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ASSIGNMENT-4
ENGINEERING PHYSICS

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SECTION C-72.
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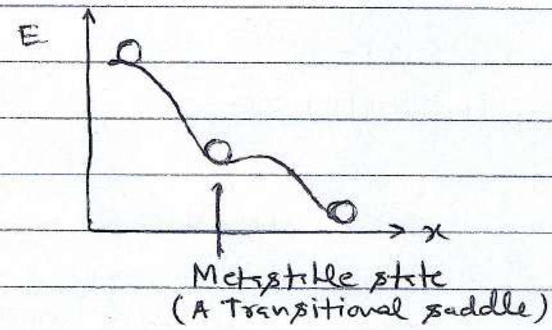
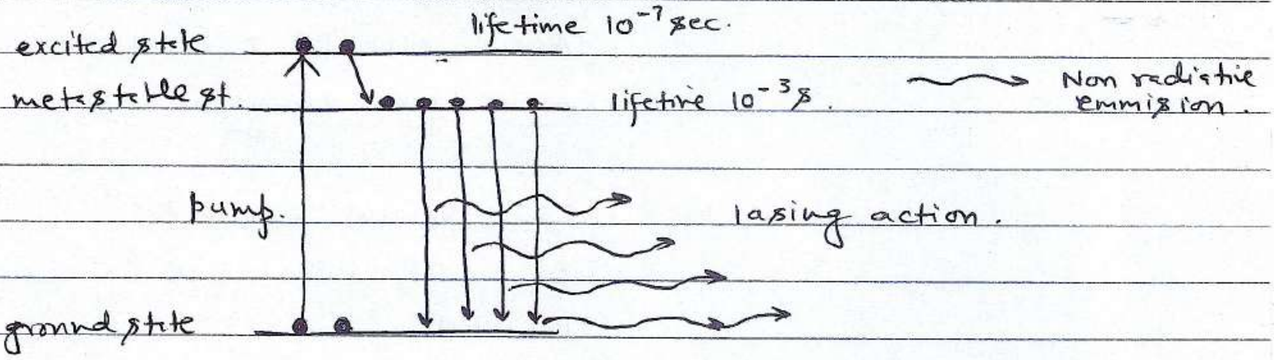
Q1. Explain (i) Metastable state.
(ii) optical pumping

Metastable state.

It is an excited state of an atom with a longer lifetime than other excited states. Atoms in metastable state remain excited for a considerable time in the order of 10^{-6} to 10^{-3} seconds. During metastable state, all the parameters associated with state hold stationary values. A larger number of excited atoms are accumulated in metastable state because it assures that spontaneous emission does not occur more often then stimulated emission causing population inversion of the lasing medium. Metastable states thus allow storage of significant amount of energy and hence are critical for Q-switched lasers.





optical pumping

It is the process in which light is used to raise (or pump) electrons from a lower energy level in an atom or molecule to a higher one. It is used in laser construction to pump to active laser medium so as to achieve population inversion some common optical pumping sources are :

Discharge lamps,

Laser diodes etc

Q2. Define spontaneous and stimulated emission of radiation?

Spontaneous Emission

The excited atoms can return back to the lower energy (After induced Absorption) state spontaneously (without any external influence) by emitting photons of the same frequency as that of stimulating photons and travel in same direction.

Stimulated Emission

In this case, the deexcitation of atoms take place when they are stimulated (or induced externally) by photons of same energy as that of deexcitation. Also, for every incident photon, there are TWO emitted photons, causing amplifications in the outgoing beam. This process is an essential part in the laser action.

Mathematics of three transition processes given by Einstein

→ Induced absorption

For absorption, radiation energy must be present. Rate of induced absorption is proportional to.

N_1 : No. of Atoms in lower energy state.

$u(\nu)$: energy density of radn incident on these atoms (impying no. of photons) b/w freq. interval ν and $\nu + d\nu$.

$$\frac{dN_{12}}{dt} \propto N_1 u(\nu) \quad \text{or} \quad \frac{dN_{12}}{dt} = B_{12} N_1 u(\nu)$$

where B_{12} : Einsteins coefficient of induced absorption

→ Sponteneous emission

Atom drops from excited state to lower state and its rate is proportional aly to

N_2 : No. of atoms in excited state.

$$\frac{dN_{21}}{dt} \propto N_2 \quad \text{or} \quad \frac{dN_{21}}{dt} = N_2 A_{21}$$

where A_{21} : Einsteins coefficient of sponteneous emission.
Reciprocal of A_{21} is time for $2 \to 1$ transition.

