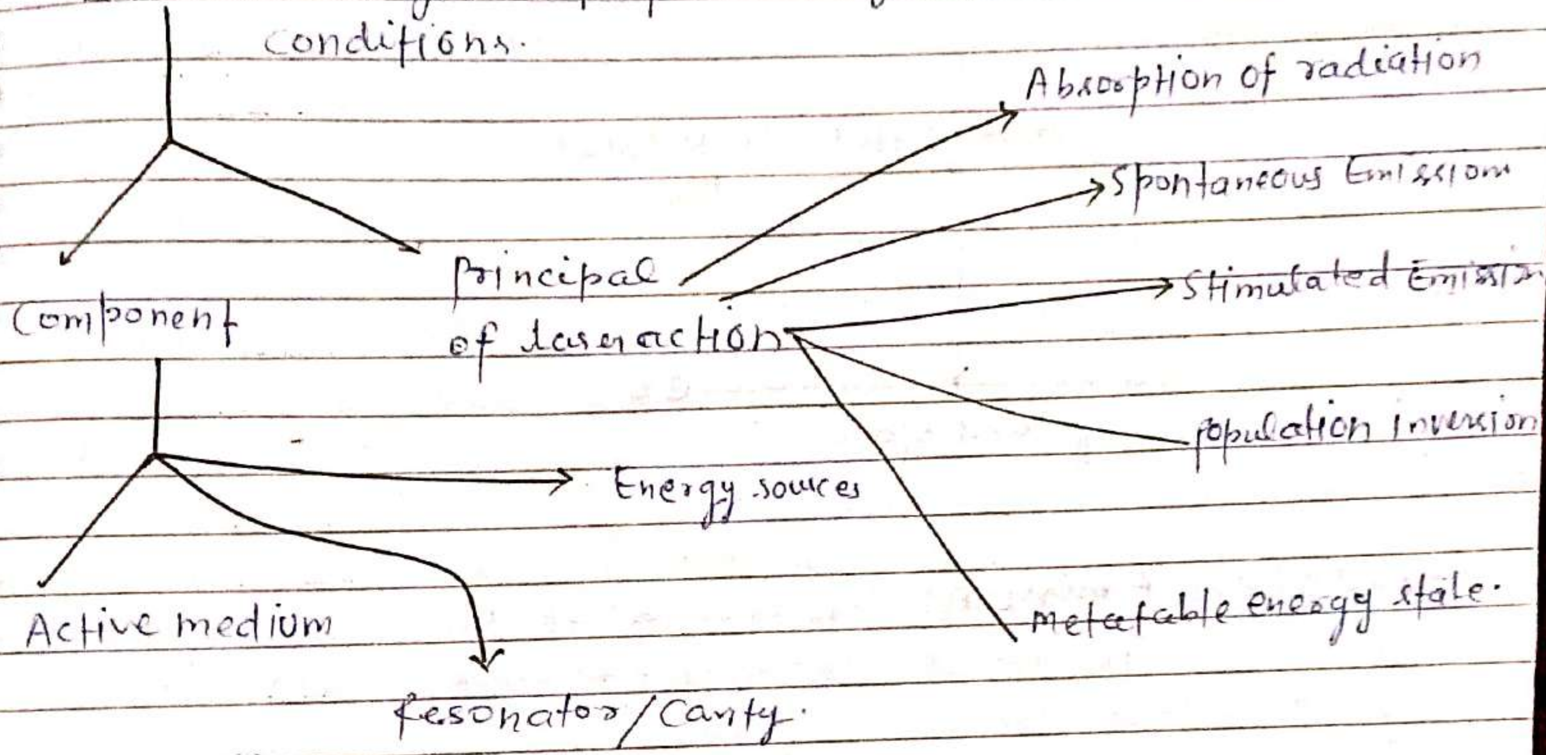
(Unit . IV)

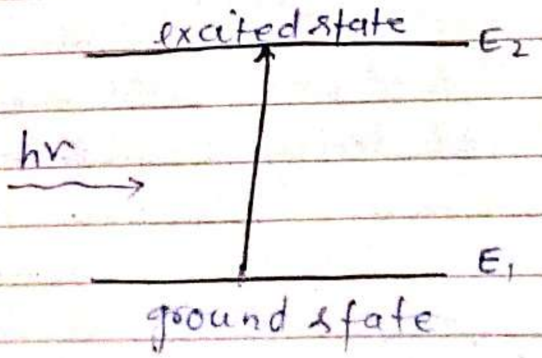
Laser and optical fibre

LASER; Light amplification by stimulated emission of conditions.

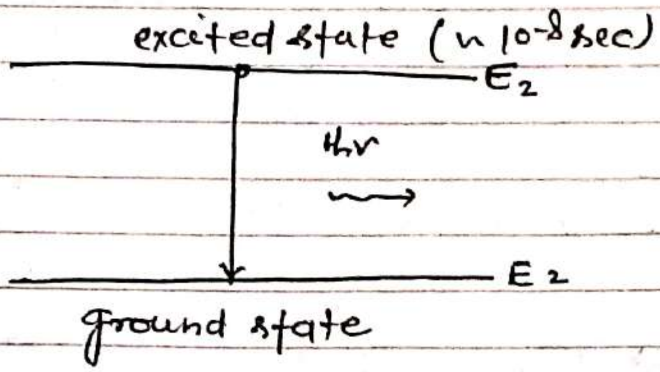


* Laser is a device which emits a monocromatic, powerful, collimated ~~deep~~ beam of light

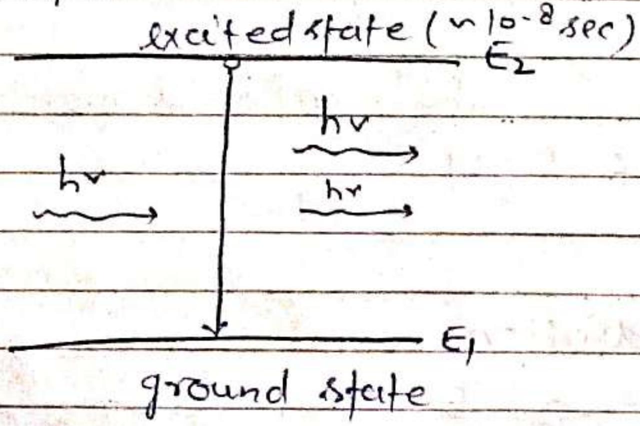
Absorption of radiation:- An atom in ground state (~~even~~) (E_1) absorve energy ($h\nu$) and go to excited state (E_2) is called absorption of radiation.



