PHYSICS

QUESTION BANK-UNIT-3

1.What is luminescence? Mention the various methods by which luminescence can be achieved. (3 or 6 marks)

Luminescence is the emission of light from a substance that is not heated to a high temperature, and can be achieved through a number of methods, including:

- Chemiluminescence: Light is emitted as a result of a chemical reaction
- Bioluminescence: Light is emitted as a result of an enzymatic reaction
- Photoluminescence: Light is emitted after the absorption of photons
- Electroluminescence: Light is emitted after an electric current passes through a substance
- Radioluminescence: Light is emitted after bombardment with ionizing radiation

2.What is a LASER? Explain its properties. (3 or 6 marks)(IMP)

LASER: The word LASER stands for Light Amplification by the Stimulated Emission of Radiation. Laser is a source producing an intense, monochromatic, and highly parallel beam of coherent light.

Properties of Laser:

1. High intensity - Laser beams are highly intense as a large number of photons are concentrated in a small region.

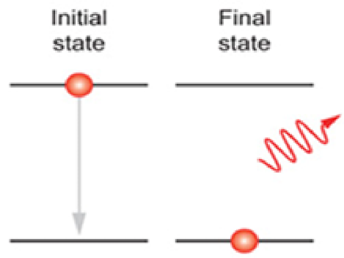
2. Monochromatic - Highly monochromatic radiation (i.e. single wavelength)

3. Coherence - Perfectly coherent as the emitted light waves has the same phase with one another.

4. High degree of directionality - Travels in a single direction as the photons are traveling along the optical axis of the system.

3.Distinguish between spontaneous emission and stimulated emission (3-6 marks) (IMP)

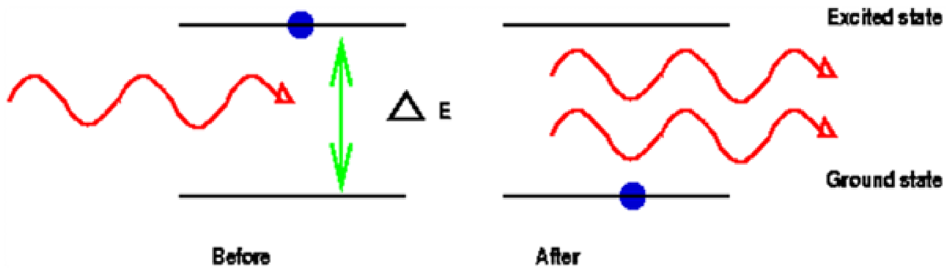
2) Spontaneous Emission: Spontaneous emission is the emission of a photon, when a system transits from a higher energy state to a lower energy state without the aid of any external agency.



Consider an atom in the excited state. Because of universal tendency for any system to attain the least available energy state the atom emits a photon of energy $\Delta E = E_2 - E_1$. Then the energy of the atom becomes equal to $E_2 - \Delta E = E_1$, and is shown in level E_1. Since the atom emits a photon, without the aid of external agency, it is called spontaneous emission. This process can be denoted as,

atom* $\longrightarrow$ atom + photon

3) Stimulated Emission: Stimulated emission is the emission of a photon by a system, under the influence of a incident photon of right energy due to which the system transits from a higher energy state to a lower energy state. The photon thus emitted is called the stimulated photon (emitted photon) and will have the same phase, energy and direction of movement as that of the stimulating photon (incident photon).



Consider an atom in the excited state. Let a photon having an energy $\Delta E = E_2 - E_1$ interacts with atom by passing in its vicinity. The atom emits a photon and transits to the lower energy state. The two photons travel in exactly the same direction, and same energy. The waves associated with the two photons will have identical phase and thus they are coherent. The process can be represented as,

atom* + photon $\longrightarrow$ atom + (photon+ photon)

This kind of emission is responsible for laser action.

4.Explain how Einstein's theory predicts existence of stimulated emission. (3 or 6 marks) (IMP)

iii) Case of stimulated Emission:

In stimulated emission an external photon of appropriate frequency stimulates the downward transition of an atom in the excited state. The number of stimulated emission per unit time per unit volume, ie, rate of stimulated emission is proportional to

1) number density of higher energy state N_2 and
2) the energy density $U\nu$

:. Rate of stimulated emission **α N_2U**

:. Rate of stimulated emission = **$B_{21}N_2U\nu$**

*where B_{21} is called **Einstein's coefficient of stimulated emission**.*

From **Boltzmann's law**, we know that the ratio of the population densities N_2 and N_1 in the excited state E_2 and ground state E_1 respectively at any instant at any temperature T is given by,

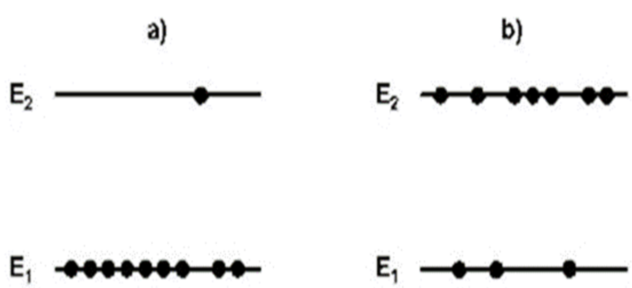
$$\frac{N_2}{N_1} = e^{-(E_2-E_1)/kT} = e^{-h\upsilon/kT} = e^{-hc/\lambda kT}$$

This equation indicates that the population at energy level E_2 is much smaller than that at E_1 at equilibrium and most of the electrons are in the lower energy state.

