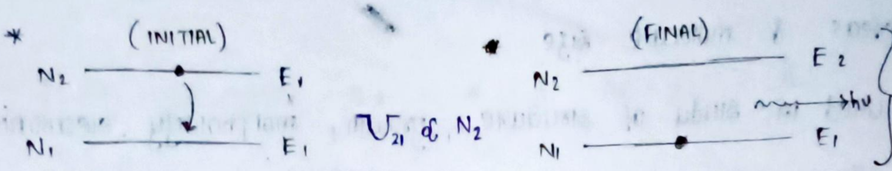
LASERS (Einstein's A, B coefficients):

* There are 3 fundamental process that we will discuss.

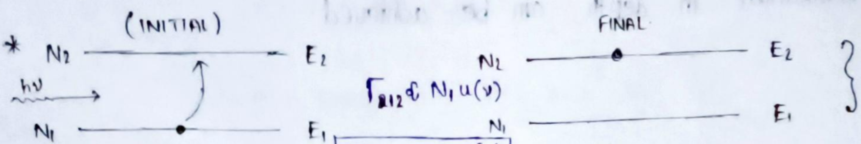
"Stimulated" & "Induced" radiation.



Spontaneous emission

$U_{21} \propto N_2$

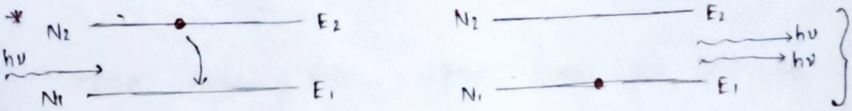
$$\boxed{U_{21} = A_{21} N_2}$$



Stimulated absorption

$\Gamma_{12} \propto N_1 u(\nu)$

$$\boxed{\Gamma_{12} = B_{12} N_1 u(\nu)}$$



Stimulated emission

$\Gamma_{21} \propto N_2 u(\nu)$

$$\boxed{\Gamma_{21} = B_{21} N_2 u(\nu)}$$

U_{ab} or $\Gamma_{ab} \longrightarrow$ no. of atoms coming from level a to level b per unit time

$u(\nu) \longrightarrow$ it is the energy density of incoming $h\nu$.

* By thermodynamical principle (principle of detailed balance)

$$\boxed{\Gamma_{12} = \Gamma_{21} + U_{21}}$$

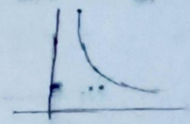
we have to compute $u(\nu)$ from above formula.

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

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

$$\therefore \frac{N_1}{N_2} = \frac{e^{-E_1/KT}}{e^{-E_2/KT}} = \exp\left(\frac{h\nu}{KT}\right)$$

As energy level (↑), prob. of e^- (↓) i.e, $e^{-E/KT}$



$$u(\nu) = \frac{A_{21}}{B_{12}\left(e^{h\nu/KT} - \frac{B_{21}}{B_{12}}\right)}$$

imp

Significance of A, B coefficient:

A coefficiant is related to rate of spont. emission of light

B coeff. is related to absorption and stimulated emission of light

* from Black body radiation:

$$u(\nu) = \frac{8\pi h\nu^3}{c^3\left(e^{h\nu/KT} - 1\right)}$$

$$\therefore \frac{A_{21}}{B_{12}} = \frac{8\pi h\nu^3}{c^3}, \quad \frac{B_{21}}{B_{12}} = 1$$

⇒ write relation of Einstein's A, B coefficients: (15 M) ↳ FAT

* Note:

The ratio of stimulated emission over spontaneous emission is the following:

$$\frac{\Gamma_{21}}{U_{21}} = \frac{B_{21} N_2\, u(\nu)}{A_{21} N_2} = \frac{1}{\left(e^{h\nu/KT} - 1\right)}$$

⇒ for what condition the ratio $\left(\frac{\text{stimulated em. rate}}{\text{spontane. em. rate}}\right)$ is 1?

Soln

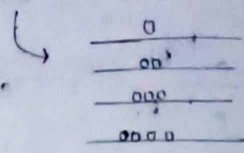
$$e^{\frac{h\nu}{KT}} = 2$$

$$\boxed{\frac{h\nu}{KT} = \ln 2}$$

1) Statement :

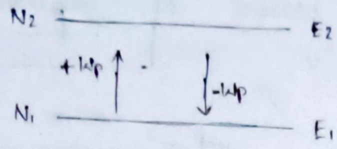
* In a two level system population inversion , is not possible.