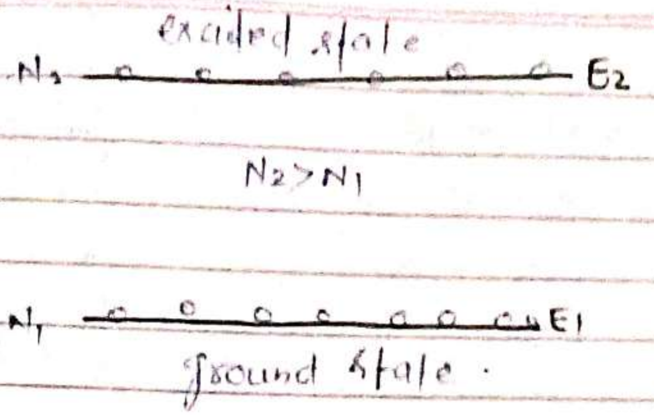
Spontaneous emission: The emission of radition form higher energy state to lover energy state without any external infulance is called spontanious emission.



Stimulated Emission: The process of forced Emission of photon, caused by the incident photon is called stimulated Emission.

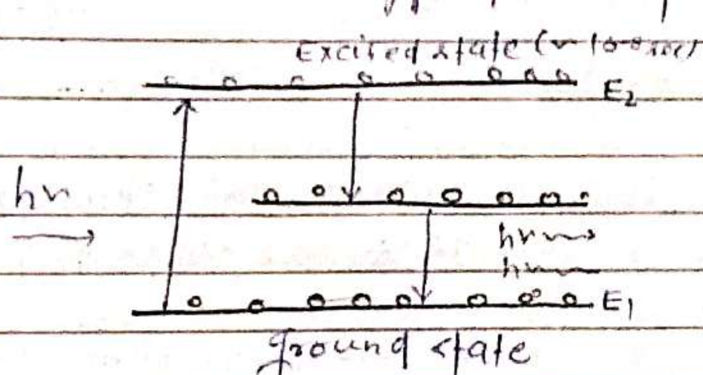


population inversion: The situation in which the number of atom in the higer energy state is grater than that in the lower energy state is called population inversion.



$$\frac{N_2}{N_1} = e^{-h\nu/kT}$$

Metastable state: A long lived energy state ($\sim 10^{-3}$ sec) from where the excited atom do not return to the lower level energy state spontaneously.



Pumping: The process of achieving population inversion is known as pumping.

optical pumping: optical pumping is a process in which light is used to rais an atom from lower energy state to higher energy state is called optical pumping.

Two level laser system: A laser system whose atom have only two energy state is called to level laser system.

* To level laser system unsuitable for acheiving population inversion. (metastable state are not created).

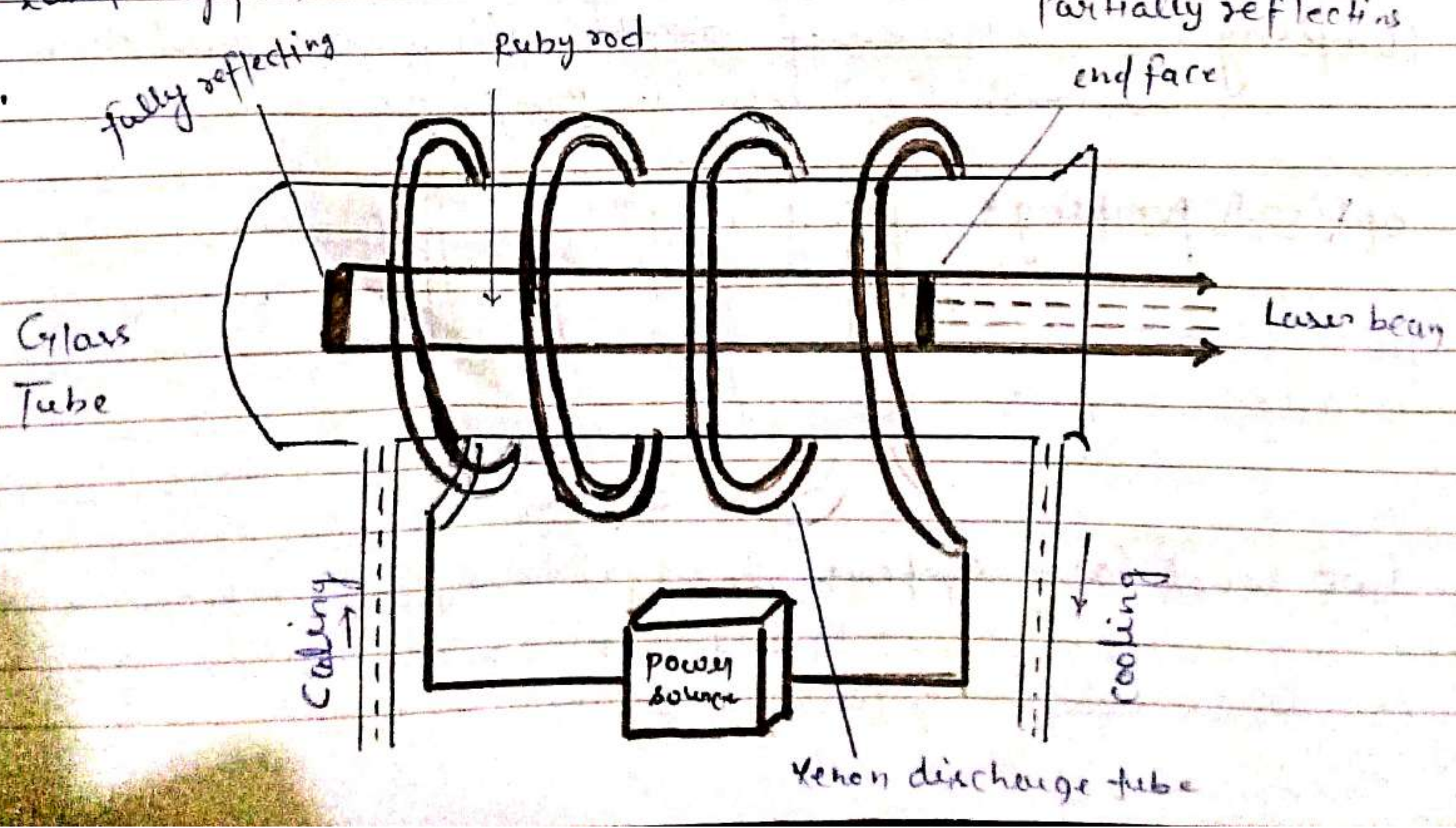
Ruby laser :- The ruby laser was first develop by T. H. Maiman in 1960.

Construction
* Ruby was the first solid material use in the production of laser.

* It consist of single crystal of pink ruby (Al_2O_3) doped with 0.05% Cr^{+3} ions [$Al_2O_3 \cdot CrO_3$]

* The crystal is in the from of cylindrical. The ruby rod is sourrended by a 'helical xenon flash tube'

* The Ruby is a three level laser system (pulsed) laser system.



