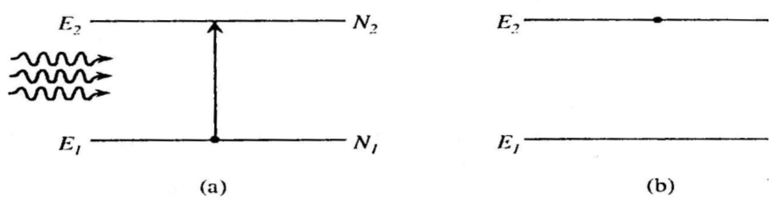
LASERS

The acronym for LASER is Light Application by Stimulated Emission of Radiation.

Transport phenomena: In lasers the interaction between matter and light is of three different types.

1. Stimulated absorption (or) induced absorption.
2. Spontaneous emission.
3. Stimulated emission

1.Stimulated absorption(or) Induced absorption:

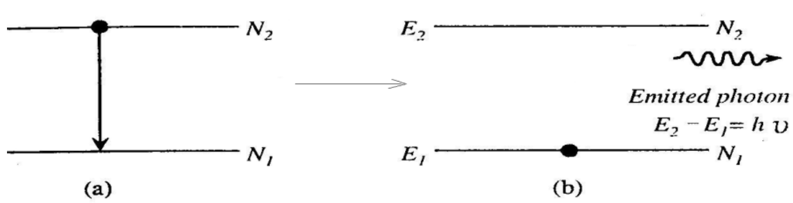


(a) Before absorption (b) After absorption

$$A + h\upsilon \rightarrow A^*$$

Initially the atom is in ground state. up on this ground state atom we incident some amount of energy $h\upsilon = E_2 - E_1$ then the atom is excited to higher energy level by absorbing incident energy .This is called stimulated absorption

Spontaneous emission:



(a) Before emission (b) After emission

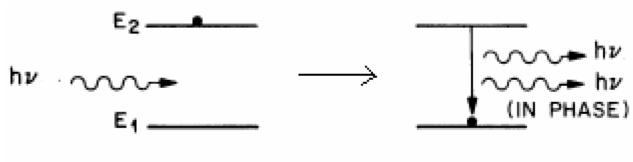
$$A^* \rightarrow A + h\upsilon$$

Initially the atom is in the excited state. This excited atom comes to ground state by emitting photon of Energy $h\upsilon = E_2 - E_1$ on its own after the lifetime of excited state (i.e. 10^{-8}sec).This type of emission without any external agency is called spontaneous emission .

The emitted photons are out phase and travel in all directions so the intensity of light is very low

Ex: Light from Ordinary Source.

Stimulated emission:



$$A^* + h\upsilon \to A + 2h\upsilon$$

Initially the atom is in the excited state .Upon this excited atom we incident a photon of energy $h\upsilon = E_2 - E_1$, then this incident photon may force the atom to come down by emitting a photon .This type of forceful emission is called stimulated emission.

In this case the emitted photons are in phase and travel along the same direction so the intensity of light is very high

Ex: Laser

Relation between Einstein coefficients (B_{12} , A21 & B_{21})

Consider a system contain N_1 no of atoms per unit volume in lower energy level E_1, N_2 be the no of atoms per unit volume in higher Energy level in E_2. Let $\rho(\upsilon)$ is energy density which is supplied to system

1. Stimulated absorption rate $\alpha.\rho(\upsilon)$

$\alpha.N_1$

Stimulated absorption rate $= B_{12}\rho(\upsilon)N_1$..............(1)

Where B_{12} is the Einstein coefficient of stimulated absorption

2. Spontaneous emission rate $\alpha.N_2$

. Spontaneous emission rate $= A_{21}N_2$.................(2)

Where A_{21} Einstein coefficient of spontaneous emission

3. Stimulated emission rate αN_2

Stimulated emission rate $\alpha.\rho(\upsilon)$

Stimulated emission rate $= B_{21}\rho(\upsilon)N_2$..............(3)

Where B_{21} Einstein coefficient of stimulated emission

At thermal equilibrium

Up ward transition = Down ward transition

$\therefore$ *Stimulated absorption = spontaneous emission + stimulated emission*

$$B_{12}\rho(\upsilon)N_1 = A_{21}N_2 + B_{21}\rho(\upsilon)N_2$$

$$(B_{12}N_1 - B_{21}N_2)\rho(\upsilon) = A_{21}N_2$$

$$\rho(\upsilon) = \frac{A_{21}N_2}{B_{12}N_1 - B_{21}N_2}$$

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

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

According to Boltzman distribution law

$$N_1 = N_0 e^{-E_1/kT}$$

$$N_2 = N_0 e^{-E_2/kT}$$

$$\frac{N_1}{N_2} = e^{E_2 - E_1/KT} = e^{\frac{h\upsilon}{KT}}$$

$$\therefore \rho(\upsilon) = \frac{A_{21}}{B_{21}(\frac{B_{12}}{B_{21}} e^{\frac{h\upsilon}{KT}} - 1)} \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

According to the plank energy distribution law

$$\rho(\upsilon) = \frac{8\pi h\upsilon^3}{c^3(e^{\frac{h\upsilon}{KT}} - 1)} \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

On comparing Eq (4) *and* (5)

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\upsilon^3}{c^3} \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$\frac{B_{12}}{B_{21}} = 1 \Rightarrow B_{12} = B_{21} \ldots\ldots\ldots\ldots(7)$$

The Eq (6) *&* (7) *are called Einstein Relations*

Conditions for light Amplifications:

At thermal equilibrium.

