Topics in Module - III

Laser.

Laser: Light amplification by simulated emission of radiation.

A laser is a device that can produce a very narrow intense beam of monochromatic coherent light.

Characteristics Of Laser.

- High monochromaticity
- High Directional
- High intensity
- High Coherent → face or angle of direction

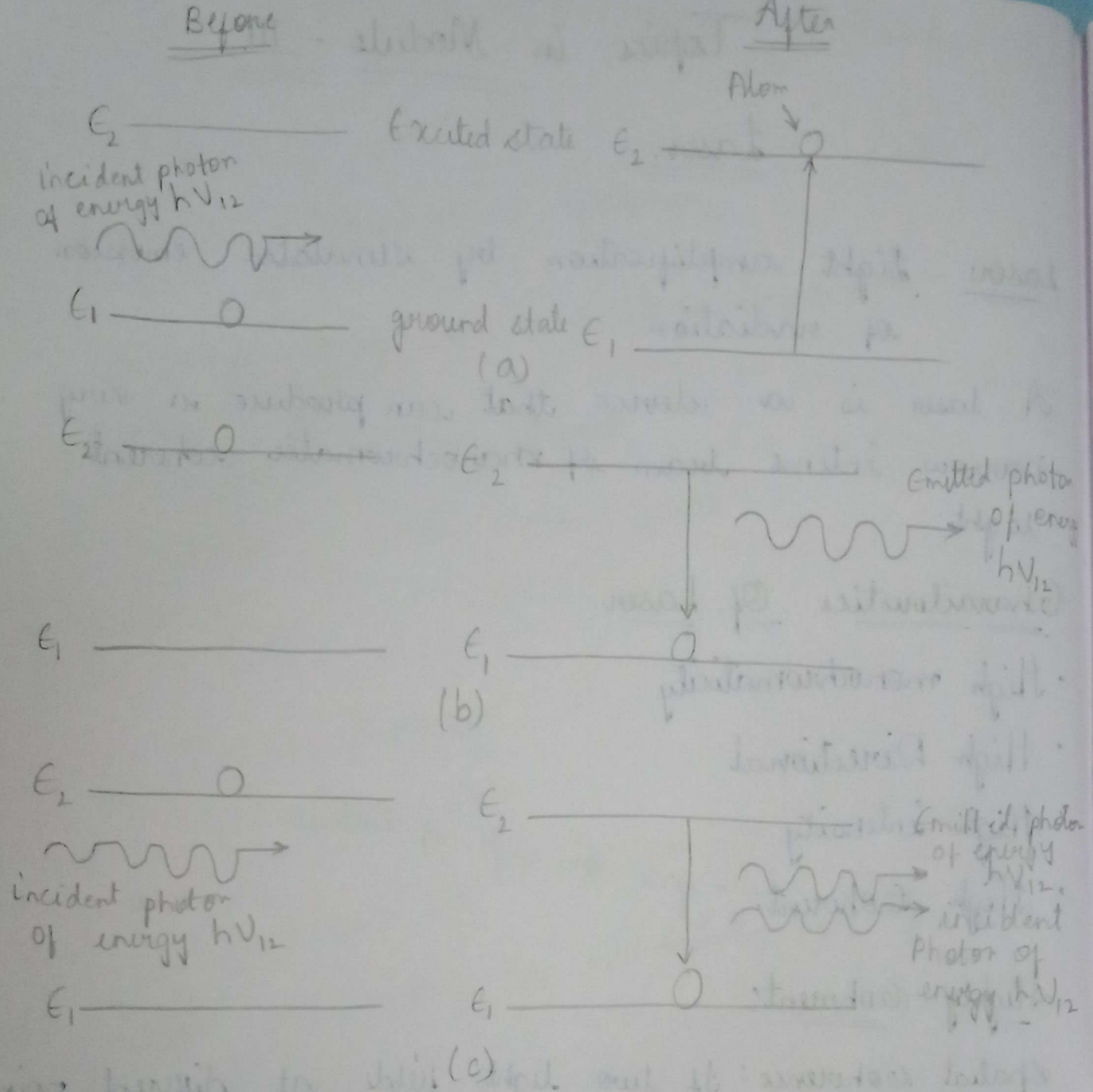
Highly Coherent:

Spatial Coherence: If two light fields at different points in space maintain constant phase difference over any time t, then they said to have spatial coherence. The distance up to which same phase or constant phase difference is maintained is called coherent length.

Temporal Coherence: refers to the correlation of phase b/w the light fields at a point, over a period of time.

Transitions.

- Absorption
- Spontaneous Emission
- Stimulative Emission.



Difference b/w Spontaneous & Stimulated Emission

Spontaneous Emission	Stimulated Emission
1) Spontaneous emission takes place when excited atoms make a transition to lower energy level voluntarily without any external stimulation.	2) Stimulated emission takes place when a photon of energy equal to $h\nu_{12} (= E_2 - E_1)$ stimulates an excited atom to make transition to lower energy level

2) polychromatic radiation	2) Monochromatic radiation
3) Less intensity	3) High itensity.
4) Less directionally. more angular spread during propagation.	4) High directionally. so less angular spread during propagation.
5) Spatially and temporarily in coherent radiation	5) Spatially and temporarily coherent radiation
6) Ex:- Light from oridary source.	6) Ex: Light from Laser.

Metastable state:

The excited states which have a relatively long lifetime due to slow relative and non-relative decay are called metastable state.

The life time of metastable state is 10^{-6} to 10^{-3} s.

Population Inversion:

Usually in a system the number of atoms (N_1) present in the ground state (E_1) is larger than the number of atoms (N_2) present in the higher energy state. The process of making $N_2 > N_1$ is called population inversion.

Conditions for population inversion are:

- The system should posses at least a pair of energy levels ($E_2 > E_1$) separated by an energy of equal to the energy of a photon ($h\nu$)
- There should be continuous supply of energy to the system such that the atoms must be raised continuously to excited state.

There could be no population inversion and no laser action, if metastable state do not exist.

