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63/1 (SEM-5) CC11/PHYHC5116

2023

**PHYSICS**

Paper : PHYHC5116

**(Quantum Mechanics and Applications)**

Full Marks : 60

Pass Marks : 24

Time : Three hours

**The figures in the margin indicate  
full marks for the questions.**

1. Choose the correct option from the following :  
**(any five)** 1×5=5

(a) Probability density  $\psi^*(x,t)\psi(x,t)$  is  
always

- (i) real
- (ii) complex
- (iii) zero
- (iv) negative

Contd.

(b) The spin-orbit interaction energy depends on

- (i)  $n$  only
- (ii) only  $s$
- (iii)  $s$ ,  $l$  and  $j$
- (iv) only  $j$  and  $l$

(c) The value of orbital angular momentum for a d-electron is

- (i)  $\sqrt{2} \hbar$
- (ii) 0
- (iii)  $\sqrt{6} \hbar$
- (iv)  $\sqrt{5} \hbar$

(d) The energy of the hydrogen atom depends on

- (i)  $n$  only
- (ii)  $l$  only
- (iii)  $m_l$  only
- (iv) both  $n$  and  $l$

(e) A wave packet travels with

- (i) phase velocity
- (ii) zero velocity
- (iii) group velocity
- (iv) velocity of light

(f)  $\psi(x)$  is well-behaved if  $\psi(x)$  is single valued and

- (i)  $|\psi(x)| \rightarrow 0$  as  $x \rightarrow \pm \infty$
- (ii)  $|\psi(x)| \rightarrow \infty$  as  $x \rightarrow \pm \infty$
- (iii)  $|\psi(x)| \rightarrow 0$  as  $x \rightarrow 0$
- (iv)  $|\psi(x)| \rightarrow$  finite value as  $x \rightarrow \pm \infty$

(g) If  $\alpha$  be the length of a one-dimensional closed box in which a particle is enclosed, then its energy is proportional to

- (i)  $\alpha$
- (ii)  $1/\alpha$
- (iii)  $\alpha^2$
- (iv)  $1/\alpha^2$

(h) The probability of finding the particle trapped in a one-dimensional box is maximum for  $n = 1$  at

(i)  $x = 0$

(ii)  $x = \alpha/2$

(iii)  $x = \alpha$

(iv)  $x = -\alpha$

where  $\alpha$  is the length of the box.

(i) Particles described by symmetric wave functions are

(i) electrons

(ii) photons

(iii)  $\pi$ -mesons

(iv)  $H^+$

(j) For a particular value of angular momentum quantum number  $l$ , the possible orientations of the electron orbit in space are

(i)  $l$

(ii)  $(l + 1)$

(iii)  $(2l + 1)$

(iv)  $(2l - 1)$

2. Answer the following questions : **(any five)**

$2 \times 5 = 10$

(a) What is a Gaussian wave packet ? Express its wave function.

(b) Using the vector atom model, determine the possible value of total angular momentum of an  $f$ -electron.

(c) A pendulum with a length of 1m has a bob with a mass of 0.1 kg. What is the zero-point energy ?

(d) Compare the total energy and orbital angular momentum of electron in hydrogen atom as predicted by Bohr and Schrödinger.

(e) Differentiate between Zeeman effect and Stark effect.

(f) What does stationary state mean ? Does it mean that the particle is at rest ?

(g) Why does the normal Zeeman effect occur only in atoms with even number of electrons ?

3. Answer **any five** of the following : 5×5=25

(a) Prove the relation

$$\frac{\partial P}{\partial t} + \vec{\nabla} \cdot \vec{S} = 0$$

where  $P$  is the probability density and  $\vec{S}$  is the probability density current.

(b) Derive the three-dimensional time-independent Schrödinger equation from the time-dependent equation.

(c) Obtain the expectation value of potential energy of an electron in ground state of hydrogen atom.

(d) Discuss how Stern-Gerlach experiment verifies the concept of space quantization and spin of electron.

(e) Differentiate between L-S and J-J coupling schemes.

(f) What is linear harmonic oscillator ? Express its energy quantum states. What is its zero-point energy ?

2+2+1=5

(g) What is Lande's g-factor ? Calculate Lande's g-factor for  $2P_{3/2}$  state. 2+3=5

(h) Write a short note on Larmor's theorem.

(i) What are energy eigenvalues and eigenfunctions ? Show that any arbitrary wave function can be expressed as a linear combination of energy eigenfunctions.

2+3=5

4. Answer **any two** of the following : 10×2=20

(a) Derive the Schrödinger equation in spherical polar coordinates from the Cartesian coordinates.

(b) Give the experimental arrangement for observing the Zeeman splitting of spectral line. Deduce the theory of normal Zeeman effect and obtain an expression for Zeeman shift. Distinguish between normal and anomalous Zeeman effects.

3+5+2=10

(c) State and explain Pauli's exclusion principle. How does it account for the periodic table of elements ?

- (d) At time  $t = 0$  a particle is represented by the wave function

$$\psi(x,0) = \begin{cases} A(x/a), & 0 \leq x \leq a \\ A(b-x)/(b-a), & a \leq x \leq b \\ 0, & \text{otherwise} \end{cases}$$

where  $A$ ,  $a$  and  $b$  are (positive) constants.

- (i) Normalize  $\psi$  (that is, find  $A$ , in terms of  $a$  and  $b$ ).
- (ii) Sketch  $\psi(x, 0)$  as a function of  $x$ .
- (iii) Where is the particle most likely to be found, at  $t = 0$  ?
- (iv) What is the probability of finding the particle to the left  $a$  ? Check your result in the limiting cases  $b = a$  and  $b = 2a$ .
- (v) What is the expectation value of  $x$  ?  
 $2 \times 5 = 10$