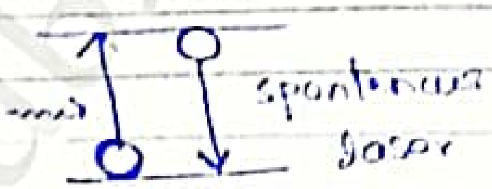
LASER PHYSICS:-

Light Amplification by stimulated emission of radi-ation 1900 started by Einstein (Light emit in discrete nature it is from maxwell) Light fall on material ⟶ electron emit ⟶ are in discreate form

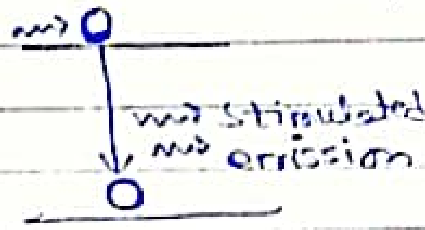
When material absorb light state.

Charles Town first gives the idea of lasers (light can be amplified in microwave region) than normal laser.



UV Laser.

Helium Neon laser 1100-5001Å (light emit)



In electromagnetic region, amplifies all light. 1960, Theofore mainon used Ruby by flash lamp ⟶ excitation ⟶ Lower energy level to life time ⟶ then in this life time any of photon strike ⟶ so laser produced. ⟶ Active medium ⟶ optical Resonator ⟶ pumping source.

1 cm ⟶ Ruby Rod.

- Flash Lamp ⟶ initial pumping source

⟶ Every material has own energy level and excitation levels ⟶ Some specific materials have active medium.

1967 → Q switching concept

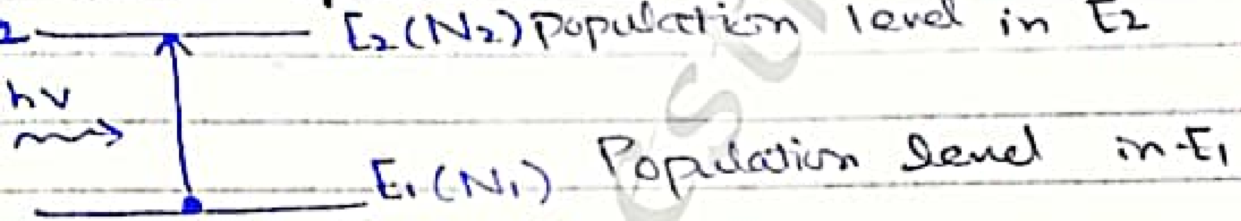
- → laser ka andar intensity ↑ by using (shutter) → chemical e.t.c.
- → Specific time tak reflection.

Mode locking 1963 (remove the tumor)

→ laser used in different things are much better than other techniques.

There are main 3 processes of laser. (Principle of laser Ch#1)

1) Absorption:



There is a change in population of the level E_1 and also there is a change in level E_2 during the absorption.

$$-\frac{dN_1}{dt} \propto N_1$$

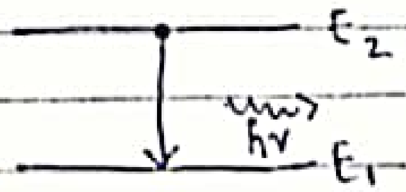
$$\boxed{-\frac{dN_1}{dt} = W_{12}}$$

← −ve sign → Decrease in population of level 1

change in level 1 due to absorption.

In cross-sectional area: $W_{12} = \sigma_{12} F$

2) Emission: (Spontaneous Emission)



Rate of change of level 2 :

$$-\frac{dN_2}{dt} \propto N_2$$

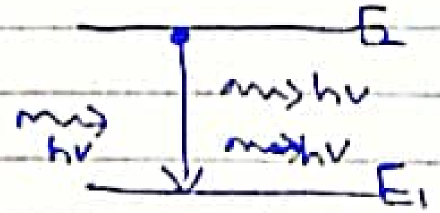
$$-\frac{dN_2}{dt} = A_{21} N_2$$ Spontaneous emission probability

$$\boxed{\frac{dN_2}{dt} = -A_{21} N_2}$$

A_{21} is the coefficient of spontaneous emission.