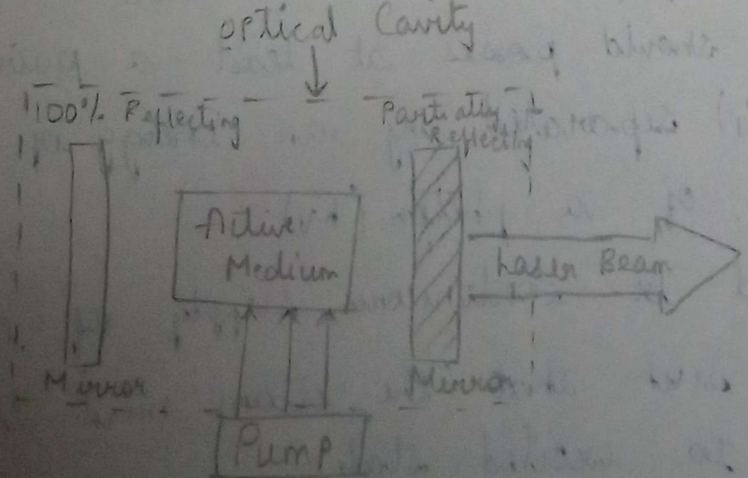
Pumping:

For maintaining a state of population inversion atoms have to be raised continuously to excited state. It requires energy to be supplied to the system. The process of supplying energy to the medium with a view to transfer it into state of population inversion is known as pumping. Simply the population of process of attaining population inversion is called pumping.

Used types are:

- Optical pumping: Exposure to Electromagnetic radiation or light
- Electric discharge: By inelastic atom - atom collisions
- Atom - Atom collision
- Direct conversion
- Chemical reaction
- Injection Current.

Components of LASER:



Nudium → Nd

YAG → Yitrium Aluminium garnate

Different types of lasers:

- Solid Laser : Ruby laser, Nd :YAG laser
- Gas Laser : He - Ne, CO_2 Laser, Arg-ion laser.
- Liquid Laser: Europium Chelate Laser, $SeOCl_2$ laser
- Dye Laser: Rhodamine 6G Dye laser, Cowmarin Dye Laser
- Semiconductor Laser: InP laser, GaAs laser.

Ruby Laser: → Pulsed laser

working principle & construction

Active material: Ruby crystal in the form of rod [$Al_2O_3 + Cr_2O_3$]

Resonating cativity: A fully reflecting surface at the left end of the ruby crystal and partially reflecting end of at the right side of the ruby crystal are to be arranged

For this, both the ends of the ruby rod are highly polished and painted with silver ~~th~~ such that one end is fully reflecting and other end is partially reflecting. Both the reflecting surfaces are optically flat and are exactly parallel to each other.

Pumping system: Optical Pumping

For this, a helical Xenon flash lamp with a power supply to pump Cr^{+3} ions to high levels is used

- Ruby laser is a pulsed laser

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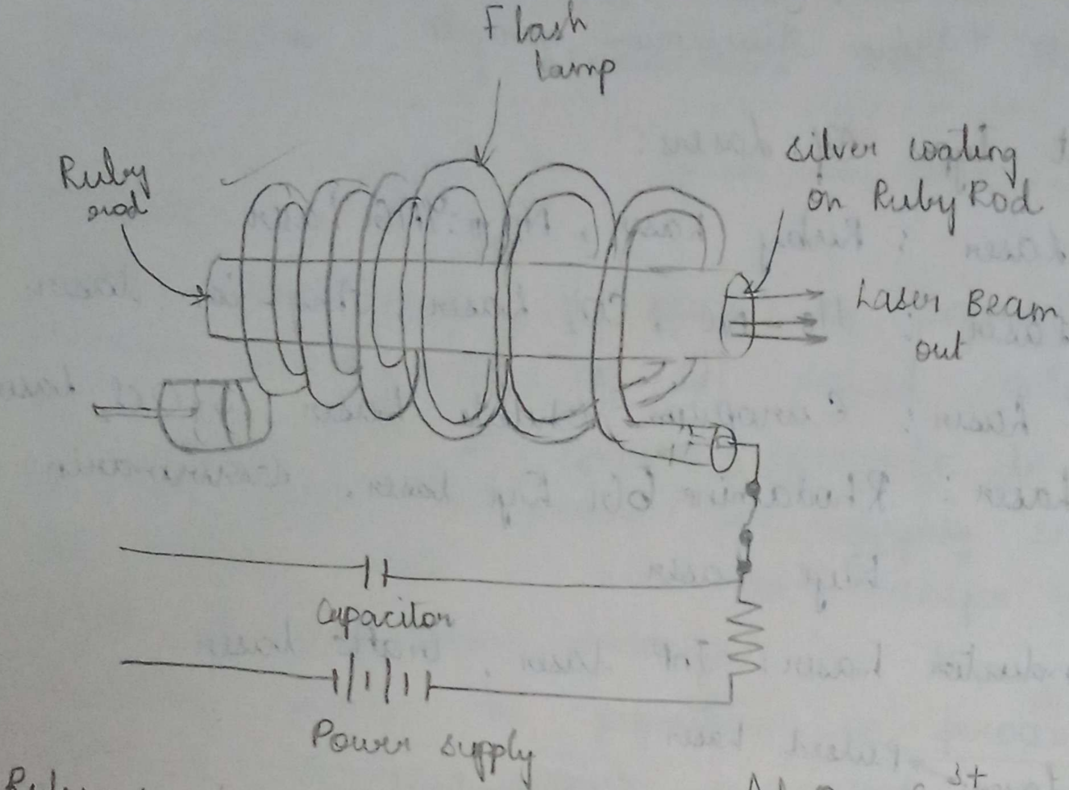
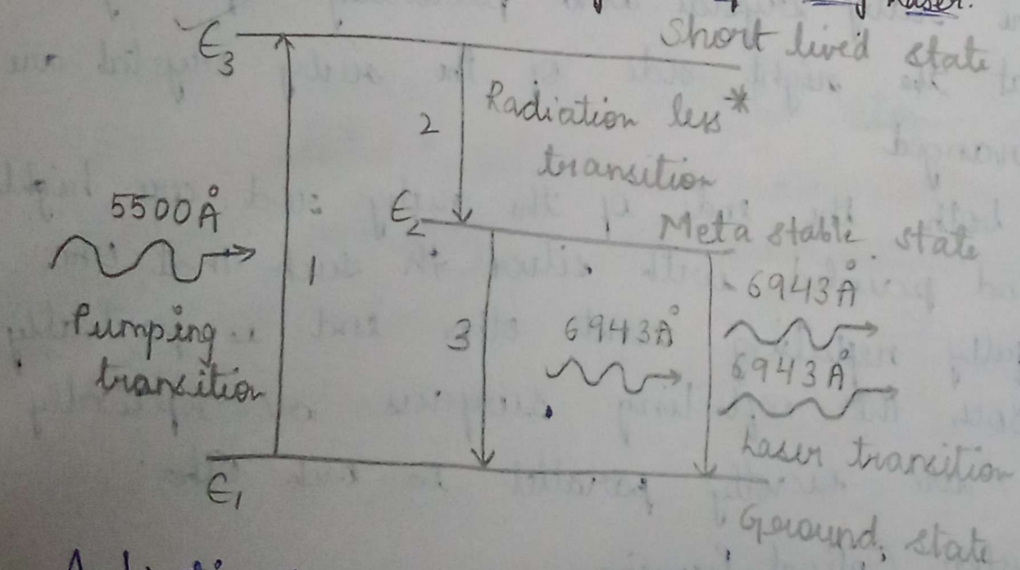