Working

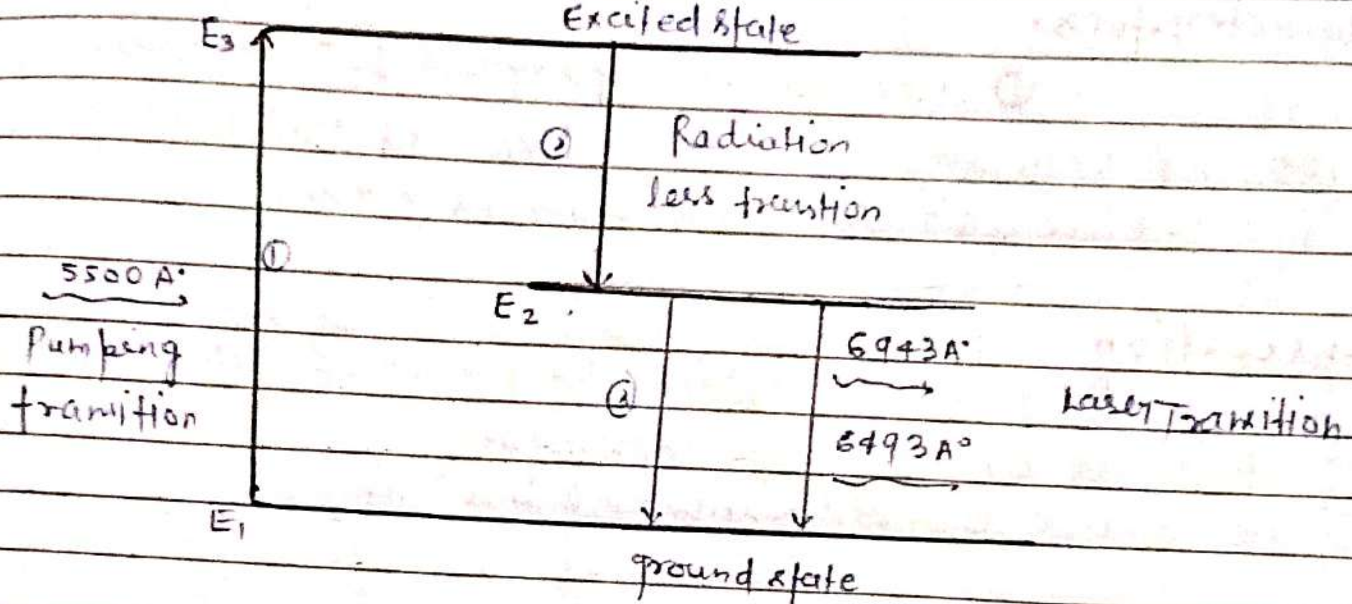


fig. Energy level of Ruby laser.

* Most of the cromium ion is ground state (E_1).
* The ruby rod is pump by Xenon flash tube.
* The 5500 A° radiation are absorve by cromium ion and which are pump to excited state (E_3).
* And excited from the metastable state (E_2) drooped down ground state even.
* It emits a photon of wavelength 6973 A°.

Drawback/ Disadvantage.

① High pumping power required.
② The efficiency is very small.
③ Output laser beam is form of pulses.
④ Cooling is required

Characteristics.

① The power output is $10^4 - 10^6$ watts.

② The frequency of output beam is 4.32×10^{14} Hz

③ The wavelength of output beam is 6943A°.

Application

① It is use in the treatment of detached retina.

② It is use in laboratory experiment.

③ It is use in soldering and building.

He-Ne Laser:- In 1961 A Javan W. Bennett and D. Herriot reported a Contineous He-Ne gas laser.

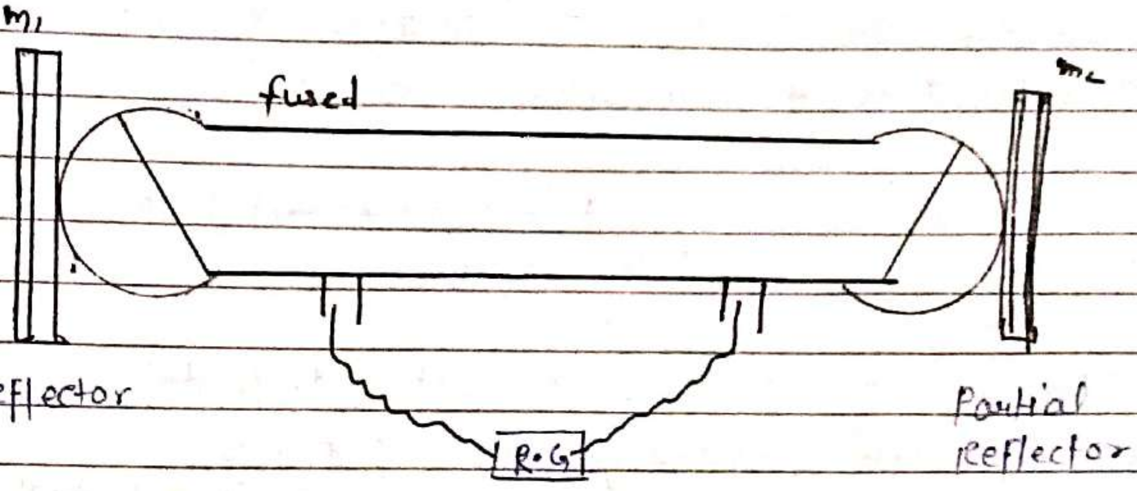
Construction.

1. Active medium
2. Resonator
3. Electrical discharge tube

① Active medium: A mixture of helium and neon gas (7:

② Resonator: Discharge tube, the reflector M_1 & M_2 are placed outside the tube.