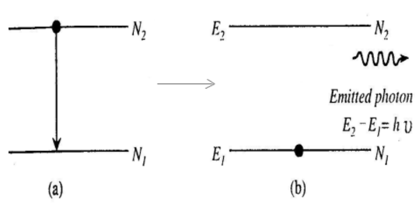
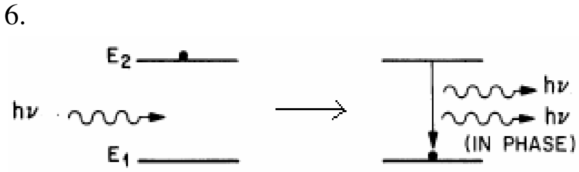
$$\frac{Stimulated\ emission}{Spontaneous\ emission} = \frac{B_{21} N_2 \rho(v)}{A_{21} N_2} = \frac{B_{21}}{A_{21}} \rho(v)........(8) \qquad \text{And}$$

$$\frac{Stimulated.emision}{Stimulated.absorption} = \frac{B_{21} N_2 \rho(v)}{B_{12} N_1 \rho(v)} = \frac{N_2}{N_1}........(9)$$

From Eq(8) & (9) *we concluded that for* getting *light amplification(gettingLaser)*

1. *The radiation density* $\rho(v)$ *is to be made larger.*
2. $N_2 > N_1$ *(Population inversion)*

DIFFERNCE BETWEEN SPONTANEOUS AND STIMULATED EMISSION

SPONTANEOUS EMISSION	STIMULATED EMISSION
1. Transition occurs from a higher energy level to lower energy level.	1.Transition occurs from a higher energy level to lower energy
2.NO incident photon is required	2. Photon whose energy is equal to the difference of two energy levels is required.
3. Single photon is emitted.	3. Two photons with same energy are emitted.
4. The energy of emitted photon is equal to the energy difference of two energy levels.	4. The energy of the emitted photons is double the energy of stimulated photons.
5. This was postulated by Bohr.	5. This was postulated by Einstein.
6.  (a) Before emission (b) After emission	6. 

POPULATION INVERSION

Making the number of particles N_2 more in higher energy level is less than the number of particles N_1 in lower energy level ($N_2>N_1$) is called as population inversion or inverted population.

The method of raising the particles from lower energy state to higher energy state is called as **pumping.**

METHODS OF ACHIEVING POPULATION INVERSION

There are several methods for achieving the condition of population inversion necessary for laser action to takes place. Some of the most commonly used methods are

1. **Optical pumping:-** In case of optical pumping, an external light source like a Xenon flash lamp is employed to supply luminous energy and to produce a high population in the higher energy level of the laser medium.

This method of excitation is used in solid-state lasers like RUBY laser.

2. **Electric discharge: -** This method is used in some of the gaseous ion lasers, such as an argon laser. In this type of excitation, the laser medium itself carries the discharge current under suitable conditions of pressure and temperature.

In this method, the electrons directly excited the active atoms to achieve higher population in certain higher energy levels compared to lower energy level.

3. **Inelastic atom-atom collision:-** Here the electric discharge is employed to cause collision and excitation of the atom. In this method the combination of two types of gases is used, say A and B both having the same excited states A*and B* that coincide (or) nearly coincide.

In the first step, during electric discharge, A gets excited to A* due to collision with electron is

$$A+e \rightarrow A^* + e,$$

$$A^*+ e \rightarrow A + B^*.$$

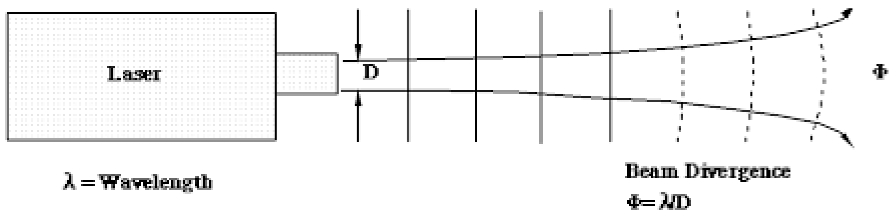
The excited A atom now collide with B atoms so that the later atom gets excited to higher energy B*.this type of transition is used in He- Ne laser.

4. **Chemical reaction:-** In this method the molecules undergo chemical changes in which one of the products of the reaction excites a molecule or an atom to excited state under appropriate conditions. Under such conditions population inversion occurs. An example this type of lasers is the hydrogen fluoride chemical laser, in which hydrogen fluoride molecules can be excited to a higher energy state with help of heat energy released due to the following chemical reaction.

$$H_2 + F_2 \rightarrow 2HF + heat.$$

Characteristics of laser

1. **Directionality**: the light beam can travel as a parallel beam up to a distance of $\frac{d^2}{\lambda}$, where d is the diameter of the aperture and λ is wave length of light used. After traveling the distance $\frac{d^2}{\lambda}$ the light beam spreads radially. In ordinary light, the angular spread is 1m per 1m travel. But in Laser the angular spread is only 1mm per 1m travel .this indicates Lasers are highly directional.



2. **Intensity:** the intensity of the laser beam is very high. If a person is allowed to observe an ordinary light emitted by 1000W bulb at distance of 1foot from the source, he can receive only $\frac{1}{1000}W$ of light .if the person is allowed to observe the laser beam from the same distance; the entire laser beam penetrates through his eye. It will damage the eye of the observer.

