LASER

LASER is the acronym of Light Amplification by Stimulating Emission of Radiation.

- Laser is an 'opto-electronic' device

Laser light has special characteristics different from those of light from conventional sources.

Lasers are characterized by highly monochromatic (very short single frequency (or) wavelength)

- highly directional (moves in straight line)
- spacially temporal coherent (same wavelength & frequency)
- Laser light have high power density and brightness
- The laser beam spreads in the order of a few millions-radians
- *** The production of laser light is a particular consequence "interaction of radiation with matter"

- Any matter, irrespective of its state of existence is reffered to as "a quantized system" (system energy referred by same no's called quantum no's)

★ Radiation of Interaction with matter:

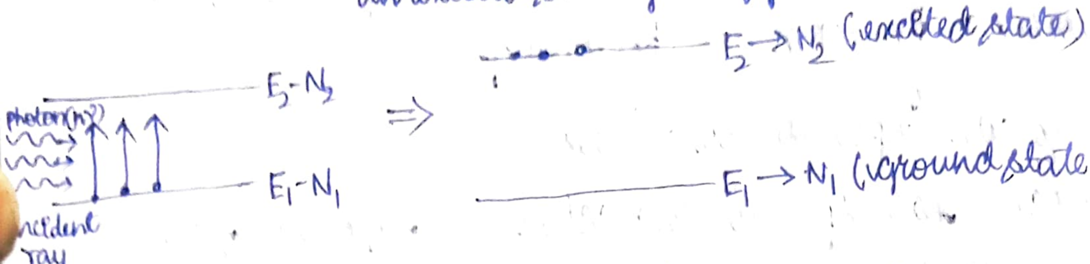
Q) Discuss different type of interaction b/w radiation and matter?

Induced absorption:~

There are 3 possible ways through which interaction of radiation with matter can take place. They are:~

1. Induced absorption:~ (or) stimulated absorption.
2. spontaneous emission
3. stimulated emission

Stimulated (or) Induced absorption:- Atom in the ground state of energy E_1 absorbs a photon of energy $h\nu$ (of appropriate energy) and get raised to an excited state of energy E_2 is called induced absorption.



Energy density (U_λ)

$$\Delta E = (E_2 - E_1) = h\nu \Rightarrow \nu = \frac{(E_2 - E_1)}{h} \rightarrow \text{frequency}$$

rate of induced absorption:- Number of such induced absorption per unit interval of time is per unit volume of incident radiation per unit interval of time is called rate of induced absorption. i.e., the rate of induced absorption proportional to

$$\propto U_\lambda d_\lambda \text{ (or) } U_\lambda (\text{if } d_\lambda = 1) \rightarrow 1$$

Rate of induced absorption $\propto N_1$ (no. of atoms in the ground state) $\rightarrow$ 2

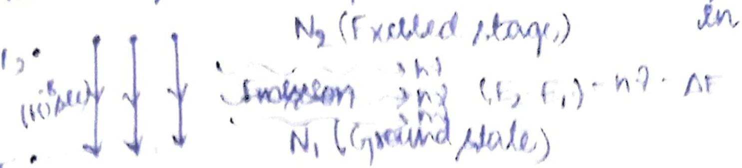
$$RA \propto N_1 U_\lambda \longrightarrow 3$$

$$\Rightarrow \boxed{RA = B_{12} N_1 U_\lambda} \rightarrow 4$$

where B_{12} Einstein's coeffecient of induced absorption.

2. Spontaneous Emission:- It is the emission of a photon, when a system transists from a higher energy level to lower energy state without the aid (support) of any external agency. Consider the atom is in the excited state of energy E_2 it doesn't remain for a long time because the excited state is most unstable state of energy, with in a short interval of time i.e., (10^{-8} sec) it will fall to its lower energy state E_1 (ground state) by emitting a photon of energy $\Delta E = (E_2 - E_1) = h\nu$. This process is known as spontaneous emission. The emitted photon can travel in any direction and they are not in phase. Hence, radiation

emitted from this phenomena are not coherent in.



