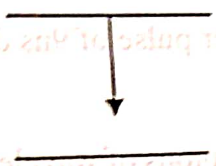
1. Calculate the number of photons emitted per second by a 25mW laser, assuming that it emits light of wavelength of 6328Å.
2. Calculate the average power output by a laser if number of 6350Å photons emitted in 5 seconds is 8.8×10^{17}.
3. Calculate the number of 625nm photons present in a continuous laser pulse of 9ns duration, emitted by a source of 5mW average power.
4. Calculate the duration of a continuous pulse containing 3.385×10^{9} photons of wavelength 585nm, emitted by a source of 50mW average power.
5. A laser pulse of duration 1ms has a power of 10mW. If the number of photons emitted in a pulse are 10^{10}, calculate the wavelength of emitted photons.
6. A laser beam of output power of 5mW is focused to a spot of diameter 1 μm. Calculate intensity of laser beam.
7. Calculate the number of photons of wavelength 1.15μm falling every second, on a circular spot of diameter 5 μm, when continuous laser pulses of 50ns duration emitted by a source of output power 5mW is focused on it.
8. The wavelength of a laser is 6342Å. The number of photons emitted in a minute by the laser is 10^{17}. Calculate the power of the laser. If the input power is 1W, what is the fraction of power converted to output?
9. A photon of wavelength 5800Å is emitted when an atom in an excited state transits to ground stat Calculate the energy and momentum of the photon. What is the ratio of populations of the two states 300K?
10. Calculate Boltzmann factor corresponding to two energy levels separated by 2.3eV, at 250°C.
11. The ratio of stimulated emission to spontaneous emission is 10^{-34}. What is the ratio of populations? If difference in energy corresponds to a wavelength of 6000Å, calculate the temperature.
12. Two energy levels are separated by 2.8 eV. Calculate the ratio of spontaneous to stimulated emissi 450K.

13. Calculate the ratio of spontaneous emission to stimulated emission if the wavelength of radiation is 6400Å at 800K.

14. A system has three energy levels E_1, E_2 and E_3. The energy levels E_1 and E_2 are at 0eV and 1.5eV respectively. If the lasing action takes place from the energy level E_3 to E_2, and emits a light of wavelength 1.2μm, find the energy value of level E_3.

15. $E_2 = 2eV$



$E_1 = 0$

(a) Calculate the ratio of populations N_2/N_1 at a temperature of 400K.
(b)At what temperature will this ratio be 0.01?

16. The ratio of population of two energy levels is 1.06×10^{-30}. Find the wavelength of light emitted by spontaneous emission at 330K.

17. Two energy levels are separated by 2eV. At what temperature will the ratio of populations be 10^{-29}? Calculate A_{21}/B_{12}.

18. If the rate of stimulated emission between two energy levels is R_2 and the rate of spontaneous emission between the same two levels is R_1, show that the wavelength of the radiation emitted between the same levels at temperature T is given by, $\lambda = \frac{hc}{kT\ln\left(1+\frac{R_1}{R_2}\right)}$.

19. Calculate the maximum wavelength that can be amplified using an optical resonator of length 1μm.

20. What should be the minimum distance of separation between the mirrors in resonant cavity to amplify laser of wavelength 625nm?

Term : Aug to Dec 2019

Tutorial Lasers

Calculate the no. of photons emitted per second by a 25mW laser, assuming that it emits light of wavelength 6328 Å.

Ans
$$P = 25\ mW \qquad t = 1\ sec$$
$$P = \frac{nE}{t} = \frac{nhc}{\lambda}$$
$$n = \frac{\lambda P}{hc} = \frac{6328\times10^{-10} \times 25\times10^{-3}}{6.63\times10^{-34}\times3\times10^{8}}$$
$$= 7.95\times10^{16}$$

2. Calculate the average power output by a laser if no. of 6350 Å photons emitted in 5 sec is 8.8×10^{17}.

Ans
$$P = \frac{nE}{t} = \frac{nhc}{\lambda t}$$
$$= \frac{8.8\times10^{17}\times6.63\times10^{-34}\times3\times10^{8}}{6350\times10^{-10}\times5}$$
$$= 5.513\times10^{-2}\ W$$

Calculate the no. of 625 nm photons present in a continous laser pulse of 9ns duration, emitted by a source of 5mW average power.

