UNIT-I
PHYSICAL OPTICS, LASERS AND FIBER OPTICS

Basic terms and definitions

Optics	Optics is the branch of physics which includes the study of light and the phenomena associated with its generation, transmission and detection.
Superposition principle	The principle of superposition states that, when two or more waves of the same type cross at some point, the resultant displacement at that point is equal to the sum of the displacements due to each individual wave.
Interference	Interference of light is defined as:"When two or more light waves having same frequency,same wavelength and same amplitude meet together in a medium at a point,they cancel or enhance the effect of each other at that point.This phenomenon is called interference of light waves."
Condition for Interference	1.Two light sources emitting light waves should be coherent 2. The separation between the two sources should be small 3.The distances between two sources and screen should be large 4. The source should be monochromatic 5. Background should be dark
Condition for Interference by reflection	Condition for bright ---$2\mu t\cos r=(2n-1)\lambda/2$ Condition for dark ---- $2\mu t\cos r=n\lambda$
Constructive interference.	When two light waves superpose with each other in such a way that the crest of one wave falls on the crest of the second wave,and trough of one wave falls on the trough of the second wave,then the resultant wave has larger amplitude and intensity.Such type of interference is called constructive interference
Destructive interference	In **destructive interference** When two light waves superpose with each other in such a way that the crest of one wave coincides the trough of the second wave,then the amplitude and intensity of resultant wave become zero.
Coherence	Two wave sources are perfectly *coherent* if they have a constant phase difference and the same frequency, and the same wavelength
Temporal coherence	If it is possible to predict the amplitude and phase relation at a point on the wave w.r.t another point on the same wave then the wave has temporal coherence
Spatial coherence	If it is possible to predict the amplitude and phase relation at a point on the wave w.r.t another point on the second wave then the wave has spatial coherence
Newton Rings	When a plane-convex lens of large focal length is placed as a plane glass plate, A thin film of air is formed between the lower surface of the plate. The thickness of the air film is very small at the point of contact and gradually increased from the centre upwards. If a monochromatic light is allowed to fall normally on this film, a set of alternate dark and bright fringes will be seen in the film. The fringes are concentric circle with their centre dark. These circles or rings are called Newtons Rings.

Diffraction	It is defined as the bending of light around the corners of an obstacle or aperture into the region of geometrical shadow of the obstacle
Condition for diffraction	Diffraction of light takes place if the size of obstacle is comparable to the wavelength of light.
Types of diffraction	(a) Fresnel diffraction is produced when light from a point source meets an obstacle, the waves are spherical and the pattern observed is a fringed image of the object. (b) Fraunhofer diffraction occurs with plane wave-fronts with the object effectively at infinity.
LASER	A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation
LASER full form	"light amplification by stimulated emission of radiation"
Characteristics of LASER	i) monochromaticity, ii) directionality, iii) coherence and iv) brightness.
Stimulated Absorption of radiation	When a photon of light having energy $E_2 – E_1 = h\upsilon$ is incident on an atom in the ground state, the atom in the ground state E_1 may absorb the photon and jump to higher energy state E_2. This process is called stimulated absorption.
Stimulated emission of radiation	Stimulated emission is the process by which an incoming photon of a specific frequency can interact with an excited atomic electron (or other excited molecular state), causing it to drop to a lower energy level.
Spontaneous emission	Spontaneous emission electron drops from an excited state to a lower state (no outside mechanism) by itself emitting a photon.
Meta stable state	Meta stable state is an excited state of an atom or other system with a longer lifetime than the other excited states.
Population inversion	A stage of making the population of the higher energy level to be greater than the population of the lower energy level
Excitation Mechanism	1.Optical pumping 2.Electric discharge 3.Inelastic atom-atom collisions 4.Direct Conversion 5.Chemical reactions
Optical resonator	Consisting of two mirrors, one highly reflective and one partly reflective, placed on either side of a laser pump. Amplified light bounces back and forth between the mirrors, enhancing stimulated emission within the pump, eventually being emitted through the partly reflective mirror.
Optical fiber	*optical fiber* is a thin fiber of glass or plastic that can carry light from one end to the other
Fiber optics	The study *of optical fibers* is called fiber optics
Acceptance angle	Acceptance angle is defined as the maximum external incidence angle for which the light will propagate in the fiber.
Acceptance cone	By rotating the acceptance angle about the fiber axis ,we get an incident cone with semi vertical angle θ_a.This incident light cone at core of an optical fiber will be accepted by the fiber for guidance through it through it.
Numerical Aperture	It is defined as the light gathering ability of the fiber

Step Index optical fiber	Step Index Fiber is a fiber in which the core is of a uniform refractive index and there is a sharp decrease in the index of refraction at the cladding.
Graded index optical fiber	Graded index optical fiber whose core has a refractive index that decreases with increasing radial distance from the optical axis of the fiber. ... The most common refractive index profile for a graded-index fiber is very nearly parabolic.
Attenuation	Attenuation is a general term that refers to any reduction in the strength of a signal. Attenuation occurs with any type of signal, whether digital or analog. Sometimes called loss,

Concepts:

The modification in the distribution of intensity in the region of superposition is known as **Interference.**

If crest and crest or trough and trough of two light meets at a point, The intensity of light is maximum that means bright fringes is formed**(constructive interference)** and if crest and through or vice versa meet at a point, The intensity of the light is minimum that means dark fringes is formed **(destructive interference)**.

Coherent sources:

Two sources of light is said to be coherent sources, if they emit the light wave of same wavelength (frequency), same amplitude and having zero phase or constant phase continuously. Two independent sources cannot be coherent sources. Two sources derived from the single point source are coherent sources.

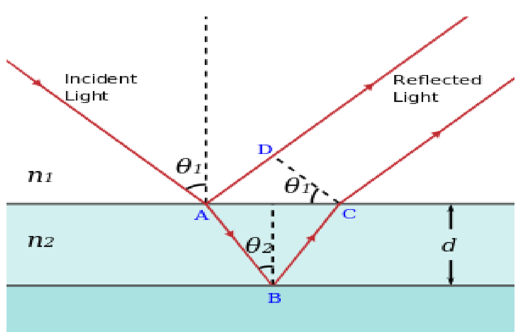
Interference in Thin Films by Reflection:

When light is incident on a plane parallel thin film, some portion gets reflected from the upper surface and the remaining portion is transmitted into the film. Again some portion of the transmitted light is reflected back into the film by the lower surface and emerges through the upper surface. These reflected beams from the top and bottom surfaces of the film super impose with each other, producing interference and forming interference patterns.

Total Path difference: $2\mu t \cos r + \frac{\lambda}{2}$

Bright band condition (or) condition for constructive interference: $2\mu t \cos r = (2n-1)\frac{\lambda}{2}$,n=1,2,3….

Dark band condition (or) condition for destructive interference: $2\mu t \cos r = n\lambda$, n=1,2,3….

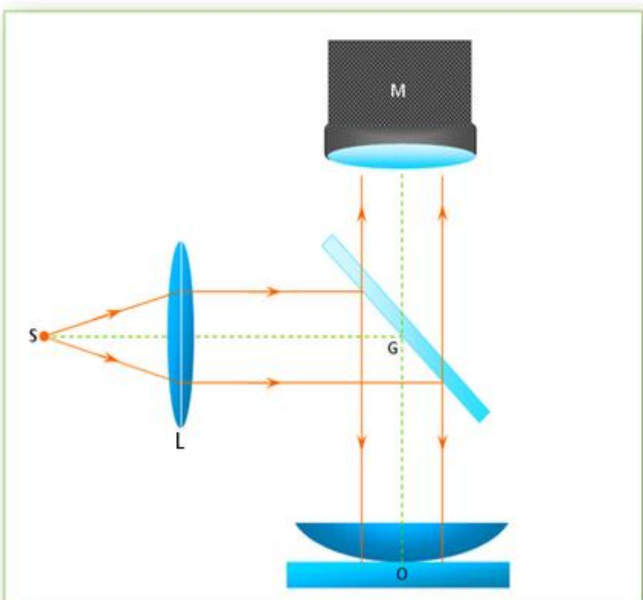


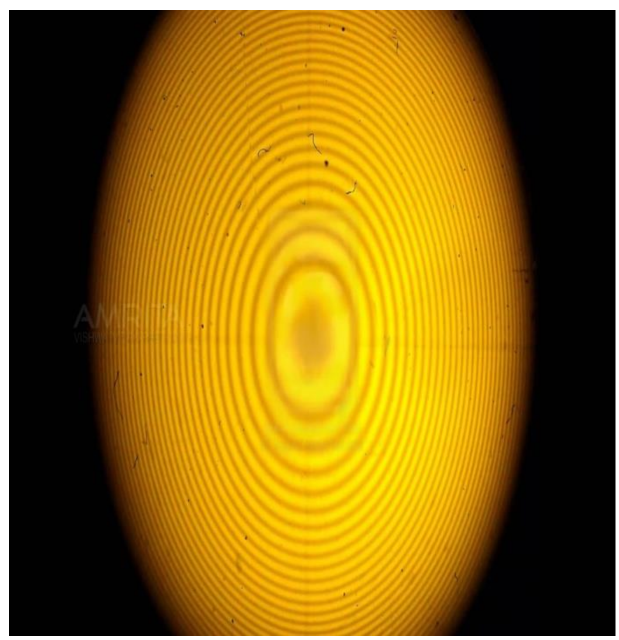
Newton's Rings:

When a Plano convex lens of long focal length is placed in contact on a plane glass plate (*Figure given below*), a thin air film is enclosed between the upper surface of the glass plate and the lower surface of the lens. The thickness of the air film is almost zero at the point of contact **O** and gradually increases as one proceeds towards the periphery of the lens. Thus points where the thickness of air film is constant, will lie on a circle with **O** as center.

