12/10/2022

Optical Fibre Communication

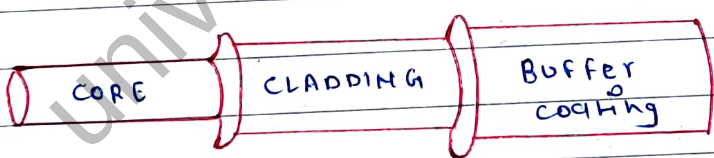
Main components of optical fibre

Transmission ⟶ Communication channel ⟶ Recievel

→ Optical fibres are wave guides that are used for transmitting optical (light) signals from one end to another.

→ Optical fibres are made of glass or silica is combination of core & cladding.

→ Core is inner portion of fibre

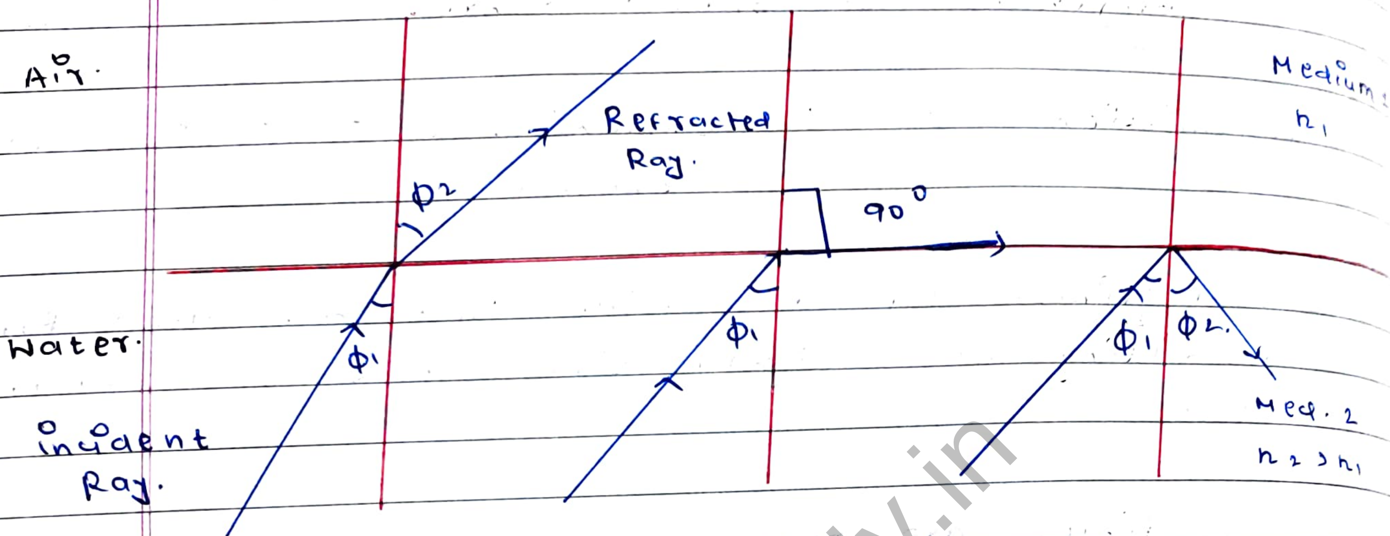


Parts of an optical fibre

PROPAGATION MECHANISM

TIR → Stands for Total internal Reflection, that when light enters a rarer medium from a denser medium with the incident angle more than the critical angle. Then the incident ray gets reflected towards the same medium.

Total internal Reflection.



$i \not> i_c$. $\theta = 90^\circ$ OR $i = i_c$. $i > i_c$

$i > i_c$

Light signal

The R.I of core is always greater that cladding

Acc. to Snell's Law.

$$n_1 \sin\phi_1 = n_2 \sin\phi_2$$

$$\phi_1 = i_c$$

$$\phi_2 = 90^\circ$$

It means.