Ruby rod → 10cm - 30cm (length)
diameter → 1 - 5cm

$Al_2O_3 - Cr^{3+}$
(0.01 to 0.05 wt%)
98%

Energy level Diagram of Ruby Laser.



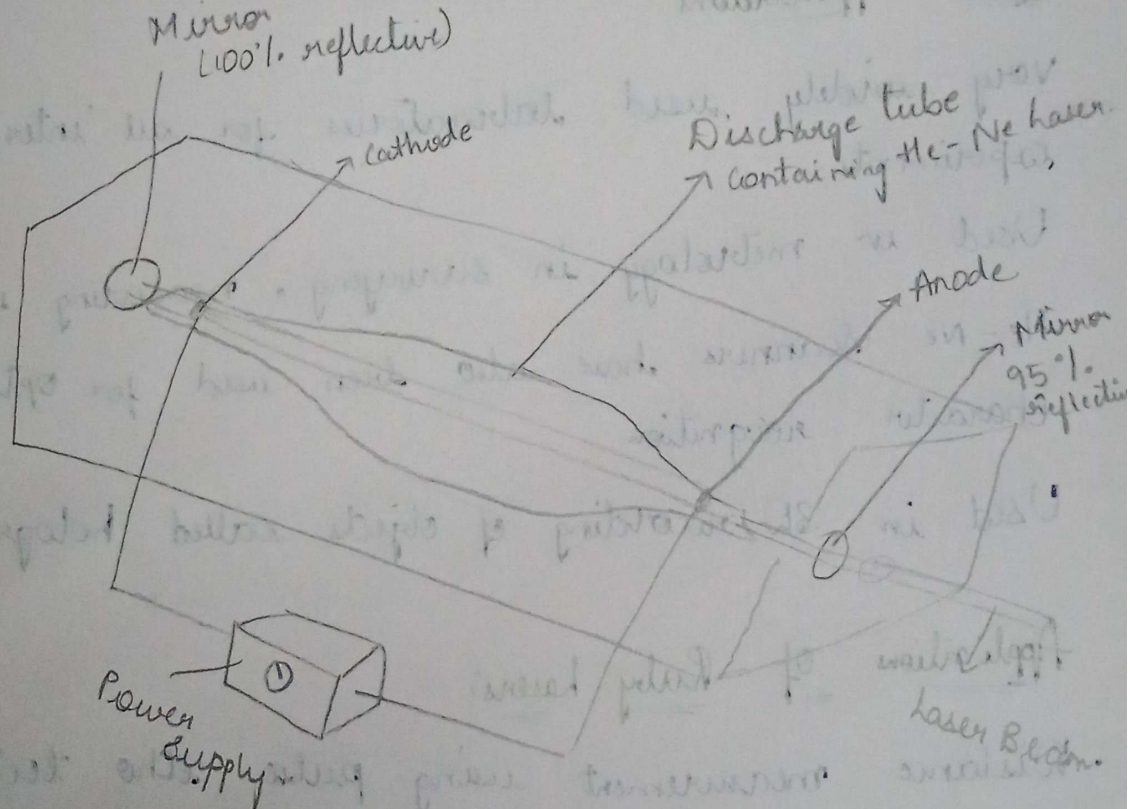
Applications:

* ~~Monography.~~
* holography.

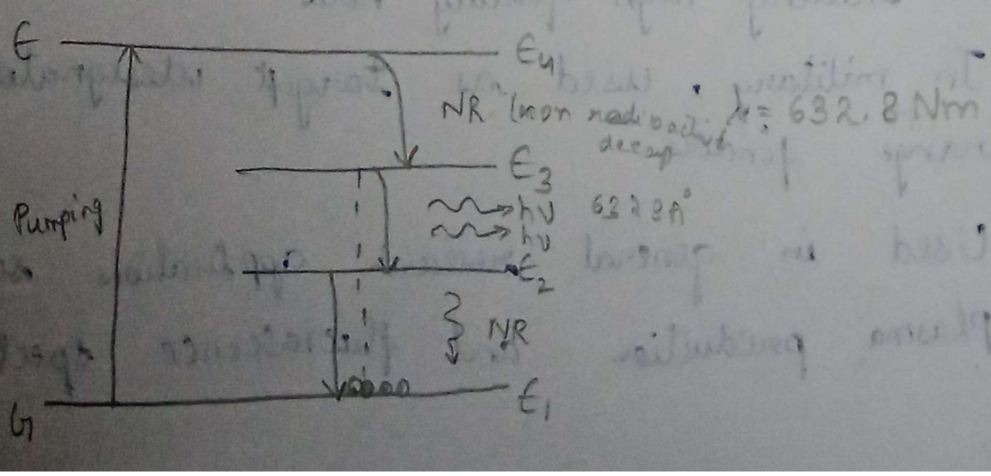
He-Ne structure is introduced by Dr. Ali Jawan in 1961's