By means of a sheet of glass **G**, a parallel beam of monochromatic light is reflected towards the lens **L**. Consider a ray of monochromatic light that strikes the upper surface of the air film nearly along normal. The ray is partly reflected and partly refracted as shown in the figure. The ray refracted in the air film is also reflected partly at the lower surface of the film. The two reflected rays, i.e. produced at the upper and lower surface of the film, are coherent and interfere constructively or destructively. When the light reflected upwards is observed through microscope **M** which is focused on the glass plate, series of dark and bright rings are seen with center as **O**. These concentric rings are known as " Newton's Rings ".

At the point of contact of the lens and the glass plate, the thickness of the film is effectively zero but due to reflection at the lower surface of air film from denser medium, an additional path of **λ/2** is introduced. Consequently, the center of Newton rings is dark due to destructive interference.





Condition for the Bright Ring: $2t=(2n-1)\frac{\lambda}{2}$, n=1,2,3…..

Condition for the Dark band: $2t=n\lambda$, n=1,2,3……

Diameter of Bright ring: D=$\sqrt{(2n-1)2\lambda R}$

$$D \propto \sqrt{2n-1}$$

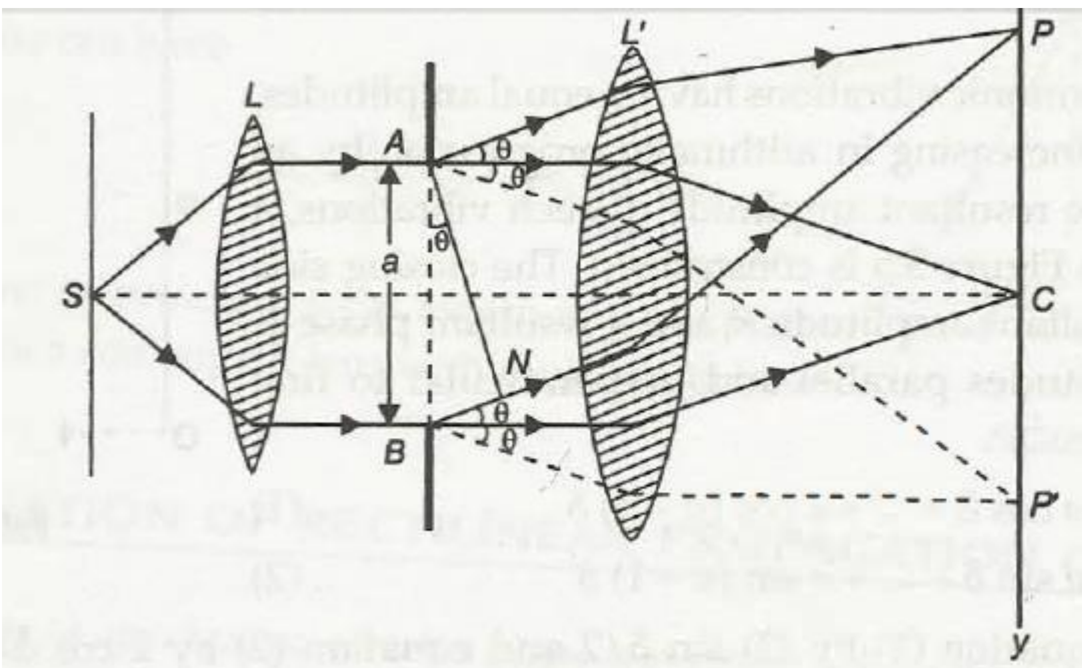
The diameter of the bright rings is proportional to the square root of odd natural numbers

Diameter of Dark ring : $D = \sqrt{4nR\lambda}$

$$D \propto \sqrt{n}$$

The diameter of the dark rings is proportional to the square root of natural numbers

Fraunhofer Diffraction at Single Slit:

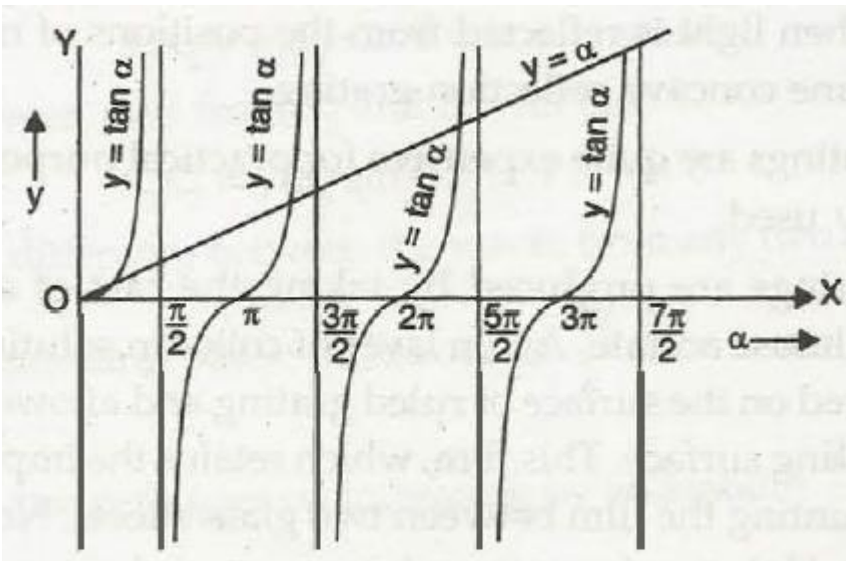


Intensity Equation: I=R^2=A$^2\left(\frac{\sin\alpha}{\alpha}\right)^2$

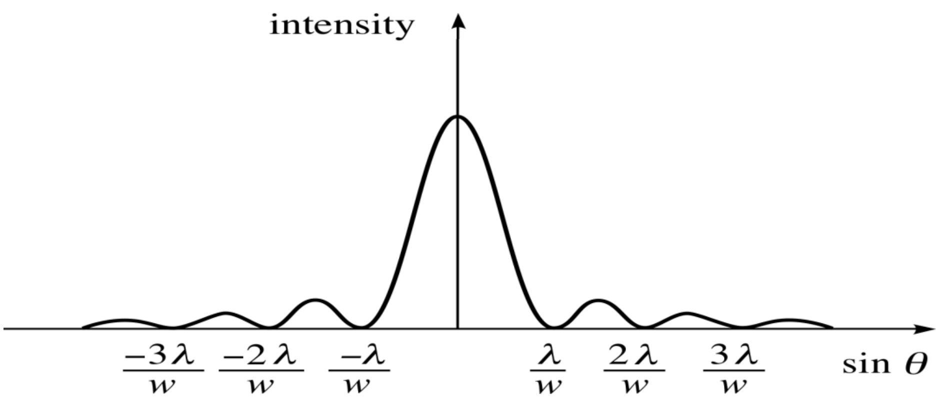
Condition for Principal maxima: $\theta = 0^0$

Condition for minimum Intensity: $a\sin\theta = n\lambda$,n=1,2,3…..

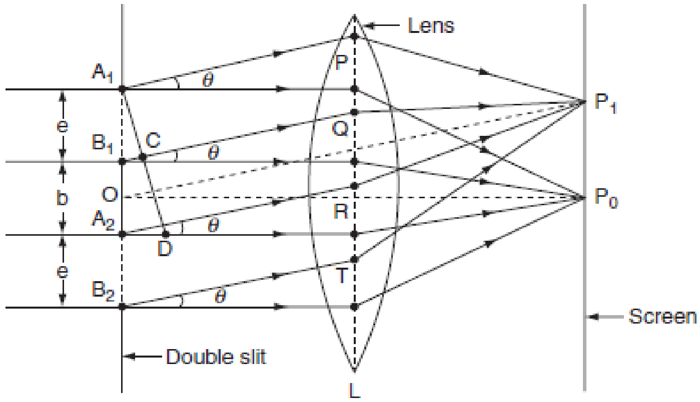
Condition for Secondary Maxima : $a\sin\theta = \pm(2n+1)\frac{\pi}{2}$,n=1,2,3…..



