# UNIT-03

## LAQ'S

Q1) Enumerate the Characteristics of Lasers? Depict The Construction and Working of Any One Laser.

Q2) what are Einstein's Coefficient? Infer the relation between them.

Q3) Bring out the Analogy Between Ruby & He-Ne Laser?

Q4) What is meant by Acceptance Angle? Obtain the expression for acceptance angle and numerical aperture of the given optical fiber?

Q5) Discuss the classification of Optical fiber Based on refractive index profile?

Q6) Write shorts notes on

i) Losses in optical fibre.

ii)Fibre drawing process (Double crucible method)

## SAQ'S

Q1) what is meant by population inversion?

Q2) Distinguish between Spontaneous & Stimulated Emission?

Q3) Write few application of Ruby/Semiconductor/He-Ne Lasers?

Q4) Problems on E = HV

Q5) Problems on En = (n^2/h^2)/8ml^2

Q6) What is meant by acceptance cone?

Q7) Define Numerical aperture and Acceptance angle of the given Optical fiber?

Q8) Distinguish between step index optical fiber and graded index optical index?

Q9) Write few applications of Optical fiber?

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Laq's

1)

## Characteristics of Laser (Enumerated and Briefly Explained):

1. **Monochromatic**
   Laser light has a single wavelength or color, unlike ordinary light which contains multiple wavelengths.

2. **Coherent**
   The emitted light waves are in phase (same frequency and direction), which makes the beam stable and focused.

3. **Highly Directional**
   Laser beams travel in a very narrow, straight line with minimal spreading.

4. **High Intensity**
   Because the energy is concentrated in a small area, laser beams are extremely bright and powerful.

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3. **Highly Directional**
   Laser beams travel in a very narrow, straight line with minimal spreading.

4. **High Intensity**
   Because the energy is concentrated in a small area, laser beams are extremely bright and powerful.

5. **Polarized**
   The electric field of laser light usually oscillates in one direction, making it linearly polarized.

6. **Stimulated Emission**
   Lasers amplify light by stimulated emission, where one photon causes the release of another identical photon.

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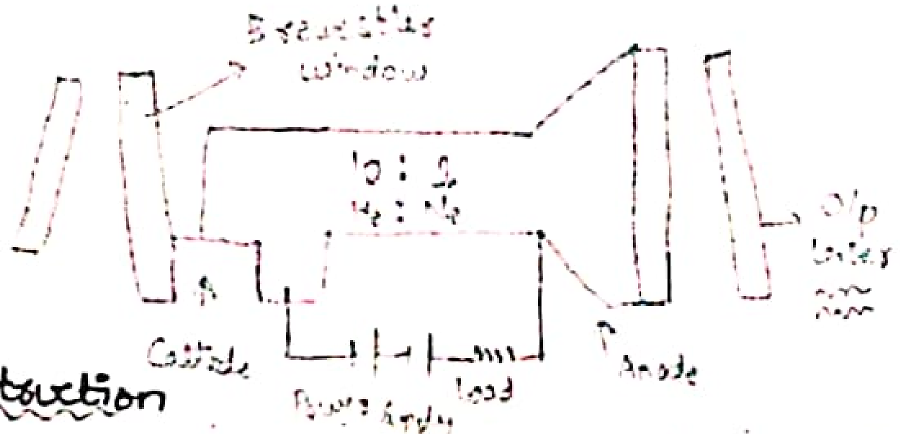
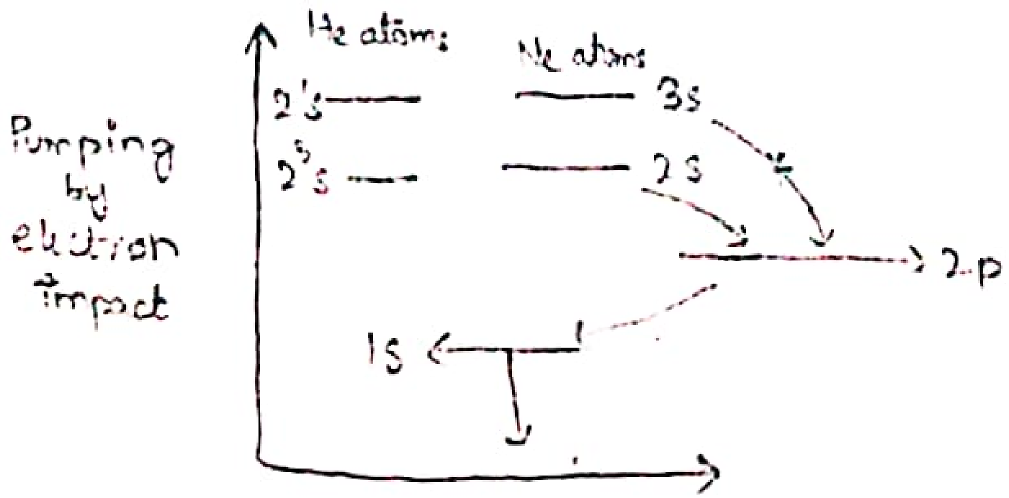
pair which lies is coloured in the visible spectrum.

