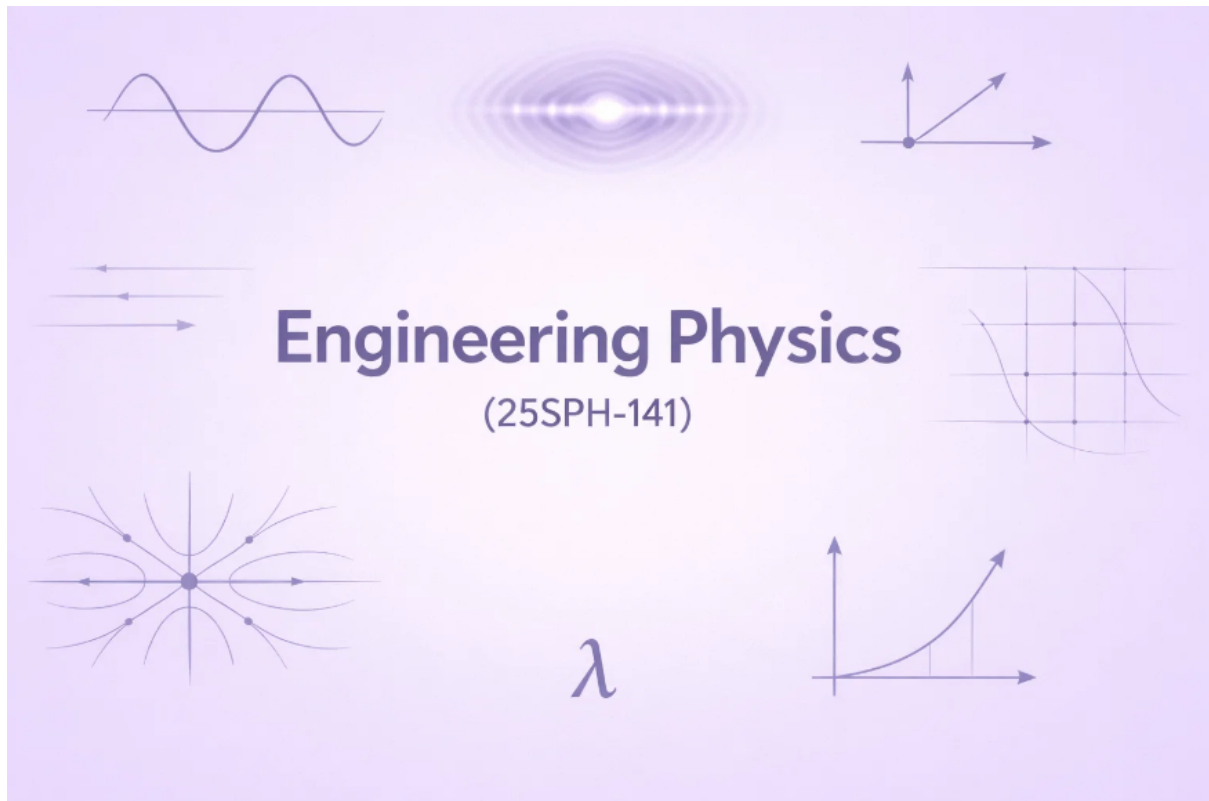




Unit 3 - Resources & Questions

Compiled by : Subhayu



Syllabus Covered So Far

Unit 1

Chapter 1 : Quantum Physics and Nanotechnology

Quantum theory (postulates only), 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 approaches, ball milling method, sol-gel method

Chapter 2 : Recent Inventions in Quantum Physics and Nanotechnology

Quantum computing – applications in weather forecasting and cryptography, edge computing – applications in IoT, driverless cars and healthcare, carbon nanomaterials – carbon-based nano additives, semiconductor nanodevices – nanomanipulators and nano-transistors, green nanotechnology – bioremediation and biotransformation of soil, wastewater, oil spills and toxic pollutants, nanocomposites for coatings, additives, catalysts and structural components, nano-sensors for contamination detection, environmental measurements, remote sensing and communication, nanoencapsulation for drug delivery, bioimaging, theragnosis and immunization, nanomaterials for water treatment, nanotechnology for energy harvesting – electrodes and solar cells

