HOME ASSIGNMENT (PHIC101)

UNIT III —LASER PHYSICS

1. Define coherence time and coherence length. Calculate the coherence length of LASER beams having bandwidths of $1000\,\text{Hz}$and $1.5\,\text{GHz}$. Which one is preferable for interference experiments? Give reasons.

2. What is meant by temporal and spatial coherence of a LASER beam? Explain why a LASER possesses a much higher degree of spatial coherence than an ordinary light source. How does spatial coherence influence the visibility of interference fringes?

3. What are coherent and incoherent light sources? Prove that the superposition of two incoherent waves does not produce a sustained interference pattern.

4. Explain the important characteristics of LASER light. Discuss the concepts of (i) monochromaticity, (ii) directionality, (iii) beam divergence, (iv) coherence, and (v) high intensity. Explain how these properties distinguish LASER radiation from ordinary light sources.

5. A LASER beam has a diameter of $2\,\text{mm}$when it emerges from the LASER. After travelling a distance of $20\,\text{m}$, its diameter becomes $12\,\text{mm}$. Calculate the half-angle divergence of the LASER beam using geometrical considerations. Calculate the full angular spread (divergence angle) of the beam. Determine the diameter of the beam after travelling $1\,\text{km}$, assuming the same divergence.

6. A LASER beam has an initial diameter of $4\,\text{mm}$. At a distance of $50\,\text{m}$, its diameter is measured to be $14\,\text{mm}$. Determine: the half-angle divergence, the full divergence angle, the beam diameter at a distance of $500\,\text{m}$.

7. A LASER beam has a diameter of $4\,\text{mm}$ immediately after leaving the LASER. Due to divergence, its diameter becomes $14\,\text{mm}$ after travelling $25\,\text{m}$. Calculate the increase in beam radius. Calculate the half-angle divergence using $\tan\theta = \frac{\Delta r}{L}$. Calculate the beam diameter after travelling $100\,\text{m}$.

8. A LASER beam has a diameter of $2\,\text{mm}$ at a distance of $10\,\text{m}$ from the LASER source. At a distance of $50\,\text{m}$, the diameter of the beam becomes $6\,\text{mm}$. Calculate the angle of divergence of the LASER beam. Calculate the diameter of the beam at a distance of $100\,\text{m}$, assuming uniform divergence.

9. Explain, with neat and relevant energy-level diagrams, the processes of absorption, spontaneous emission and stimulated emission. Why does spontaneous emission generally dominate over stimulated emission under ordinary thermal equilibrium conditions?

10. Prove that LASER action at a wavelength of $5900\,\text{Å}$is not possible at room temperature ($300\,\text{K}$) under thermal equilibrium conditions.

11. What is population inversion? How can it be achieved? Explain the importance of a metastable state in obtaining population inversion.

12. What do you understand by directionality or high collimation of a LASER beam? Estimate the angular spread of a LASER beam of wavelength $693\ \text{nm}$and spot size $3\ \text{mm}$due to diffraction. Calculate the diameter of the beam when it strikes a satellite $300\ \text{km}$above the Earth.

13. What do you understand by monochromaticity of LASER radiation? A He-Ne LASER emits radiation of wavelength $6300\ \text{Å}$. Analyze the monochromaticity of the emitted radiation if the coherence time is $10\ \text{ns}$.

14. What are semiconductor LASERs? Explain how population inversion is achieved in a semiconductor LASER.

15. Why is LASER action not possible in an ideal two-level system? Discuss the significance of a three-level LASER system. Explain how stimulated emission occurs in a He-Ne LASER.

16. Describe how optical feedback is achieved in a LASER cavity. Why is optical feedback essential for sustained LASER oscillation?

17. Explain the effect of temperature on the population of energy states in a LASER medium. Find the ratio of populations of two energy states in a He-Ne LASER producing radiation of wavelength $328\ \text{Å}$ at room temperature.

18. A He-Ne LASER operates at a wavelength of $632.8\ \text{nm}$. Calculate the energy of a single photon emitted by the LASER.

19. Calculate the threshold population inversion required for a LASER with gain coefficient $g = 0.01\ \text{cm}^{-1}$ and cavity length $L = 50\ \text{cm}$. Assume that the reflectivity of both mirrors is 100%.

20. Find the LASER wavelength at which the rates of spontaneous emission and stimulated emission become equal at $T = 500\ \text{K}$. Comment separately on whether such radiation would be appropriate for LASIK surgery.

21. At what temperature will the rates of spontaneous emission and stimulated emission become equal for radiation of wavelength $5000\ \text{Å}$

22. For LASER radiation of wavelength $6000\ \text{Å}$, if the coefficient of spontaneous emission is $10^6\ \text{s}^{-1}$, determine the corresponding coefficient of stimulated emission.

