LASERS

1. What is laser? Mention its engineering applications.

→ The word 'LASER' is the acronym for Light Amplification through Stimulated Emission of Radiation. However, laser is not a simple amplifier of light but it is a generator of light. It is an artificial light source and is more akin to radio and microwave transmitters. It produces a highly directional coherent monochromatic polarized light beam. T.H. Maiman built the first laser device in 1960. Since then, it has many applications like, CO_2 laser used in cosmetics, ~~ND:G~~ Nd:YAG ~~lased~~ laser used in machining, Argon laser used in surgery, diode laser in communications, dye lasers in spectroscopy, weapon guidance in wars, Nd: Glass laser in nuclear fusion, etc.

2. Compare ordinary and laser beam.

→

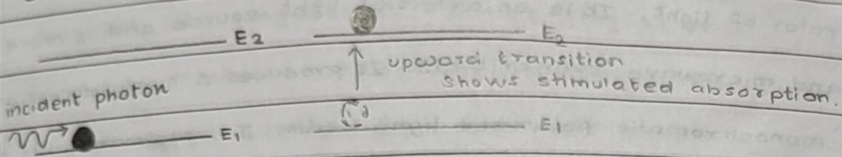
	ordinary beam	laser beam
i.	It is non-monochromatic.	it is monochromatic.
ii.	It is incoherent, i.e. the constituent waves are generally not in the same phase.	it is coherent i.e. the constituent waves are exactly in the same phase.
iii.	It does not travel as a concentrated and parallel beam.	it travels as a concentrated parallel beam.
iv.	ordinary light is produced by spontaneous emission.	laser beam is produced by stimulated emission.

3. Interaction with matter.

→ Let a monochromatic radiation of frequency ν be incident on the medium. The radiation may be viewed as a stream of photons, each photon carrying an energy $h\nu$. If $h\nu = E_2 - E_1$, the interaction of radiation with atoms leads to three distinct processes.

(a) stimulated absorption.

An atom residing in the lower state energy E_1 may absorb the incident photon and jump to the excited state E_2. The transition is known as stimulated absorption or induced absorption.



corresponding to each transition made by an atom, one photon disappears from the incident beam. It may be represented as,

$$A + h\nu \longrightarrow A^*$$

where A is the atom in lower state and A^* is the atom at the excited state.

The probability rate of transition is given by,

$$\boxed{\left.\frac{dN}{dt}\right|_{ab} = B_{12} N_1 Q}$$ where,

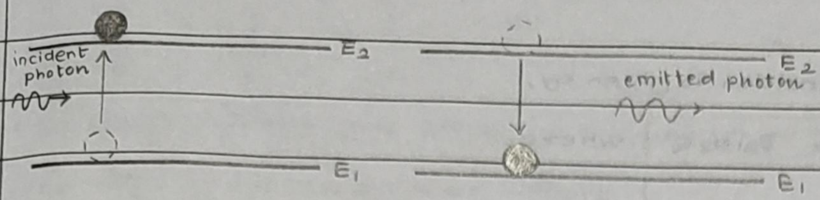
B_{12}: probability of absorption process, called as Einstein's coefficient for absorption of radiation.

N_1: no. of atoms in lower energy level

Q : energy density of incident radiation per frequency

(b) spontaneous emission:

When the excited atom in the state E_2 returns to the lower state E_1, naturally, due to the tendency to attain minimum potential energy. During the transition, the excess energy is released as a photon of energy $h\nu = E_2 - E_1$. This type of process in which proton emission occurs without any interaction with external radiation is called spontaneous emission.



It may be represented as,

$A^* \longrightarrow A + h\nu$

The probability of spontaneous emission $2 \longrightarrow 1$ depends on the properties of state 1 and state 2.

