APPLIED PHYSICS 1 Question Bank

📢 Important Note Regarding Applied Physics Question Bank

Dear First-Year Engineering Students,

We are pleased to provide you with a carefully prepared Applied Physics Question Bank based on the analysis of past year question papers (PYQs) adhering to the NEP 2020 syllabus.

Please read this **caution** carefully:

1. **Reference Material Only:** This Question Bank is solely for reference and practice purposes. It is designed to highlight the most frequently tested concepts and question structures from the past.
2. **No Guarantee:** There is absolutely no guarantee that the questions in the upcoming examination will be drawn *exclusively* from this set.
3. **Comprehensive Preparation is Key:** High scores are achieved by mastering the entire syllabus (Modules I through VI), understanding the underlying concepts, and practising both derivations and numerical problems.
4. **Do check PYQs for questions that are not given here**

Our recommendation is to **use this Question Bank as a guide to:**

- **Identify High-Priority Topics** (e.g., Numerical Aperture, He-Ne Laser, Fermi Level, Divergence of Curl).
- **Master the Standard Derivations** (5-mark questions) and practice solving **Numericals** (3-mark and 5-mark questions).

Do not limit your study to these questions alone. Ensure you cover all the concepts listed in the Applied Physics syllabus for complete and thorough preparation.

Read the question bank till the **Last Page** for maximum benefit.

Best of luck with your studies!

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List of IMP/Frequent Questions Module Wise:

Module I: Lasers

1. What is a **metastable state**? What is the **role of metastable state in LASER**?
2. With a neat energy level diagram, explain the **construction and working of He-Ne Laser**.
3. What is **resonant cavity**? Explain its use in the generation of Laser beams
4. What is **Lidar technology** and how does it work?
5. Define **Spontaneous and Stimulated Emission**. Why is stimulated emission essential for LASER action?

Module II: Fibre Optics

1. **Derive an expression for Numerical Aperture (NA)** of a step index optical fibre. Give its physical significance.
2. Define the terms: **Critical angle, Acceptance angle, and Attenuation**.
3. The refractive indices of core and cladding are 1.48 and 1.45 respectively. Calculate: (i) Numerical Aperture, (ii) Acceptance Angle, and (iii) Critical Angle.
4. **Compare Step Index fiber and Graded Index Fiber** (based on structure, propagation, and attenuation).

Module III: Interference

1. Obtain the **condition for maxima and minima** of the light **reflected from a thin transparent film of uniform thickness**.
2. In a Newton's ring experiment, the diameter of the 5th dark ring was 0.336 cm and the 15th dark ring was 0.590 cm. Find the **radius of curvature** of the plano-convex lens if the wavelength is 5890 A (angstrom).
3. With the experimental setup, explain the determination of the **refractive index of a liquid** using **Newton's rings**.
4. What is **antireflection coating**? What should be the refractive index and minimum thickness of the coating?

Module IV: Electrodynamics

1. Show that the divergence of the curl of a vector is zero.
2. State **Ampere's Circuital Law**. **Derive Maxwell's fourth equation** in differential form ($\nabla \times H = J + \partial D/\partial t$).
3. What is **Gradient**? If $\Phi = 3(x^2y - y^2x)$, find $\nabla\Phi$ at the point (1, -2,-1).
4. Determine the **Curl** of the vector field A= $yz\hat{a}_x + 4\,xy\hat{a}_y + y\hat{a}_z$

Module V: Quantum Physics

1. **Derive the Schrödinger's Time Independent wave equation** for matter waves.
2. An electron and a photon each have a wavelength of 2A(angstrom). What are their **momentum and energies**?
3. An electron is bound in an **1D potential well of infinite height** and width 2A(angstrom). Find its **energy values** in the **ground state** and in **first excited state**.
4. Explain the **de Broglie hypothesis** of matter waves and state its **properties**.
5. Prove using the Uncertainty Principle that an **electron cannot reside inside the nucleus of an atom**.

Module VI: Semiconductor Physics

1. **Derive an expression for the Fermi level** for an **intrinsic semiconductor** (or show it lies midway of the conduction band and valence band).
2. Write the **Fermi-Dirac distribution function** and explain the terms involved in it.
3. Explain **mobility of electrons**. Calculate the mobility if the resistivity of Cu is $1.72 \times 10^{-8}\ \Omega \cdot m$ and the number of electrons per unit volume is $10.41 \times 10^{28}\ m^{-3}$.

Extra High-Value Concepts for High Marks (if you have plenty of time, try to do these also for maximum coverage)

1. Explain the concepts of **Pumping, Population Inversion**, and **Active Medium** necessary for LASER action.
2. Define **Coherence L**
3. **Length** and **Coherence Time**. Calculate the coherence length for a LASER that emits light with a bandwidth of 100hz and a mean wavelength of 632.8 nm.
4. List and explain the key **characteristics of Lasers** (Monochromaticity, Coherence, Directionality, and High Intensity).
5. Explain the phenomenon of **attenuation in optical fibers**. List and describe the **factors affecting attenuation** (e.g., Absorption, Scattering, Bending).
6. Describe the key components of a **Fibre Optic Communication System** with a block diagram. State the main **advantages** of using optical fiber communication.
7. Draw a neat diagram and obtain the **condition for maxima and minima** for a **wedge-shaped film** (Qualitative derivation, explaining the path difference).
8. State and explain **Gauss's Law** and **Stokes' Theorem**. Explain the **physical significance** of the **Divergence and Curl** of a vector field.
9. **State all four Maxwell's equations** in their **point form** and **integral form**. Explain the physical significance of the **displacement current term** in the fourth equation.
10. State the **mathematical conditions** that a **wave function psi** must satisfy to be physically acceptable. Explain the physical significance of **probability density**
11. Distinguish between **Direct Band Gap** and **Indirect Band Gap** semiconductors with energy band diagrams. Give one example of each.

***Note -** Solutions for these questions are not given.

Module I: Lasers

Q1. What is metastable state? What is the role of metastable state in LASER?

ANS:

The higher energy state just below the excited state in which atoms can stay up to certain millisecond and population inversion condition is achieved is known as metastable state.

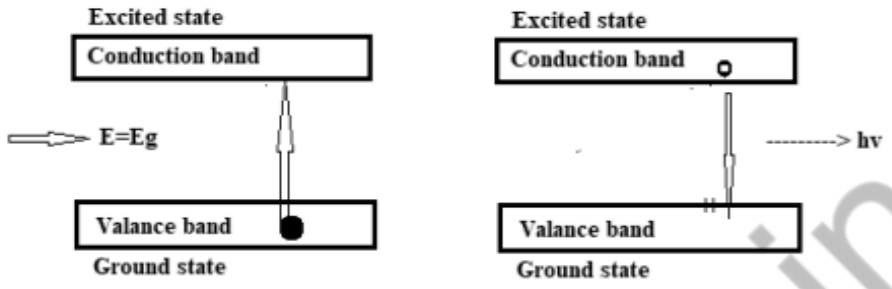
- A metastable state is an **excited energy level** in an atom, ion, or molecule.
- Unlike typical excited states (which have a very short lifetime, 10^-8 seconds), the metastable state has a **relatively long lifetime**, typically around 10^-3.
- Due to this longer lifetime, the probability of the atom spontaneously falling back to a lower energy level (spontaneous emission) is low.

Role of metastable state:

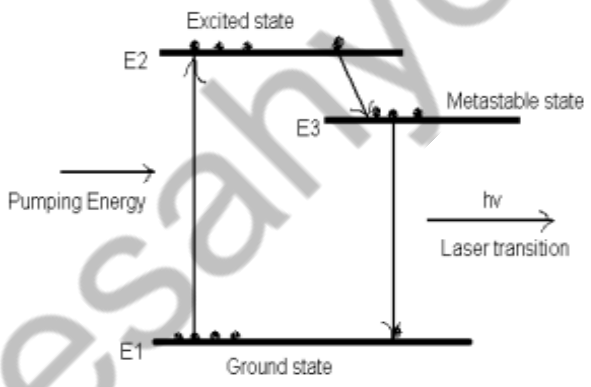
1. **Atom Accumulation (Pumping):** When the active medium is energized (pumped), atoms are excited from the ground state to a high-energy level. These atoms then quickly decay (non-radiatively) to the **metastable state**.

Pumping Scheme: -

- **Two level pumping schemes: -**



- The two level pumping scheme is exist only in direct band gap semiconductor materials like Ga, As etc. The lower energy state is valence band and higher energy state is conduction band. The electrons are transferred from valence band to conduction and they come back to valence band giving laser transition.
- **Three level pumping schemes: -**



The material or system in which three energy level are involved is called three level pumping schemes. The atoms absorb the excitation energy and raised to excited state E2. The nonradiative transition of atoms takes place from excited state E2 to metastable state E3 and population inversion takes place in metastable state. The laser transition takes place from metastable state E3 to ground state E1. The energy levels in which laser transition takes place are called upper lasing level and lower lasing level.

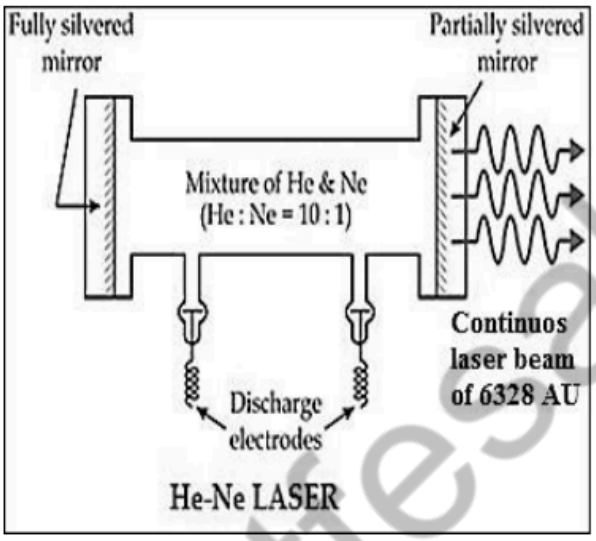
2. **Achieving Population Inversion:** Because the metastable state has a long lifetime, atoms can **accumulate** here faster than they decay. This allows the population of atoms in the metastable state (N2) to exceed the population in the lower state (N1). This condition, N2>N1, is called **Population Inversion**.

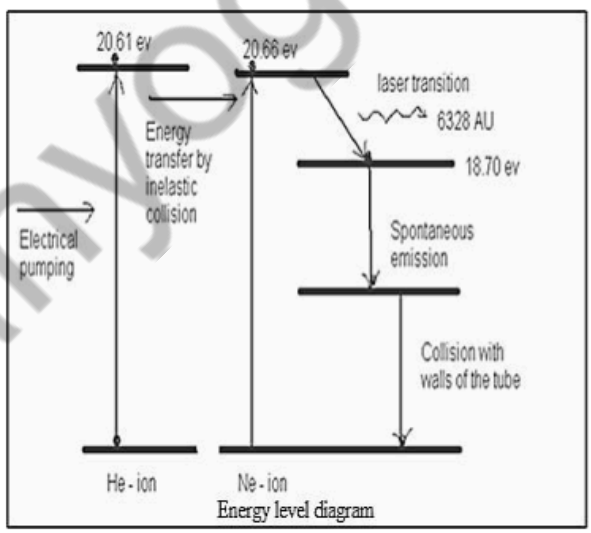
3. **Sustaining Stimulated Emission:** Population inversion is the prerequisite for **Stimulated Emission** to dominate. When a photon of the correct energy strikes an atom in the metastable state, it triggers the release of an identical photon. This continuous and controlled stimulation amplifies the light, leading to the coherent, monochromatic beam characteristic of a laser.

Q2. With a neat energy level diagram, explain the construction and working of He-Ne Laser.

