UNIT- III LASER and Optical Fibers

(i) Find the ratio of population of the two energy states of the ruby laser, the transition between which is responsible for the emission of photon of wavelength 694.3 nm. Assume temperature as 27°C

Soln:- we have $\lambda = 694.3\ nm$

$T = 27°C$

$\frac{N_2}{N_1} = ?$

we know $N_2 = N_1 \exp\left(-\frac{h\nu}{KT}\right)$

$$\frac{N_2}{N_1} = \exp\left(-\frac{h\nu}{KT}\right) = \exp\left(-\frac{hc}{\lambda KT}\right)$$

$$= \exp\left(\frac{-6.6\times10^{-34}\times 3\times10^{8}}{694.3\times10^{-9}\times1.38\times10^{-23}\times 300}\right)$$

$$= \exp\left(-\frac{19.8\times10^{-26}}{287440.2\times10^{-32}}\right)$$

$$= \exp\left(-6.888\times10^{6}\times10^{-5}\right)$$

$$= \exp\left(-6.888\times10^{1}\right)$$

$$= \exp(-68.88)$$

$$= 9.98\times10^{-31} \quad (\text{or } 12.18\times10^{-31})$$

(2) The ratio of population inversion of two energy states out of which, upper state corresponds to a metastable state is 1.059×10^{-30}. Find the wavelength of light emitted at 330 K.

Soln: we have $\frac{N_2}{N_1} = \cancel{1.059}\ 1.059 \times 10^{-30}$

$T = 330K$

$\lambda = ?$

we know that $\frac{N_2}{N_1} = \exp\left(-\frac{hc}{\lambda KT}\right)$

$$\ln\left(\frac{N_2}{N_1}\right) = -\left(\frac{hc}{\lambda KT}\right)$$

$$\ln\left(1.059 \times 10^{-30}\right) = -\frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{\lambda \times 1.38 \times 10^{-23} \times 330}$$

$$\cancel{-}\,69.02 = \cancel{-}\,\frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{\lambda \times 1.38 \times 10^{-23} \times 330}$$

$$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{69.02 \times 1.38 \times 10^{-23} \times 330}$$

$$\lambda = \frac{19.8 \times 10^{-26}}{31431.7 \times 10^{-23}}$$

$$\lambda = 6.299 \times 10^{-4} \times 10^{-3}$$

$$\lambda = \underline{\underline{630\ nm}}$$

(3) A He-Ne laser is emitting a laser beam with an average power of 4.5 mW. Find the number of photons emitted per second by the laser. The wavelength of emitted radiation is 632.8 nm

Soln: we have : Average power of laser beam = 4.5 mW

wavelength of emitted radiation = 632.8 nm

$N = ?$

we know that,

Energy of each photon $= \frac{hc}{\lambda}$

$= \frac{6.6\times10^{-34} \times 3\times10^{8}}{632.8\times10^{-9}}$

$= 3.128\times10^{-19}$ J

Energy emitted by Laser beam $= 5$ mW $= 5\times10^{-3}$ Js^{-1}

Number of photon emitted $= \frac{5\times10^{-3}}{3.128\times10^{-19}}$

$= 1.59\times10^{16}$ photon/sec

[$\because$ No of photon emitted $= \frac{\text{Energy of Laser beam}}{\text{Energy of each photon}}$]

(4) A pulsed laser emits photons of wavelength 780 nm. with 20 mW average power/pulse. Calculate the no of photons contained in each pulse, if the pulse duration is 10 ns.

Soln: we have: wavelength of photon = 780 nm

power of laser = 20 mW.

No of photon N = ?

pulse duration t = 10 ns.

we know that: Energy of photon $= \Delta E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{780\times10^{-9}}$

$= 0.0253\times10^{-17}$

$\Delta E = 2.53\times10^{-19}$ J

Energy of laser beam $= E = P\times t = 20\times10^{-3}\times10\times10^{-9} = 200\times10^{-12}$

$E = 2\times10^{-10}$ J

$\therefore N = \frac{\cancel{\Delta E}}{\cancel{E}} \quad \frac{E}{\Delta E} = \frac{2 \times 10^{-10}}{2.53 \times 10^{-19}} = 0.7905 \times 10^{+9}$

$N = 7.905 \times 10^{8}$

(5) A pulse from Laser with power 1 mW lasts for 10ns. if the no of photons emitted per second is 3.491×10^{7} Calculate the wavelength of Laser.