Ans
$$P = \frac{nhc}{\lambda t} \qquad t = 9ns$$
$$n = \frac{P\lambda t}{hc}$$

$$= \frac{5\times10^{-3}\times625\times10^{-9}\times9\times10^{-9}}{6.63\times10^{-34}\times3\times10^{8}}$$

$= 1.41\times10^{8}$ per sec

4. Calculate the duration of a continous pulse containing 3.385×10^{9} photons of wavelength 585 nm, emitted by a source of ~~1~~ 50 mW average power

Ans
$$P = \frac{nE}{t} = \frac{nhc}{t\lambda}$$

$$t = \frac{nhc}{\lambda P} = \frac{3.385\times10^{9}\times6.63\times10^{-34}\times3\times10^{8}}{585\times10^{-9}\times50\times10^{-3}}$$

$= 2.3018\times10^{-2}$

5. A laser pulse of duration 1 ms has power of 10 mW. If the no. of photons emitted in a pulse are 10^{10}, calculate the wavelength of emitted photons.

Ans
$$P = \frac{nhc}{t\lambda}$$

$$\lambda = \frac{nhc}{Pt}$$

$$= \frac{10^{10}\times6.63\times10^{-34}\times3\times10^{8}}{10\times10^{-3}\times1\times10^{-3}}$$

$= 1.989\times10^{-10}$ m

6. A laser beam of output power of 5 mW is focused to a spot of diameter 1 µm. Calculate intensity of laser beam.

Ans
$$I = \frac{\text{Power of laser}}{\text{Area of cross section of beam}} = \frac{P}{\pi r^2} = \frac{5\times10^{-3}}{3.14\times(0.5\times10^{-6})^2}$$

$= 6.369\times10^{9}$ W/m^2

Calculate the no. of photons of wavelength 1.15 μm falling every second, on a circulatar spot of diameter 5 μm, when continous laser pulses of 50 ns duration emitted by a source of output power 5 mW is focussed on it.

Ans
$$P = \frac{nE}{t} = \frac{nhc}{\lambda t}$$

$$n = \frac{P \times \lambda t}{hc} = \frac{5\times10^{-3} \times 1.15\times10^{-6} \times 50\times10^{-9}}{6.63\times10^{-34} \times 3\times10^{8}}$$

$$= 1.445 \times 10^{9}$$

$$n(\text{for area of diameter } 5\,\mu m) = 1.445\times10^{9} \times \pi r^{2}$$
$$= 2.84\times10^{-2}$$

8. The wavelength of laser is 6342 Å. The no. of photons emitted in a minute by laser is 10^{17}. Calculate power of laser. If input power is 1W, what is fraction of power converted to output.

Ans
$$n = \frac{10^{17}}{60} = 1.666\times10^{15}/s$$

$$P = \frac{nE}{t} = \frac{1.666\times10^{15} \times 6.63\times10^{-34} \times 3\times10^{8}}{6342\times10^{-10}}$$

$$= 5.22\times10^{-4}\ W$$

fraction of power converted to output $= \frac{\text{Output}}{\text{Input}} \times$

$$= 5.22\times10^{-4}$$

9. A photon of wavelength 5800 Å is emitted when an atom in an excited state transits to ground state. Calculate the energy and momentum of photon. What is ratio of population of two states at 300K?

Ans $E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{5800\times10^{-10}}$

$= 3.429\times10^{-19}$ J

$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{5800\times10^{-10}}$

$= 1.143\times10^{-27}$ kgm/s

Ratio of population $= \frac{N_2}{N_1} = e^{-\frac{hc}{\lambda kT}}$

$= e^{-\frac{6.63\times10^{-34}\times3\times10^{8}}{5800\times10^{-10}\times1.38\times10^{-23}\times300}}$

$= e^{-8.283\times10}$

$= 1.065\times10^{-36}$

10. Calculate Boltzman factor corresponding to two energy levels separated by 2.3 eV, at 250°C.

Ans $T = 250 + 273 = 523$ K , $E_2 - E_1 = 2.3$ eV

Boltzman factor $\frac{N_2}{N_1} = e^{-\frac{(E_2-E_1)}{kT}}$

$= e^{-\frac{(2.3\times1.6\times10^{-19})}{1.38\times10^{-23}\times523}}$

$= e^{-50.988}$

$= 7.181\times10^{-23}$

11. The ratio of stimulated emission to spontaneous emission is 10^{-34}. what is ratio of populations? If the difference in energy corresponds to wavelength 6000 Å, calculate the temperature.