23. Calculate the intensity of a $1\ \text{mW}$semiconductor LASER beam of wavelength $632.8\ \text{nm}$ having a spot size of $2\ \text{mm}$. Calculate the radiation pressure on: a perfectly absorbing screen, a screen reflecting $70\%$of the incident radiation. Also calculate the corresponding forces.

24. A LASER diode emits light with a power of $10\ \text{mW}$at a wavelength of $850\ \text{nm}$. Calculate the number of photons emitted per second.

25. If the refractive index of the LASER medium is 1.5, calculate the wavelength of LASER radiation inside the medium for an emitted vacuum wavelength of $632.8\ \text{nm}$.

26. A LASER emits radiation at a wavelength of $1.5\ \mu\text{m}$ with a linewidth of $10\ \text{MHz}$. Calculate its coherence length.

27. A LASER beam has wavelength $632.8\ \text{nm}$and emerges from a circular aperture of diameter $2\ \text{mm}$. Calculate the minimum angular divergence due to diffraction. Determine the approximate beam diameter after travelling $1\ \text{km}$. Explain why LASER beams are highly directional compared with ordinary light sources.

28. A LASER beam has a diameter of $3\ \text{mm}$ at $1\ \text{m}$ from the aperture and $8\ \text{mm}$ at $6\ \text{m}$. Determine the angular divergence of the beam.

29. A LASER emits radiation at $632.8\ \text{nm}$with a frequency bandwidth of $2\ \text{GHz}$. Calculate the corresponding wavelength spread $\Delta\lambda$.

30. A LASER operates at $500\ \text{nm}$with a spectral linewidth of $0.001\ \text{nm}$. Calculate: central frequency, frequency linewidth, relative spectral width $\Delta\nu/\nu$.

31. Two LASERs operate at $650\ \text{nm}$. LASER A has linewidth $100\ \text{kHz}$, while LASER B has linewidth $100\ \text{MHz}$. Calculate their approximate coherence lengths and determine which LASER is more suitable for long-path interference experiments.

32. For a two-level LASER system, show mathematically that population inversion is necessary for net stimulated amplification.

33. A two-level atomic system is continuously illuminated with radiation resonant with its transition. Can a stable population inversion be produced? Explain your answer using the rates of stimulated absorption and stimulated emission.

34. Explain the operation of a three-level LASER using an appropriate energy-level diagram. Why is intense pumping required in a three-level LASER?

35. Compare three-level and four-level LASER systems. Explain why population inversion is easier to achieve in a four-level LASER.

36. What is pumping in a LASER? Explain and compare the following pumping methods: optical pumping, electrical discharge pumping. Give one suitable LASER example for each method.

37. A LASER cavity has mirror reflectivities $R_1 = 0.90$, $R_2 = 0.80$ and cavity length $20\ \text{cm}$. Neglect internal losses. Determine the threshold gain coefficient.

38. Two otherwise identical LASER cavities have mirror reflectivities $R = 0.99$and $R = 0.50$. Which cavity requires the larger threshold gain? Explain the physical reason.

39. A LASER cavity has a length of $30\,\mathrm{cm}$. Calculate the frequency separation between adjacent longitudinal modes. If the gain bandwidth is $3\,\mathrm{GHz}$, estimate the number of longitudinal modes that can lie within the gain bandwidth.

40. A continuous-wave LASER emits $5\,\mathrm{mW}$of radiation at $532\,\mathrm{nm}$. Calculate: energy of each photon, number of photons emitted per second.

41. A $10\,\mathrm{mW}$LASER beam falls normally on a perfectly absorbing surface. Calculate: radiation pressure, force exerted by the beam. What will be the force if the surface is a perfect reflector?

42. A $20\,\mathrm{mW}$ LASER produces a circular spot of diameter $1\,\mathrm{mm}$. Calculate the intensity of the beam. If the spot diameter is reduced to half its original value, what happens to the intensity?

43. Explain why spontaneous emission is generally incoherent, whereas stimulated emission produces coherent radiation. Discuss the roles of: phase, frequency, direction, polarization.

44. An incandescent lamp emits an enormous number of photons. Why does it not produce LASER-like radiation? Discuss the role of: population inversion, spontaneous emission, spectral width, coherence, directionality.

45. A LASER emits $2\,\mathrm{mW}$radiation at $632.8\,\mathrm{nm}$. Its beam diameter is $2\,\mathrm{mm}$, spectral linewidth is $10\,\mathrm{MHz}$, and cavity length is $25\,\mathrm{cm}$. Calculate: energy of one photon, number of photons emitted per second, beam intensity, approximate coherence length.

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