He – Ne Laser. → continuous wave Laser. (10 : 1 ratio)

- Active material: He, Ne in the ratio {He – 1 mm of Hg, Ne – 0.1 mm of Hg}.
- Resonating cavity: One will have two mirrors at ends of discharge tube which are at Brewster's angle (RI = $\tan\theta$).
- Pumping system: Electrical discharge.



Energy level diagram of He–Ne Laser.



Lasing Action

Lasing action involves five steps

1) pumping
2) population inversion
3) Spontaneous Emission
4) Amplification
5) Oscillation

He Ne applications

Very widely used laboratories for all interferometer experiments.

Used in metrology in surveying, measuring etc.

He-Ne Scanners have also been used for optical Character recognition

Used in 3D recording of objects called holography.

Applications of Ruby Lasers:

- Distance measurement using pulse echo techique
- Pulsed holography.
- For drilling high quality holes.
- In military, used as target designators and range finders
- Used in general research applications such as plasma production and fluorescence spectroscopy.

1) Find the relative population of the two states in a ruby laser that produces a light beam of wavelength 6943 A° at 300K.

Sol: The population ratio is given by

$\lambda = 6943 A^\circ = 6943 \times 10^{-10} m$

$T = 3000$ ✓

$\frac{N_2}{N_1} = ?$

formula : $\frac{N_2}{N_1} = e^{-\frac{h\nu}{KT}}$

$\frac{N_2}{N_1} = e^{-\frac{hc}{\lambda KT}} = e^{-\left(\frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{1.38 \times 10^{-23} \times 300 \times 6943 \times 10^{-10}}\right)}$

$= e^{-69.1}$

2Q) For He-Ne laser at 1m and 2m distance from the laser the output beam spot diameters are 4 mm & 6 mm respectively. Calculate the divergence

$a_1 = 4 mm = 4 \times 10^{-3} m$

$a_2 = 6 mm = 6 \times 10^{-3} m$

$d_1 = 1$

$d_2 = 2m$

$\theta = ?$

formula : $\theta = \frac{a_2 - a_1}{2(d_2 - d_1)} = \frac{(6-4) \times 10^{-3}}{2(2-1)} = \frac{2 \times 10^{-3}}{2 \times 1} = 10^{-3}$ radius

3Q) A He-Ne laser emits light at a wavelength of 632.8 nm and has an output power of 2.3mW. How many photons are emitted in each minute by this laser when operating?

Sol

$\lambda = 632.8 nm = 632.8 \times 10^{-9} m$

$P = 2.3 mW = 2.3 \times 10^{-3} W$

$t = 1 min = 60 sec$

$n = ?$

Formula : $n = \frac{\text{Total energy emitted}}{\text{energy of each photon}}$

$T.E = P \times t = 2.3 \times 10^{-3} \times 60 = 13.8 \times 10^{-2} J$

$E = h\nu = \frac{hc}{\lambda} = \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}} = 3.14 \times 10^{-19} J$

$n = \frac{T.E}{E_p} = \frac{13.8 \times 10^{-2}}{3.14 \times 10^{-19}} = 4.3 \times 10^{+17}$ photons/sec

4.

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3.14×10^{-11}

4. Solve the wavelength of emitted radiation from GaAs which has a band gap of 1.44 eV.

Sol) Energy gap of a semiconductor $E_g = h\nu$
where 'h' is planck's constant $= 6.632 \times 10^{-34}$ J-s

$$E_g = h\nu = \frac{hc}{\lambda}$$

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

$$E_g = 1.44 eV = 1.44 \times 1.6 \times 10^{-19} J$$

$$E_g = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1.44 \times 1.6 \times 10^{-19}}$$

$$= 8633 \times 10^{-10} m = 8633 A^{\circ}.$$

5) A semiconductor laser diode laser has a wavelength of 1.55 μm. Estimate its energy gap in eV.

Energy gap of a semiconductor.

Energy of emitted photon, $E_g = h\nu = \frac{hc}{\lambda}$

c = velocity of light $= 3 \times 10^{8} m/s$

wavelength $\lambda = 1.55 \mu m = 1.55 \times 10^{-6} m$

Energy gap, $E_g = ?$

formula : $E_g = \frac{hc}{\lambda}$

$$= \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{155 \times 10^{-6}}$$

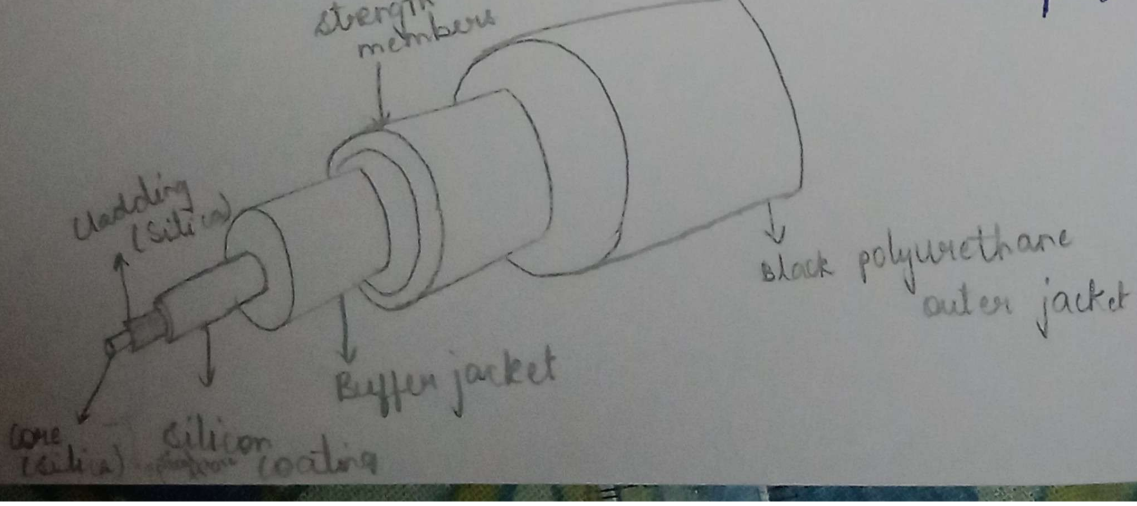
$$= \underline{\underline{1.28 \times 10^{-19}}} \text{ J}$$