In fact the spontaneous emission depend upon no. of atoms in the excited state only and independent of intensity of light.

Rate of spontaneous emission:- The number of spontaneous emission per unit time per unit volume of atomic system is called Rate of spontaneous emission.

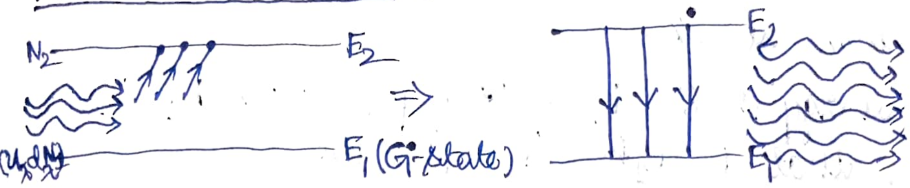
Therefore, Rate of spontaneous emission $\propto N_2$

$$\boxed{\text{Rate of spontaneous emission} = A_{21} N_2}$$

where A_{21} is proportionality constant called Einstein's coefficient of Spontaneous emission.

Most imp. for laser

3. Stimulated Emission:-



Stimulated emission is the emission of photon by a system under the influence of a passing photon of just the right (same) energy. Due to which the system transits from a higher energy state to the lower energy state. The photon thus emitted is called stimulated photon and will have the same phase energy and direction of momentum as that of the incident photon called stimulating photon.

An atom in the higher energy state E_2 is stimulated to de-excite to a lower energy state even by an external passing photon of right energy i.e., $\Delta E = E_2 - E_1$. which release 2 photons of same energy, same phase and travel in same direcⁿ and they are Coherent in nature.

This process can represent symmetrically as

$$\boxed{\text{Atom}^{*} + \text{photon} \longrightarrow 2\,\text{photons} + \text{Atom}\downarrow}$$

$$\boxed{A^* + h\nu \longrightarrow 2(h\nu) + A}$$

vimp

Rate of stimulated emission:- It is defined as the number of stimulated transition per unit volume of incident radiation per unit time is called rate of stimulated emission.

Therefore, Rate of stimulated emission proportional to N_2

Rate of stimulated emission proportional to U_ν

$\therefore$ $RSE \propto N_2 U_\nu$

(or) $\boxed{RSE = B_{21} N_2 U_\nu}$

where B_{21} is a proportionality constant called Einstein's coefficient of stimulated emission.

Populations of energy states (or) levels:-

The number of atoms in an energy state is known as population of energy state. The population of different energy states are related to the each other if the system is in thermal equilibrium at T K.

Consider two energy states E_1 & E_2 with population N_1 & N_2 respectively such that $E_2 > E_1$ i.e., $(E_2 - E_1) = +ve$

Now, consider "Maxwell - Boltzmann" Statistics (M.B)

$$\boxed{N = Ce^{-E/KT}} \rightarrow (1)$$

where N is number density of atoms

C is a constant

E is the arbitrary energy

K is Boltzmann constant

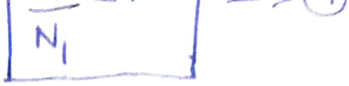
T is the temperature at thermal equilibrium

Now, $N_1 = Ce^{-E_1/KT} \rightarrow (2)$

$N_2 = Ce^{-E_2/KT} \rightarrow (3)$

$$\frac{N_2}{N_1} = \frac{Ce^{\frac{-E_2}{KT}}}{Ce^{\frac{-E_1}{KT}}} \rightarrow (4)$$

$$\boxed{\frac{N_2}{N_1} = e^{(-E_2+E_1)/KT}} \rightarrow (5)$$



$\Rightarrow N_2 < N_1$ (or) $N_1 > N_2$

Thus under ordinary conditions the population of higher energy state (E_2) is less than that of population of its lower energy state (E_1).

In contrary to it, if the population of anyone of its higher energy state is made more than that of population of any of its lower energy state then the population inversion is said to be achieved in the system.

