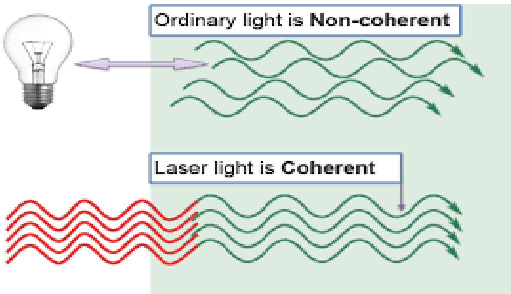
LASERS

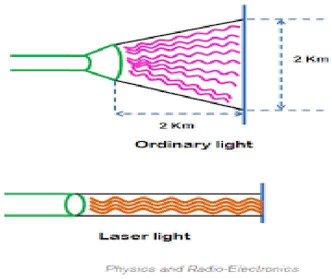
LASER is an acronym for Light Amplification by stimulated Emission of radiation

Characteristics of Lasers:

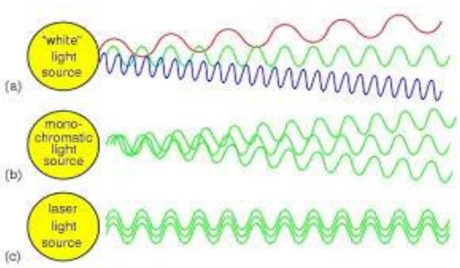
1. **Coherence:** Laser has high degree of coherence. All the photons have same amplitude, frequency and are in phase. Due to high coherence it results in an extremely high power.



2. **Directionality:** ordinary light is highly divergent where as laser light is highly directional. Angular spread of ordinary light is 1Km/Km
   Where as laser light is 1Cm/km



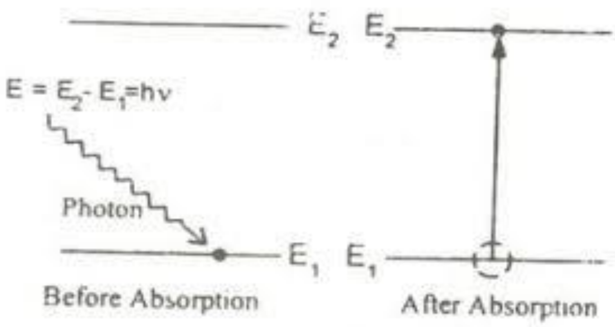
3. **Monochromaticity:** Laser beam is highly monochromatic (Single wavelength) than other sources of light. The laser beam spreads over very small frequency range where as ordinary light spreads over a large frequency range.



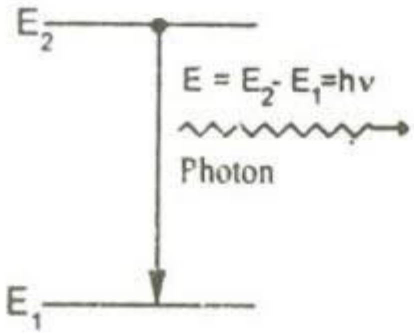
4. **High Intensity:** The intensity of laser light is thousand times more intense than an ordinary light.

Stimulated absorption, Spontaneous and stimulated emission:

1. **Stimulated absorption**: An atom in lower level of energy E1 goes to higher energy level E2 , when it absorps a photon whose energy is equal to E2-E1, this is known as stimulated absorps.

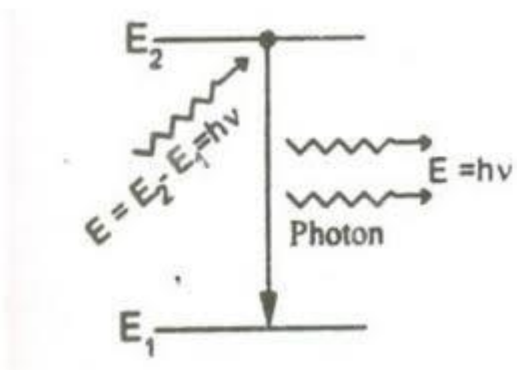


2. **Sponteneous Emission**: when the atom absorbs a photon energy it returns to ground state by emitting photon of energy $E=E_2-E_1=h\nu$, The emission occurs without any help from surrounding radiation this is known as spontaneous emission.



The spontaneous emission emits 1 photon is random and an incoherent .

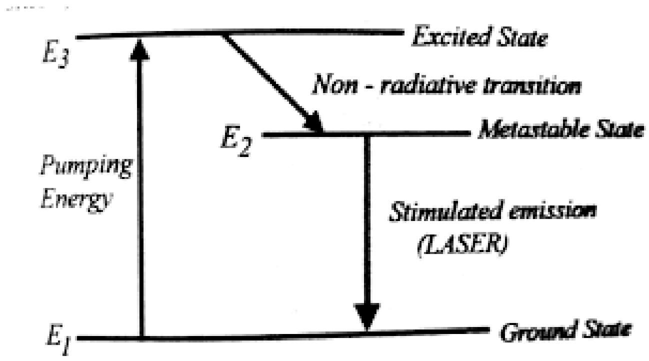
3. **Stimulated emission**: The atom in the excited state can also return to the ground state by trigging or inducement of photon of energy which is equal to energy of incident photon ie. $E=E_2-E_1=h\nu$, is known as stimulated emission.



