(1.) Coherence time: It is the time for which the phase relationship between two waves remains constant.

It is given by $\tau_c = \frac{1}{\Delta\nu}$; $\Delta\nu$ is spectral bandwidth.

Coherence length: The distance travelled by light during coherence time is called coherence length.

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

for 1000 Hz,

$$L_c = \frac{3\times10^8}{1000} = 3\times10^5 \text{ m}.$$

for 1.5 GHz, $\Delta\nu = 1.5\times10^9$

$$L_c = \frac{3\times10^8}{1.5\times10^9} = 0.2 \text{ m}$$

→ The 1000 Hz bandwidth source is preferable because it has a much larger coherence length.

→ Reason: A larger coherence length allows interference to be observed over a larger path difference.

(2.) Temporal coherence: Temporal coherence describes the correlation between the phases of a light wave at different times.

Spatial coherence: spatial coherence describes the correlation between the phases of light different point across the wavefront.

→ LASER light is produced by stimulated emission. The emitted photons have nearly the same frequency, phase, direction, polarization; therefore, LASER light has a high degree of spatial coherence.

→ Higher spatial coherence produces clearer and sharper interference fringes with greater visibility.

(3.) Coherent sources: Two sources are called coherent if they produce waves having same frequency and constant phase difference.

Incoherent sources: Sources whose phase difference changes randomly with time are called incoherent sources.

→ Let two waves are;

$y_1 = a_1 \cos \omega t$

$y_2 = a_2 \cos(\omega t + \phi)$

The resultant intensity is

$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos\phi$

For incoherent sources, ϕ changes randomly with time.

Therefore, the average value is $(\cos\phi) = 0$

Hence; $\boxed{I = I_1 + I_2}$; therefore, no fixed bright and dark fringes are obtained.

(4.) The important characteristics of LASER light are:

(i) Monochromaticity - LASER light has a very narrow range of wavelengths and hence nearly a single frequency.

(ii) Directionality - LASER beam travels almost in one direction it has very small divergence.

(iii) Low beam divergence - The beam spreads very little even after travelling a large distance.

(iv) High coherence - LASER light has high temporal and spatial coherence.

(v) High intensity - A large amount of energy is concentrated in a small area, giving very high intensity.

→

LASER	Ordinary Light
• Highly monochromatic	• Broad spectrum
• Highly directional	• Spreads in many directions
• Highly coherent	• Generally incoherent
• Very small divergence	• Large divergence
• High intensity	• Comparatively low intensity

5. Initial diameter, $d_1 = 2mm$; $r_1 = 1mm$
Diameter after 20m, $d_2 = 12mm$; $r_2 = 6mm$
Distance, $L = 20m$

→ Half-angle divergence (θ_h)

$$\tan(\theta_h) = \frac{r_2 - r_1}{L} = 2.5 \times 10^{-4}$$

angle is very small, $\tan(\theta_h) \approx \theta_h$;

$$\theta_h = 2.5 \times 10^{-4} \text{ rad.}$$

→ Full angular spread (θ_F)

$$\theta_F = 2 \times \theta_h = 2 \times 2.5 \times 10^{-4} = 5 \times 10^{-4} \text{ rad}$$

→ Diameter of beam after travelling 1 km,

$$d_3 = d_1 + (\theta_F \times L_3)$$

~~$= 2 \times 10^{-6} + (5 \times 10^{-4} \times 1 \times 10^{-6})$~~

~~$= 502 \times 10^{-6} m = 502 mm$~~

$$= 2 + (5 \times 10^{-4} \times 1 \times 10^{6})$$

$$d_3 = 502 mm$$

6. $d_1 = 4mm$
$d_2 = 14mm$
$L = 50m$

→ Half-angle divergence (θ_h):

$$\theta_h = \frac{7 - 2}{50} = \frac{5}{50} = 1 \times 10^{-4} \text{ rad}$$

→ Full-divergence:

$$\theta_F = 2\theta_h = 2 \times 10^{-4} \text{ rad.}$$

→ At 500 m:

$$d_3 = 4 + (2 \times 10^{-4} \times 500 \times 10^{3})$$

$$= 4 + 100$$

$$d_3 = 104 mm$$

7. $d_1 = 4mm$; $r_1 = 2mm$

$d_2 = 14mm$, $r_2 = 7mm$

$$\tan\theta = \frac{\Delta r}{L} = \frac{7-2}{25} = \frac{5}{25} = 0.2 \times 10^{-4}$$