Intensity Distribution Curve:



Fraunhofer Diffraction at Double Slit:



The intensity Pattern obtained on the screen is due to the combined effect of two phenomenon's

i) Interference due to the diffracted secondary waves from corresponding points on the two slits

ii) Diffraction due to individual slits

Intensity Equation: $I=R^2=4A^2\left(\frac{\sin\alpha}{\alpha}\right)^2\cos^2\beta$

In the intensity equation the term $\frac{\sin\alpha}{\alpha}$ explains diffraction due to single slit. The term $\cos^2\beta$ explains interference due to the diffracted secondary waves form corresponding points on the two slits.

Interference Effect:

The term $\cos^2\beta$ explains interference

i) Maxima condition: $(a+b)\sin\theta = n\lambda,$ n=1,2,3...

ii) Minima Condition : $(a+b)\sin\theta = \pm(2n+1)\frac{\pi}{2}$

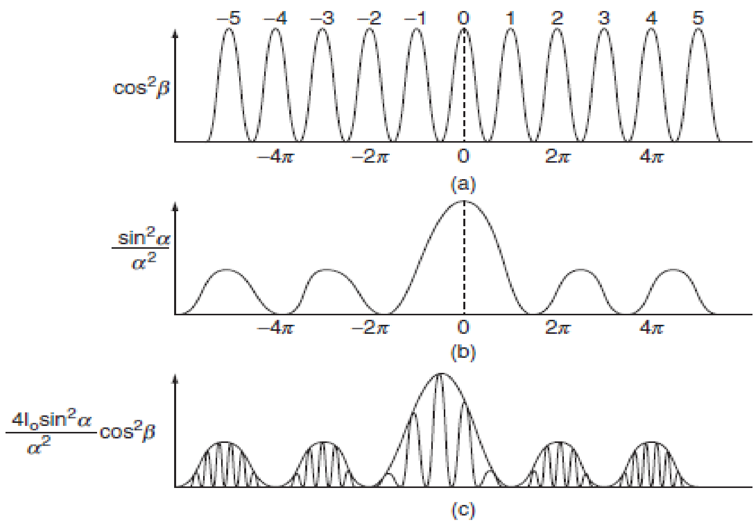
Diffraction Effect:

i) Condition for Principal maxima: $\theta = 0^0$

ii) Condition for minimum Intensity: $a \sin\theta = n\lambda$,n=1,2,3…..

iii) Condition for Secondary Maxima : $a \sin\theta = \pm(2n+1)\frac{\pi}{2}$,n=1,2,3…..

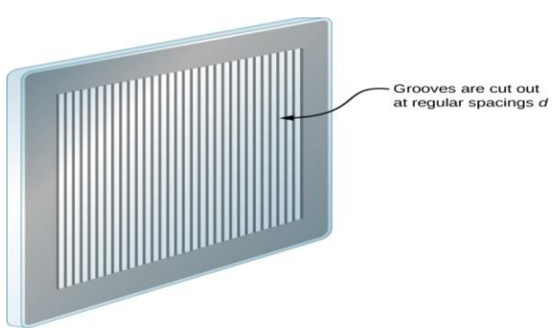
Intensity Distribution Curve:



Diffraction Grating:

An arrangement which consists of large number of parallel slits of the same width and separated by equal opaque spaces is known as Diffraction grating.

Grating Equation: $\sin\theta = nN\lambda$, $N = \frac{1}{a+b}$



Maximum Number of orders possible with a grating :

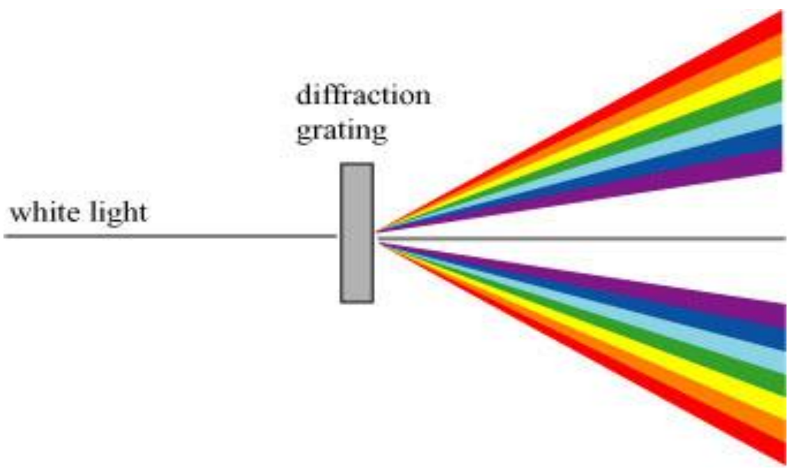
$$nN\lambda \le \frac{1}{N\lambda}$$

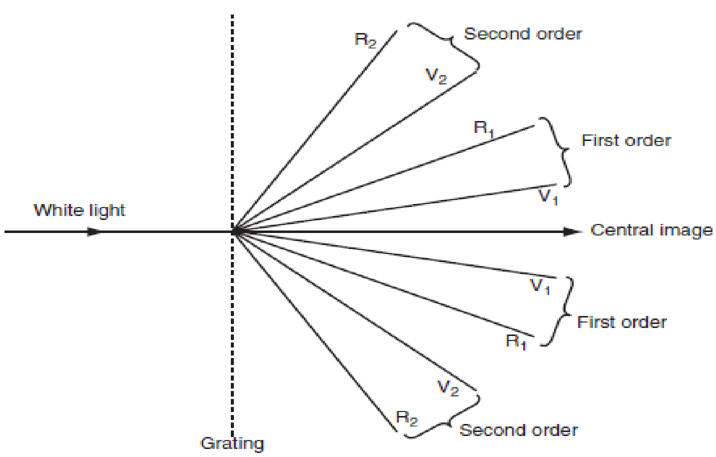
$$n \le \frac{1}{N\lambda}$$

Grating Spectrum:

The diffraction pattern formed with a grating is known as grating spectrum.

Grating equation is $\sin\theta = nN\lambda$





LASERS:

CHARACTERISTICS OF LASERS:

1. **Highly Monochromatic**: The light emitted by laser is highly monochromatic than any of the other conventional monochromatic light. A comparison b/w normal light and laser beam, ordinary sodium (Na) light emits radiation at wave length of 5893A0 with the line width of 1 A^0 . But He-Ne laser of wave length 6328A0 with a narrow width of only 10^{-7} A^0 i.e., Monochromacity of laser is 10 million times better than normal light. The degree of Monochromacity of the light is estimated by line of width (spreading frequency of line).

Let the spread in frequency and wave length be $\nu + \Delta\nu$ and $\lambda + \Delta\lambda$. The frequency spread $\Delta\nu$ is related to its wave length spread $\Delta\lambda$ as

$$\Delta\lambda = -\left(\frac{C}{\nu^2}\right)\Delta\nu$$

For laser, $\Delta\lambda = 0.001$ nm. It is clear that laser radiation is highly monochromatic.

2. Highly Directional (Directionality)(or) Less Divergence: Laser emits radiation only in one direction. The directionality of laser beam is expressed in terms of angle of divergence (ϕ) Divergence or Angular Spread is given by

$$\phi = \frac{d_2 - d_1}{2(S_2 - S_1)} -$$

Where d_1& d_2 are the diameters of the laser spots at distance S_1 & S_2 respectively.
The divergence angle for laser light is very less hence the divergence is low and it is highly directional.

3. Highly Coherent (Coherence): Two wave sources are perfectly coherent if they have a constant phase difference and the same frequency, and the same wavelength."The process of maintaining constant phase relation is known as Coherence.

Coherence is of two types:

1. **Temporal coherence**: If it is possible to predict the amplitude and phase relation at a point on the wave w.r.t another point on the same wave then the wave has temporal coherence.
2. **Spatial Coherence**: If it is possible to predict the amplitude and phase relation at a point on the wave w.r.t another point on the second wave then the wave has spatial coherence.

4. High Intensity (Brightness): Generally, light from conventional source spread uniformly in all directions. For example, take 100 watt bulb and look at a distance of 30 cm, the power enter into the eye is less than thousand of a watt. This is due to uniform distribution of light in all directions. But in case of lasers, light is a narrow beam and its energy is concentrated within the small region. The concentration of energy accounts for greater intensity of lasers.

EINSTEIN'S COEFFICIENTS:

To understand the working principle of the laser, we must study the quantum process that take place in a material medium when it is exposed to light radiation. We know that light is absorbed (or) emitted by atoms or molecules during their transition from one energy state to another. Let us consider an atom that has only two energy levels E_1 and E_2. When the atom is exposed to (light) photons of energy $E_2 - E_1 = h\upsilon$.