Thus results into 2 photons of coherent and directional.

Population inversion and Metastable state:

Population inversion: The process by which the population of higher energy state is made more than that of specified lower energy state is called as population inversion. ie. $N_2>N_1$.



The population inversion can't be achieved into 2 level energy system, so let us consider 3 level energy system of energy levels E_1, E2 and E_3. Here E_2 is metastable state suppose an appropriate energy of external source is applied to the system as a result some of atoms excite from lower energy state to higher energy state most of excited atoms undergoes spontaneous down word transition to state E_1 , while some have transition to state E_2 but the probability of transition from E_2 to E_1 is low, because atoms can stay longer time in E_2 state that population increases in E_2 than E_1 state thus a state is reached when $N_2>N_1$, So population inversion achieved.

Note: Life time of higher energy state is 10^{-8} s and Life time of metastable state is 10^{-3} s

Metastable state:

It is the energy state in which atoms can stay longer time hence population inversion can achieve called metastable state.

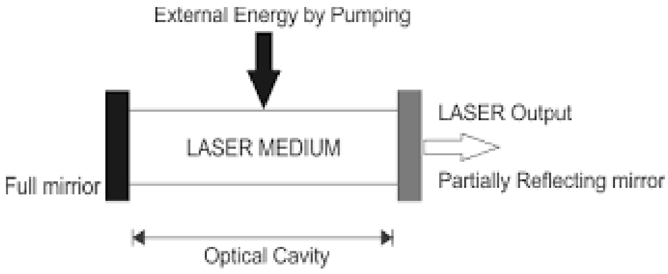
Main components of Laser:

There are 3 main components of Laser.

1. Active medium

2. Energy Source

3. Optical resonator



Components of LASER

1. Active medium: A system in which population inversion can achieved is called active medium.

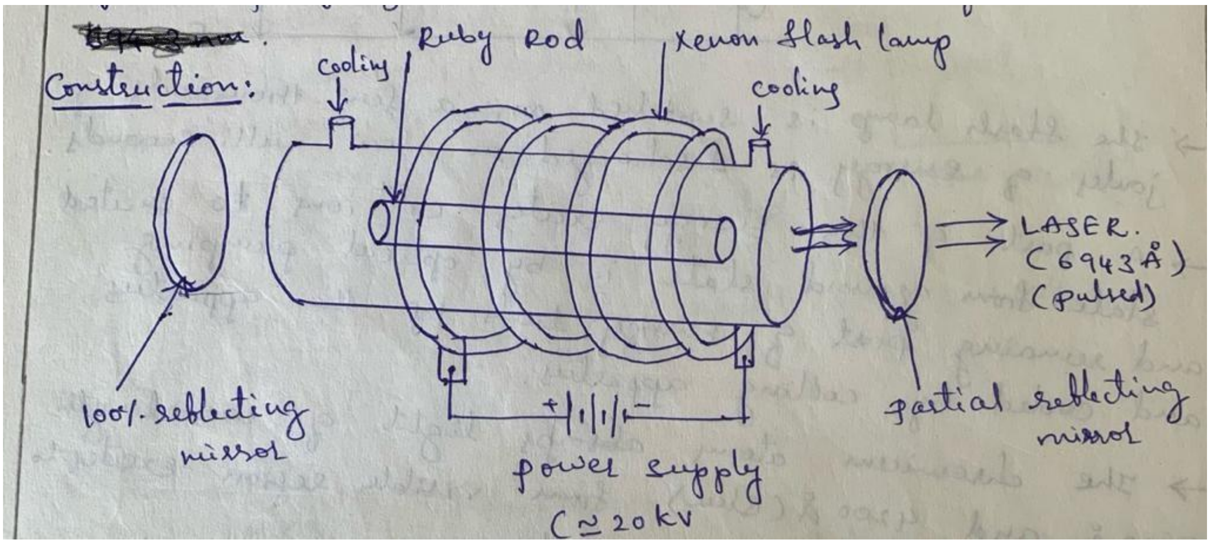
2. **Energy Source**: The energy source raise the system to the excited state

3. **Optical resonator**: The optical resonator constitutes an active medium kept in between a 100% reflecting mirror and partially reflecting mirror. The function of optical resonator is to increase the intensity of laser beam.

RUBY LASER

Introduction

- Ruby laser is a 3-level solid state laser discovered by T.H.Maiman in 1960. Ruby rod is a crystal used as active medium and the laser out put is 694.3nm.

