Course Outline

1. Basic ideas of QM

1.1. Preliminaries. The wave-particle duality. Our approach to the course. Units. References.

1.2. Wave function. The Shrödinger equation.

1.3. Operators, momentum operator.

1.4. Energy operator. The Hamiltonian.

2. Time-independent Shrödinger equation. Eigenstates. 1-d problems

2.1. Separation of variables.

2.2. The infinite square well. Boundary conditions. Stationary states. Superpositions of stationary states. Normalization.

2.3. The Harmonic Oscillator. Ladder operators. Commutators. Zero-point oscillations.

2.4. Free particle. Wave packets. Phase and group velocities. Group velocity dispersion.

2.5. The δ-function potential. Bound states. Scattering. Transmission and reflection coefficients. Tunneling. Connection between bound states and poles of the scattering amplitudes.

2.6. Finite square well. Analogy with optics. Scattering from a step-potential.

3. Elements of QM formalism

3.1. Vectors, spaces, inner products, orthonormal sets. Linear transformations. Matrix form of operators. Hermitian operators. Unitary operators. Transformation of vectors and operators. Unitary transformation invariants (determinant and trace). Eigenvalues and eigenvectors. How to find eigenvalues and eigenvectors of a matrix (diagonalization). Hermitian operators $\Leftrightarrow$ real eigenvalues.

3.2. The uncertainty principle. Compatible and incompatible observables. Minimum uncertainty states (Gaussian wave packets).

3.3. Time dependence of QM observables.

4. Approximate methods in QM

The method of dimensions. Limiting cases. Estimate of energies of stationary states. Model approximations. Examples.

5. QM in 3-d

5.1. Shrödinger equation in spherical coordinates. Central potentials. Separation of variables. The angular equation. Spherical harmonics. The radial equation. Infinite spherical well.

5.2. The hydrogen atom. Gross structure of the energy levels -- the Bohr formula. The Bohr radius and the four scales of the microworld. Hydrogenic ions. The spectrum of hydrogen (series).

5.3. Angular momentum. Commutation relations. Angular momentum operators in polar coordinates. Eigenstates of angular momentum. The vector model.

5.4. The Stern-Gerlach experiment. Spin. Spinor formalism. Pauli matrices. Spin in a magnetic field, precession. Measurement in QM illustrated with spin-1/2.

5.5. Rotations in quantum mechanics. Euler angles. Rotation matrices for J=1/2 and J=1. A few words about spin-statistics connection.

5.6. Addition of angular momenta. The vector model. Clebsch-Gordon coefficients. Examples from atomic and elementary particle physics.

6. Time-independent perturbation theory

6.1. First order corrections to energies and eigenfunctions. Second-order correction to energy. Elements of degenerate perturbation theory. The secular equation.

6.2. Fine structure in hydrogen spectrum. Relativistic correction to kinetic energy.

> Interlude: elements of relativistic QM (the Klein-Gordon equation, the Dirac equation, 4-component spinor formalism, nonrelativistic limit, first-order relativistic corrections).

Spin-orbit interaction. Classical model of the magnetic moment. Estimate of the spin-orbit correction. Thomas precession. The Darwin term. The fine structure formula. Finer than the fine structure: Lamb shift and hyperfine structure. High-resolution spectroscopic experiments in hydrogen.