For Unit-1 Notes: [Click here](#)

Unit 2

Chapter 3 : Solid State Physics

Classification of solids, crystal structure, Bravais lattices, simple cubic (SC), body-centered cubic (BCC) and face-centered cubic (FCC) structures, atomic packing efficiency, coordination number and related parameters, Miller indices, interplanar spacing, superconductors, critical temperature, Meissner effect, Type-I and Type-II superconductors, applications of superconductivity

Chapter 4 : Recent Inventions in Solid State Physics

High-performance solid-state batteries with superionic electrolytes, graphene superconductivity – applications in biosensors and foldable smartphones, improved performance of electronic devices with minimum energy losses

For Unit-2 Notes: [Click here](#)



Syllabus for Unit 3

Engineering Physics (25SPH-241)

Chapter 1 : Lasers – Introduction to lasers, spontaneous emission and stimulated emission of radiation, conditions for amplification, main components of a laser, ruby laser, semiconductor laser, holography

Chapter 2 : Fiber Optics – Principle of optical fiber, basic structure of optical fiber, types of optical fibers, acceptance angle and acceptance cone, numerical aperture, losses in optical fibers

Chapter 1

Lasers

1.1 Introduction to Lasers

1.1.1 What is a Laser?

A **LASER** stands for *Light Amplification by Stimulated Emission of Radiation*. It is a device that produces a highly **coherent, monochromatic, and directional beam of light**.

1.1.2 Key Characteristics of Laser Light

- **Monochromatic:** Single wavelength (single color)
- **Coherent:** Waves are in phase
- **Directional:** Travels in a narrow beam with very little divergence
- **High Intensity:** Concentrated energy

Important Insight

Unlike ordinary light sources (like bulbs), lasers produce **organized and highly focused light**.

1.1.3 Basic Components of a Laser System

- **Active Medium:** Material where light amplification occurs (e.g., ruby, gas)
- **Energy Source (Pump):** Supplies energy to excite atoms
- **Optical Resonator:** Two mirrors to amplify light through reflection

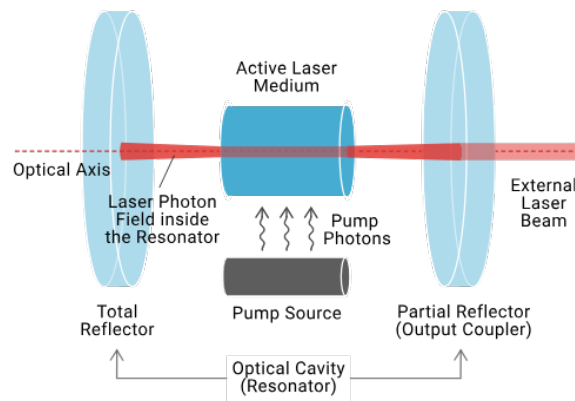


Figure 1.1: Laser System Components

1.1.4 Working Principle (Overview)

- Atoms in the active medium absorb energy and get excited
- They emit light through stimulated emission
- Light bounces between mirrors, getting amplified
- A strong beam emerges as laser output

1.1.5 Example

Laser pointers, medical lasers, and barcode scanners are common real-life applications of lasers.

1.2 Spontaneous Emission and Stimulated Emission

1.2.1 Spontaneous Emission

Definition:

Spontaneous emission is the process by which an excited atom returns to a lower energy state **on its own**, emitting a photon.

Characteristics:

- Random direction of emission
- Random phase and frequency
- Incoherent light



1.2.2 Example

Light emitted from a glowing filament (bulb) is due to spontaneous emission.

Common Doubt

Q: Why is spontaneous emission not suitable for lasers?

A: Because it produces **incoherent and random light**, which cannot be amplified effectively.

1.2.3 Stimulated Emission

Definition:

Stimulated emission occurs when an incoming photon forces an excited atom to emit another photon **identical in phase, frequency, and direction**.