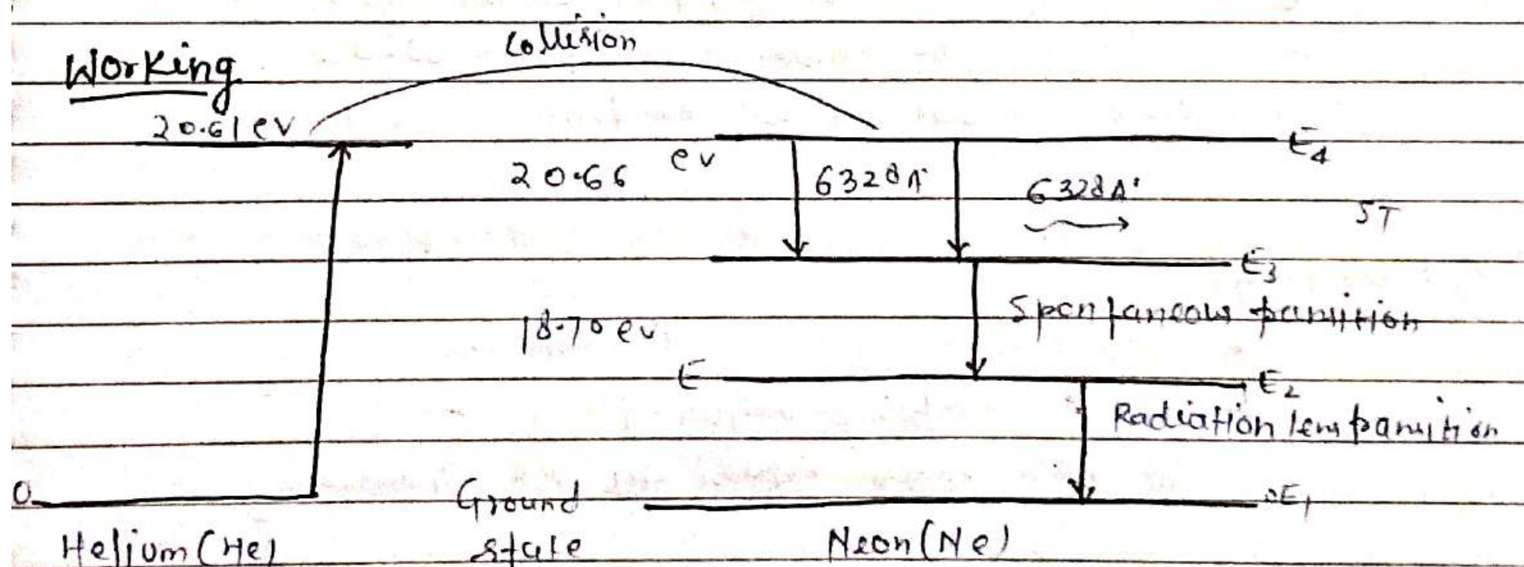
③ Energy source: Electrical discharge method.



* The gas laser consist of a discharge tube with diameter 1.5cm and 80cm long.

* This tube filled with mixture of helium and Neon gas.
* There is a majority of helium atom of & minority of neon atom

Working



* When an electric discharge passess through the gas mixture
* The electron in the discharge tube collides with the helium and Neon atom excited them to the metastable state (20.01ev) and 20.66 ev respetively.

* Some of the excited Helium atom transfer their energy to Neon atom by collision.

* Thus lighter Helium atom help in acheving population inversion in the heavier Neon atom.

* Then heavey ecited Neon atom drops down metastable state to lower enenergy state (18.70eV)

* It emits 6328A° photon in the visible region.
* Helium Neon gas laser is a four level laser system.

Characteristics.

① The frequency of out put beam is 4.7×10^{14} Hz.

(ii) The wavelength of laser output is 6328 A°

(iii) The nature of output is continious wave.

Advantage:

* No cooling is requred.
* Low pumping requred.
* It has high stability of frequency.

Einsteins' coefficient: Einsteins was the first to calculate the probability of transition. The atomic system to be in equilibrium condition.

Rate of absorption.

$$R_1 = \propto N_1 u(\nu)$$

$$\left[R_{12} = B_{12} N_1 u(\nu) \right]$$

where B_{12} is known as Einsteen Cofficient of absorbtion of radiation.

Rate of spontaneous emission:

$$R_{21} \propto N_2$$

$$R_{21} = A_{21} N_2$$

where A_{21} is known as Einsteins cofficent of spontaneous Emission of radiation.

(induced)
Rate of stimulated emission:

$$R_{21} \propto N_2 . u(\nu)$$

$$\left[R_{21} = B_{21} N_2 u(\nu) \right]$$

where B_{21} is known as ~~Einst~~ Einsteins cofficent of stimulated emission of radiation.

∴ Under equilibrium condition.

The rate of absorption = The rate of emission

$$R_{12} = (R_{21})_{sp} + (R_{21})_{ST}$$

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

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

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

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

$$u(\nu) = \frac{A_{21}}{B_{21}} \frac{1}{\left[\frac{B_{12}}{B_{21}} e^{h\nu/kT} - 1\right]} \quad \text{--- (1)} \qquad \frac{N_2}{N_1} = e^{-h\nu/kT}$$

According to Plank's law of energy distribution in term of frequency.

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{\left[e^{h\nu/kT} - 1\right]} \quad \text{--- (2)}$$

Compared eqn (1) & (2) we get

$$\frac{B_{12}}{B_{21}} = 1 \qquad (\because B_{12} = B_{21})$$

$$\left[\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}\right] \quad \text{Or} \quad \left[\frac{A_{21}}{B_{21}} \propto \nu^3\right]$$

The ratio of Eintelns coficient of spontaneous to stimulated is directly proportional to qube of fequency.

* Difference b/w spontenious and stimulated

Spontenious	Stimulated emission
* In Coherent radiation.	* Coherent radiation.
* Emission has many wavelength	* Emission has single wavelength.
* Low directionlity.	* high directionlty.
* Low intance.	* High intence.
* High angular spered.	* Low angular spered.

Q. In a Rubi laser total number of cromium ion. 2.8×10^{19}. If the laser emits radiation of a wavelength 7000A°. Calculate the energ of the laser pulx.

$\lambda = 7000\,A°$

$= 7000 \times 10^{-10} m$ $\quad n = 2.8 \times 10^{19}$

$$E = \frac{nhC}{\lambda}$$

$$= \frac{2.8 \times 10^{19} \times 6.623 \times 10^{-34} \times 3 \times 10^{8}}{7000 \times 10^{-10}}$$

[E = 7.94 Joule]

Q. Calculate the energy and photon of a laser beam of wavelength 6328 A°.

$\lambda = 6328 \times 10^{-10} m$

$E = h\nu$

$= \frac{hc}{\lambda}$

$= \frac{6.623 \times 10^{-34} \times 3 \times 10^{8}}{6328 \times 10^{-10}}$

$E = 3.14 \times 10^{-19}$ joule

$E = 1.96 eV$

$\lambda = \frac{h}{p}$

$p = \frac{h}{\lambda} = \frac{6.623 \times 10^{-34}}{6328 \times 10^{-10}}$

$= \frac{1.04 \times 10^{-34}}{10^{-10}}$

$p = 1.04 \times 10^{-24}$ Nm/s.

V.M

Q. Calculate the population ratio in Helium Neon laser that produce digit of wavelength 6000 A° at 300K

Sol

$\lambda = 6000 A°$

$\lambda = 6000 \times 10^{-10} m$

$K = 1.38 \times 10^{-23} J/K$

$h = 6.623 \times 10^{-34} J \cdot s$

$T = 300 K$

$$\frac{N_2}{N_1} = e^{-hc/\lambda kT}$$

$$= e^{-6.623\times10^{-34}\times3\times10^{8}/6000\times10^{-10}\times1.38\times10^{-23}\times300}$$

$$\left[\frac{N_2}{N_1} = e^{-80}\right]$$

Calculate the relative population of two states of the laser that produces light of wavelength 5461 A° at 27 C°

Solve..