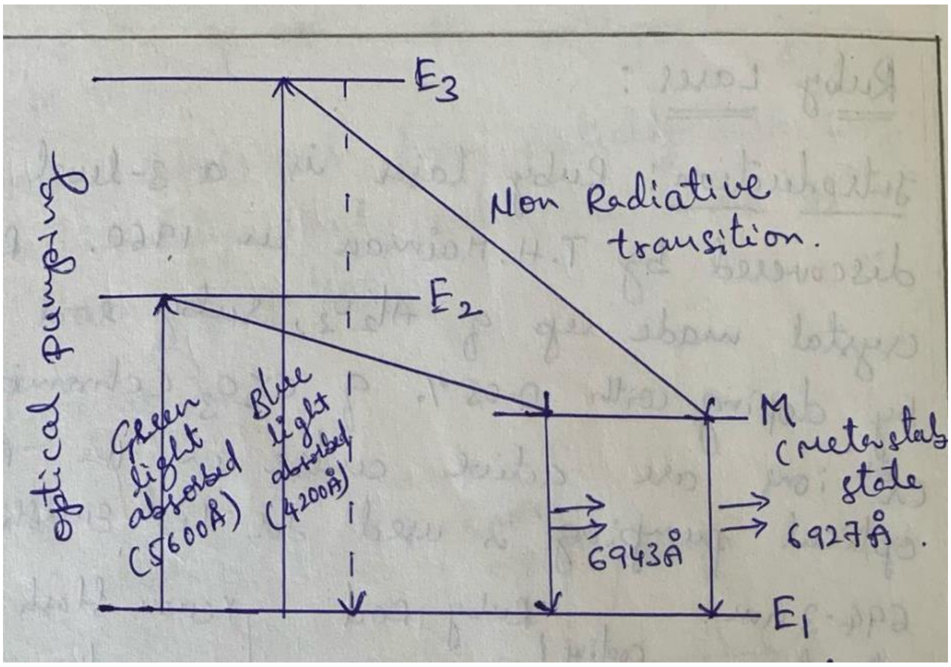


Construction:

- Ruby is crystal made up of Al_2O_3.

- Ruby rod can be prepared by doping Cr_2O_3 with 0.05% of chromium oxide.
- Chromium ions Cr^{3+} are **active centre** in ruby crystal.
- Ruby rod is cylindrical rod nearly 10cm long and 0.5cm in diameter.
- The ends of ruby rods are grounded and polished such that ends of ruby faces are exactly parallel and also perpendicular to axis of rod. Ends of ruby rod acts as internal mirrors, one end acts as 100% reflecting and other end acts as partially reflecting mirror, so its acts like optical resonator.
- Optical pumping source used as xenon flash lamp which is wounded spirally over ruby rod and connected to power supply as shown in figure.

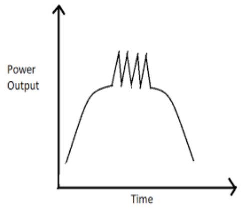
Working:



- The flash lamp is switched on, a few thousands of joules of energy is dishcharged in few milli seconds.
- A part of this energy excites Cr^{3+} ions to excited state from ground state ie. by optical pumping and remaining part of energy heats up the device and cooled by cooling apparatus.
- The chromium atoms absorbs light of wavelength 5600 Å and 4200 Å from visible region excites to E_2 and E_3 energy states respectively.
- From E_2 and E_3 energy states o non radiative transition takes place and accumulations of excited atoms increases at metastable state and achives population inversion.
- The lasing action is trigged by the spontaneously emiited photos, results stimulated emission from metastable state to ground state.

- The photons travelling parallel to ruby rod are used for stimulation while photos moving random come out from ruby rod in the form of heat.
- The stimulated photons are allowed to under go multiple reflection by optical resonator. Hence the intense beam of wavelength 6943 Å emerges out to corresponding absoption of Cr_3 with corresponding transition from M to E_1
- Thus LASER beam comes out from partially reflecting mirror with directionality, high coherence and out put is in the form of pulses.

Out put beam characteristics:



Once flash lamp is fired within 0.5sec population exceeds the threshold value and stimulated emission repeats itself many times. Hence out put consists spikes about 1μs, so out put is in pulsed form.

Applications:

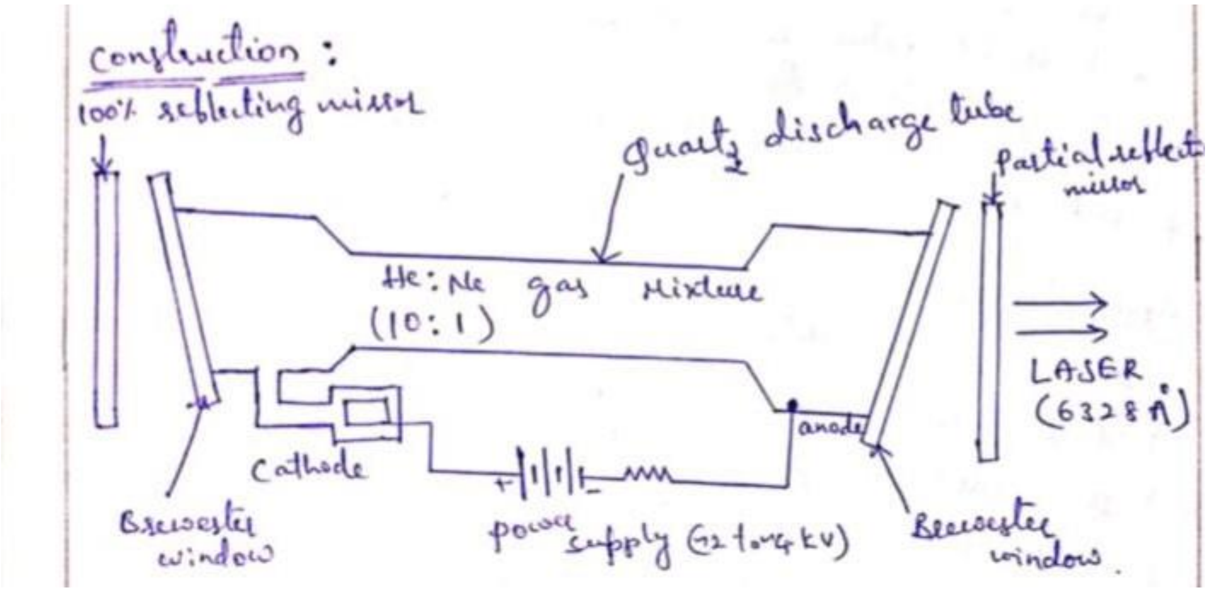
- It is used in holography.
- It is used in LIDAR.
- It is used in remote sensing.
- It is used in Ophthalmology.
- It is used in drilling small areas.
- In military, used as target designators and range finders.

He-Ne LASER:

Introduction: He-Ne is the gas laser discovered by Ali Javan in December 1960, in Bell laboratory. This is designed to get continuous out put beam.

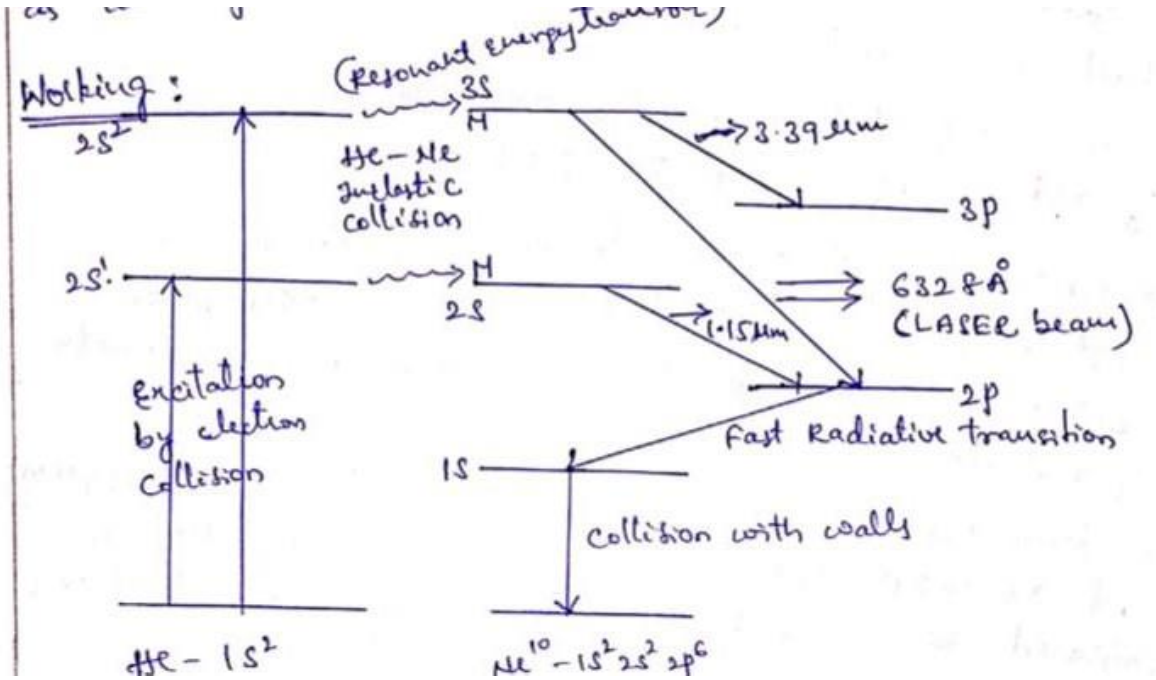
Here He-Ne gas is the active medium, Ne are the active centres achieves the population inversion and stimulated emission takes place of wavelength 632.8 nm. Or 6328 Å

Construction :



- It consists of a glass discharge tube which is made up of quartz and filled with the mixture of helium and neon in the ratio of 10:1 under low pressure i.e the number of Helium atoms are greater than the number of Neon atoms.
- Here Ne atoms are active centres.
- The **electrical discharge** is used as pumping source through anode and cathode which are present at the ends of discharge tube and connected to a direct current or radio frequency discharge created by applying a high voltage (~2 to 4kv).
- The ends of the discharged tube is tilted by an angle called Brewster angle called Brewster windows it is used to produce plane polarized light from perpendicular polarized light.
- Two mirrors are kept at the ends of the discharge tube one is 100% reflecting mirror and another is partial reflecting mirror, which is act like optical resonator. as shown in figure.