## He-Neon laser




**Construction**

* He-Neon laser consist of He-Neon in ~~ra~~ra. 10:1 inside a long narrow discharge tube
* The pumping mechanism used in the He-Neon laser is electric discharge. The gas system is inclosed between brewstle window which are partially and perfectly reflecting windows
* The load resistance used in the He-Neon laser system to limit the current after every discharge.




**Working**

* Neon atoms provides energy levels for laser transition where as He-atoms are not directly involved in laser transition but they provide necessary energy i.e., efficient excitation for Neon atoms.

* The pumping mechanism by which the Neon atoms excite to the metastable states 2s and 3s.
* The transition between 3s energy level of Neon with 2p energy level give rise to laser transition of wavelength 6328 Å or 632.8 nm The laser output obtained is continous wave form.

Semiconductor laser

2) Einstien - co-efficients.

Let us consider atomic System which contains ground State $E_1$ and excited State $E_2$. If $N_1$ is the no. of atoms in the ground State per unit volume and $N_2$ is the no. of atoms in the excited State per unit volume, if $U(\nu)$ is the intensity of the incident radiation of the external source

$$E.S \xrightarrow{N_2} E_2$$

$$G.S \xrightarrow{N_1} E_1$$

Einstien Relation b/w its co-efficients

External source $U(\nu)$

$$\xrightarrow{N_2} E_2$$

$$\xrightarrow{N_1} E_1$$

$R_{12}$. St. Ab $\propto U(\nu).N_1$

$$R_{12}.\text{St. Ab} = B_{12}\,U(\nu)\,N_1 \rightarrow (1)$$

External source $U(\nu)$

$$\xrightarrow{N_2} E_2$$

$$\longleftarrow E_1$$

$R_{21}$ St. Em $\propto U(\nu).N_2$

$$R_{21}.\text{St. Em} = B_{21}\,U(\nu).N_2 \rightarrow (2)$$

No External source

$$\xrightarrow{N_2} E_2$$

$$\xrightarrow{N_1} E_1$$

$R_{21}$. Sp. Em $\propto N_2$

$$R_{21}\text{ Sp. Em} = A_{21}.N_2 \rightarrow (3)$$

At equilibrium

Upward transition = downward transition

$$B_{12}U(\nu).N_1 = B_{21}.U(\nu).N_2 + A_{21}.N_2$$

$$B_{12}.U(\nu).N_1 - B_{21}.U(\nu).N_2 = A_{21}.N_2$$

$$U(\nu)\left[B_{12}.N_1 - B_{21}.N_2\right] = A_{21}.N_2$$

$$U(\nu) = \frac{A_{21}.N_2}{B_{12}.N_1 - B_{21}.N_2} \rightarrow (4)$$

$\div$ R.H.S of eqn (4) with $B_{21}.N_2$

$$U(\nu) = \frac{\dfrac{A_{21}.N_2}{B_{21}.N_2}}{\dfrac{B_{12}.N_1}{B_{21}.N_2} - \dfrac{B_{21}.N_2}{B_{21}.N_2}}$$

$$U(\nu) = \frac{\dfrac{A_{21}}{B_{21}}}{\left(\dfrac{B_{12}}{B_{21}}\right)\left(\dfrac{N_1}{N_2}\right) - 1} \rightarrow (5)$$

