Lasers

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2. Define: (i) Population Inversion
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   (iii) Spontaneous emission
   (iv) Stimulated emission
   (v) Pumping

3. Discuss briefly the components of a laser – (i) Laser medium
   (ii) Pump
   (iii) Optical Resonator

4. Name various kinds of pumping.

5. Discuss 3-level and 4-level laser.

6. Discuss Einstein's theory of radiations and find relationship among three Einstein coefficients; B_{12}, B_{21} & A_{21}. i.e. prove

$$B_{12} = B_{21}$$

and

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3}{c^3}$$

7. Discuss construction & working of
(i) Ruby Laser (ii) He-Ne laser
(iii) CO_2 laser (iv) Semiconductor/diode laser.

8. Applications of lasers

Optical fibers (OF) → Give advantages of OF over copper cable.

1. Define TIR.

2. Define acceptance angle & numerical aperture of an OF. Find relation between the two.
   i.e. Show that $\theta_0 = \sin^{-1} \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$

3. Discuss the structure or component layers of an OF — (i) Core
   (ii) Clad
   (iii) Protective Sheath

4. Define — (i) fractional change in refractive index (Δ)
   (ii) Index profile
   (iii) Mode of an OF

5. Classification of OF
   - based on index profile
     - I) Step Index
     - Graded (GRIN) Index
   - Based on no. of modes
     - Single mode fiber (SMF)
     - Multimode fiber (MMF)

6. losses in an OF → $\alpha = \frac{10}{L} \log_{10} \frac{P_{in}}{P_{out}}$
   (discuss briefly various losses.) (no need to derive)

7. Explain briefly – Splice (2 marks each)
Connector
Coupler

8. Application of OF

9. V-no. of an OF.

$$V = \frac{2\pi a}{\lambda} \times N.A.$$

$a \rightarrow$ core radius

$\lambda \rightarrow$ wavelength of the carrier wave

$NA \rightarrow$ Numerical Aperture

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

n_1 is ref. index of core

n_2 is ref. index of clad.

Cut off value of $V = 2.405$

If $V < 2.405 \rightarrow$ fiber is SMF

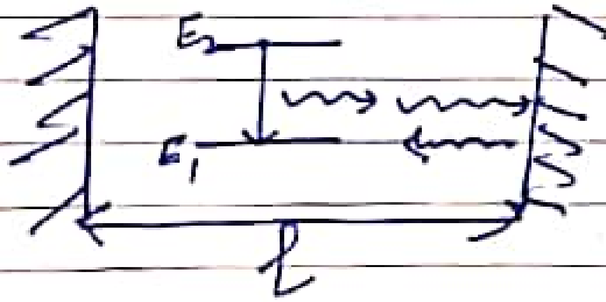
If $V > 2.405 \rightarrow$ fiber is MMF.

Check notes on your e-mail or guru portal.

Prepare final papers (previous years) thoroughly.

Q. How to decide which λ we have to consider, when there are multiple emissions in He-Ne, CO_2 etc?

Ans. Here comes the role of optical resonator, In which two mirrors are facing each other forming a cavity. One mirror is 100% reflecting & other is partially reflecting & partially transparent.



$l \to$ distance b/w two mirrors.

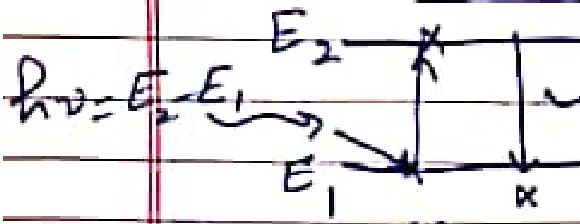
When photon is emitted, it hits one of the mirror and gets reflected back. When incident & reflected photons interfere, standing waves are formed. The condition for the same is

$$2l = n\lambda \quad , \quad n = 1, 2, 3 \ldots$$

Now l is fixed, so λ is fixed. If there are multiple transition then only that wavelength will be amplified max for which $2l = \lambda$ & $n=1$ and for other values slowly n slowly photons will be destructed via collisions.