5.Define the terms 'Metastable state' and 'Population inversion". (3 or 6 marks)

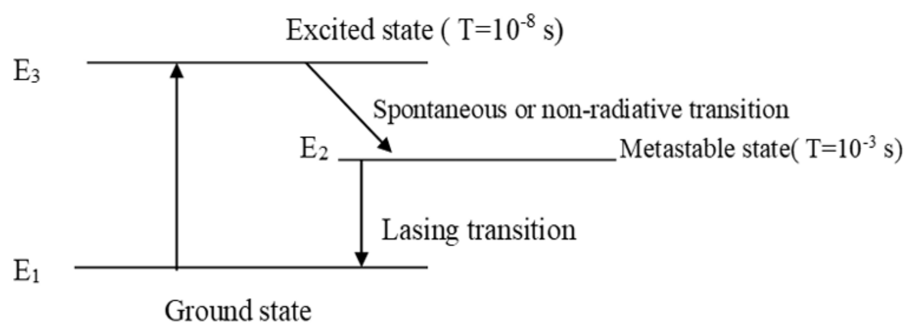
1) Population Inversion: Under normal condition the population of ground state is more than the excited state (Fig a). Hence the probability of absorption is more than the emission.

The population inversion is the state of a system at which the population (or number of electrons) of an excited state is higher than that in the lower state (Fig b). When population inversion is achieved there will be more number of emissions than absorptions. It is not possible to achieve population inversion with only two energy levels. The condition of population inversion can be achieved with the help of metastable states with which the atoms or molecules of the active medium are associated.



2) Metastable States: The lifetime of excited atom in ordinary excited states is of the order of 10^{-8} second which is very small. Within 10^{-8} second the atoms return to one of the lower energy states by spontaneous emission.

A metastable state is one which has a relatively longer lifetime which is of the order of 10^{-3} to 10^{-2} second and atoms excited to these levels will come down to lower levels at a much smaller rate than the rate at which they are excited. This property helps in achieving the population inversion.



By supplying appropriate energy, the atoms are excited from E_1 to E_3 state. From E_3 state the atoms undergo spontaneous transition to E_1 and E_2. But E_2 is a metastable state, where the atoms stay for longer duration. Hence population of which increases steadily. Under these conditions a stage will be reached wherein the population of E_2 exceeds that of E_1, which is known as population inversion.

6. Mention the basic conditions for laser action. How can they be materialised? (3 or 6 marks)

(i) An inverted population must be in the excited state, i.e. more atoms than in the ground state.

(ii) The excited state out of all the states should be a metastable state.

(iii) The emitted photons must stimulate further emission.

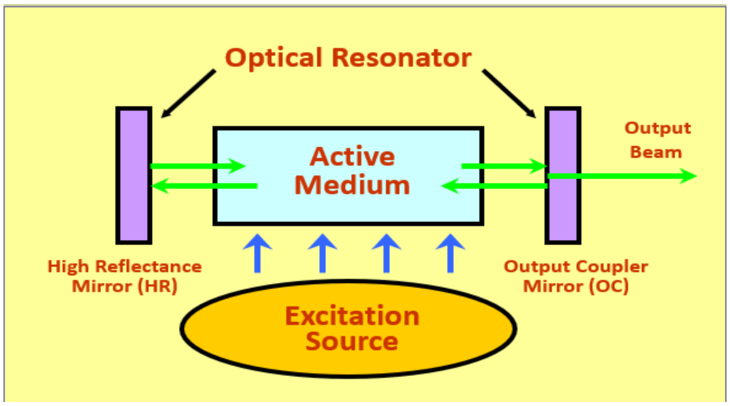
OR

(i) Rate of stimulated emission should be more than the rate of spontaneous emission
(ii) Rate of stimulated emission should be more than the rate of absorption

To materialize these conditions, energy is supplied to lower energy states to excite the atom from lower energy state to higher energy state.