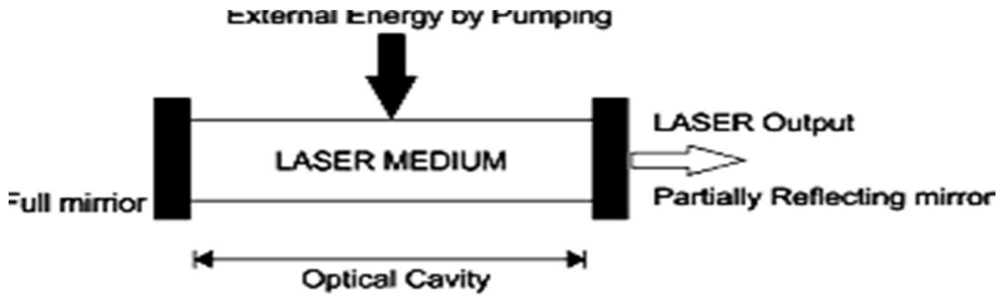
3. **Monochromaticity**: the laser beam is strictly monochromatic than any other conventional monochromatic source. the band width($(\Delta\upsilon = 0)$ of laser beam is narrow, while ordinary light spreads over a wide range of frequency .the line width $\Delta\lambda$ emitted by laser is very small.

4. **Coherence**: the degree of coherence of laser beam is very high than the other sources. The laser beam consists of wave trains that are identical in phase and direction of propagation.

CONSTRUCTION AND COMPONENTS OF LASER

Any laser system consists of three important components.

1. Source of energy.
2. Active medium.
3. Optical resonant cavity.



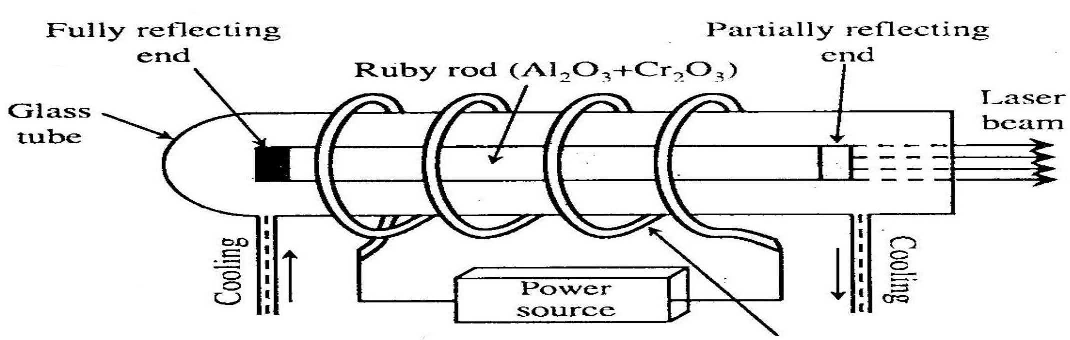
Components of LASER

Source of energy: - To get laser emission, first we must have population inversion in the system. the source of energy supplies sufficient amount of energy to the active medium by which the atoms (or) molecules in it can be excited to the higher energy level. As a result we get population inversion in an active medium. That means the source of energy supply energies and pumps the atoms (or) molecules in the active medium to excited states.

Active Medium(or) Laser Medium:-This is the medium where stimulated emission of radiation takes place. After receiving energy from the source, the atoms or molecules get excited to higher energy levels. While transiting to a lower energy level, the emitted photons start the stimulated emission process which result in laser emission. Depending upon the type of active medium, we have solid state, liquid state, gaseous state and semiconductor laser.

Optical cavity (or) Resonator: - The active medium is enclosed between after reflective mirror and a partially reflective mirror. These mirrors constitute an optical cavity (or) resonator. The reflective portion of the mirrors reflects the incident radiation back into the active medium. These reflected radiations enhance the stimulated emission process with in the active medium. As a result we get high- intensity mono chromatic and coherent laser light through the non-reflecting portion of the mirror

Ruby Laser



A schematic diagram of Ruby laser

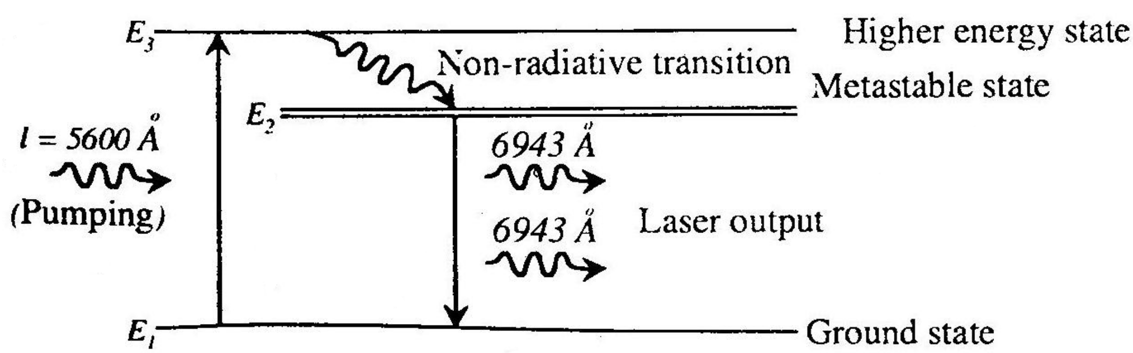
Basically Ruby is a Al_2O_3 crystal congaing 0.05% of chromium atoms

1. **Active medium: Ruby rod.**
2. **Active centers: chromium atoms**
3. **Exciting source: Xenon flash tube**
4. **Cavity Resonator: The partially silvered face and fully silvered face of ruby rod acts as Resonating cavity**

Construction:

Ruby is taken in the form of rod. then end face are grounded and polished such that the end faces Are exactly parallel to each other .one of the face is silvered fully to get fully reflection and other partially silver to get partially reflection .These two silver faces acts as resonating cavity .The Ruby rod is surrounded by helical xenon glass tube which act as exciting source

Working:



Energy level diagram of Chromium ion

The energy levels of Cr3+ ions in the crystal lattice are shown in the fig.