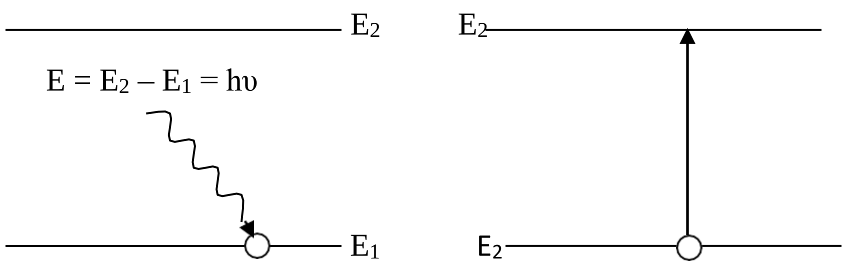
Three distinct processes take place.

(i) Stimulated Absorption

(ii) Spontaneous emission

(iii) Stimulated emission

Stimulated Absorption: An atom in the ground state with energy E_1 absorbs a photon of energy $h\upsilon$ and goes to the excited state (Higher state) with energy E_2 as shown in fig. This provided the photon energy $h\upsilon$ is equal to the energy difference (E_2 - E_1). This process is called **Stimulated Absorption** or simply **Absorption**.



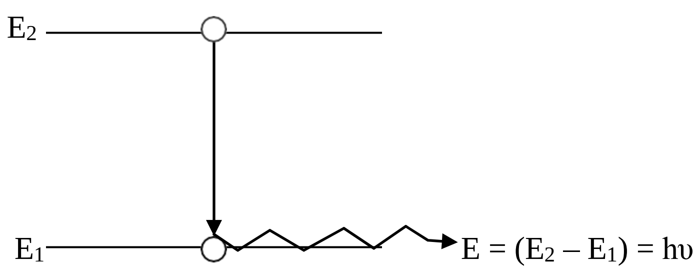
Before Absorption After Absorption

Number of Stimulated Absorptions $\propto N_1 \rho(\nu)$

$$= N_1 B_{12} \rho(\nu)$$

Where B_{12} =Einstein's co-efficient of stimulated absorption of radiation

Spontaneous emission: The atoms in the excited state returns to the ground state by emitting a photon of energy $E = (E_2 - E_1) = h\upsilon$, spontaneously without any external triggering as shown in fig. This process is known as Spontaneous emission. Such an emission is random and is independent of incident radiation.



Spontaneous emission

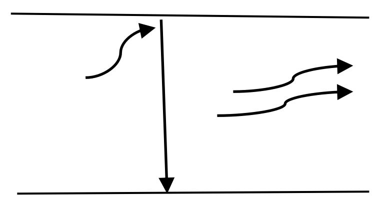
If N_1 and N_2 are the numbers of atoms in the ground state (E_1) and the excited state (E_2) respectively, then

Number of spontaneous emissions $\propto N_2$

$$= N_2 A_{21}$$

Where A_{21} =Einstein's co-efficient of spontaneous emission of radiation

Stimulated emission: The atom in the excited state can also return to the ground state by external triggering (or) inducement of photon thereby emitting a photon of energy equal to the energy of the incident photon, known as stimulated emission. Thus results in two photons of same energy, phase difference and of same directionality as shown in Fig.



Number of Stimulated Emisionss $\propto N_2 \rho(\nu)$

$$= N_2 B_{21} \rho(\nu)$$

Where B_{21} =Einstein's co-efficient of stimulated emission of radiation

Einstein's Theory:

Transition between the atomic energy states is a statistical process. It is not possible to predict which particular atom will make a transition from one state to another at a particular instant. However in an assembly of a very large number of atoms, it is not possible to calculate the rate of transitions between two states based on the laws of probability.

Einstein was the first to calculate the probability of such transition assuming the atomic system to be in equilibrium with electromagnetic radiation. Einstein's theory of absorption and emission of light by an atom is based on Planck‟s theory of radiation. Also under thermal equilibrium, the populations of energy levels obey the Boltzmann's distribution law.(i.e.) under thermal equilibrium

The rate of absorption = The rate of emission

No. of stimulated absorption of radiation =No. of spontaneous emission of radiation +

No. of stimulated emission of radiation

$$\frac{B_{21}}{B_{12}} = 1 \Rightarrow B_{21} = B_{12}$$

$$\frac{A_{21}}{B_{12}} = \frac{8\pi h\nu^3}{c^3} \text{ (or) } \frac{A_{21}}{B_{12}} = \frac{8\pi h}{\lambda^3}$$

Population inversion: The population inversion is a state at which the number of atoms in the excited state is more than that in the ground state. This is achieved by the process of pumping.

Active Medium: A medium in which population inversion can be achieved is known as active medium.

Pumping Action: The process to achieve population inversion in the medium i.e. raising more number of atoms to excited state by artificial means.

Methods for pumping action:

The most commonly used methods are

(i) Optical pumping (excitation by photons)

(ii) Electrical discharge method (excitation by electrons)

(iii) Direct conversion

(iv) Inelastic atom-atom collision

(v) Chemical process

(i) Optical pumping : Excitation of atoms by means of photons emitted by an external optical source. (e.g) Ruby Laser, Nd-YAG Laser.

(ii) Electric discharge method : The electrons are accelerated to very high velocities by strong electric field and they collide with the gas atoms and these atoms are raised to excited state . (e.g) He-Ne Laser, CO_2 Laser, argon Laser etc.

(iii) Direct conversion : In this method, electrical energy is applied to direct band gap semiconductor like GaAs. The recombination of electrons and holes takes place. During the recombination process, the electrical energy directly converted to light energy.(e.g - GaAs Laser).

(iv) Inelastic atom –atom collision: In this method, a combination of to gases (A & B) is used. Excited states of A & B nearly coincide in energy. During electric discharge atom A get excited due to collision with electrons. The excited atom A*now collide with atom B so that be goes to excited state B*.

(e.g He-Ne Laser,CO2 Laser).

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

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

(i) Chemical Method: In this method the atoms are excited due to some chemical reaction. The energy released in the reaction excite the atoms from lower energy state to higher state. (e.g. Dye Laser).

Basic Components of a laser system:

A basic laser system has three important components. They are

Active Medium: It is a basic material in which atomic transitions take place and leading to laser action. This material may be solid, liquid, gas, dye or semiconductor.

Pumping system: It is a device with which population inversion in the active medium can be achieved.

Optical resonator: An Optical resonator (or) a resonance cavity is a feed back system, which consist of an active medium kept in between a 100% mirror and partial mirror. Here, the intensity of light produced in the active medium is increased by making the light to bounce back and forth between the mirrors. Finally the laser beam comes out through the partial mirror.

$$\nu = \frac{nc}{2L}$$

Types of lasers: Based on type of active medium, laser system are broadly classified into the following categories

1. Solid state laser (e.g. Ruby laser, Nd. – YAG laser).
2. Liquid laser (e.g. Europium benzoyl acetonate dissolved in alcohol)).
3. Gas lasers (e.g. He-Ne laser,CO_2 laser).
4. Semiconductor lasers (e.g. GaAs laser).

Nd-YAG laser:

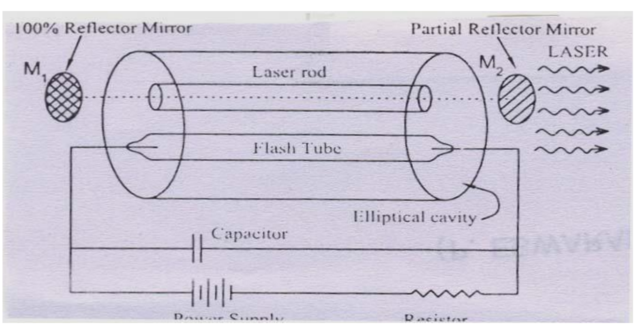
Introduction: Nd-YAG laser is a doped insulator laser. It is a four level system in which the active medium is taken in the form of a crystal. Here the crystal is intension ally doped during its growth. Those types of lasers have number of energy levels with same energy. The laser is used to generate high power intensity.

Principle: The term "Doped insulator laser" refers to the active medium, Yttrium Aluminum garnet doped with neodymium Nd^{3+}. The neodymium ion has many energy levels. Due to optical pumping these ions are raised to excited levels. During the transition from metastable state to ground state, the laser beam of wavelength 1.064 µm is emitted.

Construction:

The active medium is made as a rod which has Yttrium Aluminum Garnet [Y_3 Al_5 O_{12}] doped with a rare earth metal ion neodymium Nd^{3+}. The Nd^{3+} ion normally occupies the Yttrium ions and provides the energy levels for both the lasing transitions and pumping. This rod is placed inside a highly reflecting elliptical cavity as shown in fig.

A close optical coupling is made by placing the xenon flash lamp near by the laser rod, in such a way that most of the radiation from the flash tube passes through the laser rod due to the elliptical cavity. The flash tube may be switched ON and controlled with the help of a capacitor. The discharge of capacitor is initiated using high voltage source.



The optical resonator is formed by grinding the ends of the rods and coated with silver accompanied by two mirrors, one is 100% reflecting and the other is partially reflecting which included increasing the efficiency of the out put beam.

