বিদ্যাসাগর বিশ্ববিদ্যালয়

VIDYASAGAR UNIVERSITY

Question Paper

B.Sc. Honours Examinations 2021

(Under CBCS Pattern)

Semester - V

Subject : PHYSICS

Paper : C 11-T & P

Full Marks : 60 (Theory - 40 + Practical - 20)

Time : 3 Hours

Candidates are required to give their answers in their own words as far as practicable.
The figures in the margin indicate full marks.

[QUANTUM MECHANICS AND APPLICATIONS]

(Theory)

Group-A

A. Answer any *three* of the following questions : 12×3=36

1. (a) Define probability density and probability current density for a quantum state. Deduce an expression of probability current density for 3D motion and the law of conservation of probability density starting from Schrodinger equation. 2+4

(b) The ground state and the first excited state wave functions of an atom are ψ_0 and ψ_1, respectively. The corresponding energies being ε_0 and ε_1. If the system has 30% probability of being found in the ground state and 70% probability of being found in the first excited state (i) Write down the wavefunction of the atom? (ii) What is the average energy of the atom?

2+1

(c) Normalise the wave function $\psi(x)=\dfrac{1+ix}{1-ix}$, where $-\infty < x < \infty$. 3

2. (a) Consider a particle of mass m moving in a 1D potential specified by

$$V(x)=\begin{cases}0 & -2a < x < 2a \\ \infty & otherwise\end{cases}$$

Find the energy eigenvalues and eigenfunctions. 6

(b) An electron is in the ground state of a 1D infinite square well with $a=1\mathring{A}$. Compute the force that the electron exerts on the wall during an impact on either wall. 3

(c) Explain the term degeneracy. Find out the degeneracy of the first excited state for a particle confined in a 3D potential box. 1+2

3. (a) Find the expectation value of the potential energy in the n^{th} state of the harmonic oscillator. 3

(b) A particle in the harmonic oscillator potential starts out in the state

$$\psi(x,0)=A\left[3\psi_0(x)+4\psi_1(x)\right]$$

(i) Find A, (ii) Construct $\psi(x,t)$ and $|\psi(x,t)|^2$ (iii) Find $<x>$ and $<p>$.

2+2+3

(c) Using the uncertainty principle, show that the lowest energy of an oscillator is $\hbar\omega/2$. 2

4. (a) The normalised ground state wavefunction of one electron atom is given by $\psi(r,\theta,\varphi)=\left(\dfrac{z^3}{\pi a_0^3}\right)^{\frac{1}{2}} e^{-r/a_0}$, where the notations have usual meaning. Evaluate the probability of finding the electron at a distance greater than $2a_0/z$. 3

(b) The ground state wave function of an electron in hydrogen atom is given by $\psi(r)=\left(\dfrac{1}{\pi a_0^3}\right)^{\frac{1}{2}} e^{-r/a_0}$ where a_0 is the Bohr radius. Find the expectation value of potential energy of the electron. 3

(c) At time $t = 0$, the wave function for hydrogen atom is—

$$a.\ \psi(r,0) = \frac{1}{\sqrt{10}}\left(2\psi_{100} + \psi_{210} + \sqrt{2}\psi_{211} + \sqrt{3}\psi_{21-1}\right)$$

Where the subscripts are the values of quantum numbers *n, l, m*.

(i) What is the expectation value of the energy of the system? (ii) What is the probability of finding the system with $l = 1$, $m = 1$. 2+1

(d) What is parity operation? Show that spherical Harmonics are function of definite parity? 1+2

5. (a) Describe the Stern Gerlach experiment with necessary theory. Discuss the significance of it. 4+1

(b) Can Stern Gerlach experiment be performed with ions rather than neutral atoms? 2

(c) In Stern Gerlach experiment, on turning of the magnetic field the beam splits into seven components. What is the angular momentum of the atom in the beam? 2

(d) What is spin-orbit coupling? Find the magnitude of the spin-orbit energy for the state ${}^2P_{1/2}$ of the hydrogen atom. The radius of the orbit is 1.5Å. 1+2

6. (a) Discuss the general quantum mechanical theory of the anomalous Zeeman effect with special reference to Zeeman pattern for D_1 and D_2 lines of sodium. 4+3

(b) Explain why normal Zeeman effect occurs only in atoms with even number of electrons. 2

(c) What are the values of *L, S, J* and multiplicity of the state having spectral terms ${}^4D_{7/2}$. 3

Group-B

B. Answer any *two* of the following questions : 2×2=4

7. Write down the formula of the frequency of Larmour precession. An atom is placed in a magnetic field of strength 1T. Calculate the rate of precession.

8. State and explain the Ehrenfest's theorem.

9. Find the expectation value $< x^2 >$ for a Gaussian wave packet given by

$$\psi(x)=\left(\frac{1}{\sigma\sqrt{\pi}}\right)^{1/2} exp\left(-\frac{x^2}{2\sigma^2}\right) exp\left(ik_0 x\right)$$

10. Calculate the transmission coefficient for an electron of total energy $2ev$ incident upon a rectangular potential barrier of height $4ev$ and width $1nm$.

(Practical)

Group-A

A. Answer any *one* of the following questions : 15×1=15

1. Solve the S-wave Schrödinger equation for the ground state and first excited state of the hydrogen atom.

$$\frac{d^2y}{dr^2}=A(r)U(r)A(r)=\frac{2m}{\hbar^2}\left[V(r)-E\right], \text{ where } V=\frac{-e^2}{r}$$

S-wave Schrödinger equation for the ground state and first excited state of the Hydrogen atom : m is the reduced mass of the electron. Obtain the energy eigenvalues and plot the corresponding wave functions.

Ground state of H_2 atom is $\approx -13.6ev$,

$e=3.795\left(eV\mathring{A}\right)\frac{1}{2};\ \hbar c=1973\left(eV\mathring{A}\right);\ m=0.511\times 10eV/c^2$ 15

2. Solve the S-wave radias Schrödinger equation for an atom

$$\frac{d^2y}{dr^2}=A(r)U(r); A(r)=\frac{2m}{h^2}\left[V(r)-E\right]$$

where m is the reduced mass of the system (which can be choosen to be the mass of an electron) for the Screened coulomb potential $V(r)=\frac{e^2}{r}e^{-r/a}$. Find the energy (in eV) of the ground state of the atom to an accuracy of three significant digits. Also plot corresponding wave functions.

Take $e=3.795\left(eV\mathring{A}\right)\frac{1}{2}$, $m=0.511\times 106eV/cz$ and $a=3\mathring{A},5\mathring{A},7\mathring{A}$.

In this units $\hbar c=1973\left(eV\mathring{A}\right)$. The ground state energy is expected to be above $-12eV$ in all three cases. 15

3. To show the tunnelling efect using tunnel diode using I-V characteristics. Write down the followings :

   (a) Theory 4

   (b) Draw the energy level diagram 3

   (c) Experimental procedure 5

   (d) Remarks 2

Group-B

B. Compulsory Questions : (Answer any *one* question) **5×1=5**

4. Write down the theory to study the normal zeeman effect with external magnetic field.

5. Give the experimental arrangement through a block diagram of ESR.

6. Lab notebook / Viva-Voce.