The rate of spontaneous emission is denoted by,

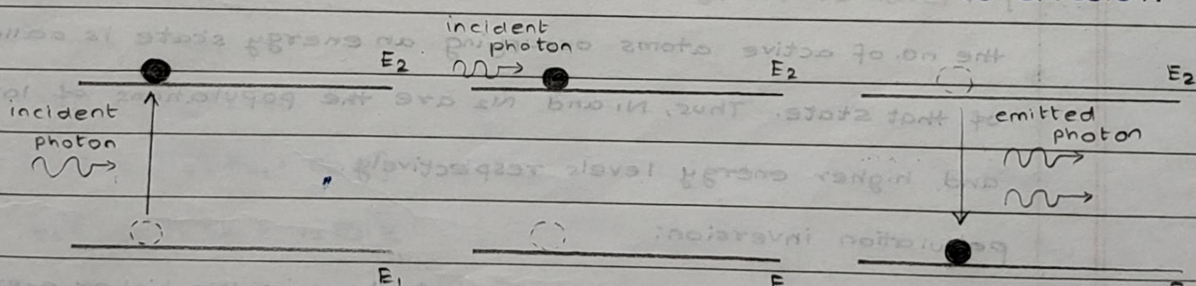
$$\boxed{\left.\frac{dN}{dt}\right|_{sp} = A_{21}N_2}$$ where,

A_{21}: probability of spontaneous emission process, called Einstein's coefficient of spontaneous emission of radiation.

N_2 : no. of atoms in higher energy level

(c) Stimulated i.e. triggered emission

An atom in the excited state need not wait for spontaneous emission to happen. There is an alternative mechanism. An incoming photon for which the quantum energy $h\nu$ is equal to the energy difference between its present level can induce the excited atom to make a downward transition releasing the energy in the form of a photon. The phenomenon of forced emission of photons are called induced or stimulated emission.



The emitted photon is identical to ~~that~~ the incident photons in all respects. It has the same frequency, phase and state of polarization as that of incident proton. Both photons travel in the same direction.

The rate of transition is given by,

$$\left.\frac{dN}{dt}\right|_{st} = B_{21} N_2 Q$$

where,

B_{21}: probability of stimulated emission process

N_2: no. of atoms in higher energy levels

Q: energy density of incident radiation per unit frequency.

4. Explain the important physics laser terms.

→ coherent and incoherent light:

coherent light is the light in which definite phase relationships exist between the waves constituting the light. ~~Incoho~~ Incoherent light is the light in which there is no definite phase relationship between the waves constituting the light.

active medium:

A medium in which light gets amplified is called an active medium. the medium may be solid, liquid or gas. Out of diff atoms in the medium, only a small fraction of atoms of particular species are responsible for stimulated emission. They are called active centres.

metastable state:

special energy levels having unusually high lifetime.

population:

the no. of active atoms occupying an energy state is called population of that state. Thus, N_1 and N_2 are the populations of lower and higher energy levels respectively.

population inversion:

the phenomenon in which the no. of atoms in the higher energy state becomes comparatively greater than the no. of atoms in the lower energy state is known as population inversion.

pumping:

the process of supplying energy to the medium to transfer it into the state of population inversion, is called pumping.

optical pumping:

the medium is excited by supplying luminous energy from a light source. the energy is supplied in the form of short flashes of light. this type of pumping is used in ~~ruby~~ ruby laser.

electric discharge:

this method is employed in gaseous ion lasers. a slowing electric field accelerates the electrons. the accelerated electrons collide with atoms of the medium. consequently, atoms are ionized and excitation is produced.

direct conversion:

the electric energy is converted directly into light energy with the help of light emitting diodes. this is used in semiconductor lasers.