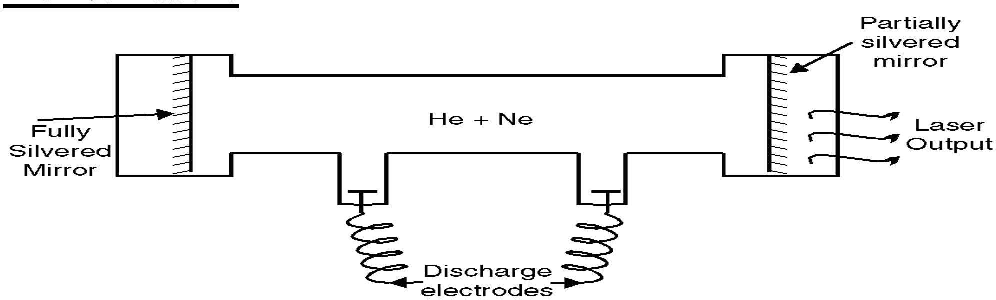
In normal state, the chromium ions are in the lower levels, when the ruby crystal is irradiated with light of xenon flash, the chromium atoms are excited and pass to E3 and E3. The excited levels are highly unstable. So the excited atoms return to grand level E1 directly or via. E2. The transition E3→E2 and E3→E2 are non-irradiative. i.e. Cr atoms gives part of energy to the crystal lattice in the form of heat. Here E2 is the Meta stable state. Therefore Cr atoms accumulate there, after a few mille sec. The population at level E2 exceeds E1. So, there is a population inversion established between E2 and E1 levels, then stimulated emission takes plate. This leads to the production of laser beam.

Drawbacks of ruby laser:

1. In this case the laser beam is not continuous and contains pluses

2. Intensity of laser beam is very poor

He Ne laser:



Active medium : mixture of He and Ne in the ratio 10:1

Active centers : Ne atoms

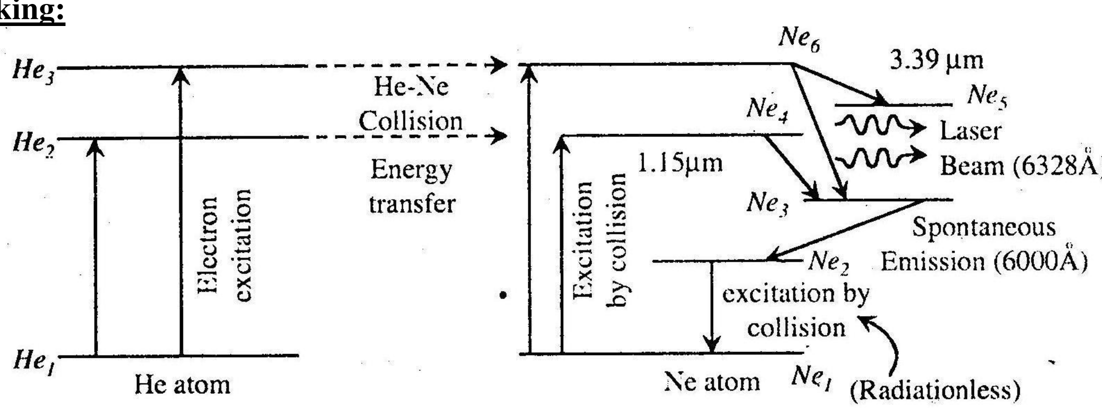
Exciting Source : Electric discharge

Resonating Cavity : Partially & fully reflecting Mirrors.

Construction:

The schematic of a typical He-Ne laser is as shown in the fig. It consists of long discharge tube containing a mixture of He and Ne gases in the ration 10:1. Electrodes are provided to produce a discharge in the gas and they are connected high voltage power supply. The tube is sealed by two windows. Two mirrors are fixed in both sides of the tube, which acts as a resonating cavity.

Working:



When a discharge is passed through the gas, the electrons are accelerated towards the positive electrode. During their passage, they collide with He atoms and excite them into the upper states. i.e. from He_1 to He_2 and He_3. He_2 and He_3 are Meta stable states. So excised He atoms accumulate in He_2 and He_3 levels. The excited He atoms can return to the ground state by transferring their energy to neon atoms through collisions. Here the Ne_6 and Ne_4 levels of Ne atom nearly coincide in energy with He_3 and He_2 levels of Helium atom. So the Ne atoms directly go to Ne_4 & Ne_6 levels. In case of Ne, Ne_4 & Ne_6 are Meta stable states. So Ne atoms accumulate more & more at these levels. After some time population inversion is achieved between Ne_6 & Ne_5, Ne_6 & Ne_3 and Ne_4 & Ne_3 levels. Consequently three laser transitions can occur.