$$E_g = \frac{1.28 \times 10^{-19}}{1.6 \times 10^{-19}} = 0.8 \text{ e.v}$$

Optical Fibre

Principle & constructions of Optical fibre

- **Core:** A typically cylinder glass material of diameter 50 µm surrounded by a clad.
- **Clad:** A glass material of slightly lower refractive index than core.
- **Silicon Coating:** It is provided between clad and buffer jacket in order to improve the quality of transmission of light.
- **Buffer jacket:** It is covered over silicon coating which is made up of plastic material and protects from moisture and abrasion.
- **Strength Members:** This layer is arranged over the buffer jacket to provide necessary toughness and tensile strength to the buffer.
- **Outer jacket:** Finally a black polyurethane outer jacket to avoid damages during hard pulling, bending, streching or rolling of the fibre in the real field.

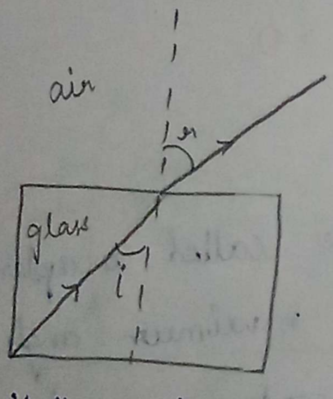


→ Fiber Optics is a branch of physics based on the transmission of light through transparent filters of glass or plastic.

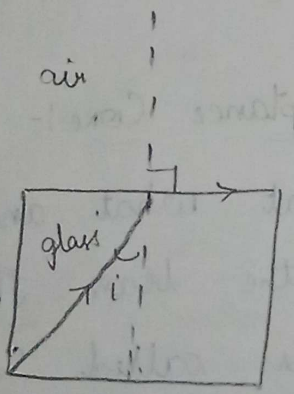
→ Optical fibre is a cylinder of transparent dielectric medium designed to guide visible and infrared light, over long distances

→ Optical fibre works on the principle of total internal reflection

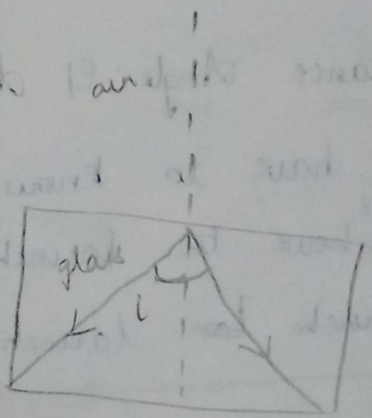
→ When a ray of light travels from a denser medium into a rarer medium and if angle of incidence is greater than the critical angle then the light gets ~~tottaly~~ totally reflected.



if the angle of incidence is less than critical angle, the light refracts away from the normal



If the angle of incidence is equal to the critical angle ~~of~~ the light refracts at 90° to the normal



If the angle of incidence is greater than the critical angle, total internal reflection occurs.

According to law of refraction

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

If $\theta_1 = \theta_c$

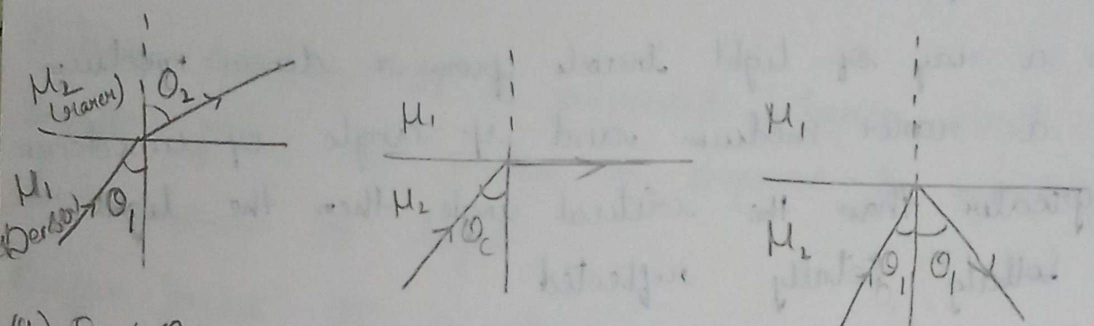
$\theta_2 = 90°$

So, $n_1 \sin\theta_c = n_2 \sin 90^\circ$

$\sin\theta_2 = n_2 / n_1$

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

As there is no loss of light energy during reflection optical fibers are designed to guide light wave over long distances



(a) $\theta_1 < \theta_c$ (b) $\theta_1 = \theta_c$ (c) $\theta_1 > \theta_c$

Acceptance Angle & Acceptance Cone:-

We have to know at what angle called acceptance angle we have to launch the beam. The maximum angle of ~~lanch~~ ~~lan~~ launch is called "acceptance angle".