Characteristics:

- Produces coherent light
- Photons are identical
- Leads to amplification of light

1.2.4 Key Difference

Aspect	Spontaneous Emission	Stimulated Emission
Control	Uncontrolled	Controlled
Light Type	Incoherent	Coherent
Direction	Random	Same direction
Use in Laser	Not useful	Essential

1.2.5 Solved Example

Problem: Why is stimulated emission preferred in lasers?

Solution:

- Produces identical photons
- Ensures coherence and directionality
- Enables amplification of light



1.3 Conditions for Amplification

1.3.1 Introduction

For a laser to work, light must be **amplified**. This requires specific physical conditions.

1.3.2 Population Inversion

Definition:

A condition where the number of atoms in the excited state is **greater** than those in the ground state.

Key Concept

Population inversion is the **essential requirement** for laser action.

1.3.3 Why Population Inversion is Needed

- Ensures more stimulated emission than absorption
- Leads to net amplification of light

1.3.4 Metastable State

- An excited state where atoms stay longer than usual
- Helps in achieving population inversion

1.3.5 Optical Feedback (Resonator)

- Mirrors reflect photons back and forth
- Increases chances of stimulated emission

1.3.6 Condition for Amplification

- Rate of stimulated emission $>$ rate of absorption

1.3.7 Example

In a laser medium, if 70% atoms are excited and 30% are in ground state, stimulated emission dominates, leading to amplification.



1.3.8 Solved Example

Problem: Why cannot laser action occur without population inversion?

Solution:

- Without inversion, absorption dominates emission
- No net amplification occurs
- Hence, laser action is not possible

Final Insight

Laser action requires **stimulated emission + population inversion + optical feedback**.

1.4 Laser Systems and Applications

1.4.1 Overview

Every laser system consists of three essential components that work together to produce coherent light.

1.4.2 1. Active Medium

- The material in which laser action occurs
- Can be solid (ruby), liquid (dye), or gas (He-Ne)
- Atoms in this medium undergo excitation and emission

1.4.3 2. Pumping Source

- Supplies energy to excite atoms
- Types: Optical pumping (flash lamp), electrical pumping, chemical pumping

1.4.4 3. Optical Resonator

- Consists of two mirrors:
 - One fully reflecting mirror
 - One partially reflecting mirror
- Amplifies light by repeated reflections



Key Insight

Laser output is produced when amplified light escapes through the **partially reflecting mirror**.

1.4.5 Solved Example

Problem: What happens if the resonator is removed from a laser system?

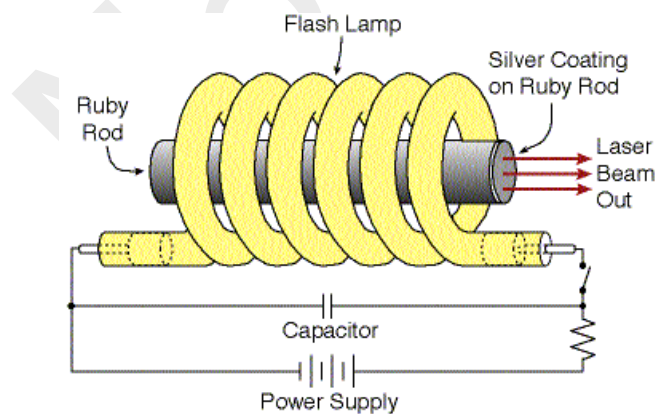
Solution:

- No amplification through repeated reflections
- Only spontaneous emission occurs
- Laser action fails

1.5 Ruby Laser

1.5.1 Introduction

The **ruby laser** is a **solid-state laser** that uses a ruby crystal as the active medium.



1.5.2 Construction

- Active medium: Ruby rod (Al_2O_3 doped with Cr^{3+} ions)
- Pumping source: Xenon flash lamp
- Resonator: Two mirrors at the ends of the rod



1.5.3 Working Principle

1. Flash lamp excites chromium ions to higher energy levels
2. Electrons move to metastable state
3. Population inversion is achieved
4. Stimulated emission produces coherent red light

1.5.4 Output

- Wavelength: 694.3 nm (red light)

Important Concept

Ruby laser operates on a **three-level energy system**.