→ Stimulated emission

Like induced absorption, incident energy is repuired for the stimulated emission to take place. Hence its rate is proportional to

N_2 : No. of atoms in excited state.
$u(\nu)$: the energy density of radn incident on these atoms

$$-\frac{dN_2}{dt} \propto N_2 u(\nu) \quad \rightarrow \quad \frac{dN_2}{dt} = B_{21} N_2 u(\nu)$$

where B_{21} : is the einsteins coefficient for stimulated emission.

At Thermal equilibrium, the number of upward transitions must be equal to the no. of downward transitions.

$$\therefore \quad B_{12} N_1 u(\nu) = A_{21} N_2 + B_{21} N_2 u(\nu)$$

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

Further from Boltzmann law,

$$\frac{N_1}{N_2} = \exp\left(\frac{E_2 - E_1}{kT}\right) = \exp\left(\frac{h\nu}{kT}\right)$$

$$\therefore \quad u(\nu) = \frac{A_{21}}{B_{12} \exp\left(\frac{h\nu}{kT}\right) - B_{21}} \quad — (1)$$

According to planck's law, energy density of radn is given by

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{\exp(h\nu/kT) - 1} \quad — (2)$$

comparing (1) & (2) we get

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

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$$

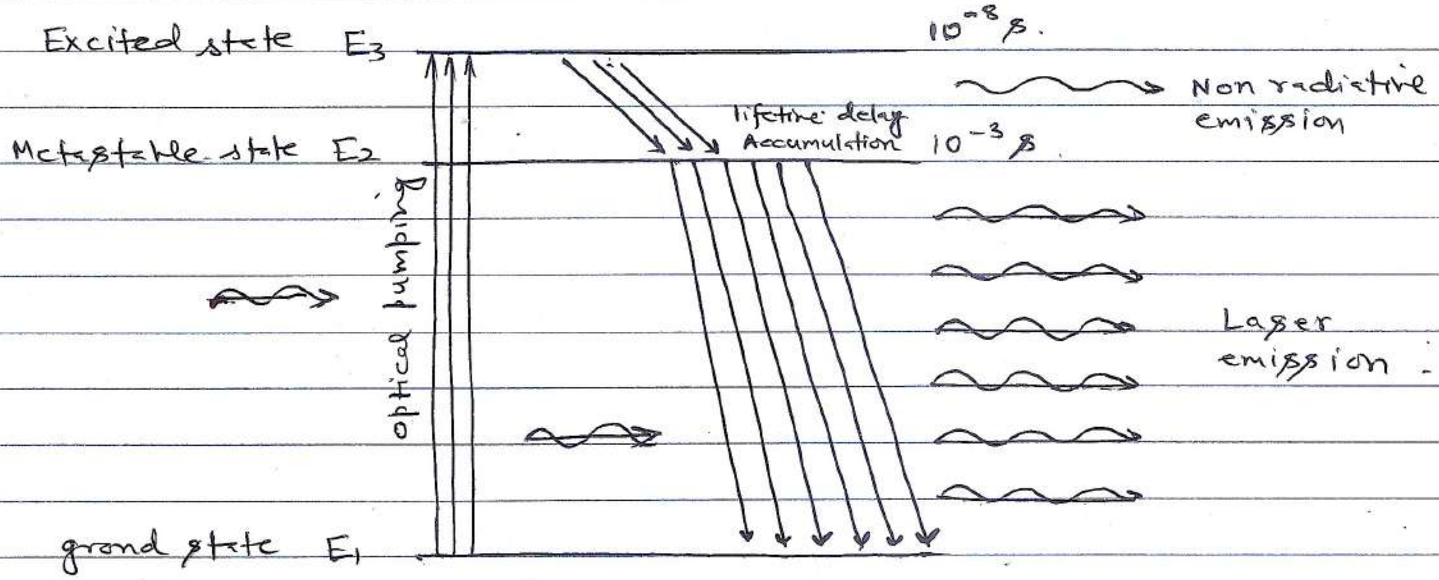
Further,

$$\boxed{\frac{A}{B u(\nu)} = \exp\left(\frac{h\nu}{kT} - 1\right)}$$

Under the condition $h\nu << kT$, stimulated emission is much greater than spontaneous emission which is desired for lasing action.