ANS:

He – Ne laser:





CONSTRUCTION:

- He-Ne laser is a first gas laser prepared by scientist hall and his coworkers in 1961.
- It consists of long narrow discharge tube of length 10 cm to 80 cm and diameter 0.5 cm.
- The discharge tube contains mixture of He and Ne gas in the ratio of 10:1 with a pressure of 0.1 and 1 mm of Hg respectively. The 'He' gas is an active medium and Ne ions are the active centers.
- The two electrodes are fitted to discharge tube which is connected to high voltage power supply. Thus, electrical pumping is used to provide the excitation energy.
- The discharge tube is placed between two mirrors M1 and M2 which forms resonance cavity. The mirror M1 has fully reflecting surface while mirror M2 has partially reflecting surface.

WORKING: -

- When power supply is ON, the electric discharge is produced and the electrons produced in the discharge tube collides with the He and Ne ions. By absorbing the electrical energy, the He and Ne ions are excited to higher energy state.
- The metastable state of He ions is at 20.61 ev and for Ne ions at 20.66 ev above the ground state.
- Since the He ions are lighter than Ne ions, first He ions are excited to their metastable state at 20.61 ev. The density of He ions is more than Ne ions (for every Ne ion there are 10 He ions in the discharge tube) and He ions has good thermal conductivity. The excited He-ions collide with the

  Ne-ions and transfer their energy to Ne-ions by inelastic collision. By absorbing the energy difference of 0.05 ev from the He ions, the Ne ions are excited to their metastable state at 20.66 ev. **Thus, He ions help for the population inversion of Ne ions as well as He gas acts as coolant due to its good thermal conductivity.**
- When Ne ions de excite from metastable state at 20.66 ev to next lower energy state at 18.70 ev, then laser transition takes place and a photon of wavelength 6328 AU is emitted spontaneously. The laser is operated at wavelength 6328 AU by using resonant cavity.

- The balance of excitation energy is lost by spontaneous emission and collision with the walls of the discharge tube.
- The spontaneously emitted photons bouncing back and forth between two reflecting mirrors and stimulates the number of other photons. The number of light waves that are identical in phase, wavelength, amplitude and direction go on increasing. The distance between the two mirrors are adjusted to integral multiple of half the wavelength of emitted photons, so that optical standing wave is set up inside the discharge tube and continuous laser beam comes out through partially reflecting mirror M2.
- **Efficiency:** -The ratio of output optical power to the input power required to operate the laser is known as efficiency of laser. The efficiency of He-Ne laser is less (1 mW to 50 mW), but it is popular due to directionality and coherence. Four level pumping scheme is used. The emitted light is highly directional & coherent; therefore, this laser is used for research applications.

Summary:

- **Types of laser:** Gas laser
- **Active material:** Mixture of He-Ne gas.
- **Active centers:** Ne ions.
- **Pumping scheme:** Four level pumping scheme.
- **Pumping method:** Electrical pumping.
- **Pumping process:** Continuous pumping.
- **Laser output:** Continuous laser beam of wavelength 6328 AU.
- **Efficiency:** Low.
- **Output power:** 1 mW to 50 mW.
- **Laser output:** Emitted laser beam is highly directional & coherent.
- **Applications:** In research field, Barcode scanners, Tool alignment, Non-contact measuring and monitoring, Blood analysis, Particle counting and food sorting

Q3. What is resonant cavity? Explain its use in the generation of Laser beams

Ans:

The resonant cavity, also known as an **Optical Resonator** or **Fabry-Perot cavity**, is one of the three principal components of a laser system (along with the pump source and the active gain medium). It is a precisely engineered structure that confines light and provides the necessary optical feedback to sustain laser action.

1. What is a Resonant Cavity?

A resonant cavity is an arrangement of **two highly reflective mirrors** placed facing each other, usually parallel, with the active gain medium situated between them.

- **Structure:**
  - **Mirror 1 (High Reflector):** Typically **fully reflective** (reflectivity 99.9%) to reflect all photons back into the medium.
  - **Mirror 2 (Output Coupler): Partially reflective** (e.g.,95% reflective) to reflect most photons for continued amplification, while allowing a small portion of the amplified light to **escape as the coherent laser beam**.
- **Principle:** The cavity traps light waves, causing them to reflect back and forth multiple times through the gain medium, similar to how sound waves resonate in a musical instrument.

2. Use in the Generation of Laser Beams

The resonant cavity performs four crucial functions required to transform scattered photons into a single, intense, coherent laser beam:

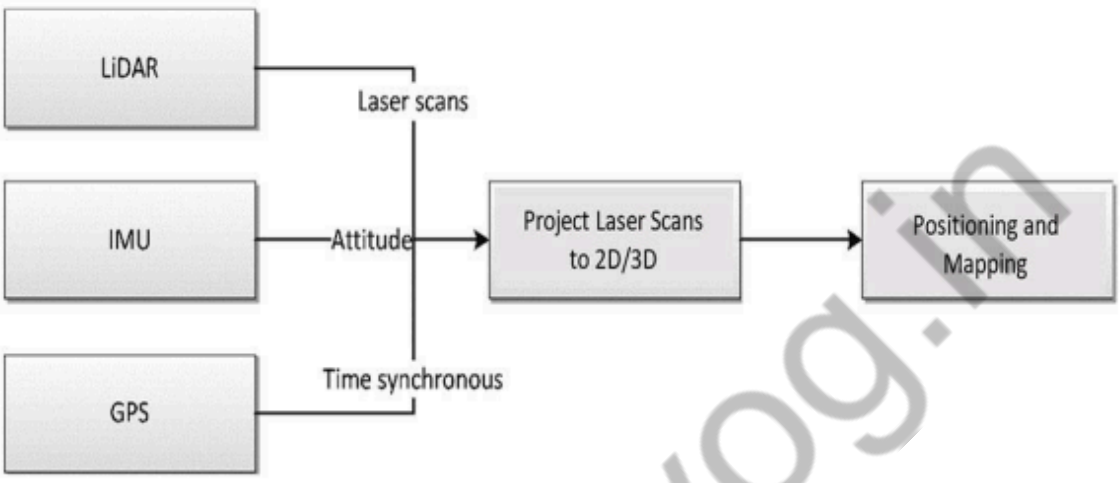
Function	Explanation
I. Light Amplification (Gain)	The mirrors reflect spontaneously or stimulatedly emitted photons back and forth, forcing them to pass repeatedly through the excited active medium. Each pass triggers more **stimulated emission**, exponentially increasing the number of coherent photons (optical gain).

II. Optical Feedback	The mirrors provide the necessary feedback. Without it, the stimulated photons would simply travel in a straight line and escape, making amplification unsustainable. The continuous reflection ensures the light energy builds up inside the cavity.
III. Mode Selection and Coherence	Only photons traveling **parallel to the axis** of the cavity (longitudinal axis) and having a wavelength (lambda) that satisfies the **standing wave condition** are sustained through **constructive interference**. The condition is: $L = n\lambda/2$ where L is the cavity length and n is an integer. Photons that do not meet this condition are quickly suppressed by destructive interference and lost, ensuring the output beam is **highly monochromatic and coherent**.
IV. Beam Directionality	The repeated reflections along the fixed longitudinal axis force the amplified light to travel in a narrow, highly parallel path. This results in the final laser beam having very **low divergence** (high directionality).

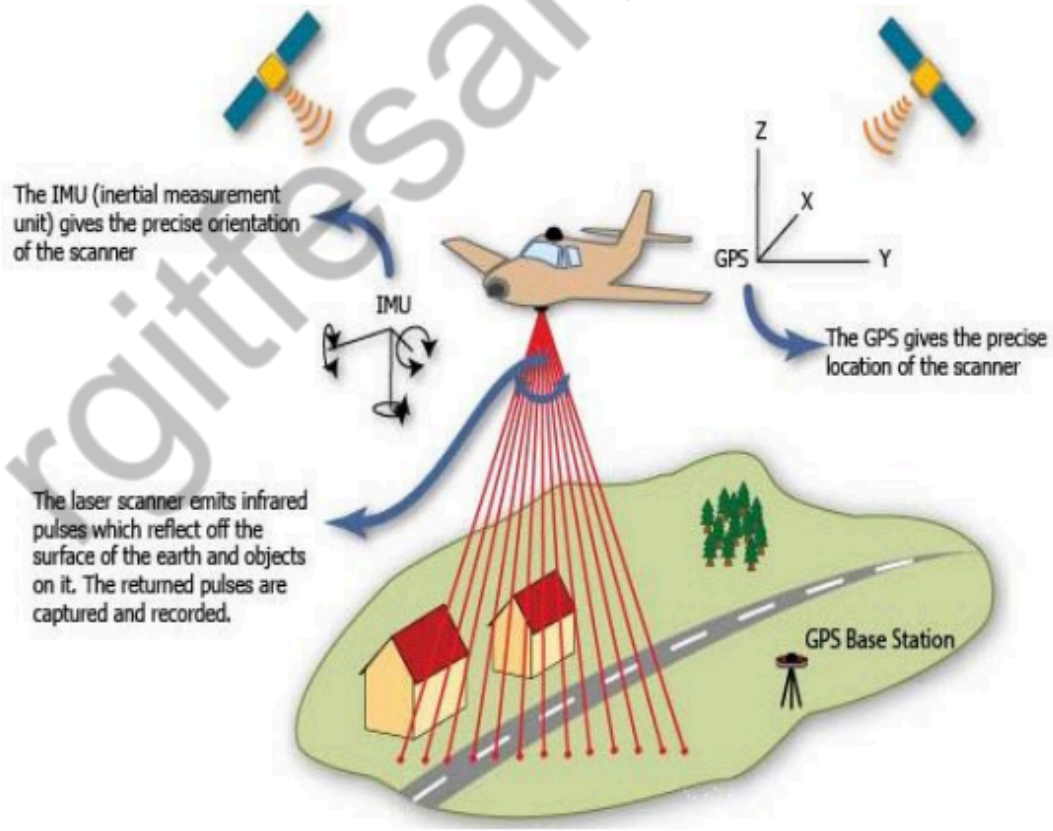
YT link to help - https://www.youtube.com/watch?v=-v0xf-Fba54

Q4. What is Lidar technology and how does it work?

ANS:



Block Diagram of LiDAR Technology



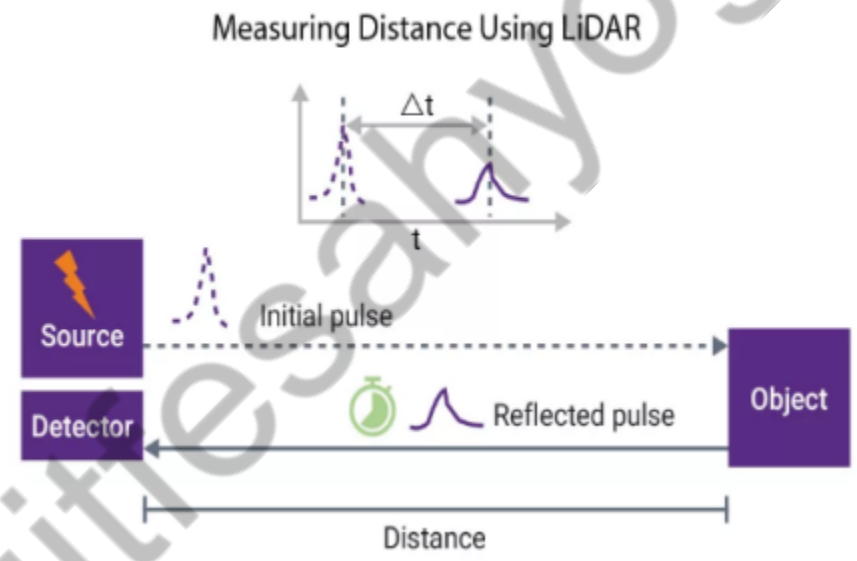
LiDAR stands for Light Detection and Ranging.