2) Goal : in a two level system this can't happen



$N \propto e^{-E/kT}$ → in General

But in this two level system it is opposite



Sign convention :

$1 \longrightarrow 2 \ (+)$

$2 \longrightarrow 1 \ (-)$

* At a normal temp. the population of lower level is greater than upper level.

i.e, $N_1 > N_2$ initially.

* So the (atom/e^-) must be pumped in the upper level by producing energy equal to energy to the energy diff. b/w two level.

* The rate of change in the population in upper level

$$\frac{dN_2}{dt} = (+W_p N_1) + (-W_p N_2) + \left(-\frac{N_2}{\tau}\right)$$

* The total population is $N = N_1 + N_2 \Rightarrow \frac{dN_1}{dt} = -\frac{dN_2}{dt}$

$\frac{dN}{dt} = 0$ → because rate of incoming & outgoing is same

* At steady state : $\frac{dN_2}{dt} = 0$ then

$$\Rightarrow \frac{N_2}{N_1} = \frac{W_p}{W_p + 1/\tau}$$

* If we need population inversion then

$$N_2 > N_1$$

$$\Rightarrow N_2 > N - N_2$$

$$\Rightarrow \boxed{N_2 > \frac{N}{2}}$$

* $$N_2 = \frac{W_p}{W_p + 1/\tau} (N_1)$$

$$\Rightarrow N_2 = \frac{W_p}{W_p + 1/\tau} (N - N_2)$$

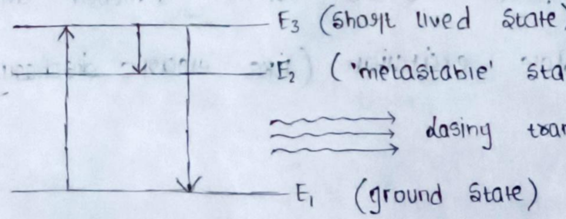
$$\Rightarrow N_2 = \frac{W_p}{2W_p + 1/\tau} N \Rightarrow \frac{W_p}{2W_p + 1/\tau} N > \frac{N}{2} \quad \left(\because N_2 > \frac{N}{2}\right)$$

$$\Rightarrow 2W_p \tau > 2W_p \tau + 1$$

$$\Rightarrow 0 > 1 \ (!!!)$$

* Derivations & Conceptual $\longrightarrow$ 80% $\Big\}$ FAT.
  Numerical $\longrightarrow$ 20%

THREE LEVEL SYSTEM : (LASER)



* In three level pumping scheme the atoms originally in the ground state are pumped into the excited state by some external source of energy (electric discharge, Xe flash lamp)
* The excited atoms decay by spontaneous emission very rapidly into a lower excited state which is known as "Metastable State".

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* Atoms stay in metastable state for about 10^{-6} to 10^{-3} s

Therefore it is possible for a large no. of atoms to accumulate in the metastable state.

* In the metastable state population can exceed the population of lower level and it leads to "population inversion".

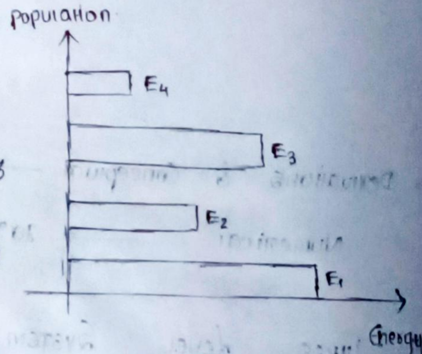
Four - level System :

Laser
* Silfrast
* Ghatak
* Laud

Books

* Atoms are pumped from ground state (E_1) to level four (E_4).

From this level, the atoms decay to the "metastable state" and the population in this level grows rapidly.



* If the "lifetime" of level 4 to level 3 (i.e, τ_{43}) is short compared to level 3 to level 2 (i.e, τ_{32}).

* A population inversion from $3 \rightarrow 2$ can be achieved and maintained with moderate excitation (like electric discharge, Xe flash lamp, etc)

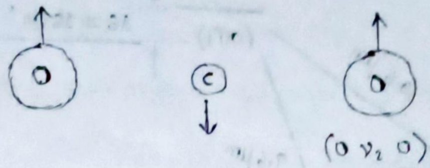
Few PUMPING MECHANISM :

* Optical pumping.
* Chemical rx^n
* Electrical discharge
* Injection current.