$T = 27°C \quad T = 300K$

$\lambda = 5461\,A = 5461\times10^{-10}\,A$

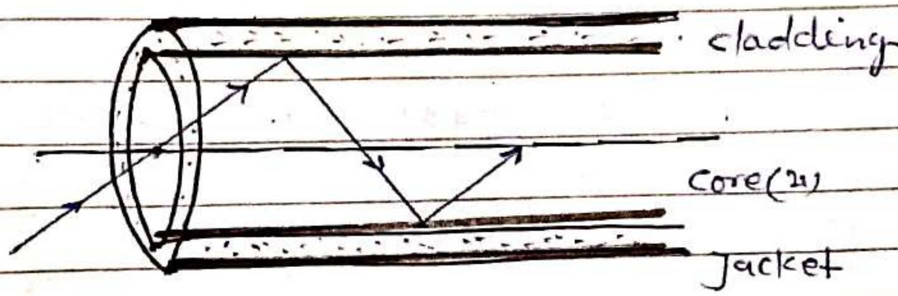
$$\frac{N_2}{N_1} = e^{-hc/\lambda kT}$$

$$= e^{-6.623\times10^{-34}\times3\times10^{8}/5461\times10^{-10}\times1.38\times10^{-23}\times300}$$

$$\left[\frac{N_2}{N_1} = e^{-87.89}\right]$$

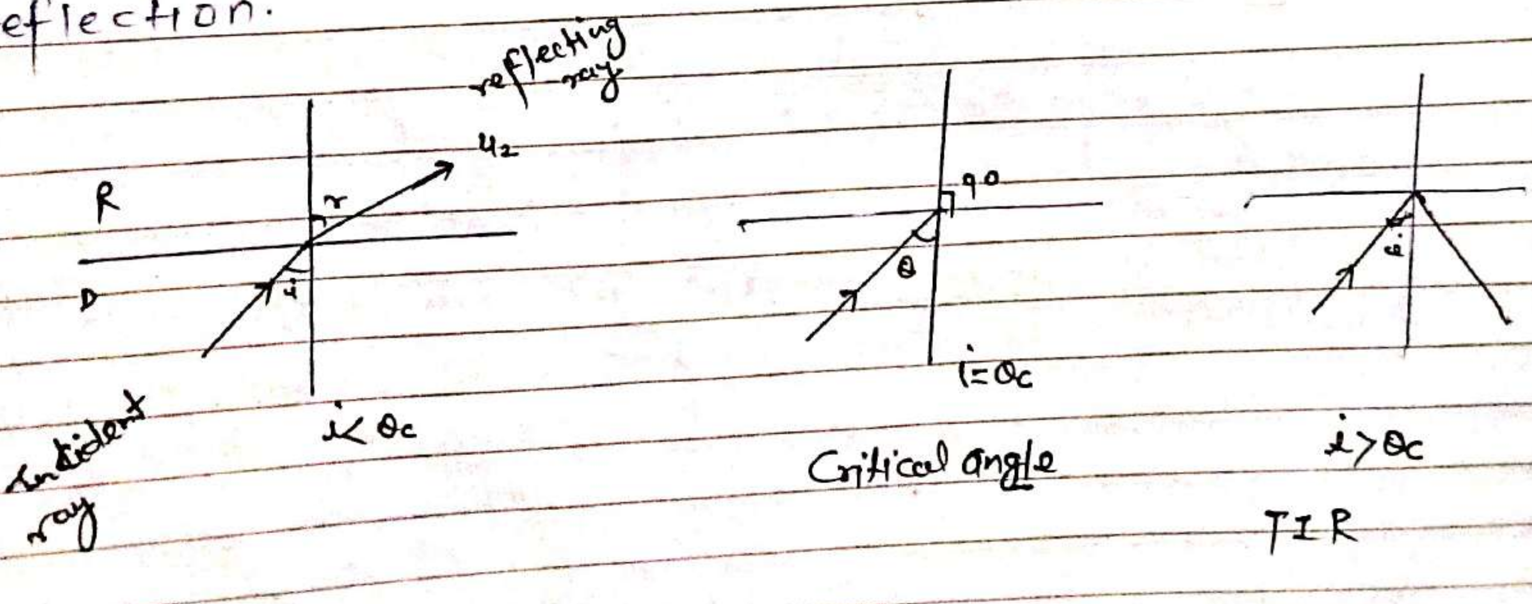
Optical fiber : Optical fiber is a hair thin flexible transparent medium of glass or plastic that transmits light single over long distance
The optical fiber has three principle section.

1. Core (μ_1)
2. Cladding (μ_2)
3. Jacket



[$\mu_1 > \mu_2$]

* **propagation Machanisum:-** The optical fiber are based on the principal of total internal reflection.



* Critical angle: Critical angle is the angle of incident where the angle of refraction is 90°

$$\theta_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)$$

Modes of propagation:

The light along different path rays is known as modes of propagation.

$$\text{Number of modes } (N) = \frac{V^2}{2}$$

* Normalize frequency:

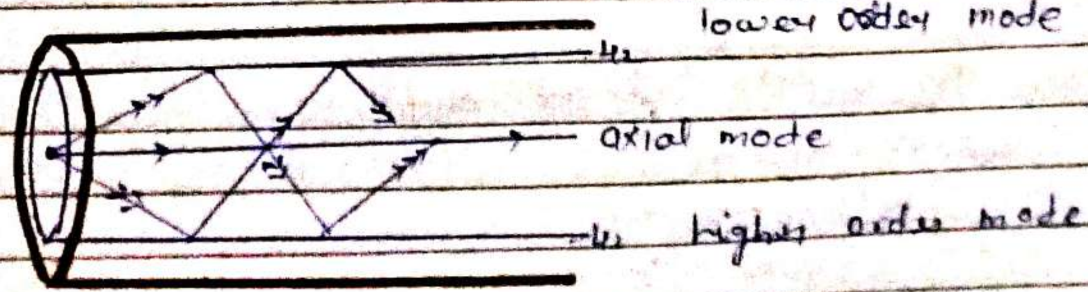
The number of modes supported by an optical fiber is often cut-off condition is called normalised frequency or cut-off parameter.

$$V = \frac{\pi d}{\lambda}\sqrt{\mu_1^2 - \mu_2^2}$$

or

$$V = \frac{\pi d}{\lambda}(NA)$$

* for single mode fiber supported $V < 2.405$
* for multimode fiber supported $V > 2.405$



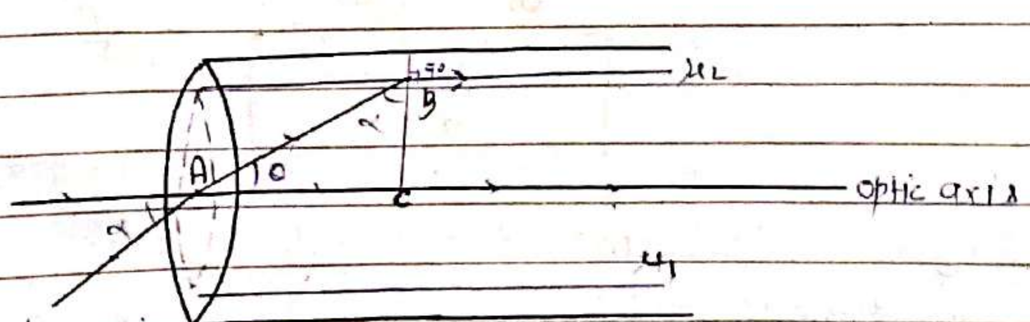
* optical fibre are made by molted ~~by~~ from of silica and small ~~amb~~ amount of Dopant like B_2O_5, P_2O_5. GeO_2 etc.