The Difference between Radar and LiDAR?

LiDAR and Radar both emit pulses to determine the time it takes to hit a surface and return to the sensor. Radar, however, uses radio waves instead of light pulses. LiDAR technology creates accurate measurements through 3D models, whereas the primary use for Radar is for military purposes i.e. on battleships to detect objects in the vicinity.

LiDAR scanning operating principle

In LiDAR, laser light is sent from a source (transmitter) and reflected from objects. The reflected light is detected by the receiver. The distance between the object and sensor is calculated using the velocity of light, referred to as the Time of Flight (TOF). The time of flight (TOF) is used to develop a distance map of the objects.



The accuracy of LiDAR can vary based on several factors, including the type of LiDAR system, the technology used, the quality of the equipment, and the specific application.

Working of LiDAR

LIDAR system incorporates a laser device, a navigational Inertial Measurement Unit (IMU), a highprecision airborne Global Positioning System (GPS), and a computer interface. The technology uses ultraviolet, visible, or near-infrared light to image objects. The laser emits light pulses and detects the light reflected by the objects. The sensor measures the time between the emission and return of the laser pulse and calculates the distance traveled. Distance traveled is then converted to elevation. These

measurements are made using a LiDAR system's key components, including a GPS that identifies the X, Y, Z location of the light energy and an IMU that impart the orientation. This process is also called 'Time of Flight'(ToF) measurement. Contemporary LiDAR systems are sufficiently powerful to fire up to 900,000 pulses every second.

Lidar Formula

The entire process of bouncing a beam of light or laser off an object, receiving the returned signal, and calculating its absolute position in space can be represented mathematically using this formula: The distance of the object = Speed of Light x Time of Flight/ 2

d = c * t / 2

Types of LiDAR:

Three main types of LiDAR systems - airborne, terrestrial and satellite LiDAR.

Airborne LiDAR is utilised through helicopters or drones for data collection.

Terrestrial LiDAR is installed on moving vehicles or on stationary tripods. These types of LiDAR systems are perfect for modeling and observing static topography.

Satellite or space-borne LIDAR platforms are mounted on satellites that orbit the Earth and tend to cover large areas but with less detail.

Applications of LiDAR

A LiDAR scanner provides ultra-detailed 3D mapping, allowing augmented reality systems to overlay the data on top of a precise and reliable map. A LiDAR created point cloud scanner enhances the accuracy of augmented reality experiences.

LiDAR from Space:

LiDAR systems evolve for several space applications where imaging is needed to identify safe landing sites for vehicles, docking, and driving. LiDAR technology satellites are also used to survey, map, and generate climate prediction models of Earth and other celestial bodies.

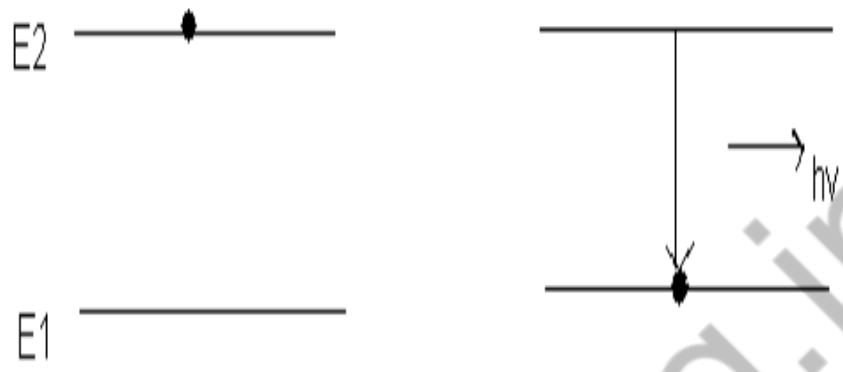
LiDAR for Autonomous Cars:

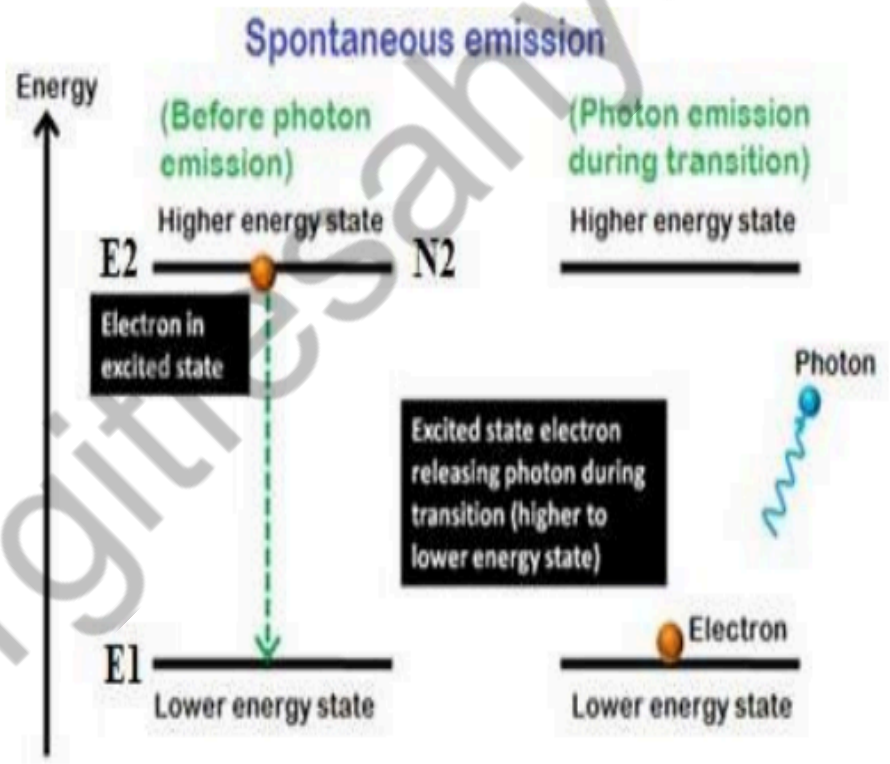
LiDAR technology is a convenient solution to enable obstacle detection, avoidance, and safe navigation through different environments in various vehicles. The technology is sprinkled across many critical automotive and mobility applications, including Advanced Driver Assistance Systems (ADAS) and Autonomous driving.

Q5. Define Spontaneous and Stimulated Emission. Why is stimulated emission essential for LASER action?

ANS:

Spontaneous emission:-





The life time of the atoms to remain in the excited state is very short of the order of 10^{-8} second due to electrostatic force of attraction between positively charged nucleus and negatively charged electrons.

Therefore, the excited atoms again jump in to the ground state. During this transition a photon of energy

$$h\nu = E_2 - E_1 \text{ is emitted spontaneously.}$$

The emitted photons are random in phase and direction. Therefore, the emitted light is highly incoherent.

If N_2 – no. of atoms in the excited state.

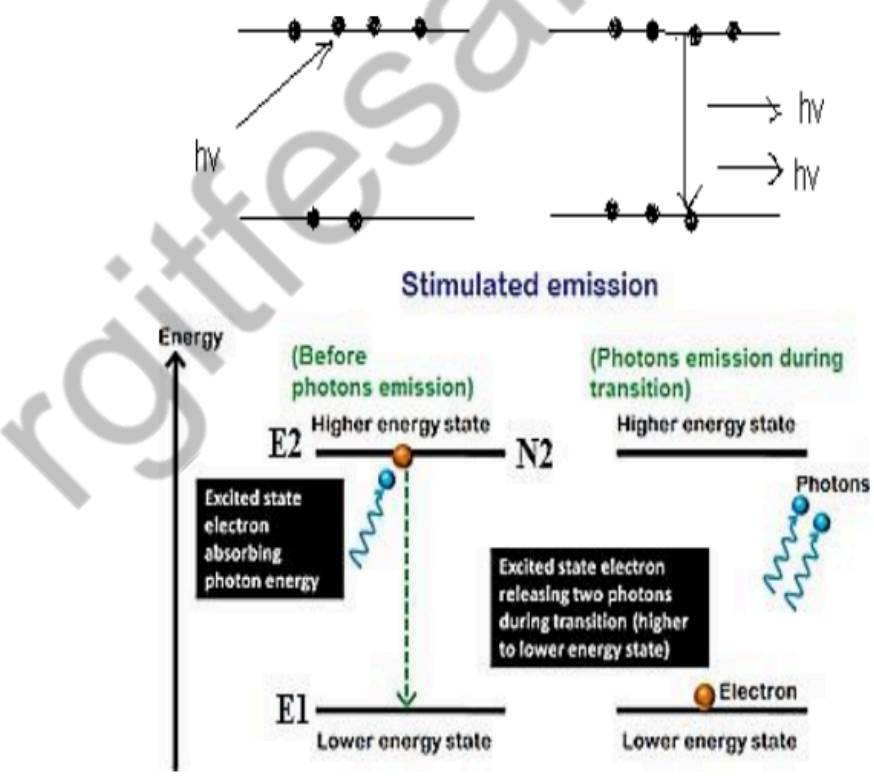
The probability of spontaneous emission is directly proportional to N_2.

$$P_{sp} \alpha N_2$$

$$P_{sp} = A_{21} N_2$$

Proportionality constant A_{21} is known as Einstein's coefficient of spontaneous emission.

3) Stimulated emission of radiation: -



If the numbers of atoms in the excited state are more than the number of atoms in the ground state, then spontaneously emitted photons take the collision with the excited atom and force this atom to jump in to the ground state. During this transition a photon which is identical to incident photon is emitted. The both photons are identical in all respect. Thus, spontaneously emitted photons stimulate the number of other photons which are identical in their direction, phase, wavelength, and amplitude known as light amplification by stimulated emission of radiation (LASER). **Emitted light is highly coherent**.

If N_2 – no. of atoms in the ground state.

Q – Incident energy density.

The probability of stimulated emission is directly proportional to N_2 and

$$Q.\ P_{st} \propto N_2\ Q$$

$$P_{st} = B_{21}\ N_2\ Q$$

Proportionality constant B_{21} is known as Einstein's coefficient of stimulated emission.

According to law of conservation of

energy Upward transition = Downward

transition $P_{ab} = P_{sp} + P_{st}$

$$\mathbf{B_{12}N_1Q = A_{21}N_2 + B21\ N_2\ Q}$$

This is known as Einstein equation and B_{12}, B_{21}, B_{21} are known as Einstein coefficient.

Stimulated emission is essential for laser action for two primary reasons:

1. **Light Amplification (Optical Gain):** Stimulated emission is an amplifying process. When a photon interacts with an excited atom, it forces the atom to drop to a lower energy level, releasing a second, identical photon. This process is crucial because it ensures that for every photon incident, two photons are generated, leading to an **exponential increase in light intensity** (optical gain).
2. **Coherence:** The emitted photon in stimulated emission is **identical** to the incident photon—it has the same phase, direction, polarization, and frequency. This ensures that the generated light is **coherent**, which is the defining characteristic of a laser beam.

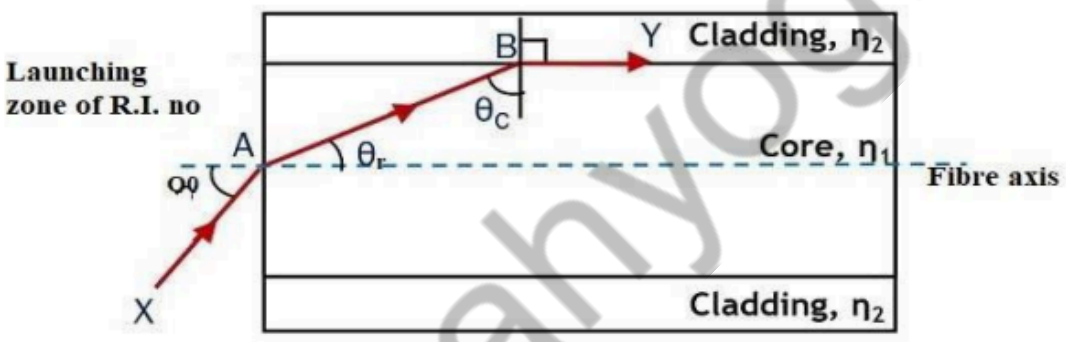
Module II: Fibre Optics

Q1. Derive an expression for Numerical Aperture (NA) of a step index optical fibre. Give its physical significance.