$\tan\theta \approx \theta$; $\theta = 2 \times 10^{-4}$ rad

→ Increase in beam radius = $7 - 2 = 5mm$

→ Beam diameter after 100 m.

$$d_3 = 4 + 2(2 \times 10^{-4} \times 100 \times 10^3)$$

$$= 4 + 2(20)$$

$$d_3 = 44\ mm$$

8. $d_1 = 2mm$

$d_2 = 6mm$

$L_1 = 10\ m$

$L_2 = 50\ m$

→ half angle of divergence;

$$\theta_h = \frac{3-1}{50-10} = \frac{2}{40} = 0.5 \times 10^{-4}\ rad.$$

→ Full angle divergence;

$$\theta_f = 2 \times 0.5 \times 10^{-4} = 10^{-4}\ rad.$$

→ Beam diameter after 100 m.

~~$d_3 = d_1 + 2 \times \theta_f \times L_3$~~

~~$= 2 + 2 \times 10^{-4} \times 100 \times 10^3$~~

~~$= 2 + 2 \times 10$~~

~~$= 22\ mm$~~

$$d_3 = d_1 + 2\theta \times (L_3 - L_1)$$

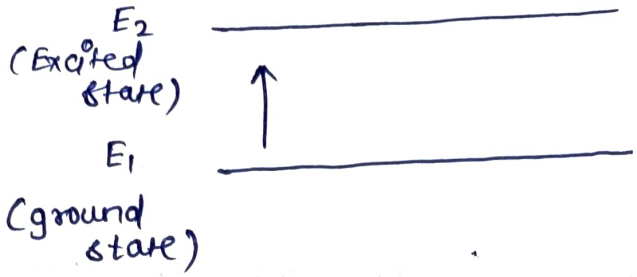
$$= 2 + 2 \times 0.5 \times 10^{-4} \times 90 \times 10^3$$

$$= 2 + 9$$

$$d_3 = 11\ mm$$

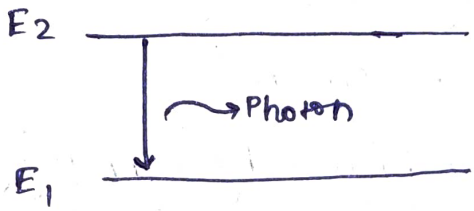
9. **Absorption** - An atom in lower energy state E_1 absorbs a photon of energy, $h\nu = E_2 - E_1$ and moves to higher energy state E_2.

$E_1 + h\nu \rightarrow E_2$

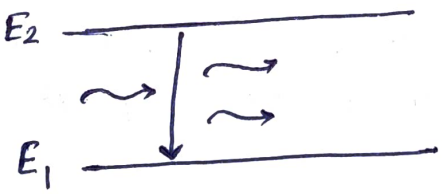


Spontaneous emission - An excited atom naturally returns from E_2 to E_1 and emits a photon.

$E_2 \rightarrow E_1 + h\nu$. The emitted photon has random phase and direction.



Stimulated emission - An incoming photon of energy $h\nu$ causes an excited atom to emit another photon. The emitted photon has the same frequency, phase, direction & polarization as the incident photon. This process is responsible for LASER action



→ At thermal equilibrium, the number of atoms in the excited state is small because most atoms remain in the lower energy state. Therefore, stimulated emission is generally small compared with spontaneous emission.

10. $\lambda = 5900\,\text{Å} = 5.9 \times 10^{-7}\,m$

At thermal equilibrium,

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

$$= e^{-\frac{hc}{\lambda KT}} \quad ; T = 300\,K$$

$$\frac{N_2}{N_1} \approx 4.8 \times 10^{-36}$$

This very small, hence, there cannot be population inversion under normal thermal equilibrium.

11. Population inversion - It is the condition in which the number of atoms in the upper energy state is greater than the number in the lower energy state. $\boxed{N_2 > N_1}$

→ Population inversion is achieved by supplying energy to the LASER medium. This process is called pumping.
Methods include - optical pumping, electrical pumping & chemical pumping.

→ Metastable state - A metastable state is an excited state in which atoms remain for a relatively longer time. It acts as a temporary storage stable for excited atoms. Therefore, a large number of atoms can accumulate there, making population inversion possible.