3) STIMULATED EMISSION:

The phase of two photon will be same.



This photon hit this atom and are deexited and move from upper to lower level.

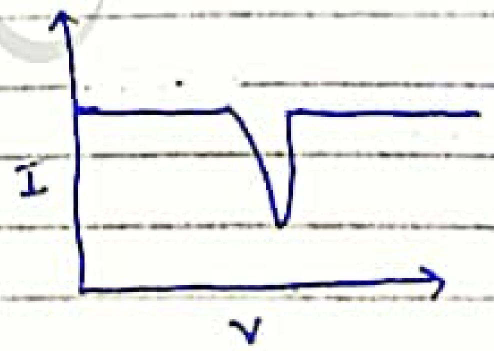
$$-\frac{dN_2}{dt} \propto N_2$$

$$\boxed{-\frac{dN_2}{dt} = -W_{21} N_2}$$

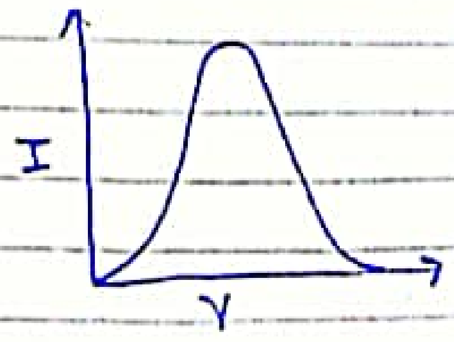
$W_{21} = \sigma_{21} F$ → cross-sectional area.

W_{21} is the coefficient of stimulated emission.

Absorption Graph



Spontaneous Emission.



$\omega_{21} F(N_2 - g_2/g_1 N_1) > 0$

$$\boxed{N_2 > \frac{g_2 N_1}{g_1}}$$

Active medium behave like amplifer.

Absorber:-

Population of level 2 is less than population level 1

$$\frac{dF}{dz} < 0$$

$$\boxed{N_2 < \frac{g_2 N_1}{g_1}}$$

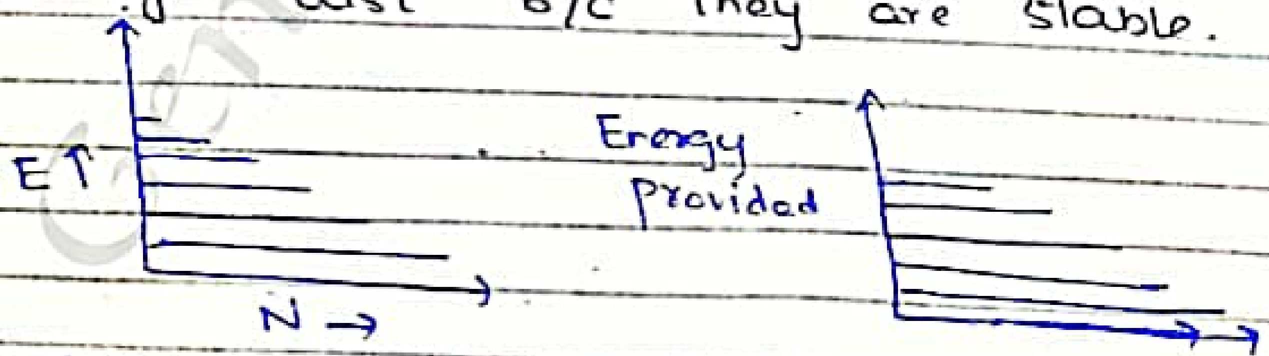
Active medium behave like absorber.

Practical laser → flash lamp → time lag → (upper level jan ka liya time chaiya hota h)

This condition is satisfied by Boltzman distribution.

$$N_i = N_0 \exp\left(-\frac{\varepsilon_i}{k_B T}\right)$$

Initial atoms are in ground state and this obeys dist b/c they are stable.



$$N_1^0 = N_0 g_1 \exp\left(\frac{-E_1}{K_B T}\right)$$
$$N_2^0 = N_0 g_2 \exp\left(\frac{-E_2}{K_B T}\right)$$

Non Degenerate energy levels b/c we have the value of g

$$\frac{N_2^0}{N_1^0} = \frac{g_2}{g_1} \exp\left(-\frac{(E_2 - E_1)}{K_B T}\right)$$