- **Acceptance cone (2α):** A cone within which all rays incident will be collected and propagated through the fiber is called exptance cone.

- **Acceptance angle (α):** The maximum angle from the fiber axis at which light may enter the fiber so that it will propgate in the core by TIR is called Acceptance angle.

$$\alpha = \sin^{-1}\left(\frac{1}{\mu_0}\sqrt{\mu_1^2 - \mu_2^2}\right)$$

Proof



from fig Snell's law at point B

$$\mu_1 \sin\theta_c = \mu_2 \sin 90$$

$$\mu_1 \sin\theta_c = \mu_2$$

$$\sin\theta_c = \frac{\mu_2}{\mu_1} \quad \text{—— (1)}$$

Snell's law at point A

$\mu_0 \sin\alpha = \mu_1 \sin\theta$ $[\theta = 90 - \theta_c]$

$= \mu_1 \sin(90 - \theta_c)$

$= \mu_1 \cos\theta_c$

$\mu_0 \sin\alpha = \mu_1 \sqrt{1 - \sin^2\theta_c}$ —— (11)

from eqn (1) & (2) we get

$\mu_0 \sin\alpha = \mu_1 \sqrt{1 - \frac{\mu_2^2}{\mu_1^2}}$

$\mu_0 \sin\alpha = \sqrt{\mu_1^2 - \mu_2^2}$

$\sin\alpha = \frac{1}{\mu_0} \sqrt{\mu_1^2 - \mu_2^2}$

$$\left[\alpha = \sin^{-1}\left(\frac{1}{\mu_0} \sqrt{\mu_1^2 - \mu_2^2} \right) \right]$$

Numerical aperture (NA): The light gathering capacity of an optical fiber is known as numerical aperature.

$$\boxed{NA = \sin\alpha}$$

or

$$\left[NA = \sqrt{\mu_1^2 - \mu_2^2} \right] \quad \text{or} \quad \left[NA = \mu_1 \sqrt{2\Delta} \right]$$

where PRI $(\Delta) = \frac{\mu_1 - \mu_2}{\mu_1}$

proof

$\Delta = \frac{\mu_1 - \mu_2}{\mu_1}$

$\Delta = \frac{(\mu_1 - \mu_2)(\mu_1 + \mu_2)}{\mu_1(\mu_1 + \mu_2)}$

$$\Delta = \frac{n_1^2 - n_2^2}{n_1(2n_1)}$$

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$

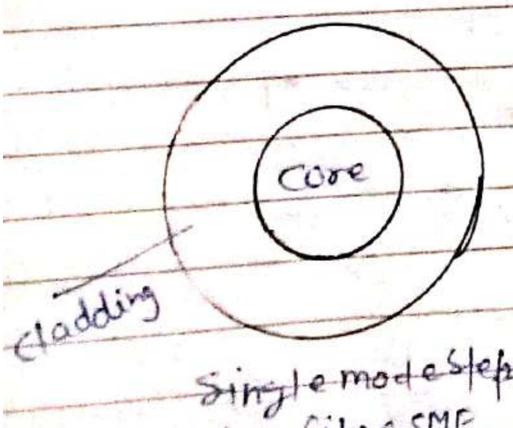
$$n_1^2 - n_2^2 = \Delta 2n_1^2$$

$$(NA)^2 = \Delta 2n_1^2$$

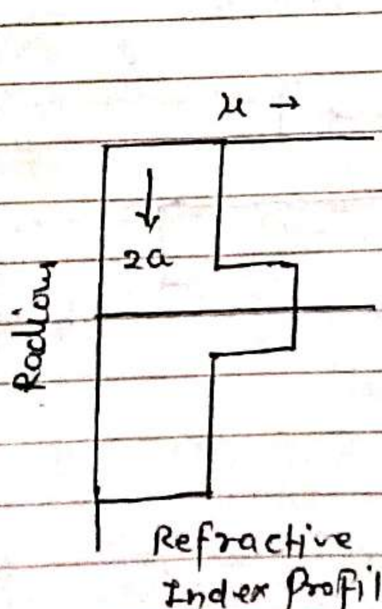
$$[NA = n_1\sqrt{2\Delta}]$$

* Classification of optical fiber: On the basis of number of modes and refractive index profile on the core and the way of light. In which light signal propagate in the core.

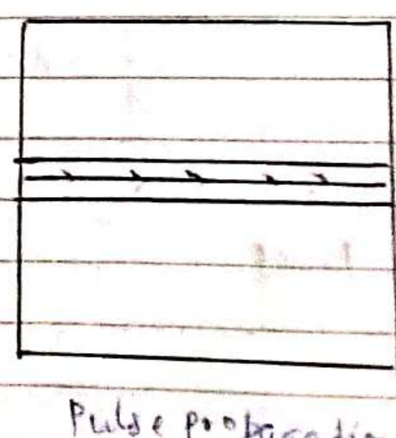
① Step index single mode fiber (SMF): when only a single mode transmitted through an optical fiber than it is known as single mode fiber.

