

# Quantum Physics III (8.06) Spring 2005

## Outline

I begin this outline with an abbreviated outline for 8.05, to remind you of what you have already done.

1. **General structure of quantum mechanics.**
2. **Quantum dynamics.**
3. **Two-state systems.**
4. **Angular momentum and spin**
5. **The radial equation and operator methods.**
6. **Addition of angular momentum.**
7. **Introduction to the quantum mechanics of identical particles.**
8. **Natural Units.**

Reading: Supplementary notes.

- The cgs system of units.
- Natural units.
- Examples.

9. **Degenerate Fermi systems.**

Reading: Griffiths, Ch. 5.3; Cohen-Tannoudji, Ch. XI Complement F.

- Fermions in a box at zero temperature: density of states, energy, degeneracy pressure.
- White dwarf stars. Equation of state at  $T = 0$ , Chandrasekhar limit, neutron stars.
- Electrons in metals: Periodic potentials, Bloch waves, introduction to band structure, metals vs. insulators.

## 10. Charged particles in a magnetic field.

Reading: Supplementary notes. Griffiths, Section 10.2.4; Cohen-Tannoudji, Ch. VI Complement E.

- Canonical quantization.
- The classical Hamiltonian for a particle in a static magnetic field.
- The quantum mechanical analysis of a charged particle in a magnetic field, via canonical quantization.
- Landau levels. Energy eigenvalues. Energy eigenstates. Energy eigenvalues in another gauge.
- Gauge invariance and the Schrödinger equation.
- Landau level wave functions. Counting the states in a Landau level.
- de Haas–van Alphen effect.
- Integer Quantum Hall Effect. Introduction to the ordinary Hall effect. Quantum mechanical problem of a particle in crossed magnetic and electric fields. Calculation of Hall current due to a single filled Landau level. From this idealized calculation to real systems: the role of impurities.
- The Aharonov-Bohm effect.

## 11. Time-independent perturbation theory.

Reading: Griffiths, Ch. 6; Cohen-Tannoudji, Ch. XI including Complements A-D; Cohen-Tannoudji, Ch. XII. If you wish, see also Shankar, Ch. 17 and Sakurai, Ch. 5.1-3.

- Time-independent perturbation theory for degenerate states: diagonalizing perturbations and lifting degeneracies.
- Time-independent perturbation theory for nondegenerate states: Energy and wavefunction perturbations through second order.
- Degeneracy reconsidered.
- Simple examples: perturbing a two-state system, a simple harmonic oscillator, and a bead on a ring.
- The fine structure of hydrogen, revisited: relativistic and spin-orbital effects.
- The hydrogen atom in a magnetic field, revisited: the Zeeman effect.
- The hydrogen atom in an electric field: the Stark effect.
- Van der Waals interaction between neutral atoms.

## 12. Variational and semi-classical methods.

Reading: Griffiths, Chs. 7,8; Cohen-Tannoudji, Ch. XI Complements E, F, G. If you wish, see also Shankar, Ch. 16 and Sakurai, Ch. 5.4.

- The variational method.
- Ground state of helium. Screening.
- First excited state of helium. Direct and exchange integrals.
- A one electron molecule ( $\text{H}_2^+$ ).
- The Semi-classical (or WKB) approximation. Form of wave functions in classically allowed and classically forbidden regions. Handling turning points: connection formulae. Tunnelling. Semiclassical approximation to bound state energies.

## 13. The adiabatic approximation and Berry's phase.

Reading: Griffiths, Ch. 10.

- The Born-Oppenheimer approximation and the rotation and vibration of molecules.
- The adiabatic theorem.
- Application to spin in a time-varying magnetic field.
- Berry's phase, and the Aharonov-Bohm effect revisited.
- Resonant adiabatic transitions and The Mikheyev-Smirnov-Wolfenstein solution to the solar neutrino problem.

## 14. Scattering.

Reading: Griffiths, Ch. 11; Cohen-Tannoudji, Ch. VIII. If you wish, see also Shankar, Ch. 19.

- Definition of cross-section  $\sigma$  and differential cross section  $d\sigma/d\Omega$ . General form of scattering solutions to Schrödinger equation, the definition of scattering amplitude  $f$ , and the relation of  $f$  to  $d\sigma/d\Omega$ . Optical theorem.
- The Born approximation. Derivation of Born approximation to  $f$ . Application to scattering from several spherically symmetric potentials, including Yukawa and Coulomb. Scattering from a charge distribution.
- Low energy scattering. The method of partial waves. Definition of phase shifts. Relation of scattering amplitude and cross section to phase shifts. Calculation of phase shifts. Behavior at low energies. Scattering length. Bound states at threshold. Ramsauer-Townsend effect. Resonances.

**15. Time-dependent perturbation theory.**

Reading: Griffiths, Ch. 9; Cohen-Tannoudji, Ch. XIII. If you wish, see also Shankar, Ch. 18 and Sakurai, Ch. 5.5-8.

- General expression for transition probability. Adiabatic theorem revisited.
- Sinusoidal perturbations. Transition rate.
- Emission and absorption of light. Transition rate due to incoherent light. Fermi's Golden Rule.
- Spontaneous emission. Einstein's A and B coefficients. How excited states of atoms decay.

**16. Quantum Computing.**

- Using many two-state systems as a quantum computer.
- Grover algorithm. Shor algorithm.