Q3. Explain principle of laser / Lasing action.

When ground state atoms are illuminated with a suitable light, a large no. of atoms can be excited (through induced absorption) to the highest energy level E_3 directly (optical pumping). From level E_3, they decay to the metastable state level E_2. If the optical pumping is continued, a significant no. of atoms (even larger than in ground state) can be pumped to level E_2 to obtain population inversion. In metastable state, after population inversion is achieved, stimulated emission can be trigerred by a photon of energy $E_2 - E_1$ which by avalanche effect releases the accumulated energy very fast in form of coherent photons which constitute a narrow beam of radiation with very high energy density.



Q4. A He-Ne laser light emits light at a wavelength of 632.8 nm and has an output power of 5mwatts. Calculate the number of photons emitted per second.

$$\text{Energy of 1 photon} = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}}$$

$$= \frac{6.63 \times 3}{632.8} \times 10^{-34+8+9}$$

$$\approx 0.0314 \times 10^{-17}$$

$$E_p \approx 3.14 \times 10^{-19}\ J$$

P : Energy emitted per second $= 5 \times 10^{-3}\ J/s$. (power).

$\therefore$ No. of photons released/sec $= P/E_p = \frac{5 \times 10^{-3}}{3.14 \times 10^{-19}}$

$$\boxed{\approx 1.6 \times 10^{16}\ \text{photons/sec}}$$

Q5. Describe the construction, principle and working or Ruby laser with relevent energy diagram.

1. Principle : Ref to Q3.
2. Construction
   (i) Active medium

It is a solid state laser, in which a rod of a synthetic ruby crystal is used as an active medium (one which contains metastable states). The ruby crystal is obtained by doping a small amount (~ 0.05% by weight) of chromium oxide (Cr_2O_3) in Aluminium oxide (Al_2O_3), so that some aluminium ions Al^{3+} are replaced by chromium ions (Cr^{3+}). These chromium ions give crystal a pink or red colour depending on doping concentration. Al_2O_3 only acts as the host while the chromium ions act as active centres in ruby crystal and responsible for laser action. The length of ruby rod is usually 2cm to 30 cms and diameter is 0.5 cm to 2cm

(ii) Optical resonator.

To construct optical resonator cavity, the ends of the rods are polished such that they become flat and parallel to each other. Now one of the ends is coated with silver completely while the other one is partially silvered. Thus the two silver coated ends of the rod act as optical resonator system. In advanced laser a spring may be added at the permanent mirror side to somehow vary the column length to adjust frequency of laser (ie $f = nc/2L$)

(iii) Pumping system.

The ruby rod is placed inside a helically shaped Xenon flash lamp to excite Cr^{3+} ions. Thus in ruby laser, population inversion is obtained by optical pumping.

3. Working

Ruby is a three energy level laser system. After absorbing light photons of wavelength 5000Å from Xenon flash lamp, some of the Cr^{3+} ions at ground energy level E_1 get excited to higher energy level E_3. At this energy level, they are unstable and by loosing a part of their energy to the crystal lattice, they fall to the metastable energy level E_2, whose lifetime is much longer ($\sim 10^{-3}$ s). Therefore the no. of Cr^{3+} goes on increasing in E_2 state while the number of these ions in ground state goes on decreasing due to pumping by flash lamp and soon population inversion is achieved

Now, some of the Cr^{3+} ions will decay spontaneously to the ground state E_1 by emitting photons of wavelength 6943 Å. The photons that are moving parallel to the axis of rod will reflect back and forth by the silvered ends of the rod and stimulate other excited Cr^{3+} ions to radiate another photon with same phase. Thus, due to successive reflections of these photons at the ends of the rod, the number of photons multiplies exponentially. After a few microseconds, a monochromatic, intense and collimated beam of red light of wavelength 6943 Å emerge through the partially silvered end of the rod. The ruby laser is a pulsed laser which emits light in form of very short pulses.