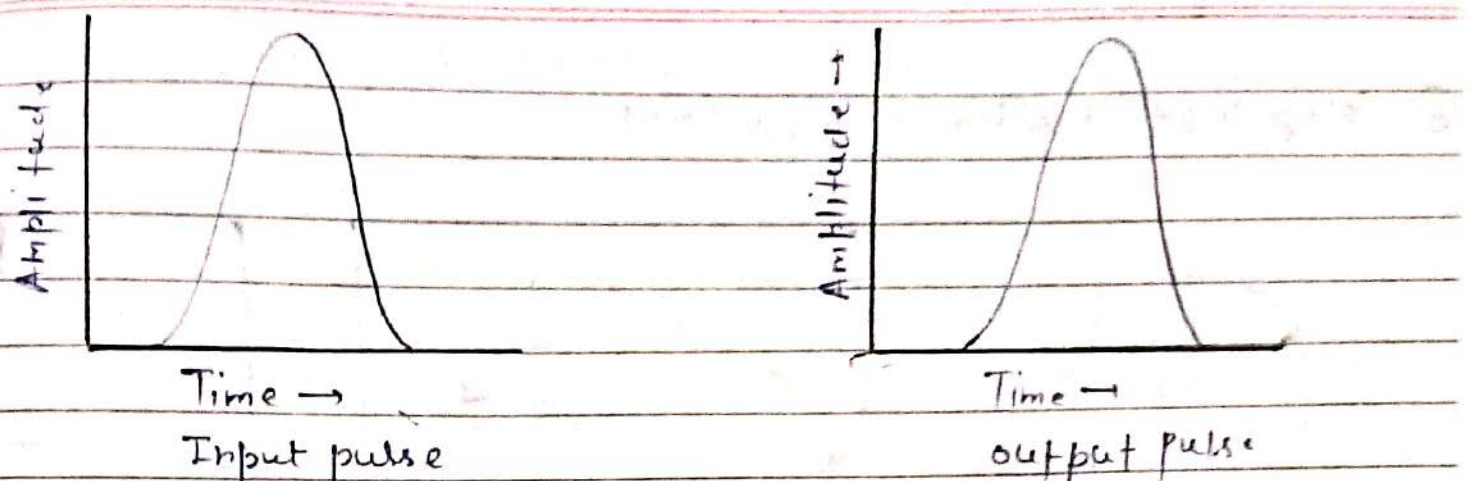


Single mode step index fibre SMF



Refractive Index Profile.

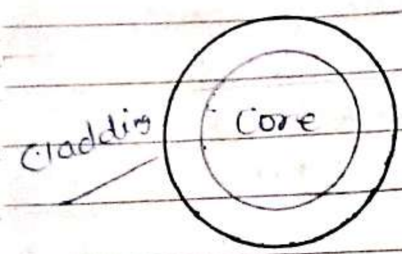

Pulse propagation



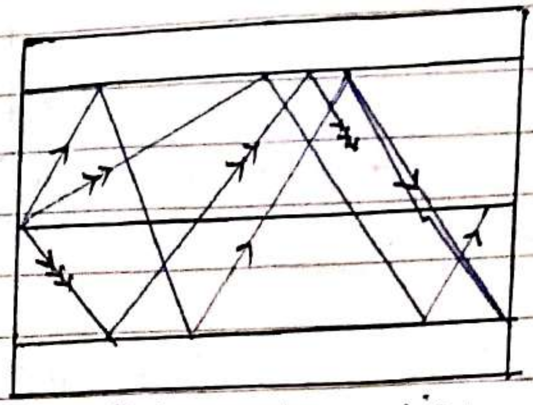
* The core daimeter has 5 to 10 micrometer.
* The cladding daimeter has 50 to 125 micrometer.
* The diffrance b/w refrective index ~~core~~ of core and cladding very small.
* The core has a uniform refrective index of higher value than uniform. R.I of cladding.

Characteristics * ~~Single m~~ S.M.F can support only one mode of propagation.
* Suitable for long distance communication such as telephone lines.
* The light is pass through laser diode.
* ~~factor~~ fabrication is very difficult and costly.
* S.M.F are frequently use under sea water.

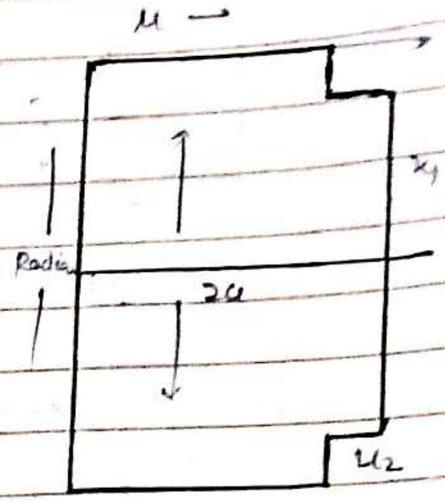
② step index multimode fiber (MMF):



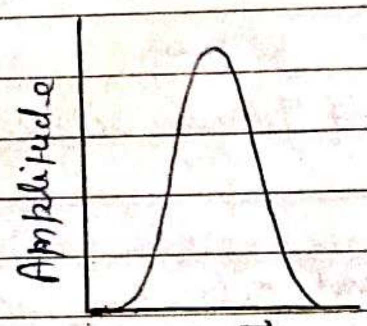
multimode step
Index fibre (MMF)



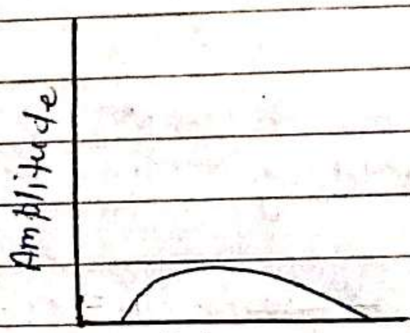
Pulse propagation



Refractive Index
profile



Time Input
pulse



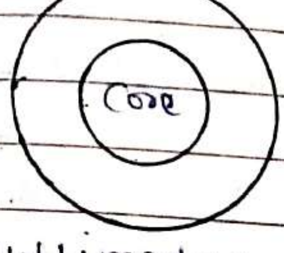
Time
outputpuls.

* When more than one mode is transmitted through an optical fiber is called multimode fiber.

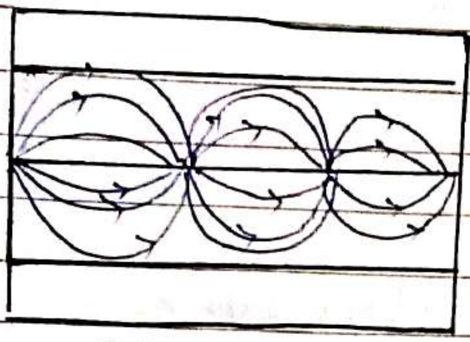
Characteristics: The core daimeter has 50 to 200 micrometer.
The cladding daimeter has 125 to 300 micrometer.
The relative refrective index is larger than SMF.
The core has uniform refrective index and cladding material are laser R.I than that core.

* The multimode can supported.
* propagation of light is easy.
* The light is pass throug using LED
* The fablication is not possible.
* Not suitable for long distance communication.