1. $Ne_6 \rightarrow Ne_3$ transition : This transition generated a beam of Red Laser
2. $Ne_4 \rightarrow Ne_3$ transition : Gives a laser beam in infrared region.
3. $Ne_6 \rightarrow Ne_5$ transition : Gives a laser beam in far infrared region.

APPLICATIONS OF LASER

1. **In consumer electronics:** Telecommunications, and data communications, lasers are used as the transmitters. They are used to store data in compact discs and DVD's as well as magneto optical discs.
2. **In science**: Lasers are employed in wide variety of interferometric techniques, atmospheric remote sensing and investigation of non-linear optics phenomena and Holographic techniques.
3. **In industry:** laser cutting is used to cut steel and other metals. Laser lines are used in surveying and constructions. Lasers are used for guidance for aircraft.
4. **In medicine:** laser is used for laser vision correction and surgical techniques. Laser also used for dermatological procedures including removal of tattoos, birth marks and hair.
5. **In law of enforcement**: lasers are used for detect the speed of vehicles. In military used as target destinations for other weapons

PREVIOUS QUESTIONS

1. What is population inversion and how can it be achieved.
2. Explain the three level and four level laser systems. What are the advantages of four level laser system over three level laser system?
3. What is meant by population of an energy state?
4. With neat diagram, describe the construction and working of Ruby laser.
5. What are the characteristics of laser beam? Explain.
6. Distinguish between spontaneous and stimulated emissions.
7. Derive the expression for energy density of radiation in terms of Einstein coefficients.
8. Explain construction and working of He-Ne laser.

FIBER OPTICS

Optical fiber:

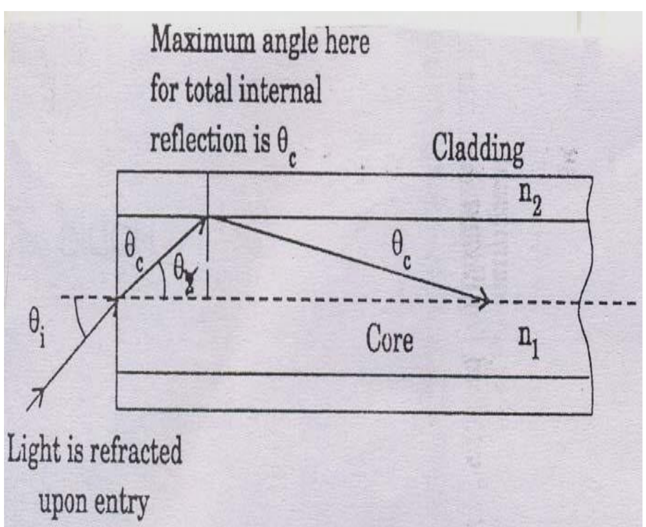
Optical fiber is a wave guide, made of transparent dielectric (Glass or Plastic) in a cylindrical form. It guides light waves to travel over long distances without much loss of energy.

Features of Optical fibers:

1. It is light in weight.
2. It is smaller in size and flexible, so that it can bend to any position.
3. It is non-conductive, non-radiative and non inductive.
4. It has high band width and low loss.
5. There is no short circuiting as in metal wires.
6. There is no internal noise/cross talks
7. It can withstand to any range of temperature and moisture condition.
8. There is no need to ground and hence no voltage problem occurs.

PRINCIPLE OF FIBER (**Total internal reflection**):

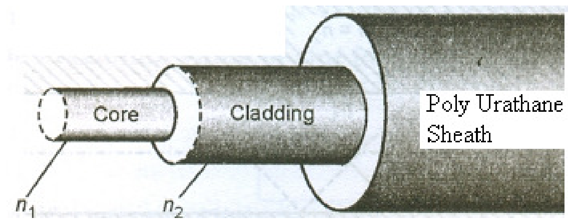
The principle behind the transmission of light waves in a optical fiber is total internal reflection. Consider a ray of light traveling from a core (medium of high refractive index n_1) to a cladding (medium of low refractive index n_2).



When an angle of incidence (θ_1) is greater than the critical angle of incidence (θ_c), the incident light ray totally reflected back into the originating medium as per the laws of reflection. This phenomenon is known as total internal reflection.

CONSTRUCTION OF OPTICAL FIBER:

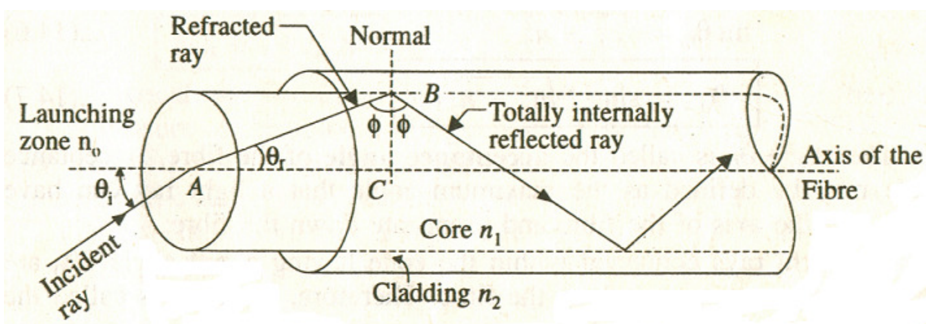
An optical fiber is a long cylindrical transparent structure made up of a high quality of glass or plastic usually with a circular cross section.



