Quantum Mechanics Syllabus

Prerequisites

- Calculus (single and multivariable)
- Linear Algebra
- Differential Equations
- Classical Mechanics (Newtonian & Lagrangian)
- Introductory Electromagnetism
- Basic Complex Analysis (desirable)

1. Mathematical Foundations

- Hilbert Spaces, Dirac Notation (Bra-Ket)
- Linear Operators, Eigenvalues, and Eigenvectors
- Hermitian Operators, Unitarity, Commutators
- Function Spaces and Inner Products
- Tensor Products of Hilbert Spaces

2. Postulates of Quantum Mechanics

- State Vectors and Wavefunctions
- Observables and Measurement
- The Schrödinger Equation
- Time Evolution (Unitary Operators)
- The Collapse Postulate

3. The Schrödinger Equation

- Time-dependent vs Time-independent Form
- Stationary States
- Probability Interpretation, Born Rule

- Conservation of Probability, Continuity Equation

4. One-Dimensional Systems

- Infinite Square Well
- Finite Square Well
- Potential Step and Barrier (Tunneling)
- Harmonic Oscillator (Algebraic & Analytical Solutions)
- Delta Function Potential

5. Operators and Commutation

- Momentum Operator, Position Operator
- Heisenberg Uncertainty Principle
- Commutator Algebra
- Ehrenfest Theorem

6. Formalism & Representations

- Position and Momentum Representations
- Unitary Transformations
- Heisenberg Picture vs Schrödinger Picture
- Density Operators & Mixed States

7. Angular Momentum

- Orbital Angular Momentum
- Ladder Operators
- Spin Angular Momentum (Spin-1/2 Systems)
- Addition of Angular Momenta
- Clebsch-Gordan Coefficients

8. Central Potential Problems

- Hydrogen Atom (Analytical Solution)
- Radial Equation
- Degeneracy, Quantum Numbers (n, l, m)
- Fine Structure (intro level)

9. Approximation Methods

- Time-Independent Perturbation Theory (Degenerate & Non-degenerate)
- Time-Dependent Perturbation Theory
- Fermi's Golden Rule
- Variational Principle
- WKB Approximation

10. Quantum Dynamics and Scattering

- Wave Packets and Group Velocity
- Scattering Theory (1D and 3D)
- Born Approximation
- Partial Wave Analysis
- Phase Shifts

11. Identical Particles and Statistics

- Bosons vs Fermions
- Symmetrization Postulate
- Pauli Exclusion Principle
- Many-Particle Wavefunctions
- Second Quantization (optional for undergrads)

12. Quantum Entanglement and Measurement

- EPR Paradox
- Bell's Inequality
- Density Matrices
- Quantum Decoherence
- Quantum Information Basics (optional)

13. Advanced Topics

- Path Integrals (Feynman Formalism)
- Quantum Field Theory Intro
- Relativistic Quantum Mechanics (Klein-Gordon, Dirac Equation)
- Quantum Computing Basics

Recommended Texts & Resources

- Griffiths & Schroeter: *Introduction to Quantum Mechanics*
- Shankar: *Principles of Quantum Mechanics*
- Sakurai: *Modern Quantum Mechanics*
- Cohen-Tannoudji et al.: *Quantum Mechanics*
- MIT OCW: `https://ocw.mit.edu`
- Quantum Country: `https://quantum.country`