When it is a good absorber, you must have

1st condition:

$$\frac{N_2^0}{N_1^0} = \frac{g_2}{g_1}$$

$$N_2^0 < \frac{g_2}{g_1} N_1^0$$

(Amplification):-

2 condition:

$$N_2^0 > \frac{g_2}{g_1} N_1^0$$

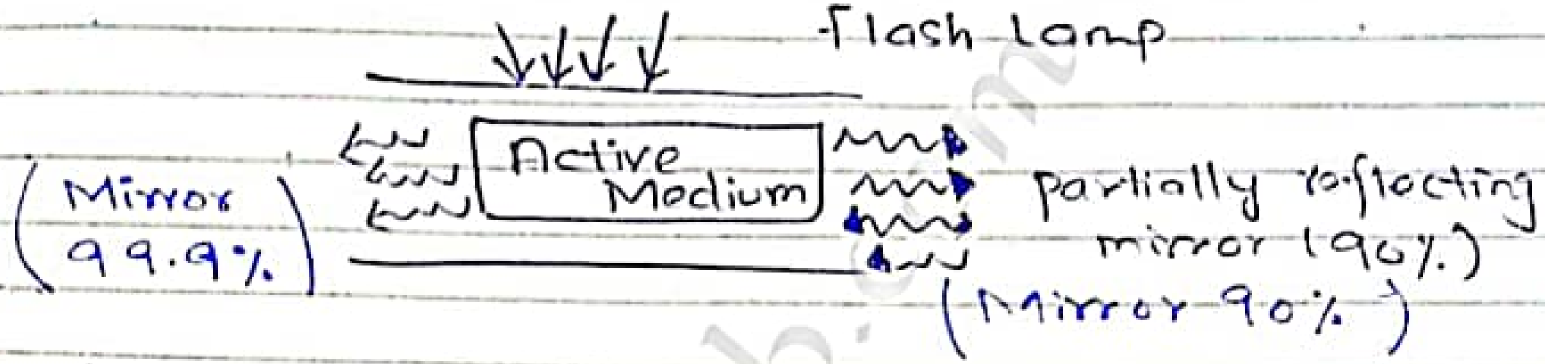
These are all ideal cases.

Oscillator for an Amplifier:-

How to make a oscillators?

- Oscillators allow to and form motion.
- Laser is itself a process but in a device in which laser is used so it is called laser device.
- Oscillators is a cavity in which

Photon oscillate within the cavity



Mirrors are highly reflective mirrors.

- Spontaneous emit photon further strike within an atom. Then two photons with the partially reflective mirror. Then the photon will reflect stimulated emission for photons. will strike the reflecting 99.9% mirrors
- Oscillator is designed due to amplification. Flash lamp strike so they (photons) have different directions and this is a loss.

Inside Cavity → Heat produced due to losses liquid flow from one place to another.

Heat is absorbed through cold fluid.

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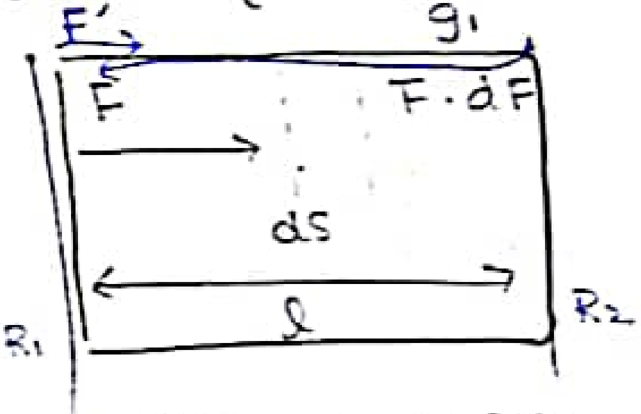
$$dF = \alpha F \left(N_2 - \frac{g_2}{g_1} N_1\right) dz$$



