25PHP102/22PHP103N

PSG COLLEGE OF ARTS & SCIENCE
(AUTONOMOUS)

MSc DEGREE EXAMINATION DECEMBER 2025
(First Semester)

Branch - **PHYSICS**

QUANTUM MECHANICS - I

Time: Three Hours Maximum: 75 Marks

SECTION-A (10 Marks)
Answer **ALL** questions
ALL questions carry **EQUAL** marks (10 × 1 = 10)

Module No.	Question No.	Question	K Level	CO
1	1	Which of the following is a property of a linear vector space? a) Non-associative addition b) Distributive scalar multiplication c) Non-commutative vector addition d) Vector multiplication	K1	CO1
	2	The expectation values of an observable $\underline{r}$ is given by: $a) <\psi\|\underline{r}\|\psi>$ $b) \|<\psi\|\underline{r}\|\psi>\|^2$ $c) <\psi\|\psi>$ $d) \psi\underline{r}\psi$	K2	CO1
2	3	For a spin-1/2 particle, the spin operators are represented by: a) 3 X 3 matrices b) 2 X 2 matrices c) Scalars d) Differential operators	K1	CO2
	4	The commutation relation $[L^2, L_z] = 0$ implies : $a)$ L^2 and L_z have no common eigenfunctions $b)$ L^2 and L_z are incompatible observables $c)$ L^2 and L_z can be simultaneously measured precisely $d)$ L_z is not Hermitian	K2	CO2
3	5	The ground state wavefunction of a harmonic oscillator is: a) A Gaussian function b) A delta function c) A spherical harmonic d) A plane wave	K1	CO1
	6	In the presence of an electric field, the n=2 states of hydrogen exhibit: a) No splitting b) Zeeman splitting of the field free line c) Quadratic Stark effect for some states d) Only Zeeman splitting	K2	CO1
4	7	First-order perturbation theory is applicable when: a) The perturbation H' is much larger than H_0 b) The perturbation H' is small compared to H_0 c) The system is highly nonlinear d) Energy levels are always degenerate	K1	CO3
	8	Raman scattering involves: a) Inelastic scattering of photons b) Elastic scattering of photons c) Absorption of photons only d) Emission of electrons	K2	CO3
5	9	In the Heisenberg picture, the time dependence is carried by: a) States b) Energy levels c) Both states and operators d) Operators	K1	CO4
	10	Second quantization is a method used for: a) Many-particle systems b) Single-particle systems only c) Classical fields d) Non-relativistic particles exclusively	K2	CO4

SECTION - B (35 Marks)
Answer **ALL** questions
ALL questions carry **EQUAL** Marks (5 × 7 = 35)

Module No.	Question No.	Question	K Level	CO
1	11.a.	What are eigenfunctions and eigenvalues of an operator? Illustrate with an example from quantum mechanics.	K1	CO1
		(OR)		

Cont...

1	11.b.	Derive the general uncertainty relation for two observables and discuss its implications.	K2	CO2
2	12.a.	The vector J gives the sum of angular momentum J_1 and J_2. Prove that $[J_x, J_y] = i\hbar J_z$, $[J_y, J_z] = i\hbar J_x$, $[J_z, J_x] = i\hbar J_y$. Is $J_1 - J_2$ an angular momentum?	K3	CO3
		(OR)		
	12.b.	Obtain the normalized eigenvectors of σ_x and σ_y matrices.	K3	CO2
3	13.a.	Explain the significance of spherical harmonics as eigenfunctions of angular momentum operators.	K2	CO1
		(OR)		
	13.b.	List the spin eigenvectors for a spin-½ particle and briefly describe their key properties.	K3	CO2
4	14.a.	Derive the electric dipole selection rules for transitions in a one-dimensional quantum harmonic oscillator, and explain the physical basis for allowed and forbidden transitions.	K1	CO1
		(OR)		
	14.b.	Consider a quantum particle undergoing a transition from a bound state to a continuum state under the influence of a weak perturbation. Derive and state Fermi's Golden Rule for the transition rate, clearly identifying the role of the perturbation matrix element and the density of final states.	K1	CO1
5	15.a.	Describe the interaction picture in quantum mechanics, highlighting its formal structure and advantages in analyzing time-dependent perturbations and quantum field interactions.	K1	CO2
		(OR)		
	15.b.	Solve the one-dimensional quantum harmonic oscillator using the Schrödinger picture. Derive the normalized wavefunctions and explicitly determine the quantized energy eigenvalues."	K2	CO2

SECTION -C (30 Marks)

Answer **ANY THREE** questions

ALL questions carry **EQUAL** Marks (3 × 10 = 30)

Module No.	Question No.	Question	K Level	CO
1	16	State and explain the postulates of quantum mechanics, focusing on the aspects related to state vectors, observables, and measurement outcomes in the context of Dirac notation.	K1	CO1
2	17	Discuss the rules for addition of angular momenta in quantum mechanics and the concept of Clebsch-Gordan coefficients. Obtain the matrix of Clebsch-Gorden coefficients for $j_1 = 1$ and $j_1 = 2$.	K2	CO2
3	18	Consider one dimensional anharmonic oscillator with a potential $V(x) = \frac{1}{2}m\omega^2x^2 + \lambda x^4$, where λ is a small parameter. a) Using perturbation theory, calculate the first-order correction to the energy of the ground state (n=0) of the harmonic oscillator due to the anharmonic term λx^4. b) Explain the limitations of perturbation theory for anharmonic oscillators and outline alternative methods, such as the variational approach, that can be used instead.	K3	CO3
4	19	Consider a two-level atomic system with energy levels E_1 and E_2 ($E_2 > E_1$) interacting with electromagnetic radiation in thermal equilibrium at temperature T. a) State the mathematical expressions for Einstein's A_{21}, B_{12} and B_{21} coefficients and identify the physical process each one describes. b) Derive the connection between Einstein's A_{21}, B_{12} and B_{21} coefficients using thermal equilibrium conditions, and relate the result to Planck's radiation law.	K3	CO3
5	20	Analyze the dynamics of a linear harmonic oscillator within the Heisenberg picture. Derive the Heisenberg equations of motion for the position and momentum operators, and demonstrate how these quantum results correspond to the classical equations of motion.	K1	CO1

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