Inner region A is called light guiding core having refractive index n_1 1.7.core acts as denser medium. core is surrounded by a second cylindrical shell called cladding having refractive index slightly less than core, n_2 1.6.

The cladding is surrounded by a circular shell which is made up of polyurethane to protect fiber from sun light and shocks.

PROPOGATION OF ELECTROMAGNETIC WAVE IN FIBERS



Let us consider an optical fiber into which light is launched. The end in which light enters into the fiber is called launching end.

Let the refractive index of the core be n_1 and the cladding be n_2 where $n_1>n_2$. Let n_0 be the refractive index of the medium from which light is launched into the fiber.

Let a light ray enter the fiber at an angle θ_i with the axis of the fiber. The ray refracts at an angle θ_r and strikes the core and cladding interface at an angleϕ. If ϕ is greater than critical angle ϕ_c the ray undergoes total internal reflection.

Applying Snell's law of refraction to the launching face of the fiber, we get

$n_0 \sin \theta_i = n_1 \sin\theta r$

or $\sin \theta_i = \dfrac{n_1}{n_0} \sin\theta r$ -----------(1)

From the fig. in Δ ABC $\sin\theta r = \sin(90 - \phi) = \cos\phi$

Sub. The above value in equ.(1), we get

$\sin \theta_i = \dfrac{n_1}{n_0} \cos\phi$ ----------(2).

When $\phi = \phi_c$, the angle of incidence θ_i becomes maximum

$\therefore \sin \theta_{i\,max.} = \dfrac{n_1}{n_0} \cos\phi_c$ ----------- (3)

Applying Snell's law of refraction at point B, we have

$n_1 \sin\phi_c = n_2 \sin 90$ or

$\sin\phi_c = \dfrac{n_2}{n}$ or $\cos\phi_c = \dfrac{\sqrt{(n_1^2 - n_2^2)}}{n_1}$

Substitute the above value in equation (3), we get

$\sin \theta_{i\,max.} = \dfrac{n_1}{n_0} \dfrac{\sqrt{(n_1^2 - n_2^2)}}{n_1}$ or

$\mathbf{\sin \theta_{i\,max}} = \dfrac{\sqrt{(n_1^2 - n_2^2)}}{n_0}$ --------------(4)

for air medium $n_0 = 1$ so the above equation becomes

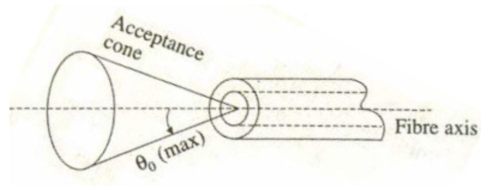
$\theta_0 = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$ ------------ (5) where $\theta_0 = \mathbf{\sin \theta_{i\,max}}$

Equation (5) gives the expression for the acceptance angle of the fiber.

Any angle of incidence of light is always less than the θ_0 .

ACCEPTANCE ANGLE OF FIBER: ***Acceptance angle of fiber can be defined as "The maximum angle of incidence for which light confines to the denser medium"***

Acceptance Cone: The light rays contained within the cone having a full angle 2 θ_0 are accepted and transmitted along the fiber. Therefore, the cone is called **acceptance cone.**



FRACTIONAL REFRACTIVE INDEX CHANGE (Δ):

The fractional difference Δ between the refractive indices of the core and the cladding is known as fractional refractive index change. It is expressed as

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

This parameter is always positive because n_1 must be greater than n_2 for the total internal reflection condition. In order to guide light rays effectively through a fiber, Δ <<1. Typically Δ is of the order of 0.01.

NUMERICAL APERTURE (NA):

The numerical aperture is defined as the sine of acceptance angle. Thus,

$$NA = \sin\theta_0$$

$$NA = \sqrt{(n_1^2 - n_2^2)} \text{ ----------- (1)}$$

$$n_1^2 - n_2^2 = (n_1 + n_2)(n_1 - n_2)$$

$$=2\left(\frac{n_1+n_2}{2}\right)n_1\left(\frac{n_1-n_2}{n_1}\right)$$

Approximating $\frac{n_1+n_2}{2} \approx n_1$, we can express the above relation as

$$n_1^2 - n_2^2 = 2n_1^2\Delta$$

$$NA = n_1\sqrt{2\Delta} \text{ ----------- (2)}$$

Numerical aperture determines the light gathering ability of the fiber. NA ranges from 0.13 to 0.50.

Types of Optical fibers:

Types of optical fibers based on number of modes.

Optical fibers are classified into two types based on the number of modes of propagation in the guide they are

Single mode fiber – One mode

Multi mode fiber – many mode

1. Single mode fiber: In a fiber, if only one mode (light ray path) is transmitted through optical fiber, then it is called Single mode fiber.

2. Multi mode fiber: If more than one mode is transmitted through optical fibers, then it is called multimode fiber.

Differences between single and multimode fiber:

Sl.No.	Single mode fiber	Multimode fiber
	Properties:	
1.	In single mode fiber only one mode can be propagate.	This fiber it allows large number of modes for light to pass through it.
2.	The single mode fiber has a small core diameter& small refractive index difference between core and cladding .	The multi mode fiber has a large core diameter& large refractive index difference between core and cladding

1. **2.**	**Advantages:** No dispersion The fiber can carry information to longer distances.	**Disadvantages:** Dispersion is more. Information can be carried to shorter distances only.
1. **2.**	**Disadvantages:** Launching of light and connecting two fibers are difficult Fabrication is difficult and Installation cost is more.	**Advantages:** Launching of light and connecting two fibers are easy. Fabrication is easy and the installation cost is low.

