M. Sc. (Physics) 3rd Semester Examination 2018
PHY 511 (Atomic, Molecular and Laser Physics)

Full Marks – 50 **Time: 2 hours**

Answer Q.No.1 and other three questions taking at least one from each group

1. *Answer any five questions*: 4 x 5

(a) Considering only the first order fine structures of energy correction, indicate which energy difference in each pair is larger and why.

(i) $5f_{5/2}$— $5d_{3/2}$, $5d_{5/2}$ — $5p_{3/2}$; hydrogen atom in both cases
(ii) $6f_{5/2}$— $6p_{3/2}$, $5d_{5/2}$ — $5d_{3/2}$; doubly ionized Li^{2+} atom in both cases
(iii) $4d_{3/2}$— $4p_{1/2}$, $4f_{5/2}$—$4p_{3/2}$; hydrogen atom in both cases
(iv) $E_{n=3}$— $E_{n=2}$ for hydrogen atom, $E_{n=3}$— $E_{n=2}$ for doubly ionized Li^{2+} atom.

4

(b) Consider an electron moving under a restoring force where the motion is weakly damped and far from resonance. Establish the expression of electric dipole moment from quantum mechanical point of view. Compare the above expression with classical result.

4

(c) Write down the trial electronic wave function for a molecule following the LCAO approximation. Obtain the secular equation for the electronic energy of the molecule using the variational method.

2+2

(d) Write the electronic configuration of O_2 molecule. Show that the double bond of O_2 molecule can be inferred from the molecular orbital (MO) theory.

2+2

(e) Calculate the rotational energy of a symmetric top molecule. What will be the difference in energy if the top spins clockwise and anti-clockwise?

3+1

(f) 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.

1+3

Group – A

2. (a) What are the chosen basis in cases of single electron atom subject to (i) moderate magnetic field and (ii) weak magnetic field? Provide appropriate reasons for these choices.
(b) Establish the expressions for the correction of energy for single electron atom subject to (i) moderate magnetic field and (ii) weak magnetic field.
(c) Plot the transition scheme for transitions from n=2 to n=1for single electron atom subject to (i) moderate magnetic field and (ii) weak magnetic field.

(1+1)+(2+3)+(1+2)

3. (a) Construct the state vectors in $|n, l, j, m_j\rangle$ basis for quantum numbers n=5, j=7/2. Comment on the parity of these states. How does the parity change for n=5, j =9/2?

(b) Using the necessary selection rules plot the transition scheme for fine structure of spectral lines of a single electron atom between n=1 and n=2 and between n=2 and n=3.

(c) Plot the schematic diagram of splitting of different levels in case of hyperfine interaction in presence of magnetic field of $2p_{3/2}$ level (i) when hyperfine interaction is stronger than magnetic interaction and (ii) when hyperfine interaction is weaker than magnetic interaction. (Assume I=1).

(2+1+1)+3+3

4. (a)Establish how the spin singlet state is coupled with space dependent para state and spin triplet states are coupled with space dependent ortho state. Explain the reason.

(b) "Para states are energetically slightly higher than ortho states in two electron atom." Establish the statement mathematically and also from qualitative physical arguments.

(c) Explain what is meant by genuinely discrete excited state in two electron atom.

(d) In the list below mention with proper reason when the condition of orthogonality is intrinsic property and when it is imposed.

(i) $1s\ ^1 2s$; (ii) $1s\ ^1 2p$; (iii) $1s^3 2s$.

Explain with an example how you proceed to impose the condition of orthogonality.

2+3+1+(3+1)

Group – B

5. (a) Write down 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. Considering the diagonal component of the coupling term, show that the effective potential in which the nuclei move is different for different isotopes.

(b) For a particular diatomic molecule the equilibrium vibration frequency (ω_e) is 215 cm^{-1} and the anharmonicity constant (χ_e) is 0.003. What is the intensity of the v=1 to v=2 band transition relative to that of the fundamental band transition (v=0 to v=1) at a temperature 300 K? Assume that the transition probabilities are same for the two bands. Given k/hc=0.695030 $K^{-1}cm^{-1}$.

(1+3+1+2)+3

6. (a) Construct the character table in the irreducible representation for a molecule belonging to the C_{2v} point group. Considering H_2O as a C_{2v} point group molecule, identify the irreducible groups representing the normal modes of vibration of the molecule.

(b) Starting from the rate equations obtain an expression for the variation of photon number (n) in the laser cavity with the rate of pumping (R). Plot the variation of number of photons (n) as a function of pumping rate (R) around the threshold pumping rate (R_t).

(2+3)+(4+1)