5. Derive the relation between 'A' and 'B' coefficients.

→ Let us consider an assembly of atoms in thermal equilibrium at temp. T with radiation of frequency ν and energy density Q. Suppose N_1 and N_2 are the no. of atoms in energy states 1 and 2 resp. at any instant. At thermal equilibrium, the absorption probability is equal to the total emission (spontaneous + stimulated) probability, so, we have,

$$N_{12} = N_{21}$$

$$\therefore \quad N_1 P_{12} = N_2 P_{21}$$

$$\therefore \quad N_1 B_{12} Q = N_2 [A_{21} + B_{21} Q]$$

$$\therefore \quad N_1 B_{12} Q = N_2 A_{21} + N_2 B_{21} Q$$

$$\therefore \quad Q (N_1 B_{12} - N_2 B_{21}) = N_2 A_{21}$$

$$\therefore \quad Q = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}}$$

$$\therefore \quad Q = \frac{A_{21}/B_{21}}{\left[\frac{N_1 B_{12}}{N_2 B_{21}} - 1\right]} \quad \text{— (1)}$$

lasing
two level
three, four
optical resonator

According to Boltzmann distribution law, no. of atoms N_1 and N_2 in energy states E_1 and E_2 in thermal equilibrium at temperature T are given by,

$N_1 = N_0 e^{-(E_1/K_BT)}$ and $N_2 = N_0 e^{-(E_2/K_BT)}$

where, N_0 is the total no. of atoms and K_B is boltzmann's constant.

$$\frac{N_1}{N_2} = e^{\left(\frac{E_2}{K_BT}\right)-\left(\frac{E_1}{K_BT}\right)} = e^{\left(\frac{E_2-E_1}{K_BT}\right)}$$

$$\therefore \boxed{\frac{N_1}{N_2} = e^{(h\nu/K_BT)}}$$ where,

$E_2 - E_1 = h\nu$ is the energy of each photon of the radiation.

from (1),

$$Q = \frac{(A_{21}/B_{21})}{\left[\frac{B_{12}}{B_{21}} e^{(h\nu/K_BT)} - 1\right]} \quad \text{— (2)}$$

According to planck's radiation formula,

$$\boxed{Q = \frac{8\pi h\nu^3}{c^3} \frac{1}{\left[\exp\left(\left(\frac{h\nu}{K_BT}\right)-1\right)\right]}} \quad \text{— (3)}$$

comparing (2) and (3),

$$\boxed{B_{12} = B_{21} \quad \text{and} \quad \frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}}$$

these equations present the relation between einstein's coeffecient

laser transition → ⇒
non-radiative → - - ->
spontaneous → — — →
pumping → ⟶

6. why is population
→ A population inver
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7. Threshold conditi
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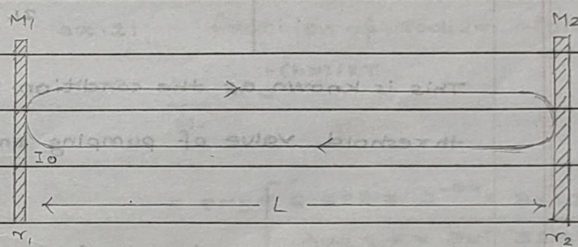
6. Why is population inversion not possible in two-level pumping scheme?

→ A population inversion cannot be achieved with just two levels because the probability for stimulated absorption and for stimulated emission is exactly the same, as expressed by Einstein in his A and B coefficients. The lifetime of a typical excited state is about 10^{-8} seconds, so, in practical terms, electrons drop back down by photo emission about as fast as we can pump them up to the upper level.

Thus, the upward transitions would be accomp~~lished~~ anied by premature downward stimulated transitions and the population in level E_2 would not accumulate to the required extent. Hence, a two-level pumping scheme is not suitable for obtaining population inversion.

7. Threshold condition for lasing.

→ Let us assume that the laser medium fills the space between the mirrors M_1 and M_2 which have reflectivity r_1 and r_2 respectively. Let the mirrors be separated by a distance L. Further, let the intensity of the light beam be I_0 at M_1. Then, in travelling from mirror M_1 to M_2, the beam intensity increases from I_0 to $I(L)$, which is given by,



$$I(L) = I_0 e^{(\gamma - \alpha_s)L}$$

where, γ is the gain coefficient and α is the loss coefficient of the active medium.