Working:

- The xenon flash lamp is switched ON and the light is allowed to fall on the laser rod.
- The intense white light excites the neodymium (Nd^{3+}) ions from the ground state to various energy levels above E_2. Hence the atoms are raised to group of higher

in E_3 as illustrated in the energy level diagram Fig

- From these energy levels the ions make non-radioactive decay and is gathered in a state called as meta stable state, until the population inversion is achieved
- Once the population inversion is achieved, the stimulated emission builds up rapidly.
- Hence, pulsed form of laser beam of wavelength 1.064 µm is emitted during the transition from E_4 to E_1 (Lower).
- A large amount of heat is produced by the flash tube during the working. Hence cooling arrangement is made either by blowing air (or) circulating water over the crystal.

Applications of Nd-YAG Laser:

Nd-YAG laser find many applications in range finders and illuminators.

- They also find applications in resistor trimming, scribing, micro machining operations as well as welding, drilling etc.,
- They find applications in medicine field like Endoscopy, Urology, neurosurgery, ENT, Gynaecology, Dermatology, Dental surgery and General surgery.

Advantages (or) Merits of Nd-YAG Laser:

1. It has high output energy.
2. It has very high repetition rate operation.
3. It is much easier to achieve the population inversion in this laser.
4. YAG is a crystalline material and the corresponding line width is much smaller which implies much lower thresholds.

Disadvantages (or) Demerits of Nd-YAG laser:

The electron energy level structure of Nd^{3+} in YAG is complicated.

Semiconductor Diode Laser

Definition: It is a specially fabricated p-n junction diode ,emits laser light when it is forward biased.

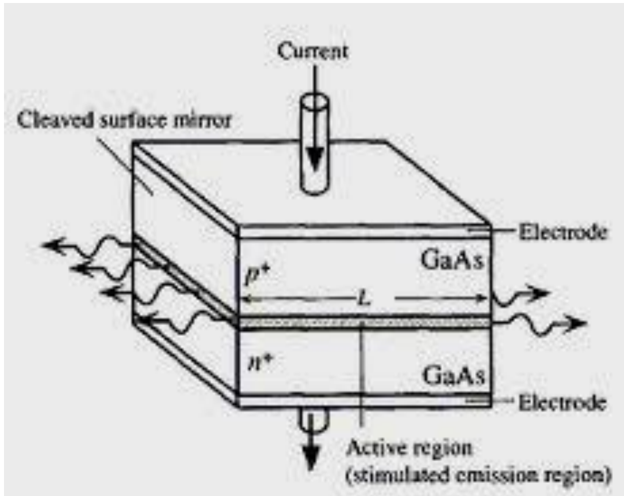
Types of semiconductor diode lasers:

There are two types of semiconductor lasers. They are Homo- junction semiconductor lasers and Hetero- junction semiconductor lasers.

Homojunction Semiconductor Laser: A pn junction made up of same semiconductor material is known as homojunction laser. E.g. GaAs laser.

Principle:

The electron in the conduction band combines with a hole in the valence band and hence the recombination of electron and holes produces energy in the form of light.



Working:

When the p-n junction is forward- biased with large applied voltage, the electrons and holes are injected into junction region in considerable concentration.

The region around the junction contains a large amount of electrons in the conduction band and large amount of holes in the valence band. If the population density is high, a condition of population inversion is achieved. The electrons and holes are recombined with each other and these recombinations produce radiation in the form of light.

When the forward-biased voltage is increased, more and more light photons are emitted and the light production instantly becomes stronger. These photons will trigger a chain of stimulated recombination resulting in the release of photons in phase.

The photons moving at the plane of the junction travels back and forth by reflection between two sides placed parallel and opposite to each other and grow in strength. After gaining enough strength, it gives out the laser beam of wavelength 8300Å - 8500Å. The wavelength of laser light is given by $E_g = h\nu = \dfrac{hc}{\lambda}$

Advantages:

(i) It is easy to manufacture the diode.

(ii) The cost is low

Disadvantages:

(i) It produces low power output.

(ii) The output wave is pulsed and will be continuous only for some time.

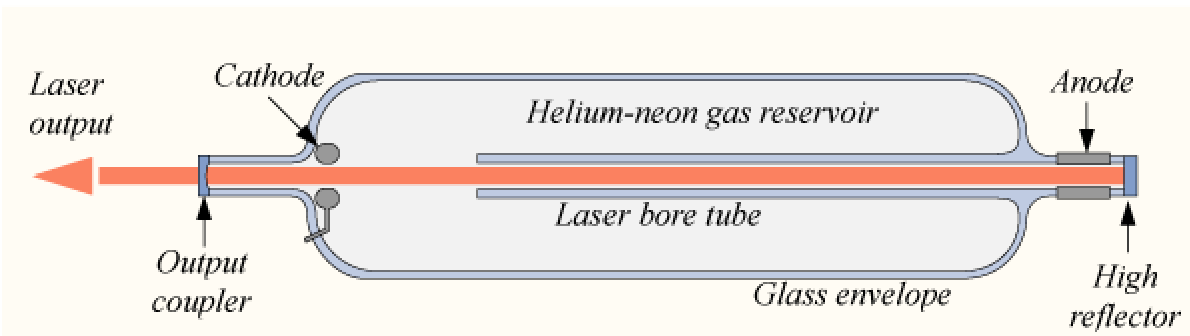
(iii) The beam has large divergence.

(iv) They have high threshold current density.

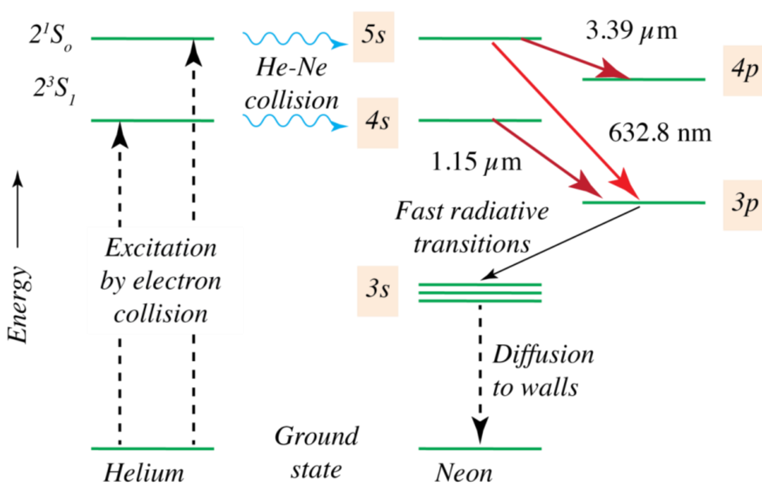
He-Ne Laser:

Introduction: He-Ne laser is a continuous four level gas laser. It was the first successfully operated gas laser. It was first fabricated by Ali Javan and others in Bell Telephone Laboratory in 1961.

Construction:



Working:



Advantages:

1. He-Ne laser emits continuous laser radiations

2. The output laser is linearly polarized due to setting of end windows at Brewster's angle.

3. Gas lasers emit more monochromatic and high directional laser radiations when compared to solid state lasers.

4. He-Ne laser has very good coherence property

Disadvantages:

1. It is relatively low power device means its output power is low.

2. It requires high voltage

Applications:

1. Red He-Ne lasers have many industrial and scientific uses. They are widely used in laboratory demonstrations in the field of optics because of their relatively low cost and ease of operation compared to other visible lasers producing beams of similar quality in terms of spatial coherence (a single-mode Gaussian beam) and long coherence length (however since about 1990 semiconductor lasers have offered a lower-cost alternative for many such applications). A consumer application of the red He-Ne laser is the Laser Disc player, made by Pioneer. The laser is used in the device to read the optical disc.

2. It is widely used in laboratories for all interferometric experiments.

3. It is widely used in metrology in surveying, alignment etc

4. It is used in three dimensional recording of objects caused called holography

Applications of Lasers:

According to the gain material, lasers can be divided into the following types. Several common used lasers are listed in each type.

