Program : **B.Tech**

Subject Name: **Engineering Physics**

Subject Code: **BT-201**

Semester: **2nd**

UNIT-4
LASERS

Q.1 What is a Laser? Give major properties of laser light. **(Jun 16)**

Or

Explain in brief the characteristics of a laser beam. **(Jun 15, Dec 12)**

Or

How does laser differs from ordinary light? **(Dec 12)**

Ans: **Laser Characteristics**

The word LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. In a laser light amplification occur due to stimulated emission. Laser light differs from ordinary light sources in following respects

1. **Coherent:** Laser posses' high degree of coherence in comparison to ordinary light sources. In other words the phase relationship remains constant temporally and spatially for longer span of time and space.
2. **Monochromatic:** Lasers posses' high degree of monochromaticity i.e. the line width for a laser is very less in comparison to ordinary light source. In ordinary light source the value of $\Delta\lambda$ ranges from 100 to 1000 A^0 while for a laser the value of $\Delta\lambda$ remains within few angstroms
3. **Intensity:** The intensity of laser beam is extremely high in comparison to ordinary light.
4. **Directionality:** Lasers are highly directional and show least divergence upon travelling distances. This occurs because of photon selection by optical resonator.

Q.2 What are Einstein's coefficients? Derive Einstein's relation. **(Jun 13)**

Or

Obtain the relation between the transition probabilities of Einstein's A and B coefficients. **(Dec 10 & 13)**

Or

Establish the relationship between Einstein's coefficients A and B. **(Jun 10)**

Or

Explain the three quantum processes of interaction of radiation with the matter and derive the relationship between Einstein's coefficients.

Ans: **Einstein coefficients** are mathematical quantities which are a measure of the probability of absorption or emission of light by an atom or molecule. The Einstein A coefficient is related to the rate of spontaneous emission of light and the Einstein B coefficients are related to the absorption and stimulated emission of light.

Interaction of radiation with matter and Einstein's Coefficients

Three quantum processes when light interacts with matter are

1. Absorption: Consider an atomic system with energy levels E_1 and E_2. Electron is present in the ground state. The schematic of absorption process is presented in the figure 1

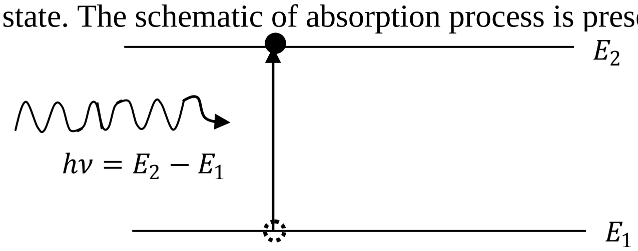


Figure 1: Electron gets excited by absorption of incident photon

When a photon having energy equal to $h\nu = E_2 - E_1$ is incident on such a system then electron absorbs this photon and gets excited to upper energy level.

The number of photons absorbed can be expressed as-

$$N_a = B_{12} N_1 u(\nu) \qquad (1)$$

Here N_a- No. of photons absorbed, B_{12} Einstein's coefficient, N_1 is the number of electrons in the energy state E_1 and $u(\nu)$ is the density of electromagnetic radiation.

2. Spontaneous Emission: Consider an atomic system with energy levels E_1 and E_2. Electron is present in the excited state. The schematic of spontaneous emission is presented in the figure 2

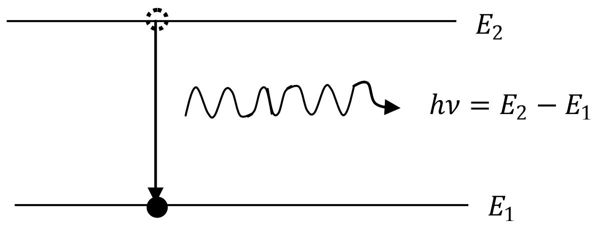


Figure 2: Electron making downward transition spontaneously

In this system the electron is in the excited state. This electron makes a downward transition when its life time is completed in the excited state. In this process it emits a photon of energy $h\nu = E_2 - E_1$. The number of photons emitted by the process of spontaneous emission can be expressed as

$$N_{sp} = A_{21}N_2 \qquad (2)$$

Here N_{sp}- No. of photons emitted spontaneously, A_{21} Einstein's coefficient, N_2 is the number of electrons in the energy state E_2.

3. Stimulated Emission: Consider an atomic system with two energy levels E_1 and E_2 as shown in the figure 2. In this system the electron is in the excited state and a photon is incident on such a system having energy equal to $h\nu = E_2 - E_1$. Thus electron is forced for a premature downward transition. In this process two photons are obtained incident and emitted. These photons are identical in all respects.

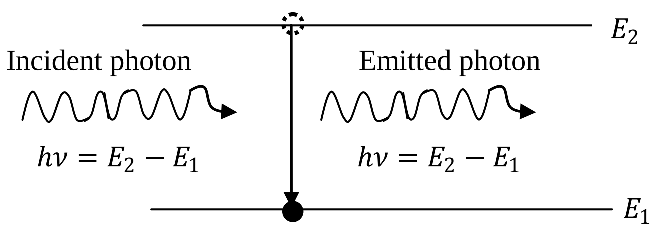


Figure 3: Electron making downward transition under the influence of incident photon

The number of photons emitted by the process of stimulated emission can be expressed as

$$N_{st} = B_{21}N_2u(\nu) \qquad (3)$$

Here N_{st}- No. of photons emitted by stimulated emission, B_{21} Einstein's coefficient, N_2 is the number of electrons in the energy state E_2 and $u(\nu)$ is the density of electromagnetic radiation.

To make the process of stimulated emission dominant the number of electrons in the excited state should be more than in the lower lasing energy level. The density of electromagnetic radiation should also be higher. Both facts are established by the ration of equation 3 to the equation 1.