Soln: Given : Power of laser $P = 1\ mW$

Time $t = 10\ ns$

No of photon $N = 3.49 \times 10^{7}$

wavelength $\lambda = ?$

we know that $E = \text{Power} \times \text{time} = 1 \times 10^{-3} \times 10 \times 10^{-9}$

$= 1 \times 10^{-11}\ J$

we have $N = \frac{E}{\Delta E} \Rightarrow \Delta E = \frac{E}{N} = \frac{hc}{\lambda} \quad (\because \Delta E = \frac{hc}{\lambda})$

$\therefore \lambda = \frac{hc}{\Delta E} \quad \frac{hcN}{E}$

$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8} \times 3.49 \times 10^{7}}{1 \times 10^{-11}}$

$= 69.1 \times 10^{-8}$

$\lambda = 691\ nm$

(6) A ruby laser emits pulses of 20ns duration with average power/pulse being 0.1 mW. If the number of photon in each pulse is 6.98×10^{15}, Calculate the wavelength of photon?

$[E = P.t, \quad \lambda = \frac{hcN}{E}]$

(7) Find the intensity of a laser beam of 20mW power and having a diameter of 1.3mm. Assume the intensity to be uniform across the beam.

Soln: we have ~~Intensity~~ Power of laser = 20mW.

Diameter = 1.3 mm

Intensity of laser = ?

we know $I = \frac{P}{A}$ [Intensity = Power per unit area]

$$= \frac{20\times10^{-3}}{\pi r^2}$$

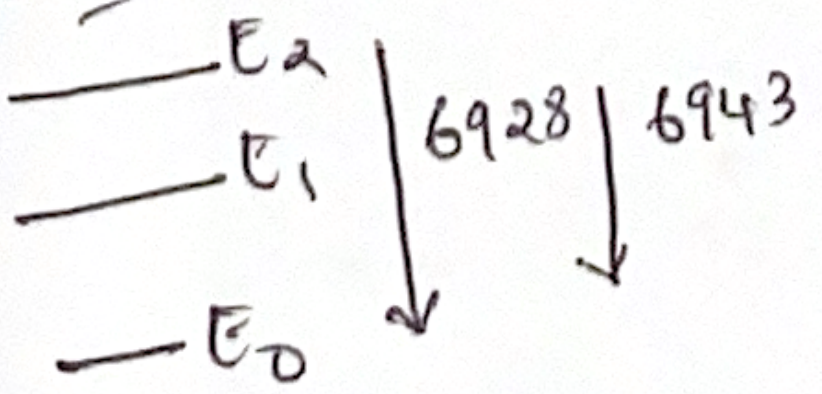
$$= \frac{20\times10^{-3}}{3.14\times(0.65\times10^{-3})^2}$$ [D = 1.3 mm, $r = \frac{D}{2} = 0.65$ mm]

$$= 15.07\times10^{3}$$

$$I = 15.07 \text{ kW}$$

(8) The transition ~~of~~ to the ground state from the upper and lower energy states in a Ruby laser results in emission of photons of wavelength 6928 Å & 6943 Å respectively. Estimate the energy gap of the two energy levels in eV & also their ratio of population inversion.

