MASTER OF SCIENCE EXAMINATION, 2025

[2nd Year 1st Semester (DAY)]

PHYSICS

PAPER : SC/PHY/PG/CBS/TH/209

ATOMIC, MOCLECULAR AND OPTICAL PHYSICS (I)

Time : *Two Hours* *Full Marks* : 40

Answer *ALL* questions

1. *(a)* What is normal Zeeman effect? Considering the interaction of an atom with a strong magnetic field, estimate the number of atomic spectral transitions between atomic levels $^1D2 \rightarrow {}^1P_1$.

(b) Explain why the linear stark effect is not observed for the ground state of hydrogen atom.

(c) What do you understand by electric dipole approximation? 4+3+3

(CO1/CO2)

(OR)

2. *(a)* The Zeeman pattern of a spectral line consists of nine equidistant components. Considering the *L-S* coupling, determine the lowest state spectroscopic term and draw a schematic diagram showing the possible electric dipole transitions.

(b) In the strong field limit what are the rules for polarization and intensities of the π and σ Zeeman components?

(c) Show that in the limit of strong magnetic fields in transverse observation, the intensity of the π Zeeman component is twice of the σ component.

5+2+3

(CO1/CO2)

3. *(a)* Estimate, in terms of the fine-structure constant, how small is the energy of relativistic kinematic correction in comparison to the unperturbed energy obtained as solution of the Schrodinger equation for a hydrogenic atom.

(b) Derive the expression for correction to energy due to relativistic kinemetic correction using first order perturbation theory. 4+6

(CO3)

(OR)

4. *(a)* Considering the electron in a hydrogenic atom as a relativistic charged particle moving in an electrostatic field, derive the expression for the Hamiltonian that accounts for spin-orbit coupling.

(b) What are the coupled basis states? Explain why they are the correct basis states for calculating the energy corrections arising due to spin-orbit coupling. 7+3

(CO3)

(b) In steady condition, find the ratio of the number of active centres per unit volume in two different energy levels.

(c) Hence derive the expression for the saturation intensity (Is) 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 $\omega = \omega_0$. (3+1)+3+3

(CO5)

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5. *(a)* How do the normal coordinates behave with respect to symmetry operations? Show the normal vibrations observed in the IR absorption spectra of CO_2 with proper labelling.

(b) Obtain the selection rule that governs the transitions between the vibrational energy levels of diatomic molecules.

(c) The normal modes of vibration of CO_2 molecule are $\bar{\nu}_1 = 1330\,\text{cm}^{-1}$, $\bar{\nu}_2 = 667\ \text{cm}^{-1}$ and $\bar{\nu}_3 = 2349\ \text{cm}^{-1}$. Calculate the zero point energy.

3+4+3

(CO4)

(OR)

6. *(a)* How many rotational degrees of freedom a linear diatomic molecule has? Considering a linear diatomic molecule as a rigid rotator, show that the rotational energy of a diatomic molecule can be expressed as $\varepsilon_J = BJ(J+1)\ \text{cm}^{-1}$, where B is the rotational constant and J is the rotational quantum number.

(b) Using recurrence relations of spherical harmonics, obtain the selection rule that governs the electronic transitions between the rotational energy levels of diatomic molecules.

(c) 'Water molecule shows rotational spectrum but Carbon Disulfide (CS_2) molecule does not show rotational spectrum' – Comment. (1+4)+4+1

(CO4)

7. *(a)* For a two-level system, define the Einstein's 'A' and 'B' coefficients in the context of spontaneous and stimulated emissions. For such system with two energy levels E_1 and E_2 ($E_2 > E_1$), show that Einstein's B coefficients B_{12} and B_{21} are equal. Hence show that the Einstein's A coefficient A_{21} scales inversely with the spontaneous lifetime (τ_{sp}) associated with the transition $2 \rightarrow 1$. [Symbols A_{21}, B_{12} and B_{21} have their usual meanings].

(b) A laser beam of pulse power 10^{12} W is focused on an object of area $10^{-4}\ \text{cm}^2$. Calculate the energy flux of the laser beam at the point of focus.

(c) How many photons are emitted per second from a 1 Watt Ar^+ laser operating at 488 nm? (2+3+1)+1+3

(CO5))

(OR)

8. *(a)* For a two-level system, obtain the laser rate equations that describe the rate at which the populations of active centres at two energy levels change in the presence of external pumping, stimulated and spontaneous transitions. Hence show that the total number of active centres per unit volume is constant.