ANS:

Numerical Aperture (N.A.) of optical fiber:

Numerical aperture is light gathering capacity of optical fiber. The ability of optical fiber to accept the light and to guide the light efficiently throughout its entire length using the principle of TIR is known as numerical aperture (N.A.). Numerical aperture is always less than 1 for total internal reflection of light.



Consider step index optical fiber of core

radius r. If n_1 – R.I. index of core.

n_2 – R.I of cladding

n_0 – R.I of launching zone

θ_0 – angle of incidence with fiber axis known as acceptance

angle. θr – angle of refraction.

θc – Critical angle of incidence at core- cladding interface.

At air-glass boundary (point A) by Snell's law of refraction,

$$n_0 \sin \theta_0 = n_1 \sin \theta r \text{-----(1)}$$

The maximum angle of incidence made by the incident light waves with fiber axis is known as acceptance angle θ_0.

Sine of the acceptance angle θ_0 is also known as numerical aperture of optical fiber.

sin θ_0 is the N.A. of optical fiber.

At core-cladding interface (point B), if θc is critical angle of incidence, then angle of refraction is 90^0. $n_1 \sin \theta c = n_2 \sin 90^0$ (2)

$n_1 \sin \theta c = n_2$ since $\sin 90^0 = 1$

$$\sin\theta_c = \frac{n_2}{n_1}$$

From fig. angle of refraction $\theta r = 90^0 - \theta c$ Therefore equation (1) => $n_0 \sin \theta_0 = n_1 \sin (90^0 - \theta c)$

$$n_0 \sin \theta_0 = n_1 \cos\theta c$$

$$n_0 \sin \theta_0 = n_1\sqrt{1 - sin^2\theta c}$$

$$n_0 \sin \theta_0 = n_1 \sqrt{1 - \left(\frac{n2}{n1}\right)^2}$$

$$n_0 \sin \theta_0 = \sqrt{n1^2 - n2^2}$$

$$\sin \theta_0 = \frac{\sqrt{n1^2 - n2^2}}{n0}$$

$$\mathbf{NA} = \frac{\sqrt{n1^2 - n2^2}}{n0}$$

If light wave incident from air medium, $n_0 = 1$

$$\mathbf{Sin\ \theta_0 = \sqrt{n1^2 - n2^2}}$$

$$NA = \sqrt{n_1^2 - n_2^2}$$

The maximum angle of incidence made by the incident light waves with fiber axis is known as acceptance angle.

$$\mathbf{Acceptance\ angle\ \theta_0 = \sin^{-1}\sqrt{n1^2 - n2^2}}$$

$$\mathbf{\theta_0 = \sin^{-}(N.A)}$$

N.A. in terms of fractional refractive index difference (Δ)

$$NA = \sqrt{n_1^2 - n_2^2}$$

$$\mathbf{N.A = \sqrt{(n1 - n2)(n1 + n2)}}$$

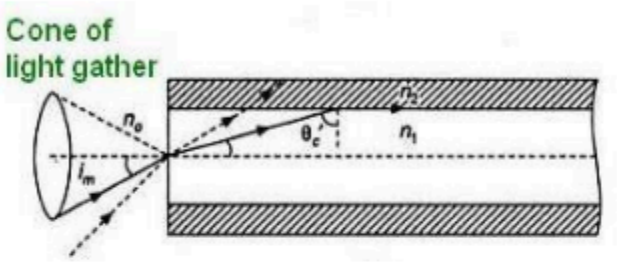
But $n_1 \approx n_2$ therefore $n_1 + n_2 = 2n1^2$

$$N.A = \sqrt{2n1\,(n1 - n2)}$$

$$N.A = \sqrt{\frac{2n1^2\,(n1-n2)}{n1}}$$

Where $\Delta = \frac{n1-n2}{n1}$ $\quad N.A = n1\sqrt{2\,\Delta}$

is known as fractional refractive index difference.



V - Number or normalized frequency:

An optical fiber is characterized by another parameter called as the V- number or normalized frequency. It is given by

$$V = \frac{2\pi a}{\lambda}\sqrt{n1^2 - n2^2}$$

$$V = \frac{2\pi a}{\lambda} N.A$$

Where 'a' is core radius and λ is wavelength of light.

When V = 2.405, then λ is known as cutoff wavelength of the optical fiber.

Hence cutoff wavelength is $\lambda_{cutoff} = \frac{2\pi a}{2.405} N.A$

For single mode propagation V <

2.405 For multimode propagation V

> 2.405

The maximum number of modes the fiber can support is given by

$N_m = \frac{V^2}{2}$ **for step index fiber.**

$N_m = \frac{V^2}{4}$ **for graded index fiber.**

The Numerical Aperture (NA) is a crucial, dimensionless parameter of an optical fiber that dictates its ability to handle and guide light.

1. **Light-Gathering Ability (Acceptance):** The NA defines the maximum angle at which light rays can enter the fiber core and still be guided by Total Internal Reflection (TIR). A **higher** NA corresponds to a larger acceptance angle, meaning the fiber can **gather more light** from the source.
2. **Light Confinement:** The NA is calculated from the refractive index difference between the core (n_1) and the cladding (n_2) ($\mathrm{NA} = \sqrt{n_1^2 - n_2^2}$). A **higher** NA indicates a **stronger light confinement** within the core, which minimizes light leakage.

Q2. Define the terms: Critical angle, Acceptance angle, and Attenuation.
ANS:

1. Critical Angle (θ_c or ϕ_c) (Approx. 1.5 Marks)

The critical angle is a concept related to **Total Internal Reflection (TIR)**.

- **Definition:** It is the **angle of incidence** in the optically **denser medium** (the fiber core) for which the corresponding angle of refraction in the less dense medium (the cladding) is exactly 90°.
- **Role in Fiber:** For light to be successfully guided down the fiber core, the angle at which the ray strikes the core-cladding interface (θ) must be **greater than the critical angle** ($\theta > \theta_c$).
- **Formula:** The critical angle is determined by the core (n_1) and cladding (n_2) refractive indices:

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

2. Acceptance Angle (θ_a or $i_{\max}$) (Approx. 1.5 Marks)

The acceptance angle is a concept related to the light entering the fiber from the surrounding air/medium.

- **Definition:** It is the **maximum angle of incidence** that a light ray, entering the fiber core from the external medium (usually air), can make with the fiber axis such that the ray is still coupled into the fiber and guided by TIR.
- **Significance:** It determines the **size of the acceptance cone** and, therefore, the fiber's **light-gathering ability**.
- **Relation to NA:** It is related to the Numerical Aperture (NA) by the simple relation: $\mathrm{NA} = n_0 \sin(\theta_a)$.

3. Attenuation (α) (Approx. 2 Marks)

- **Definition:** Attenuation is the **reduction** or **loss of optical power/signal strength** as light travels along the length of an optical fiber.
- **Effect:** It causes the signal to weaken over distance, potentially leading to degraded signal quality or complete loss.
- **Measurement:** It is typically measured and expressed in units of **decibels per kilometer ($\mathrm{dB/km}$)**.
- **Causes:** The primary causes are inherent properties of the fiber material, such as **absorption** (by impurities) and **scattering** (Rayleigh scattering).

Q3.The refractive indices of core and cladding are 1.48 and 1.45 respectively. Calculate: (i) Numerical Aperture, (ii) Acceptance Angle, and (iii) Critical Angle.

ANS:

Given Data

- Refractive index of the Core (n_1) = 1.48
- Refractive index of the Cladding (n_2) = 1.45
- Refractive index of the external medium (Air, n_0) = 1.00

(i) Numerical Aperture (NA)

The numerical aperture is calculated using the formula derived from the core and cladding refractive indices:

$$\mathrm{NA} = \sqrt{n_1^2 - n_2^2}$$

Substitution:

$$\mathrm{NA} = \sqrt{(1.48)^2 - (1.45)^2}$$

$$\mathrm{NA} = \sqrt{2.1904 - 2.1025}$$

$$\mathrm{NA} = \sqrt{0.0879}$$

$$\mathrm{NA} \approx \mathbf{0.2965}$$

(ii) Acceptance Angle (θ_a)

The acceptance angle is related to the numerical aperture by the equation:

$$\mathrm{NA} = n_0 \sin(\theta_a)$$

Since $n_0 = 1$ (for air):

$$\sin(\theta_a) = \mathrm{NA}$$

$$\theta_a = \sin^{-1}(\mathrm{NA})$$

Substitution:

$$\theta_a = \sin^{-1}(0.2965)$$

$$\theta_\mathbf{a} \approx \mathbf{17.25}^\circ$$

(iii) Critical Angle (θ_c)

The critical angle occurs at the core-cladding interface and is calculated using Snell's Law:

$$\sin(\theta_c) = \frac{n_2}{n_1}$$

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

Substitution:

$$\theta_c = \sin^{-1}\left(\frac{1.45}{1.48}\right)$$

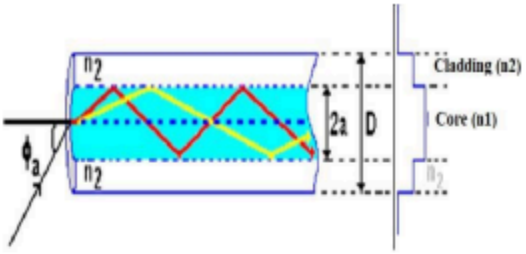
$$\theta_c = \sin^{-1}(0.9797)$$

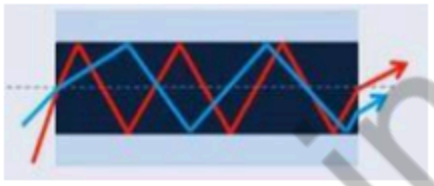
$$\theta_c \approx \mathbf{78.58}^\circ$$

Q4. Compare Step Index fiber and Graded Index Fiber (based on structure, propagation, and attenuation).