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According Maxwell Boltzmann (The ratio of equilibrium population of energy levels)

$$\frac{N_1}{N_2} = \exp\left(\frac{h\nu}{KBT}\right)$$

Now Substitute $\frac{N_1}{N_2}$ value in eq (5)

$$U(\nu) = \left[\frac{\frac{A_{21}}{B_{21}}}{\frac{B_{12}}{B_{21}} \exp\left(\frac{h\nu}{KBT}\right) - 1}\right] \rightarrow (6)$$

According to plank's law the radiation density per unit frequency range is given as

$$U(\nu) = \frac{4\pi h\nu^3 n_0^3}{c^3}\left[\frac{1}{\exp\left(\frac{h\nu}{KBT}\right).\left(\frac{B_{12}}{B_{21}}\right) - 1}\right] \rightarrow (7)$$

Compairing eqn (6) and eqn (7)

$$\frac{A_{21}}{B_{21}} \propto \nu^3 \rightarrow (8)$$

$$\frac{B_{12}}{B_{21}} \propto 1$$

$$\frac{B_{12}}{B_{21}} = 1 \Rightarrow B_{12} = B_{21} \rightarrow (9)$$

Eqn (8) significe spontaneous emission is domenating stimulated emission

Eqn (9) significe that in the presence of constant radiation the probability of stimulated absorption is equal to stimulated emission.

$B_{12}$ is einstien coefficient of stimulated / Induced absorption.
$B_{21}$ is einstien coefficient of stimulated emission.
$A_{21}$ is the einstien coefficient of spontaneas emission.

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## Q3) Bring out the Analogy Between Ruby and He-Ne Laser

Ruby and He-Ne lasers are both types of lasers that emit red light, but they differ in several aspects.

The **Ruby laser** is a **solid-state laser** that uses a **ruby crystal ($Al_2O_3$ doped with $Cr^{3+}$)** as its active medium. It is pumped using a **flash lamp** and works in **pulsed mode**, emitting light at **694.3 nm**.

In contrast, the **He-Ne laser** is a **gas laser** that uses a **mixture of helium and neon gases**. It is pumped using an **electric discharge** and operates in **continuous wave (CW) mode**, emitting light at **632.8 nm**.

Ruby lasers require more cooling due to

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light at **632.8 nm**.

Ruby lasers require **more cooling** due to heat from the flash lamp, while He-Ne lasers, using a gas medium, **generate less heat**. The **beam from a He-Ne laser is more coherent and stable**, whereas the ruby laser produces **short, intense pulses**.

In summary, ruby lasers are used where high power pulses are needed (like in surgery), and He-Ne lasers are used where a stable, precise beam is required (like in lab experiments and barcode scanners).

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## 4) Acceptance Angle (in Optical Fibers):

**Acceptance angle** is the **maximum angle** at which light can enter the **core of an optical fiber** and still be guided through it by **total internal reflection.**

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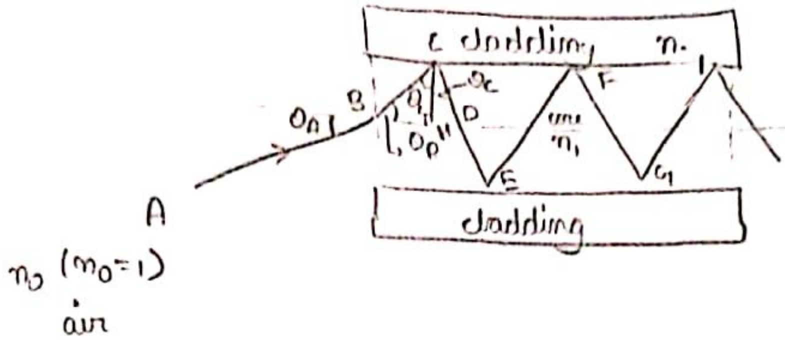
## Expression for Numerical aperture and acceptance angle