$$n_1 \sin i_c = n_2 \sin 90^\circ$$

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

$\because\ n_1 > n_2.$

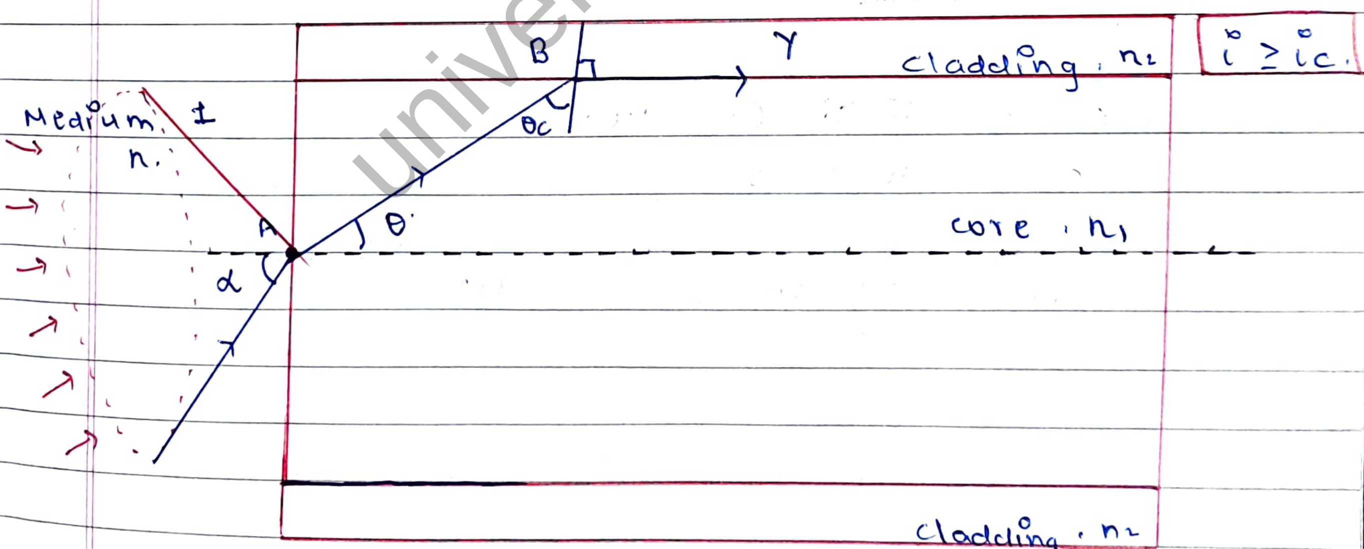
Q. $n_1 = 1.50$

$n_2 = 1.48$

$$i_c = \sin^{-1}\left(\frac{1.48}{1.50}\right)$$

$$= \sin^{-1}\left(\frac{1.48}{1.50}\right)$$

ACCEPTANCE ANGLE & ACCEPTANCE CONE.



$\alpha \rightarrow$ Acceptance angle

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→ $n \to$ R.I of Launching Medium.
$n = 1$ (Air)

→ Acceptance angle is the maximum angle of ray (againts the fibre axis) hitting the fibre core which allows the incident light to be guided by the core.

→ Sine of Acceptance of angle is Numerical Aperture & it represents the light gathering capacity of an optical fibre.

Acc. to snell's law

$\theta_e = \alpha$
$\theta_i = \theta_c$

$n \sin \alpha = n_1 \sin \theta.$
$\theta = 90 - \theta_c$

$n \sin \alpha = n_1 \sin (90 - \theta_c)$
$n \sin \alpha = n_1 \cos \theta_c$

$\sin \alpha = \frac{n_1}{n} \cos \theta_c$ ...... (1)

on appluing snell's law at core & cladding

$n_1 \sin \theta_c = n_2$
$\sin \theta_c = \frac{n_2}{n_1}$

$\cos \theta_c = \sqrt{1 - \sin^2 \theta_c}.$

$$= \sqrt{1 - \left\{\frac{n_2}{n_1}\right)^2}$$

From Equation ①

so, $\sin \alpha = \frac{n_1}{n} \cos \theta_c = \frac{n_1}{n} \sqrt{1 - \left\{\frac{n_2}{n_1}\right\}^2}$

$$= \frac{1}{n} \sqrt{n_1^2 - n_2^2}$$

For air, $n = 1$

$$\sin \alpha = \sqrt{n_1^2 - n_2^2} \quad \ldots\ldots \text{②}$$

$$\alpha = \sin^{-1} \sqrt{n_1^2 - n_2^2}$$ (acceptance angle)

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

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

V - NUMBER OR CUT OF PARAMETER

→ The V no. is dimensionless parameter which is often used in the context of step-index fibres.

$$V = \frac{2\pi a}{\lambda} \sqrt{n_1^2 - n_2^2}$$

→ Where λ is the vaccum wave length, a is the radius of the fibre core, & NA is the numerical aperture.

$$\boxed{V = \frac{2\pi a}{\lambda} NA}$$

→ For V values below ≃ 2.405, a fibre supports only one mode per polarization direction (→ single-mode fibres)