(5)

$$\frac{R_{21}^{*}}{R_{21}} = \frac{1}{e^{\frac{hc}{\lambda kT}} - 1} = 10^{-34}$$

$$e^{\frac{hc}{\lambda kT}} - 1 = 10^{34}$$

$$e^{\frac{hc}{\lambda kT}} = 10^{34}$$

$$e^{\frac{-hc}{\lambda kT}} = 10^{-34}$$

$$\frac{N_2}{N_1} = e^{\frac{-hc}{\lambda kT}} = 10^{-34}$$

Taking natural log

$$\frac{hc}{\lambda kT} = \ln 10^{34}$$

$$\frac{hc}{\lambda kT} = 78.287$$

$$T = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{6 \times 10^{-7} \times 1.38 \times 10^{-23} \times 78.287}$$

$$= 306.84 K$$

12. Two energy levels are separated by 2.8 eV. Calculate the ratio spontaneous to stimulated emission at 450 K.

As

$$\frac{\text{Spontaneous emission}}{\text{Stimulated emission}} \quad \frac{R_{21}}{R_{21}^{*}} = e^{\frac{h\nu}{kT}} - 1$$

$$= e^{\frac{2.8 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 450}} - 1$$

$$= 2.141 \times 10^{31}$$

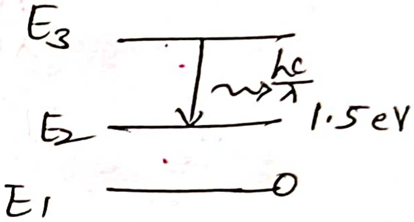
13. Calculate the ratio of spontaneous emission to stimulated emission if the wavelength of radiation is 6400 Å at 800 K.

Ans $$\frac{R_{21}}{R_{21}^{*}} = e^{\frac{hc}{\lambda KT}} - 1$$

$$= e^{\frac{6.63\times10^{-34}\times3\times10^{8}}{6400\times10^{-10}\times1.38\times10^{-23}\times800}} - 1$$

$$= 1.681\times10^{12}$$

14. A system has three energy levels E_1, E_2 and E_3. The energy levels E_1 and E_2 are at 0eV and 1.5eV respectively. If the lasing action takes place from energy level E_3 to E_2 and emits light of wavelength 1.2μm, find the energy value of level E_3.



Ans $$E_3 - E_2 = \Delta E = \frac{hc}{\lambda}.$$

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{1.2\times10^{-6}}$$

$$= 16.575\times10^{-20}\ J$$

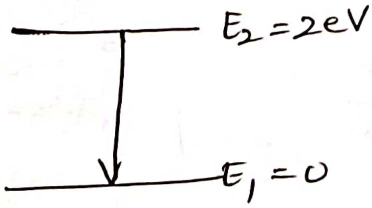
$$E_3 - E_2 = 1.0359\ eV$$

$$E_3 = E_2 + 1.0359$$

$$= 1.5 + 1.0359$$

$$= 2.5359\ eV$$

15.



a) Calculate the ratio of population $\frac{N_2}{N_1}$ at temp 400K

Ans $$\frac{N_2}{N_1} = e^{-\frac{(E_1-E_1)}{kT}}$$

$$= e^{\frac{-2\times1.6\times10^{-19}}{1.38\times10^{-23}\times400}}$$

$$= e^{-57.971}$$

$$= 6.66\times10^{-26}$$

At what temperature will this ratio be 0.01 ?

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

$$0.01 = e^{-\frac{(2\times1.6\times10^{-19})}{1.38\times10^{-23}\times T}}$$

Taking natural log

$$T = -\frac{2\times1.6\times10^{-19}}{1.38\times10^{-23}\ \ln(0.01)}$$

$$= 5.035\times10^{3}\ k$$

16. ~~That~~ The ratio of population of two energy levels is 1.06×10^{-30}. Find the wavelength of light emitted by spontaneous emission at 330k.