Soln: we have ~~E_2 ≠ 4.~~ $\lambda_2 = 6943$ Å & $\lambda_1 = 6928$ Å



$E_1 = ?$, $E_2 = ?$, $\frac{N_2}{N_1} = ?$

$$E_1 = \frac{hc}{\lambda_1} = \frac{6.6\times10^{-34}\times3\times10^{8}}{6943\times10^{-10}} = 2.85\times10^{-3}\times10^{-16} \text{ J}$$

$$E_1 = \frac{2.85\times10^{-19}}{1.6\times10^{-19}} = 1.781 \text{ eV}$$

$$E_2 = \frac{hc}{\lambda_2} = \frac{6.6\times10^{-34}\times3\times10^{8}}{6928\times10^{-10}} = \cancel{3.176}\times10^{-3}\times10^{-16}$$

$$= \cancel{3.17}^{\,2.857}\times10^{\cancel{-19}}\,J = 2.857\times10^{-19}$$

$$\cancel{E_2 = \frac{3.17\times10^{-20}}{1.6\times10^{-19}} = 1.981}$$

$$E_2 = \frac{2.857\times10^{-19}}{1.6\times10^{-19}} = \underline{1.786\ eV}$$

$\therefore E_1 = 1.781\ eV$

$E_2 = \underline{1.786\ eV}$

~~Thus we have~~ $\cancel{N_2 = N_1\, exp\left(-\frac{hc}{\lambda KT}\right)}$

$$\cancel{N_2 = N_1\, exp\left(-\frac{h\nu}{KT}\right)}$$

$$\cancel{\frac{N_2}{N_1} = exp\left(-\frac{E}{KT}\right)}$$

$$\cancel{= exp\left(-\frac{E_2 - E_1}{KT}\right)}$$

$$\cancel{= exp\left(-\frac{0.005}{1.6\times10^{-23}\times}\right)}$$

we know that $E = h\nu = \frac{hc}{\lambda}$

$$\therefore E = Nh\nu = N\frac{hc}{\lambda}$$

$$\Rightarrow E_1 = N_1\frac{hc}{\lambda_1}$$

$$E_2 = N_2\frac{hc}{\lambda_2}$$

$$\frac{E_1}{E_2} = \frac{N_1\lambda_2}{N_2\lambda_1}$$

$$\frac{N_1}{N_2} = \frac{E_1 \lambda_1}{E_2 \lambda_2}$$

$$= \frac{1.781 \times 69\cancel{28}^{43} \times 10^{-10}}{1.786 \times 6928 \times 10^{-10}}$$

$$\frac{N_1}{N_2} = 0.9993 \simeq \underline{\underline{1}}$$

(9) A He-Ne Laser emits light at wavelength of 632.8 nm and has an output power of 2.3 mW. How many photons are emitted in each minutes by this Laser when operating?

Soln: We ~~kno~~ have wavelength $\lambda = 632.8$ nm

Power $P = 2.3$ mW.

To find: $N = ?$

Energy of photon $\Delta E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}}$

$$= \frac{19.8 \times 10^{-26}}{632.8 \times 10^{-9}}$$

$$\Delta E = 0.0312 \times 10^{-17}$$

$$\Delta E = 3.12 \times 10^{-19} \text{ J}$$

Energy of Laser $E = 2.3 \times 10^{-3} \times 60$ $(\because E = Pt)$ (t = per minute = 60 second)

$E = 138 \times 10^{-3}$

$\therefore$ no of photon $= \frac{\cancel{\Delta E}}{\cancel{E}} = \cancel{3.12 \times 10^{-19}}$

$$\frac{E}{\Delta E} = \frac{138 \times 10^{-3}}{3.12 \times 10^{-19}} = 44.23 \times 10^{16}$$

$$= \underline{\underline{4.423 \times 10^{17}}} \text{ photon/minute}$$

(10) Calculate the energy difference between two energy levels of Ne atoms of a He-Ne gas laser when the wavelength of emitted light is 632.8 nm. Also find the no of photon emitted / second if the output power is 1 mW.