→ Multimode fibres can have much higher V numbers. For large values, the no. of supported modes of a step-index fibre (including polarization multiplicity) can be calculated as

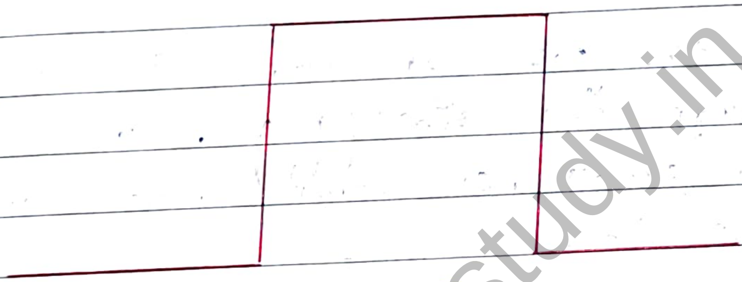
$$\boxed{M = \frac{V^2}{2}}$$

TYPES OF OPTICAL FIBRES

Optical fibres are Based on

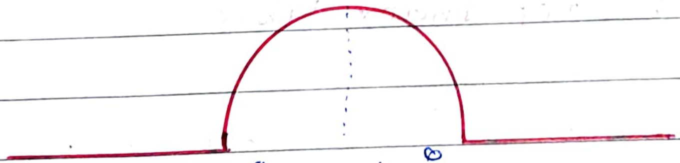
- Material
  - Glass Fibre
  - Plastic Fibre
- No. of Modes
  - Single Mode
  - Multi Mode
- R.I profile
  - Step Index
  - Graded Index (GRIN)

STEP INDEX: For a step-index fibre (both single mode & multi-mode optical fibres) the R.I of the core is uniform throughout the cladding region and undergoes an abrupt change at the core cladding boundary. step-index fibres obtain their name from this abrupt change called the step change in R.I.



Step-Index profile.

GRADED INDEX: For a graded-index fibre if, we draw the R.I from the cladding region to the core, we can see it varies gradually as a function of radial distance from the fibre centre as shown below.



Graded index profile.

Multimode Step-Index Fibres

→ In optical fibres, a step-index fibre is a fibre where a uniform refractive index exists within the core and a sharply decre-ased refractive index exists in the core-cladding interface because of the lower R.I in cladding.

→ Diff. in the R.I of core & cladding is very large. $i_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$, so critical ∠ is very small, so large rays can enter into the fibre.

→ Light entering the fibre at ~~end~~ diff. angle of incidence will go through diff. paths. Although the incident light propogates at the same speed simultaneously at the input, the time to reach the output of the fibre is diff, resulting in a temporal dispersion called modal dispersion.

Single Mode Step Index Fibres.

→ A step-index fibre is a fibre where a uniform R.I exists within the core and a sharply decreased R.I exists in the core-cladding interface. because of the lower R.I in cladding

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→ Diff. in the R.I of core & cladding is very small. $i_c = \sin^{-1} \frac{n_2}{n_1}$, so critical angle is very large, so only one ray can enter into the fibre and core diameter is very small. Bcz of this reason it supports only single mode.

→ The most common type of single mode fibre has a core diameter of 8 to 10 µm & is designed for use in the near infrared (the most common are 1310 nm & 1550 nm).

→ It carries higher bandwidth than multimode fibre, but requires a light source with a narrow spectral width.

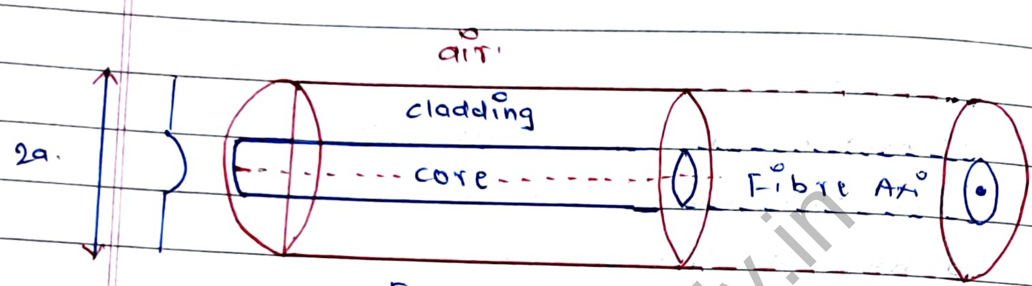
→ single mode fibre gives you a higher transmission rate & upto 50 times more distance than multimode, but it also costs more.