After reflection at M_2, the beam intensity will be $r_2 I_0 e^{(\gamma-\alpha_s)L}$ and after a complete round trip, the final intensity will be

$$\boxed{I(2L) = r_1 r_2 I_0 e^{(\gamma-\alpha_s)2L}}$$

The amplification obtained during the round trip is

$$\boxed{G = \frac{I(2L)}{I_0} = r_1 r_2 e^{(\gamma-\alpha_s)2L}}$$

The product $r_1 r_2$ represents the losses at the mirrors whereas α_s includes all the distributed losses such as scattering, diffraction and absorption occuring in that medium. The losses are balanced by gain, when $G \geq 1$ or $I(2L) = I_0$. It requires that,

$$r_1 r_2 e^{(\gamma - \alpha_s)2L} \geq 1$$

$$e^{(\gamma - \alpha_s)2L} \geq 1/r_1 r_2$$

taking logarithm on both sides, we get,

$$2L(\gamma - \alpha_s) \geq -\ln(r_1 r_2)$$

$$\gamma - \alpha_s \geq -\frac{\ln(r_1 r_2)}{2L}$$

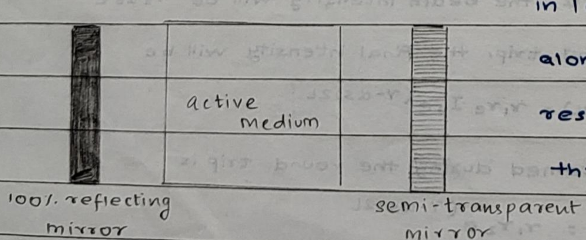
$$\gamma \geq \alpha_s - \frac{\ln(r_1 r_2)}{2L}$$

or $$\boxed{\gamma \geq \alpha_s + \frac{1}{2L} \ln\left(\frac{1}{r_1 r_2}\right)}$$

This is known as the condition for lasing. It is used to determine the threshold value of pumping energy for lasing action.

8. What is the role of optical resonator?

→ In laser, the active medium is the amplifier, which is converted into an oscillator ~~the~~ through the feedback mechanism established by an optical resonator. A pair of optically plane parallel mirrors, enclosing laser medium in between them is called an optical ~~resonator~~ resonant cavity. One of these mirrors is partially reflecting and the other is made fully reflecting.



In laser, the photons emitted along the optic axis of the resonant cavity, travel through the medium and trigg[er] stimulated emissions.

They are reflected by th[e]
The photons are thus, fe[d]
the opposite end mirror
photons are ~~thus, fed t~~
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at the mirrors and gai[n]
ultimately, when the a
the laser emerges out
of resonator cavity, th

• questions from V Rajendran:

ex. 1: energy of I excited s

→ $\lambda = 590\text{ nm} = 5900 \times$

$E = hc/\lambda$

$= \frac{6.626 \times 10^{-34} \times 3}{5.9 \times 10^{-7}}$

$\Rightarrow E = 3.369 \times 10^{-19}$

$E = \frac{3.369 \times 10^{-19}}{1.602 \times 10^{-19}}$ e

ex. 8: ratio of stimulated

→ $\frac{\text{stimulated emissi}}{\text{spontaneous emis}}$

$= \frac{1}{e^{hc/\lambda kT} - 1}$

$=$ ~~5.23~~ 5.3

They are reflected by the end mirror and reverse their path. The photons are thus, fed back into the medium and travel toward the opposite end mirror causing more stimulated emissions. The photons are ~~thus, fed back~~ once more reflected at the mirror and travel towards the opposite mirror. substantial light amplification takes place because the light beam is reflected several times at the mirrors and gains strength in each passage.

ultimately, when the amplification balances the losses in the cavity, the laser emerges out of from the front-end mirror. In the absence of resonator cavity, there would be no amplification of light.