Syllabus: Quantum Mechanics II

Spring 2025

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Objectives: The objectives of the class are to obtain a solid, deep and broad knowledge of Quantum Mechanics. The class focuses on the fundamental aspects and discusses various applications from condensed matter, particle physics and astrophysics, emphasizing conceptual and calculational frameworks, discussing in depth the mathematical background and physical principles.

Prerequisites: Quantum Mechanics I.

Content: Review of time independent perturbation theory: non-degenerate and degenerate cases, examples: spin-orbit, fine and hyperfine structure of the H-atom: the 21 cm astrophysical line. Zeeman and Paschen-Back effects in magnetic fields. The Van-der-Walls interaction between atoms. Non-perturbative methods: i) WKB: connection formula and bound state quantization conditions (connection with Bohr-Sommerfeld quantization), metastable states. App: Gamow's theory of alpha decay and thermonuclear fusion processes in stars, ii) Variational method: the origin of the chemical (covalent) bonds. Scattering theory: fluxes and cross sections. Lippman-Schwinger equation, scattering amplitudes, Born approximation. Rutherford scattering: classical and quantum. Partial wave analysis, optical theorem. Phase shifts, examples. Coulomb scattering. Connection between scattering amplitudes and bound states. Coherent vs. incoherent scattering: Bragg scattering. Mean free path and relaxation time. Indistinguishable particles, bosons and fermions, spin statistics connection. Scattering of indistinguishable particles. Many indistinguishable particles: a primer on second quantization: many particle Fock states. Dynamics: two level systems, Larmor presession of spins: classical and quantum, basics of NMR and spin resonance: pi pulses and population inversion. App: the physics of neutrino oscillations. Time dependent perturbation theory: interaction picture and Dyson series, S-matrix, Harmonic perturbations: comparison to exact treatment. Transition rates. Fermi's Golden rule and exponential decay. App: a model for decay of a two level system. Density matrix: the von-Neumann equation of motion, pure vs. mixed states, two-level systems and the Bloch vector. Quantization of the electromagnetic field: gauge invariance, photons and their polarizations. Coupling of charged particles to electromagnetic fields: minimal coupling and gauge covariance of the Schroedinger equation. Examples: Aharonov-Bohm effect, Landau levels in a constant magnetic field. Interaction of atoms and light: stimulated and spontaneous emission and absorption. Dipole transitions and selection rules. Quadrupole transitions. Higher order processes: Raman scattering. Einstein's A,B coefficients and approach to thermal equilibrium, black body radiation. Relativistic quantum mechanics: the Klein-Gordon equation and its caveats. The Dirac equation: spinors, main predictions: relativistic corrections, gyromagnetic and Thomas factors.

Suggested Textbooks: The material is standard and there are several excellent textbooks:

Lectures on Quantum Mechanics by G. Baym,

Modern Quantum Mechanics by J. J. Sakurai,

Principles of Quantum Mechanics by R.Shankar,

Quantum Physics by M. Le Bellac,

Quantum Mechanics: Fundamentals by K. Gottfried, T-M. Yan