2022

PHYSICS

Paper : PHY-511

(Atomic, Molecular and Laser Physics)

Full Marks : 50

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

Answer ***any five*** questions.

1. (a) Suppose an electromagnetic wave with propagation vector, electric and magnetic fields along the z, x and y -axes respectively interacts with a free electron. Write down the Hamiltonian in the Coulomb gauge. What are the electric dipole, magnetic dipole and electric quadrupole approximations?

   (b) Consider transition between two atomic levels in an Hydrogen atom due to such an electromagnetic radiation. Establish that the selection rules in the dipole approximation are given by : $\Delta l = \pm 1$, $\Delta m = 0, \pm 1$.

   (c) Consider only electric dipole ($E1$) and magnetic dipole ($M1$) approximations. Find out the ways that an electron at $n = 3$ state can jump to $n = 1$ state. What are the strongest lines and why? (1+3)+2+(3+1)

2. (a) What is a central field approximation (CFA)? Write the many-electron Hamiltonian in this approximation explicitly identifying the perturbing terms H_1 and H_2. Sketch how the various energy levels of $npn'p$ electrons in CFA will be modified due to H_1 and H_2 in LS coupling scheme.

   (b) What are the reasons behind isotope shifts? Show that the isotope energy shift for nucleus of size R scales as Z^4/n^3, Z and n being the atomic number and principal quantum number respectively.

   (c) Show that the corresponding lifetime of hydrogenic ions with atomic number Z in electric dipole approximation is proportional to Z^{-4}. (1+1+2)+(1+3)+2

3. (a) Show explicitly that the two particle spin wave function $\chi(1, 2) = \alpha(1)\beta(2)$ is an eigenfunction of S_z operator but not of S^2.

   (b) Write the Hamiltonian of an atom in a magnetic field. Show that in Paschen-Back effect, the l-degeneracy of the atom is completely removed.

   (c) Out of $^3P_{3,2}$, $^4D_{1,2}$, $^2D_{3,2}$, $^3P_1$, which of the level(s) cannot show anomalous Zeeman effect and why? 3+(1+3)+3

4. (a) Write the Hamiltonian of a polyatomic molecule consisting of K nuclei and N electrons. Separate the nuclear and electronic part of the wave equation of the molecule using the adiabatic approximation. Explain the physical significance of the coupling term.

(b) Consider the energy calculation of molecular electronic states. Show that the energy calculat with approximate wave functions is always above those calculated with exact (true) wave functio Following the LCAO technique, obtain the secular equation for the ground state energy of diatomic molecule. (1+3+1)+(3+

5. (a) What will be the shapes of the molecular orbitals formed by combining two p_x atomic orbitals

(b) The molecular state of Boron monohydride (BH) molecule is given by : $(1s\sigma)^2(2s\sigma)^2(2p\sigma)(2p$ Obtain the term symbols of the BH molecule.

(c) Considering NH_3 as a C_{3v} point group molecule, construct the character table in reducible representation considering all degrees of freedom. The character table for point group C_{3v} in irreducible representation is given below.

C_{3v}	e	$2C_3$	$3\sigma_v$	Rotation and translation
A_1	1	1	1	T_z
A_2	1	1	−1	R_z
E	2	−1	0	(T_x, T_y); (R_x, R_y)

(Symbols have their usual meanings).

Determine the irreducible groups representing the vibrational modes of the NH_3 molecule. 2+3+(2+3)

6. (a) Assuming the lines in a rotational spectra to be located at 2B(J + 1), derive the expression for the rotational quantum number (J), where the intensity of the rotation spectra is maximum. B is the rotational constant and J is the rotational quantum number.

(b) Derive an expression for wave number of the P and R branch transitions for a diatomic molecule undergoing rotation-vibration transition.

(c) Write Frank-Condon principle for vibrational electronic spectra. With the help of a schematic diagram, explain how dissociation energy of a diatomic molecule could be estimated from vibrational-electronic spectra. 3+4+(1+2)

7. (a) Obtain an expression for the number of photons in a laser cavity as a function of the pumping rate.

(b) For a laser system, define the Quality Factor (Q) of a mode. Show that, the width of the output spectrum depends inversely on Quality Factor. Derive the corresponding expression.

(c) Cite a practical example of four level solid state laser system. State its working principle. 3+(1+3)+(1+2)