Under the condition of equilibrium the number of photons must equal the number of photons emitted. We can write

Number of photons absorbed= Number of photons emitted by spontaneous emission + Number of photons emitted by stimulated emission

Thus

$$B_{12}N_1u(\nu) = A_{21}N_2 + B_{21}N_2u(\nu) \; (4)$$

Upon rearranging the terms we can write

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

Or

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

$$u(\nu) = \frac{A_{21}}{B_{21}}\frac{1}{\frac{B_{12}N_1}{B_{21}N_2} - 1}$$

Under the condition of equilibrium it can be shown that

$$B_{12} = B_{21}$$

Hence $u(\nu) = \frac{A_{21}}{B_{21}}\frac{1}{\frac{N_1}{N_2}-1}$; As $\frac{N_1}{N_2} = e^{\frac{h\nu}{kT}}$

Therefore $u(\nu) = \frac{A_{21}}{B_{21}}\frac{1}{e^{\frac{h\nu}{kT}}-1}$

According to the theory of black body radiation the density of electromagnetic radiation is given as

$$u(\nu) = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}}-1}d\nu$$

Therefore the relation between the Einstein's coefficient can be written as

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}d\nu$$

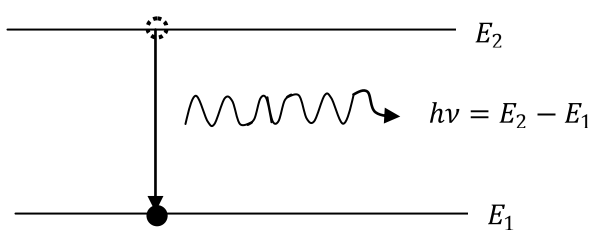
It shows that the probability of spontaneous emission increases with the energy difference between two states.

Q.3 What is meant by stimulated emission? Explain the basic condition in which stimulated condition dominates. **(Dec 14)**

Or

What do you understand by spontaneous and stimulated emission? **(Dec 15)**

Ans: **1. Spontaneous Emission:** Consider an atomic system with energy levels E_1 and E_2. Electron is present in the excited state. The schematic of spontaneous emission is presented in the figure 2



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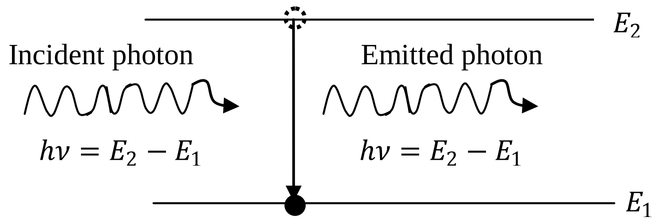
	transition. In this process two photons are obtained incident and emitted. These photons are identical in all respects.  Figure 3: Electron making downward transition under the influence of incident photon The number of photons emitted by the process of stimulated emission can be expressed as $$N_{st} = B_{21}N_2u(\nu) \qquad (3)$$ Here N_{st}- No. of photons emitted by stimulated emission, B_{21} Einstein's coefficient, N_2 is the number of electrons in the energy state E_2 and $u(\nu)$ is the density of electromagnetic radiation. Stimulated emission will dominate spontaneous emission when $N_2 > N_1$.
Q.4	What is population inversion in lasers and how it is achieved? **(Jun 11 Dec 11 & 15)** **Or** State necessary condition for strong stimulated emission. **(Jun 13)** **Or** Define population inversion and show that it is necessary for amplification of light in active medium. **(Apr 10 Jan 16)**
Ans:	**Population inversion:** The number of atoms per unit volume occupying a certain energy state is called population. In any atomic system ordinarily the number of electrons in the lower energy state (N_1) is more in comparison to the population of excited state (N_2). For achieving the light amplification an artificial situation is created in which the number of electrons at the excited state is more than the number of electrons in lower energy state. This situation is called as population inversion. In any atomic system number of photons absorbed may be written as: $$N_a = B_{12}N_1u(\nu)$$ It means absorption is proportional to the N_1, whereas number of photons emitted by stimulated emission may be written as: $$N_{st} = B_{21}N_2u(\nu)$$ Equation above indicates that stimulated emission is directly proportional to the N_2 i.e. the population of excited state. It clearly establishes that if the number of electrons at excited state N_2 is more than the number of electrons at ground state N_1, then probability of stimulated emission will be more in comparison to the absorption and the light amplification will take place.
Q.5	What are the principle pumping schemes? **(Dec 11 & 15)** **Or** Explain three and four level pumping scheme and give reason which one is more efficient.
Ans:	**Three level** pumping schemes in laser essentially refer to the lasing mechanism in which population inversion is achieved between an excited and the ground energy state. Since population inversion in such system is achieved between excited and the ground energy state therefore more pumping energy is required as naturally more number of electrons stay in the ground energy state. The schematic diagram of a three level energy system is shown in the figure below.

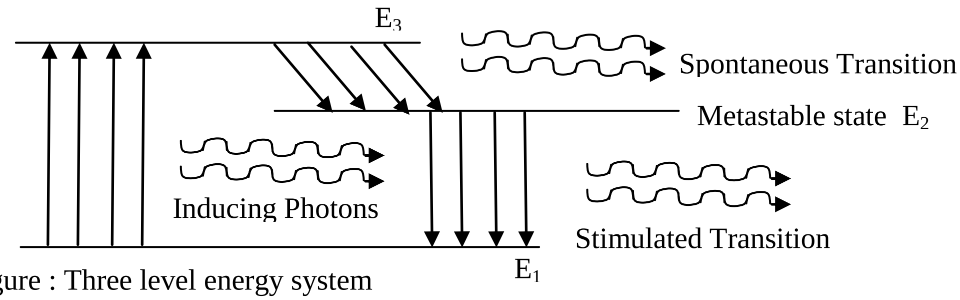


Figure : Three level energy system

Mechanism: In three level systems initially electrons are excited to the energy level E_3 by means of pumping. Energy level E_3 is ordinary excited state and electrons rapidly decay to energy level E_2 which is Metastable state. Here electrons stay longer than usual and situation of population inversion is achieved between ground state (E_1) and energy level E_2.

Now photons having energy equal to $h\nu = E_2 - E_1$ is incident over this system to initiate stimulated emission and light amplification.

Four level pumping schemes in laser essentially refer to the lasing mechanism in which population inversion is achieved between two excited states. Since population inversion in such system is achieved between two excited states therefore less pumping energy is required as naturally more number of electrons stay in the ground energy state.

The schematic diagram of a four level energy system is shown in the figure below.

