications.

2.3 Carbon Nanomaterials

Carbon nanomaterials such as graphene, carbon nanotubes (CNTs), and fullerenes represent one of the most revolutionary discoveries in materials science.



2.3.1 Structure and Properties

- **Graphene:** A single atomic layer of carbon arranged in a honeycomb lattice; it is 200 times stronger than steel and an excellent conductor.
- **Carbon Nanotubes:** Cylindrical structures derived from rolled graphene sheets; exhibit ballistic electron transport and high tensile strength.
- **Fullerenes:** Spherical molecules like C_{60} (Buckminsterfullerene) used in drug delivery and electronics.

$$\sigma = \frac{I}{V} \times \frac{L}{A}$$

where σ is the electrical conductivity — CNTs show conductivities comparable to metals, despite their nanoscale size.

2.3.2 Applications

Used as nano-additives in lubricants and polymers, in energy storage devices, and in sensors for gas detection.

2.4 Semiconductor Nanodevices

Semiconductor nanodevices leverage quantum-scale control to achieve faster operation, reduced power consumption, and enhanced miniaturization.

2.4.1 Nanomanipulators

These are nanoscale robotic tools used to position atoms or molecules with atomic precision inside electron microscopes, essential for nanofabrication.

2.4.2 Nano-transistors

Nano-transistors, such as FinFETs (Fin Field Effect Transistors), control current through channels measured in nanometers, enabling the production of high-speed microprocessors.

Application

Modern 3-nm and 2-nm chip technologies by TSMC and IBM are based on FinFET and GAAFET nanotransistors, allowing billions of transistors on a single chip.



2.5 Green Nanotechnology

Green nanotechnology emphasizes environmental protection and sustainable development using nanomaterials.

2.5.1 Principles and Uses

- **Bioremediation:** Nano-iron particles remove heavy metals from wastewater.
- **Oil Spill Cleanup:** Superhydrophobic nanoparticles absorb oil while repelling water.
- **Biotransformation:** Enzyme-coated nanoparticles accelerate the decomposition of toxic organic pollutants.

$$\text{Efficiency of Degradation (\%)} = \frac{C_0 - C_t}{C_0} \times 100$$

where C_0 and C_t are initial and final pollutant concentrations.

2.6 Nanocomposites

Nanocomposites combine nanoparticles with base materials (like metals, ceramics, or polymers) to produce materials with enhanced mechanical, electrical, and chemical characteristics.

2.6.1 Applications

- **Coatings:** Anti-corrosive and heat-resistant layers on machinery.
- **Additives:** Lightweight, stronger composites for automobile and aerospace parts.
- **Catalysts:** Metal-oxide nanocomposites increase catalytic efficiency in chemical industries.

2.7 Nano-sensors

Nano-sensors are devices capable of detecting extremely small quantities of chemical or biological substances with high sensitivity.

2.7.1 Mechanism

They operate by detecting changes in electrical resistance, fluorescence, or magnetic properties when interacting with a target molecule.



2.7.2 Applications

- Environmental monitoring for pollutant gases like CO, NO₂, and SO₂.
- Remote sensing for agricultural soil and air parameters.
- Biomedical sensors for glucose, cholesterol, or pathogen detection.

2.8 Nanoencapsulation

Nanoencapsulation involves enclosing active agents like drugs, nutrients, or enzymes within nanoscale carriers for controlled delivery.

2.8.1 Applications in Medicine

- **Drug Delivery:** Targets specific tissues (e.g., cancer cells) while minimizing side effects.
- **Bioimaging:** Quantum dots improve the resolution of medical imaging.
- **Theragnosis:** Integration of therapy and diagnosis in a single nano-system.

Key Concept

The release rate of encapsulated drugs depends on the diffusion coefficient (D) and nanoparticle radius (r), governed by:

$$J = -D \frac{dC}{dr}$$

2.9 Nanomaterials for Water Treatment

Nanomaterials provide high reactivity and surface area for advanced water purification.

2.9.1 Mechanisms

- **Adsorption:** Metal oxides like Fe₃O₄ remove arsenic and lead.
- **Photocatalysis:** TiO₂ nanoparticles degrade organic dyes under UV light.
- **Magnetic Separation:** Contaminants bound to magnetic nanoparticles are extracted easily using external magnets.



2.10 Nanotechnology for Energy Harvesting

Nanotechnology enhances the performance of renewable energy systems.

2.10.1 Applications

- **Solar Cells:** Quantum dots increase photon absorption efficiency.
- **Electrodes:** Nanostructured electrodes improve charge collection in lithium-ion batteries.
- **Thermoelectric Devices:** Nanocomposites convert waste heat into electricity efficiently.

Summary

Recent inventions in nanotechnology and quantum research are transforming industries from computing to clean energy. These advances are steering humankind toward a smarter, cleaner, and more sustainable future.

Unit – 2

Solid State Physics

Ch 3 : Solid State Physics - Classification of Solids, Crystal Structure, Bravais Lattices, SC, BCC, FCC Structures, Atomic packing efficiency, Coordination Number and other parameters. Miller Indices, Interplanar spacing. Superconductors, Critical Temperature, Meissner Effect, Type-I and Type-II Superconductors. Applications of Superconductivity.