1.5.5 Advantages and Limitations

- **Advantages:**
 - High output intensity
- **Limitations:**
 - Low efficiency
 - Requires high pumping energy

1.5.6 Solved Example

Problem: Why is ruby laser less efficient?

Solution:

- It uses a three-level system
- Requires more energy to achieve population inversion

1.6 Semiconductor Laser

1.6.1 Introduction

A **semiconductor laser** (or diode laser) uses a **p-n junction** as the active medium.

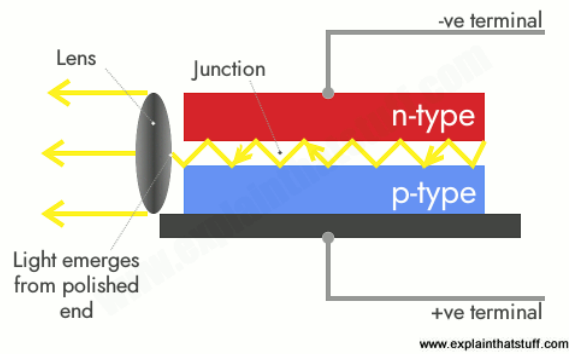


Figure 1.2: Semiconductor Laser

1.6.2 Construction

- Active medium: Semiconductor material (e.g., GaAs)
- Pumping: Electrical current
- Resonator: Cleaved crystal surfaces act as mirrors

1.6.3 Working Principle

1. Forward bias is applied across p-n junction
2. Electrons and holes recombine
3. Energy is released as photons
4. Stimulated emission leads to laser output

1.6.4 Characteristics

- Compact and efficient
- Operates at low power
- High modulation speed

Key Insight

Semiconductor lasers are widely used in **optical communication and CD/DVD players**.

1.6.5 Solved Example

Problem: Why are semiconductor lasers preferred in communication systems?

Solution:



- Small size and low cost
- High efficiency
- Fast response time

1.7 Holography

1.7.1 Introduction

Holography is a technique of recording and reconstructing **three-dimensional images** using laser light.

1.7.2 Principle

Based on **interference and diffraction** of light waves.

1.7.3 Types of Waves Used

- **Reference Wave:** Direct beam from laser
- **Object Wave:** Light reflected from the object

1.7.4 Recording of Hologram

1. Laser beam is split into two parts
2. One beam illuminates the object (object wave)
3. Other beam acts as reference wave
4. Interference pattern is recorded on a photographic plate

1.7.5 Reconstruction

- Illuminating the hologram recreates the 3D image

Important Insight

Holography records both **amplitude and phase** of light, unlike photography.

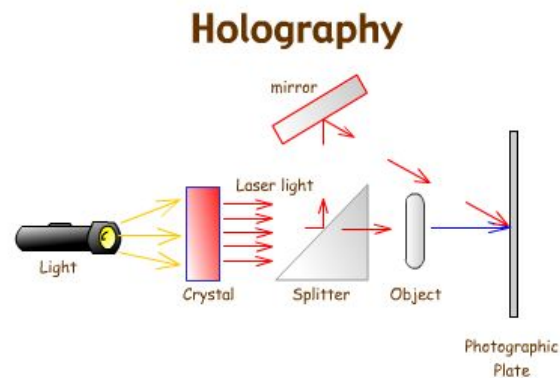


Figure 1.3: Holography

1.7.6 Applications

- Security holograms (credit cards, currency)
- Medical imaging
- Data storage

1.7.7 Solved Example

Problem: Why does holography produce 3D images while photography does not?

Solution:

- Holography records phase information
- Photography records only intensity

Chapter 2

Fiber Optics

2.1 Principle of Optical Fiber

2.1.1 Introduction

Optical fiber is a technology used for transmitting light signals through a thin glass or plastic medium. It is widely used in communication systems due to its high speed and low loss.

2.1.2 Basic Principle: Total Internal Reflection (TIR)

Definition:

Total Internal Reflection is the phenomenon in which light is completely reflected back into a denser medium when it strikes the boundary at an angle greater than the **critical angle**.