$$\frac{dF}{F} = \alpha \left(N_2 - \frac{g_2}{g_1} N_1\right) dz$$

$$\ln(F) = \alpha \left(N_2 - \frac{g_2}{g_1} N_1\right) l$$

$$F = \exp\left\{\alpha \left(N_2 - \frac{g_2}{g_1} N_1\right) l\right\}$$

$$F' = F\left\{\exp\left(\alpha \left(N_2 - \frac{g_2}{g_1} N_1\right) l\right) \times R_2 \times (1 - L_i)\right.$$
$$\times \exp\left(\alpha \left(N_2 - \frac{g_2}{g_1} N_1\right) l\right) \times (1 - L_i) \times R_1$$

$$F' = F \exp\left(2\alpha \left(N_2 - \frac{g_2}{g_1} N_1\right) l\right) \times R_1 R_2 \times (1 - L_i)^2$$

$$F' = F$$

$$\exp\left(2\alpha \left(N_2 - \frac{g_2}{g_1} N_1\right) l\right) \times R_1 R_2 \times (1 - L_i)^2 = 1$$

$$2\alpha \left(N_2 - \frac{g_2}{g_1} N_1\right) l + \ln R_1 + \ln R_2 + 2\ln(1 - L_i) = 0$$

→ Ground state can't be zero
After some time maximum reaches at excited state after than this can't be happen again as compare to R (photon flux greater than R photon flux)
Realization condition
$F = F'$

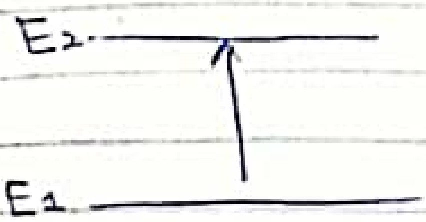
F = Active medium
$F' = M$

we know that
$$T + R = 1$$
$$R = 1 - T$$
$$\boxed{T = 1 - R}$$

→ 3 process:
- Absorption
- Transmission
- Reflection

Lec:-

→ Spotaneous Emission:-



* When light absorbs, it move to upper level transition from E_1 to E_2.

$$\psi_1(r,t) = U_1(r)\exp(-iE_1t/\hbar) \rightarrow 1(a)$$

$$\psi_2(r,t) = U_2(r)\exp(-iE_2t/\hbar) \rightarrow 1(b)$$

$$\psi = a_1\psi_1 + a_2\psi_2 \rightarrow (2)$$

$$|a_1|^2 + |a_2|^2 = 1$$

$$\mu = \int e|\psi|^2 r\,dV \rightarrow (3)$$

$$\psi = a_1(t)U_1(r)\exp\left(\frac{-iE_1}{\hbar}t\right) + a_2(t)(r)\exp\left(\frac{-iE_2}{\hbar}t\right) \rightarrow (4)$$

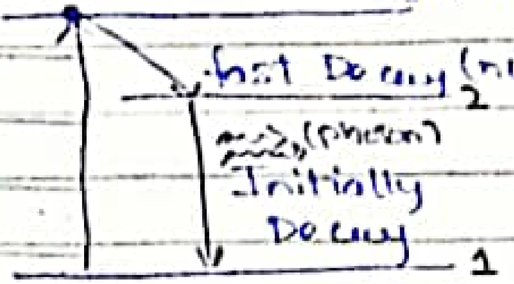
$$\mu = \int \mu$$

$$\mu = \int er|a_1(t)U_1(\bar{r}) + a_2(t)U_2(r)|^2 dV \rightarrow (5)$$

Probability of one, Probability of two, Transition b/w two levels.

$$= \int er[|a_1|^2|U_1|^2]dV + \int^{*} er[|a_2|^2|U_2|^2]dV$$

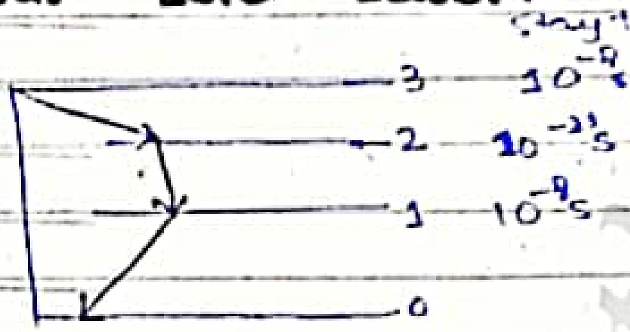
⊙ **Three level Laser:**



→ fast Decay than stimulated emission photon (can equal to how many atoms strike at 2 state)