Ch 4 : Recent Inventions -

1. High-Performance Solid-State Batteries with Superionic Electrolytes
2. Graphene Superconductivity – Bio Sensors, Foldable Smart Phones
3. Improved Performance of Electronic Devices with Minimum Energy Losses

Chapter 3

Solid State Physics

3.1 Classification of Solids

Solids are materials characterized by closely packed atoms or molecules, giving them definite shape and volume. Depending on the arrangement of atoms, solids are classified into:

1. **Crystalline Solids:** These have a long-range periodic arrangement of atoms or ions. The repeating structural unit is called the **unit cell**.
 - Have definite geometrical shape.
 - Sharp melting points.
 - Exhibit anisotropy (properties depend on direction).
 - Examples: NaCl, Quartz, Diamond.
2. **Amorphous Solids:** These lack a regular arrangement of atoms; they exhibit short-range order only.
 - No definite geometrical shape.
 - Melt over a range of temperatures.
 - Exhibit isotropy (properties are same in all directions).
 - Examples: Glass, Rubber, Plastic.



3.2 Crystal Structure

A crystal structure is the ordered arrangement of atoms, ions, or molecules in three-dimensional space. The entire crystal can be generated by repeating a small building block called the **unit cell**.

3.2.1 Lattice and Basis

- **Lattice:** An infinite array of points in space where each point has identical surroundings.
- **Basis (Motif):** The atom or group of atoms attached to each lattice point.

Hence, the crystal structure = **Lattice** + **Basis**.

3.2.2 Unit Cell Parameters

A unit cell is defined by:

- **Lattice constants:** Edge lengths a , b , and c .
- **Interaxial angles:** α (between b and c), β (between a and c), γ (between a and b).

3.3 Bravais Lattices

According to Auguste Bravais (1848), there are **14 distinct lattice types** in 3D space, known as the **Bravais lattices**, grouped into 7 crystal systems:

Crystal System	Axes and Angles	Bravais Lattices
Cubic	$a = b = c, \alpha = \beta = \gamma = 90^\circ$	SC, BCC, FCC
Tetragonal	$a = b \neq c, \alpha = \beta = \gamma = 90^\circ$	SC, BCT
Orthorhombic	$a \neq b \neq c, \alpha = \beta = \gamma = 90^\circ$	SC, BCC, FCC, Base-centered
Monoclinic	$a \neq b \neq c, \alpha = \gamma = 90^\circ \neq \beta$	SC, Base-centered
Triclinic	$a \neq b \neq c, \alpha \neq \beta \neq \gamma$	SC
Hexagonal	$a = b \neq c, \alpha = \beta = 90^\circ, \gamma = 120^\circ$	SC
Rhombohedral	$a = b = c, \alpha = \beta = \gamma \neq 90^\circ$	SC

Table 3.1: Seven crystal systems and their Bravais lattices.



3.4 Cubic Crystal Structures

3.4.1 Simple Cubic (SC)

- Atoms at 8 corners of a cube.
- Number of atoms per unit cell: $N = \frac{1}{8} \times 8 = 1$.
- Coordination number = 6.
- Atomic packing factor (APF):

$$APF = \frac{\text{Volume of atoms in unit cell}}{\text{Volume of unit cell}} = \frac{(4/3)\pi r^3}{a^3} = 0.52$$

- Examples: Polonium.

3.4.2 Body-Centered Cubic (BCC)

- Atoms at 8 corners and 1 at center.
- $N = \frac{1}{8} \times 8 + 1 = 2$.
- Coordination number = 8.
- Relation between a and r :

$$\sqrt{3}a = 4r \implies a = \frac{4r}{\sqrt{3}}$$

- APF = 0.68.
- Examples: Iron, Chromium, Tungsten.

3.4.3 Face-Centered Cubic (FCC)

- Atoms at 8 corners and 6 faces.
- $N = \frac{1}{8} \times 8 + \frac{1}{2} \times 6 = 4$.
- Coordination number = 12.
- Relation:

$$\sqrt{2}a = 4r \implies a = \frac{4r}{\sqrt{2}}$$

- APF = 0.74.
- Examples: Aluminium, Copper, Silver, Gold.



3.5 Atomic Packing Efficiency (APE)

Atomic packing efficiency is the ratio of the volume occupied by atoms in the unit cell to the total volume of the cell.

$$APE = \frac{\text{Number of atoms} \times \frac{4}{3}\pi r^3}{a^3}$$

The comparison:

$$SC = 52\%, \quad BCC = 68\%, \quad FCC = 74\%$$

Hence, FCC has the highest packing density.

3.6 Coordination Number

The coordination number (C.N.) is the number of nearest-neighbor atoms surrounding a given atom.

$$SC = 6, \quad BCC = 8, \quad FCC = 12$$

3.7 Miller Indices

Miller Indices are a set of three integers (h, k, l) that denote the orientation of a plane in a crystal lattice.

3.7.1 Determination of Miller Indices

1. Find intercepts of the plane along axes in terms of lattice constants a, b, c .
2. Take reciprocals of intercepts.
3. Clear fractions and reduce to smallest integers.

Example: A plane cuts axes at $a, \infty, \infty \rightarrow (1, 0, 0)$ plane.

3.7.2 Special Planes

- $(100) \rightarrow$ Plane perpendicular to x-axis.
- $(110) \rightarrow$ Plane cutting x and y axes equally.
- $(111) \rightarrow$ Plane cutting all three axes equally.