12. Directionality means the ability of a LASER beam to travel in almost one direction with very small angular spread.

For a circular aperture,

$$\theta = 1.22 \frac{\lambda}{D}$$

$\lambda = 693\,nm$, $D = 3\,mm$

$$\theta = 1.22 \times \frac{693 \times 10^{-9}}{3 \times 10^{-3}}$$

$$\theta = 2.82 \times 10^{-4}\ rad$$

At 300 Km;

$$d_{final} = D + 2d\theta$$

$$= 0.003m + 2 \times 300 \times 10^3 \times 2.82 \times 10^{-4}$$

$$= 169.095\,m$$

$$\simeq 169.1\,m$$

13. Monochromaticity - It means that LASER radiation has a very narrow range of wavelengths or frequencies.

$\lambda = 6300\ \text{Å}$

$\tau_c = 10 \times 10^{-9}\ s$

$$\Delta\nu = \frac{1}{\tau_c} = \frac{1}{10^{-8}} = 10^8\ Hz$$

The wavelength spread is

$$\Delta\lambda = \frac{\lambda^2}{c}\Delta\nu = \frac{(6300\times10^{-10})^2}{3\times10^8} \times 10^8$$

$$\Delta\lambda = 1.32\times10^{-3}\ nm$$

This is very small compared with 630 nm. Hence, the He-Ne LASER is highly monochromatic.

14. Semiconductor LASER - A semiconductor LASER is a LASER in which the active medium is a semiconductor material.

eg:- semiconductor diode LASERs.

→ Population inversion in semiconductor LASER -

A semiconductor LASER generally uses a p-n junction.

When the junction is forward biased:

- electrons are injected into the conduction band.
- holes are injected into the valence band.
- electrons and holes recombine.
- photons are emitted.

With sufficiently high injection current, a large population of electrons and holes is produced in the active region.

Thus, population inversion is achieved between the relevant electronic states.

Stimulated emission then produces LASER light.

15. Consider two levels E_1 and E_2.
For stimulated absorption = $N_1 B_{12} \rho$
For stimulated emission = $N_2 B_{21} \rho$
For equal degeneracies, $B_{12} = B_{21}$
For amplification, we need $N_2 > N_1$
But continous pumping of a two-level system cannot maintain $N_2 > N_1$. At best, the populations approach equality.
Therefore, a stable population inversion cannot be produced.

→ Three-level LASER - A three-level system has - ground state E_1
- metastable state E_2
- pumping state E_3

Atoms are pumped from E_1 to E_3, quickly fall to metastable E_2, and then undergo stimulated emission from E_2 to E_1.

→ He-Ne LASER - In a He-Ne LASER, an electrical discharge excites He atoms. Excited He transfers energy to Ne atoms through collisions. Neon atoms reach excited states, producing population inversion. Stimulated emission between appropriate Ne energy levels produces the LASER beam.

16. Optical feedback - A LASER cavity consists mainly of two mirrors placed around the active medium. One mirror is highly reflecting and the other is partially transmitting. Photons travelling inside the cavity are reflected repeatedly between the mirrors. This produces optical feedback.

→ Feedback is essential because:
(i) It increases interaction between photons and excited atoms.
(ii) Produces more stimulated emission.
(iii) Amplifies the radiation.
(iv) Allows the radiation to build up to a high Invensity.
(v) Produces sustained LASER oscillation.

17. A/c to Boltzman distribution law:

$$\frac{N_2}{N_1} = e^{-\frac{\Delta E}{K_B T}}$$

N_1 & N_2 → population (no of atoms) in energy states E_1 & E_2 respectively.

→ At Room Temperature ($T > 0K$) :- Since $E_2 > E_1$, the ration $N_2/N_1 < 1$ This means the lower energy state (E_1) is always more populated than the higher energy state (E_2).

→ As temp. increases - The value of $\Delta E/K_B T$ decreases causing $e^{-\frac{\Delta E}{K_B T}}$ to approach 1. Thus, higher temperatures increases the population of the higher state (N_2), but N_2 can never exceed N_1 through pure thermal heating alone.

→ For LASER operation, a state called population inversion ($N_2 > N_1$) is strictly required. Since thermal eqm always results in $N_2 < N_1$, thermal energy alone cannot create a laser. External energy sources called pumping are required to achieve population inversion.