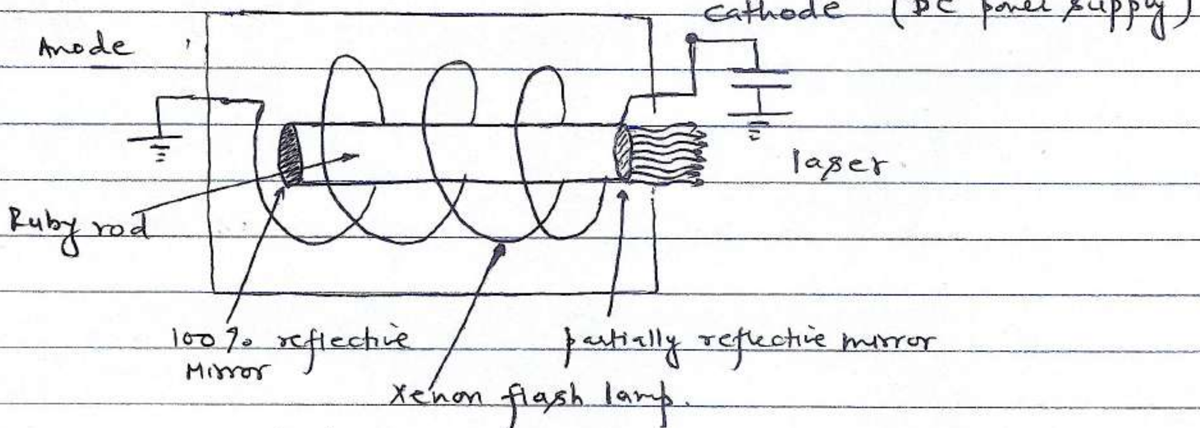


Fig. construct of ruby laser.

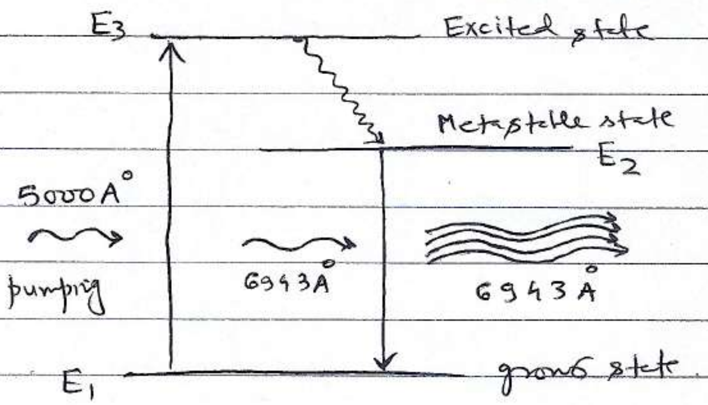


Fig: Energy diagram of ruby laser.

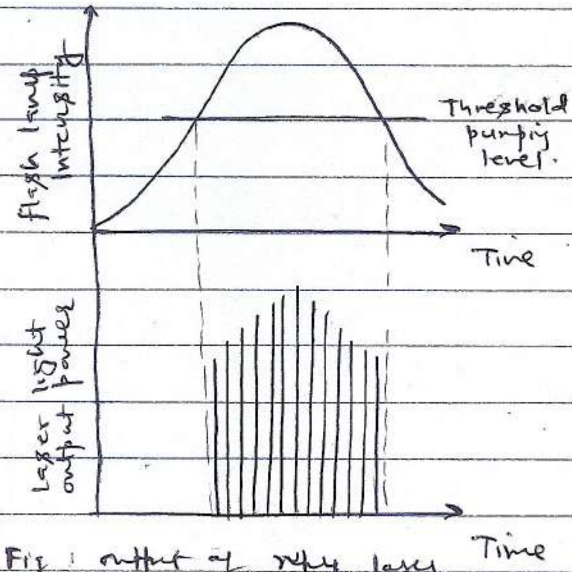


Fig: output of ruby laser.

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