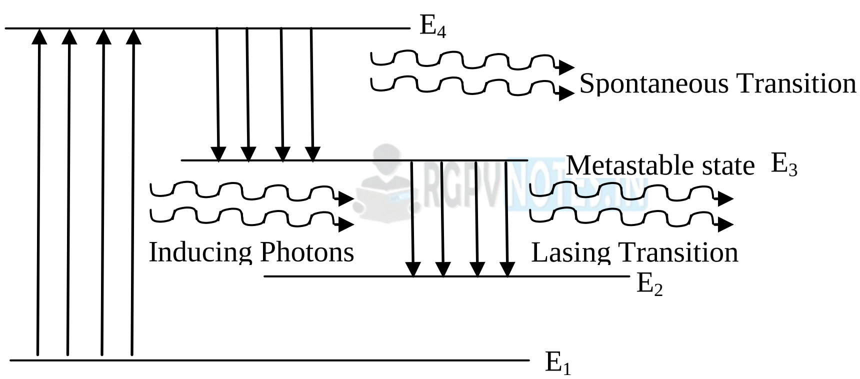


Figure: Four level energy system

Mechanism: In four level system initially electrons are excited to the higher levels of energy by means of pumping. This higher level of energy level is ordinary excited state and electrons rapidly decay to lower excited energy level E_3 which is Metastable state. Here electrons stay longer than usual and situation of population inversion is achieved between upper excited state (E_3) and lower excited state (E_2).

Now photons having energy equal to $h\nu = E_3 - E_2$ are incident over this system to initiate stimulated emission and light amplification.

Since in four level energy system population inversion is achieved between two excited states, therefore it requires less pumping. Whereas in three energy level system lower lasing level is ground state, therefore more than 50% of electrons need to be excited. As a result more pumping is required for three energy level systems in comparison to four level energy systems. Hence four energy level laser systems are better.

Q.6 Explain the different components of laser.

Or

Write short note on optical resonators. **(Jun 10)**

Ans: **Components of Laser**

Active Medium: The active medium is a collection of atoms or molecules, which can be excited to achieve population inversion situation for amplification of light by stimulated emission. The active medium can be in any state of matter: solid, liquid, gas or plasma. The active medium determines the emitted wavelengths possible by lasing transition.

Pumping: Pumping is an energy source working on an active medium for achieving population inversion. Various pumping mechanisms are:

i. Optical Pumping
ii. Electric Discharge
iii. Inelastic Atomic Collisions
iv. Direct Conversion
v. Chemical reaction

Optical Resonator: Optical resonator is a pair of mirror facing each other. The active medium is enclosed in this cavity. In optical resonator one of the mirrors is partially polished while other mirror is completely polished. Optical cavity ensures the availability of photons for stimulated emission and contributes for light amplification by optical feedback. A schematic diagram of optical resonator is given in the figure below.

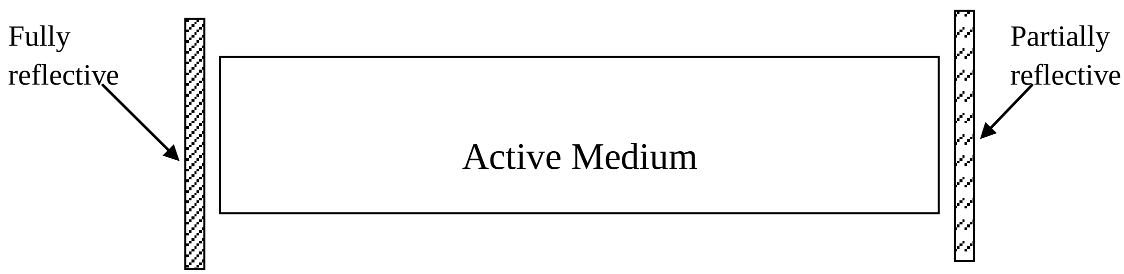
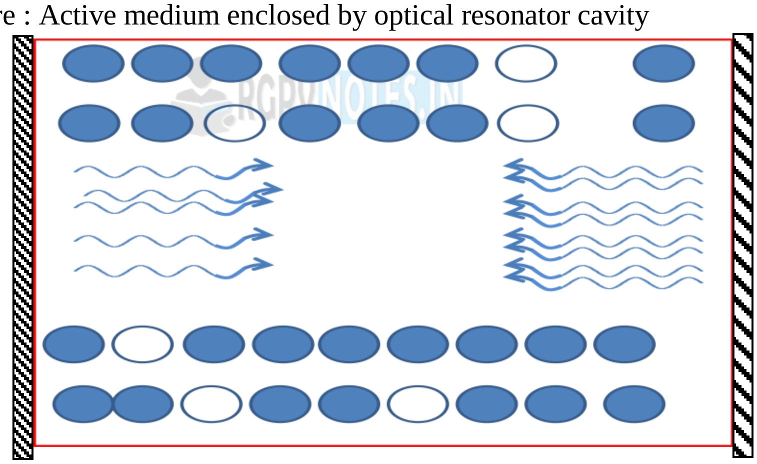


Figure : Active medium enclosed by optical resonator cavity



Action of Optical resonator: In the above figure an active medium enclosed between two parallel mirrors is shown. In the active medium hollow spheres present electrons in the ground state while filled sphere presents electrons in the excited state.

Step1: Some of the electrons from the excited makes down ward transition spontaneously resulting in the emission of photons.

Step2: Out of the emitted photons, The photons traveling in the axial direction is reflected back into active medium.

Step3: These reflected photons initiates the process of stimulated emission into active medium and more photons are obtained.

Step4: After multiple reflections a strong laser beam emerges out from partially reflective end of the optical resonator.

Q.7 Describe the construction and working of one laser with help of diagram. **(Jun10)**

Or

Describe the construction and working of ruby laser with help of a necessary diagram. **(Jun12 Dec15)**

Or

Explain the construction and working of ruby laser with necessary energy level diagram. **(Jun13 Dec14)**

Or

Explain how the population inversion and pumping scheme processes are realized in Ruby laser? **(Dec11)**

Or

Describe the construction and working of a solid state laser with help of a necessary diagram.

Or

Describe the construction and working of a three energy level laser with help of a necessary diagram.

Ans: **Construction:** Ruby laser is three energy level laser. It consists of a cylindrical ruby rod. The ends of ruby rod are polished to act as optical resonator. This ruby rod is wrapped with helical shaped xenon lamp.

Xenon lamp acts as optical pumping source. The active medium in ruby laser is Cr^+ ions in the host material Al_2O_3. Construction of Ruby laser is shown in the figure 1.