3-level, 4-level laser discussion

① For emission, two levels are reqd.



$h\nu = E_2 - E_1$, here emission will be spontaneous and it is really difficult to have stimulated emission with only two levels.
Before going to 3-level, lets discuss various possibilities of 2-level laser.

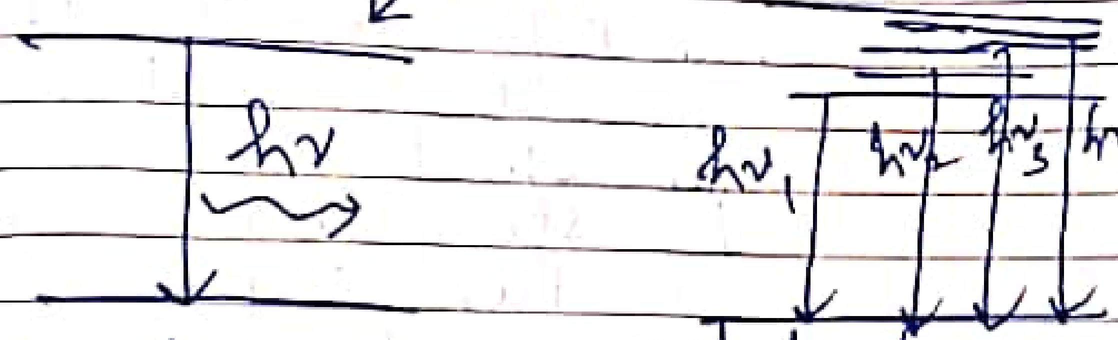
(i) Note I/p energy = O/p energy

∴ efficiency $\eta = 1$ which is an ideal case, practically not possible.

(II) When a photon of energy $h\nu = E_2 - E_1$ is made incident, this photon has two choices: either it can take electron in E_1 upstairs or it can bring e^- in E_2 downstairs.
So probability for both the steps is same ($B_{12} = B_{21}$).

But for laser $B_{21} > B_{12}$ i.e stimulated emission should dominate over all other processes.
So, it becomes difficult with two levels to have population inversion ($N_2 > N_1$). We will be having $N_1 = N_2$ because of equal probability.

(iii) Moreover, for lasing action to be there, excited state should be metastable. i.e excited state should preferably be single state so that emission is monochromatic.



monochromatic emission (laser)

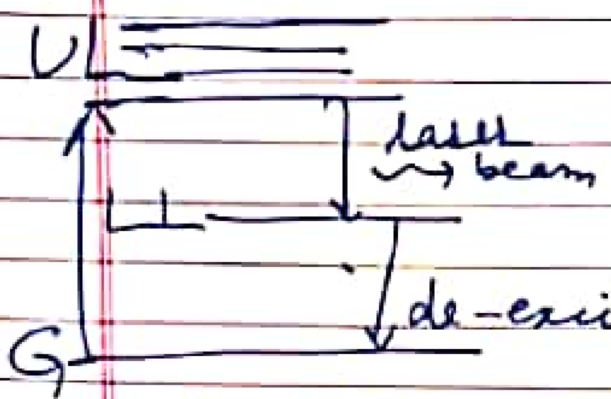
polychromatic if excited state is in the form of band. (normal light)

But for efficient pumping, excited state should be in the form of band. It becomes contradictory either the excited state will be single or it will be band.

(iv) Also ~~life~~ E_1 happens to be ground state, it will be the most stable state, so huge amount of work will have to be done (once the particle is back to ground state) to excite the particle.

So with 2 levels, emission can be there, but we can't have lasing action.