7. What are the basic components required for the construction of a laser? Explain the method of production of laser. (4 or 10 marks)

- The Active Medium contains atoms which can emit light by stimulated emission.Solid (Crystal) ,Gas ,Liquid (Dye),Semiconductor (Diode)
- The Excitation source (pumping mechanism) is a source of energy to excite the atoms to the proper energy state.(Optical ,Electrical ,Chemical)
- The Optical Resonator or laser cavity reflects the laser beam through the active medium for amplification.(HR Mirror and Output Coupler)



8. Discuss the relative advantages and disadvantages of three level and four level lasers. (4 or 10 marks)

Three-level and four-level lasers have several advantages and disadvantages, including:

- **Output**: Three-level lasers typically produce pulsed output, while four-level lasers can produce continuous output.
- **Threshold frequency**: Four-level lasers have a lower threshold frequency than three-level lasers.
- **Efficiency**: Four-level lasers are highly efficient.
- **Pumping rate**: Four-level lasers require a lower pumping rate.
- **Population inversion**: In a four-level laser, the condition of population inversion can be maintained continuously. In a three-level laser, the lower energy level rapidly becomes highly populated, preventing further lasing until the atoms relax.
- **Terminal level**: In a three-level laser, the terminal level is ground level, which transfers more than half of the atoms.

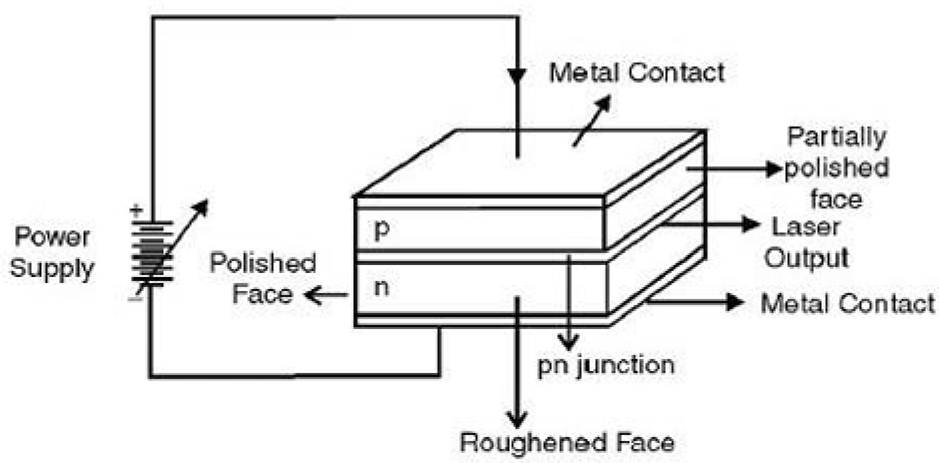
9. What are the different methods of achieving population inversion? (3 or 6 marks)

1. Optical Pumping : By using high intensity light or flash tubes for excitation.
   Ex: Ruby laser, Nd:YAG laser

2. Electrical Pumping: By applying very high potential between the plates of discharge tube, gas gets discharged, leads to atom – atom collision and pumping.
   Ex: He-Ne laser, CO_2 laser, Argon laser.

3. Chemical Pumping :Exothermic chemical reactions liberate energy. This energy is used in pumping the atoms. Ex: Dye lasers.

10.Describe the construction and working of a semiconductor laser. (4 or 10 marks)(IMP)



GaAs Laser

Construction: GaAs laser diode is a single crystal of GaAs and consists of heavily doped n and p sections. The n- section is formed by doping with Tellurium and p- section is formed by doping with Zinc. [The doping concentration is very high is of the order of 1017 to 1019 dopant atoms/cm3]. A pair of parallel planes of the crystal are cleaved or polished at right angle to the p-n layer. These planes play the role of reflecting mirror. The other two remaining sides perpendicular to the junction are roughened to suppress reflection of the photons. The end surfaces of the p and n sections parallel to the plane of the junction are provided with electrodes for the application of forward bias voltage.

Working: GaAs laser diode is subjected to a forward bias as shown in figure. Due to the forward bias, the holes are injected into the p-side of the junction and electrons are injected into the n-side. During the flow when a hole meets an electron recombination takes place resulting in the emission of a photon. In a GaAs laser by heavy doping, a large number of electrons are available in an n- type material and a large number of holes are available in a p-type material.When the current in the diode is low, the concentration of the electrons at the bottom of conduction band will be still lesser than that in the valence band, and the recombination result in only spontaneous emissions. But as the current is increased, a threshold for lasing will be attained beyond which a population inversion can be achieved between the conduction band and valence band and an active region is formulated very near the junction. At this stage a photon released by a spontaneous emission may trigger stimulated emission over a large number of recombination, leading to the buildup of laser radiation of high power. Since the energy gap of GaAs is 1.4 eV, the wavelength of the emitted light is $\lambda = hc/E_g = 8400$ Å

11.Explain the construction and working of a Nd-YAG laser, with a neat diagram (8 marks)(VERY IMP)