For Snell's law we have

$n_0 \sin\alpha_i = n_1 \sin\alpha_r$

$n_0 \sin\alpha_i = n_1 \sin(90-\theta)$

$n_0 \sin\alpha_i = n_1 \cos\theta$

if θ is less than critical angle θ_c, the ray will be cost by refraction.

when $\theta = \theta_c$; $\alpha_r = \alpha_m$ = maximum 'α' value

Therefore, $\sin\alpha_m = \frac{n_1}{n_0}\cos\theta_c$

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

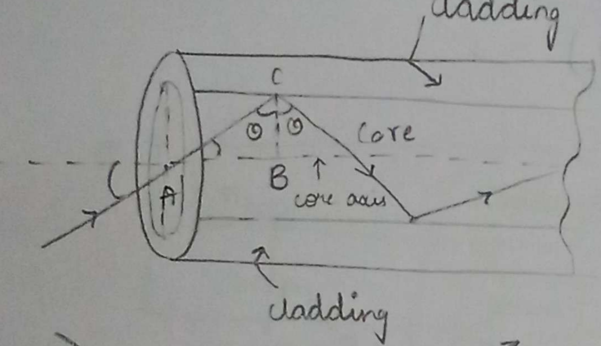
So, $\cos\theta_c = \sqrt{1 - \sin^2\theta_c} = \sqrt{1 - \frac{n_2^2}{n_1^2}}$

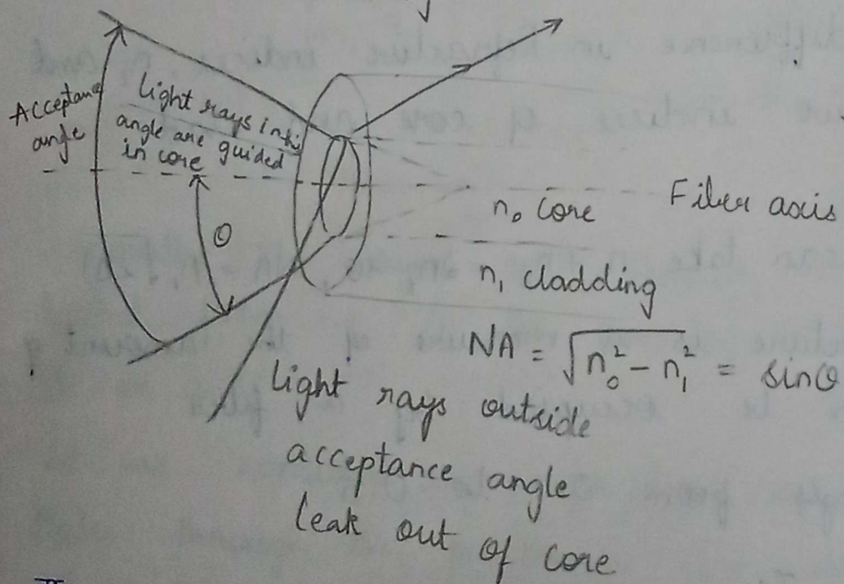
Therefore,

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

so, $n_0 \sin\alpha_m = \sqrt{n_1^2 - n_2^2}$ if $n_0 = 1$ {medium in air}

$$\sin\alpha_m = \sqrt{n_1^2 - n_2^2}$$





This maximum angle α_m is called acceptance angle (or) the acceptance cone half angle of the fibre. The acceptance angle may be defined as the maximum angle that a light ray can have with axis of the fibre and propagate through the fibre. Rotating acceptance angle about the fibre axis describes acceptance cone of the fibre

Numerical Aperture.

- The numerical aperture defines the acceptance angle more clearly.
- The sine of acceptance angle is called numerical aperture.

The value of Numerical Aperture, N_A is

$$NA = \sin \alpha_m = \sqrt{n_1^2 - n_2^2}$$
$$= \sqrt{(n_1+n_2)(n_1-n_2)}$$
$$= \sqrt{((n_1+n_2)n_1\Delta)}$$

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

is fractional diffrenence in Refractive indices, n_1 and n_2 are refractive indices of core and clad respectively.

As $n_1 \sim n_2$ we can take $n_1 + n_2 = 2n_1$ so, $NA = n_1\sqrt{2\Delta}$

- Numerical aperture is a measure of the amount of light that can be occupied by a fiber
- N_A values ranges from 0.1 to 0.5

Types Of Optical Fibres:

Depending on the relation b/w refractive indices of core and clad they are divided into two types Step index fibre and graded index fibre. Additional to these there are also single mode fibre and multimode fibre.

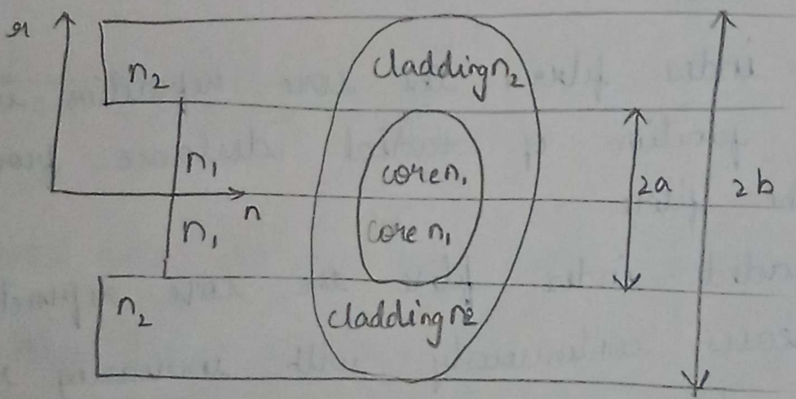
Step-index fibre:

- In the step-index fibre, the refractive index of core is uniform and undergoes an abrupt change (or) at the cladding boundary.

The refractive index profile may be defined as.