Working:



- Switch on battery , by electrical discharge in a gas tube the helium atoms are excited from ground state to higher energy state ($2S^1$ &$2S^2$), the excitation occurs due to the collision of discharged electrons with atoms.
- The excited helium atoms collide with neon atoms which have closer energy levels as that of helium energy levels.
- Therefore helium atoms deliver energy to neon atoms by the process known as resonant collision energy transfer.
- This resonant energy transfer takes place because the corresponding energy levels of helium $2S^1$ &$2S^2$ to closer energy levels of neon 2S & 3S respectively.
- The probability of energy transfer from neon to helium decrease because of high pressure in He than Ne.
- Some helium atoms dexcited and they come back to ground state .
- The laser transition takes between two sets of sub energy levels (3S & 2S) and (2P &3P)
- The first resonant energy transfer made from 2S2 to 3S and stimulated emission takes place between 3S and 2P gives 6328 Å wavelength of radiation.
- Stimulated emission between 3S to 3P gives 3.39μm and 2S to 2P gives 1,15μm of radiation lies in infrared region and its absorbed by quartz discharge tube.
- Atoms under goes the transition from 2P to 1S & 1S to ground state by non radiative transition.
- Since electron density in 3S and 2S level of neon always greater than the other levels of neon. We get continuous LASER out put of wavelength 6328 Å with few milli watts of 0.5mW to 100Mw.

Applications :

- Due to high power it is used in open air communication.
- It is used to produce holograms.
- Widely used in in laboratories for all interferometric experiments.
- Widely used in metrology in surveying.
- He –Ne laser scanner used to read bar decoder.

Applictions of LASER

1. Laser in industry :

   Welding :

   - Dissimilar metal can be welded.
   - Micro welding can be done with great ease.
   - Very high rating of welding are possible (10Kw CO_2 laser 5mm thickness stainless steel plates can be welded at speed of 10cm/sec).

   Cutting :

   - Any desired shape cuts easily, complicated cuts made easy with laser.
   - Cut finish use to be very smooth required no further treatment such as grinding and polishing.
   - With high power CO_2 laser glass, quartz and diamonds can be cut easily.

   Drilling :

   - Lasers are used to drill holes in difficult to drill material such as ceramic, etc.
   - Hole of micron order can be easily drilled .

2. Laser in electronic industry:
   - Scribbling: drawing fine lines in brittle ceramic and semiconductor wafers scribbling done with laser.
   - Soldering: thin sheets 25 micron can soldered without any damage of sheets.
   - Trimming: film register trimming made easy with laser.

3. Laser in medicine:
   - Ophthalmologist using for eye treatment.
   - For cataract removal lasers are used.
   - Lasers scalps are used for bloodless surgeries.
   - Lasers are used angioplasty for removal artery block in heart.
   - In dermatology laser are used to remove freckles , acne , birth marks and tattoos.

- Lasers are used in destroying kidney stones and gall stones.
- Used in cancer diagnosis and therapy.

4. Lasers in scientific fields and military:
   - Laser in metrology survey to measure distance like earth to moon .
   - Lasers act like weapon, target finder and ranging.
   - Lasers are used to guide missiles.
   - Lasers used to find the enemy targets.

5. Lasers in communication:
   - It is widely used in open air communication (satellite), because it is free from dust , fog and rain.

6. Laser in other fields:
   - Used as laser scanner in super market to scan bar code.
   - Used in storage technique of CD player to increase storage capacities.

Fiber Optics

Introduction

An optical fiber is a flexible, transparent cable made by drawing glass (silica) or plastic to a cylindrical wire of diameter slightly thicker than that of a human hair.

Fibers are used instead of metal wires because signals travel along them with less loss

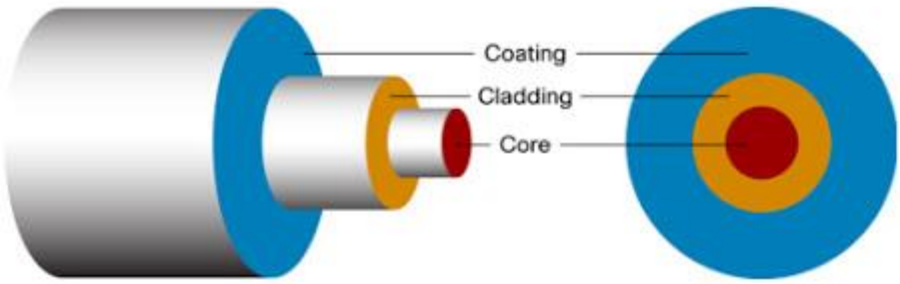
Fibers are immune to electromagnetic interference, a problem from which metal wires suffer.