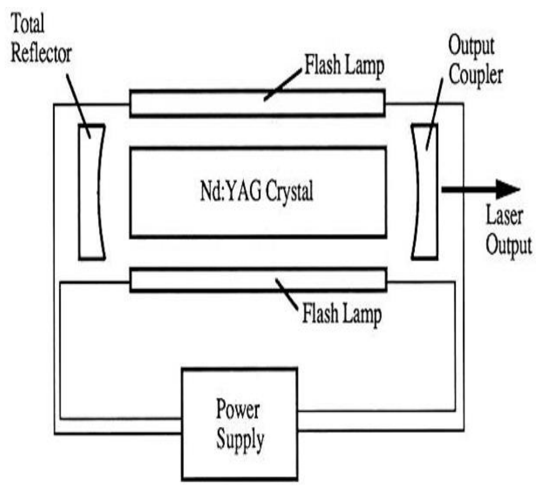


Figure: Schematic of Nd: YAG Laser

Construction: Neodymium-doped Yttrium Aluminium Garnet (Nd: YAG) laser is a solid-state laser in which Nd:YAG is used as a laser medium. It is a four-level laser system. These lasers operate in both pulsed and continuous mode. Nd stands for neodymium and YAG for Yttrium aluminium garnet (Y3Al5O12). [It is developed by J.E. Geusic, H.M. Marcos and L.G. Van Vitert in 1964]. The rod of Y3Al5O12 is doped 1% with triply ionized (trivalent) neodymium. Nd3+ ions will replace the Y3+ ions in the crystal. The YAG crystal is transparent and colourless. When doped with approximately 1% Nd (1.38 x 1020 Nd ions per cm3), the crystal takes a light blue colour. Maximum length of the rod is about 10 cm and diameter is 12 mm.

Active medium: Nd^{3+} ions act as active medium or active centers. YAG is just the host.

Pumping source: The pumping of Nd^{3+} ions to upper levels is done by krypton arc lamp or Xenon lamp. Thus, the optical pumping is used to achieve population inversion

Optical resonator system: The ends of the Nd: YAG rod are polished and silvered or Nd: YAG rod placed between two mirrors so as to act as the optical resonator system.

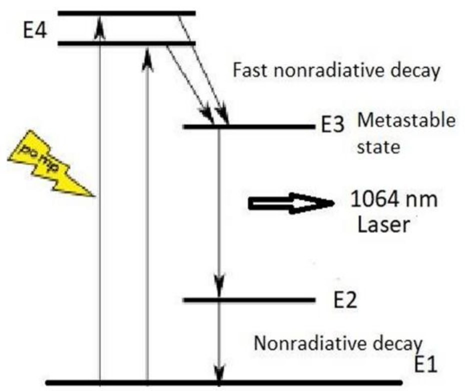


Figure: Energy level diagram of Nd:YAG laser

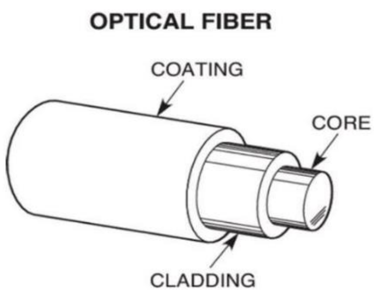
Working: Nd:YAG is a four level laser system. The optical pumping is used in this laser The pumping of neodynium (Nd3+) ions to upper state (E4) is done by using krypton arc lamp. The wavelength of light of wavelength 720 nm to 800 nm excites the ground state (E1) Nd3+ ions to E4 states (lifetime ~ ns). From E4 states, they make a non-radiative transition to E3 state. E3 is a metastable state (lifetime ~ ms) so population inversion is achieved between the levels E3 and E2. After this, the process of stimulated emission will occur. Thus, the laser emission will occur in between the levels E3 and E2 with the process of stimulated emission. So E3 is the upper laser level and E2 is the lower laser level. Then Nd3+ ions come back to the ground state E1. Laser emission will have wavelength of 1064 nm so occur in the infrared range of spectrum.

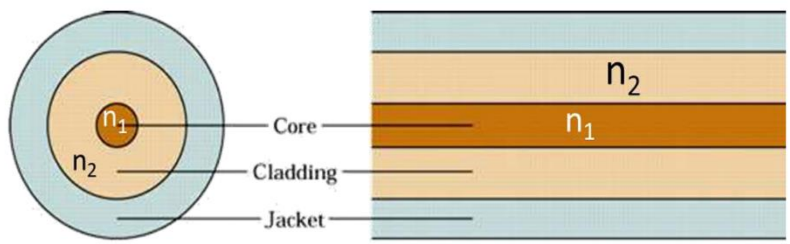
12. Briefly mention the applications of lasers. (3 or 6 marks)

