

## **PHY-813 Advanced Quantum Mechanics**

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**Credit Hours:** 3-0

**Pre-requisite:** None

**Course Objectives:**

This course will provide a base for many subjects in physics such as quantum information and computation, quantum optics, condensed matter theory and high energy physics.

**Core Contents:**

Fundamental concepts of quantum theory, quantum dynamics, theory of angular momentum, group theoretic approach, approximation methods, relativistic quantum mechanics.

**Detailed Course Contents:**

The Stern-Gerlach experiment; kets, bras, and operators, base kets and matrix representations; measurements, observables, and the uncertainty relations, change of basis; position, momentum and translation, wave functions in position and momentum space; time evolution and the Schrodinger equation, the Schrodinger versus the Heisenberg picture; simple harmonic oscillator, Schrodinger's wave equation, spin  $\frac{1}{2}$  systems: eigen values and eigenstates of angular momentum, orbital angular momentum: addition of angular momentum, Density operator and pure versus mixed ensembles, time-independent perturbation theory: degenerate and non-degenerate case; hydrogen-like atoms: fine structure and the Zeeman effect; variational methods; time dependent perturbation theory, Relativistic quantum mechanics: Klein Gordon Equation and difficulty with probability density associated Klein Gordon equation, Dirac Hamiltonian and Covariant form of Dirac equation, Equation of continuity associated with Dirac Equation. Dirac Gamma matrices and Properties of Dirac gamma matrices, How Dirac equation leads to Spin associated with Dirac particles, Solution to the Dirac equation: Particle at rest and General free particle solution. The Dirac Sea interpretation, The Feynman-Stuckelberg interpretation, Antiparticle spinors

**Course Outcomes:** On successful completion of this course, students will know the basic formalism of quantum mechanics, the evolution, and dynamics of quantum systems like harmonic oscillators and hydrogen atom, the concept of angular momentum, associated algebra, and the approximation methods. At the end of the course, the students will also be

able to understand why Schrodinger's equation is not applicable for relativistic case and how to develop equations for relativistic case.

**Textbook:**

1. J. J. Sakurai (JJS), Modern Quantum Mechanics, revised ed. Addison-Wesley Publishing Company 1994.
2. Mark Thomson (MT), Modern Particle Physics, Cambridge University Press, 2013.

**Reference Books:**

1. R. Shankar, Principles of Quantum Mechanics, 2nd ed. Plenum Press 1994.
2. D. H. McIntyre, Quantum Mechanics: A Paradigms Approach, Pearson 2012.
3. Fayyazuddin and Riazuddin Modern Introduction to Particle Physics, Third Edition, World Scientific (referred as FR)
4. David J. Griffith's, Introduction to Particle Physics, John Wiley & Sons, INC.

**Weekly Breakdown**

<i>Week</i>	<i>Section</i>	<i>Topics</i>
1	JJS Sec. 1.1	The Stern-Gerlach Experiment
2	JJS Sec. 1.2-1.3	Kets, Bras, and Operators, Base Kets and Matrix Representations
3	JJS Sec. 1.4-1.5	Measurements, Observables, and the Uncertainty Relations, Change of Basis
4	JJS Sec. 1.6-1.7	Position, Momentum and Translation, Wave Functions in Position and Momentum Space
5	JJS Sec. 2.1-2.2	Time Evolution and the Schrodinger Equation, The Schrodinger versus the Heisenberg Picture
6	JJS Sec. 2.3-2.4	Simple Harmonic Oscillator, Schrodinger's Wave Equation
7	JJS Sec. 3.2	Spin $\frac{1}{2}$ Systems and Finite Rotations

8	JJS Sec. 3.4	Density operator and pure versus mixed ensembles
<b>Mid Term</b>		
9	JJS Sec. 3.5- 3.6	Eigen values and Eigenstates of Angular Momentum, Orbital Angular Momentum.
10	JJS Sec. 3.8	Addition of Angular Momentum
11	JJS Sec. 5.1- 5.2	Time-Independent Perturbation Theory: Degenerate and Non degenerate case
12	JJS Sec. 5.3- 5.4	Hydrogen-like Atoms: Fine Structure and the Zeeman Effect; Variational Methods (optional)
13	JJS Sec. 5.6	Time Dependent Perturbation Theory
14	MT 4.1, Handouts	Relativistic Quantum Mechanics: Klein Gordon Equation, Equation of continuity associated with K.G equation and difficulty with probability density associated with Klein Gordon equation.
15	MT 4.2, 4.3, 4.4	Dirac equation: Dirac Hamiltonian, Covariant form of Dirac equation, Dirac Pauli's representation, Properties of Dirac Gamma Matrices, Adjoint Dirac Equation, Probability density and current density associated with Dirac equation.
16		Revision