3.8 Interplanar Spacing

Interplanar spacing (d_{hkl}) is the perpendicular distance between two adjacent planes having same Miller indices (hkl). For cubic systems:

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

Example: For (111) plane, $d_{111} = \frac{a}{\sqrt{3}}$.

3.9 Numerical Example

Example: Find the interplanar spacing for (220) planes in an FCC crystal with $a = 4.05$ Å.

$$d_{220} = \frac{a}{\sqrt{h^2 + k^2 + l^2}} = \frac{4.05}{\sqrt{2^2 + 2^2 + 0^2}} = \frac{4.05}{2.828} = 1.43 \text{ Å}$$

3.10 Key Takeaways

- Crystals are periodic arrangements of atoms.
- Bravais Lattices form the foundation of solid-state structure.
- FCC structures have the highest packing efficiency.
- Miller indices provide a systematic way to identify crystal planes.
- Interplanar spacing helps in X-ray diffraction and material identification.



3.11 Superconductors

3.11.1 Introduction

Superconductivity is a phenomenon where certain materials, when cooled below a specific temperature, lose all electrical resistance and expel magnetic fields. This temperature is called the **Critical Temperature** (T_c).

Discovered by: Heike Kamerlingh Onnes (1911) while studying mercury at extremely low temperatures.

3.11.2 Characteristics of Superconductors

- **Zero Electrical Resistance:** Below T_c , the resistivity of a superconductor drops abruptly to zero.
- **Perfect Diamagnetism:** Superconductors expel magnetic flux from their interior (Meissner effect).
- **Critical Magnetic Field:** Above a certain magnetic field (H_c), superconductivity is destroyed.
- **Persistent Currents:** A current once set in motion continues indefinitely without any decay.

3.11.3 Critical Temperature (T_c)

The temperature below which a material becomes superconducting is called its **critical temperature**.

T_c = Temperature at which resistance $R \rightarrow 0$

Typical values:

Material	Critical Temperature (T_c)
Mercury (Hg)	4.2 K
Lead (Pb)	7.2 K
Niobium (Nb)	9.3 K
YBa ₂ Cu ₃ O ₇ (High- T_c Ceramic)	92 K

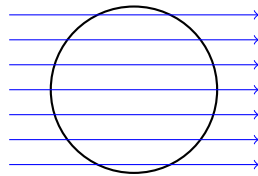
Table 3.2: Examples of superconductors and their critical temperatures.



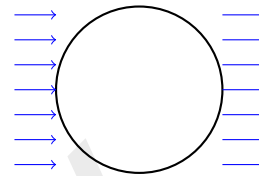
3.11.4 Meissner Effect

The **Meissner Effect** is the expulsion of magnetic flux lines from the interior of a superconductor when it transitions into the superconducting state.

- Discovered by Meissner and Ochsenfeld (1933).
- Demonstrates that superconductivity is not just perfect conductivity but also a distinct thermodynamic phase.



Normal Metal (Magnetic field passes through)



Superconductor (Flux expelled)

Mathematical Expression:

$$B = \mu_0(H + M)$$

For a perfect diamagnet, $B = 0 \Rightarrow M = -H$.

3.11.5 Critical Magnetic Field (H_c)

For a given temperature T , the maximum magnetic field below which superconductivity exists is called the **critical magnetic field**.

$$H_c(T) = H_c(0) \left[1 - \left(\frac{T}{T_c} \right)^2 \right]$$

where $H_c(0)$ is the critical field at absolute zero.

Interpretation: As $T \rightarrow T_c$, $H_c \rightarrow 0$.

3.11.6 Types of Superconductors

Superconductors are broadly classified into two types based on their behavior in magnetic fields.

Type-I Superconductors

- Exhibit a sharp transition from superconducting to normal state.
- Completely expel magnetic fields below H_c (perfect Meissner effect).
- Single critical field H_c .



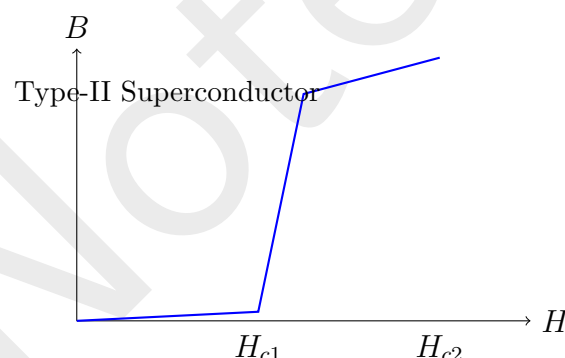
- Usually pure elemental metals.
- Examples: Pb, Hg, Sn.

Magnetic Field vs. Temperature:

$$H_c(T) = H_c(0) \left[1 - \left(\frac{T}{T_c} \right)^2 \right]$$

Type-II Superconductors

- Exhibit two critical fields: lower (H_{c1}) and upper (H_{c2}).
- Between H_{c1} and H_{c2} , magnetic flux penetrates partially in quantized tubes called **vortices**.
- Exhibit **mixed state** or **vortex state**.
- Usually alloys or high- T_c ceramics.
- Examples: NbTi, Nb₃Sn, YBa₂Cu₃O₇.