Ans $$\frac{N_2}{N_1} = 1.06\times10^{-30}\ ,\ T = 330K$$

$$e^{-\frac{hc}{\lambda KT}} = 1.06\times10^{-30}$$

Taking natural log

$$-\frac{hc}{\lambda KT} = \ln(1.06\times10^{-30})$$

$$\lambda = \frac{-hc}{kT\ \ln(1.06\times10^{-30})}$$

$$= 632.89\ nm$$

17. Two energy levels are separated by 2 eV. At what temperature will the ratio of population be 10^{-29}?

Calculate $\frac{A_{21}}{B_{12}}$

Ans $$\frac{N_2}{N_1} = e^{-\frac{h\nu}{KT}} = 10^{-29}$$

$$\cancel{\frac{A_{21}}{B_{21}} = e^{\frac{h\nu}{KT}}}$$

$$\frac{R_{21}}{R_{21}^*} = \frac{A_{21} N_2}{B_{21} N_2 U_\nu}$$

$$= \frac{A_{21}}{B_{21}} \frac{1}{\left[e^{\frac{h\nu}{KT}} - 1\right]}$$

$$= e^{\frac{h\nu}{KT}} - 1$$

$$e^{-\frac{h\nu}{KT}} = 10^{-29}$$

Taking natural log both sides

$$\frac{h\nu}{KT} = \ln(10^{29})$$

$$\frac{2 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23}\, T} = \ln 10^{29}$$

$$T = 347.26\ K$$

$$h\nu = 2\ eV$$

$$\nu = \left(\frac{2 \times 1.6 \times 10^{-19}}{h}\right)$$

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

$$= \frac{8\pi \cancel{h} (2 \times 1.6 \times 10^{-19})^3}{c^3\, h^3}$$

$$= \frac{8 \times 3.14 \times (2 \times 1.6 \times 10^{-19})^3}{(3 \times 10^8)^3\, (6.63 \times 10^{-34})^2}$$

$$= 6.935 \times 10^{-14}$$

18. If the rate of stimulated emission between two energy levels is R_2 and the rate of spontaneous emission between the same two levels is R_1 show that the wavelength of the radiation emitted between the same levels at temperature T, is given by $\lambda = \frac{hc}{kT \ln\left(1 + \frac{R_1}{R_2}\right)}$

$$\frac{R_2}{R_1} = \frac{B_{21}\cancel{N_2}\, U_\nu}{A_{21}\cancel{N_2}}$$

$$= \frac{\cancel{B_{21}}}{\cancel{A_{21}}}\ \frac{\cancel{A_{21}}}{\cancel{B_{21}}}\ \frac{1}{\left[e^{\frac{h\nu}{KT}} - 1\right]}$$

$$\frac{R_2}{R_1} = \frac{1}{e^{\frac{h\nu}{KT}} - 1}$$

$$e^{\frac{h\nu}{KT}} - 1 = \frac{R_1}{R_2}$$

$$e^{\frac{h\nu}{KT}} = \frac{R_1}{R_2} + 1$$

$$e^{\frac{hc}{\lambda KT}} = 1 + \frac{R_1}{R_2}$$

Take natural log

$$\frac{hc}{\lambda KT} = \ln\left(1 + \frac{R_1}{R_2}\right)$$

$$\lambda = \frac{hc}{KT \ln\left(1 + \frac{R_1}{R_2}\right)}$$

19. Calculate the maximum wavelength that can be amplified using an optical resonator of length 1 μm.

Ans $$L = \frac{n\lambda}{2}$$

$$\lambda = \frac{2L}{n}$$

For max. wavelength $n = 1$

$$\boxed{\lambda = 2L}$$

$$\lambda = 2 \times 1$$

$$= 2\ \mu m$$

20. What should be minimum distance of separation between the mirror in resonant cavity to amplify laser of wavelength 625 nm?

Ans
$$L = \frac{n\lambda}{2}$$

For min. distance $n = 1$

$$L = \frac{625}{2}$$

$$\boxed{L = 312.75\ nm}$$