→ Much smaller core than Multimode.

GRADED INDEX OPTICAL FIBRES

→ Graded index fibre is another type of optical fibre in which the R.I of the core is non-uniform. This non-uniformity is present because the R.I is higher at the axis of the core and continously reduces with the radial movement away from the axis.

→ However, the R.I of the cladding is constant in the case of graded index fibre. Hence the nature of R.I of the core is somewhat parabolic.



→ The diameter of core in graded-index multimode fibre is somewhat b/w 50 to 100 um mm. The large diameter of the core allows multiple rays to propagate through the fibre.

→ cladding : 125 um diameter
core : 50 um diameter.

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ATTENUATION.

→ Attenuation means a loss of optical power. The atten of an optical fibre is expressed by the attenuation coefficient which is defined as the loss of the attenuation coefficient fibre per unit length. in dB/km. The attenuation of the optical fibre is a result of two factors, absorption & scattering.

loss in optical fibre : (dB/km)

$$= \frac{-10}{L} \log \left(\frac{P_o}{P_i} \right)$$

- ABSORPTION :- The absorption is caused by the absorption of the light and conversion to heat by molecules in the glass. Primary absorbers are residual OH+ and dopants used to modify the R.I of glass. The absorption occurs at discrete wavelength, determined by the elements absorbing the light.

- SCATTERING :- The largest cause of attenuation is scattering. Scattering occurs when light collides with individuals atoms in the glass and is anisotropic. Light that is scattered at angles outside the numerical apperture of the fibre will be absorbed into the cladding or transmitted back toward the source. Scattering is also a fn wavelength, proportional to the inverse fou[rth] power of the wavelength of light. Thus if [you] double the wavelength of the light, you red[uce] the scattering losses by 2 to 4th power of 16 times.

- Dispersion in multimode and singlemode fi[bres]

→ Dispersion refers to the widening or spreading of pulses of light as they travel down an optical fibre. Dispersion is one of the factors that limits the bandwidth of a optical fibre link along with the bandwidth of the transmit[ter] source.

Application of optical fibres

- Data Storage
- Telecommunications
- Networking
- Broadcast / CATV
- Medical
- Defense / Government.

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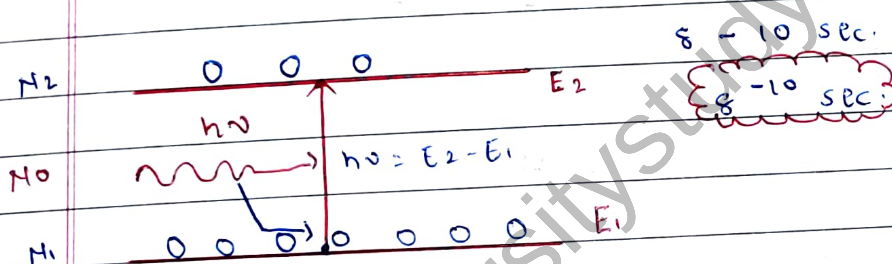
LASERS

LASER stands for " Light Amplification by Stimulated Emission of Radiation"

→ Laser is a device in which we use process of stimulated emission to amplify the infrared, visible or ultraviolet electromagnetic radiation.

Stimulated Absorption.

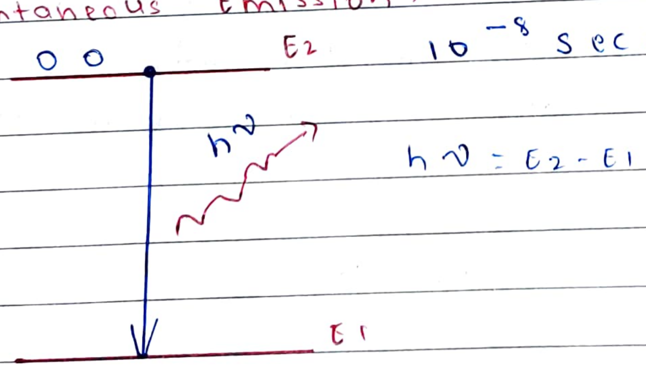
Total atoms $= N_0$.



$1 \longrightarrow 2$

This process is known as stimulated absorption

Spontaneous Emission.



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→ The process is referred to as spontaneous emission of radiation.

