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B.Sc./5th Sem (H)/PHS/22(CBCS)

2022

## 5th Semester Examination PHYSICS (Honours)

[Quantum Mechanics and Applications]

Paper: C 11-T

[CBCS]

Full Marks: 40

Time: Two Hours

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

## Group - A

- 1. Answer any *five* of the following questions:  $2 \times 5 = 10$ 
  - (a) Show that the momentum operator is Hermitian. 2
  - (b) Which one of the following wave functions is a well-behaved wave function in the range  $-\infty < x < \infty$ ? Justify your answer.

(i) 
$$\psi_1 = A \exp(-x)$$

(ii) 
$$\psi_2 = A \exp\left(-x^2\right)$$

(c) The operator  $\left(x + \frac{d}{dx}\right)$  has the eigenvalue  $\alpha$ .

Derive the corresponding eigenfunction.

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- (d) In case of a quantum harmonic oscillator, show that zero-point energy is equal to (1/2) ħω using Heisenberg's uncertainty principle.
- (e) Plot the ground state and the first excited state wave functions of a linear harmonic oscillator. Also plot the corresponding probability density functions.
- (f) Two particles (masses m<sub>1</sub> and m<sub>2</sub>) are attached to the ends of a massless rigid rod of length "a". The system is free to rotate in three dimensions about the (fixed) center of mass. Find out the allowed energy levels.
- (g) In the Stem-Gerlach experiment why is it necessary to use a beam of neutral atoms and not ions?
- (h) What are the values of L, S, and J and the multiplicity of the level having spectral term  ${}^4P_{52}$ ?

## Group - B

Answer any *four* from the following questions:  $5\times4=20$ 

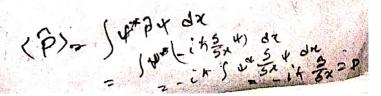
2. Set up the time-independent Schrödinger equation for the one-dimensional potential

$$V(x) = 0 \text{ for } 0 < x < L$$

 $=\infty$  elsewhere.

Write the appropriate boundary conditions. Obtain the energy eigenvalues and the corresponding eigenfunctions.

1+2+2

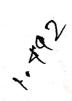


3. Determine the position probability density and the probability current density for the Gaussian wave packet

$$\psi(x,0) = A \exp\left(ikx - \frac{a^2x^2}{2}\right)$$
 2+3

4. Suppose a spin ½ particle is in a state :  $\chi = \begin{pmatrix} 1+i \\ 2 \end{pmatrix}$ .

What are the probabilities of getting  $\hbar/2$  and  $-\hbar/2$  if you measure  $S_x$  and  $S_z$ ?



- 5. What is the most probable value of "r" in the ground state of Hydrogen? (Ground state is given by  $R_{10}(r) = 2a^{-3/2} \exp(-r/a)$  What are the sources of *l*-degeneracy and *m*-degeneracy.
  - 6 (a) Show that the quantum mechanical probability of finding the linear harmonic oscillator in the ground state outside the classical limits of motion, is approximately 16%. (Given,  $\int_0^1 e^{-z^2} dz \approx 0.746$ )



- (b) What new information do we get from the quantum picture of a harmonic oscillator compared with the classical picture?
- 7/ (a) Explain the origin of sodium D1 and D2 lines.

(b) Show that  $\left[\hat{x}^3, p\right] = i\hbar 3\hat{x}^2$ .

3+2

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## Group - C

Answer any one of the following questions:

 $10 \times 1 = 10$ 

8. A particle in the harmonic oscillator potential starts out in the state:

$$\Psi(x,0) = A \left[ 3 \Psi_0(x) + 4 \Psi_1(x) \right]$$

(a) Find A.

1

(b) Construct  $\psi(x,t)$ .

1

(c) What is the frequency of oscillation of  $\psi(x,t)|^2$ ?

2

- (d) How the answer of "c" will change if  $\psi(x,0) = A[3\psi_0(x) + 4\psi_2(x)]?$
- (e) What will be the average energy of the system in both the cases?

9. What is Larmor precession? Explain the theory of Anomalous Zeeman Effect. Why Paschen Back effect and Normal Zeeman effect have certain similarity?

3+5+2