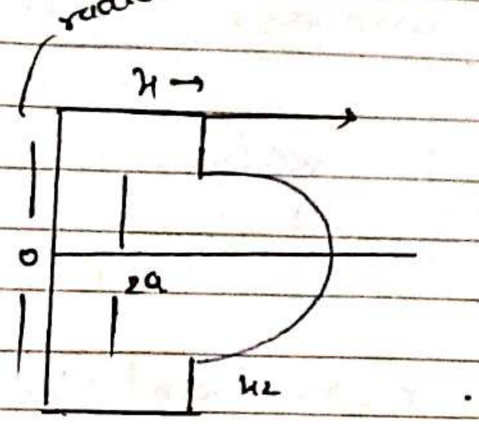
③ Graded index multimode fiber (GRIN):



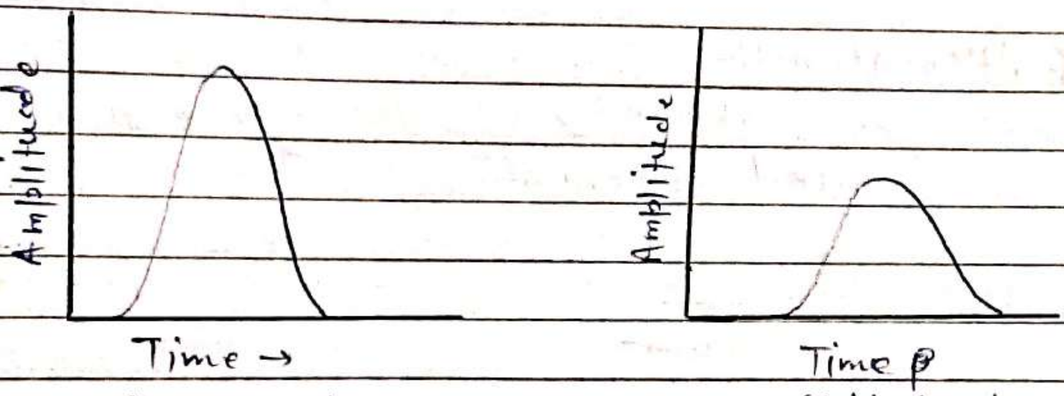
multimode graded index fiber (GRIN)



Pulse propagation



Refractive index profile



Input pulse   output pulse

" If the core has Non-uniform refrective index that gradually decreases from the centre towards; the core cladding interphase. The fibre is called graded index fiber.

* The core and cladding daimeter are about 50 to 70 Micrometer respectively.

* The light to not cross the fibre axis at any time.
* The light propagate around the fibre axis in helical rays.

Advandge: Despersion is low.
Bandwidth is grater than that step index multimode fibre.

* Easy to couple with optical source.

* Disadvantage: * Very expensive.
* Very difficult manufacture

Power loss (Attenuation):- The power loss of optical singnal when they travel through optical fiber cable is called Attenuation.

$$P_L = -10 \log_{10} \frac{P_{out}}{P_{input}}$$

Attenuation constant (α): The power loss per unit length in optical fibre (dB/Km) is called Attenuation constant.

$$\alpha = \frac{P_L}{L} \quad dB/K$$

$$\alpha = -\frac{10}{L} \log_{10} \frac{P_{out}}{P_{input}} \quad dB/K$$

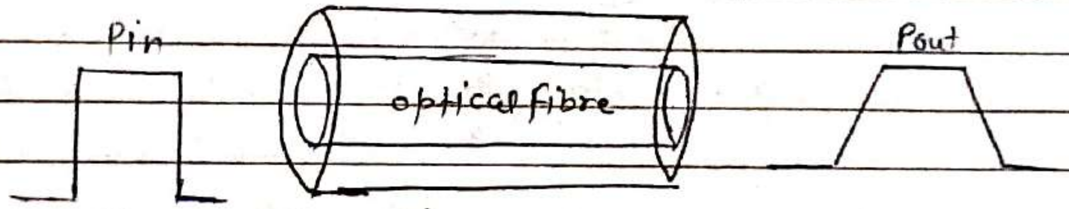
Types of loses:

① Absorbtion loss: The light can be absorbe the pure material of the core.

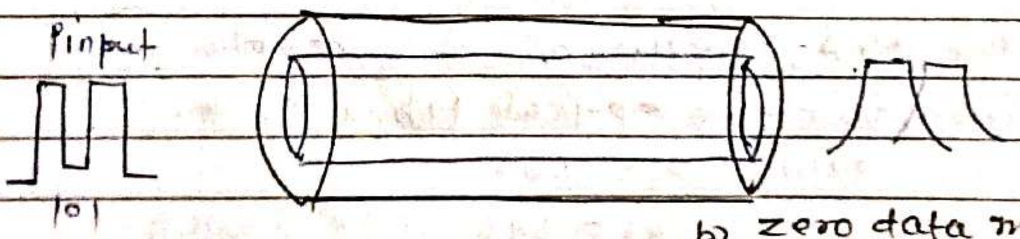
Scattering loss: The light travelling through the core can get scattered by impurity with suddenly change refractive index.

Bending loss: These losses are due to change in angle of incident on the core cladding interface because bending of cable.

Dispersion: The broadening of light pulse as it propagate from one end to other end within in fibre is called dispersion.



a) Pulse height decreases due to Broading



b) zero data missing due to dispersion

Type of dispersion:

① Intermodal dispersion. Due to presence of many wavelength.

② Chromatic dispersion: Due to different pulses having different velocity.

(3) waveguide dispersion: Due to guiding it Homogentic of coave guide

Numerical formula

① $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$ $NA = \sin\alpha = \sqrt{n_1^2 - n_2^2} = n_1\sqrt{2\Delta}$

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

$V = \frac{\pi d}{\lambda} NA$

$N = \frac{V^2}{2}$

$P_L = -10\log_{10}\frac{P_o}{P_i}$ dB

$\alpha = -\frac{10}{L}\log_{10}\frac{P_o}{P_i}$ dB/cm

Q. Compute the N.A, Critingal & acceptance of the optical fibre from the optical fibre of the optical fallowing data $n_1 = 1.48$
$n_2 = 1.46$

$N.A = \sqrt{n_1^2 - n_1^2}$
$= \sqrt{(1.48)^2 - (1.46)^2}$

$N.A = 0.242$

Critical angle
$\sin\alpha = N.A$

$\alpha = \sin^{-1}(0.242)$

$[\alpha = 14°]$

$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

$[\theta_c = 80.56°]$ Ans

Q. An optical fiber has a following characteristic $n = 1.36$ and relative diffrence in idex $\Delta = 0.025$ find the value NA and Acceptence angle.

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

$= 1.36\sqrt{2 \times 0.025}$

$[NA = ~~0.048~~]$ 0.304

$\sin\alpha = NA$

$\alpha = \sin^{-1}(NA)$

$= \sin^{-1}(0.304)$

$[\alpha = 17.69°]$ Ans

Q. if the factional diffrance b/w core and cladding refective indexes. of fibre is ~~0.13~~ 0.0135 and N.A is ~~0.02042~~ 0.2425 calcalate the refective index of core cladding.

$\Delta = 0.0135$

$N.A = 0.2425$

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

$n_1 = \frac{0.2425}{\sqrt{2 \times 0.0135}} = \frac{0.2425}{0.1643}$

$[n_1 = 1.475]$