Gas Lasers:

Laser Gain Medium	Operation Wavelength(s)	Pump Source	Applications and Notes
Helium-neon laser	632.8nm	Electrical discharge	Interferometry, holography, spectroscopy, barcode scanning, alignment, optical demonstrations
Argon laser	454.6 nm, 488.0 nm, 514.5 nm	Electrical discharge	Retinal phototherapy (for diabetes), lithography, confocal microscopy, spectroscopy pumping other lasers
Carbon dioxide laser	10.6 µm, (9.4 µm)	Electrical discharge	Material processing (cutting, welding, etc.), surgery
Excimer laser	193 nm (ArF), 248 nm (KrF), 308 nm (XeCl), 353 nm (XeF)	Excimer recombination via electrical discharge	Ultraviolet lithography for semiconductor manufacturing, laser surgery

Solid State Lasers:

Laser Gain Medium	Operation Wavelength(s)	Pump Source	Applications and Notes
Ruby laser	694.3nm	Flash Lamp	Holography, tattoo removal. The first type of visible light laser invented; May 1960.
Nd:YAG laser	1.064 µm, (1.32 µm)	Flash Lamp, Laser Diode	Material processing, laser target designation, surgery, research, pumping other lasers. One of the most common high power lasers.
Erbium doped glass lasers	1.53-1.56 µm	Laser diode	um doped fibers are commonly used as optical amplifiers for telecommunications.
F-center laser	Mid infrared to far infrared	Electrical current	Research

Metal-vapor Lasers:

Laser Gain Medium	Operation Wavelength(s)	Pump Source	Applications and Notes
Helium-cadmium (HeCd) metal-vapor laser	441.563 nm, 325 nm	Electrical discharge in metal vapor mixed with helium buffer gas.	Printing and typesetting applications, fluorescence excitation examination (ie. in U.S. paper currency printing)
Copper vapor laser	510.6 nm, 578.2 nm	Electrical discharge	Dermatological uses, high speed photography, pump for dye lasers

Other types of lasers:

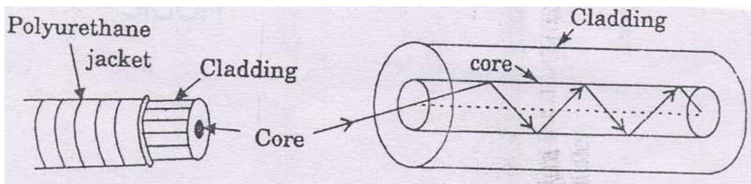
Laser Gain Medium	Operation Wavelength(s)	Pump Source	Applications and Notes
Dye lasers	Depending on materials, usually a broad spectrum	Other laser, flashlamp	Research, spectroscopy, birthmark removal, isotope separation.
Free electron laser	A broad wavelength range (about 100 nm - several mm)	Relativistic electron beam	Atmospheric research, material science, medical applications

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.

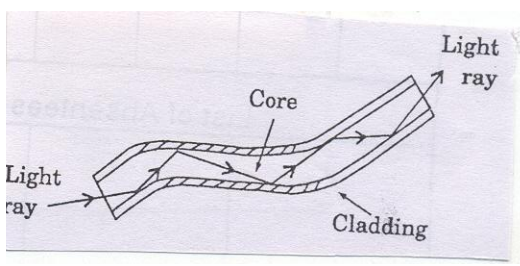
Optical fiber consists of an inner cylinder made of glass or plastic called core. This core has a very high refractive index n_1. The core is surrounded by a cylindrical shell of glass or plastic of lower refractive index n_2 called cladding. While electrical cable is a cooper wire carrying current by means of flow of electrons, optical fiber is glass wire carrying light by means of flow of photons.



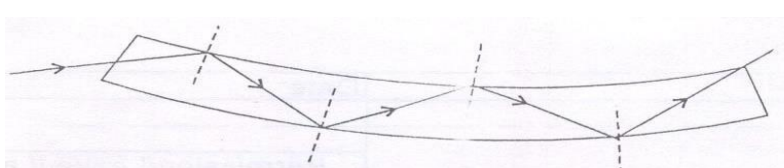
The cladding is covered by a socket which protects the fiber from moisture and abrasion.

Guiding Mechanism:

The light wave enters at one end of the fiber and it strikes the interface of the core and cladding only at large angles of incidence. The light beam is total internally reflected and passing through the length of the cable.



Most of the light propagated along the length of the fiber and comes out from the other and of the fiber. Thus, the optical fiber functions as a wave guide.The reasons for the confinement of the light beam inside the fiber is the total internal reflections of light waves by the inside surface of the fiber. Fiber obeys the laws of reflection and refraction of light waves.



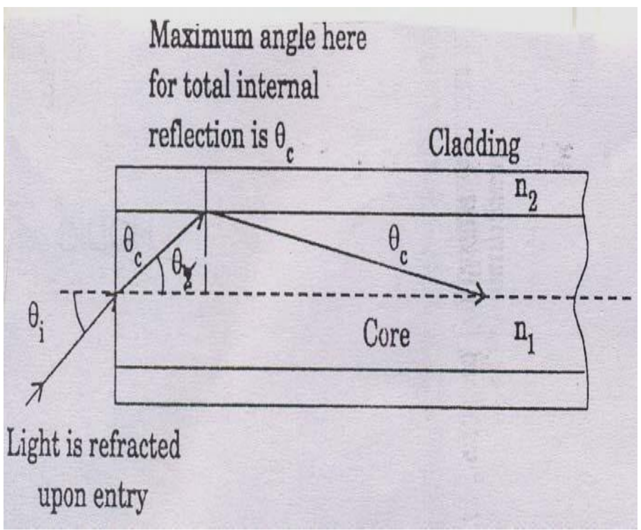
The light which enters at one end of a fiber at a slight angle to the axis of the fiber follows a zig-zag path due to series of reflections along the length of the fiber.

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.

Total internal reflection in a fiber:

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).

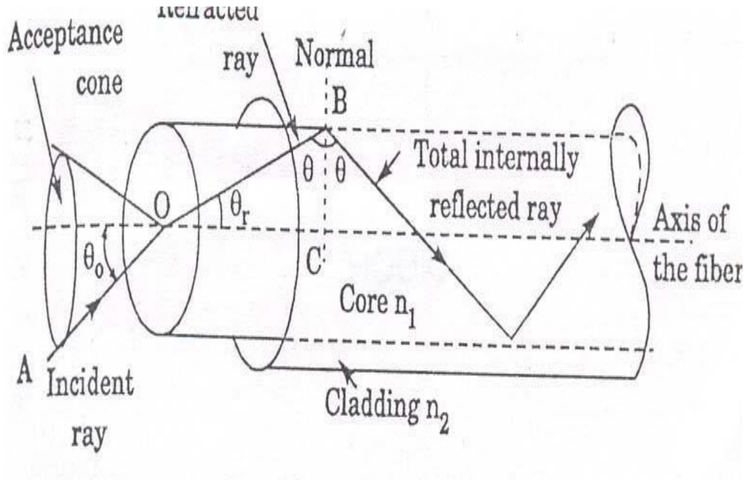


When an angle of incidence (θ_1) is greater than the critical angle of incidence (θ_c), the incident light ray totally reflected back into the originating medium as per the laws of reflection. This phenomenon is known as total internal reflection.

Propagation of light in Optical fiber:

Let us consider an optical fiber into which the light is injected.

The light ray travels along AO and enter into the core at an angle θ_o to the axis of the fiber.
The light ray is refracted along OB at an angle θ_r in the core. It further proceeds to fall at critical angle of incidence $\theta = (90- \theta_r)$ on the interface between core and cladding at B.



If „θ" is greater than the critical angle at the core cladding interface, the light ray get total internally reflected and propagates through the fiber i.e., the light will stay inside the fiber.

=

Acceptance angle:

The maximum angle „θ_a" with which a ray of light can enter through one end of the fiber and still be total internally reflected is called acceptance angle of the fiber.

Acceptance angle $\theta_a = \sin^{-1}\sqrt{n_1^2 - n_2^2}$

Thus, the light which travels within a cone defined by the acceptance angle is trapped and guided. This is the fundamental property of light propagation in a fiber. This cone is referred to as acceptance cone.

Numerical Aperture:

The sin of the acceptance angle of the fiber is known as numerical aperture. It denotes the light gathering capability of the optical fiber.

So, the Numerical Aperture (NA) of the fiber is given by

$$NA = \sin \theta$$

$$NA = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

If the medium surrounding the fiber is air, then $n_0 = 1$, therefore NA= $\sqrt{n_1 2 - n_2^2}$

Fractional Index Change (Δ):

Refractive index between the core and cladding

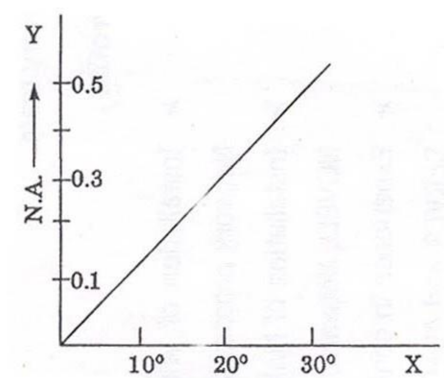
Fractional index change **Δ = ---**

Refractive index of core of an optical fiber

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

$$NA = n_1 \sqrt{2\Delta}$$

An increase in the value of Δ increases N.A. and this enhance the light gathering capacity of the fiber. We cannot increases Δ to a very large value since it leads to what is called „intermodal dispersion‟ which causes **signal distortion.**



The fig shows the variation of NA with acceptance angle. It is noted that numerical apertures for the fibers used in short distance communication are in the range of to 0.5 whereas for long distance communications numerical aperture are in the range of 0.1 to 0.3.