(a) 3-level



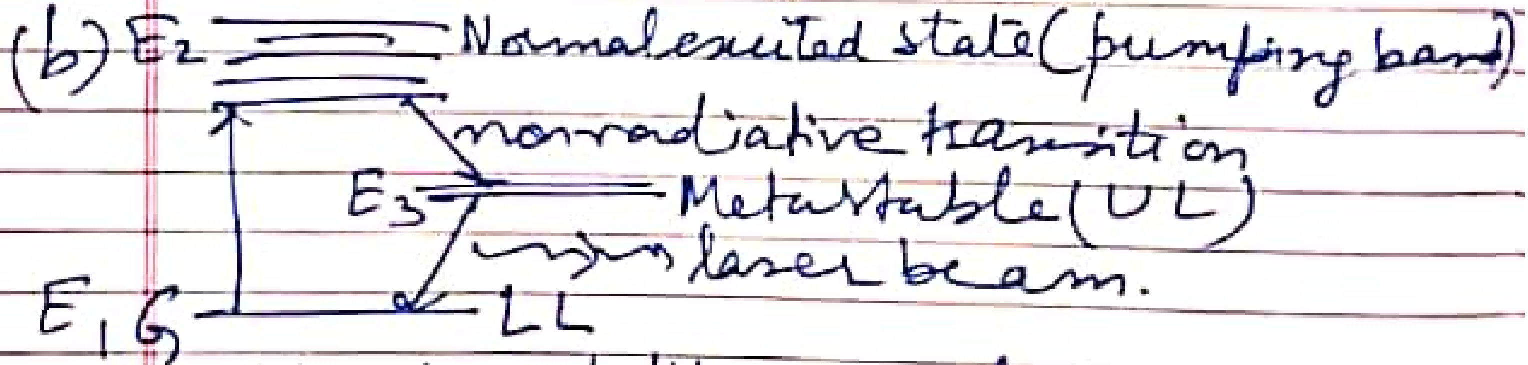
UL → upper lasing level (should be metastable)

LL → lower lasing level

G → Ground state

Now see, excited state has to act like pumping band (where e⁻s will reach after gaining energy from pump) as well as metastable state! which is contradictory as discussed in 2-level case.
So this possibility will not work.

(b)