→ Spontaneous emission ho ga -tu Stimulated ho ga

⊙ **Four Level Laser:**



Four level is much better than three level laser b/c of time

→ absorb → Excit → Stimulation → Initially population Inversion → Finally laser achieved

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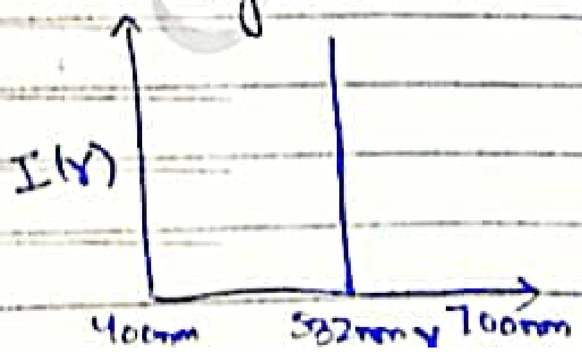
PROPERTIES OF LASER:

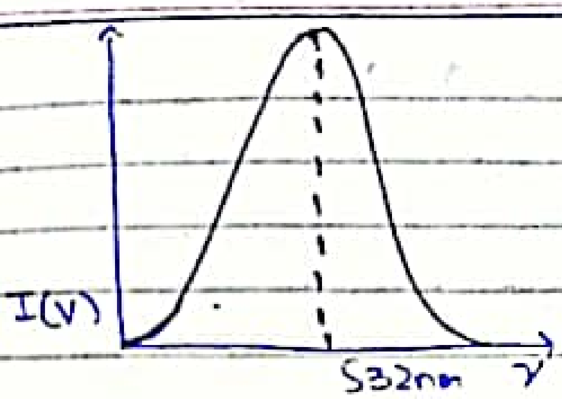
① **Monochromaticity:-**

↓

Single wavelength



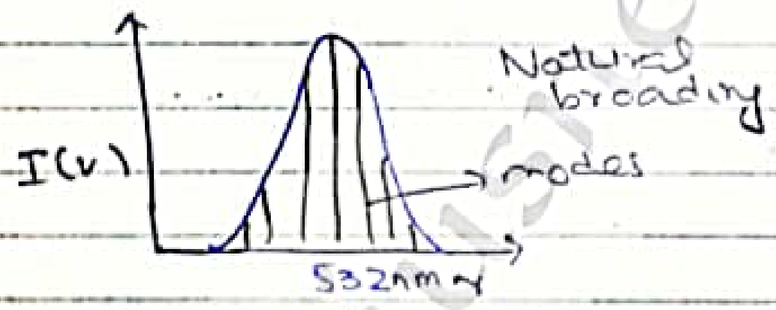
There is a single wavelength but actually this is not this way.

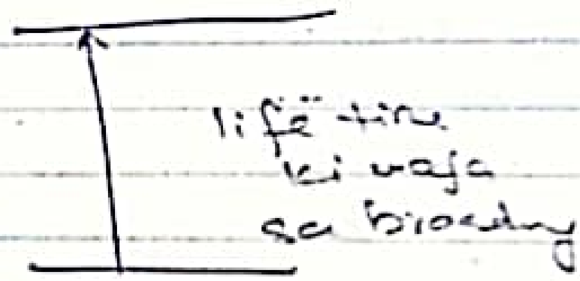


Laser light is not absolute monochromatic there is some broadening due to different mechanism so there is a doppler broading and collisional breading and we can minimize these broading mechanism but one broading which is not minimize is a natural broading. Whenever there is natural broading so there is uncertainity principle → energy (momentum) and position can never find at same time.