3.11.7 Applications of Superconductivity

1. **Magnetic Levitation (Maglev Trains):** Based on Meissner effect — superconductors repel magnetic fields, enabling frictionless, high-speed travel.
2. **MRI Machines:** Use superconducting magnets for strong, stable magnetic fields required in imaging.
3. **Particle Accelerators:** Superconducting magnets guide and accelerate charged particles efficiently.
4. **SQUIDS (Superconducting Quantum Interference Devices):** Extremely sensitive magnetometers used for detecting minute magnetic fields.



5. **Superconducting Cables and Power Transmission:** Enable lossless power transport and efficient energy storage.
6. **Quantum Computing:** Superconducting circuits form qubits in many quantum processors.

3.11.8 Summary

- Superconductivity is the complete loss of electrical resistance below T_c .
- Meissner effect distinguishes superconductors from perfect conductors.
- Type-I $\rightarrow$ Single H_c ; Type-II $\rightarrow$ Two critical fields, H_{c1} and H_{c2} .
- Superconductivity enables applications in medicine, transportation, and computing.

Chapter 4

Recent Inventions

4.1 Introduction

The field of materials science and nanotechnology has led to revolutionary advances in electronics, energy storage, and communication systems. Recent inventions in this domain have largely been driven by the need for higher efficiency, miniaturization, environmental sustainability, and faster data transfer. This chapter discusses three groundbreaking innovations that are reshaping modern technology:

- High-Performance Solid-State Batteries with Superionic Electrolytes
- Graphene Superconductivity for Advanced Devices
- Enhanced Electronic Device Efficiency with Minimal Energy Loss

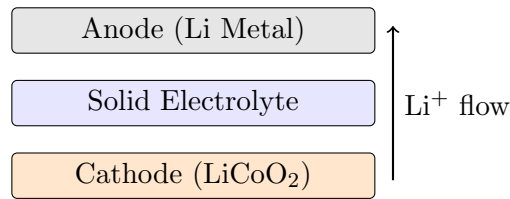
4.2 High-Performance Solid-State Batteries with Superionic Electrolytes

4.2.1 Overview

Traditional lithium-ion batteries rely on liquid electrolytes, which pose safety risks such as leakage, flammability, and limited lifespan. **Solid-state batteries (SSBs)** overcome these challenges by replacing liquid electrolytes with solid electrolytes that allow ionic conduction without the risk of leakage.



4.2.2 Structure and Working Principle



In SSBs:

- Lithium ions move through a **solid-state electrolyte (SSE)** rather than a liquid.
- Superionic conductors such as **Li₁₀GeP₂S₁₂ (LGPS)** or **Li₇La₃Zr₂O₁₂ (LLZO)** provide high ionic mobility comparable to that in liquids.
- The absence of liquid improves stability and enables **higher energy density**.

4.2.3 Advantages

- **Safety:** Non-flammable and thermally stable.
- **Longer life:** Reduced degradation and dendrite formation.
- **High energy density:** Allows for lighter and smaller batteries.
- **Fast charging:** Enhanced ionic conductivity enables rapid charge/discharge cycles.

4.2.4 Applications

- Electric vehicles (EVs)
- Wearable electronics
- Aerospace systems

Numerical Example: If a solid-state battery has an energy density of 900 Wh/L and a smartphone battery volume of 10 cm³, then:

$$E = 900 \times \frac{10}{1000} = 9 \text{ Wh}$$

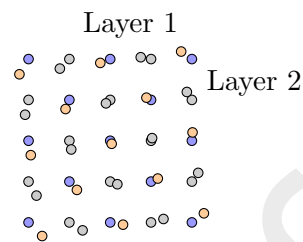
Thus, such a phone could last nearly twice as long as one using a traditional Li-ion battery.



4.3 Graphene Superconductivity and Its Applications

4.3.1 Introduction

Graphene, a single layer of carbon atoms arranged in a hexagonal lattice, exhibits remarkable electrical, mechanical, and thermal properties. In recent years, experiments have revealed **superconductivity in twisted bilayer graphene** (TBG) — when two layers of graphene are stacked at a small angle (1.1°), known as the *magic angle*.



4.3.2 Key Features of Graphene Superconductivity

- **Zero resistance:** Enables efficient current flow.
- **Quantum coherence:** Supports supercurrents and Josephson effects.
- **High flexibility:** Ideal for **foldable smartphones** and **wearable sensors**.

4.3.3 Applications

1. **Biosensors:** Graphene superconductors enhance sensitivity in detecting biomolecules due to quantum tunneling effects.
2. **Foldable Smart Devices:** Graphene's flexibility and high conductivity enable next-generation flexible screens and microcircuits.
3. **Quantum Circuits:** Used in superconducting qubits for quantum computing.

Formula for Surface Conductivity:

$$\sigma = ne\mu$$

where n = carrier density, e = electron charge, μ = carrier mobility.

For graphene, $\mu \approx 2 \times 10^5 \text{ cm}^2/\text{V}\cdot\text{s}$, making it one of the most conductive materials known.