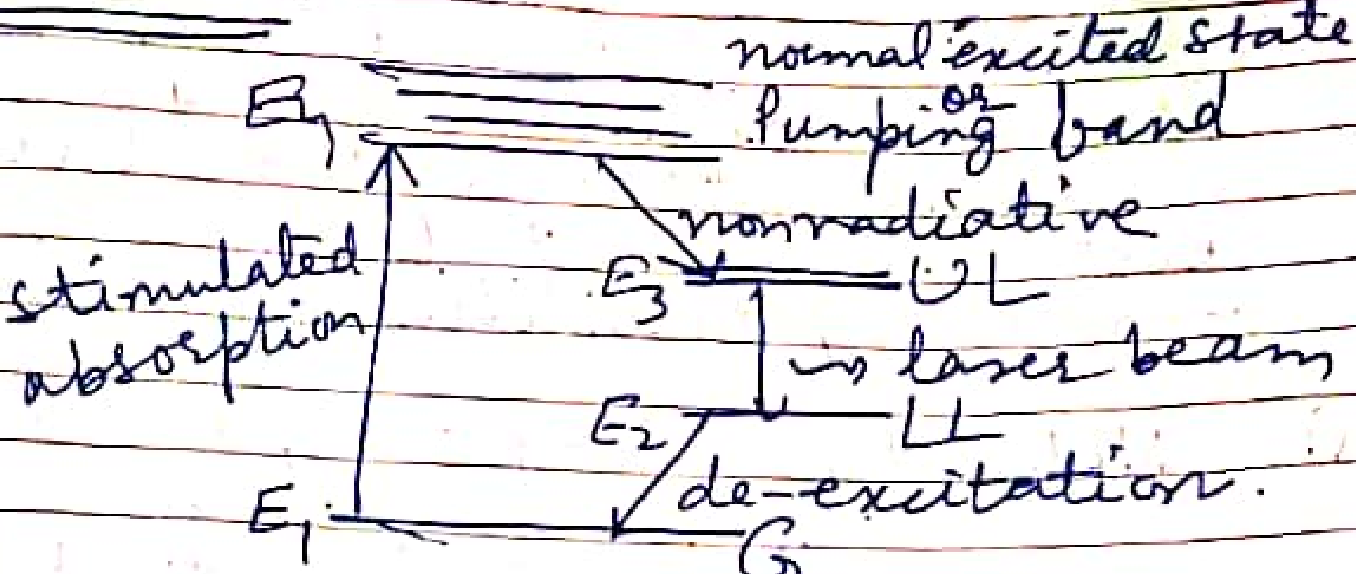


This possibility of 3-level is OK.
e⁻s are pumped to pumping band from there via collisions they jump to metastable state which will have longer lifetime than excited state. Particles will stay there for longer time, population inversion will be achieved w.r.t. LL. From UL to LL lasing action will take place.
LL is same as ground state.

$$\eta_{3\,\text{level}} = \frac{E_3 - E_1}{E_2 - E_1} < \eta_{2\,\text{level}} = 1$$

but we have laser action

4-level



All the four levels (G, LL, UL, pumping state) are separately defined so it is case of an ideal laser.

$$\eta_{4\text{-level}} = \frac{E_4 - E_1}{E_3 - E_2} < \eta_{3\text{-level}}$$

Efficiency of 4-level laser is the least, but it is an ideal laser.

Pump → supplies resonant energy to excite e's from lower state to excited state.

E_2

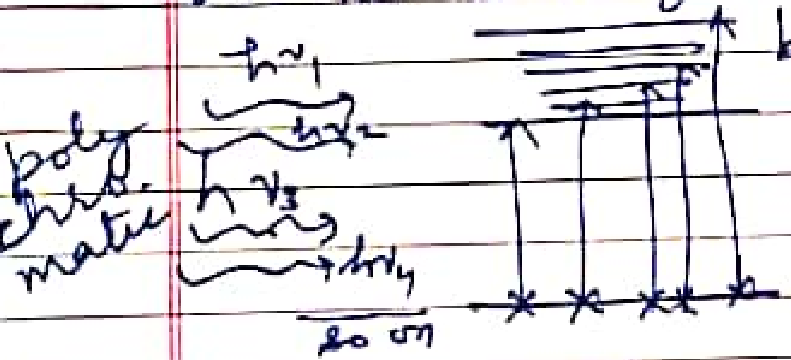
$h\nu = E_2 - E_1$

monochromatic

E_1

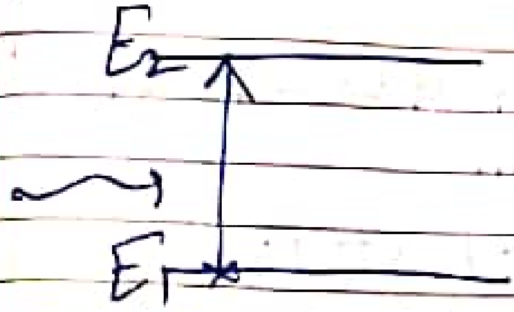
Clearly in this case monochromatic value of energy will be made incident but monochromatic energy will be given by laser only i.e. to make laser, laser is reqd. to excite electrons.

Now note beta ji, excited state will usually be in the form band in case of solids.