- One of the major applications is in pure science to investigate the interaction of matter with intense electromagnetic radiation. The directionality and coherence of the laser beam are useful in the measurement of distances based on interferometric methods.
- In the field of communication, laser has been used with proper modulation for information transmission.
- Because of the high intensity and energy associated with laser beams, they can be utilized for applications such as welding, cutting and ablation of materials.
- Laser has also been used for medical applications like treatment of dental decay, destruction of tumors, treatment of skin diseases and eye surgery.
- Holography is another important application which helps in recording the amplitude as well as the phase of light reflected from objects thereby preserving the three-dimensional information.
- Used in various fields like Medicine Research Supermarkets Entertainment, Industry, Military, Communication, Art, Information technology etc

13.What is an optical fiber? What is the principle on the basis of which optical transmission is achieved through a fiber? Explain. (3 or 6 marks)

- An optical fiber is essentially a waveguide for light.
- It is long, thin, cylindrical in shape and it consists of mainly two regions.
- The central cylindrical region is the light guiding region known as the Core.
- The coaxial region surrounding the core is known as Cladding.
- The refractive index of the core material is higher than that of the cladding (n1>n2). The core and cladding are made of either glass or plastic.
- The outermost region surrounding cladding is called the sheath or protective buffer coating or jacket





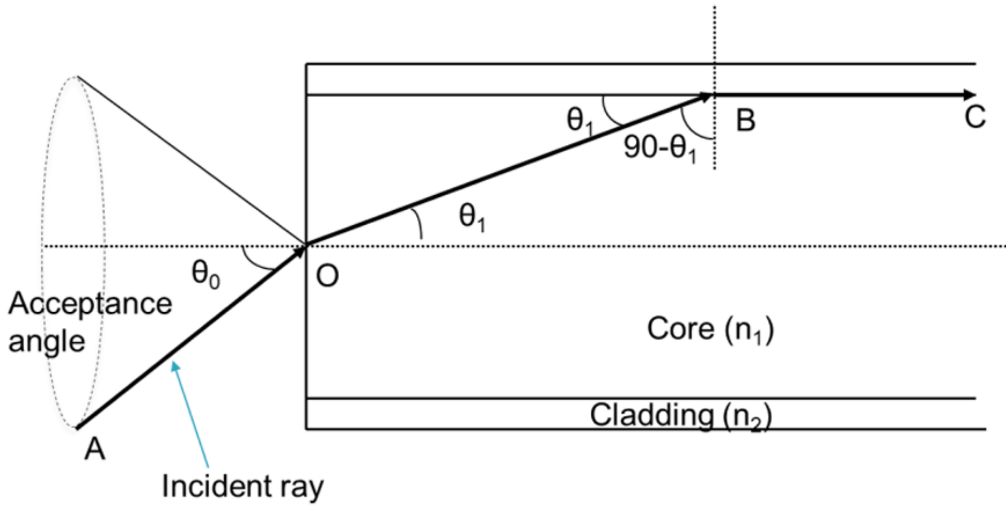
- Optical fibers work on the principle of total internal reflection.
- The **refraction** at the interface between two media is governed by Snell's law where n_1 and n_2 are refractive indices of medium 1 and medium 2 θ_1 - angle of incidence & θ_2 - angle of refraction.
- When the angle of incidence is increased angle of refraction also increases
- For particular angle of incidence ($\theta_1 = \theta_c$) refracted ray grazes the interface of the two media. This angle of incidence is called critical angle (θ_c).
- For critical incidence $\theta_1 = \theta_c$ and $\theta_2 = 90°$, the critical angle of incidence θ_c is given by

$$n_1 \sin \theta_c = n_2 \sin 90°$$

- The ray will be totally internally reflected into the denser medium when the angle of incidence is greater than the critical angle known as total internal reflection.

14.Explain the terms numerical aperture, semi angle of the cone of acceptance and relative refractive index difference. (4 or 10 marks)

Consider a ray of light AO enters into the core of an optical fiber at an angle θ0 to the fiber axis as shown in figure. This ray is refracted along OB at an angle θ1 in the core and further proceeds to fall at critical angle (90-θ1) at B on the core-cladding interface. Hence the ray is refracted at 90° to the normal to the interface, i.e. it grazes along BC.



It is clear from the figure that, any ray that enters the core at an angle less than θ0, will have angle of incidence (90-θ1) at the interface greater than the critical angle and hence undergoes total internal reflection.

On the other hand, any ray that enters at an angle greater than θ0 at O, will have angle of incidence less than the critical angle at the interface. Hence it refracts into the cladding and is lost from the core.

Numerical Aperture (N.A.) is a measure of light-gathering or light-collecting ability of an optical fiber. It is defined as the sine of the angle of acceptance.

$$\therefore\ \boldsymbol{N.A. = n_0\, sin\theta_0 = n_0\sqrt{(n_1^2 - n_2^2)}}$$

Angle of acceptance **(**semi-angle of the cone of acceptance) is the maximum allowed angle that the incident ray can make with the fiber axis for transmission through the fiber by total internal reflection.