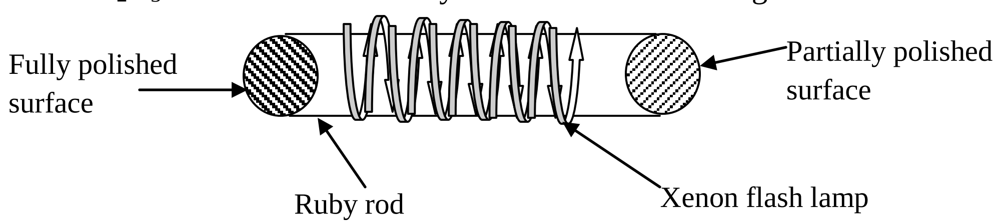
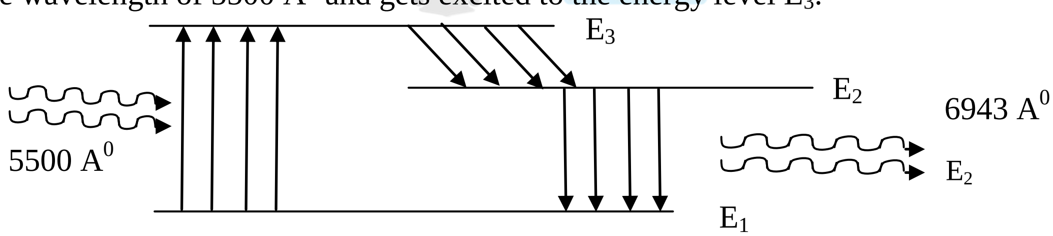


Figure 1: Ruby Laser

Working: The energy level diagram for Cr^+ ion is shown in figure 2. Initially most of the electrons occupy ground state. When the light from xenon lamp falls on ruby rod then the electron absorbs the wavelength of 5500 A^0 and gets excited to the energy level E_3.



Energy level E_3 is an ordinary excited state and the electrons from this excited state rapidly decay to the Metastable energy state E_2. As E_2 is Metastable state electrons start to accumulate at this level and a situation of population inversion is achieved between the E_2 and ground state. Photons emitted due to spontaneous decay and reflected back by polished ends initiates the stimulated emission. Thus emitted photons reflect back and forth between two polished ends and when the beam of photons become sufficiently large it emerges out from the partially polished end in the form of pulse of wavelength 6943 A^0.

Limitations: Ruby laser is a three level laser and has very low efficiency. The output is in the form of pulse. As xenon flash lamp is used for optical pumping and only small fraction of spectrum is used for excitation.

Applications: Ruby laser is used in creating 3-D images using holography it is also used in medical filed for tattoo removal.

Q.8 Explain with the help of a neat diagram the principle and working of He-Ne laser. **(Jan 16)**

Or

Explain construction and working of He-Ne laser with neat diagrams. **(Dec12 & 13)**

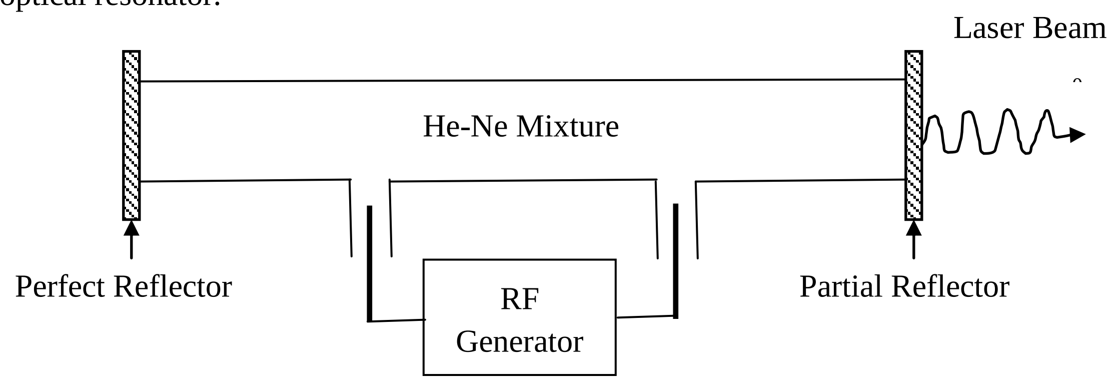
Or

Explain construction and working of He-Ne laser with the help of energy level diagrams. **(Feb10, Apr10,Jun11, 14 & 16)**

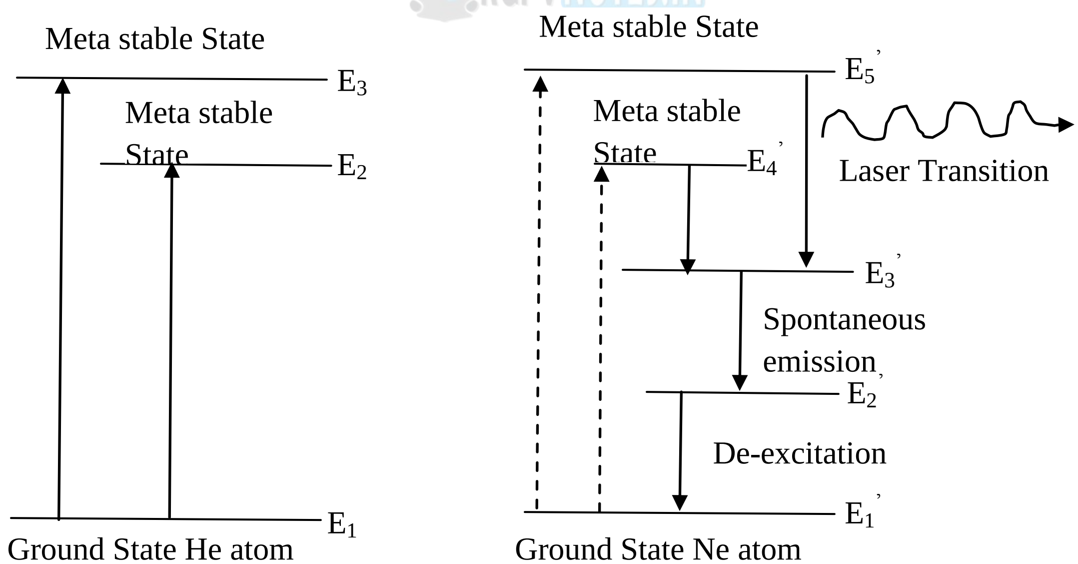
Or
Explain construction and working of any gaseous laser.
Or
Explain construction and working of any four level laser.