Let us consider the ~~or~~ across-sectional view of along the length of optical fibre

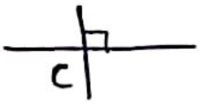
Using Snell's law

$$\mu = \frac{\sin i}{\sin r}$$

Applying Snell's law at B


$\cancel{\angle A + \angle B}$ $n_0 \sin \theta_A = n_1 \sin \theta_R$

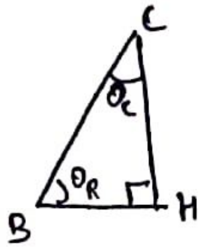
Applying Snell's law at C




$$n_1 \sin \theta_c = n_2 \sin 90$$

$$n_1 \sin \theta_c = n_2$$

$$\sin \theta_c = \frac{n_2}{n_1} \rightarrow (2)$$




$$\angle A + \angle B + \angle C = 180$$

$$\theta_R + \theta_c + 90 = 180$$

$$\theta_R = (90 - \theta_c) \quad - (3)$$

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Taking sine on both sides (in eq 3)

$$\sin \theta_R = \sin(90 - \theta_c)$$

$$\sin \theta_R = \cos \theta_c$$

Using equation (1)

$$n_0 \sin \theta_A = n_1 \sin \theta_R$$

Since $n_0 = 1$

$$\sin \theta_A = n_1 \cos \theta_c \quad (\text{Since } \because \sin \theta_A = \cos \theta_c)$$

$$\sin \theta_A = n_1 \sqrt{1 - \sin^2 \theta_c} \quad \left[\text{Since } \sin \theta_c = \frac{n_2}{n_1}\right]$$

$$\sin \theta_A = n_1 \sqrt{1 - \left(\frac{n_2}{n_1}\right)^2} \Rightarrow$$

$$\sin \theta_A = \frac{\cancel{n_1} \sqrt{n_1^2 - n_2^2}}{\cancel{n_1}}$$

$$\sin \theta_A = \sqrt{n_1^2 - n_2^2} \quad (\text{Numerical aperture})$$

~~Accepta.~~

Acceptance Angle

$$\theta_A = \sin^{-1}\left(\sqrt{(n_1)^2 - (n_2)^2}\right)$$

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## Q5) Discuss the Classification of Optical Fiber Based on Refractive Index Profile

Optical fibers can be classified based on how the **refractive index** of the core changes from the center of the fiber outward. This classification affects how light travels through the fiber and how efficiently it is transmitted.

There are **two main types** based on the **refractive index profile**:

### 1. Step Index Fiber:

In this type, the **refractive index of the core is uniform** throughout, and there is a **sudden drop (step)** at the core-cladding boundary.

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**1. Step Index Fiber:**

In this type, the **refractive index of the core is uniform** throughout, and there is a **sudden drop (step)** at the core-cladding boundary.

- **Core:** Has a constant refractive index.
- **Cladding:** Has a lower refractive index than the core.
- **Light propagation:** Light rays reflect sharply at the core-cladding boundary (total internal reflection).
- **Used in:** Short-distance communication, like LED-based systems.
- **Types:** Can be single-mode or multi-mode.

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**2. Graded Index Fiber:**

In this type, the **refractive index of the core gradually decreases** from the center toward the cladding.

- **Core:** Highest refractive index at the center, decreasing gradually towards the edges.
- **Cladding:** Has a uniform refractive index lower than the outer core.
- **Light propagation:** Light rays bend gradually in a curved path, reducing modal dispersion.
- **Used in:** Long-distance and high-speed communication.
- **Always:** Multi-mode fiber.

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## Comparison:

- **Step Index** fibers have more signal distortion due to modal dispersion.
- **Graded Index** fibers reduce dispersion and provide better performance over longer distances.

## Conclusion:

The classification of optical fibers based on refractive index profile—**step index** and **graded index**—is crucial in determining their performance in communication systems. The choice depends on the application, required bandwidth, and transmission distance.