ANS:

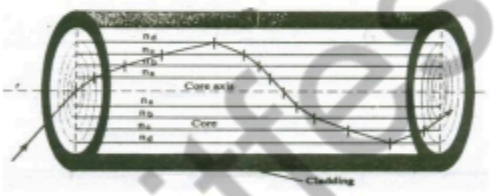
Step index fiber:

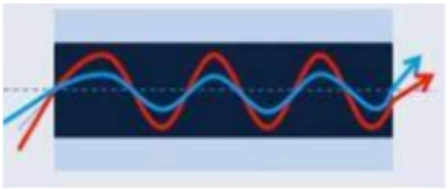




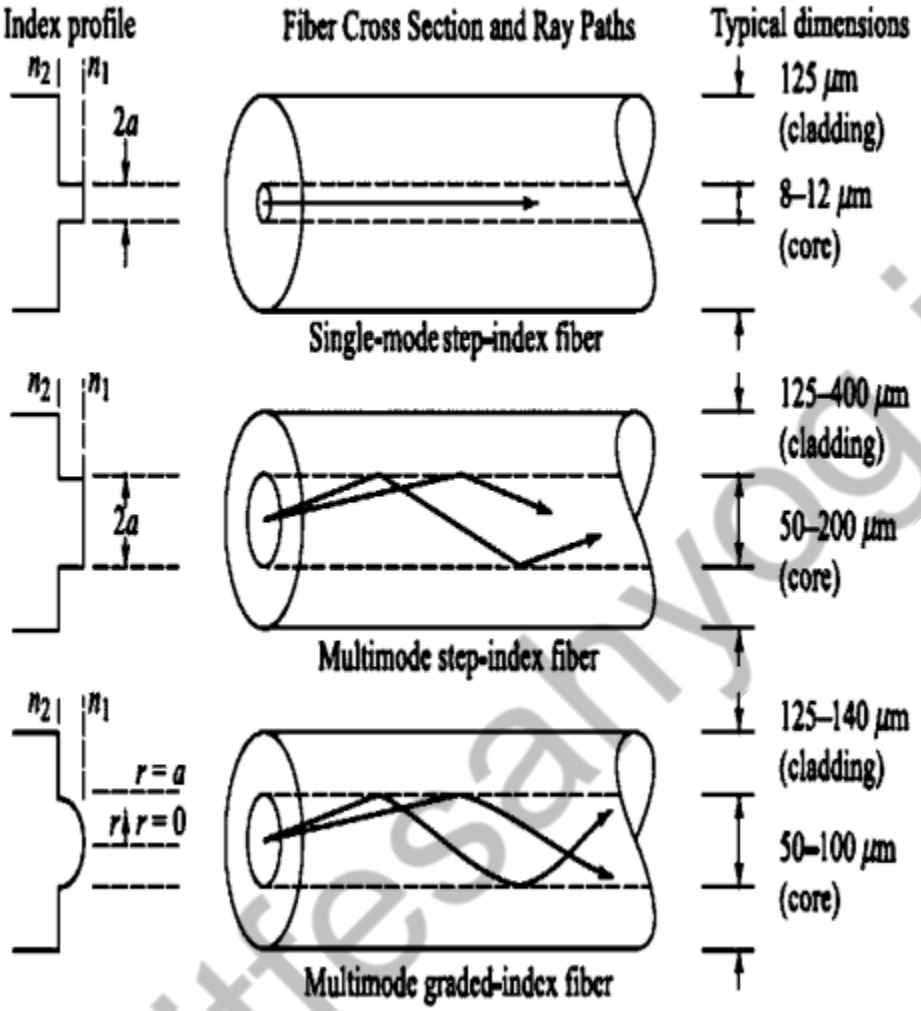
1) Consist of core of uniform diameter and refractive index and cladding of slightly less R.I. than core.
2) Light rays are travel along zig-zag triangular path.
3) All light rays travel with same speed along different path and arrive at the other end at different time, therefore signal distortion takes place.
4) Bandwidth is small.
5) Numerical aperture is high.
6) Attenuation is higher.
7) They can be single mode or multimode depending upon core diameter.

Graded index fiber:



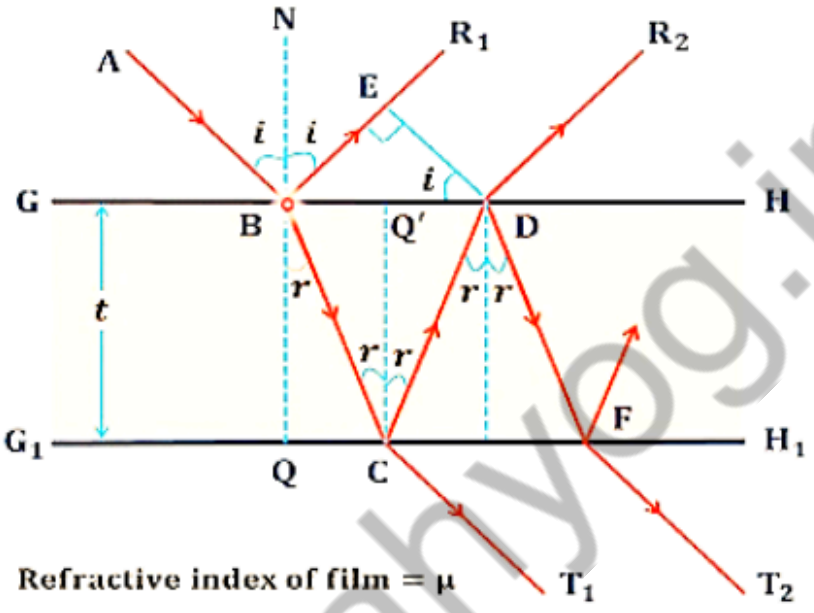


1) No core and cladding separately, but fiber is made with a material of varying R.I. The R.I. is maximum along the axis and decreases away from the axis along the diameter (na>nb>nc>nd).
2) Light rays are travel along sinusoidal path.
3) All light rays are travel with different speed having different degree of curvature and will arrive at the other end at same time; therefore, signal distortion not takes place.
4) Bandwidth is high.
5) Numerical aperture is small.
6) Attenuation is lower.
7) They are only multimode.



Module III: Interference

Q1. Obtain the condition for maxima and minima of the light reflected from a thin transparent film of uniform thickness.



1) Consider a thin film bounded between two surfaces S1 andS2.

   μ- R.I. of the film and

   t – Thickness of the film.

   The film is illuminated by the monochromatic source of light of wave length λ. depending upon the conditions of interference; the entire film is appeared dark or bright.

2) The incident light beam AB make an angle i with normal to the film. Due to multiple reflections with in a thin film, we get reflected light rays R1, R2..... and transmitted light rays T1, T2.....

3) To determine optical path difference between reflected light rays R1 and R2 draw perpendicular CQ' and DE.

4) The optical path difference between reflected light rays R1 & R2 is

   Δ = Path (BC + CD) with in a film – Path BE in air

   Δ = (BC + CD) μ - BE---------- (1) since μ = 1 for air.

From ΔBQC and ΔDQ'C, we can write -

$$BC = CD = \frac{t}{\cos r} \qquad (2)$$

To determine BE, in Δ BED, sin i = BE/BD

$$BE = BD \sin i$$

$$= 2\, BQ' \sin i \qquad \text{As } \tan r = \frac{BQ'}{CQ'} = \frac{BQ'}{t}$$

$$= 2\, t \tan r \sin i$$

$$= 2\, t \frac{\sin r}{\cos r} \sin i$$

$$= 2\, t \frac{\sin r}{\cos r} \frac{\sin i}{\sin r} \sin r \qquad \text{As } \frac{\sin i}{\sin r} = \mu$$

$$\therefore BE = 2\, \mu\, t \frac{\sin^2 r}{\cos r} \qquad (3)$$

Eqn (1) =>

$$\Delta = \mu \left(\frac{t}{\cos r} + \frac{t}{\cos r} \right) - 2\, \mu\, t \frac{\sin^2 r}{\cos r}$$

$$\therefore \Delta = \frac{2\, \mu\, t}{\cos r} (1 - \sin^2 r)$$

$$\therefore \Delta = \frac{2\, \mu\, t}{\cos r} \cos^2 r$$

$$\therefore \Delta = 2\, \mu\, t \cos r \qquad (4)$$

As One reflection at point B occurs at the surface at denser medium. So additional path change of $\frac{\lambda}{2}$ is introduced. And effective optical path difference becomes -

$$\therefore \Delta = 2\, \mu\, t \cos r \pm \frac{\lambda}{2}$$

Condition for Maximum:	Condition for Minimum:
$\Delta = n\lambda$	$\Delta = (2n \pm 1)\frac{\lambda}{2}$
where $n = 0, 1, 2, 3 \ldots$	where $n = 0, 1, 2 \ldots$
$\therefore \Delta = 2\mu t \cos r \pm \frac{\lambda}{2} = n\lambda$	$\therefore \Delta = 2\mu t \cos r \pm \frac{\lambda}{2} = (2n \pm 1)\frac{\lambda}{2}$
$\therefore 2\mu t \cos r = (2n \pm 1)\frac{\lambda}{2}$	$\therefore 2\mu t \cos r = n\lambda$

For transmitted light, there is no phase change or path difference change between incident and transmitted light rays, therefore effective optical path difference between incident & transmitted light rays is

$$\Delta = 2\mu t \cos r \pm \frac{\lambda}{2}$$

Therefore

Condition for Maximum:	Condition for Minimum:
$\Delta = n\lambda$	$\Delta = (2n \pm 1)\frac{\lambda}{2}$
where $n = 0, 1, 2, 3 \ldots$	where $n = 0, 1, 2 \ldots$
$\therefore \Delta = 2\mu t \cos r \pm \frac{\lambda}{2} = n\lambda$	$\therefore \Delta = 2\mu t \cos r \pm \frac{\lambda}{2} = (2n \pm 1)\frac{\lambda}{2}$
$\therefore 2\mu t \cos r = (2n \pm 1)\frac{\lambda}{2}$	$\therefore 2\mu t \cos r = n\lambda$

Thus fringe system is complimentary in nature.

Q2. In a Newton's ring experiment, the diameter of the 5th dark ring was 0.336 cm and the 15th dark ring was 0.590 cm. Find the radius of curvature of the plano-convex lens if the wavelength is 5890 A (angstrom)

ANS:

Given Data

- Diameter of the 5^{th} dark ring, $D_5 = 0.336 \text{ cm}$
- Diameter of the 15^{th} dark ring, $D_{15} = 0.590 \text{ cm}$
- Wavelength of light, $\lambda = 5890 \text{ Å}$
- $m = 5$ (initial order number)
- $p = 15 - 5 = 10$ (number of rings between m and $m + p$)

Required Calculation

The standard formula for the radius of curvature (R) of the lens using the diameters of two non-consecutive dark rings (D_m and D_{m+p}) is:

$$R = \frac{D_{m+p}^2 - D_m^2}{4p\lambda}$$

Step 1: Convert Units to SI (Metres)

The formula requires all lengths to be in the same unit, typically metres (m).

1. **Diameters (D_{m+p} and D_m):**

$$D_{15} = 0.590 \text{ cm} = 0.590 \times 10^{-2} \text{ m}$$

$$D_5 = 0.336 \text{ cm} = 0.336 \times 10^{-2} \text{ m}$$

2. **Wavelength (λ):**

$$\lambda = 5890 \text{ Å} = 5890 \times 10^{-10} \text{ m} = 5.89 \times 10^{-7} \text{ m}$$

Step 2: Substitute Values into the Formula

Here, $m = 5$, $m + p = 15$, so $p = 10$.

$$R = \frac{(0.590 \times 10^{-2})^2 - (0.336 \times 10^{-2})^2}{4 \times 10 \times (5.89 \times 10^{-7})}$$

Step 3: Calculation

1. **Calculate the squares of the diameters:**

$$D_{15}^2 = (0.590)^2 \times 10^{-4} = 0.3481 \times 10^{-4}\ \text{m}^2$$

$$D_5^2 = (0.336)^2 \times 10^{-4} = 0.112896 \times 10^{-4}\ \text{m}^2$$

2. **Calculate the numerator ($D_{m+p}^2 - D_m^2$):**

$$\text{Numerator} = (0.3481 - 0.112896) \times 10^{-4}$$

$$\text{Numerator} = 0.235204 \times 10^{-4}\ \text{m}^2$$

3. **Calculate the denominator ($4p\lambda$):**

$$\text{Denominator} = 40 \times 5.89 \times 10^{-7}$$

$$\text{Denominator} = 235.6 \times 10^{-7}\ \text{m}$$

$$\text{Denominator} = 2.356 \times 10^{-5}\ \text{m}$$

4. **Calculate R:**

$$R = \frac{0.235204 \times 10^{-4}}{2.356 \times 10^{-5}} \approx \frac{2.352 \times 10^{-5}}{2.356 \times 10^{-5}}$$

$$R \approx 0.9983\ \text{m}$$

Final Answer

The radius of curvature of the plano-convex lens is approximately 0.9983 metres or 99.83 cm

Q3. With the experimental setup, explain the determination of the refractive index of a liquid using Newton's rings.