4.4 Improved Performance of Electronic Devices with Minimum Energy Losses

4.4.1 Background

Energy loss due to resistive heating (I^2R losses) and leakage currents in microelectronic components limits efficiency and performance. Recent material and architectural innovations aim to reduce these losses through:

- Quantum tunneling transistors
- High- k dielectric materials
- Low-power nano-switching devices

4.4.2 Techniques to Reduce Energy Loss

1. **Use of Wide Bandgap Semiconductors:** Materials like **SiC (Silicon Carbide)** and **GaN (Gallium Nitride)** withstand high voltages with low conduction losses.
2. **Quantum Dot Devices:** Operate through discrete energy levels, minimizing scattering and leakage.
3. **Spintronics:** Exploits electron spin instead of charge, reducing heat generation.
4. **Superconducting Circuits:** Enable dissipationless current flow — used in next-gen computing systems.

4.4.3 Example: Power Reduction in GaN Devices

For a GaN transistor operating at $V = 5$ V, $I = 0.1$ A, and $R = 0.1$ Ω :

$$P_{\text{loss}} = I^2 R = (0.1)^2 \times 0.1 = 0.001 \text{ W}$$

For a silicon transistor with $R = 1$ Ω ,

$$P_{\text{loss}} = 0.01 \text{ W}$$

Hence, the GaN device reduces losses by nearly 90

4.4.4 Future Prospects

- Development of **superconducting logic circuits**.



- Integration of **graphene** and **GaN** for ultra-low-power processors.
- Use of **neuromorphic chips** inspired by human brain energy efficiency.

4.5 Summary

- **Solid-state batteries** with superionic electrolytes provide safe, long-lasting, and energy-dense storage.
- **Graphene superconductivity** opens the path for quantum devices, biosensors, and foldable electronics.
- **Advanced semiconductor materials** such as GaN and SiC minimize power loss, enhancing device efficiency.

Unit – 3

Lasers and Fiber Optics

Ch 5 : Lasers - Introduction, Spontaneous and Stimulated Emission of Radiation, Conditions for Amplification, Main Components of Laser, Ruby Laser, Semiconductor Laser, Holography

Ch 6 : Fiber Optics - Principle of Optical Fiber, Basic Structure, Types of Fibers, Acceptance Angle and Cone, Numerical Aperture, Losses in Fibers.

Chapter 5

Lasers

5.1 Introduction

A **Laser** (Light Amplification by Stimulated Emission of Radiation) is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. Unlike ordinary light sources, lasers emit coherent, monochromatic, and highly directional light.

- **Coherent:** All emitted photons are in phase and have the same frequency.
- **Monochromatic:** The emitted light consists of a single wavelength.
- **Directional:** The beam spreads very little; it is highly collimated.
- **High Intensity:** Laser light has a very high energy density compared to ordinary light sources.

5.2 Spontaneous and Stimulated Emission of Radiation

Atoms or molecules can occupy various energy levels. The interaction between photons and these energy levels gives rise to different emission phenomena.

5.2.1 Spontaneous Emission

When an excited atom returns to a lower energy level without external influence, it emits a photon.

$$E_2 - E_1 = h\nu$$

where E_2 and E_1 are the higher and lower energy states respectively, h is Planck's constant, and ν is the frequency of emitted radiation.

**Characteristics:**

- Random direction and phase.
- Source of incoherent light (e.g., ordinary lamps).

5.2.2 Stimulated Emission

When an incident photon of energy $h\nu$ interacts with an atom in an excited state, it can cause the atom to emit another photon of the same energy, phase, and direction.

Key Point: This process forms the basis of laser action — both photons travel coherently in the same direction.

5.2.3 Population Inversion

For stimulated emission to dominate spontaneous emission, the number of atoms in the excited state (N_2) must exceed those in the lower state (N_1):

$$N_2 > N_1$$

This condition is called **population inversion**, and it is achieved using a **pumping mechanism** (optical, electrical, or chemical).

5.3 Conditions for Laser Amplification

1. **Population Inversion:** Must be established between two energy levels.
2. **Optical Resonator:** Mirrors at both ends reflect photons back and forth to amplify stimulated emission.
3. **Gain Medium:** Material where population inversion is achieved.

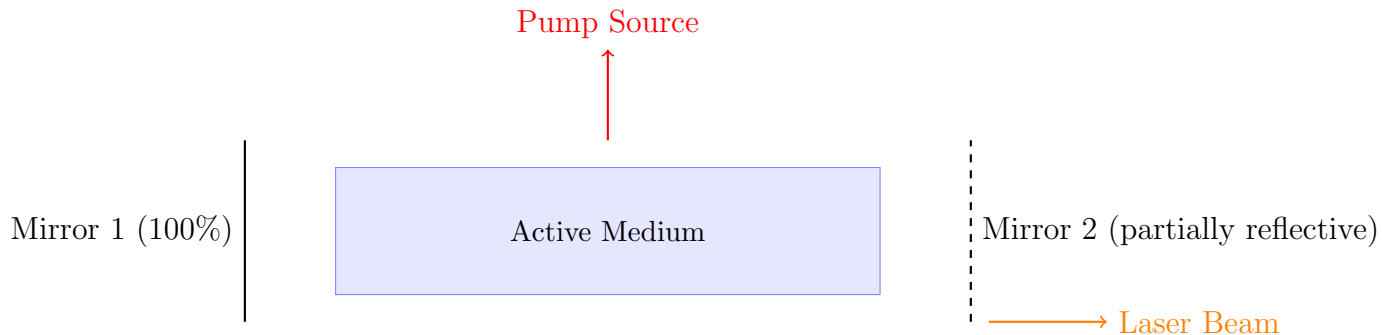
When these conditions are satisfied, photons stimulate further emissions, causing an avalanche effect — a chain reaction of light amplification.