The angle **θ_0** is called **angle of acceptance**

Fractional index Change or Relative Refractive index difference (Δ): It is the ratio of the refractive index difference between core and cladding to the refractive index of the core of an optical fiber.

$$\Delta = \frac{n_1 - n_2}{n_1}$$

15. Derive an expression for numerical aperture of an optical fiber in terms of R.I. of core and cladding. (4 or 10 marks)(VERY IMP)

Let n_0, n_1 and n_2 be the refractive indices of surrounding medium, core and cladding respectively.

By applying Snell's law for refraction at the point of entrance at O,

$$n_0 \sin \theta_0 = n_1 \sin \theta_1$$

$$n_0 sin\theta_0 = n_1\sqrt{1 - cos^2\theta_1} \qquad \text{-------(1)}$$

Applying Snell's law for refraction at B on the interface,

$$n_1 \sin (90-\theta_1) = n_2 \sin 90°$$

or $\quad n_1 \cos \theta_1 = n_2$

or $\quad \cos \theta_1 = n_2/ n_1 \qquad$ ---------(2)

Substituting (2) in (1)

$$n_0\, sin\theta_0 = n_1\sqrt{1 - cos^2\theta_1} = n_1\sqrt{1 - \frac{n_2^2}{n_1^2}} = \sqrt{(n_1^2 - n_2^2)}$$

$$\therefore\ \boldsymbol{N.A. = n_0\, sin\theta_0 = n_0\sqrt{(n_1^2 - n_2^2)}}$$

If the surrounding medium is air, then, $n_0 = 1$.

Then

$$\boldsymbol{N.A. = sin\theta_0 = \sqrt{n_1^2 - n_2^2}}$$

If θ_i is the angle of incidence of an incident ray, then the condition for ray propagation is

$$\theta_i < \theta_0$$

or $\quad \sin \theta_i < \sin\theta_0$

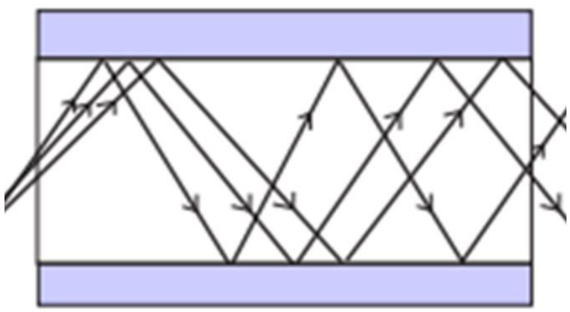
or $\quad \sin \theta_i <$ N.A.

16.What are the different modes of propagation possible in optical fibers. Explain in detail with necessary diagrams. (4 or 10 marks)

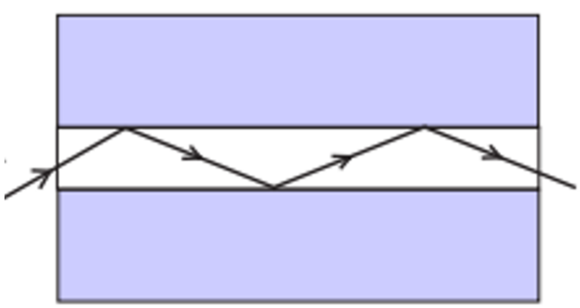
There are various modes by which light waves can be made to propagate in an optical fiber. The mode of propagation depends on the construction of the optical fiber.

Modes of propagation refers to the number of paths for the light rays along which the waves are in phase inside the fiber.

Multimode means several paths are available, This type of fiber supports multiple transverse guided modes for a given optical frequency and polarization. It's commonly used for short range.



Single mode means single ray propagation ,this type of fiber is designed to carry only the transverse mode of light. It's often used for long distances and performs better than multimode fibers with lower attenuation.



17.Write any four differences between single mode and multi-mode fibers. (3 or 6 marks)

S.No.	Single mode fiber	Multi mode fiber
1.	Only one mode is transmitted through the fiber.	Many modes are transmitted through the fiber.
2.	It has smaller core diameter	It has larger core diameter.
3.	Difference between the refractive index of core and cladding is very small.	Difference between the refractive index of core and cladding is large.
4.	NA is small.	NA is large.
5.	High information carrying capacity.	Low information carrying capacity.
6.	Short distance communication.	Long distance communication.
7.	Free from intermodal dispersion	Suffer intermodal dispersion
8.	Light source is Laser	Light source is LED
9.	Fabrication is difficult and costly.	Fabrication is less difficult and cheap.
10.	App: Submarine Cable system	App: Telephone links

18.What is attenuation in an optical fiber? Mention the possible reasons for the same. (3 or 6 marks)

Attenuation is the loss of optical power suffered by the optical signal as it propagates through the fiber.