Types of optical fibers based on the refractive index profile:

Optical fibers are also classified into two types on the basis of the refractive index. They are

1. Step index fiber
2. Graded – index fiber

1. Step index fiber: If the refractive index difference in the core and cladding is varied step by step, then the fiber is called step index fiber.

2. Graded index fiber: If the refractive index difference in the core and cladding is gradually varied in a number of small decreasing index steps, then the fiber is called Graded index fiber.

Refractive index profile:

In any optical fiber, the cladding has a uniform refractive value. But the refractive index of the core may either remain constant or vary in a particular way. The curve which denotes the variation of refractive index with respect to the radial distance from the axis of the fiber is called the **refractive index profile.**

Advantages:

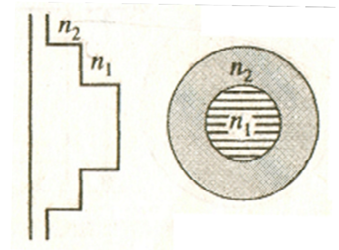
1. It has very high capacity.
2. The 80% of all fibers that are manufactured in the world today are of thistype.

Disadvantages:

In spite of so many good qualities, the use of very thin cores creates mechanical difficulties in the manufacture and handling. Hence this type of fiber is very expensive.

Step Index Fibers:

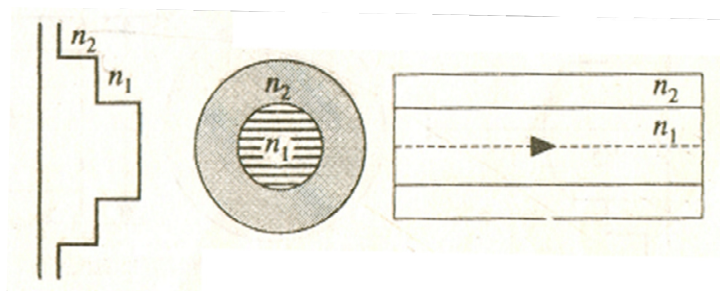
In step index fibers refractive index of the core is constant throughout the diameter of the core. At the core and cladding boundary the refractive index suddenly changes which is shown in fig.



Single Mode Step Index Fiber (SMF):

In single mode fiber the core diameter is of the order of 4μm.

so it can support few wavelengths of light only.

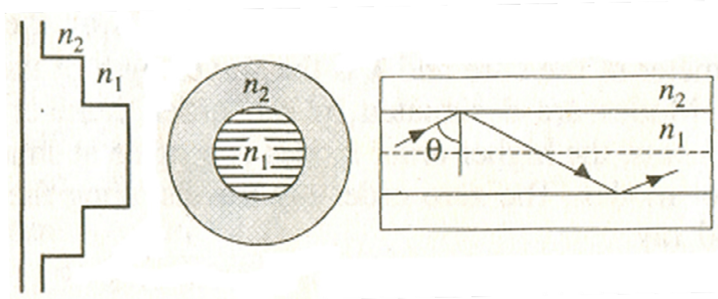


Transmission of Signal:

- Light travels in SMF along a single path that is along the axis of the fiber. This is known as zero order propagation.
- Due to smaller core diameter, signal distortion is very less. That is there is only small waveguide dispersion only.
- Since these fibers have low transmission loss and low dispersion or pulse broadening, these are used in long distance optical fiber communication.
- A SMF has very small value of Δ. It is of the order of 0.002.

Multi Mode Step Index Fiber (MMF):

Multimode step index fiber is similar to that of single mode fiber except in core diameter. MMF has larger core diameter of the order of 100 µm. so it can support multi wavelengths.



Transmission of signal:

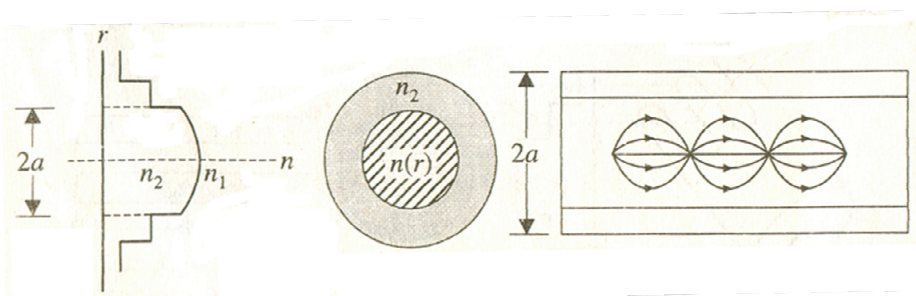
• Light follows zigzag paths inside the fiber. Many zigzag paths are permitted in MMF by changing the frequency of the light.

•Light rays propagating through these fibers are in the form of ***meridional rays*** which will cross the fiber axis during every reflection at the core-cladding boundary and are propagating in a zigzag manner as shown in figure.

• Signal distortion is more in multimode step index fiber due to large pulse dispersion or intermodal dispersion.

• The NA of the MMF is of the order of 0.3.

Graded Index Fiber:



A graded index fiber is a multimode fiber with a core consisting of concentric layers of different refractive indices. Therefore the refractive index of the core is not constant throughout the diameter of core. Refractive Index of the core varies in parabolic path. It is maximum at the centre of the core and decreases away from the center which is shown in fig.