5.4 Main Components of a Laser

1. **Active Medium:** The lasing material that provides amplification (e.g., Ruby crystal, He-Ne gas, semiconductor diode).
2. **Pump Source:** Supplies energy to achieve population inversion (e.g., flash lamp, electric discharge).



3. **Optical Resonator:** Consists of two mirrors placed at opposite ends of the active medium — one fully reflective and the other partially reflective for output coupling.



5.5 Types of Lasers

5.5.1 Ruby Laser

Active Medium: A single crystal of ruby ($\text{Al}_2\text{O}_3 : \text{Cr}^{3+}$). **Pump Source:** Flash lamp.

Wavelength: 694.3 nm (red light).

Working Principle:

1. Flash lamp excites Cr^{3+} ions from ground state to higher levels.
2. They quickly relax to a metastable state, creating population inversion.
3. Stimulated emission produces coherent red light.

Characteristics:

- First operational laser (Maiman, 1960).
- Operates in pulsed mode.

5.5.2 Semiconductor Laser (Diode Laser)

Active Medium: p-n junction semiconductor (e.g., GaAs). **Pumping:** Forward bias current. **Wavelength:** Typically between 630 nm to 1550 nm.

Working:

- Electrons and holes recombine at the junction, releasing photons.
- Mirrors on the chip edges form a resonant cavity.
- Output beam emerges through the partially reflecting facet.



Advantages:

- Compact and efficient.
- Widely used in CD/DVD players, barcode scanners, and fiber-optic communications.

5.6 Holography

Definition: Holography is a technique for recording and reconstructing the **three-dimensional** image of an object using the interference of coherent laser light.

Steps:

1. A laser beam is split into two parts — *object beam* and *reference beam*.
2. The object beam reflects off the object, while the reference beam directly hits the photographic plate.
3. The interference pattern formed on the plate is called a **hologram**.
4. When illuminated with the same laser light, the hologram reconstructs a 3D image of the object.

Applications:

- 3D imaging and data storage.
- Security holograms on bank cards and currency.
- Medical imaging and microscopy.

5.7 Applications of Lasers

1. **Industrial:** Cutting, welding, drilling, and material processing.
2. **Medical:** Eye surgeries (LASIK), cancer treatment, and tissue repair.
3. **Communication:** Optical fiber transmission.
4. **Scientific Research:** Spectroscopy, interferometry, and isotope separation.
5. **Defense:** Target designation, range finding, and directed energy weapons.



5.8 Key Formulae and Numerical Concepts

- Photon Energy: $E = h\nu = \frac{hc}{\lambda}$
- Power of Laser Beam: $P = \frac{E}{t}$
- Intensity: $I = \frac{P}{A}$
- Example: Calculate energy of a photon of wavelength 632.8 nm:

$$E = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{632.8 \times 10^{-9}} = 3.14 \times 10^{-19} \text{ J}$$

5.9 Conclusion

Lasers represent one of the most powerful and versatile technologies in modern science. From medical advancements to precision manufacturing and communications, their coherent, monochromatic, and directional nature makes them indispensable in numerous fields of technology and research.

Chapter 6

Fiber Optics

6.1 Introduction

Fiber optics is a technology that transmits light signals through thin strands of glass or plastic fibers. It plays a crucial role in high-speed communication systems, offering low loss, high bandwidth, and immunity to electromagnetic interference.

Definition: An **optical fiber** is a flexible, transparent fiber made of glass (silica) or plastic, slightly thicker than a human hair, used to transmit light between the two ends.

6.2 Principle of Optical Fiber

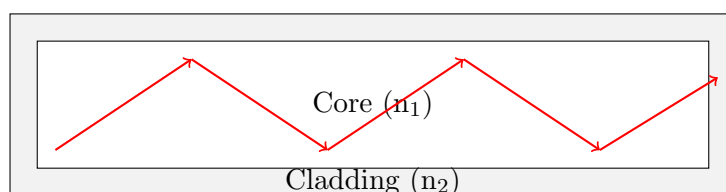
The working of optical fibers is based on the principle of **Total Internal Reflection (TIR)**.

Total Internal Reflection: When light travels from a denser medium (core) to a rarer medium (cladding) and the angle of incidence exceeds the **critical angle**, the light is completely reflected within the core.

$$\text{Condition for TIR: } i > i_c \quad \text{where } i_c = \sin^{-1} \left(\frac{n_2}{n_1} \right)$$

Here, n_1 and n_2 are the refractive indices of the core and cladding respectively ($n_1 > n_2$).

Working: Light entering one end of the fiber at a suitable angle is reflected repeatedly along the length of the fiber, thus propagating from one end to the other with minimal loss.

