RAN-2403080103033001

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M.Sc. (Sem.-III) Examination October - 2025

Physics (Laser Fundamentals and Applications) PH-533

Time: 3 Hours] **[Total Marks: 70**

સૂચના : / Instructions

(1) ઉપરોક્ત દર્શાવેલ વિગતો ઉત્તરવહી પર અવશ્ય લખવી.
Fill up strictly the above details on your answer book

(2) Assume the data if required.

(3) Figures to right hand side indicate marks of each question.

(4) Attempt any two of each question

Seat No.:

Student's Signature

Q.1. (a) (i) Write the laser rate equations for the four level laser system. What is the condition to obtain population inversion between levels 3 and 2? Show that **6**

$$\frac{N_3 - N_2}{N} = \left(\frac{W_P}{W_P + T_{32}}\right) \frac{1}{\left[1 + \frac{W_1(2W_P + T_{21})}{T_{21}(W_P + T_{32})}\right]}$$

(ii) Given that the optimum external coupling occurs at **3**

$$\frac{1}{t_e} = \frac{1}{t_i}\left(\frac{R}{Rt} - 1\right)$$

Calculate the optimum output power for which the volume and the refractive index of the active material is 10 cm^3 and 1.5 respectively. Assume that the transition is mostly radiative. The average loss per unit length due to all loss mechanisms is 2.0 and the pumping rate is 10^{28} atoms per unit volume. Where $\lambda = 1.06\ \mu m$ and $g(\omega) = 2 \times 10^{-14}$ sec.

(b) (i) Consider an optical resonator consisting of a pair of plane mirrors facing each other. The active medium is placed inside the cavity. One of the mirror is made partially transparent to couple out the laser beam. Derive the expression for threshold condition, **3**

(ii) Describe lasing action in three level laser system. Write the rate equations of it. Show that below threshold for laser oscillation **6**

$$\frac{N_2 - N_1}{N} = \left(\frac{W_P - T_{21}}{W_P + T_{21}}\right)$$

(c) (i) Explain the working of a dye laser with energy level diagram. Also showing the arrangement for wavelength variation in it and explain briefly. **6**

(ii) In the 2P→1S transition in the hydrogen atom, the lifetime of the 2P state for spontaneous emission is 1.6×10^{-9} second. Calculate the Einstein coefficients Where $n_0 = 1$and $\nu = 2.47 \times 10^{15}\ sec^{-1}$. **3**

Q. 2. (a) (i) Using the following equations, show that the variation of photon number and the population inversion as a function of time in the cavity **4**

$$\frac{d(N_2 V)}{dt} = - knN_2 + knN_1 - T_{21}N_2 V + RV$$

(ii) Define the quality factor and show that the FWHM is **2**

$$\Delta v_p = \frac{C}{4\pi n_0 d}(2\alpha_1 d - \ln R_1 R_2).$$

(iii) Explain in detail the transverse modes election. What is the importance of fundamental transverse mode ? **3**

(b) (i) Explain the technique of Q-switching based on Acousto-optic effect. **4**

(ii) Explain the technique of longitudinal mode selection using Fabry- Perot etalon. **5**

(c) (i) Explain various techniques of mode locking in laser. **5**

(ii) Derive the expression of the ultimate linewidth of the laser. **4**

Q.3. (a) (i) What is hyper Raman effect? Discuss it for classical treatment. **3**

(ii) Discuss the phase matching condition in second harmonic generation. Show that the coherence length **6**

$$L = \frac{\lambda}{4(n_\omega - n_{2\omega})}$$

Also show that for phase matching criterion $k_2 = 2k_1$

(b) (i) Discuss the results of $CaF_2:Eu^{++}$crystals in which the two photon process is observed. **4**

(ii) What do you mean of spin flip Raman scattering? Explain how the transition between two states of same value of n is possible **5**

(c) (i) What do you understand in free electron laser? What are the characteristics of it? **4**

(ii) Explain Photo-acoustic Raman spectroscopy with a schematic diagram, **4**

(iii) The exciting line in an experiment is 5460 $\overset{0}{A}$ and the stokes line is at 5520 $\overset{0}{A}$. Find the wave number of anti stokes line **1**

Q.4. (a) (i) Explain the combined effect of multipath dispersion and material dispersion in optical fiber during the signal transmission **2**

(ii) What is material dispersion? Explain the cause of this effect. Derive Sellmeier dispersion formula using the differential equation **6**

$$\frac{d^2x}{dt^2} + \gamma_k \frac{dx}{dt} + \omega_{ok}^2 x = \frac{e}{m} E_1 \exp(-j\omega t)$$

(b) (i) Derive the expression of (NA) in step index fiber using a ray model. **4**

(ii) Consider a step index fiber for which $n_1 = 1.475$, $n_2 = 1.460$ and core diameter is 50 μm. What is the maximum value of Φ for which the rays will be guided through the fiber ? Corresponding to the maximum value of Φ, calculate the number of reflections that would take place in traversing 1Km length of the fiber **4**

(c) (i) For pure silica $\lambda_0 = 1.28$ μm, **3**

$$\lambda_0^3 \left(\frac{d^3 n}{d\lambda^3}\right)_{\lambda 0} = - 0.048 \text{ and } \lambda_0^4 \left(\frac{d^4 n}{d\lambda^4}\right)_{\lambda 0} = 0.2274$$

Calculate the dispersion caused by source having spectral half width of 50 nm about λ_0.

(ii) What is the importance of RMS pulse width? Define it. Also express the RMS **5**

linewidth in terms of spread of angular frequencies and wavelength. Derive the expression of total RMS pulse width when both multipath dispersion and material dispersion present together.

Use the following data if required :

$K_B = 1.38 \times 10^{-23}$ J/^{0}K
H = 6.62×10^{-34}J.sec
Electron mass = 9.1×10^{-31} Kg
C = 3×10^8m/sec
1 eV = 1.6×10^{-19} Joule

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