→ $\lambda = 328 \text{ Å}$, $T = 300K$

$$\frac{N_2}{N_1} = e^{-\frac{\Delta E}{K_B T}} = e^{-\frac{hc}{\lambda K_B T}}$$

$$\frac{N_2}{N_1} = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{328 \times 10^{-10} \times 1.38 \times 10^{-23} \times 300} \approx 0$$

18. $\lambda = 632.8 \text{ nm}$

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

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

$$E = 3.14 \times 10^{-19} \text{ J}$$

19. Threshold gain condition is

$$g_{th} = \frac{1}{2L} \ln\left(\frac{1}{R_1 R_2}\right)$$

given: $g = 0.01\ cm^{-1}$, $L = 50\ cm$ & $R_1 = R_2 = 1$

Therefore,

$$g_{th} = \frac{1}{100} \ln(1) = 0$$

$$\boxed{g_{th} = 0}$$

For perfectly reflecting mirrors and no internal losses, the ideal cavity has zero mirror-loss threshold again.

20. At thermal eqm, equality of spontaneous and stimulated emission gives.

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

therefore,

$$e^{h\nu/KT} = 2$$

$$\frac{h\nu}{KT} = \ln 2$$

since ; $\nu = c/\lambda$

$$\lambda = \frac{hc}{KT \ln 2}$$

for $T = 500K$:

$$\lambda \approx 4.15 \times 10^{-5} m$$

$$\boxed{\lambda \approx 41.5\ \mu m}$$

This is far-infrared radiation and is not the wavelength used for corneal photoablation in conventional LASIK. Therefore, it would not be appropriate for LASIK.

21. $\frac{\text{Rate of Spontaneous Emission}}{\text{Rate of Stimulated Emission}} = e^{hc/\lambda KT} - 1$

$$1 = e^{hc/\lambda KT} - 1$$

$$2 = e^{hc/\lambda KT}$$

$$\ln 2 = \frac{hc}{\lambda KT}$$

$$T = \frac{hc}{\lambda K \ln(2)}$$

$$T \approx 41,562\ K$$

22. $\lambda = 6000\ \text{Å}$

$A_{21} = 10^6$

B_{21} $\quad \frac{A_{21}}{B_{21}} = \frac{8\pi h}{\lambda^3}$

$$B_{21} = \frac{A_{21} \cdot \lambda^3}{8\pi h}$$

$$B_{21} = \frac{10^6 \times (6000 \times 10^{-10})^3}{8\pi \times 6.626 \times 10^{-34}}$$

$$B_{21} = 1.30 \times 10^{19}\ m^3\ J^{-1} s^{-2}$$

23. $P = 1mW = 10^{-3} W$

$d = 2mm$, $r = 10^{-3} m$

$A = \pi r^2 = \pi \times (10^{-3})^2 = 3.14 \times 10^{-6}\ m^2$

$$I = \frac{P}{A} = \frac{10^{-3}}{3.14 \times 10^{-6}} = 318.3\ W/m^2$$

→ perfectly absorbing screen,

$$p = \frac{I}{c} = 1.06 \times 10^{-6}\ N/m^2$$

$$F = pA = 3.33 \times 10^{-12}\ N$$

→ 70% reflecting screen,

For reflectivity $R = 0.70$

$$p = \frac{(1+R)I}{c}$$

$$p = \frac{1.7 \times I}{c} = 1.80 \times 10^{-6}\ N/m^2$$

$$F = pA = 5.67 \times 10^{-12}\ N$$

24. $P = 10mW = 0.01\ W$

$\lambda = 850\ nm$

Energy per photon:

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

No° of photons per second:

$$N = \frac{P}{E}$$

$$N = \frac{P\lambda}{hc}$$

$$N = \frac{0.01 \times 850 \times 10^{-9}}{6.626 \times 10^{-34} \times 3 \times 10^8}$$

$$N = 4.28 \times 10^{16}\ \text{photons/s}$$

25. $n = 1.5$

$\lambda_0 = 632.8\ nm$

$\lambda = \frac{\lambda_0}{n} = \frac{632.8}{1.5}$

$\boxed{\lambda = 421.9\ nm}$

26. $d = 1.5\ \mu m$

$\Delta\nu = 10\ MHz$

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

$= \frac{3 \times 10^8}{10 \times 10^6}$

$\boxed{L_c = 30\ m}$

27. $d = 632.8\ nm$

$D = 2\ mm$

$\theta = 1.22 \frac{\lambda}{D}$

$\theta = 1.22 \times \frac{632.8 \times 10^{-9}}{2 \times 10^{-3}}$

$\theta \approx 3.86 \times 10^{-4}\ rad$

At 1 km:

$d = 2L\theta + D$

$= 2(1000)(3.86 \times 10^{-4}) + 2$

$= 0.772\ m + 2\ mm$

$= 0.774\ mm$

→ LASER beams are highly direction because LASER radiation has very low divergence and high spatial coherence. The photons travel nearly parallel to each other.