2.1.3 Conditions for Total Internal Reflection

- Light must travel from a denser medium to a rarer medium
- Angle of incidence must be greater than the critical angle

Key Concept

Optical fibers work because light is continuously reflected within the core due to **Total Internal Reflection**.

2.1.4 Working of Optical Fiber

- Light enters the fiber core at a specific angle
- It undergoes multiple internal reflections
- Travels long distances with minimal loss

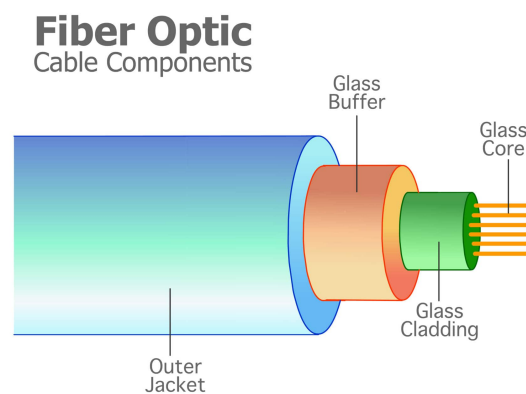


Figure 2.1: Optical Fiber

2.1.5 Solved Example

Problem: Why does light not escape from an optical fiber?

Solution:

- Due to total internal reflection at the core-cladding interface
- Light is confined within the core

2.2 Basic Structure of Optical Fiber

2.2.1 Components of Optical Fiber

- **Core:**
 - Central region through which light propagates
 - Made of high refractive index material
- **Cladding:**
 - Surrounds the core
 - Has lower refractive index than core
 - Enables total internal reflection
- **Protective Coating (Jacket):**
 - Outer layer for protection against damage



2.2.2 Refractive Index Condition

$$n_{\text{core}} > n_{\text{cladding}}$$

Important Insight

Difference in refractive index between core and cladding is essential for **light confinement**.

2.2.3 Example

In communication cables, optical fibers transmit internet data at high speeds using light pulses.

2.2.4 Solved Example

Problem: What happens if the refractive index of cladding becomes higher than the core?

Solution:

- Total internal reflection will not occur
- Light will escape the core
- Fiber will fail to guide light

2.3 Types of Optical Fibers

2.3.1 Based on Mode of Propagation

1. Single Mode Fiber

- Allows only one light path (mode)
- Small core diameter
- Used for long-distance communication

2. Multimode Fiber

- Allows multiple light paths
- Larger core diameter
- Used for short-distance communication



2.3.2 Based on Refractive Index Profile

1. Step Index Fiber

- Sudden change in refractive index between core and cladding
- Light reflects sharply at boundary

2. Graded Index Fiber

- Gradual change in refractive index
- Reduces signal distortion

2.3.3 Comparison of Fibers

Aspect	Single Mode	Multimode
Core Size	Small	Large
Distance	Long	Short
Dispersion	Low	High
Cost	High	Low

2.3.4 Applications

- Telecommunication systems
- Internet data transmission
- Medical instruments (endoscopy)

Exam Insight

Single mode fibers are preferred for **long-distance, high-speed communication**.

2.3.5 Solved Example

Problem: Which fiber type is suitable for long-distance communication and why?

Solution:

- **Single mode fiber**
- Because it has low dispersion and minimal signal loss

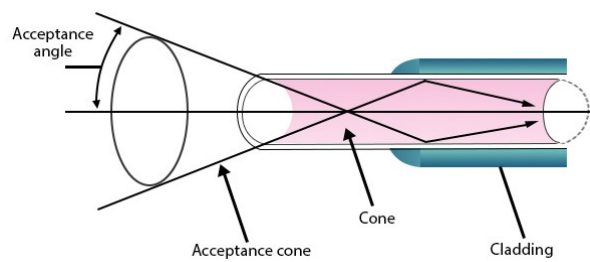


Figure 2.2: Acceptance angle and cone

2.4 Acceptance Angle and Acceptance Cone

2.4.1 Introduction

For efficient transmission of light through an optical fiber, light must enter within a specific range of angles. This range is defined using the concepts of **acceptance angle** and **acceptance cone**.