The main reason for the loss of light intensity over the length of the fiber is due to

<u>(1)Light Absorption </u>:In this case loss of signal occurs due to absorption of photons

Photons are absorbed by

a) Impurities

- Metal ions – iron, chromium, cobalt and copper
- OH (hydroxy) ions

b) Intrinsic absorption by the glass material itself.

(2) Scattering losses: Photons scatter because of sharp change in localized R.I.

Variation of R.I occurs due to localized structural inhomogeneities during fiber fabrication process. Rayleigh scattering takes place due to scatter spot is less than light wavelength.

(3) Radiation Losses: The radiation losses are mainly due to bending of fibbers and occurs in two ways.

a) Macroscopic bending

b) Microscopic bending

19.Describe how the optical fiber can be used in communication. Mention its advantages. (3 or 6 marks)

Optical fiber communication is the transmission of information by propagation of optical signal through optical fibers over the required distance , which involves deriving optical signal from electrical signal at the transmitting end, and conversion of optical signal back to electrical signal at the receiving end. It is known as point to point communication

Convert to light An electronic signal is converted into light using a laser or light-emitting diode (LED).

Transmit light The light travels through the core of the fiber, bouncing off the walls and undergoing multiple reflections and refractions.

Detect light A photodiode or other light-sensitive device detects the light at the end of the fiber.

Convert back to electronic signal The light signal is converted back into an electronic signal.

Amplify and process The signal is amplified, processed, and transmitted to its final destination

Advantages of Optical Fibers:

- Fiber optic communications-

  Telecommunications ,Local Area Networks, Cable TV,CCTV
- Optical Fiber Sensors
- Applications in medicine - Endoscope
- Applications in industry

  or

- Less Expensive, Small size, lighter weight and more compact than copper cables.
- They have higher signal carrying capacity (bandwidth up to 2 Gbps, or more), because of which the cost/meter/channel for the fiber would be lesser than that for metallic cable.
- Lower attenuation and less signal degradation - Repeaters can be spaced 75 miles apart (fibers can be made to have only 0.2 dB/km of attenuation)
- Signals are transmitted in the form of light signals, so higher speeds can be achieved
- High Security – as optical signals are transmitted through the fiber, there is no energy radiation and hence it is impossible to tap information.
- Optical fibers have longer life (20-30 years) than copper cables (12-15 years).

20.Describe an optical fiber with working principle. Write any two advantages of an optical fiber communication system over conventional communication system. (4 or 10 marks)

For working principle refer question number 19

<u>The advantages of an optical fiber communication system over conventional communication system.</u>

- Optical fiber communication has advantages such as high-speed data transmission, data security, and data reliability.
- Optical fiber cables have higher bandwidth than copper conductor cables.

21.Describe the different types of optical fiber along with the sketches of geometry, refractive index profile and ray propagation. (4 or 10 marks)

(1) <u>Single mode fibers (SMF)</u>

A step-index fiber has a central core with a uniform refractive index and outside cladding surrounding the core also has a uniform refractive index; however, the refractive index of the cladding is less than that of the central core. (Fig. 1).

The R.I. profile is a step-index profile as the refractive index changes abruptly at the interface between the core and the cladding. The diameter of the core is very small about 8-10 μm and external diameter of cladding is 60-70 μm. In a single mode fiber, the core is so small that there is a single path for the light to propagate in the fiber. Only laser can be used as a source of light.

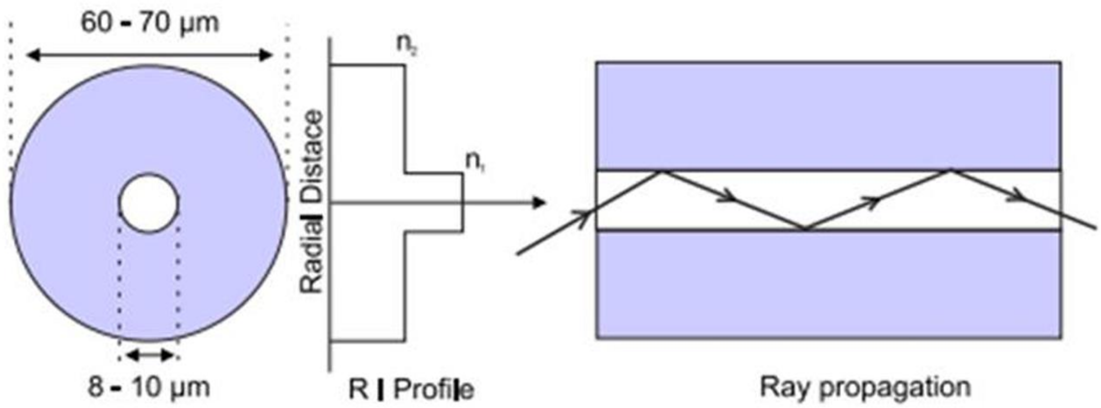


Fig. 1: Single mode step index fiber

(2) Step Index Multi mode fibers

: A step-index Multi mode fibers has a central core with a uniform refractive index and outside cladding also has a uniform refractive index; however, the refractive index of the cladding is less than that of the central core. (Fig. 1).