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

1. Single mode fiber – One mode
2. 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 smaller core diameter and difference in refractive index of core and cladding is small.	Here, both the core and cladding in refractive indices difference is large as the core diameter is large.
	Advantages:	**Disadvantages:**
1.	No dispersion (i.e. there is no degradation of signal during propagation).	Dispersion is more due to degradation of signal due to multimode.
2.	Since the information transmission capacity is inversely proportional to dispersion. The fiber can carry information to longer distances.	Information can be carried to shorter distances only.
	Disadvantages:	**Advantages:**
1.	Launching of light and connecting two fibers are difficult	Launching of light and also connecting two fibers is easy.
2.	Installation (fabrication) is difficult as it is more costly.	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.**

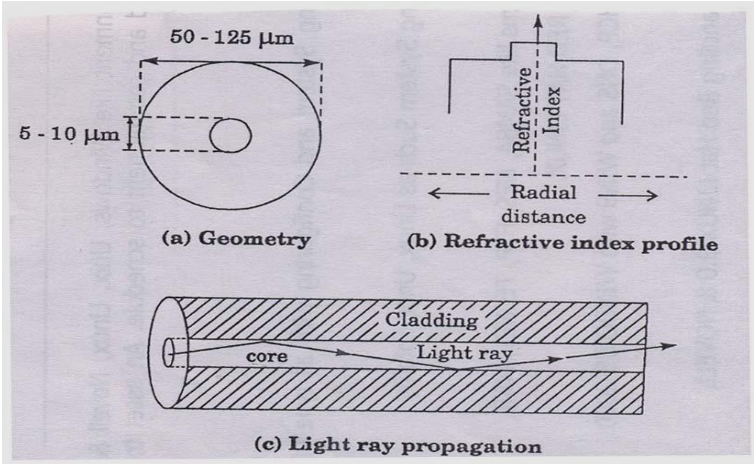
Types of optical fibers based on the refractive index profile and the number of modes:

The optical fibers are also classified depending on the refractive index profile and the number of modes that the fiber can guide. There are

1. Step – index single mode fiber
2. Step – index multimode fiber
3. Graded index multimode fiber

Step – Index single mode fiber:

The Basic structure of step index fiber is as shown in fig.



It has very thin core of uniform refractive index of higher value. The core is surrounded by a cladding of uniform refractive index of lesser value than that of the core.

A typical step index single mode fiber may have a core diameter of cladding 50 – 125μm. A refractive index changes abruptly (or in step) at the core-cladding boundary. So its refractive index profile takes the shape of a step. Due to its small core diameter only a single mode of light ray transmission is possible as shown in above fig.

Characteristic of Step Index fiber:

The chief characteristics of step index single mode fibers are as follows.

1. It has very small core diameter.
2. The value of numerical aperture is very small.
3. It can support only one mode in which the entire light energy is concentrated.
4. Because of less number of modes of propagation of light, the modal dispersion loss is completely reduced.
5. It has very high band width.
6. The light is passed into the single mode fiber through laser diodes

Advantages:

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

Disadvantages:

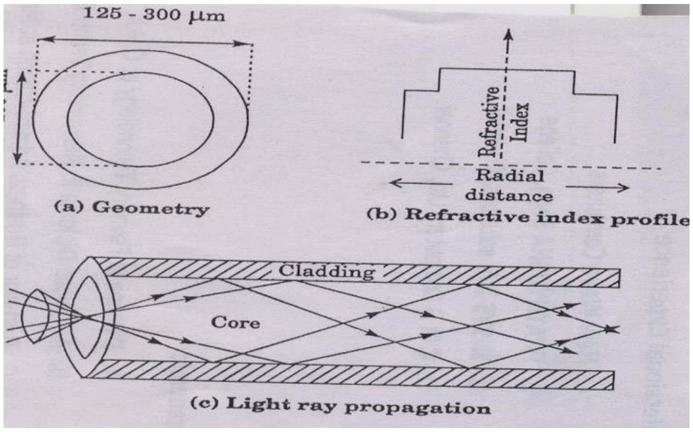
In spite of so many good qualities, the use of very thin cores creates mechanical difficulties in the manufacture and handling. Hence this type of fiber is very expensive.

Applications and Uses:

1. This type of fiber is used as under – sea cables where the expense is justified by the high return of earned income.
2. It finds particular application in submarine cable system.
3. It is used in long distance applications (telephone lines)

Step – Index Multimode fiber:

The geometry of the normal cross-section of a typical step – index multimode fiber is shown in fig.



Its core has a much larger diameter which makes it easier to support propagation of large number of modes. A typical step index multimode fiber has a diameter of 50 to 200µm and an external diameter of cladding 125 to 300µm.

It has a core material with uniform refractive index value and a cladding material of lesser refractive index than that of the core. There is sudden increase in the value of refractive index from cladding to core. Thus its refractive profile takes of a step.

Because of larger diameter of core, the propagation of many modes within the fiber is allowed. This is explained in fig. by many different possible light ray paths through the fiber.

Characteristics:

1. The light can be launched into a multimode fiber using light emitting diode source.
2. It has high core diameter.
3. It has low bandwidth.
4. It has high numerical aperture.
5. It has high attenuation.

Advantages:

1. Since LED is used as source of light, they are easier to make.
2. They are less expensive and require less complex circuitry.
3. They have longer life times than the laser diodes, thus making them more desirable in many applications.
4. It is the least expensive of all the fibers.

Disadvantages:

They suffer from intermodal dispersion loss or transmit time dispersion.

Applications & uses:

They are widely used in data links which require low bandwidth.

Intermodal Dispersion:

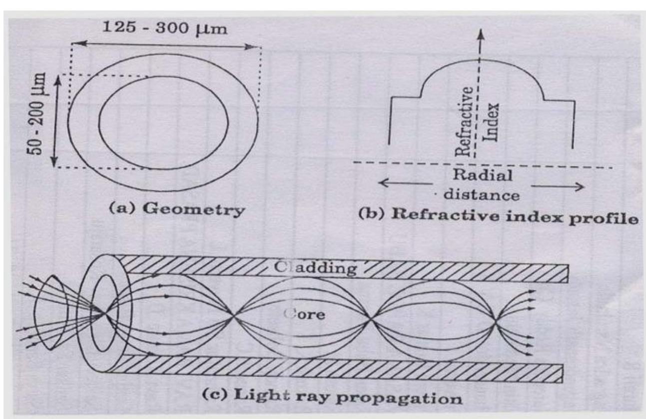
When an optical pulse is launched into a fiber, the optical power in the pulse is distributed over all (or most) of the modes of the fiber. Each of the modes that can propagate in a multimode fiber travels at a slightly different velocity.

This means that the modes in a given optical pulse arrive at the fiber end at slightly different times, thus causing the pulse to spread out in time as it travels along the fiber.

This effect is known as intermodal dispersion. This can be reduced by using a graded – index profile in the fiber.

Graded index Multimode fiber:

The geometry of the normal cross-section of a typical graded – index fiber is as shown in



A typical graded index multimode fiber has a core diameter of 50 to 200µm and the external diameter of cladding is 100 to 250µm. Here, the refractive index of the core is maximum at the axis of the fiber and it gradually decreases towards the cladding. The refractive index profile is shown in fig.

If the diameter of the core is high, then the intermodal dispersion loss must be high. But because of the gradual decreases in the refractive index of the core, the modal dispersion loss is minimized. The light ray propagation for this fiber is shown in fig. It is also denoted GRIN (**GRADED – INDEX**)

Characteristics:

1. It has an intermediate bandwidth and capacity.
2. It has low attenuation.
3. It has a small numerical aperture.
4. The source for this fiber is either a laser or LED.

Advantages:

1. Intermodal dispersion can be reduced by using this type of fiber.
2. It is a high quality fiber.

Disadvantages:

1. It is the most expensive of all types of fibers.
2. Its splicing could be done with some difficulty.

Applications and Uses:

Optical fibers find their applications in the field of communication, medicine and industry.

Differences between step index fiber and Graded index fiber:

Sl.No.	Step Index Fiber	Graded Index Fiber
1.	The difference is refractive indices is obtained in single step and hence called as step index fiber.	Due to non-uniform refractive indices, the difference in refraction index is obtained gradually from the centre towards interface and hence called graded index fiber.
2.	The light ray propagation is in the form of meridional rays and it passes through the fiber axis.	The light propagation is in the form of skew rays and it will not cross the fiber axis.
3.	The path of light propagation is in Zig-Zag manner	The path of light propagation is Helical (i.e) Spiral manner

4.	Step index fiber has lower bandwidth. (multimode)	Graded index fiber has higher bandwidth.(multimode)
5.	Distortion is more in multimode step index fiber. **Explanation:** When ray travels through longer distances there will be same difference in reflected angles. Hence high angle rays arrive later than low angle rays. Therefore the signal pulses are broadened (dispersed) thereby results in a distorted output.	Distortion is less/no due to self focusing effect. **Explanation:** Here, the light waves travel with different speeds indifferent paths because of the variation in their refractive indices. At the outer edge it travels faster than the near the centre. But almost all the rays reach the exit end at same time due to helical path. Thus, there is no dispersion in the pulses and hence the output is not a distorted output.
6.	**No. of modes of propagation:** $N_{step} \quad 4.9\left(\frac{d.NA}{\lambda}\right)^2 = \frac{V^2}{2}$ Where d – diameter of the fiber core λ – Wavelength NA – Numerical Aperture V – V- number which is less than or equal to 2.405 for single mode fibers and greater than 2.405 for multimode fibers.	**No. of modes of Propagation:** $N_{Graded} = \frac{4.9\left(\frac{d.NA}{\lambda}\right)^2}{2} = \frac{V^2}{4}$ (or) $N_{Graded} = \frac{N_{step}}{2}$

Attenuation: It is defined as the ratio of the optical power out (P_{out}) from a fiber of length „L‟ to the power input (P_{in}).