Ans: Helium Neon laser is a four level gas laser. In this laser lasing transition occur between energy levels of Neon atom.

Construction: The schematic diagram of He-Ne laser is shown in the figure 1. It consists of a long discharge tube with diameter 1 cm and length about 50 cm. Discharge tube is filled with mixture of Helium and Neon in ratio of 10:1. Both ends of discharge tube is equipped with mirrors to act as optical resonator.



Working: The energy level diagram for Helium and Neon is shown in the figure 2. When the current is passed through the mixture of He and Ne. The helium atoms are excited to the nearest excited state. When these excited helium atoms collides with the neon atoms then they transfer their energy to neon atoms. Thus neon atoms are raised to energy level E_5.

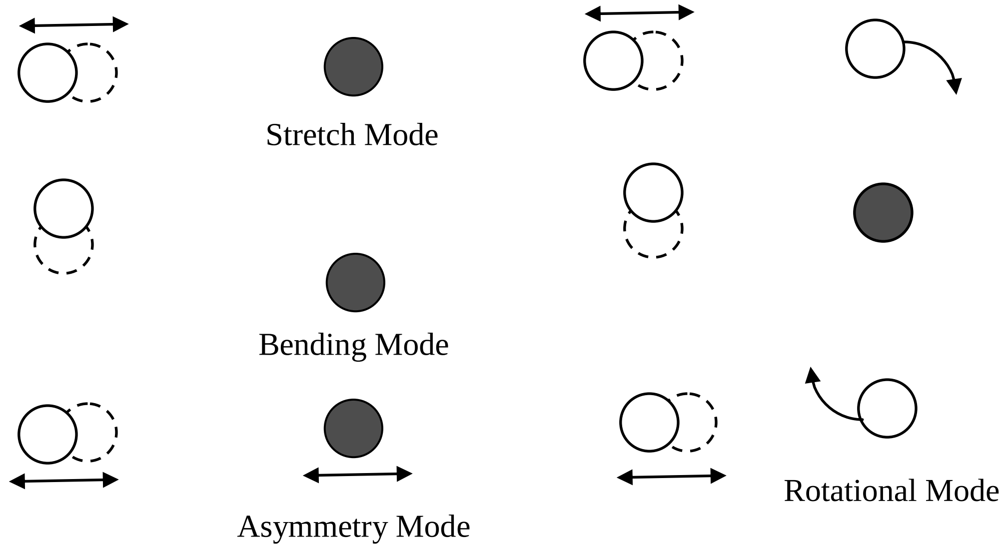


As a result population inversion is achieved between E_5' and E_3'. The transition between two emits light of wavelength 6328 A^0. Helium Neon laser operates in CW mode. The energy level E_2' is depopulated by collision with the walls of discharge tube, so that laser operation continues without interruption.

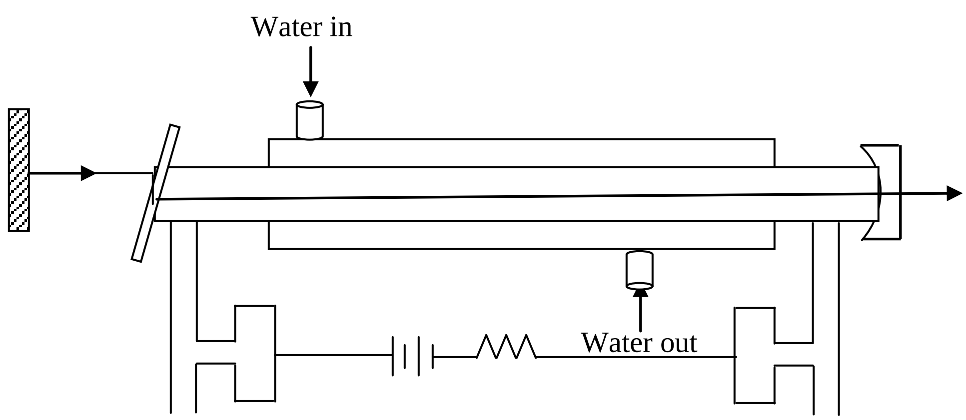
Q.9 Explain with the help of a neat diagram the principle and working of CO_2 laser.
Or
Explain construction and working of CO_2 laser with neat diagrams.
Or

Explain construction and working of CO_2 laser with the help of energy level diagrams.
Or
Explain construction and working of any gaseous laser.
Or
Explain construction and working of any four level laser.

Ans: **Construction:** CO_2 is a four level molecular laser, which depends upon the transition between the different vibrational states of CO_2 molecule. Different vibrational states of CO_2 molecule are presented in the figure 1.

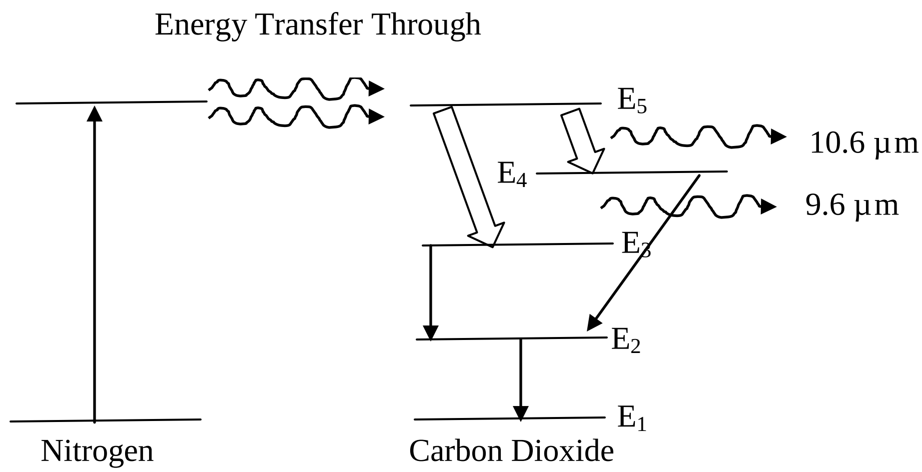


In the figure 1 we can see the carbon atom at the center and two oxygen atoms are attached at both sides of carbon atom. Hence carbon dioxide molecule can possess three independent modes of vibration namely: Stretch, asymmetric and bending mode.
Figure 2 shows schematic diagram of CO_2 laser. It consists of a discharge tube having cross sectional area about 1.5 mm^2 and length about 260 mm. The discharge tube is filled with CO_2, N_2 and He in the ration 1:2:3. CO_2 molecules serves as the active medium for lasing transition.
A high voltage DC source is connected across discharge tube.