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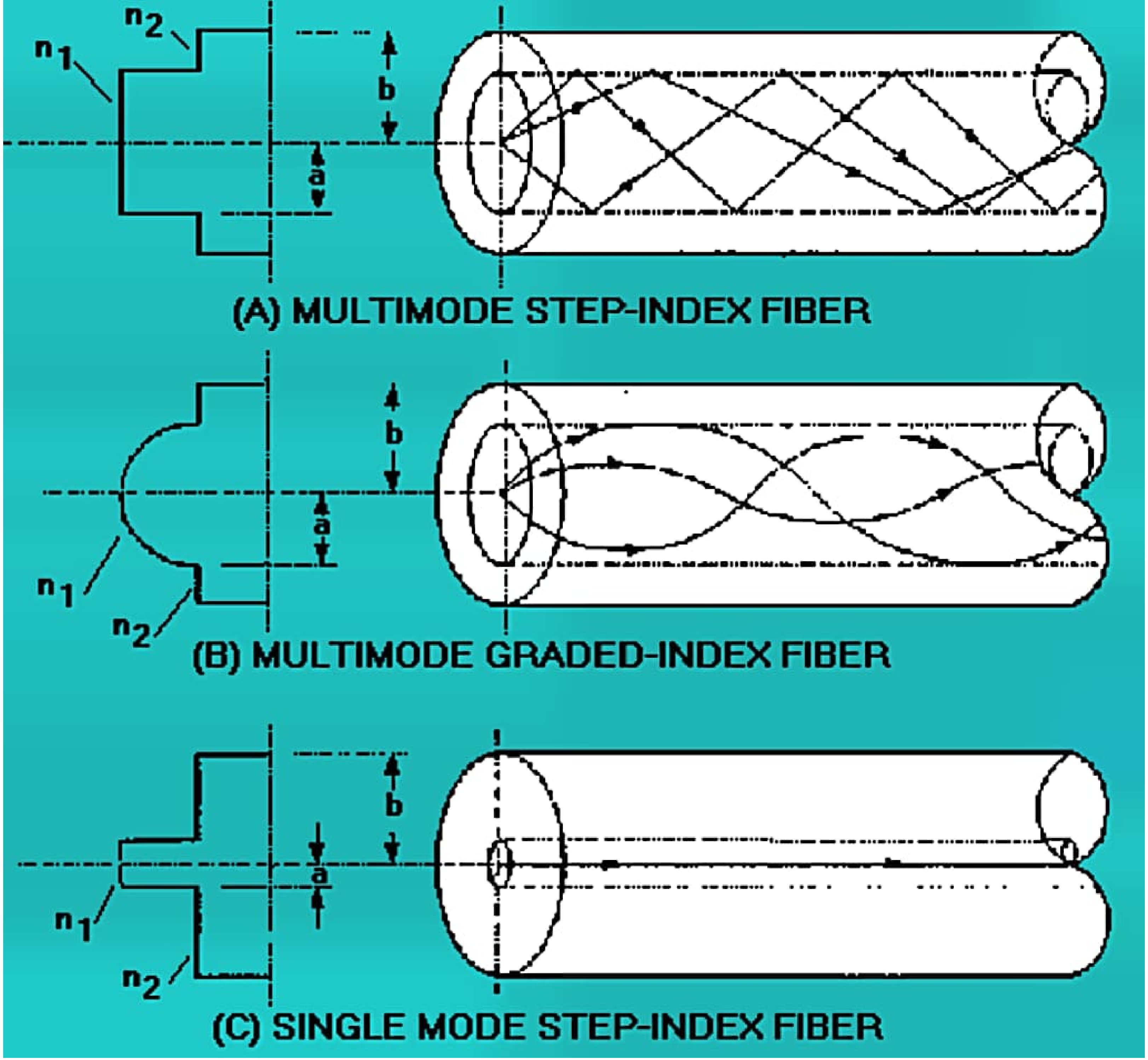


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6) ## Losses in Optical Fibre

When light travels through an optical fiber, some of its energy is lost. This is called loss in optical fiber. Losses reduce the strength and quality of the signal. These losses are measured in decibles per kilometer (dB/km)

### Types of Losses in Optical Fibre:-

1. **Intrinsic Losses**

These are natural losses caused by the fiber material itself.

a) **Absorption loss**

* Caused by the absorption of light by the fiber material (like silica)
* Some energy is converted into heat.
* Due to impurities like iron, water ($OH^-$), etc.

b) **Scattering loss (Rayleigh Scattering)**

* Caused due to tiny irregularities in the glass.
* Light is scattered in different directions.
* Increases at shorter wavelengths.