Fibers are also used for illumination and imaging, and are often wrapped in bundles so they may be used to carry light into, or images out of confined spaces.

Specially designed fibers are also used for a variety of other applications, some of them being fiber optic sensors and fiber lasers.

Components of an optical fiber

A typical optical fiber comprises three main co-axial sections: Core, Cladding and outer Jacket/protective buffer coating.



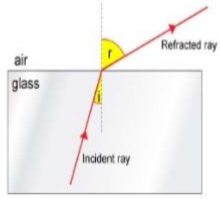
<u>Core</u>: The innermost cylindrical region which carries light. It is the denser medium and is made up glass/ plastic.

<u>Cladding</u>: The middle layer, which serves to confine the light to core. It is the rarer medium as its refractive index is slightly less than that of core.

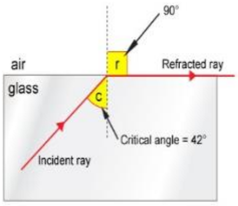
<u>Outer jacket/ Protective buffer coating:</u> The outermost layer which protects the fiber from physical damage and environmental effects.

Principle of optical fiber: Optical fibers work on the principle of total internal reflection.

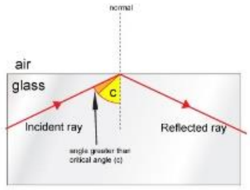
➢ When light travels from denser to rarer medium, it refracts away from the normal.



➢ At a particular angle of incidence, Called critical angle, the refracted ray traces the boundary such that angle of refraction becomes 90^0.



➢ When the angle of incidence of the light ray is greater than the critical angle then no refraction takes place. Instead, all the light is reflected back into the denser material . This Phenomenon is called **total internal reflection**.



So for total internal reflection to occur

❖ The light must travel from a denser medium to a rarer medium.
❖ Angle of incidence should be greater than the critical angle.

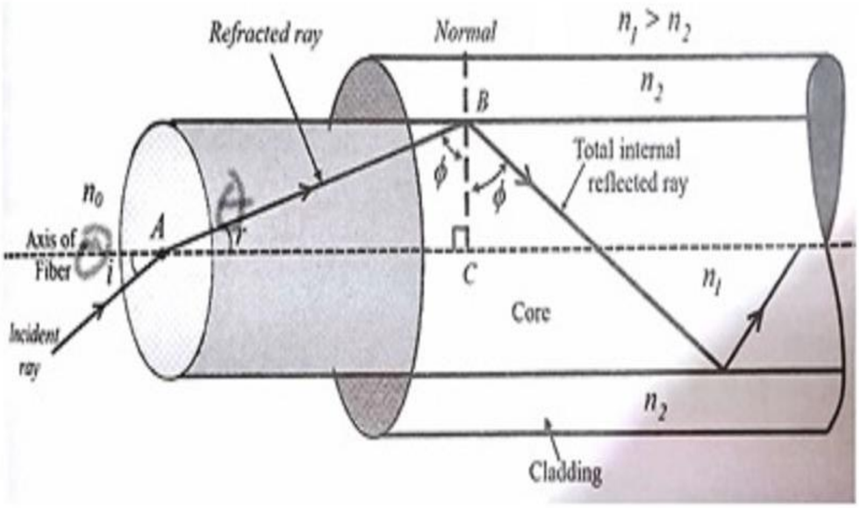
Acceptance angle and Numerical aperture

The maximum possible launching angle with the axis of the fiber up to which a light ray accepted into the core of the fiber is called ***acceptance angle***. By rotating the acceptance angle about the core axis, a cone will be appeared and is called **acceptance cone**. The light rays that enter the fiber beyond acceptance cone refracts into cladding.

The sine of the acceptance angle is called **numerical aperture**. So it is a measure of light collecting capacity of given optical fiber.

Expression for Numerical aperture and Acceptance angle:

Consider an ***optical fiber*** which consists of a core with refractive index n_1 and a cladding with refractive index n_2 such that ($n_1 > n_2$). The refractive index of the launching medium is n_0. Let us consider a light ray enters the fiber making an angle $\boldsymbol{\theta}_i$ with its axis. AB is the refracted ray that makes an angle $\boldsymbol{\theta}_r$ with the axis and strikes core-cladding interface at an angle $\boldsymbol{\phi}$, which is greater than critical angle $\boldsymbol{\phi}_c$. Thus, it undergoes total internal reflection at the interface.



It is clear from the figure that as the value of angle θ_i increases, θ_r will also increase and ϕ will decrease.For light propagation through the fiber, it is compulsory that the value of angle ϕ should not be less than critical angle ϕ_c. Thus we may increase the incident angle θ_i up to a certain value that is acceptance angle θ_{max}.