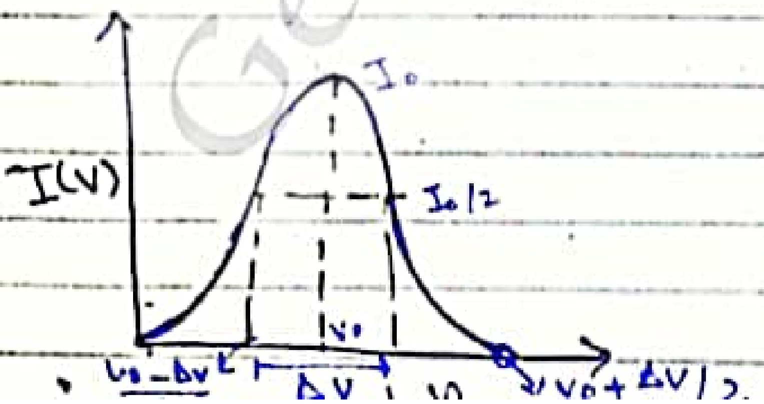
From uncertainity principle.

$$\Delta x \, \Delta p \approx 1$$





Natural broading principle lies on uncertainity principle



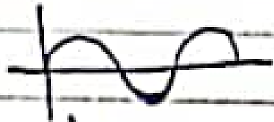
Now we can find full width half maximum of curve.

- When intensity I_0 becomes half $I_0/2$ in this width so this is called full width half maximum.
This tells the degree of monochromaticity.
Degree of monochromaticity $= \frac{\Delta\nu}{\nu_0} \approx 0$

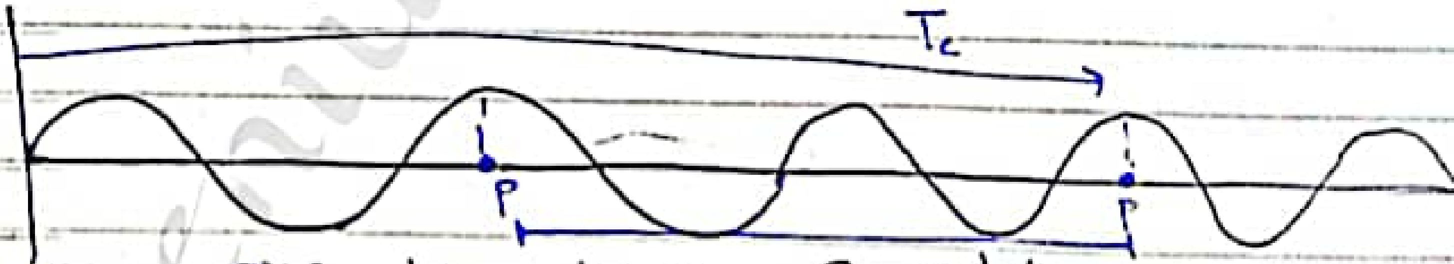
if $\Delta\nu = 0$ (highly monochromaticity light.

It means it is absolute monochromatic light which is impossible. There will exist some spread. Band width of ordinary light $\times 10^{10}$ Hz. Band width of laser light $\times$ 500

② Cohrense:- (same phase)



Related with monochromatic beam, directionally beam divergence.



There are two types of cohrence
(i) Temporal cohrence (related with time.
↓
cohrence in time, represented as T_c.

→ The time at which light is cohrent

than... it is cohrent in Times Tc (τ_c)

$\therefore \tau_c = 1/\Delta\nu$.

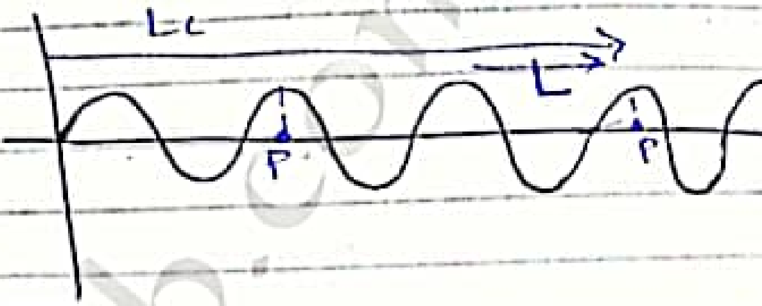
(iii) Special cohrence:-

We can fix the time and find τ_c and L_c

$L_c = c\,\tau_c$

$$L_c = \frac{c}{\Delta\nu}$$

This is the cohrence length (L_c)



→ Ordinary Light:-

Cohrence Light 10^{-10}

ordinary source = cohrence length ≃ 3×10^{-2} m = 0.03 m

→ Laser Light:- $\tau \simeq 10^{-3}$ s

Laser light = 1c ≃ 300km (in phase)