$\boxed{\text{i.e., } N_2 > N_1}$

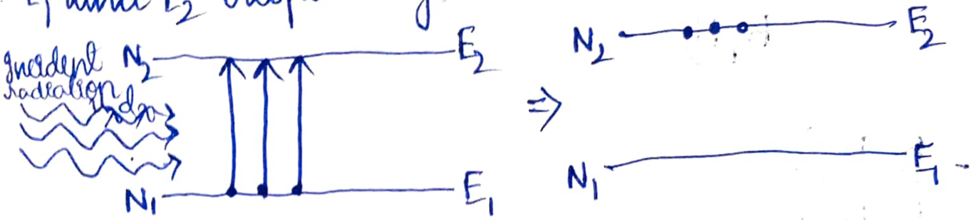
***Q: obtain the expression for energy density of radiation using Einstein A & B coefficients.**

→ The energy density of radiation is the total energy per unit volume per unit wavelength range of radiation in the radiation field. It is given by plank's radiation law as

$$U_\lambda d_\lambda = \left(\frac{8\pi hc}{\lambda^5}\right) \times \frac{1}{\left(e^{hc/\lambda KT} - 1\right)} \cdot d_\lambda \longrightarrow ①$$

Energy density of radiation } =

consider two energy states E_1 & E_2 of a system of atoms. Let N_1 be the no. of atoms with energy E_1 and N_2 be the no. of atoms with energy E_2 per unit volume of the system. N_1 and N_2 are called no. density of atoms in the energy state E_1 and E_2 respectively.



Let the radiation with a spectrum of wavelength be incident on the system.

Let $U_\lambda d_\lambda$ is the energy density of the radiation be incident on the system.

Then the rate of induced absorption $\propto N_1 u_\lambda d_\lambda \rightarrow (2)$

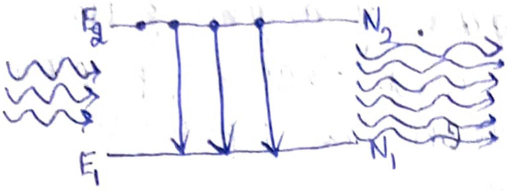
(or) rate of induced absorption $= B_{12} N_1 u_\lambda d_\lambda \rightarrow (3)$

where B_{12} Einstein coefficient of induced absorption

Now atoms in the excited state come to the ground state spontaneously nearly 10^{-8} sec.

$\therefore$ Rate of spontaneous emission $\propto N_2 \rightarrow (4)$

(or) rate of spontaneous emission $= A_{21} N_2 \rightarrow (5)$



Now if the atoms are in the excited state (E_2) deexcited to ground state due to the stimulation of incident radiation of energy density $u_\lambda d_\lambda$ then rate of stimulated emission of radiation $\propto N_2 u_\lambda d_\lambda \rightarrow (6)$

(or) Rate of stimulated emission radiation $= B_{21} N_2 u_\lambda d_\lambda \rightarrow (7)$

At thermal equilibrium (i.e., $T^\circ K$), we have rate of induced absorption = Rate of spontaneous emission + Rate of stimulated emission.

i.e., $B_{12} N_1 u_\lambda d_\lambda = A_{21} N_2 + B_{21} N_2 u_\lambda d_\lambda \rightarrow (8)$

If $d_\lambda = 1$ unit

then $\boxed{B_{12} N_1 u_\lambda = A_{21} N_2 + B_{21} N_2 u_\lambda} \rightarrow (9)$

$\Rightarrow u_\lambda (B_{12} N_1 - B_{21} N_2) = A_{21} N_2$

(or) $\boxed{u_\lambda = \dfrac{A_{21} N_2}{(B_{12} N_1 - B_{21} N_2)}} \rightarrow (10)$

Divide Numerator & Denominator by $B_{21} N_2$

$$u_\lambda = \frac{\left(\dfrac{A_{21} N_2}{B_{21} N_2}\right)}{\left(\dfrac{B_{12} N_1}{B_{21} N_2} - \dfrac{B_{21} N_2}{B_{21} N_2}\right)}$$

$$u_\lambda = \frac{A_{21}/B_{21}}{\left(\dfrac{B_{12} N_1}{B_{21} N_2} - 1\right)}$$