Now, by applying Snell's law at the launching end

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_1}{n_0} \qquad \text{or} \qquad \sin\theta_i = \frac{n_1}{n_0}\sin\theta_r \qquad (1)$$

But in right angled triangle ABC, $\sin\theta_r = \sin(90^\circ - \emptyset) = \cos\emptyset$

$$\therefore \qquad \sin\theta_i = \frac{n_1}{n_0}\cos\emptyset \qquad (2)$$

When $\phi = \phi_c$ then $\theta_i = \theta_{max}$

$$\text{Thus,} \qquad \sin\theta_{max} = \frac{n_1}{n_0}\cos\emptyset_c \qquad (3)$$

Now, applying Snell`s law at core-cladding interface,

$$\frac{\sin \emptyset_c}{\sin 90^\circ} = \frac{n_2}{n_1} \qquad \text{or} \qquad \sin \emptyset_c = \frac{n_2}{n_1}$$

or $$\sqrt{(1 - cos^2 \emptyset_c)} = \frac{n_2}{n_1}$$

or $$1 - cos^2 \emptyset_c = \frac{{n_2}^2}{{n_1}^2}$$

$\therefore$ $$\cos \emptyset_c = \frac{\sqrt{{n_1}^2 - {n_2}^2}}{n_1} \tag{4}$$

Hence, $$\sin \theta_{max} = \frac{\sqrt{{n_1}^2 - {n_2}^2}}{n_0} \tag{5}$$

Therefore acceptance angle

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

For air $n_0 = 1$

$$\boxed{\theta_{max} = \sin^{-1} \sqrt{{n_1}^2 - {n_2}^2}} \tag{6}$$

Fractional refractive index change or relative refractive index

Fractional refractive index change or relative refractive index is the ratio of difference between the refractive index of core and cladding to the refractive index of core. It is denoted by Δ. *i.e.*

$$\Delta = \frac{(n_1 - n_2)}{n_1} \tag{7}$$

Δ is always positive and generally of the order of 1/100.

Numerical aperture

It is a very important parameter, which is a measure of amount of light that can be accepted by the fibre. It is defined as the sine of the acceptance angle, *i.e.*,

$$NA = \sin\theta_{max} = \frac{\sqrt{{n_1}^2 - {n_2}^2}}{n_0} \tag{8}$$

For air $n_0 = 1$

$$\therefore \qquad NA = \sin\theta_{max} = \sqrt{{n_1}^2 - {n_2}^2} \tag{9}$$

Now, $${n_1}^2 - {n_2}^2 = (n_1 + n_2)(n_1 - n_2) = \frac{(n_1 + n_2)}{2}\frac{(n_1 - n_2)}{n_1} 2n_1$$

We can take approximately $\frac{(n_1+n_2)}{2} \approx n_1$ and since $\Delta = \frac{(n_1 - n_2)}{n_1}$

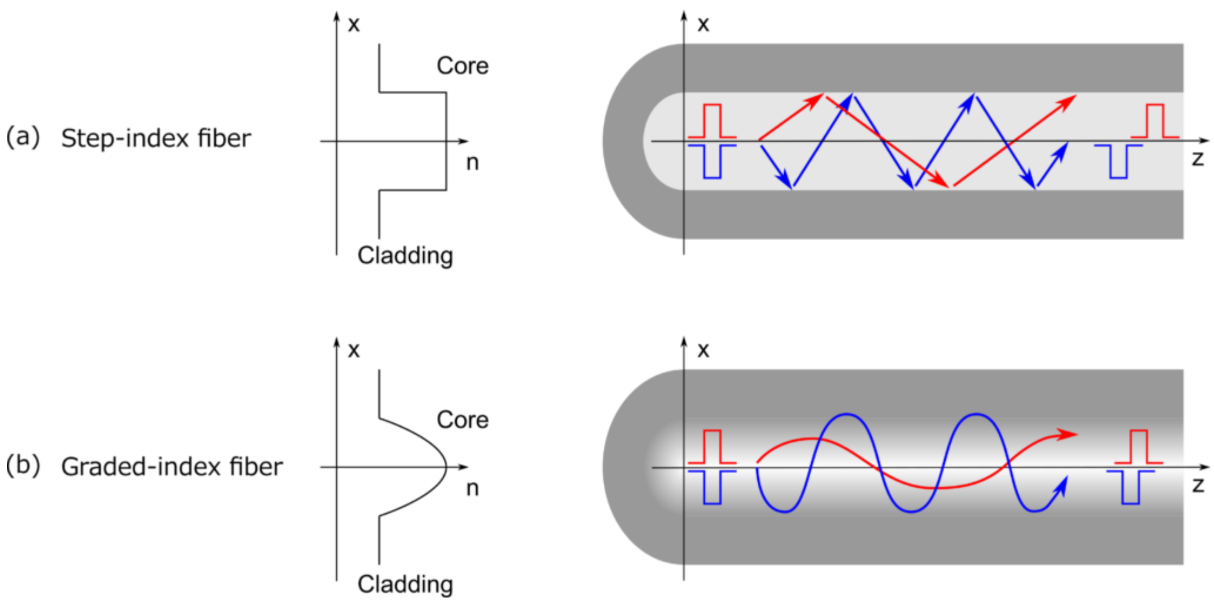
$$\therefore \qquad {n_1}^2 - {n_2}^2 = 2n_1^2\Delta$$

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

The values of NA typically range from about 0.1 to 0.5.