Working: Different vibrational states of CO_2 molecule and lowest excited state of N_2 is shown in the figure 3.

When current is passed through discharge tube, Nitrogen gets excited to the first excited state. Now Nitrogen transfers its energy to CO_2 molecules through inelastic collisions. Thus CO_2 atoms are raised to the energy level E_5, which is a metastable state. As a result situation of population inversion is achieved between E_5 and E_4, also between E_5 and E_3.
Initial spontaneous transition initiates stimulated emission and light amplification occur by multiple oscillation between optical resonator. The lasing transition corresponds to the wavelengths 9.6 μm and 10.6 μm.

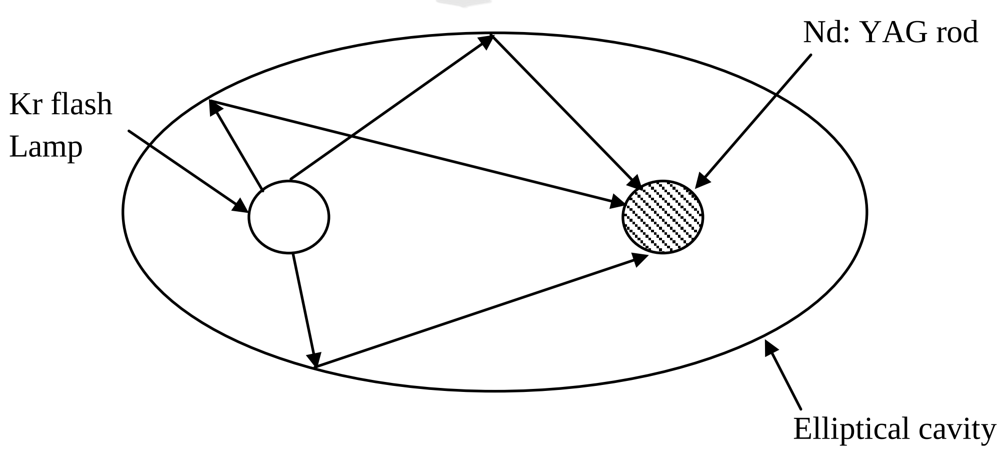


Applications: carbon dioxide laser is used in industry for cutting and welding, it also used in surgery to seal small blood vessels.

Q.10 Describe construction and working of Ruby laser with the help of necessary diagrams.
Or
Explain the working of any solid state laser
Or
Explain the working of four level solid state laser

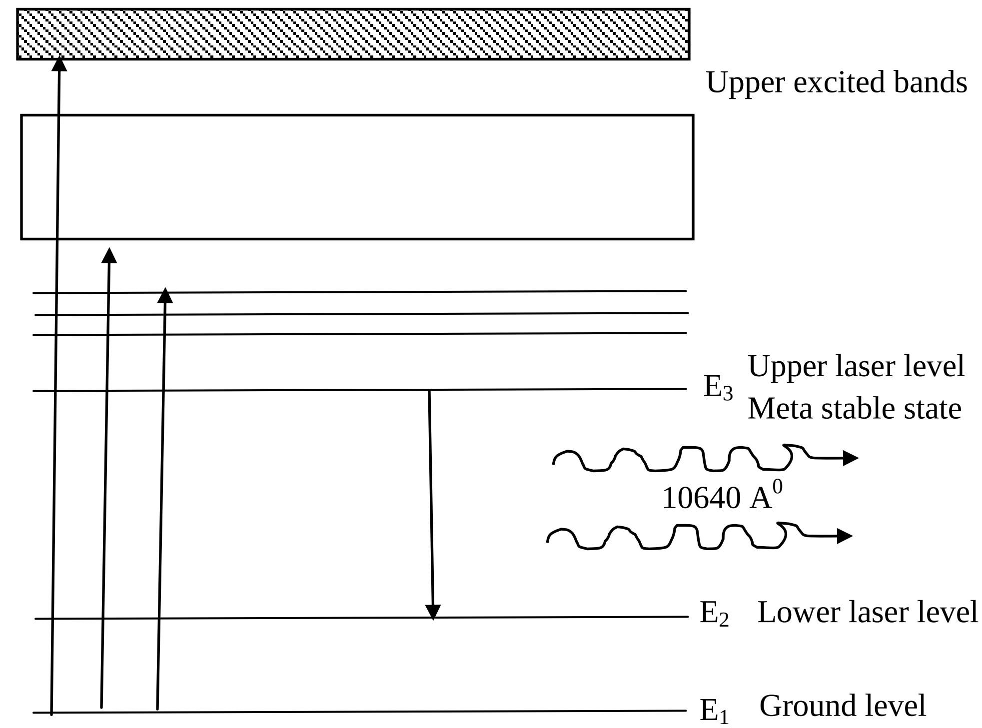
Ans: Nd: YAG laser is a four level solid state laser. Here Nd stands for Neodymium and YAG stands for Yttrium aluminum garnet ($Y_3Al_5O_{15}$). In this laser Neodymium ions acts as active medium.

Construction: Construction of Nd: YAG laser is shown in the figure 1. In this laser Nd: YAG rod and krypton arc lamp are placed in an elliptical cavity. Krypton lamp provides the optical pumping for excitation of Neodymium ions. Elliptical cavity ensures that all emitted radiations form Krypton lamp falls on Nd: YAG rod. Thus optical pumping efficiency of Nd: YAG laser is far better than Ruby laser.

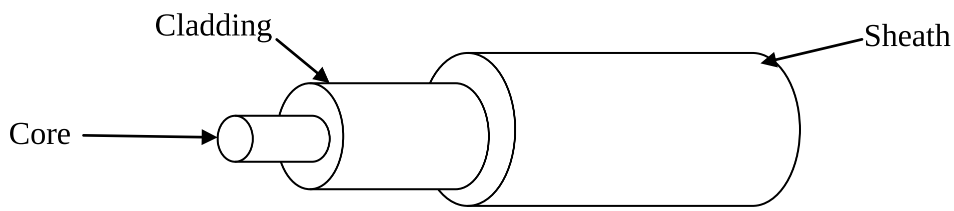


Working: Energy levels of Nd^{3+} ions are shown in the figure 2.