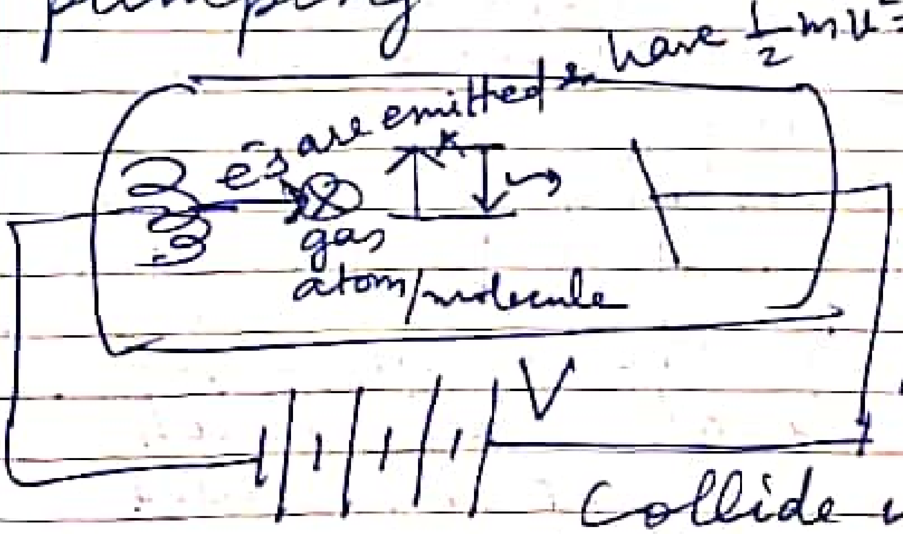
So we can't make monochromatic energy incident in such a case. We make use of polychromatic radiation with different wave-lengths here so that different e's in lower state will absorb different energy photons and will be excited to different states in ~~a~~ a ~~excited~~ band. This will maximize the efficiency of the pump. It is very easy to have polychromatic light from normal source like xenon lamp so on.

But in case of gases, band formation is either absent (Ideal gases) or is least (real gases).



Case of gases — no or less band formation.

Clearly sharp value of energy $E_2 - E_1$ is required to excite gas atoms or molecules. Now we can't make use of laser as a pump to make laser. So in case of gases, we make use of electric discharge pumping.



first electrons are energized with reqd. value of energy. These e^-s will collide with gas atoms/molecules & will transfer their energy to gas atoms/molecules which will go to excited state and will give lasing action.

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In CO_2 laser, it is the combination of CO_2, N_2 and He as well

$CO_2 \rightarrow$ active med.

$N_2 \longrightarrow$ supporting (host) medium

He $\longrightarrow$ is added to increase the number density so that CO_2 in excited state can collide with He to come back to ground state. 'He' is very good heat absorber.

$CO_2 : N_2 : He :: 1 : 2 : 3$

This conc. ratio is to be decided depending on the length and diameter of the discharge tube so that pressure exerted by the gases molecules is fixed in such a way that band formation is least.

In He-Ne laser, this ratio is usually 5 : 1 to 10 : 1
He Ne He Ne

Laser → stimulatedemission

↓

population inversion

created by → pump

maintained by. → metastable state

pump → is a device which supplies energy to the laser medium such that $h\nu = E_2 - E_1$

can be of many types

(i) optical (ii) electricdischarge

(iii) electric (iv) chemical

metastable state → lifetime ~ 10^{-3} sec.

LASER → Light Amplification by Stimulated emission of radiation.

Light → em radiation (400-800 nm)

Amplification → to increase intensity of photons by making them move in one particular direction (beam)

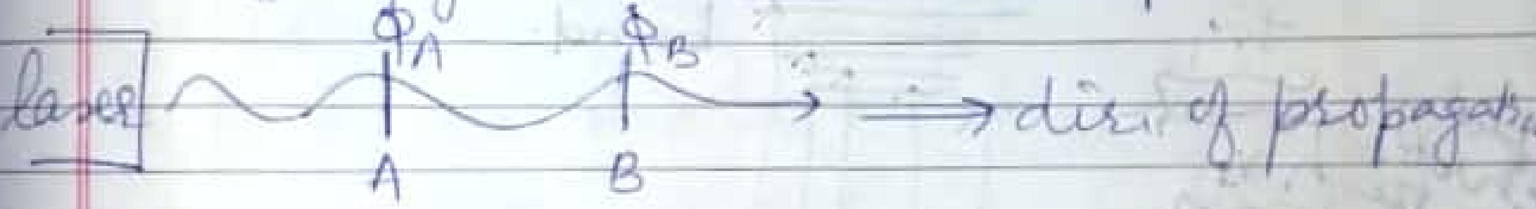
Also note $I \propto A^2$

Stimulated emission → which takes place with external help

Coherence → phase diff. between two waves is either zero or constant.

