Tut - 8

Laser

Ques 1: A typical He-Ne emits light of 632.8 nm. How many photons would be emitted by a 1mW the He-Ne Laser per second.

Sol^n:

$\lambda = 632.8\ nm$

Power = 1 mW

$$\text{Power} = \frac{\text{Energy}}{\text{Time}}$$

We can calculate the energy of single photon $= \frac{hc}{\lambda} = E_1$

$h = 6.626 \times 10^{-34}\ Js$

$c = 3 \times 10^{8}\ m/s$

$\lambda = 632.8\ nm$

$$E_1 = \frac{hc}{\lambda} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}}\ J$$

no. of photons emitted per second

$$\boxed{n = \frac{\text{power of the laser}}{\text{Energy of a single photons}}}$$

formula-1

$$= \frac{1 \times 10^{-3} \times 632.8 \times 10^{-9}}{6.626 \times 10^{-34} \times 3 \times 10^{8}}$$

$= 3 \times 10^{15}$ photons/sec.

Ques 2: He-Ne laser & Nd: YAG laser are respectively having power 1 mW & 10^{12} W. Find their photon output & compare with the thermal output 10^{9} photons/sec. from a thermal source.

Sol^n: Same as above for He-Ne laser.

Nd: YAG

$$n = \frac{10^{12}\,W}{hc/1060\,nm} = \frac{10^{12} \times 1060 \times 10^{-9}}{6.626 \times 10^{-34} \times 3 \times 10^{8}} = 5.33 \times 10^{30}$$

or 5×10^{30} photons/sec.

Thermal source. $n = 10^9$ photons/sec.
photon output from He-Ne & Nd:YAG laser is 10^6 and 10^{21} orders higher than thermal source.

Que 3:- The half width ($\Delta\lambda$) of a LASER source of wavelength 543 nm. is 0.01 nm. Compute its coherence length & coherence time.

Sol^n:- The coherence length of LASER is defined as

$$\boxed{L_c = \frac{\lambda^2}{\Delta\lambda}}$$ $\Delta\lambda$ → spectral width (0.01 nm)

formula 2

$\lambda = 543\,nm$

$$\therefore \quad L_c = \frac{\lambda^2}{\Delta\lambda}$$

$$= \frac{(543 \times 10^{-9})^2}{0.01 \times 10^{-9}}$$

$$\boxed{L_c = 2.95 \times 10^{7}\,nm}$$

Coherence time is given as

coherence time

$$\boxed{t_c = \frac{L_c}{c}}$$ formula 3 L_c = coherence length

$$= \frac{2.95 \times 10^{7}\,nm}{3 \times 10^{8}\,m/s}$$

$t_c = 0.1\,ns$

Que 4. Calculate the temporal coherence length for mercury vapour lamp emitting in green portion of the spectrum at $\lambda = 546.1\,nm$ with emission band width of $\Delta\nu = 6 \times 10^8\,Hz$.

Sol^n: Relation b/w speed of light & frequency & λ is

$$c = \nu\lambda \quad -(1)$$

differentiating

$$0 = \nu\Delta\lambda + \lambda\Delta\nu$$

$$\Delta\nu = -\frac{\nu\Delta\lambda}{\lambda}$$

from (1) $\nu = \frac{c}{\lambda}$ | $\Delta\nu = -\left(\frac{c}{\lambda}\right)\left(\frac{\Delta\lambda}{\lambda}\right) \Rightarrow -\frac{c\Delta\lambda}{\lambda^2}$

$$\Delta\lambda = -\frac{\lambda^2}{c}\Delta\nu \Rightarrow |\Delta\lambda| = \left|\frac{\lambda^2}{c}\Delta\nu\right| \Rightarrow \Delta\lambda = \frac{\lambda^2}{c}\Delta\nu \quad -(2)$$

Now temporal coherence length :

$$L_c = \frac{\lambda^2}{\Delta\lambda} = \frac{(546.1\times10^{-9})^2}{\lambda^2 \Delta\nu / c} = \frac{(546.1\times10^{-9})^2 \times 3\times10^8}{(546.1\times10^{-9})^2 \times 6\times10^8}$$

$$\boxed{L_c = 0.5\,m}$$

Ques 5 :- The coherence time for an ordinary source of light & for a LASER light are respectively 0.1ns & 10 μs. Deduce the corresponding frequency widths & coherence lengths. Also comment.

Ans: from eqn (2) of Ques(4)

Relation b/w time & freq

$$\Delta\lambda = \frac{\lambda^2}{c}\Delta\nu$$

$$\Delta\nu = \frac{c\,\Delta\lambda}{\lambda^2}$$

Also $L_c = \frac{\lambda^2}{\Delta\lambda}$, $t_c = \frac{L_c}{c}$

$$\Delta\nu = \frac{c}{L_c}$$

$$\Delta\nu = \frac{1}{t_c}$$

The coherence time (t_c) for ordinary source of light = 0.1 ns

laser light = 10 μs

$$(\Delta\nu)_{\text{ordinary light}} = \frac{1}{0.1\,ns} = 10^{10}\,sec^{-1} \qquad (1ns = 10^{-9}s)$$

$$(\Delta\nu)_{\text{Laser}} = \frac{1}{10\,\mu s} = 10^{5}\,sec^{-1} \qquad (1\mu s = 10^{-6}s)$$

Coherence length → $(L_c)_{\text{ordinary light}} = c\,t_c$

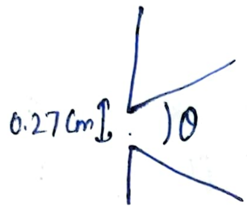
$$= 3\times10^8 \times 0.1\times10^{-9} = 3\,cm$$

$$(L_c)_{\text{Laser}} = 3\times10^8 \times 10\times10^{-6} = 3\,cm$$

Laser light maintains its coherence for very larger distance in comparison to ordinary source.

Ques 6: What is the angular spread of LASER of $\lambda = 0.85\,\mu m$? Also find how far from us a heavenly body should be if the given laser forms on it spot of size, 200 km. The aperture of the laser is 0.27 cm.

Sol^n: (i)



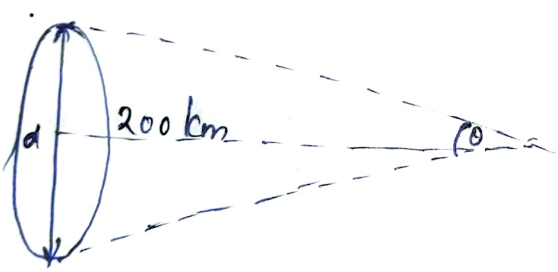
Angular spread (θ)

$$\boxed{\theta \approx \frac{1.22\lambda}{D} \text{ (radian)}} \quad (4)$$

$$\theta \approx \frac{1.22 \times 0.85 \times 10^{-6}}{0.27 \times 10^{-2}}$$

$$= 4 \times 10^{-4} \text{ radian.}$$

(ii)



$\theta \approx \frac{d}{X}$. where d is the spot size

X is the distance of heavenly body.

$$X = \frac{d}{\theta} = \frac{200 \times 10^3}{4 \times 10^{-4}}$$

$$= 0.5 \times 10^9 m$$