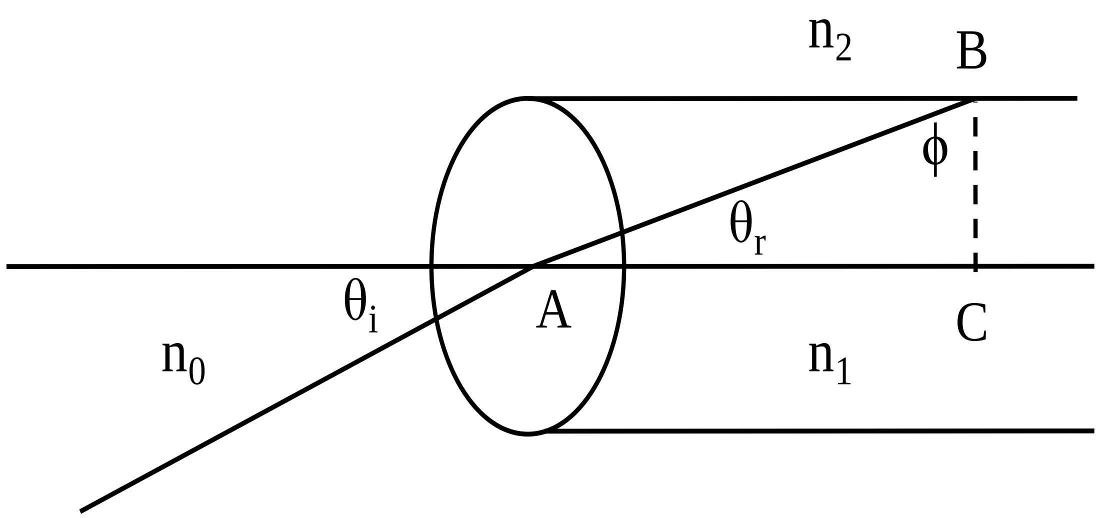
When the light from Kr lamp falls on Nd: YAG rod. Then electrons of Nd^{3+} ions absorbs the energy spectrum 5500 A^0 to 8000 A^0 and gets excited to the upper energy bands. From these energy bands electrons rapidly decays to energy levels E_3 which is a meta stable state. As a result population inversion is achieved between E_3 and E_2. Transition between E_3 and E_2 emits light in the infrared region having wavelength 10640 A^0. Energy level in Nd^{3+} ions is far above from ground state and hence can't be populated by thermal excitations. Nd: YAG laser can be operated in CW and pulsed mode



Upper excited bands
E_3
Upper laser level
Meta stable state
10640 A^0
E_2
Lower laser level
E_1
Ground level

<table>
<tr><th colspan="2">UNIT-4
Fiber Optics</th></tr>
<tr><td>Q.11</td><td>What is an optical fiber? (Jun12, Dec10, Jan16)
Or
Describe the structure of a typical optical fiber used in practice. (Dec10)
Or
Describe the construction of an optical fiber. (Feb10, Apr10, Dec14)</td></tr>
<tr><td>Ans:</td><td>An optical fiber is thin transparent wire made up of glass or plastic and is used to guide the light waves by means of total internal reflection with minimum losses.
Construction: Typical structure of an optical fiber is shown in figure below. Optical fiber consists of three sections. Innermost part of an optical fiber is called as core its refractive index is shown as n_1. Outer layer surrounding the core is called as cladding its refractive index is shown by n_2. Outermost layer of an optical fiber is a protective layer of plastic which is termed as sheath and it protects the core and cladding of optical fiber. For an Optical Fiber $n_1 > n_2$.

</td></tr>
<tr><td>Q.12</td><td>Explain the principle of propagation of light waves in the optical fiber. What are acceptance angle, acceptance cone and numerical aperture? (Feb10, Apr10,Jun10, Dec14)
Or
With the help of Ray diagram show how optical fibers can guide light waves? Derive an expression for acceptance angle of optical fiber. What is meant by acceptance cone? (Jun13)
Or
Derive expression for numerical aperture of a step index fiber. (Jun11,16,Dec14)
Or
Define acceptance angle and acceptance cone in fiber optics. Derive expression for acceptance angle. (Dec10,11)
Or
Explain how glass fiber guides light from one end to other. Define acceptance angle of an optical fiber. (Jun12)</td></tr>
<tr><td>Ans:</td><td>Light ray travel the length of optical fiber by phenomenon of total internal reflection. When a light ray travels from denser to the rarer medium then it moves away from the normal. When the angle of incidence in the denser medium is greater than a particular value then total light is reflected back into the denser medium. This angle of incidence is known as critical angle and the phenomenon is known as total internal reflection. In an optical fiber refractive index of core (n_1) is greater than the refractive index of cladding (n_2). Maximum value of the launching angle for the light in an optical fiber which satisfies the condition of total internal reflection is known as acceptance angle. Three dimensional structure around the fiber launch end made by acceptance angle is termed as acceptance cone.
Derivation of Acceptance angle: A ray of light incident from the outer medium of refractive index n_0 at the launching end of the fiber (core of RI n_1)by making an angle θ_i with the axis of the fiber</td></tr>
</table>

which refract through angle θ_r. Angle made by refracted ray at the core-cladding interface is ϕ .