Coherence is of two types

(i) Longitudinal or temporal



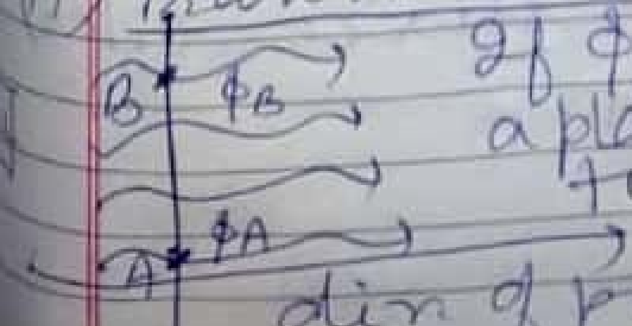
ϕ_A, ϕ_B → phase at pt. A & at pt. B

A & B are two pts. along the dir. of propagation of light.

If $\phi_A - \phi_B$ is constant for all waves or photons emitted by the laser, then it is longitudinal or temporal coherence.

It will simply lead to mono-chromatic nature of laser.

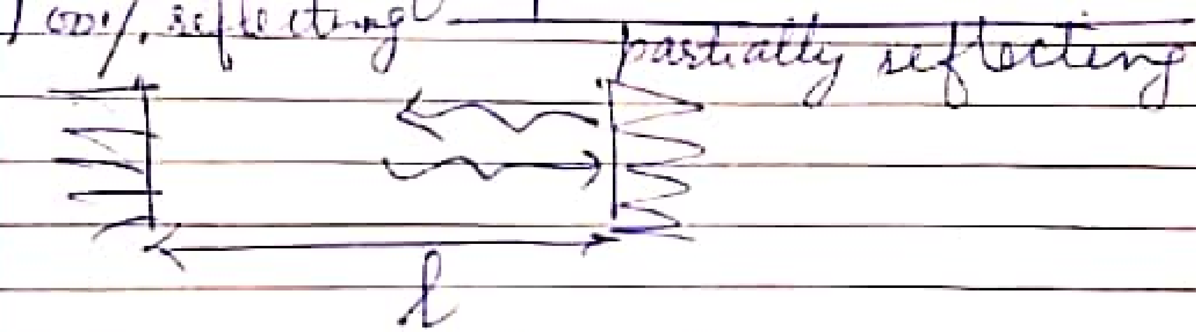
(ii) Transverse or spatial



If $\phi_A - \phi_B$ is constant along a plane or dir. perpendicular to dir. of propagation

then it is called transverse or spatial coherence.
It will control the brightness or intensity of the laser beam.

Functions of optical Resonator



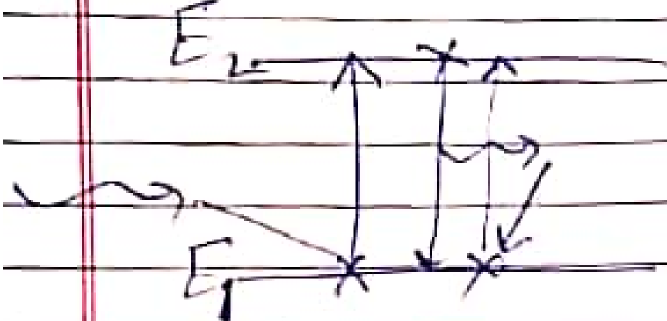
(i) It makes the photons move to and fro between two mirrors and increases the intensity of the photons moving in one particular direction. It is for this reason LASER is also known as LOSER because amplification (A) is due to oscillations (O) of the photons.

(ii) It helps us to select one particular wavelength to be amplified by making use of

$$2l = n\lambda$$ (standing wave eqn.)