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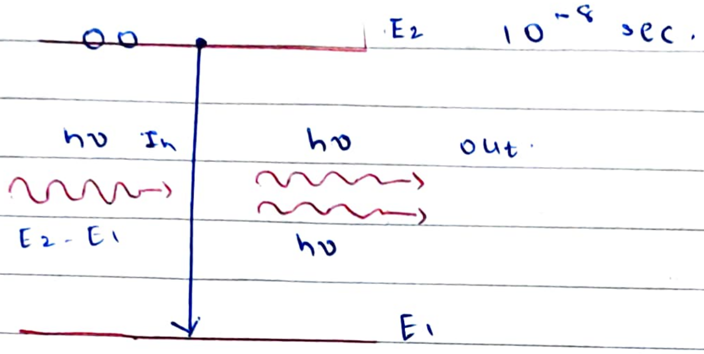
Stimulated Emission



These two photons are perfectly cohrent. This process is known as stimulated emission of radiation.

Principle of Laser action

Population inversion.

→ Population inversion is the process of achieving greater population of higher energy state as compared to the lower energy state. Population inversion technique is mainly used for light amplification. The population inversion is required for laser operation (stimulated emission).

No.

$N_1 \rightarrow E_1$

$N_1 >> N_2$

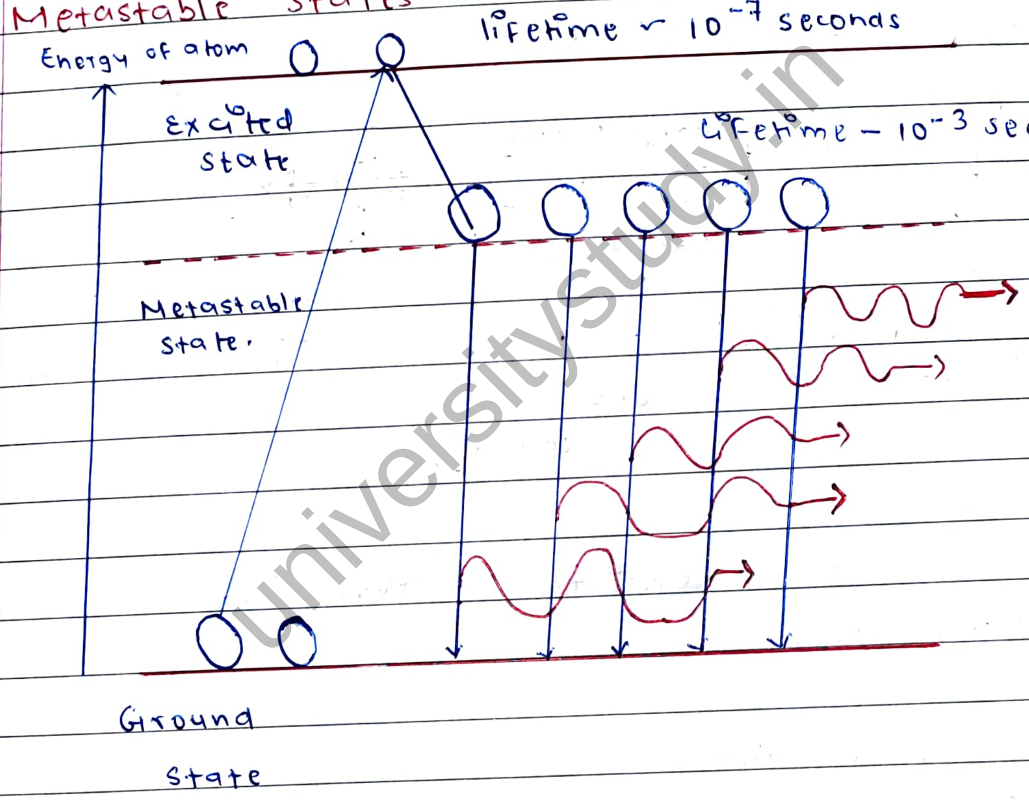
$N_2 \rightarrow E_2$

Population inversion occur when more electrons in a particular situation, are in a higher energy energy state than in a lower energy state.

$[N_2 >> N_1]$

→ amplification of laser light.

Metastable states.

