Engineering Physics

(PHY1701)

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Contents

- Laser Characteristics,
- Spatial and Temporal Coherence,
- Einstein Coefficient & its significance,
- Population inversion,
- Two, three & four level systems,
- Pumping schemes,
- Threshold gain coefficient,
- Components of laser,
- Nd-YAG, He-Ne, CO2 and their engineering applications

❖ William Silfvast, Laser Fundamentals, 2008, Cambridge University Press.

Problem 1

Q) Find the ratio of population of the two states in He-Ne laser that produces light of wavelength 6328 Å at 27^{o}C.

Given data:

Wavelength, $\lambda = 6328$ Å

Temperature, $T = 27°C = 300$ K

Solution

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

$$E_2 - E_1 = \frac{12400}{6328}\ \text{eV} = 1.96\ \text{eV}$$

$$\therefore \frac{N_2}{N_1} = \exp\left[\frac{-1.96\ \text{eV}}{(8.61 \times 10^{-5}\ \text{eV/K})\ 300\ \text{K}}\right]$$

$$= e^{-75.88} = 1.1 \times 10^{-33}$$

Problem 2

Q) The CO_2 laser is one of the most powerful lasers. The energy difference between the two lasers is 0.117 eV. Determine the frequency and wavelength of radiation.

$$\lambda = \frac{12400}{E\,(eV)} = \frac{12400}{0.117}$$

$$\lambda = 105983\ \text{Å} = 10.5\ \mu m.$$

$$\gamma = \frac{c}{\lambda} = \frac{3 \times 10^{8}}{10.5 \times 10^{6}} = 2.9 \times 10^{13}\,Hz$$

Problem 3

Q) A He-Ne laser produces an output power of 5 mW. If it emits light of wavelength 632.8 nm, calculate the number of photons emitted by the laser in one second.

Given data:

Output power, P = 5 mW

Wavelength, λ = 632.8 nm

Solution

$$\text{Energy of one photon,} \quad h\nu = \frac{hc}{\lambda} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}}$$

$$= 3.141 \times 10^{-19}\ \text{J}$$

$$= 1.96\ \text{eV}$$

$$\text{Number of photons emitted} = \frac{\text{output power}}{\text{energy of one photon}} = \frac{5 \times 10^{-3}}{3.141 \times 10^{-19}}$$

$$= 1.591 \times 10^{16}\ \text{photons per second}$$

Problem 4

Q) Calculate the relative population of the energy levels N_1 and N_2 at 300K, λ=500 nm.

From Maxwell and Boltzmann law, the relative population is given by

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

Substituting the values of T and λ, we get

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

$$= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{500 \times 10^{-9} \times 1.38 \times 10^{-23} \times 300} = \exp(96.029)$$

$$= 5.068 \times 10^{41}$$

The relative population between N_1 and N_2 is 5.068×10^{41}.

Problem 5

(a) The He-Ne system is capable of lasing at several different IR wavelengths, the prominent one being 3.3913 μm. Determine the energy difference (in eV) between upper and lower levels for this wavelength.

Given data:

Wavelength, $\lambda = 3.3913\ \mu m$

Solution

$$E = \frac{12400\ (\text{eV})}{\lambda\,(\text{Å})} = \frac{12400}{33913}\ (\text{eV})$$

$$= 0.37\ \text{eV}$$

Problem 6

(b) Calculate the efficiency of a He-Ne laser, if it produces an output power of 5 mW and if it is operated with a current of 10 mA at 3 kV.

Given data:

Output power, $P = 5\ \text{mW} = 5 \times 10^{-3}\ \text{W}$

Current, $I = 10\ \text{mA} = 10 \times 10^{-3}\ \text{A}$

Voltage, $V = 5\ \text{kV} = 3 \times 10^{3}\ \text{V}$

Solution

$$\text{Efficiency} = \frac{\text{output power}}{\text{input power}} \times 100\ \%$$

$$= \frac{5 \times 10^{-3}}{10 \times 10^{-3} \times 3 \times 10^{3}} \times 100\ \% = 0.016667\ \%$$

The efficiency of the laser $= 0.016667\ \%$

Problem 7

Q) A transition between the energy level E_2 and E_1 produces a light of wavelength 632.8 nm, calculate the energy of the emitted photons..

Given data:

Wavelength, $\lambda = 632.8$ nm

Solution

$$\text{Energy of the emitted photon, } E = h\nu = \frac{hc}{\lambda}$$

$$= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}}$$

$$= 3.141 \times 10^{-19}\ \text{J} = 1.96\ \text{eV}$$

The energy of the photon $= 1.96$ eV

Problem 8

Q) A system has three energy levels E_1, E_2 and E_3. The energy levels E_1 and E_2 are at 0 eV and 1.4 eV respectively. If the lasing action takes place from the energy level E_3 to E_2, and emits a light of wavelength 1.15 μm, find the value of E_3?

Given data:

The value of first energy level, E_1 = 0 eV

Value of second energy level, E_2 = 1.4 eV

Wavelength, λ = 1.15 μm

Solution

Energy of the emitted photon, $E = h\nu = \dfrac{hc}{\lambda}$

Problem 8

$$= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{1.15 \times 10^{-6}}$$

$$= 1.728 \times 10^{-19}\ \text{J}$$

$$= 1.079\ \text{eV}$$

The energy value of $E_3 = E_2 + h\nu$

$$= 1.4\ \text{eV} + 1.079\ \text{eV}$$

$$= 2.479\ \text{eV}$$

The energy value of $E_3 = 2.479\ \text{eV}$

Problem 9

A laser transition takes place from an energy level at 3.2 eV to another level at 1.6 eV. Calculate the wavelength of the laser beam emitted.

Given data:

The value of higher energy level $E_1 = 3.2 \text{ eV}$

The value of lower energy level $E_2 = 1.6 \text{ eV}$

Solution

$$\text{Energy difference, } E_2 - E_1 = 3.2 - 1.6$$

$$= 1.6 \text{ eV}$$

$$\text{Wavelength, } \lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{1.6 \times 1.6 \times 10^{-6}}$$

$$= 7.7648 \times 10^{-7} \text{ m}$$

The wavelength of the photon, $\lambda = 7.7648 \times 10^{-7} \text{ m}$

Problem 10

The band gap of GaAs is 1.42 eV. What is the wavelength of the laser beam emitted by a GaAs diode laser?

Given data:

Band gap of GaAs = 1.42 eV

Solution

Wavelength of laser emitted by GaAs,

$$\lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{1.42 \times 1.6 \times 10^{-6}}$$

$$= 8.749 \times 10^{-7} \text{ m}$$

The wavelength of the laser emitted by GaAs, $\lambda = 8.749 \times 10^{-7}$ m

Problem 11

A laser beam emits an output power of 1 mW. If it is focused as a spot havin a diameter of 1μm, calculate the intensity of the laser beam.

Given data:

Output power, $P = 1\ mW = 1 \times 10^{-3}\ W$

Diameter $= 1\ \mu m$

Radius, $r = 0.5\ \mu m = 0.5 \times 10^{-6}\ m$

Solution

$$\text{Intensity of laser} = \frac{\text{power}}{\text{area of cross section}} = \frac{1 \times 10^{-3}}{\pi \left(0.5 \times 10^{-6}\right)^2}$$

$$= 1.273 \times 10^{9}\ W\ m^{-2}$$

The intensity of the laser $= 1.273 \times 10^{9}\ W\ m^{-2}$