2.4.2 Acceptance Angle

Definition:

The **acceptance angle** (θ_a) is the maximum angle at which light can enter the fiber and still be guided through total internal reflection.

Expression:

$$\sin \theta_a = \sqrt{n_{\text{core}}^2 - n_{\text{cladding}}^2}$$

2.4.3 Acceptance Cone

Definition:

The **acceptance cone** is the three-dimensional cone of light rays that can enter the fiber and propagate successfully.

Key Idea:

- Axis of cone = fiber axis
- Half-angle of cone = acceptance angle

Key Insight

Only light entering within the **acceptance cone** will undergo total internal reflection and propagate through the fiber.



2.4.4 Solved Example

Problem: What happens if light enters beyond the acceptance angle?

Solution:

- It will not undergo total internal reflection
- Light will escape into the cladding
- Signal loss occurs

2.5 Numerical Aperture

2.5.1 Introduction

Numerical Aperture (NA) is a measure of the light-gathering ability of an optical fiber.

2.5.2 Definition

$$NA = \sin \theta_a$$

2.5.3 Alternate Expression

$$NA = \sqrt{n_{\text{core}}^2 - n_{\text{cladding}}^2}$$

2.5.4 Significance

- Higher NA $\Rightarrow$ more light can enter the fiber
- Lower NA $\Rightarrow$ less light acceptance

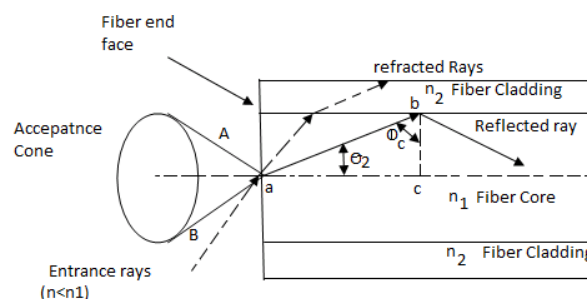


Figure 1.3: Numerical Aperture Rays

Important Concept

Numerical Aperture determines the **efficiency of light coupling** into the fiber.



2.5.5 Example

If a fiber has high NA, it is easier to couple light from a source like an LED.

2.5.6 Solved Example

Problem: If NA increases, what happens to acceptance angle?

Solution:

- Since $NA = \sin \theta_a$
- Increase in NA $\Rightarrow$ increase in θ_a
- Acceptance cone becomes wider

2.6 Losses in Optical Fibers

2.6.1 Introduction

While optical fibers are efficient, some loss of signal occurs during transmission. These are called **attenuation losses**.

2.6.2 Types of Losses

1. Absorption Loss

- Caused by impurities in the fiber material
- Converts light energy into heat

2. Scattering Loss

- Due to microscopic variations in material density
- Causes light to scatter in different directions

3. Bending Loss

- Occurs when fiber is bent
- Light escapes from the core

Common Doubt

Q: Why should optical fibers not be bent sharply?

A: Because sharp bends cause **bending losses**, leading to signal leakage.



2.6.3 Other Losses

- Connector losses
- Splicing losses

2.6.4 Impact of Losses

- Reduces signal strength
- Limits transmission distance

Key Insight

Minimizing losses is essential for **efficient long-distance communication**.

2.6.5 Solved Example

Problem: Which type of loss occurs due to impurities in fiber?

Solution:

- **Absorption loss**



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.

Q.No.	Statement
Section A (5×2 = 10 marks)	
1	A researcher wants to synthesize nanoparticles with minimal defects. Recommend a suitable method between ball milling and sol-gel and justify your choice.
2	A superconductor has a critical temperature of 7 K. Determine whether it will exhibit superconductivity at 5 K and justify.
3	Compare single-mode and multimode fibers and assess their suitability for different communication scenarios.
4	Calculate the numerical aperture of an optical fiber if $n_{\text{core}} = 1.5$ and $n_{\text{cladding}} = 1.4$.
5	A fiber optic cable is bent sharply during installation. Analyze the type of loss introduced and its impact on performance.
Section B (4×5 = 20 marks)	
6	Calculate the de Broglie wavelength of an electron moving with a velocity of 2×10^6 m/s. (Given: $h = 6.626 \times 10^{-34}$ Js, $m = 9.1 \times 10^{-31}$ kg)
7	Compare Type-I and Type-II superconductors and assess their suitability for practical applications.