$n = 1, 2, 3$

Radiation Trapping:



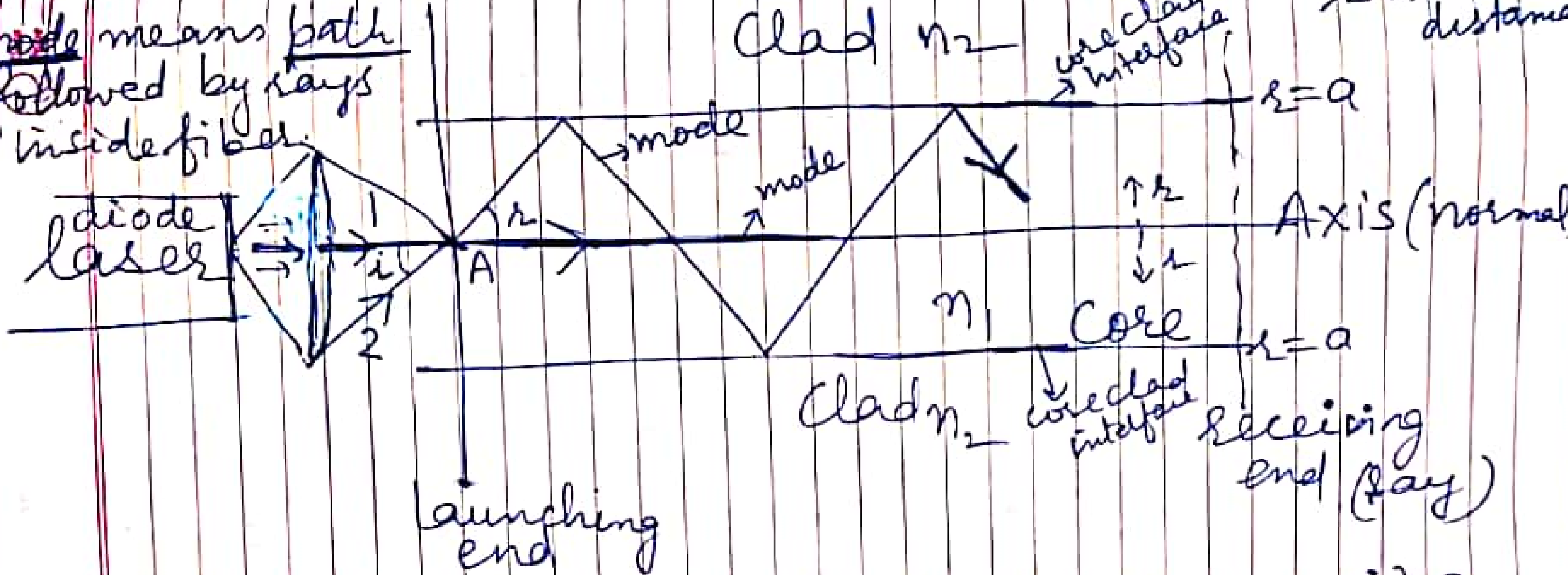
When we consider two levels and if the life time of lower level is quite large (like ground state) then after de-excitation the emitted photon is absorbed by another $\bar{e}$ in lower state So radiation instead of coming out of the system, gets trapped b/w two levels.

To avoid this trapping, we have to mix two types of atoms/molecules like, He+Ne, CO_2+N_2.
'He' alone can't give lasing action because radiation gets trapped b/w two levels of Helium. When He, after de-excitation comes down, the emitted energy will be absorbed by Ne which will give lasing action. Only thing is energy levels of the two should match with other.

$n_1 \rightarrow$ Refractive index of core, constant & uniform
$n_2 \rightarrow$ " " " Clad, " "

$r \rightarrow$ radial distance

<u>mode</u> means <u>path</u> followed by rays inside fiber.