28. $D_1 = 3mm$, $D_2 = 8mm$

$\Delta L = 6 - 1 = 5m$

$\Delta r = \frac{8-3}{2} = 2.5mm$

$\tan\theta = \frac{2.5 \times 10^{-3}}{5}$

$\theta = 5 \times 10^{-4}\ rad$

full divergence = $2\theta = 10^{-3}\ rad$

29. $\lambda = 632.8\ nm$

$\Delta\nu = 2\ GHz$

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

$\Delta\lambda = \frac{(632.8\times10^{-9})^2 (2\times10^9)}{3\times10^8}$

$\Delta\lambda \approx 2.67\times10^{-12}\ m$

30. $\lambda = 500\ nm$

$\nu = \frac{c}{\lambda} = \frac{3\times10^8}{500\times10^{-9}}$

$\nu = 6\times10^{14}\ Hz$

$\Delta\lambda = 10^{-12}\ m$

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

$\Delta\nu = 1.2\times10^9\ Hz$

Relative spectral width:

$\frac{\Delta\nu}{\nu} = \frac{1.2\times10^9}{6\times10^{14}}$

$\frac{\Delta\nu}{\nu} = 2\times10^{-6}$

31. For LASER A; $\Delta\nu = 1000\ KHz = 10^5\ Hz$

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

$L_c = \frac{3\times10^8}{10^5} = 3\ km$

For LASER B; $\Delta\nu = 100\ MHz = 10^8\ Hz$

$L_c = \frac{3\times10^8}{10^8} = 3\ m$

LASER A has much greater coherence length & can maintain a clear interference pattern over optical path differences up to 3 km.

32. For stimulated absorption, transition rate is proportional to $N_1 B_{12} \rho(\nu)$

Stimulated emission rate is proportional to $N_2 B_{21} \rho(\nu)$

For equal degeneracies,

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

Net stimulated emission:

$R_{net} = B\rho(N_2 - N_1)$

For amplification, $R_{net} > 0$

$\therefore N_2 - N_1 > 0$

Hence, $\boxed{N_2 > N_1}$

Thus, population inversion is necessary for net stimulated amplification.

33. No, stable inversion cannot occur in a two-level system because when radiation is continuously applied to a two-level system:

→ Absorption takes atoms from E_1 to E_2.

→ Stimulated emission takes atoms from E_2 to E_1.

At equilibrium, the populations tend toward $N_1 = N_2$ rather than $N_2 > N_1$. Therefore, a stable population inversion cannot be produced.

34. A three-level LASER consists of:

E_1: Ground state, E_2: Metastable state, E_3: Pumping state

Operation -

(i) Atoms are pumped from E_1 to E_3.

(ii) Atoms rapidly decay from E_3 to E_2.

(iii) Atoms accumulate in metastable state E_2.

(iv) Population inversion is produced between E_2 and E_1.

(v) Stimulated emission occurs from E_2 to E_1.

→ Initially almost all atoms are in the ground state. To achieve $N_2 > N_1$, more than half of the atoms must be pumped to the upper LASER level. Therefore, intense pumping is required.

35.

Three-Level LASER	Four-Level LASER
→ Lower LASER level is ground state.	Lower LASER level is above ground state.
→ More than half atoms need pumping	Much fewer atoms need pumping.
→ High pumping power required.	Lower pumping power required.
→ Population inversion is difficult.	Population inversion is easier.
Example: Ruby LASER	Example: He-Ne LASER

→ In four-level LASER after stimulated emission, atoms quickly leave the lower LASER level.
Therefore, the lower level remains almost empty.
Hence, $N_2 > N_1$ can be achieved more easily.

36. Pumping means supplying external energy to the LASER active medium to achieve population inversion.

Optical pumping - Energy is supplied using light. suitable for solid-state systems
eg - Ruby LASER.

Electrical discharge pumping - Energy is supplied by an electrical discharge through the active medium. suitable for gas LASERs.
eg - He-Ne LASER.