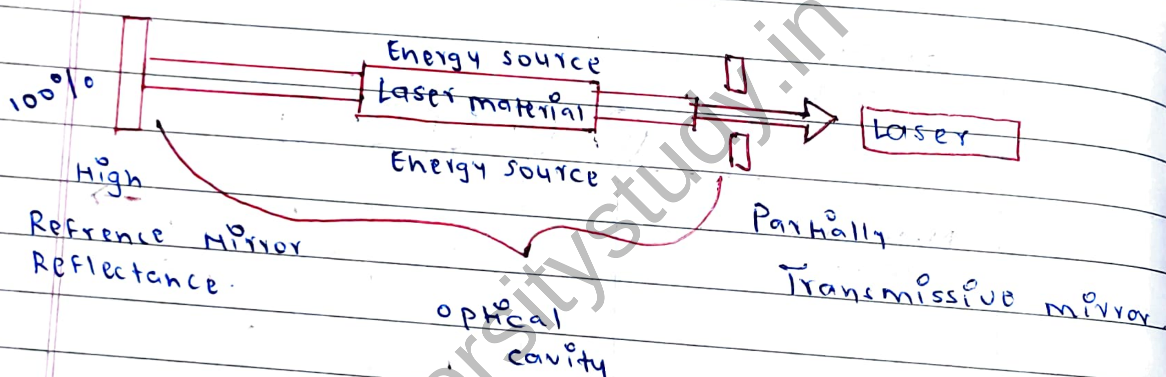


→ Metastable state is an excited state of an atom or other system with a longer lifetime than the other excited states. However it has shorter wavelength lifetime than the stable ground state. Atoms in the metastable state remains excited for a consid. times in the order of $10^{-6} - 10^{-3}$ sec.

→ During metastable state, all the parameters associated with state hold stationary values. A large no. of excited atoms are accumulated in the metastable states.

M.S → ULL — Upper Label Lasing
G.S → LLL — Lower Lasing Level.

Main component of Lasers.



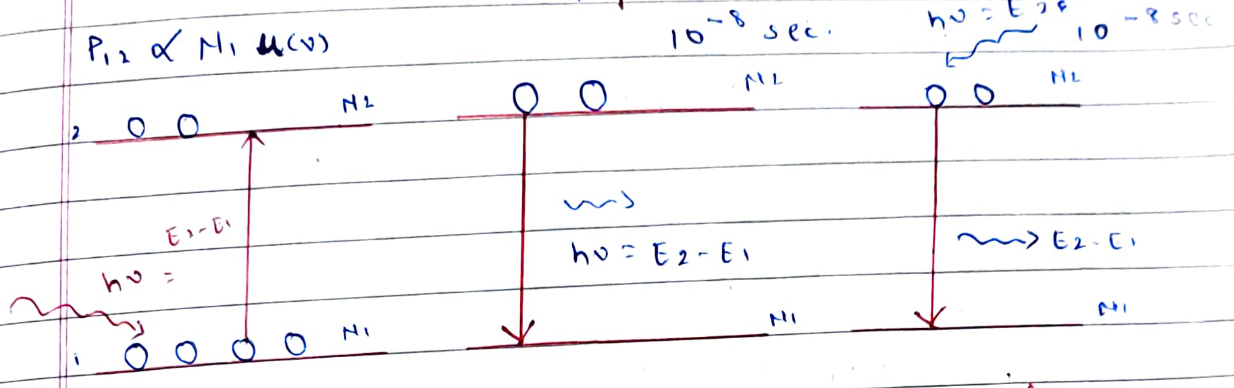
→ Every LASER consists of three basic component. These are,

→ Active medium
→ External energy source | Pumping source.
→ optical resonator.

A laser 'material' which can be gas, solid or gas liquid or a microchip, is 'stimulated' by an external 'energy source'. so that it produces lots of little photons of the same wavelength (colour).

Einstein's coefficient's

$P_{12} \propto N_1 u(\nu)$ $\quad P_{21})_{sp} \propto N_2$



$P_{21})_{st} \propto N_2 u(\nu)$

Stimulated absorption

$P_{12} = B_{12} N_1 u(\nu)$ → E.C of stimulated absorption.

$P_{21} = A_{21} N_2$ → E.C of spontaneous emission.

$P_{21} = B_{21} N_2 u(\nu)$ → E.C of stimulated emission

Einstein Relation between Einstein coefficient.

- In thermal equilibrium at temperature T, with radiation frequency ν and energy density $u(\nu)$. Let N_1 & N_2 be the no. of atoms in energy states 1 & 2 respectively at any instant. The no. of atoms in state 1 absorbs photon & give rise to absorption per unit time.

For Equilibrium

$$P_{12} = P_{21} \text{ .... (i)}$$

$$N_1 B_{12} u(\nu) = N_2 [A_{21} + B_{21} (\nu) u] \text{ .... (ii)}$$

solving For $u(\nu)$

$$\boxed{u(\nu) = \frac{N_2 A_{21}}{(N_1 B_{12} - N_2 B_{21})}}$$

For thermal equilibrium.