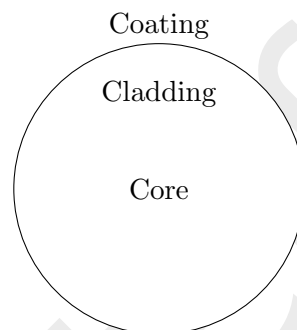




6.3 Basic Structure of an Optical Fiber

An optical fiber consists of three main parts:

1. **Core:** Central region where light travels; made of glass or plastic with a high refractive index.
2. **Cladding:** Surrounds the core with a slightly lower refractive index to ensure total internal reflection.
3. **Protective Coating (Buffer):** Outer layer that protects the fiber from physical damage and moisture.



6.4 Types of Optical Fibers

Optical fibers are classified based on the **refractive index profile** and **mode of propagation**.

6.4.1 Based on Refractive Index Profile

1. **Step Index Fiber:** Refractive index changes abruptly between core and cladding.

$$n(r) = \begin{cases} n_1 & r < a \\ n_2 & r \geq a \end{cases}$$

2. **Graded Index Fiber:** Refractive index decreases gradually from the center to the edge of the core, reducing modal dispersion.

$$n(r) = n_1 \sqrt{1 - 2\Delta \left(\frac{r}{a}\right)^2}$$

$$\text{where } \Delta = \frac{n_1^2 - n_2^2}{2n_1^2}.$$



6.4.2 Based on Mode of Propagation

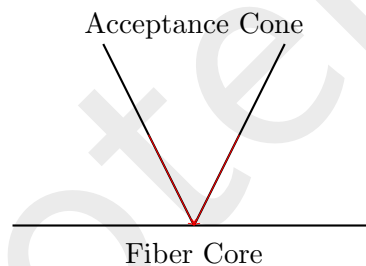
- **Single-Mode Fiber (SMF):** Small core diameter (8–10 μm); allows only one path (mode) for light; used for long-distance communication.
- **Multi-Mode Fiber (MMF):** Larger core diameter (50–100 μm); multiple paths; used for short-distance data links.

6.5 Acceptance Angle and Cone

Only rays entering within a certain angle from the fiber axis will be guided through the fiber by total internal reflection. This maximum angle is called the **acceptance angle** (θ_a).

$$\sin \theta_a = \sqrt{n_1^2 - n_2^2}$$

The cone formed by all such rays is called the **acceptance cone**.



6.6 Numerical Aperture (NA)

The **Numerical Aperture** defines the light-gathering capacity of an optical fiber and is given by:

$$\text{NA} = n_0 \sin \theta_a = \sqrt{n_1^2 - n_2^2}$$

where n_0 is the refractive index of the medium outside the fiber (usually air, $n_0 = 1$).

Example: If $n_1 = 1.48$ and $n_2 = 1.46$,

$$\text{NA} = \sqrt{1.48^2 - 1.46^2} = 0.242$$

$$\theta_a = \sin^{-1}(0.242) = 14.0^\circ$$

6.7 Losses in Optical Fibers

During propagation, some signal power is lost due to various mechanisms. Major losses include:



1. **Absorption Loss:** Due to impurities (OH^- , transition metals) in the glass absorbing light energy.
2. **Scattering Loss:** Caused by microscopic variations in the glass density — known as **Rayleigh scattering**.

$$\alpha_s \propto \frac{1}{\lambda^4}$$

(Loss decreases with increasing wavelength.)

3. **Bending Loss:**

- **Macrobending:** Large-scale bends causing leakage of light.
- **Microbending:** Small, irregular distortions causing scattering loss.

4. **Connector and Splice Loss:** Due to misalignment or imperfect joining between fiber ends.

6.8 Advantages of Optical Fibers

- Extremely high bandwidth.
- Low transmission loss.
- Immunity to electromagnetic interference.
- Lightweight and flexible.
- Secure data transmission (difficult to tap).

6.9 Applications of Fiber Optics

1. **Telecommunication:** Long-distance and high-speed internet communication.
2. **Medical:** Endoscopy and laser surgeries.
3. **Industrial:** Sensors for temperature and pressure monitoring.
4. **Defense:** Secure communication links and missile guidance.
5. **Lighting:** Decorative and illumination systems.



6.10 Conclusion

Fiber optics has revolutionized modern communication by offering high-speed, low-loss data transmission over long distances. Its principle of total internal reflection and superior material design make it an essential technology in networking, medicine, and sensing applications.

Notefity

Solved Practice Questions on Lasers and Fiber Optics

Lasers

Q1. What is the basic difference between spontaneous and stimulated emission?

Solution:

- In **spontaneous emission**, an excited atom returns to a lower energy state on its own, emitting a photon randomly in phase and direction.
- In **stimulated emission**, an incoming photon induces an excited atom to emit another photon with the *same phase, frequency, and direction*, leading to **coherent light**.

Q2. Derive the condition for population inversion in a laser medium.

Solution: For amplification, the population of the upper energy level must exceed that of the lower level:

$$N_2 > N_1$$

From the Boltzmann distribution:

$$\frac{N_2}{N_1} = e^{-\frac{E_2 - E_1}{kT}}$$

Normally $N_2 < N_1$, so population inversion requires an external pumping mechanism (optical, electrical, or chemical) to achieve $N_2 > N_1$.



Q3. Calculate the wavelength of laser light if the energy difference between two levels is 2.0 eV.