Soln: we have wavelength of emitted light = 632.8 nm = λ

output power of laser = 1 mW.

we know $N = \frac{E}{\Delta E}$

$$\Delta E = h\nu = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}}$$

$$= 0.0312 \times 10^{-17}$$

$$= 3.12 \times 10^{-19} \text{ J}$$

$$\Delta E = \frac{3.12 \times 10^{-19}}{1.6 \times 10^{-19}} = 1.95 \text{ eV}$$

(~~Thus~~ ~~N~~ = $\cancel{\frac{E}{\Delta E}}$ = ~~1×10~~

$\cancel{E = P.t} = 1 \times 10^{-3} \times \cancel{60} = \frac{1}{\cancel{60}} \times 10^{-3}$ ~~J = 37.5×10^{16} eV~~ ~~0.625×10^{16}~~

$\therefore \cancel{N = \frac{E}{\Delta E}} = \cancel{\frac{37.5 \times 10^{16}}{1.95}} = 19.23 \times 10^{16}$ atom)

$$E = \text{power} \times \text{time} = 1 \times 10^{-3} \times 1 = 1 \times 10^{-3} \text{ J}$$

$$E = \frac{1 \times 10^{-3}}{1.6 \times 10^{-19}} = 0.625 \times 10^{16} \text{ eV}$$

Thus $N = \frac{E}{\Delta E} = \frac{0.625 \times 10^{16}}{1.95} = 0.320 \times 10^{16}$

$N = 3.2 \times 10^{15}$ atom/sec

11. Laser operating at 632.8 nm emits 3.182×10^{16} photons per second. Calculate the (output) o/p power of the Laser if the input power is 100watt. Also find the percentage of power converted into coherent light energy?

Soln: we have wavelength $\lambda = 632.8$ nm

$N = 3.182 \times 10^{16}$

Input power = 100 watt.

O/p power = ?

we know that $\Delta E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}}$

$= \frac{19.8 \times 10^{-34}}{632.8 \times 10^{-9}}$

$\Delta E = 0.0313 \times 10^{-\cancel{17}}$

$\Delta E = 3.13 \times 10^{-19}$ J

we have $N = \frac{E}{\Delta E}$

$\Rightarrow E = N \cdot \Delta E$

$= 3.182 \times 10^{16} \times 3.13 \times 10^{-19}$ J

$= \cancel{9.95 \times 10}\ 9.959 \times 10^{-3}$

$= 0.009959 \simeq \cancel{0.00}$

$E \simeq 0.01$ W

Thus percentage of power $= \frac{\text{O/p power}}{\text{I/p power}} \times 100$

$= \frac{0.01}{100} \times 100 = 0.01\%$

12. Calculate the wavelength of emission from GaAs Semiconductor Laser whose band gap energy is 1.44 eV.

Soln: We have band gap energy = 1.44 eV

$\Delta E = 1.44 \times 1.6 \times 10^{-19}$

$= 2.304 \times 10^{-19}$ J

Thus $\Delta E = \frac{hc}{\lambda}$

$$\lambda = \frac{hc}{\Delta E}$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{\cancel{1.44}\ 2.304 \times 10^{-19}}$$

$$\lambda = 8.59 \times 10^{-7}$$

$$\lambda = 859 \text{ nm}$$

(13) The ratio of population of two energy levels is 1.08×10^{-30}. Calculate the temperature if the wavelength of the emitted photon is 696 nm.

Soln: We have $\frac{N_2}{N_1} = 1.08 \times 10^{-30}$

$$\lambda = 696 \times 10^{-9} \text{ m}$$

$$T = ?$$

We have $N_2 = N_1 \exp\left[-\frac{hc}{\lambda KT}\right]$

$$\frac{N_2}{N_1} = \exp\left[-\frac{hc}{\lambda KT}\right]$$

$$1.08 \times 10^{-30} = \exp\left[-\frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{696 \times 10^{-9} \times 1.38 \times 10^{-23} \times T}\right]$$

$$\ln\left[1.08 \times 10^{-30}\right] = \left[-\frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{696 \times 10^{-9} \times 1.38 \times 10^{-23} \times T}\right]$$

$$\cancel{-}69 = \cancel{-}\frac{0.0206 \times 10^{6}}{T}$$

$$T = \frac{0.0206 \times 10^{6}}{69}$$

$$\underline{T = 298.5\ K}$$