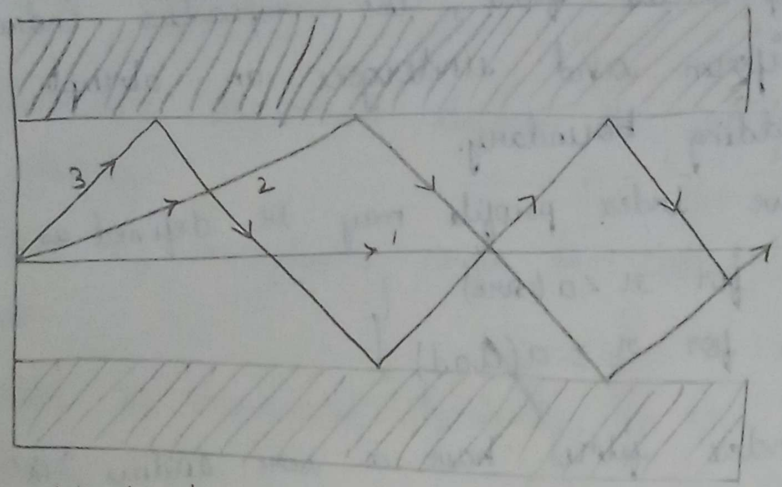
$$n(r) = \begin{cases} n_1 & \text{for } r < a \text{ (core)} \\ n_2 & \text{for } r \geq a \text{ (clad)} \end{cases}$$

The step index fibres have a core radius 'a' and $n_2 = n_1(1-\Delta)$ or $\Delta \approx \frac{n_1 - n_2}{n_1}$



- Generally the signal sent through the fibre is in digital form i.e. in the form of pulses representing 0's ~~in~~ and 1's.
- Let us consider the propagation of one, such ~~plane~~ Pulse through the multimode step index fibre.
- The same pulsed signal travels in different paths.
- If we see the diagram it is clear that ray '1' travels shorter distance and ray '3' travels longer distance.
- Hence, the three rays reach the recieved end at different times. Therefore, the pulsed signal received at the other end gets broadend. This is called

inter modal dispersion



Signal transmission in step index fiber

Grad - Index fiber:

- In graded - index fiber, the core refractive index varies as a function of radial distance from the centre of the fibre
- In the graded - index fibre the core refractive index decreases continuously with increasing radial distance 'r' from the centre of the fibre, but is generally const in the cladding

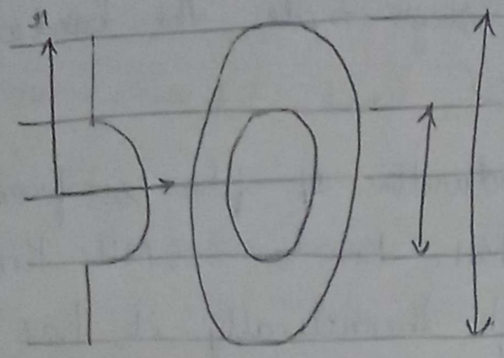
The most commonly used construction for the RI variation in the core is given by

$$n(r) = \begin{cases} n_1[1 - 2\Delta(r/a)^{\alpha}]^{1/2} & \text{for } r < a \text{ (core)} \\ n_1[1-2\Delta]^{1/2} \approx n_1(1-\Delta) = n_2 & \text{for } r \geq a \text{ (clad)} \end{cases}$$

where n_1 = RI of the core at the centre

a = radius of core, α = grading profile of RI in the core material.

$\Delta = \dfrac{n_1 - n_2}{n_1}$ = fractional total change of the core RI, $\alpha \approx 2$



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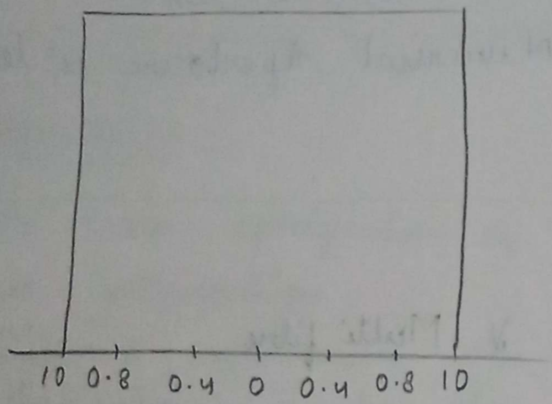

*** Difference b/w ~~set~~ step-Index and Grad-Index fibre

Step Index fibre	Grad-Index fibre
* The RI of the core is uniform throughout and undergoes sudden change at cladding boundary.	* The RI of the ~~code~~ core is made to vary in parabolic manner such that the maximum RI is present at the centre of core.
* The diameter of core is about 100μm for multimode fibre and 10μm for single mode fibre.	* The diameter of the core is about 50μm in case of multimode fibre.
* The light rays propagating through it are in the form of meridional rays.	* The light rays propagating are mainly skew rays, which follow a helical path.
* Signal distortion is more in multi mode step index fibre.	* Signal distortion is low because of self-focusing effect.

* Bandwidth of step-index fiber is about 50MHz Km for multimode step-index fibre, but for single mode, the bandwidth is more than 1000 MHz Km

	Grad - Index
* Attenuation is more for multimode step index fibre	* Bandwidth of fiber is from 200MHz Km to 600MHz Km even though theoretically it has infinite bandwidth
* Numerical apperature for multimode Si fibre but for single mode it is very less.	* Attentuation is less.
	* Numerical Aperture is less

** Difference b/w Single Mode & Multi fibre

Single Mode fiber	Multimode fibre
* In single mode fiber only one mode (HE_{11}) can propagate through the fibre	* Multimode fibre allows a large number of paths or modes for the light rays travelling through it
* The condition for single mode operation is given by V-number, given as $V = 2\pi / \lambda n_1 a\sqrt{2\Delta}$; $V \leq 2.405$	* Here $V > 2.405$ (V-no - of the normalized frequency Parameter of a fibre)
* The single mode fiber has smaller core diameter <10μm and the ~~ri~~ difference b/w RI of core & cladding is very small.	* In multimode fibre the core diameter and the relative refractive index difference are more than the single mode fiber
* There is no dispersion. (Spreading of light)	* There will be some dispersion

* The single mode fibres are more suitable for long distance communication.	* These fibres are used in local area networks.
* Launching of light into single mode fiber and splicing ^joining together^ of two fibers is very difficult.	* Launching of light into fibre & splicing of two fibres is easy.
* Fabrication is very difficult and fiber is costly.	* Fabrication is easy & the fiber is cheaper.