Q.No.	Statement
8	Analyze the concept of holography and evaluate how it differs fundamentally from conventional photography.
9	Discuss the conditions required for population inversion and explain why it is essential for laser operation.
Section C (3×10 = 30 marks)	
10	Analyze the significance of Heisenberg's uncertainty principle in limiting the precision of measurements at the atomic level. How does it impact experimental physics?
11	Classify solids based on their structure and evaluate how this classification affects their physical properties. Compare SC, BCC, and FCC crystal structures in terms of packing efficiency and coordination number.
Optional Question for Section C	
12	Compare the working principles of ruby laser and semiconductor laser and evaluate their applications.
OR	
13	Critically evaluate different types of losses in optical fibers and suggest methods to minimize them.

Answer Key

Section A

1. Nanoparticle Synthesis Method (Ball Milling vs Sol–Gel)

Recommended Method: Sol–Gel Method

Justification:

- Produces **uniform and high-purity nanoparticles**
- Better control over particle size and structure
- Fewer defects compared to mechanical methods

Why not Ball Milling?

- Mechanical process introduces **defects and impurities**
- Less control over particle size distribution

2. Superconductivity at Given Temperature

Given: Critical temperature $T_c = 7\text{ K}$, Operating temperature = 5 K

Conclusion:

- Since $5\text{ K} < 7\text{ K}$
- Material will exhibit **superconductivity**

Reason:

- Superconductors behave ideally only **below critical temperature**

3. Single-Mode vs Multimode Fibers



Aspect	Single-Mode	Multimode
Core Size	Small	Large
Distance	Long-distance	Short-distance
Dispersion	Low	High
Cost	High	Low

Suitability:

- Single-mode: Long-distance, high-speed communication
- Multimode: Short-distance, cost-effective networks

4. Numerical Aperture Calculation

$$\begin{aligned} \text{NA} &= \sqrt{n_{\text{core}}^2 - n_{\text{cladding}}^2} \\ &= \sqrt{(1.5)^2 - (1.4)^2} = \sqrt{2.25 - 1.96} = \sqrt{0.29} \\ \text{NA} &\approx 0.54 \end{aligned}$$

5. Loss due to Sharp Bending of Fiber

Type of Loss: Bending Loss

Impact on Performance:

- Light escapes from the core
- Signal strength decreases
- Increased attenuation
- May lead to communication errors

Key Insight

Sharp bending disrupts total internal reflection, causing **signal leakage**.



Section B

6. de Broglie Wavelength Calculation

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

Given:

$$h = 6.626 \times 10^{-34} \text{ Js}, \quad m = 9.1 \times 10^{-31} \text{ kg}, \quad v = 2 \times 10^6 \text{ m/s}$$

$$\begin{aligned} \lambda &= \frac{6.626 \times 10^{-34}}{9.1 \times 10^{-31} \times 2 \times 10^6} \\ &= \frac{6.626 \times 10^{-34}}{1.82 \times 10^{-24}} \approx 3.64 \times 10^{-10} \text{ m} \end{aligned}$$

Final Answer: $\lambda \approx 0.364 \text{ nm}$

7. Type-I vs Type-II Superconductors

Aspect	Type-I	Type-II
Magnetic Behavior	Complete Meissner effect	Partial Meissner effect
Critical Field	Single critical field	Two critical fields
Materials	Pure metals	Alloys/compounds
Practical Use	Limited	Widely used

Assessment:

- Type-I: Simple but not suitable for strong magnetic fields
- Type-II: Preferred for practical applications (MRI, power cables)

8. Holography vs Photography

Holography:

- Records both **amplitude and phase**
- Produces **3D images**
- Uses laser light (coherent source)

Photography:



- Records only **intensity**
- Produces **2D images**
- Uses ordinary light

Aspect	Holography	Photography
Image Type	3D	2D
Information Stored	Amplitude + Phase	Intensity only
Light Source	Laser	Ordinary light

Evaluation:

Holography provides more detailed and realistic imaging, making it suitable for security and medical applications.