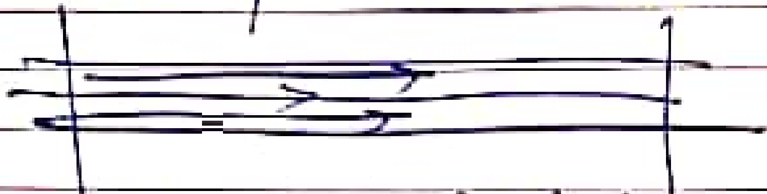
<u>Ray 1</u> goes along axis (angle of incidence $= 0°$) & follows straight line path as ref: index is uniform, it will take smallest time to come out of fiber.

<u>Ray 2</u> makes some angle i with axis will suffer refraction at pt. A and thus follow zig zag path. This path is longer than st. line path.

Now both the rays entered at same time inside the fiber. Ref. Index (opposition) is also the same inside the core.
Clearly Ray 2 will take more time to come out of fiber than ray 1. So Ray 1 will have to wait for Ray 2 to come out, otherwise intensity will decrease. This wait in terms of time is expressed in terms of Pulse Dispersion. It is expressed in ns/km. i.e. after travelling 1 km length of fiber how much time gap has been introduced among different rays.
Second pulse cannot be introduced in the fiber till the first pulse comes out of the fiber completely. This will decrease the speed of data transfer.

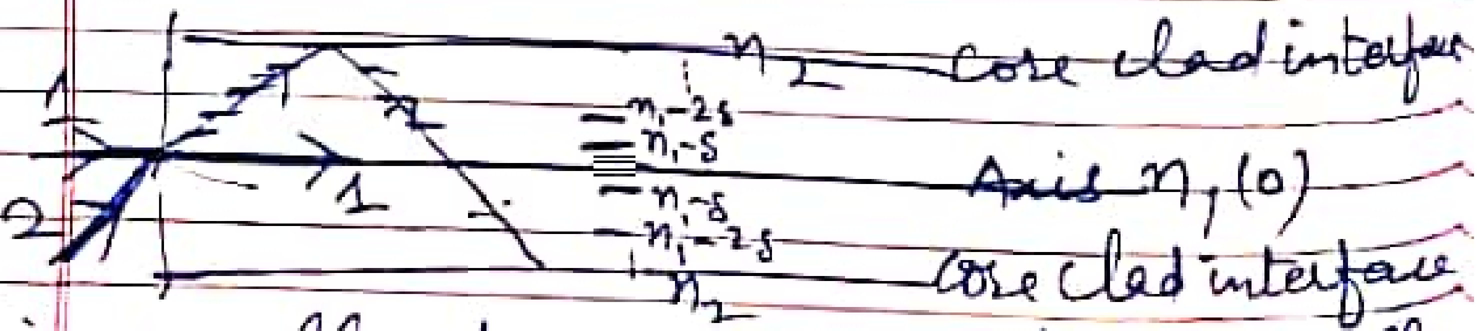
Pulse dispersion canbe solved in two ways

(i) either reduce the diameter of core to such a value that only one type of mode prevails inside the core.



then there will be no time gap. Such fiber is called Single mode fiber. otherwise fiber will be multi mode fiber.

(ii) or make the ref. index of core n_1 variable as a fn. of radial distance 'r'. Ref. index of core n_1 will decrease as we move from axis towards core clad interface. Say 'δ'



is small change in ref. index n_1 (decrease)

If n_1 is constant & uniform, then ~~fiber~~ fiber is Step index (SI) fiber

It will keep on dec. slowly & slowly till n_1 becomes $= n_2$ at core clad interface. This fiber is Graded Index fiber (GRIN)

Everytime time ray will enter from denser to rarer medium and will bend away from normal.

Now Ray 1 will face max. Ref. Index $n_1(0)$ i.e max. Opposition and Ray 2 will face comparatively less opposition as compared to Ray 1 as $n_1(0)$ is max. & then it keeps on decreasing.

On the average both rays will take nearly the same time to reach the end of fiber & dispersion will be reduced.

Remember $v = \frac{c}{n_1}$, now n_1 is variable, so will be v & so will be time.