The Newtons ring are obtained using air film & then liquid film between lens and glass plate.

The diameter of n^{th} dark rings are measured using microscope.

Diameter of n^{th} dark ring is

$$(D_n)_{liquid} = \sqrt{\frac{4nR\lambda}{\mu}} \quad (1)$$

For air film (refractive index = 1)

$$\therefore (D_n)_{air} = \sqrt{4nR\lambda} \quad (2)$$

Divide (2) by (1)

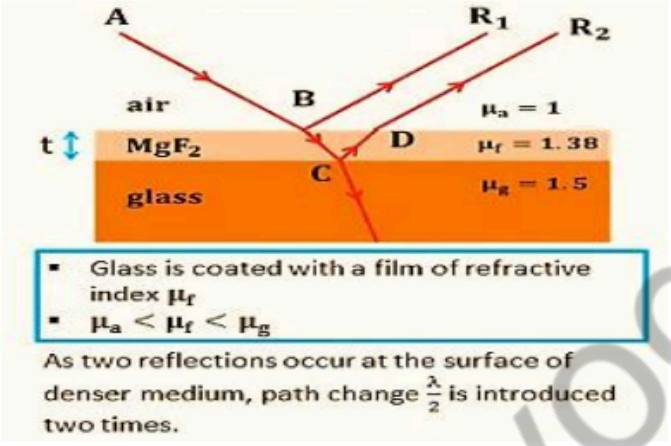
$$\frac{(D_n)_{air}}{(D_n)_{liquid}} = \sqrt{\mu}$$

$$\mu = \left(\frac{(D_n)_{air}}{(D_n)_{liquid}}\right)^2$$

This formula is used to determine RI of liquid or oil.

Q4. What is antireflection coating? What should be the refractive index and minimum thickness of the coating?

ANS:



To avoid the reflection of light from the lens surface and to increase its transmittance, the surface of the lens in optical instrument like camera, telescope, binoculars, panel of solar cell etc. is coated with thin film of transparent material known as antireflection film. When light is incident on the glass surface, the intensity of reflected light is given by

$$Ir = \frac{\mu g - \mu a^2}{\mu g + \mu a} . Ii$$

Since μg = 1.5 and μa = 1

$$Ir = 0.04Ii$$

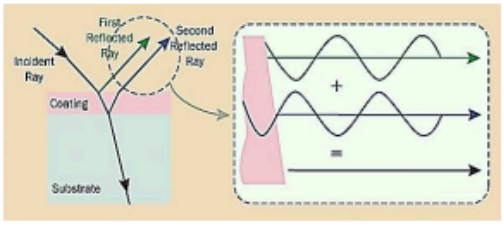
$$Ir = 4\ \%Ii$$

Thus 4 % of incident light intensity is lost due to each reflection.

From figure, to avoid reflection, light rays R1 & R2 must interfere destructively.

There are two conditions

a) **Amplitude condition**:-



Amplitude of R1 = amplitude of R2

$$\left(\frac{\mu f - \mu a}{\mu f + \mu a}\right)^2 = \left(\frac{\mu g - \mu f}{\mu g + \mu f}\right)^2$$

On solving, we get $\mu f = \sqrt{\mu g}$

Thus R.I. of thin film material must be in between 1 & 1,5. The suitable material are MgF2 (1.38) and Cryolite (1.36).

b) **Phase condition**:-

The phase or optical path difference between R1 & R2 must be λ/2.

$\Delta = 2\mu_f t \cos r = \lambda/2$

For normal incidence cos r = 1

Therefore, required thickness of the antireflection film is **t =** $\frac{\lambda}{4\mu_f}$

Highly reflecting film or lens:-

Q. Write short notes on highly reflection film? Give its applications?

To avoid the transmission of light from the lens surface and to increase its reflectivity, the surface of the lens in optical instrument like sun glasses, windows pane etc. is coated with thin film of transparent material known as highly reflecting film. Such types of the lenses or glasses are used in summer to avoid heat in summer.

To increase the reflectivity of the lens surface, the reflected light rays R1 & R2 must interfere constructively. For constructive interference, the phase or optical path difference between R1 &R2 must be λ. $\Delta = 2\mu_f t \cos r = \lambda$

For normal incidence cos r = 1

Therefore, required thickness of the highly reflecting film is **t = λ / 2μf**

Module IV: Electrodynamics

Q1. Show that the divergence of the curl of a vector is zero.

ANS:

Divergence of the curl of a vector is zero:

Let us consider $\vec{v} = v_x\hat{x} + v_y\hat{y} + v_z\hat{z}$.

Curl of $\vec{v}$ is given by - $\vec{\nabla} \times \vec{v} = \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ v_x & v_y & v_z \end{vmatrix}$

$$\vec{\nabla} \times \vec{v} = \hat{x}\left(\frac{\partial v_z}{\partial y} - \frac{\partial v_y}{\partial z}\right) + \hat{y}\left(\frac{\partial v_x}{\partial z} - \frac{\partial v_z}{\partial x}\right) + \hat{z}\left(\frac{\partial v_y}{\partial x} - \frac{\partial v_x}{\partial y}\right)$$

Divergence of Curl of $\vec{v}$ is given by -

$$\vec{\nabla} \cdot (\vec{\nabla} \times \vec{v}) = \left(\hat{x}\frac{\partial}{\partial x} + \hat{y}\frac{\partial}{\partial y} + \hat{z}\frac{\partial}{\partial z}\right) \cdot \left(\hat{x}\left(\frac{\partial v_z}{\partial y} - \frac{\partial v_y}{\partial z}\right) + \hat{y}\left(\frac{\partial v_x}{\partial z} - \frac{\partial v_z}{\partial x}\right) + \hat{z}\left(\frac{\partial v_y}{\partial x} - \frac{\partial v_x}{\partial y}\right)\right)$$

$$= \frac{\partial}{\partial x}\left(\frac{\partial v_z}{\partial y} - \frac{\partial v_y}{\partial z}\right) + \frac{\partial}{\partial y}\left(\frac{\partial v_x}{\partial z} - \frac{\partial v_z}{\partial x}\right) + \frac{\partial}{\partial z}\left(\frac{\partial v_y}{\partial x} - \frac{\partial v_x}{\partial y}\right)$$

$$= \left(\frac{\partial^2 v_z}{\partial x \partial y} - \frac{\partial^2 v_y}{\partial x \partial z}\right) + \left(\frac{\partial^2 v_x}{\partial y \partial z} - \frac{\partial^2 v_z}{\partial y \partial x}\right) + \left(\frac{\partial^2 v_y}{\partial z \partial x} - \frac{\partial^2 v_x}{\partial z \partial y}\right) = 0$$

Thus divergence of a curl is zero.

Q2. State Ampere's Circuital Law. Derive Maxwell's fourth equation in differential form (∇ x H = J + ∂D/∂t).

ANS:

Ampere's Circuital Law

Ampere's Circuital Law relates the magnetic field around a closed loop to the electric current passing through the surface enclosed by the loop.

Statement of the Law

The line integral of the magnetic field intensity (H) around any closed path is equal to the **total steady current (I)** passing through the surface bounded by the path.

Mathematically, the law is stated as:

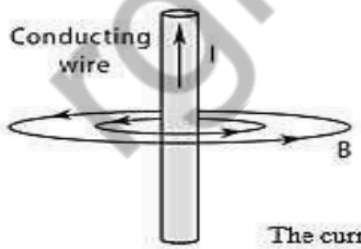
$$\oint H \cdot dl = I$$

Where:

- $\oint H \cdot dl$ is the line integral of the magnetic field intensity (H) around the closed loop.
- dl is an elemental length vector along the path.
- I is the net current enclosed by the closed path.

Fourth Maxwell equation: (Ampere circuital law for static magnetic field)

Statement: "The line integral of magnetic field intensity H around a closed path i current enclosed by that path."



$$\int_l \overline{H} \quad \overline{dl} = I$$

$$B = \mu_0 \, H$$

$$H = \frac{B}{\mu_0}$$

$$\int_l \overline{B} \quad \overline{dl} = \mu_0 \, I$$

The current I is surface integral of current density J.

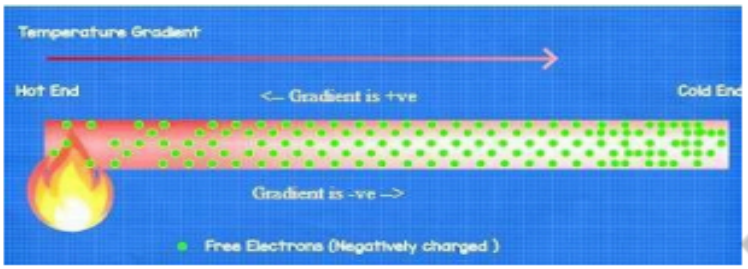
$$I = \int_s \overline{J} \quad \overline{ds}$$

$$\int_l \overline{B} \quad \overline{dl} = \mu_0 \int_s \overline{J} \quad \overline{ds}$$

This is integral form of Ampere circuital law in static magnetic field. This is integ Maxwell's fourth equation.

Q3. What is Gradient? If $\Phi = 3(x^2y - y^2x)$, find $\nabla\Phi$ at the point (1, -2,-1).

ANS:



1) Gradient is the rate of change of a physical quantity with distance.
2) When metal bar is heated at one end, the rate of change of temperature along the length of metal bar is known as temperature gradient.
3) The temperature is function of x, y, z in Cartesian coordinate system. Therefore T = T(x, y, z) is a scalar function.
4) $\vec{\nabla}$. T is called temperature gradient of a scalar function.
5) The gradient is rate of change of a function in a specified direction. Therefore, gradient of scalar function is a vector quantity.
6) The gradient is – ve when value of function is decreasing along the given direction and gradient is + ve when value of function is increasing along the given direction.

$$\vec{\nabla} = \hat{i}\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z}$$

$$\vec{\nabla}T = \hat{i}\frac{\partial T}{\partial x} + j\frac{\partial T}{\partial y} + k\frac{\partial T}{\partial z}$$

Find the gradient of $\phi(x,y,z) = 3x^2y - y^3z^2$ at point (1,-2,-1).

$$\frac{\partial\phi}{\partial x} = \frac{\partial(3x^2y - y^3z^2)}{\partial x} = 6xy \qquad \frac{\partial\phi}{\partial y} = \frac{\partial(3x^2y - y^3z^2)}{\partial y} = 3x^2 - 3y^2z^2$$

$$\frac{\partial\phi}{\partial z} = \frac{\partial(3x^2y - y^3z^2)}{\partial z} = -2y^3z$$

$$\vec{\nabla\phi} = \frac{\partial\phi}{\partial x}\hat{x} + \frac{\partial\phi}{\partial y}\hat{y} + \frac{\partial\phi}{\partial z}\hat{z}$$

$$= (6xy)\,\hat{x} + (3x^2 - 3y^2z^2)\,\hat{y} - (2y^3z)\,\hat{z}$$

$$\therefore \vec{\nabla\phi}\Big|_{(1,-2,-1)} = 6(1)(-2)\,\hat{x} + (3(1)^2 - 3(-2)^2(-1)^2)\,\hat{y} - 2(-2)^3(-1)\,\hat{z}$$

$$= -12\,\hat{x} - 9\,\hat{y} - 16\,\hat{z}$$

Q4. Determine the Curl of the vector field A= $yz\hat{a}_x + 4\,xy\hat{a}_y + y\hat{a}_z$

ANS:

Vector Field

The given vector field is:

$$A = yz\hat{a}_x + 4xy\hat{a}_y + y\hat{a}_z$$

Where the components are:

- $A_x = yz$
- $A_y = 4xy$
- $A_z = y$

Curl Calculation

The Curl of a vector field A in Cartesian coordinates is defined by the determinant of the operator matrix:

$$\nabla \times A = \text{Curl } A = \begin{vmatrix} \hat{a}_x & \hat{a}_y & \hat{a}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ A_x & A_y & A_z \end{vmatrix}$$

Substituting the components of A:

$$\nabla \times A = \begin{vmatrix} \hat{a}_x & \hat{a}_y & \hat{a}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ yz & 4xy & y \end{vmatrix}$$

Expanding the determinant:

1. $\hat{a}_x$ component:

$$(\nabla \times A)_x = \frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z}$$

$$(\nabla \times A)_x = \frac{\partial}{\partial y}(y) - \frac{\partial}{\partial z}(4xy)$$

$$(\nabla \times A)_x = 1 - 0 = 1$$

2. $\hat{a}_y$ component:

$$(\nabla \times A)_y = \frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x}$$

$$(\nabla \times A)_y = \frac{\partial}{\partial z}(yz) - \frac{\partial}{\partial x}(y)$$

$$(\nabla \times A)_y = y - 0 = y$$

3. $\hat{a}_z$ component:

$$(\nabla \times A)_z = \frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y}$$

$$(\nabla \times A)_z = \frac{\partial}{\partial x}(4xy) - \frac{\partial}{\partial y}(yz)$$

$$(\nabla \times A)_z = 4y - z$$

Final Result

Combining the components, the Curl of the vector field A is:

$$\boldsymbol{\nabla \times \mathbf{A} = (1)\hat{\mathbf{a}}_x + (y)\hat{\mathbf{a}}_y + (4y - z)\hat{\mathbf{a}}_z}$$

Module V: Quantum Physics

Q1. Derive the Schrödinger's Time Independent wave equation for matter waves.

ANS:

Schrodinger time independent equation:

If the motion of the particle is in free space i.e. force is not acting on the particle, then P.E. of particle is zero. We can separate the variables of function $\psi(x.t)$

Hence $\psi(x.t) = \psi(x)\,\Phi(t)$

Therefore Schrodinger time dependent eqn. can be written as

$$i\hbar\,\psi(x)\frac{\partial\Phi(t)}{\partial t} = -\frac{\hbar^2}{2m}\Phi(t)\frac{\partial^2\psi(x)}{\partial x^2} + V\,\psi(x)\,\Phi(t)$$

Divide both side by $\psi(x)\,\Phi(t)$

$$i\hbar\,\frac{1}{\Phi(t)}\frac{\partial\Phi(t)}{\partial t} = -\frac{\hbar^2}{2m}\,\frac{1}{\psi(x)}\frac{\partial^2\psi(x)}{\partial x^2} + V$$

RHS of this equation is only the function of 't' and LHS is only the function of 'x'. Therefore both side equal to some constant say E

$$-\frac{\hbar^2}{2m}\,\frac{1}{\psi(x)}\frac{\partial^2\psi(x)}{\partial x^2} + V = E$$

Multiply both sides by $\psi(x)$

$$-\frac{\hbar^2}{2m}\frac{\partial^2\psi(x)}{\partial x^2} + V\psi(x) = E\psi(x)$$

$$\frac{\hbar^2}{2m}\frac{\partial^2\psi(x)}{\partial x^2} + (E - V)\psi(x) = 0$$

This is Schrodinger time independent equation.

Q2. An electron and a photon each have a wavelength of 2A(angstrom) What are their momentum and energies?

Given Data

- Wavelength (λ) for both electron and photon: $\lambda = 2 \text{ Å}$
- Conversion to meters: $\lambda = 2 \times 10^{-10} \text{ m}$
- Planck's constant (h): $h = 6.626 \times 10^{-34} \text{ J} \cdot \text{s}$
- Speed of light (c): $c = 3 \times 10^{8} \text{ m/s}$

Part I: Calculation for the Photon

A photon is an electromagnetic wave governed by quantum theory and relativity.

1. Momentum of the Photon (p_p)

The momentum of a photon is given by the de Broglie relation (or Planck's relation):

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

Substitution:

$$p_p = \frac{6.626 \times 10^{-34} \text{ J} \cdot \text{s}}{2 \times 10^{-10} \text{ m}}$$

$$p_p = 3.313 \times 10^{-24} \text{ kg} \cdot \text{m/s}$$

2. Energy of the Photon (E_p)

The energy of a photon is given by:

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

Substitution:

$$E_p = \frac{(6.626 \times 10^{-34} \text{ J} \cdot \text{s}) \times (3 \times 10^{8} \text{ m/s})}{2 \times 10^{-10} \text{ m}}$$

$$E_p = \frac{19.878 \times 10^{-26} \text{ J} \cdot \text{m}}{2 \times 10^{-10} \text{ m}}$$

$$E_p = 9.939 \times 10^{-16} \text{ J}$$

Part II: Calculation for the Electron

An electron is a particle whose wave nature is described by the de Broglie hypothesis.

1. Momentum of the Electron (p_e)

The momentum of the electron is also given by the de Broglie relation:

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

Since the wavelength is the same as the photon, the momentum is identical.

Substitution:

$$p_e = \frac{6.626 \times 10^{-34}\ \text{J} \cdot \text{s}}{2 \times 10^{-10}\ \text{m}}$$

$$p_e = 3.313 \times 10^{-24}\ \text{kg} \cdot \text{m/s}$$

2. Energy of the Electron (E_e)

The energy of the electron (which is its kinetic energy, since its momentum is non-relativistic) is given by:

$$E_e = \frac{p_e^2}{2m_e}$$

Where m_e (mass of electron) $\approx 9.1 \times 10^{-31}$ kg.

Substitution:

$$E_e = \frac{(3.313 \times 10^{-24}\ \text{kg} \cdot \text{m/s})^2}{2 \times (9.1 \times 10^{-31}\ \text{kg})}$$

$$E_e = \frac{10.976 \times 10^{-48}}{18.2 \times 10^{-31}}\ \text{J}$$

$$E_e \approx 0.6030 \times 10^{-17}\ \text{J}$$

$$E_e \approx 6.030 \times 10^{-18}\ \text{J}$$

Property	Photon ($\lambda = 2$ Å)	Electron ($\lambda = 2$ Å)
Momentum	$3.313 \times 10^{-24}\ \text{kg} \cdot \text{m/s}$	$3.313 \times 10^{-24}\ \text{kg} \cdot \text{m/s}$
Energy	$9.939 \times 10^{-16}\ \text{J}$	$6.030 \times 10^{-18}\ \text{J}$

Q3. An electron is bound in an 1D potential well of infinite height and width 2A(angstrom) Find its energy values in the ground state and in first excited state.

ANS:

Given Data

- Width of the potential well (L): 2 Å
- In meters: $L = 2 \times 10^{-10}$ m
- State number for Ground state: $n = 1$
- State number for First excited state: $n = 2$
- Planck's constant (h): $h \approx 6.634 \times 10^{-34}$ J · s
- Mass of the electron (m): $m \approx 9.1 \times 10^{-31}$ kg

Formula for Energy Eigenvalues

The energy eigenvalues (E_n) for a particle in a 1D infinite potential well are given by:

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

Step 1: Calculate the Constant Term ($C = \frac{h^2}{8mL^2}$)

This term is the energy of the ground state (E_1), where $n = 1$.

$$C = \frac{(6.634 \times 10^{-34}\ \text{J} \cdot \text{s})^2}{8 \times (9.1 \times 10^{-31}\ \text{kg}) \times (2 \times 10^{-10}\ \text{m})^2}$$

1. **Calculate the numerator (h^2):**

$$h^2 \approx 43.99 \times 10^{-68}\ \text{J}^2 \cdot \text{s}^2$$

2. **Calculate the denominator ($8mL^2$):**

$$8mL^2 = 8 \times (9.1 \times 10^{-31}) \times (4 \times 10^{-20})\ \text{kg} \cdot \text{m}^2$$

$$8mL^2 = 291.2 \times 10^{-51}\ \text{kg} \cdot \text{m}^2$$

3. **Calculate C (E_1):**

$$E_1 = \frac{43.99 \times 10^{-68}\ \text{J}^2 \cdot \text{s}^2}{291.2 \times 10^{-51}\ \text{kg} \cdot \text{m}^2}$$

$$E_1 \approx 0.1511 \times 10^{-17}\ \text{J}$$

$$E_1 \approx 1.511 \times 10^{-18}\ \text{J}$$

Step 2: Energy of the Ground State ($n = 1$)

The energy of the ground state (E_1) is calculated with $n = 1$:

$$E_1 = \frac{1^2 h^2}{8mL^2} = C$$

$$\mathbf{E_1 \approx 1.511 \times 10^{-18}\ J}$$

Step 3: Energy of the First Excited State ($n = 2$)

The energy of the first excited state (E_2) is calculated with $n = 2$:

$$E_2 = \frac{2^2 h^2}{8mL^2} = 4 \times \left(\frac{h^2}{8mL^2}\right) = 4E_1$$

Substitution:

$$E_2 = 4 \times (1.511 \times 10^{-18}\ J)$$

$$\mathbf{E_2 \approx 6.044 \times 10^{-18}\ J}$$

Final Answer

- **Energy of the Ground State (E_1):** 1.511×10^{-18} J
- **Energy of the First Excited State (E_2):** 6.044×10^{-18} J

Q4. Explain the de Broglie hypothesis of matter waves and state its properties.

ANS:

Quantum physics is a branch of physics which deals with the properties and interaction of the matter.

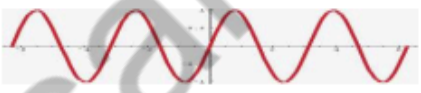
According to scientist De'Broglie, matter possess dual nature i.e. wave and particle nature.

Particle:- The constituents of matter like electrons, protons, atoms, molecules are referred as particles.

Properties:-

1. Particle has fixed mass.
2. Particle can locate at definite point.
3. Particle has ability to move from one place to another place.
4. Particle release energy when suddenly stopped.
5. Particle is specified by mass, velocity, momentum and energy.

Wave:- The oscillatory disturbance produced by a particle is known as wave.



Properties:-

1. Wave spread out over a large region of space,
2. Wave cannot locate at any particular point.
3. Wave is specified by frequency, wavelength. Amplitude and phase.

Q. State and explain De 'Broglie's hypothesis?

De'Broglies hypothesis of matter wave:

According to scientist De 'Broglie, a particle of mass 'm' moving with velocity 'V' is associate with a wave of wavelength $\lambda = \frac{h}{mv} = \frac{h}{p}$ Where p = mv is momentum of the particle.

The wave associated with the moving particle is known as De 'Broglie's wave or matter wave and wavelength is known as De 'Broglie's wavelength.

Explanation:- The radiation i.e photons has dual nature.

The phenomenon like interference, diffraction, polarization, reflection, refraction can only be explained if the radiation is to be considering as a wave.

The phenomenon like photoelectric effect, Compton Effect can only be explained if the radiation is to be consider as a particle.

If we consider a photon as a wave of frequency γ, then its energy is given by $E = h\gamma$

If we consider a photon as a particle of mass m, then its energy is given by $E = mc^2$

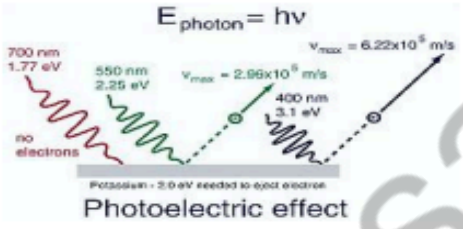
Therefore $mc^2 = h\gamma$ but $\gamma = c / \lambda$

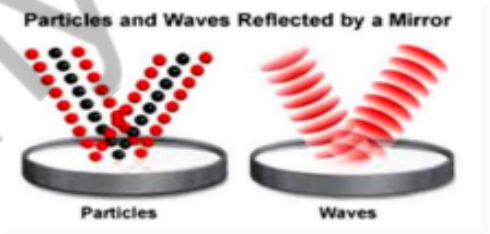
$$mc^2 = h\frac{c}{\lambda}$$

$mc = \frac{h}{\lambda}$ but mc = p momentum of photon

$p = \frac{h}{\lambda}$ therefore $\lambda = \frac{h}{p}$ this is wavelength of light wave.