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

$$u(\nu) = \frac{N_2 A_{21}}{N_2 B_{21} \{ (N_1 B_{12}) / (N_2 B_{21}) - 1 \}}$$

$$\boxed{u(\nu) = \frac{A_{21}}{B_{21} \{ (N_1/N_2) - 1 \}}}$$

According to Maxwell Boltzmann's distribution:

$$N_1 / N_2 = \exp (h\nu / kT)$$

$$u(\nu) = \frac{A_{21}}{B_{21} \{ \exp(h\nu/kT) - 1 \}} \text{ — (iii)}$$

E_1 :

$$N_0 \begin{cases} \rightarrow N_1 \rightarrow 1 & E_1 = N_0 e^{-E_1/kT} \\ \rightarrow N_2 \rightarrow 2 & \end{cases}$$

E_2 : $\qquad E_2 = N_0 e^{-E_2/kT}$

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = e^{(E_2 - E_1)/kT}$$

Acc. to planck's radiation law:

$$u(\nu) = \frac{8\pi h \nu^3}{C^3 e^{h\nu/kT} - 1} \quad \text{--- (4)}.$$

Comparing (3) & (4) we get,

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3}{C^3} \quad \ldots\ldots (5).$$

$$= \left(\frac{8\pi h}{C^3}\right) \nu^3$$

$$\frac{A_{21}}{B_{21}} \propto \nu^3$$

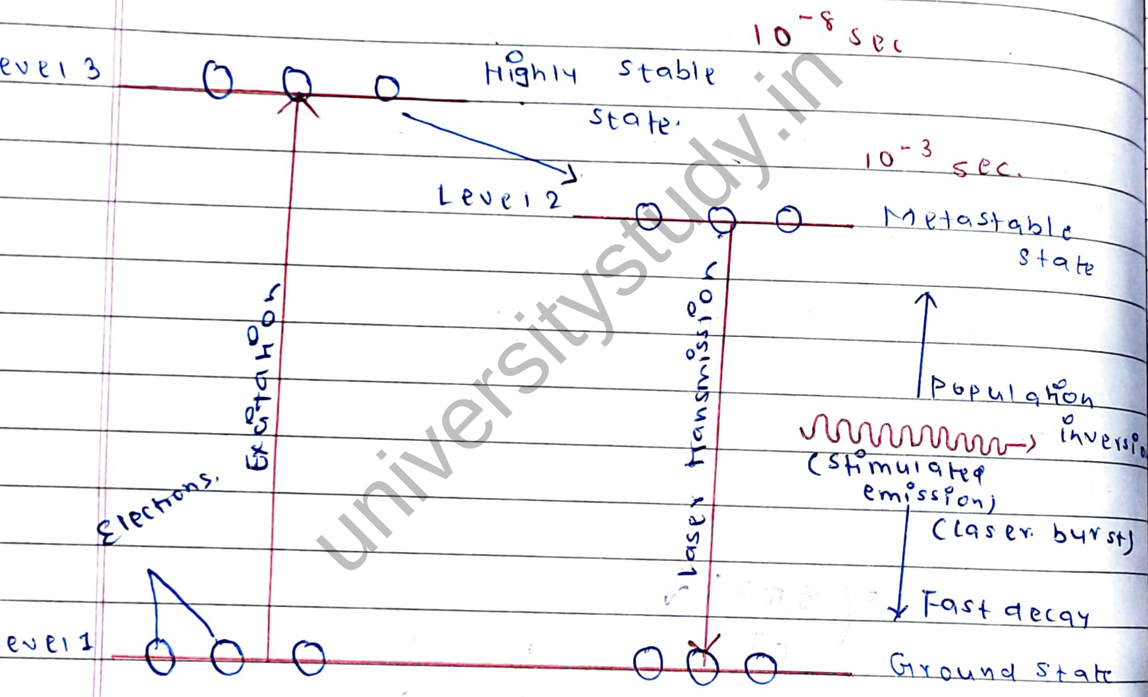
This relation is called Einstein relation b/w Einstein coefficient.

Three level lasers

Level 1 :- Ground state

Level 2 :- Metastable state

Level 3 :- Excited state.



Transition

1 ⟶ 3 : Pumping Transition

3 ⟶ 2 : Radiative / Non-Radiative Transition.

