DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 13
ADVANCED QUANTUM MECHANICS - I

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Advanced Quantum Mechanics-I DSE 13	4	3	1	0	Quantum Mechanics-I (DSC 14), Mathematical Physics III (DSC 7) or equivalent courses. Knowledge of Linear Algebra will be helpful.

Course Objectives

- Equips students with the mathematical tools enabling them for transition from concrete wavefunction-based methods to the general abstract formalism of non-relativistic quantum mechanics.
- Presents the full dynamical structure of quantum theory, including both Schrödinger and Heisenberg pictures of time evolution, and introduce the density matrix formalism for describing mixed and entangled states.
- Formally analyzes angular momentum in quantum mechanics, with an emphasis on operator methods, spin, and the addition of angular momentum using Clebsch–Gordan coefficients.

Learning Outcomes

At the end of this course, students will be able to

- Appreciate the necessity of abstract state vector formalism and articulate the meaning of each postulate of quantum mechanics.
- Solve time-dependent problems using both Schrödinger and Heisenberg pictures.
- Understand and compute time evolution in both ket and operator formalisms.
- Construct and interpret density matrices for pure and mixed states.
- Use ladder operator techniques and commutation relations to solve angular momentum problems and analyse spin systems.
- Apply the Pauli exclusion principle in the context of multi-fermion systems.
- Determine the angular momentum of a composite state using the concept of addition of angular momentum and C.G. coefficients.

<u>SYLLABUS OF DSE 13</u>
<u>THEORY COMPONENT</u>
(Credits: 3; Hours: 45)

Unit I **(18 Hours)**

Abstract formulation of Quantum Mechanics
Motivation for developing a linear vector space formulation to describe quantum phenomena. Brief review of linear vector spaces with Dirac's ket notation, Inner product and norm, Schwarz Inequality. Dual space and Bra vectors. Orthonormal basis. Infinite dimensional (discrete) vector space. Hilbert Space of state vectors. Completeness. Dynamical observables as linear operators, Adjoint of a linear operator, Hermitian or self-adjoint operators, eigenvalues and eigenvectors. Projection operator and complete set of basis. Matrix representation of state vectors and operators. Unitary operators and change of basis.
Postulates of quantum mechanics. Continuous basis, position and momentum representations. Degenerate eigenvalues and complete set of commuting observables. Generalized uncertainty principle.

Unit II **(12 Hours)**

Quantum Dynamics
Unitary time-evolution and Schr**ö**dinger equation in ket notation and correspondence with wave mechanics. Momentum as generator of translation in space and Hamiltonion as generator of translation in time. Schrödinger vs Heisenberg picture. Evolution of a system in Heisenberg picture with example of simple harmonic oscillator. Classical Limit.
Density matrix Formalism
Density operator and matrix, pure and mixed states, expectation value of an observable, time evolution of density matrix, Reduced density matrix for subsystems of a composite system with example of entangled spin-1/2 pair.

Unit III **(15 Hours)**

Angular Momentum: Abstract operator approach to angular momentum, Commutation Relations. Ladder operators, Matrix representation of angular momentum operators and ladder operators, Eigenvalues and eigenvectors.
Pauli matrices and their properties. Matrix representation of Spin angular momentum operators. Eigenvalues, eigenvectors of S^2 and S_z for spin1/2 and spin 1 systems and General spin state for these systems.
Addition of angular momentum: Clebsch-Gordan coefficients, C. G. coefficients of addition for j = (i) 1/2, 1/2; (ii)1/2, 1 and (iii) 1, 1 systems.
Identical particles: Many-particle systems, Exchange degeneracy, concept of parity, symmetric and anti-symmetric wavefunctions. Pauli exclusion principle.

<u>References</u>

Essential Readings

1. Introduction to Quantum Mechanics, D.J. Griffith, Pearson Education (2005).

2. Principles of Quantum Mechanics by R. Shankar (Springer, 3rd Edition, 2008)
3. Quantum Mechanics, B. H. Bransden and C. J. Joachain, Prentice Hall (2000).
4. Modern Quantum Mechanics, J. J. Sakurai and Jim Napolitano, Cambridge University Press (2021).
5. Quantum Mechanics: Theory and Applications, Ajoy Ghatak and S. Lokanathan, Laxmi Publications (2019).

Additional Readings

1. Introduction to Quantum Mechanics, Volume-I and II, C. Cohen-Tannoudji
2. The Principles of Quantum Mechanics, P.A.M. Dirac, Clarendon Press, Oxford (1981).
3. A Text book of Quantum Mechanics, P.M. Mathews and K. Venkatesan, 2nd Ed., 2010, McGraw Hill.
4. Introduction to Quantum Mechanics, R. H. Dicke and J. P. Wittke, Addison-Wesley Publications, 1966.
5. Quantum Mechanics, Leonard I. Schiff, 3rd Edn. 2010, Tata McGraw Hill.
6. Quantum Mechanics, Eugene Merzbacher, 2004, John Wiley and Sons, Inc.
7. Quantum Mechanics, Walter Greiner, 4th Edn., 2001, Springer.
8. Introductory Quantum Mechanics, R. L. Liboff; 4th Ed., Addison Wesley, 2003.
9. Angular Momentum in Quantum Mechanics, A. R. Edmonds, Princeton University Press (1996).
10. Elementary Theory of Angular Momentum, M. E. Rose, Dover Publications Inc. (2003)

Advisory

The course is essential for several courses offered in the one-year M.Sc. program and is also included in the syllabi of various competitive examinations, including CSIR-NET, JEST, and GATE.
Colleges are advised to offer this as a Discipline Specific Elective (DSE). Students who intend to pursue postgraduate studies or appear for competitive exams are strongly encouraged to choose this course as a DSE.