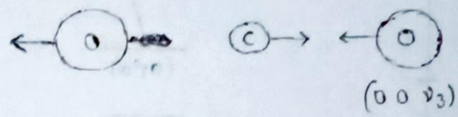
Vibrational Modes of CO_2

* Symmetric stretching mode :

* Bending mode :



* Assymmetric stretching mode :

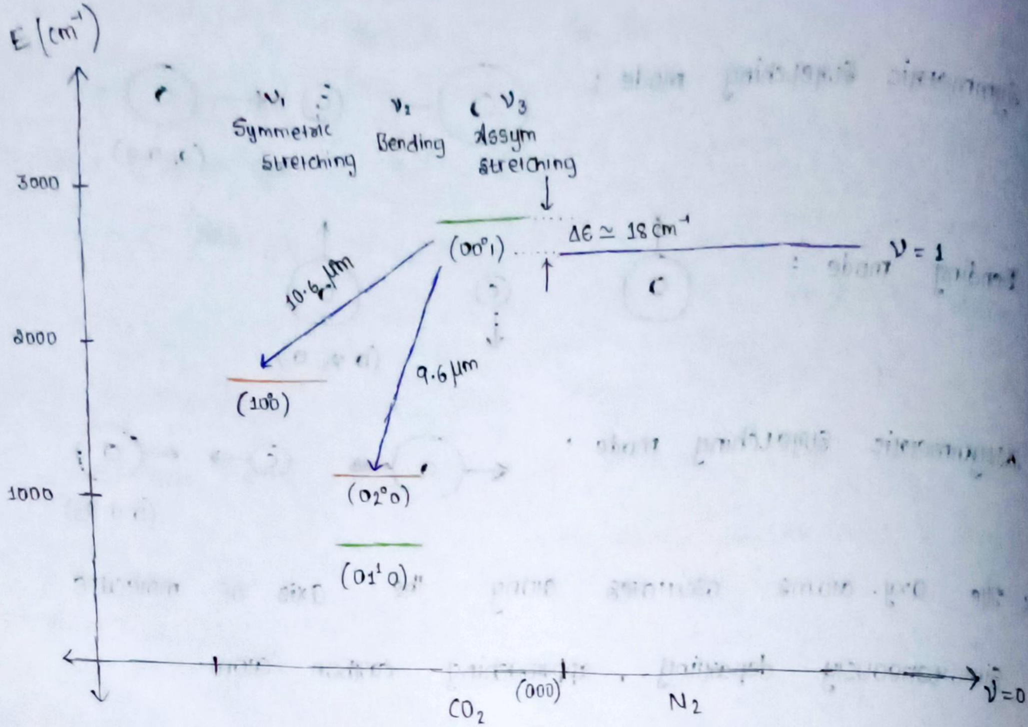


* The oxy. atoms oscillates along the axis of molecule simultaneously departing, approaching carbon atom.

* The molecule seizes to be exactly linear as the atoms move $\perp$ to molecular axis.

* All three molecules ossilate; while both oxygen atoms move in one dir^n carbon atoms move in the opp. dir^n.

CO_2 energy level diagram



* The relevant vibrational energy levels for electronic ground states of CO_2 & N_2 is given in picture :

* N_2 is diatom molecule, so it has only vibrational mode whose lowest two energy levels ($\nu = 0$, $\nu = 1$) are indicated in fig.

* But CO_2 is a triatomic molecule. It has three non degerate modes of vibration (i) Sym. stretching (ii) Bending (iii) Asym stretch

* The osc. behaviour ~~are~~ at corresponding energy levels are described by three quantum nos. , so the energy

$$E = n_1 h\nu_1 + n_2 h\nu_2 + n_3 h\nu_3$$ where ν_1, ν_2, ν_3 are freq of 3 modes.

ex: (01^10) level corresponds (superscript is for angular momentum (l)) to an osc. in which there is one vibrational quantum in mode 2. Similarly (02^00) mode can be described.

* The lasing action takes place b/w (00^01) and (10^00) level for $\lambda \simeq 10.6\,\mu m$, although it is possible to obtain osc. b/w (00^01) and (02^00) at $\lambda \simeq 9.6\,\mu m$.