2 ⟶ 1 : Spontaneous Emission

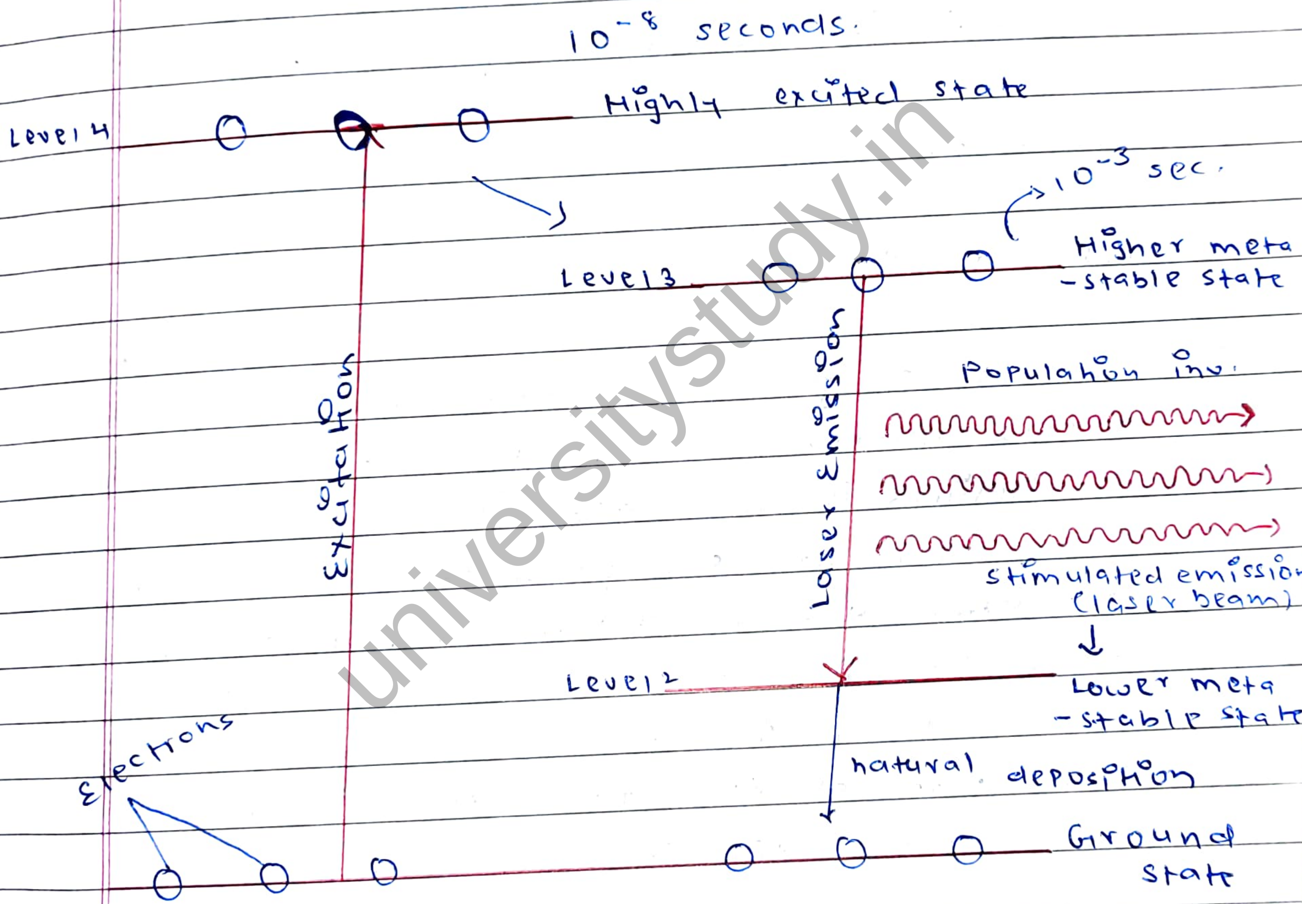
2 ⟶ 1 : Stimulated Emission.

ULL : (Upper lasing level) : Metastable state

LLL : (Lower lasing level) : Ground state

Four level Laser.

Level 1 : Ground state
Level 2 : Lower metastable state
Level 3 : Higher metastable state
Level 4 : Excited State.



$N_{MS3} > N_{MS2}$

Transitions

1 → 4 : Pumping transition
4 → 3 : Radiative / Non Radiative
3 → 2 : spontaneous emission
3 → 2 : stimulated emission
2 → 1 : Fast transition.

ULL (upper Lasing level) : M.S 2
LLL (Lower Lasing level) : M.S 1