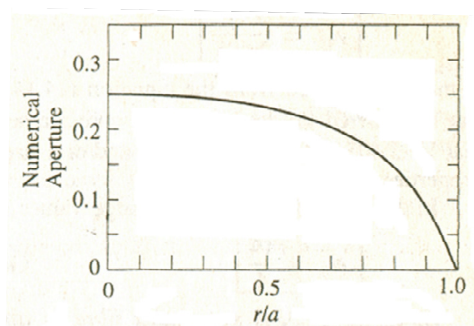


Illustration of variation of numerical apreture of a parabolic index fibre.

The refractive index of the central zone of the

fiber can be written as

$$n(r) = n_1 \sqrt{1 - \left(\frac{r}{a}\right)^{\alpha}} \quad \text{------------(1)}$$

where α is grading parameter. If α = 1, grading is linear.

α =2 grading is parabolic. For graded index fibers α = 2 is preferred. When α = ∞ grading is step

index fiber.

Transmission of Signal:

• The light rays propagating through these fibers are in the form of skew rays or helical rays which will not cross the fiber axis at any time and are propagating around the fiber axis in a helical or spiral manner as shown in figure.

• Due to parabolic refractive index profile, there is self focusing effect. So the light rays propagating at different speeds in different paths through the fiber are continuously refocused and almost all the rays reach the exit end of the fiber simultaneously.

• In these fibers transmission loss is moderate because of **self focusing effect** all rays come out at the same time.

• Practically bandwidth is 200 MHz to 600 MHz.

Difference between Single mode step index fiber (SMF) and Multi mode step index fiber(MMF):

Single Mode Step Index Fiber (SMF**)**

1. In this only one mode can propagate through the fiber

2. Core diameter is small i.e of the order of 4 micrometers.

3. The fraction difference in the R.Is of core and cladding is small

4. No dispersion occurs while travelling through the fiber

5. These are suitable for long distance communication.

6. Launching of light into SMF and joining of two fibers are difficult.

7. Fabrication is difficult and costly.

Multi Mode Step Index Fiber (MMF):

1. MMF allows more no. of modes of paths to propagate through it

2. Core diameter is high, of the order of 50-200micrometers.

3. NA is larger than SMF

4. In MMF dispersion is high but in graded index fibers it is small

5. Not suitable for long distances due to dispersion. Any how these are generally used in LANs.

6. Launching of light into the fiber and joining of two fibers are easy.

7. Fabrication is less difficult and not costly.

ADVANTAGES OF OPTICAL FIBERS OVER ORDINARY CABLES:

i. **Optical Fibers are Cheaper**: The optical fibers are made from silica (SiO_2) which is one of the most abundant (more availability) materials on the earth.

ii. **Optical fibers are small in size, light in weight, flexible and mechanically strong**:

The cross section of an optical fiber is about a few hundred micrometers whereas wires are bigger in size and heavy weight. Typically an RG-19/U coaxial cable weighs about 1100kg/km whereas a fiber weighs 60kgs/km only. Therefore fiber cables are easier to transport, quite flexible and mechanically strong.

iii.Optical fibers reduce cross talk susceptibility: The light in the fiber is completely confined to the core medium only and it cannot leak out from the fiber. Similarly light cannot couple with another fiber from sides of fiber. Because of this feature cross talk susceptibility greatly reduced.

iv.Optical fibers are immune to EMI (electromagnetic interference: In optical fibers information carried by photons. Photons are electrically neutral and cannot be disturbed by high voltages and lightning etc. so fibers are immune to externally caused back ground noise generated by electro magnetic interference and radio frequency interference

v. **Optical fibers have a wider bandwidth**: A telephone cable composed of 900 pairs of wire can handle 10,000 calls whereas 1mm fiber can transmit 50,000 calls simultaneously. Thus fibers have ability to carry large amounts of information.

vi. Losses are low: The transmission loss per unit length of an optical fiber is about 4 dB/km**.** Therefore, repeaters can be placed in the range from 30 km to 100 km. where as in case of ordinary cables transmission loss per unit length is high. So repeaters are placed about 2 km only.

DIFFERENCE BETWEEN THE STEP INDEX FIBER AND GRADED INDEX FIBER:

S.NO.	Step index fiber	Graded index fiber
1	The r.i. of core is uniform throughout the diameter of core and rapid change at the core-cladding boundary.	The r.i of core is max. at center and decreases away from the center. that is r.i of core varies parabolic manner
2	The diameter of core in MMF is about -50-200 µm, and in SMF is 4 µm.	The diameter of core is about 50 µm.
3	The light rays propagate in the form of meridional rays which will cross the fiber axis during every reflection at the core-cladding boundary and are propagating in zigzag manner.	The light rays propagating through the fiber are in the form of skew rays or helical rays which will not cross the fiber axis at any time and are propagating around the fiber axis in a helical or spiral manner.
4	Signal distortion is more in MMF since higher order rays come out of fiber early than lower order rays. But this distortion does not take place in SMF.	Signal distortion is less because of self- focusing effect. All light rays come out at the same time.
5	For MMF band width is 50MHz while for SMF it is more than 1000MHz.	Practically bandwidth is 200MHz to 600MHz.
6	Attenuation is more for MMF, for SMF it is less.	Attenuation is less.
7	NA is more for MMF while less for SMF.	NA is less than MMF.