2. **Extrinsic Losses**

These are external losses caused by fiber defects or poor handling

a) **Bending loss**

* Happens when the fiber is bent too much.
* Light escapes from the core.
* Two types:-
  • Macrobending:- Large bends in the fiber.
  • Microbending:- Small bends or pressure on the fiber.

b) **Splicing and Connector Losses**

* Occurs at the joints where fibers are connected or spliced.
* Due to misalignment, air gaps or poor polishing.

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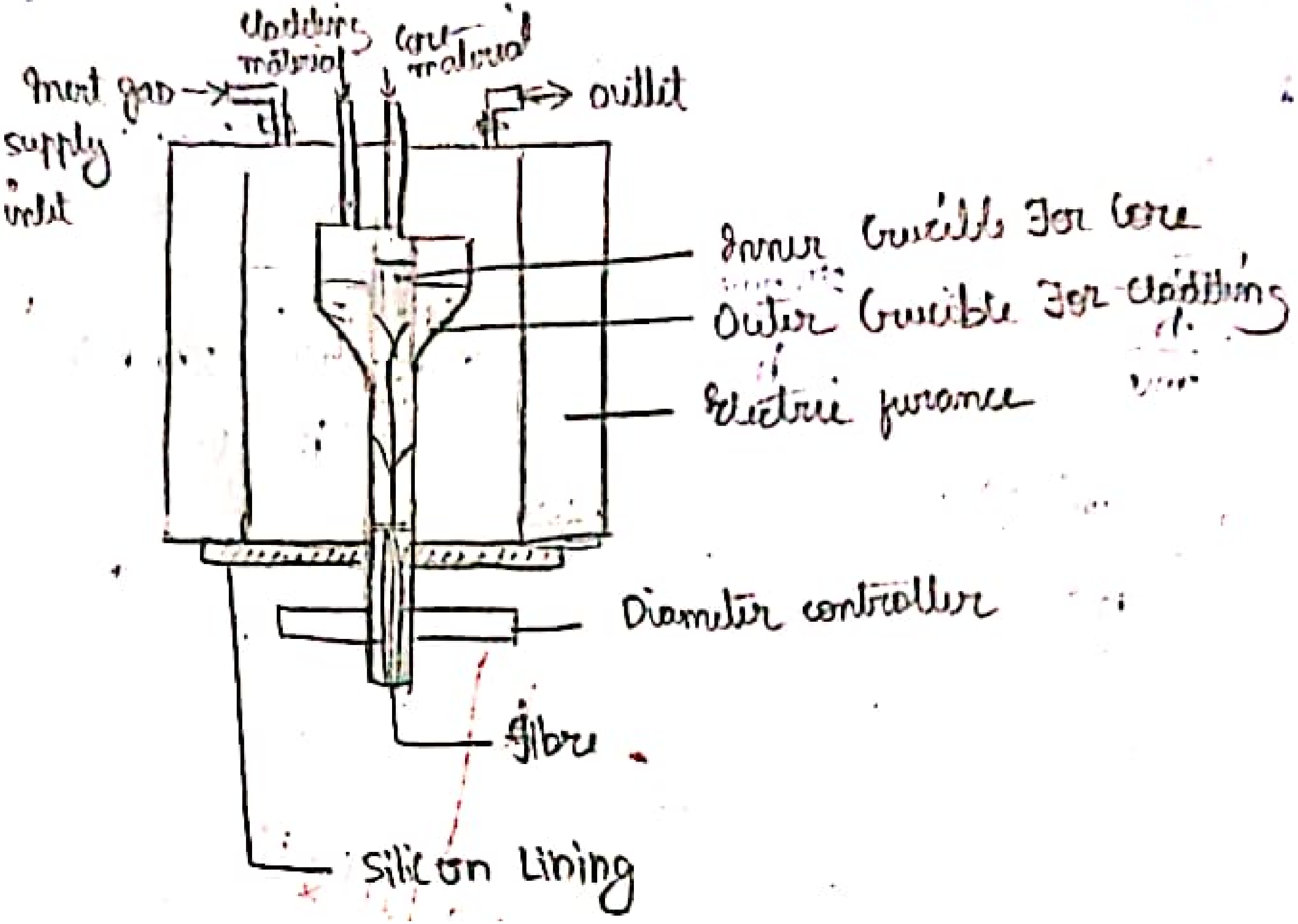
1) Double crucible method