Similarly, if a particle of mass m moving with velocity v, then a wave of wavelength $\lambda = \frac{h}{mv}$ is associated with this particle.





Properties of matter wave:

(1) Matter wave represents the probability of finding a particle in space.

(2) Matter waves are not electromagnetic in nature.

(3) de-Brogile or matter wave is independent of the charge on the material particle. It means, matter wave of de-Broglie wave is associated with every moving particle (whether charged or uncharged).

(4) Practical observation of matter waves is possible only when the de-Broglie wavelength is of the order of the size of the particles.

(5) Electron microscope works on the basis of de-Broglie waves.

(6) The phase velocity of the matter waves can be greater than the speed of the light.

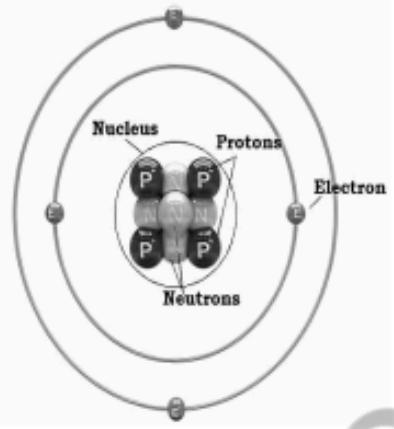
(7) Matter waves can propagate in vacuum, hence they are not mechanical waves.

(8) The number of de-Broglie waves associated with nth orbital electron is n.

(9) Only those circular orbits around the nucleus are stable whose circumference is integral multiple of de-Broglie wavelength associated with the orbital electron.

Q5. Prove using the Uncertainty Principle that an electron cannot reside inside the nucleus of an atom.

ANS:



Diameter of nucleus of an atom is 10^{-14} m.

Uncertainty in the measurement of position of electron with in nucleus is

$$\Delta x = 10^{-14}\ \text{m}$$

According to HUP, $\Delta x.\Delta p \geq \hbar$ Where $\hbar = \frac{h}{2\pi} = 1.055 \text{ X } 10^{-34}$

$$\Delta p = \frac{1.055 \text{ X } 10^{-34}}{\Delta x}$$

$$\Delta p = \frac{1.055 \text{ X } 10^{-34}}{10^{-14}}$$

$$\Delta p = 10^{-20} Kg.m/sec$$

The energy of an electron is $E = \Delta p\,.c = 10^{-20}.3X\,10^{8} = 3\,X\,10^{-12} J$

$$E = \frac{3\,X\,10^{-12}}{1.6\,X\,10^{-19}}\ eV = 19\ MeV$$

Thus energy required for electron to remain inside the nucleus is 19 MeV. It is not possible, therefore electron never exist inside the nucleus.

Alternate solution:

$\therefore$ Uncertainty in position if electron exist in nucleus = $\Delta x = 2r$

$$\therefore \Delta x = 2r \approx 10^{-14} m$$

According to HUP $\boxed{\Delta x \, \Delta p \geq \frac{h}{4\pi}}$

$$\therefore \Delta x \, m \Delta v \geq \frac{h}{4\pi}$$

$$\therefore \Delta v \geq \frac{h}{4\pi \, m \, \Delta x} = \frac{6.63 \times 10^{-34}}{4 \times 3.142 \times 9.1 \times 10^{-31} \times 10^{-14}}$$

$$\therefore \Delta v \geq 5.797 \times 10^{9} \text{ m/s}$$

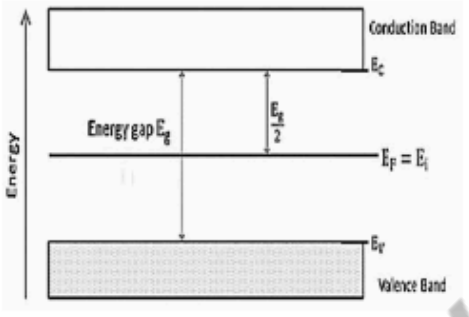
Thus velocity of electron required is greater than velocity of light, this is not possible. Therefore electron never exists inside the nucleus.

Module VI: Semiconductor Physics

Q1. Derive an expression for the Fermi level for an intrinsic semiconductor (or show it lies midway of the conduction band and valence band).

ANS:

FERMI LEVEL IN INTRINSIC SEMICONDUCTOR:-



1) In semiconductors at temp. T = O°K, the valance band is completely filled by the electrons and conduction band is empty. At temp. T°K, some electrons from the valence band can jump in to the conduction band, leaving behind equal number of holes in the valence band. Thus in semiconductors the charged carriers are electrons and holes.

2) At temp. T°K, the density of free electrons in the conduction band and density of holes in the valence band is equal. Therefore Fermi level always at the middle between the valence band and conduction band.

3) Thus in semiconductor Fermi level is not an allowed energy level for electrons in the semiconductor, but it is reference level between the valence band and conduction band.

If E_v – energy of upper level of valence band.
E_c – energy of bottom level of conduction band.
E_f – Fermi energy level.
E_g– energy gap between valence band and conduction band.

Therefore, $Ef = \frac{Ec+Ev}{2} = \frac{Eg}{2}$

Consider at temp. T°K,
n_c – Concentration of free electrons in conduction band.
n_v– Concentration of holes in the valence band.
N_c– Effective density of states in the conduction band.
N_v – Effective density of states in the valence band.

$$n_c = Nc\, e^{-(Ec - Ef)/KT}$$

$$n_v = Nv\, e^{-(Ef - Ev)/KT}$$

but $n_c = n_v$

$$Nc\, e^{-(Ec-Ef)/KT} = Nv\, e^{-(Ef-Ev)/KT}$$

$$e^{-(Ec-Ef)/KT} = \frac{Nv}{Nc}\, e^{-(Ef-Ev)/KT}$$

But Nv = Nc, therefore Nv / Nc =1

$$e^{-(Ec-Ef)/KT} = e^{-(Ef-Ev)/KT}$$

Take logarithm on both sides,

$$\frac{-(Ec-Ef)}{KT} = \frac{-(Ef-Ev)}{KT}$$

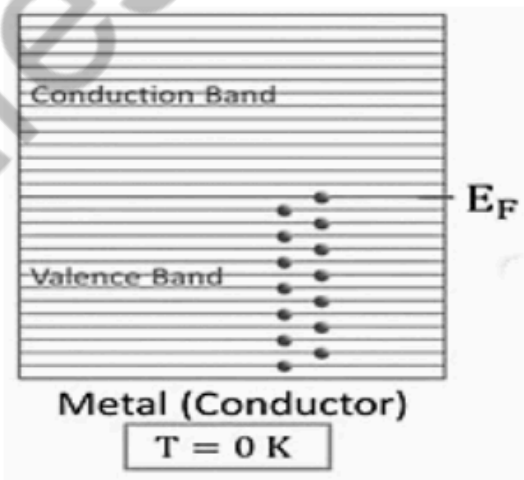
$$-Ec + Ef + Ef - Ev = 0$$

Therefore, $Ef = \frac{Ec+Ev}{2} = \frac{Eg}{2}$

Thus in intrinsic semiconductor, Fermi level always at the middle between the valence band and conduction band.

Q2. Write the Fermi-Dirac distribution function and explain the terms involved in it.

ANS:



1) In conductor's valence and conduction bands are overlap on each other. Therefore continuous range of energy levels is available for the electrons.

2) The electrons are filling up in to the various energy levels such that first lowest energy level is filled by the pair of electrons and then second lowest energy level and so on till all the electrons occupy the

particular energy level. The upper most energy level occupied by the electrons in metal is known as Fermi level and its energy is known as Fermi energy. Thus Fermi level is allowed energy level in conductors.

3) The distribution of electrons of energy E in various energy levels is given by Fermi-Dirac distribution function,

$$f(E) = \frac{1}{1+e^{\left(\frac{E-E_F}{kT}\right)}}$$

f(E) is the probability of occupancy for energy level E

E_F is Fermi energy

T is temperature in ^{0}K and

$k = 1.38 \times 10^{-23}$ J/K $= 8.625 \times 10^{-5}$ eV/K

Fermi function F(E) gives the probability that an electrons of energy E occupying particular energy level.

Q3. Explain mobility of electrons. Calculate the mobility if the resistivity of Cu is 1.72×10^{-8} Ω . m and the number of electrons per unit volume is 10.41×10^{28} m^{-3}.
ANS:

1. Explanation of Mobility of Electrons (μ_e)

Definition

- **Electron mobility (μ_e)** is defined as the magnitude of the **drift velocity (v_d)** acquired by an electron per unit **electric field (E)** applied across the material.
- It quantifies how easily electrons can move through the crystal lattice of a conductor or semiconductor.
- **High mobility** indicates that electrons can accelerate quickly and travel with less resistance from lattice vibrations or imperfections.

Mathematical Formula

$$\mu_e = \frac{v_d}{E}$$

Unit

- The standard unit of mobility is $\mathrm{m}^2/\mathrm{V} \cdot \mathrm{s}$ (square meter per volt-second).

2. Calculation of Electron Mobility in Copper (Cu)

We can calculate the mobility using the relationship between conductivity (σ), resistivity (ρ), charge (e), and electron concentration (n or N):

Given Data

- Resistivity of Copper (ρ): $1.72 \times 10^{-8}\ \Omega \cdot \mathrm{m}$
- Number of electrons per unit volume (n): $10.41 \times 10^{28}\ \mathrm{m}^{-3}$
- Charge of an electron (e): $1.6 \times 10^{-19}\ \mathrm{C}$ (Standard constant)

Formulas

1. **Relation between Conductivity (σ) and Resistivity (ρ):**

$$\sigma = \frac{1}{\rho}$$

2. **Relation between Conductivity (σ) and Mobility (μ_e):**

$$\sigma = ne\mu_e$$

Step 1: Calculate Conductivity (σ)

$$\sigma = \frac{1}{\rho} = \frac{1}{1.72 \times 10^{-8}\ \Omega \cdot \mathrm{m}}$$

$$\sigma \approx 5.814 \times 10^{7}\ \Omega^{-1} \cdot \mathrm{m}^{-1}$$

Step 2: Calculate Mobility (μ_e)

Using the conductivity formula, we rearrange to find mobility:

$$\mu_e = \frac{\sigma}{ne}$$

Substitution:

$$\mu_e = \frac{5.814 \times 10^{7}\ \Omega^{-1} \cdot \mathrm{m}^{-1}}{(10.41 \times 10^{28}\ \mathrm{m}^{-3}) \times (1.6 \times 10^{-19}\ \mathrm{C})}$$

Calculate the denominator ($n \cdot e$):

$$ne = 16.656 \times 10^{9}\ \mathrm{C} \cdot \mathrm{m}^{-3}$$

Final Calculation:

$$\mu_e = \frac{5.814 \times 10^{7}}{16.656 \times 10^{9}}$$

$$\mu_e \approx 0.3491 \times 10^{-2}$$

$$\mu_e \approx 3.491 \times 10^{-3}\ \mathrm{m}^2/\mathrm{V} \cdot \mathrm{s}$$

Final Answer

The mobility of electrons in Copper is approximately $\mathbf{3.491 \times 10^{-3}}\ \mathrm{m}^2/\mathrm{V} \cdot \mathrm{s}$.