The refractive index changes abruptly at the interface between the core and the cladding and hence the R.I. profile is a step-index profile. The diameter of the core is 50-200 µm and external diameter of cladding is 100-250 µm. The fiber supports many modes for propagation. Either a LASER or LED can be used as source of light.

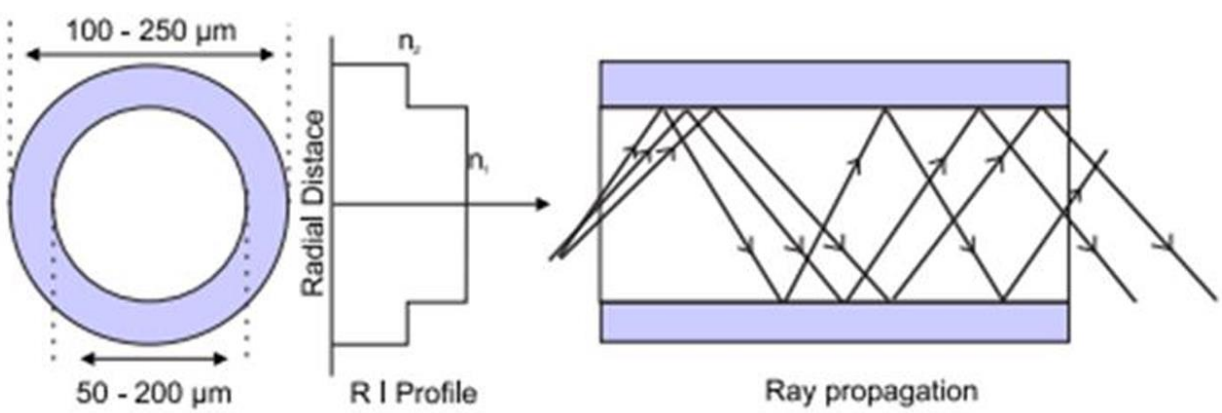


Fig. 2: Step index multimode fiber

(3)Graded index Multi mode fibers:

In a graded index multimode fiber, the refractive index of the core is maximum at the center of the core and decreases gradually and becomes equal to that of the cladding at the interface between core and cladding (Fig.1).

As the refractive index decreases gradually away from the center of the core, the R. I. profile is a graded index profile. Diameter of the core is 50-200 μm, Cladding diameter is 100-250 μm. Hence The fiber supports many modes for propagation. Either a LASER or LED can be used as source of light.

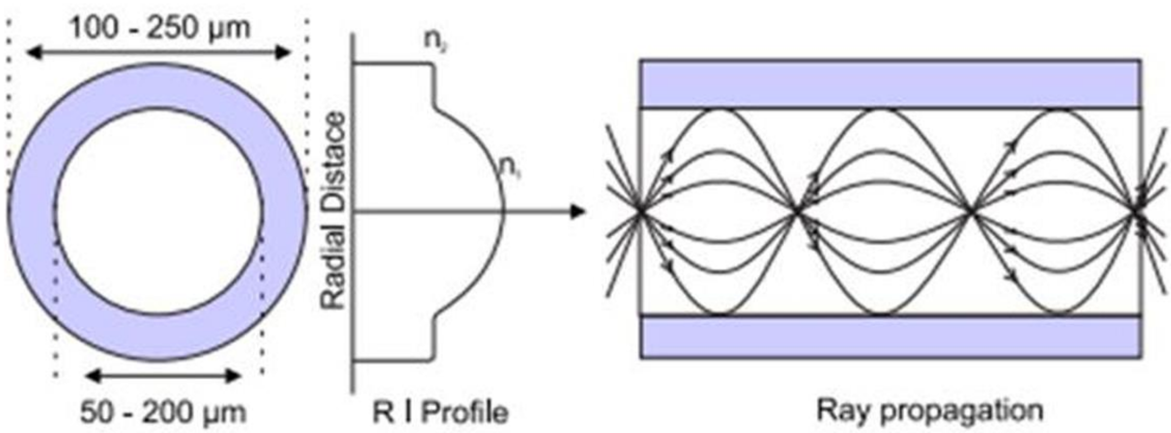


Fig. 3: Graded index multimode fiber

NOTE:Ruby laser,He-Ne laser(problems only)-theory is not necessary

BY,

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