A) The double crucible method is a fabrication technique used to produce ~~opt~~ optical fibres, particularly step-index fibres, by simultaneously drawing the core and cladding glasses from two crucible

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# Assignment - 3

## Double Crucible Method

The Double Crucible Method is a technique used for the growth of Optical and Semiconductor fibers, especially Single-crystal fibers. It is a type of melth growth method, where materials are melted and then Solidified in a controlled manner to form fibers.

### Principle:-

The method uses two concentric crucibles (containers made of heat resistant materials). The inner crucible holds the core material and the outer crucible holds the cladding materials. These materials are melted and the fiber is drawn from the bottom of the crucibles through a small orifice.

### Construction:-

* Inner Crucible:- Contains the core material (e.g., high refractive, index glass).
* Outer Crucible:- Contains the cladding material (e.g., low refractive index glass).
* Heating System:- Heats the crucible to melt the materials.
* Drawing System:- A thin fiber is drawn from the bottom opening, forming the core-cladding structure.

### Working:-

1. Both the core and cladding materials are heated until they melt.
2. The melts flow down through a small nozzle at the bottom.
3. The flow rate is controlled to ensure proper thickness of core and cladding.
4. The fiber is pulled downward at a controlled speed.
5. The melt solidfies as it moves downward, forming a single-mode or multi-mode optical fiber with proper core and cladding.

### Applications:-

* Used in the production of optical fibers for communication.
* Helpful in making semiconductor crystal fibers.

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Saq's

## Q1) What is meant by population inversion?

**Population inversion** is a condition in which the number of atoms or molecules in an excited energy state is greater than the number in the lower energy state. This condition is essential for **laser action**, as it allows **stimulated emission** to dominate over absorption.

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## Q2) Distinguish between Spontaneous & Stimulated Emission?

| Spontaneous Emission | Stimulated Er |
|---|---|
| Happens naturally without external influence. | Triggered by a incoming pho |
| Emitted photons are random in direction and phase. | Emitted photo coherent (san direction, frec |
| Basis for normal light sources (e.g., bulb). | Basis for lase operation. |

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## Q2) Distinguish between Spontaneous & Stimulated Emission?

| us Emission | Stimulated Emission |
| --- | --- |
| aturally :ernal | Triggered by an incoming photon. |
| otons are direction and | Emitted photons are coherent (same phase, direction, frequency). |
| ormal light g., bulb). | Basis for laser operation. |

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## Q3) Write a few applications of Ruby/Semiconductor/He-Ne Lasers?

- **Ruby Laser:**
  - Used in holography
  - Used in medical surgery (dermatology & eye treatment)
  - Drilling hard materials
- **Semiconductor Laser (Diode Laser):**
  - Used in barcode scanners, laser printers
  - Optical fiber communication
  - CD/DVD/Blu-ray players
- **He-Ne Laser:**
  - Used in laboratory experiments
  - Alignment and scanning devices
  - Holography

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## Q4) Problems on $E = h\nu$

**Formula:**

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

- $E$: energy (Joules)
- $h$: Planck's constant = $6.626 \times 10^{-34}, \text{Js}$
- $\nu$: frequency (Hz)
- $c$: speed of light = $3 \times 10^8, \text{m/s}$
- $\lambda$: wavelength (m)