Step index fiber

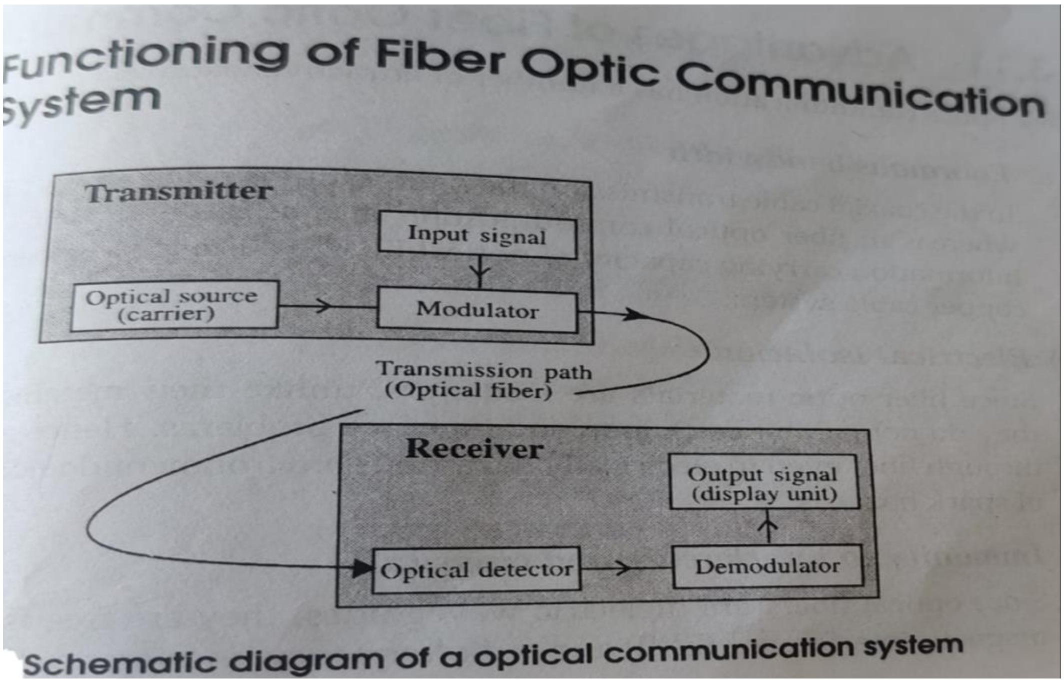
1. Step index fiber is a fiber in which the core is with uniform refractive index and there is a sharp decrease in the index of refraction at the cladding.
2. Step index fiber is found in two types, that is mono mode fiber and multimode fiber.
3. Index profiles are in the shape of step.
4. The light rays propagate in *zig–zag* manner inside the core.
5. Signal distortion is more in case of high-angle rays in multimode step index fiber. In single mode step index fiber, there is no distortion.
6. This fiber has lower bandwidth.
7. The diameter of the core is between 50-200µm in the case of multimode fiber and 10µm in the case of single mode fiber.
8. Attenuation of light rays is more in multimode step index fibers but for single mode step index fibers, it is very less.
9. Less expensive.
10. NA of multimode step index fiber is more whereas in single mode step index fibers, it is very less.
11. Pulse broadening and inter modal dispersion are present.



Graded index fiber

1. Graded index fiber is a type of fiber where the refractive index of the core is maximum at the center and decreases towards core-cladding interface.
2. Graded index fiber is of only one type, that is, multimode fiber.
3. Index profiles is in the shape of a parabolic curve (for $\alpha=2$).
4. The light rays propagate in the form of skew rays or helical rays. They will not cross the fiber axis.
5. Signal distortion is very low even though the rays travel with different speeds inside the fiber.
6. This fiber has higher bandwidth.
7. The diameter of the core is about 50µm in the case of multimode fiber.
8. Attenuation of light rays is less in graded index fibers.
9. Highly expensive.
10. NA of graded index fibers is less.
11. No pulse broadening and inter modal dispersion.

Block diagram of Optical fiber communication system



Applications of Optical Fiber

Optical fibers find applications in various fields. Some of them are

- **Medical**
  Used as light guides, imaging tools and also as lasers for surgeries.
- **Defence /Government**
  Used as hydrophones for seismic waves and SONAR , as wiring in aircraft, submarines and other vehicles and also for field networking.
- **Telecommunications**
  Fiber is used for transmission of information from transmitter to receiver.
- **Networking**
  Used to connect users and servers in a variety of network settings and help to increase the speed and accuracy of data transmission.
- **Industrial/Commercial**
  Used as sensory devices to make temperature, pressure and other measurements and as wiring in automobiles and in industrial settings.
- **Broadcast/CATV**
  Broadcast/cable companies are using fiber optic cables for wiring CATV, HDTV, internet and other applications.