9. Population Inversion and Its Importance

Conditions Required:

- Presence of a **metastable state**
- Continuous **pumping of energy**
- Higher population in excited state than ground state

Why Essential:

- Ensures **stimulated emission dominates** over absorption
- Leads to **net amplification of light**

Conclusion:

Without population inversion, laser action is not possible as absorption would exceed emission.

Key Insight

Population inversion is the **fundamental condition** for laser operation.

Section C

10. Heisenberg's Uncertainty Principle and Its Significance

Statement:

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

Significance:



- It is impossible to simultaneously measure exact **position and momentum**
- Introduces fundamental limits to precision at atomic scale

Impact on Experimental Physics:

- Prevents exact prediction of particle trajectories
- Leads to probabilistic interpretation of quantum systems
- Influences design of high-precision instruments (electron microscopes)

Evaluation:

- Challenges classical determinism
- Forms the foundation of quantum mechanics

Key Insight

Uncertainty principle shows that nature at microscopic level is **intrinsically probabilistic**.

11. Classification of Solids and Crystal Structure Comparison**Classification of Solids:**

- **Crystalline Solids:** Ordered arrangement (e.g., metals)
- **Amorphous Solids:** Random arrangement (e.g., glass)

Effect on Properties:

- Crystalline: Anisotropic, sharp melting point
- Amorphous: Isotropic, gradual softening

Comparison of Crystal Structures:

Property	SC	BCC	FCC
Atoms per Unit Cell	1	2	4
Coordination Number	6	8	12
Packing Efficiency	52%	68%	74%

Evaluation:

- FCC has highest packing efficiency → more stable and dense



- SC is least efficient → rarely found in nature
- BCC provides balance between strength and density

Key Insight

Higher packing efficiency generally leads to **greater stability and density**.

12. Ruby Laser vs Semiconductor Laser

Comparison:

Aspect	Ruby Laser	Semiconductor Laser
Type	Solid-state	Diode (p-n junction)
Pumping	Optical (flash lamp)	Electrical
Efficiency	Low	High
Size	Bulky	Compact

Working Principle:

- Ruby: Stimulated emission in a three-level system
- Semiconductor: Electron-hole recombination produces photons

Applications:

- Ruby: Medical lasers, research
- Semiconductor: Optical communication, CDs, laser printers

Evaluation:

- Semiconductor lasers are more practical due to efficiency and size
- Ruby lasers are limited but useful for high-intensity applications

13. Losses in Optical Fibers and Minimization

Types of Losses:

- **Absorption Loss:** Due to impurities
- **Scattering Loss:** Due to material irregularities
- **Bending Loss:** Due to fiber curvature

Effects:



- Signal attenuation
- Reduced transmission distance
- Lower efficiency

Minimization Methods:

- Use high-purity materials
- Avoid sharp bends
- Improve manufacturing quality
- Use proper connectors and splicing techniques

Evaluation:

- Minimizing losses is essential for long-distance communication
- Technological improvements continuously reduce attenuation

Key Insight

Efficient optical communication depends on **minimizing losses and maintaining signal integrity**.

Closing Note

I sincerely hope that these notes and the preparatory questions included alongside them prove helpful in strengthening your understanding and boosting your confidence for the examination you are preparing for.

As you revise, try not to rush through the content—pause at examples, work out the numericals on your own, and revisit sections that feel slightly uncomfortable. That discomfort usually signals learning in progress. Use these notes as a guide and a companion, not as something to be memorized line by line.

Wishing you the very best for your exams—may your preparation feel clear, structured, and calm when it matters most.

For future updates, refinements, and additional resources, keep checking **Noteify**:

<https://subhayu18.github.io/Noteify/>

If you have any doubts, suggestions, or simply wish to connect, feel free to reach out to me on LinkedIn:

<https://www.linkedin.com/in/subhayu-mukherjee-146421294/>

You can also use the direct contact options provided on the Noteify website itself.

Regards,
Subhayu