For outer medium (n_0) and core (n_1) interface
According to Snell's law

$$n_0 \operatorname{Sin}\theta_i = n_1 \operatorname{Sin}\theta_r$$

Or $$\operatorname{Sin}\theta_i = (n_1/ n_0) \operatorname{Sin}\theta_r \quad (1)$$

→ $$\operatorname{Sin}\theta_i = (n_1/ n_0) \operatorname{Sin}(90-\phi)$$

$$\operatorname{Sin}\theta_i = (n_1/n_0) \operatorname{Cos}\phi \quad (2)$$

When $\theta_i=\theta_{max}$ **Then** $\phi= \phi_c$
Therefore equation (2) can be rewritten as

$$\operatorname{Sin}\theta_{max} = (n_1/n_0) \operatorname{Cos}\phi_c \quad (3)$$

According to the Condition of Total Internal Reflection

$$\operatorname{Sin}\phi_c= (n_2/n_1) \quad (4)$$

Using equations (3) and (4) we can write

$$Sin\ \theta_{max} = \frac{n_1}{n_0}\sqrt{\left(1-\frac{n_2^2}{n_1^2}\right)}$$

This is known as numerical aperture (N.A.) of the fiber and θ_{max} is called the acceptance angle of the fiber. Acceptance angle is the maximum angle made by incident ray with the axis of fiber within which light ray can propagate through fiber.Hence **N.A. =** $\boldsymbol{\frac{\sqrt{n_1^2-n_2^2}}{n_0}}$

Acceptance angle $\boldsymbol{\theta_{max} = \sin^{-1}\frac{\sqrt{n_1^2-n_2^2}}{n_0}}$

If outer medium is air or vacuum than $n_0 \approx 1$

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

Acceptance angle $\boldsymbol{\theta_{max} = \sin^{-1}(\sqrt{n_1^2-n_2^2})}$

Q.13 Explain the types of fibers and their index profiles. **(Jan16,Jun11,15,Dec15)**

Ans: **Modes of Propagation:** In an optical fiber light travels through total internal reflection. During the travel light can take different paths inside the optical fibers. These different paths are known as the modes of propagation.

Based on the differences in the structure of core and the modes of propagation, optical fibers are classified into three categories:

1. **Single mode step index optical fiber:** As the name suggests this type of fiber supports only one mode of propagation and the refractive index of the core remains uniform. In Single mode fibers intermodal dispersion does not take place, however at the same time it has difficulty of coupling of the light into the fiber.
2. **Multimode step index optical fiber:** As the name suggests this type of fiber can support multiple modes of propagation and the refractive index of the core remains uniform. In these fibers intermodal dispersion occurs and may cause signal distortion.
3. **Multimode graded index optical fiber:** As the name suggests this type of fiber can support multiple modes of propagation and the refractive index of the core gradually decreases from the center of the core towards the outer of the core. In these fibers intermodal dispersion does occur, however it is less in comparison to the **Multimode step index optical fiber.**

   Index profiles for step index and graded index fibers is shown in the figures 1 and respectively

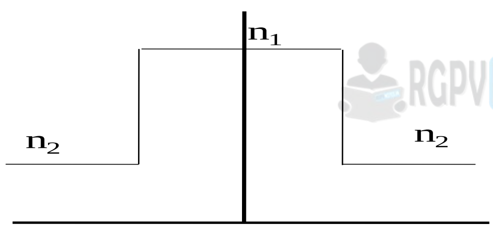


Fig 1: Index Profile of Step Index Fiber

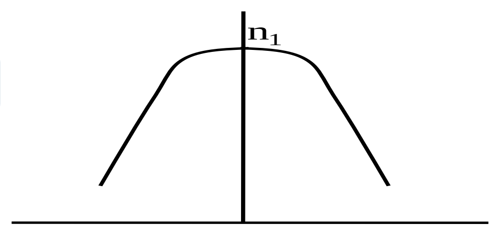
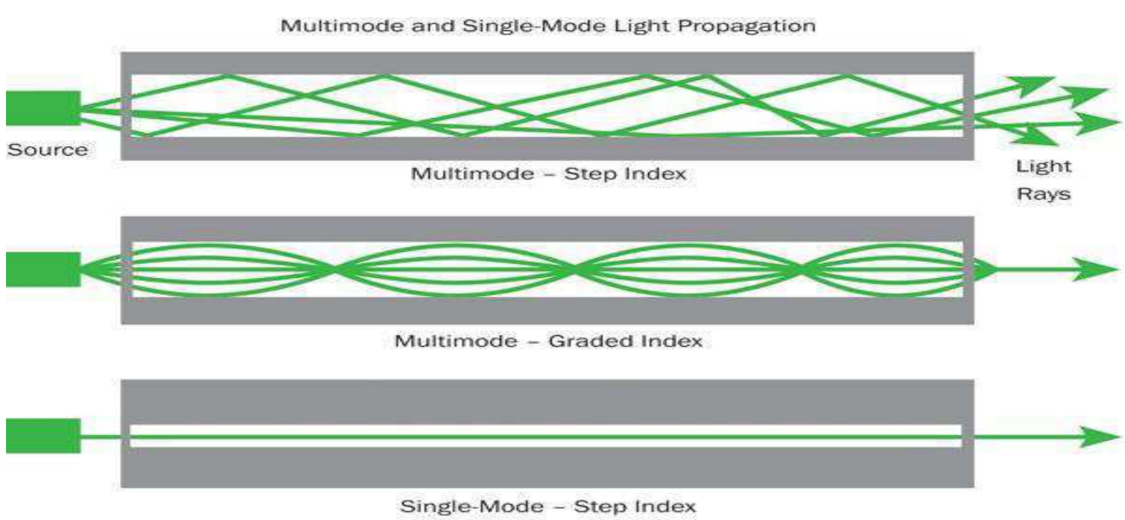


Fig 2: Index Profile of Graded Index Fiber

Figure below represents the modes of propagation in three types of the fibers.



Q.14	What is V-number or normalized frequency of an optical fiber? **(Jun10, Dec12)**
Ans:	V-number or normalized frequency gives the idea about the cutoff frequency and the number of modes supported by an optical fiber. V-number for an optical fiber is given as: $$V = \frac{2\pi a}{\lambda}\sqrt{(n_1^2 - n_2^2)}$$ Where $n_1 - Refractive\ index\ of\ core$ $n_2 - Refractive\ index\ of\ clading$ $a - Core\ Radius$ $\lambda - Wavelength$ If the value of V<2.405 then the fiber is said single mode optical fiber whereas for V>2.405 multi mode optical fiber. $Number\ of\ \ modes\ supported\ by\ step\ index\ Fiber\ is\ given\ as = \frac{V^2}{2}$ $Number\ of\ \ modes\ supported\ by\ graded\ index\ fiber\ is\ given\ as = \frac{V^2}{4}$
Q.15	What is attenuation of signal in an optical fiber?
Ans:	**Attenuation** is the rate at which the signal light decreases in intensity during the transmission of light through optical fiber. Attenuation coefficient α is given as : $$\alpha = -\frac{10}{z[\mathrm{km}]}\log\left(\frac{P(z)}{P(0)}\right)$$