③ Directionality / Beam width:-

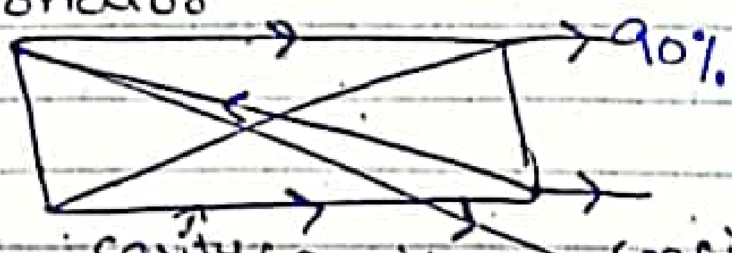
Directionality → Uni direction (they are in one direction)

↓ it means. Dire

imp property of laser light that can stay in one line (straight) for long time

→ The length for which their is no divergence is called Raleigh Length.

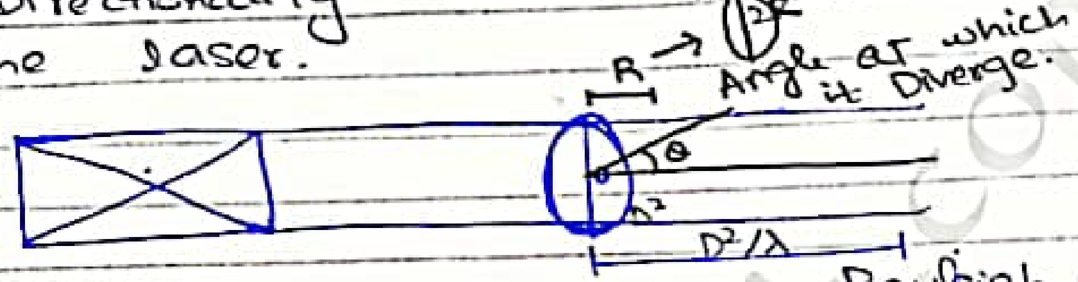
In Resonator



cavity (provides a specific path.

→ This cavity provide a path to light to go out from apperture (in mm) which is in very small size.

→ Directionality arise from the cavity of the laser.



∴ appracture by using wavelength

$$\theta = \frac{\beta\lambda}{D} \text{ (mm)}$$

β = (1) {fix value} material Displacement in

$$\theta = \lambda/D$$

apprature of diameter

$$\frac{(mm)^2}{532nm} = \frac{10^{-6}m}{10^{-9}m}$$

$$I = \frac{I_0}{e^2}$$ Intensity reduced

" = 13.5%

Initially radius R increases in radius 2R make intensity decrease at a very large distance.

Intensity also known as Irradiance

$$I = \frac{Energy}{Area \times Time} = \frac{Power}{Area} = \left(\frac{W}{m^2}\right) \text{ Unit}$$

Which is more greater?

→ 1W Laser — Area ↑ Intensity ↓

→ 100W Bulb — " ↓ " ↑

Intensity:-

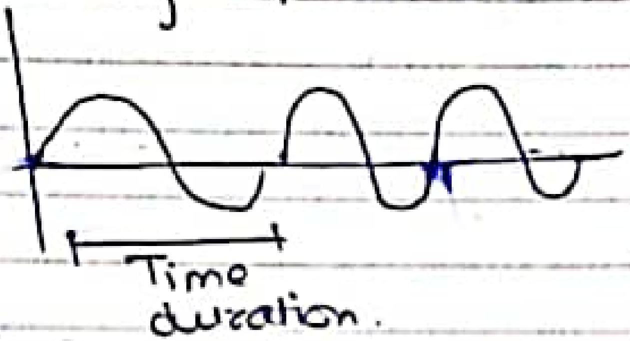
1W laser light thousand times greater than 100 w bulb because of less divergence.

$1mW = 1 \times 10^{-3} W$ laser.

$I = P/A$ {if we know spot [illegible] we can find intensity}.

④ Pulse Duration:

Every pulse has its own time duration.



Time Duration are in nanosecond.

When we have a short pulse so we have better time duration. (results)

Ruby Laser