M. Sc. Physics Examination, 2023

(2nd Year, 1st Semester)

Atomic, Molecular and Optical Physics (I)

Paper – Sc/PHY/PG/CBS/TH/209/2023

Time : Two hours　　　　Full Marks : 40

Answer question no. **1** and any *one* from question Nos. 2 and 3 and any *one* from the rest

1. Answer any ***two***: 5×2

(a) Discuss in detail the spectrum of a diatomic molecule treated as an anharmonic oscillator.

(b) In the vibration-rotation spectrum of HBr, the rotational transitions at high frequency end of R-branch are closely spaced while those at the low frequency side of P-branch are widely spaced - Explain.

(c) What do you mean by the term "line shape function"? For a system with two energy levels, write the expression for the rate of stimulated emissions per unit volume in terms of "line shape function". How the expression gets modified when the atoms interact with near monochromatic radiation?

(d) From recurrence relations, obtain the selection rule that governs the electronic transitions between the rotational energy levels of diatomic molecules.

2. (a) What are the consequences of breakdown of the Born-Oppenheimer approximation? (b) State the salient features of *Morse* function and compare with those of the potential function for LHO. (c) The equilibrium vibration frequency of I_2 molecule is 215 cm^{-1} and the anharmonicity constant, x_e is 0.003 cm^{-1}. What is the intensity of the hot band $v = 1 \rightarrow v = 2$ relative to that of the fundamental, if the temperature is 450 K? [Given: $h = 6.626 \text{ x } 10^{-34}\ J\,s$, $k = 1.381 \text{ x } 10^{-23}\ J K^{-1}$, $c = 2.998 \text{ x } 10^{-8}\ m\,s^{-1}$] 5+5+5

3. (a) What is spectral transition probability? Discuss the selection rule for anharmonic oscillator with necessary illustration. (b) (i) What are the major differences in Raman and IR spectra? (ii) What is "hot" band? (c) The fundamental and first overtone transitions of $^{14}N^{16}O$ are centered at 1876.06 cm^{-1} and 3724.20 cm^{-1} respectively. Evaluate the equilibrium vibration frequency and anharmonicity constant of the molecule. (3+3)+(2½+2½)+4

4. (a) Consider a collection of atoms and let a near monochromatic radiation of energy density u at frequency ω passes through the medium. In such a condition, obtain the differential equation that governs the rate of change of intensity of the radiation as it passes through the medium bounded by two planes each of area "A" situated at x and x+dx, x being the direction of propagation of the radiation. Comment from the expression about the factor that decides the gain or attenuation in intensity of the beam as it leaves the medium. **(b)** For a system with two energy levels, frame the laser rate equations which can describe the rate at which the populations of various atomic levels change as a function of time in the presence of external pumping, stimulated and spontaneous transitions. At the steady state condition estimate the ratio of the number of atoms per unit volume in two different energy levels. Hence obtain the expression for the saturation intensity (I_S) of the medium considering the transitions from higher to lower energy levels to be predominantly radiative and the line shape function $\widetilde{g(\omega)}$ is normalized to have unit value at $\omega = \omega_0$. **(c)** A ruby laser emits light of wavelength 694.4 nm. If a laser pulse is emitted for 1.2 x 10^{-11} second and the energy released per pulse is 0.15 Joule (i) what is the length of the pulse and (ii) how many photons are there in each pulse? **6+5+4**

5. (a) From semiclassical approach, show that the rotational energy of a diatomic molecule behaving like a non-rigid rotator is expressed as $\varepsilon_J = BJ(J+1) - DJ^2(J+1)^2 + HJ^3(J+1)^3$ cm^{-1}, where B, D, H are the rotational constants, first, second order stretching terms respectively and J is the rotational quantum number. Show with a neat diagram the different transition levels and the corresponding spectrum. **(b)** The J = 1 $\leftarrow$ J = 0 transition in HCl occurs at 20.68 cm^{-1}. Considering the molecule to be a rigid rotator, calculate the wavelength of the transition J = 15 $\leftarrow$ J = 14. **7+4+4**