Solution:

$$E = h\nu = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E}$$

Substituting, $h = 6.63 \times 10^{-34}$ J·s, $c = 3 \times 10^8$ m/s, $E = 2.0 \times 1.6 \times 10^{-19}$ J

$$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{3.2 \times 10^{-19}} = 6.21 \times 10^{-7} \text{ m} = 621 \text{ nm}$$

Hence, wavelength of the laser is **621 nm** (red region).

Q4. What are the main components of a laser?

Solution:

1. **Active medium:** Provides population inversion (e.g., ruby crystal).
2. **Energy source (pump):** Excites atoms to higher energy levels.
3. **Optical resonator:** Pair of mirrors that reflect light back and forth, amplifying coherent light.

Q5. Explain the working of a Ruby Laser.

Solution:

- Active medium: Al_2O_3 crystal doped with Cr^{3+} .
- Pumping: Optical pumping using a xenon flash lamp.
- Lasing transition: From metastable state E_2 to ground state E_1 , producing red light of wavelength 694.3 nm.

Result: Coherent and monochromatic laser beam is emitted.

Q6. What are the applications of lasers?

Solution:

- **Medicine:** Eye surgery, cancer treatment, and tissue removal.
- **Industry:** Cutting, welding, and drilling of metals.



- **Communication:** Optical fiber data transmission.
- **Scientific Research:** Spectroscopy and holography.

Fiber Optics

Q7. State the principle on which optical fibers work.

Solution: Optical fibers work on the principle of **Total Internal Reflection (TIR)**. When light travels from a denser (core) to a rarer (cladding) medium and the incident angle exceeds the critical angle:

$$i > i_c = \sin^{-1} \left(\frac{n_2}{n_1} \right)$$

Light reflects completely inside the core, propagating through the fiber.

Q8. Calculate the numerical aperture (NA) and acceptance angle for a fiber having $n_1 = 1.50$, $n_2 = 1.47$.

Solution:

$$\text{NA} = \sqrt{n_1^2 - n_2^2} = \sqrt{1.50^2 - 1.47^2} = \sqrt{0.0881} = 0.297$$

$$\theta_a = \sin^{-1}(0.297) = 17.3^\circ$$

Hence, NA = 0.297 and acceptance angle = 17.3° .

Q9. Differentiate between single-mode and multi-mode fibers.

	Single-Mode Fiber	Multi-Mode Fiber
	Small core diameter (10 μm)	Large core diameter (50 μm)
Solution:	Allows only one propagation path	Multiple propagation paths
	Low dispersion, used for long-distance	High dispersion, used for short-distance

Q10. A fiber has NA = 0.22. Calculate the acceptance angle in air.

Solution:

$$\sin \theta_a = \text{NA} = 0.22$$



$$\theta_a = \sin^{-1}(0.22) = 12.7^\circ$$

Hence, acceptance angle = 12.7° .

Q11. Explain any two types of losses in optical fibers.

Solution:

- **Absorption Loss:** Due to impurities and defects in the fiber material that absorb part of the signal.
- **Bending Loss:** Light leakage occurs when the fiber is bent beyond a critical radius.

Q12. List major applications of optical fibers.

Solution:

1. **Telecommunication:** Long-distance data transmission.
2. **Medical Field:** Endoscopy and imaging.
3. **Industrial Use:** Sensors for temperature and strain.
4. **Defense:** Secure and lightweight communication links.



Final Examination – Sample Paper

Total Marks : 60

Time Allotted : 3 hours

Instructions:

- The question paper consists of 3 sections. It is compulsory for students to attempt all questions of Section A and Section B.
- Section A has 5 questions of 2 marks each, Section B has 4 questions of 5 marks each, and Section C has 4 questions of 10 marks each (out of which any 3 are to be attempted).
- Question no. 10 & 11 of Section C are compulsory to be attempted.
- Students to attempt ANY ONE question from question no. 12 & question no. 13 of Section C.

Section A (5x2 = 10 marks)

1. How can carbon-based nanomaterials improve the performance of solar cells and energy storage devices?
2. Compare Type-I and Type-II superconductors based on their magnetic field response and critical temperature characteristics.
3. What is population inversion? Why is it essential in laser optics?
4. Differentiate between single-mode and multi-mode fibers in terms of structure, dispersion, and performance.
5. What do you mean by holography? State some of its applications.

Section B (4x5 = 20 marks)

6. A particle of mass $9.1 \times 10^{-31} \text{ kg}$ is confined in a box of length 1 nm . Calculate its minimum energy using quantum principles and explain the significance of quantization in this context.



7. Graphene has been observed to exhibit superconducting properties under certain conditions. Explain the underlying mechanism and its implications for flexible electronics.
8. Explain how total internal reflection enables light propagation in optical fibers, and discuss factors that cause signal loss during transmission.
9. Calculate the numerical aperture (NA) and acceptance angle for an optical fiber with core refractive index 1.48 and cladding refractive index 1.46 .
($\sin^{-1}(0.2425) = 14.0^\circ$).

Section C (3x10 = 30 marks)

10. Compare and contrast top-down and bottom-up approaches for the synthesis of nanomaterials with respect to scalability, precision, and cost.
11. Discuss the phenomenon of superconductivity with reference to the Meissner effect and list its applications.
12. Compare Ruby and Semiconductor lasers in terms of their construction, working principle, and applications.

OR

13. Explain the difference between spontaneous and stimulated emission of radiation. How do these phenomena lead to the principle of laser action?