I.e., Attenuation dB/Km

$$\alpha = -\frac{10}{L} \log \frac{P_{out}}{P_{in}}$$

Attenuation loss is generally measured in terms of decibel (dB).

The losses occurring in optical fiber are due to three mechanisms, they are (i) Material absorption losses, (ii) Scattering losses, (iii) Bending losses.

Dispersion: When an optical l (or) pulse is sent into the fiber, the pulse spreads or broaden as it propagates through the fiber, this phenomenon is called as **dispersion.** There are three types of dispersion in optical fiber. They are (i) Chromatic dispersion, (ii) Waveguide dispersion and (iii) Intermodel dispersion.

Fiber Optics Communication system:

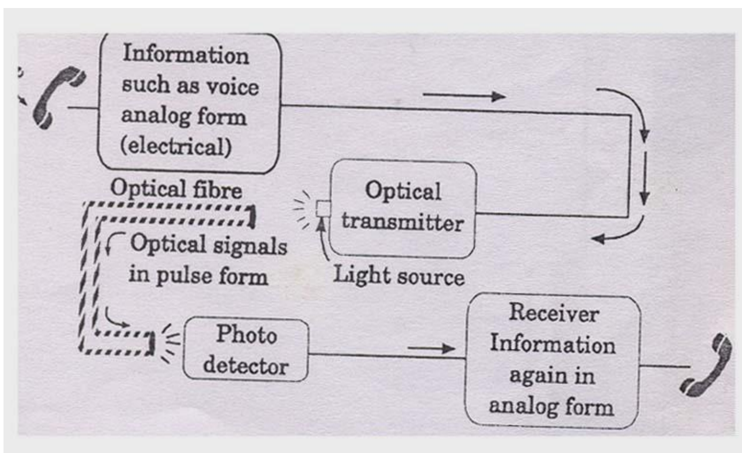
The optical fiber communication system is a communication system. Its purpose is to transfer information from source to a distance user.

Principle:

The basic optic fiber communication is the transmission of information by the propagation of optical signal through optical fibers over the required distance. It involves deriving optical signal from electrical signal at the transmitting end and conversion of optical signal back to electrical signal at the receiving end.

Construction:

A basic block diagram of fiber optic communication system is shown in fig.



The main parts of fiber optic communication system are

1. Information signal source
2. Transmitter
3. Propagation medium.
4. Light source.
5. Photo detector.
6. Receiver

1. **Information signal source:** The information signal source may be voice, music, digital data or analog voltage and video signals. Here, it is analog information.
2. **Transmitter:** It transforms an electrical signal (information signal) to be transmitted into optical signal. Transmitter includes modulator, switches, and drive circuits.

3. ***Propagation medium:*** Here, optical fiber is used as propagation medium.
4. ***Light Source:*** The optical light source generates the optical energy which serves as the information carrier. Laser or LED may be used as light sources.
5. ***Optical photo detector:*** It detects the optical energy and converts it into an electrical form.
6. **Receiver**: It consists of (i) Photo detector (ii) Amplification and signal – restoring circuitry. Its converts the optical signal into corresponding electrical signal.

Working:

Analog information such as voice of a telephone user gives rise to electrical signals in analog form coming out of the transmitter section of the telephone. These electrical pulses are transmitted into an optical signal with the help of optical transmitter. It is modulated and carried by the light emitted by an optical source (Such as an LED or laser diode).

Now this optical signal is fed into the fiber. Finally at the receiving end, the optical signal from the fiber is fed into a photo detector. The photo detector detects the optical signal and converts to pulses of electric current.

This analog signal will be the same information such as voice which was there at the transmitting end. Thus, the information is transferred one end to the other.

Medical Applications:

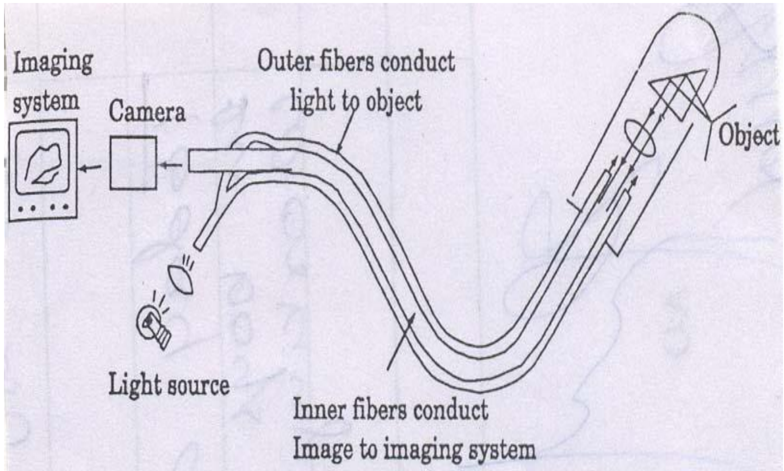
Optical fibers are also used in the medical field. One of the important applications of optical fibers as wave guides in medical field is fiber optic endoscope.

Fiber Optic Endoscope:

The fiber optic endoscope is a tubular optical instrument. It is used to view the internal parts of human body which are not visible to the naked eye normally. The photography of the internal parts of human body can also be taken with this instrument.

Principle and Construction:

The Fig. is shows the main parts of the endoscope. Usually in the endoscope, there are two fibers namely inner fiber and outer fiber. The inner fiber illuminates the inner structure of the object under study. The outer fiber is used to collect the reflected light from that area and form that we can view the inner structure of the object.



The ends of the two fibers are provided with appropriate optical components (lens, Prism etc.,) to transmit and receive light or images.

The two fibers together form the endoscopy tube remains outside and the other end is sent into the human body. There is an optical light source at the end of the outer fiber for transmitting light to illuminate the internal part of the body.

The light collecting and image viewing optical arrangements are placed at the respective ends of the fiber ends. So, the other fiber transmits the image of the particular organ or part of the body to an imaging system (usually a TV) coupled outside.

Advantages of optical fiber communication:

Extremely wide bandwidth: In optical fiber system a greater volume of information or messages can be carried out. The reason is that the rate of transmission of information is directly proportional to signal frequency. The light has higher frequencies than radio wave or micro wave frequencies.

1. **Easy handling:** Due to small diameter and light weight optical fiber s may be used more easily than copper cables.
2. **Less cross talk:** The cross talk means the other calls being heard in the background. In optical fibers, the cross-talk is negligible.
3. **Noise – free transmission:** The optical fiber communication is noise free.
4. **Economical:** The optical fiber communication is economical. They deliver signals at low cost.
5. **Safety:** In optical fibers, light signals are conducted, which are harmless. In copper cables electricity is conducted which sometimes becomes dangerous.

6. **Longer life span:** Optical fibers have life span about 20-30 years while copper cables have life span 12-15 years. Clearly optical fibers have longer life span than copper cables.
7. **Easy maintenance:** Optical fibers are more reliable and can be maintained easily than copper cables.

Important Questions:

1. Explain the interference of light due to thin films by reflection
2. Discuss the theory of Newton's rings with relevant diagram . Derive the expressions for the diameters of dark and bright bands. and hence obtain condition for dark and bright rings
3. Give the theory of Fraunhofer diffraction due to single slit and hence obtain the Condition for primary maxima ,secondary maxima and minima.
4. Explain Fraunhofer diffraction due to double slit and compare the results obtained with that due to single slit.
5. What is Grating? Explain the spectra formed by a plane transmission grating with relevant theory.
6. Explain the characteristics of laser.
7. Distinguish between spontaneous and stimulated emission of radiations
8. Derive the relation between the various Einstein coefficients of absorption and emission of radiation.
9. With the help of suitable diagram, explain the principle, construction and working of He-Ne laser.
10. With the help of suitable diagram, explain the principle, construction and working of Nd-YAG laser.
11. Describe the construction and working of semiconductor laser. List out its merits and demerits
12. Define the acceptance angle and numerical aperture. Obtain an expression for the numerical aperture of an optical fibre.
13. Distinguish between step index and graded index optical fibre
14. What are different losses in optical fibre? Write brief note on each.
15. Draw the block diagram of fibre optic communication system and explain the functions of each block.