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## Problem 1:

Calculate the energy of a photon with a wavelength of **500 nm.**

## Solution:

Given:

$$\lambda = 500\,\mathrm{nm} = 500 \times 10^{-9}\,\mathrm{m}$$

h = 6.626 \times 10^{-34} , \text{J·s}, \quad c = 3 \times 10^8 , \text{m/s}
Use formula:

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

E = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{500 \times 10^{-9}}

$$E = \frac{1.9878 \times 10^{-25}}{5 \times 10^{-7}} = 3.9756 \times 10^{-19}\,\mathrm{J}$$

**Answer:** $\boxed{3.98 \times 10^{-19}\,\mathrm{J}}$

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## Q5) Problems on $E_n = \frac{n^2h^2}{8mL^2}$

**Formula for energy levels of a particle in a box:**

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

- $E_n$ : energy of the nth level
- $n$: quantum number (1, 2, 3...)
- $h$: Planck's constant
- $m$: mass of the particle
- $L$: length of the box

Let me know if you need solved examples.

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## Problem 2:

A particle of mass $9.1 \times 10^{-31}, \mathrm{kg}$ (electron) is in a box of length $1 \times 10^{-10}, \mathrm{m}$. Find the energy of the particle in the **first energy level (n=1)**.

## Solution:

Given:

- $n = 1$
- $h = 6.626 \times 10^{-34}, \mathrm{Js}$
- $m = 9.1 \times 10^{-31}, \mathrm{kg}$
- $L = 1 \times 10^{-10}, \mathrm{m}$

Use formula:

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

E_1 = \frac{(1)^2 (6.626 \times 10^{-34})^2}{8 \tim .1 \times 10^{-31} \times (1 \times 1 0})^2}

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- $m = 9.1 \times 10^{-31}, \mathrm{kg}$
- $L = 1 \times 10^{-10}, \mathrm{m}$

Use formula:

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

E_1 = \frac{(1)^2 (6.626 \times 10^{-34})^2}{8 \times 9.1 \times 10^{-31} \times (1 \times 10^{-10})^2}

$$E_1 = \frac{4.39 \times 10^{-67}}{8 \times 9.1 \times 10^{-31} \times 1 \times 10^{-20}} = \frac{4.39 \times 10^{-67}}{7.28 \times 10^{-50}} = 6.03 \times 10^{-18}\,\mathrm{J}$$

**Answer:** $\boxed{6.03 \times 10^{-18}, \mathrm{J}}$

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## Q6) What is meant by acceptance cone?

The **acceptance cone** of an optical fiber is the cone within which light must enter the fiber to be guided properly. Its angle depends on the **numerical aperture (NA)** of the fiber.

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## Q7) Define Numerical Aperture and Acceptance Angle of the given Optical Fiber?

- **Numerical Aperture (NA):**
  It indicates the light-gathering ability of an optical fiber:

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

- **Acceptance Angle ($\theta_a$):**
  It is the maximum angle at which light can enter the fiber and still be guided:

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

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## Q8) Distinguish between Step Index and Graded Index Optical Fiber?

| Step Index Fiber | Graded Index |
|---|---|
| Refractive index changes abruptly between core and cladding. | Refractive ind changes grad center to edg |
| Light travels in zig-zag path. | Light follows path. |
| More modal dispersion. | Less modal d |
| Easier to manufacture. | More comple manufacture. |

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## Q8) Distinguish between Step Index and Graded Index Optical Fiber?

| Fiber | Graded Index Fiber |
| --- | --- |
| index ɔruptly ɔre and | Refractive index changes gradually from center to edge of core. |
| ls in zig-zag | Light follows sinusoidal path. |
| al dispersion. | Less modal dispersion. |
| ıanufacture. | More complex to manufacture. |

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## Q9) Write few applications of Optical Fiber?

- **Telecommunications** – high-speed data transmission
- **Medical endoscopy** – internal imaging
- **Sensors** – temperature, pressure, strain sensors
- **Internet & cable TV** – broadband connections
- **Military and aerospace** – secure communication

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