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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 : 2×5=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) $\psi_2 = A\exp(-x^2)$

(c) The operator $\left(x + \frac{d}{dx}\right)$ has the eigenvalue α. 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) $\hbar\omega$ using Heisenberg's uncertainty principle. 2

(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_1 and m_2) 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. 2

(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 ${}^4P_{5/2}$?

Group - B

Answer any ***four*** from the following questions : 5×4=20

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

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

$$= \infty \text{ elsewhere.}$$

Write the appropriate boundary conditions. Obtain the energy eigenvalues and the corresponding eigenfunctions. 1+2+2

$\langle \hat{P} \rangle = \int \psi^* \hat{p} \psi \, dx$

$= \int \psi^* \left(-i\hbar \frac{\partial}{\partial x} \psi\right) dx$

$= -i\hbar \int \psi^* \frac{\partial}{\partial x} \psi \, dx$

$-i\hbar \frac{\partial}{\partial x} = P$

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

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. 3+2

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 :

10×1=10

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

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

(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 $\psi(x,0) = A[3\psi_0(x) + 4\psi_2(x)]$? 4

(e) What will be the average energy of the system in both the cases? 2

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

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