37. $R_1 = 0.90$, $R_2 = 0.80$
$L = 20$ cm
Neglecting internal losses:

$$R_1 R_2 e^{2gL} = 1$$

Therefore,

$$g_{th} = \frac{1}{2L} \ln\left(\frac{1}{R_1 R_2}\right)$$

$$g_{th} = \frac{1}{40} \ln\left(\frac{1}{0.72}\right)$$

$$g_{th} = 0.0082 \text{ cm}^{-1}$$

38. For threshold:

$$g_{th} = \frac{1}{2L} \ln\left(\frac{1}{R_1 R_2}\right)$$

if one cavity has:

$R_1 = R_2 = 0.99$

and other has:

$R_1 = R_2 = 0.50$

The cavity with $R = 0.50$ has much greater mirror losses. Therefore, it requires greater gain to compensate for those losses.

Hence, the cavity with $R = 0.50$ requires the large threshold gain.

39. Frequency separation b/w adjacent longitudinal modes is

$$\Delta\nu = \frac{c}{2L} \quad ; \quad L = 30\,cm = 0.30\,m$$

$$\Delta\nu = \frac{3\times10^8}{2(0.30)} = 5\times10^8\ Hz$$

Gain bandwidth: 3GHz

No° of mode spacings, $N = \frac{3\times10^9}{500\times10^6} = \underline{6}$

40. $P = 5mW = 5\times10^{-3}\ W$

$\lambda = 532\ nm$

Energy per photon:

$$E = \frac{hc}{\lambda} = 3.73\times10^{-19}\ J$$

No' of photons per second

$$N = \frac{P}{E}$$

$$N = \frac{5\times10^{-3}}{3.73\times10^{-19}} = 1.34\times10^6\ photons/s$$

41. $P = 10\,mW = 10^{-2}\,W$

For perfectly absorbing surface, $p = \frac{P}{c}$

$$p = \frac{10^{-2}}{3\times10^8} = 3.33\times10^{-11}\ Pa$$

Force: $F = pA$ or $\frac{P}{c}$ if the beam is treated as normally incident on an area corresponding to the beam.

Thus $F = 3.3\times10^{-11}\ N$.

For perfect reflection, $p = \frac{2P}{c} = 2\times3.3\times10^{-11}\ N$

$$= 6.67\times10^{-11}\ N$$

42. $P = 20\,mW = 0.02\,W$

$d = 1\,mm$, $r = 0.5\,mm$

$A = \pi r^2 = \pi (5 \times 10^{-4})^2$

$I = \frac{P}{A} = \frac{0.02}{\pi \times (5 \times 10^{-4})^2} = 2.55 \times 10^4\ w/m^2$

If diameter is reduced to half; $d = \frac{d}{2}$

A becomes $\frac{A}{4}$ since $I = \frac{P}{A}$ intensity becomes four times.

$I' = 4I$

$I' = 1.02 \times 10^5\ w/m^2$

43. Spontaneous emission - The emitted photon has random phase, direction, polarization and emission time. Therefore, spontaneous radiation is generally incoherent.

Stimulated emission - The emitted photon has the same phase, frequency, direction and polarization as the incident photon. Therefore, stimulated emission produces coherent radiation.

→ This is the fundamental principle behind LASER operation.

44. An incandescent lamp produces a large number of photons, but it does not produce LASER-like radiation.

(i) Population inversion - No population inversion is maintained. Normally $N_1 > N_2$.

(ii) Spontaneous emission - Emission occurs mainly through spontaneous processes.

(iii) Spectral width - An incandescent lamp has a broad continuous spectrum, whereas LASER radiation has a very narrow spectral width.

(iv) Coherence - Light from the lamp is generally incoherent. LASER light is highly coherent.

(v) Directionality - An incandescent lamp emits light in many directions.
LASER light is highly directional.

Therefore, simply producing a large number of photons is not sufficient for LASER action.

45. $P = 2mW = 2 \times 10^{-3} W$

$\lambda = 632.8 nm$

Beam diameter: $d = 2mm$

Line width $\Delta\nu = 10 MHz$

Cavity length, $L = 25 cm$

(a) Energy of one photon, $E = \frac{hc}{\lambda} = 3.14 \times 10^{-19} J$

(b) No. of photons per second, $N = \frac{P}{E}$

$$N = \frac{2 \times 10^{-3}}{3.14 \times 10^{-19}}$$

$$N = 6.37 \times 10^{15} \text{ photons/s}$$

(c) Beam intensity; $r = 1 mm$, $A = \pi \times (10^{-3})^2$

$$I = \frac{P}{A} = \frac{2 \times 10^{-3}}{3.14 \times 10^{-6}} = 636.6 \, W/m^2$$

(d) Coherence length; $L_c = \frac{c}{\Delta\nu} = \frac{3 \times 10^8}{10^7}$

$$L_c = 30 m$$