Attenuation:

→ The main specification of ~~op~~ fibre optic cable is its attenuation.

→ Different mechanisms are responsible for signal attenuation in the fiber.

→ The attenuation of the signal is measured in Decibel / Km

→ Signal attenuation is defined as ratio of input optical power P_i into fiber to the output recieved optical power P_o from the fibre

→ The attenuation coefficient of the signal per unit length is given as

$$\boxed{\alpha = \frac{10}{L} \log \frac{P_i}{P_o} \ dB/Km}$$

** for sums

- Absoption loss.
- Scattering loss
- Binding Loss
- Transmission Loss

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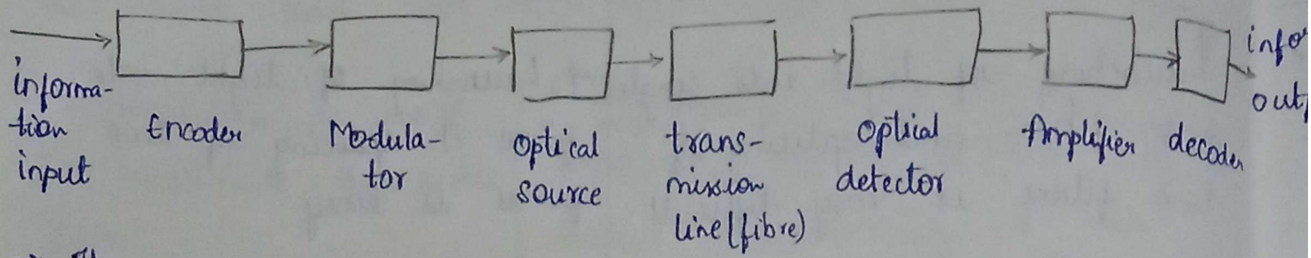
Optical fibre Communication System



→ The above fig shows the imp components of an optical fiber communication system

→ Transmitter consits of a information encoder which converts the information signal into coded pulses. Then there is modulator which controls the operation of optical source.

→ The emitted light from the source is coupled to the fiber optic cable which constitutes the transmission medium.

→ The light emerging from the other end of The optical fibre cable is given to the optical detector which converts light into electrical signal

→ The optical detector, amplifier and decoder or demodulator constitutes the receiver.

→ Amplifier amplifies the detected electrical signal and then the amplified signals ~~or~~ are decoded to original information.

→ The optical sources are semiconductor laser diodes and LED.

→ The optical detectors are PIN photo diodes and ~~avalche~~ avalanche photodiodes.

* Consider an optical fibre of core refractive index 1.48 & fractional index difference 0.05. Obtain the clad RI and Numerical aperture.

information} output

$$\Delta = \frac{n_1 - n_2}{n_1} = 0.05 \qquad n_1 = 1.48$$

* A step-index fiber is made with a core of refractive index 1.52, a diameter of 29 μm a fractional difference index of 0.0007. It is operated at a wavelength of 1.3 μm. find the V-number & the no. of modes that the fibre will support.

6) A step index fibre has a numerical aperture of 0.16 and core refractive index of 1.45. Estimate the acceptance angle of the fiber & refractive index of the cladding.

Sol: Given, NA = 0.16,
RI of core, $n_1 = 1.45$,

we have to find, acceptance angle, $i_{max} = ?$
RI of cladding, $n_2 = ?$

from, $i_{max} = \sin^{-1}(NA)$

$= \sin^{-1}(0.16)$

$= 9.206°$

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

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

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

$$n_2 = \sqrt{n_1^2 - NA^2} = \sqrt{(1.45)^2 - (0.16)^2}$$

$$= \sqrt{2.1025 - 0.0256}$$

$$= 1.44$$

7) The

7) The refractive indices of core and cladding material of a step index fibre are 1.48 and 1.45. Simulate 1) Numerical aperture 2) Acceptance angle

Sol: Given: RI of core = 1.48

R.I of Cladding = 1.45

We have to find, Numerical Aperture, NA = ?

acceptance angle i_{max} = ?

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.48)^2 - (1.45)^2} = 0.2965$$

$$i_{max} = \sin^{-1}(NA) = \sin^{-1}(0.2965) = 17°15'.$$

8) A optical fiber has a numerical aperature of 0.2 and cladding R.I of 1.59. Find the acceptance angle for the fibre in water which has a R.I of 1.33.

Sol: Given: NA = 0.2,

RI of Cladding, n_2 = 1.59

R.I of water, n_0 = 1.33

i_{max} = ?

$$NA = \sqrt{n_1^2 - n_2^2} = 0.2$$

in water, $NA = \sin^{-1}(i_{max})$

$$= \frac{\sqrt{n_1^2 - n_2^2}}{n_1} = \frac{0.2}{1.33} = 0.1504$$

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

$$= \sin^{-1}(0.1504)$$

$$= 8.65°$$

9) Calculate the fractional index change for a given optical fiber if the refractive indices of the core & the cladding are 1.563 and 1.498.

Sol: Given: RI of core, $n_1 = 1.563$

R.I of cladding, $n_2 = 1.498$

fractional index change, $\Delta = ?$

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

$= \frac{1.563 - 1.498}{1.563}$

$= 0.0416.$

10) When the mean optical power launched into an 8Km length of fiber is 120 μW. The mean optical fiber power at the fiber output is 3 μW. Find the overall signal attenuation and signal attenuation per Km.

Sol: A) overall signal attenuation or loss in decibels through the fibre is given by.

Signal attenuation $(\alpha_{dB} L) = 10 \log_{10} \frac{P_i}{P_o}$

$= 10 \log_{10} (120 \times 10^{-6} / 3 \times 10^{-6})$

$= 10 \log_{10} 40 = 16.0 dB$

B) The signal attenuation per Km for the fibers is given

$\alpha_{dB} L = 16.0 dB$

As $L = 8 Km$

$\therefore \alpha_{dB} = 16.0/8$

$\alpha_{dB} = 2.0 dB/Km.$