

MIT Subject 8.322 Quantum Theory II

R. L. Jaffe 2007

Syllabus

This is an **optimistic** syllabus. Material that may be omitted for lack of time is in [blue](#).

I Relativistic Wave Equations

- A The problem: Lorentz covariance
- B The Klein-Gordon equation
- C Dirac's equation
 - 1 Derivation, Dirac matrices (chiral and Bjorken and Drell)
 - 2 Massless case: Weyl's equation
 - 3 Operators, angular momentum and spin
 - 4 Hamiltonian form and equations of motion
 - 5 Bispinor notation
- D Non-relativistic reduction of the Dirac equation and the g factor of the electron.
- E Lorentz covariance of Dirac's equation
 - 1 Meaning, example of KG equation
 - 2 Solution and interpretation
 - 3 Bilinear covariants.
 - 4 Generalizations
- F Single particle solutions of the Dirac equation
 - 1 Counting states, projection operators
 - 2 Momentum eigenstates and their high energy limit.
- G [More applications of the Dirac equation if time permits.](#)

II Approximation Methods

- A Stationary state perturbation theory
 - 1 Brillouin-Wigner perturbation theory
 - 2 Rayleigh-Schrödinger perturbation theory
 - 3 Degenerate perturbation theory
 - 4 [Degeneracies past first order](#)
 - 5 Convergence of perturbation theory
 - A. A convergent example — radius of convergence
 - B. Asymptotic expansions
 - 6 Examples:

- A. Perturbations of the harmonic oscillator
 - B. Fine structure of hydrogenic atoms
 - C. Weak and strong field Zeeman effect in hydrogen
 - B Variational methods
 - 1 Basic theorem
 - 2 Practical considerations
 - 3 [Extensions to excited states, interlacing theorem, partial diagonalization.](#)
 - 4 Examples: Ground state of helium, bound states in open geometries
 - C Semiclassical methods
 - 1 The WKB approximation, the classical limit and the Hamilton-Jacobi equation.
 - 2 The need for connection formulae and their derivation
 - 3 Interpretation of the connection formulae.
 - 4 Applications: Bohr-Sommerfeld quantization, quantum tunneling, etc.
 - 5 Reflection above the barrier.
 - D [Adiabatic approximation](#)
 - 1 Discussion and “derivation”
 - 2 [Transition rate in the adiabatic limit — relation to WKB](#)
 - 3 [Born-Oppenheimer approximation](#)
 - 4 [Berry’s phase, theory, applications, relation to Hannay’s angle.](#)
- III Many particle systems
- A Indistinguishability and statistics
 - B Exchange symmetry, spin and statistics
 - C Two particle systems, exchange interaction, effective spin dependence, the classical limit and the significance of statistics.
 - D Permutation symmetry
 - 1 Permutations
 - 2 The totally symmetric and totally antisymmetric representations
 - 3 Slater determinant
 - 4 [Representations of the permutation group](#)
 - 5 [The representations of \$S_3\$.](#)
 - 6 [Young diagrams and Young tableaux](#)
 - 7 [States of three particles](#)
 - 8 [The \$p\$ -states of nitrogen](#)

[9 Obtaining wave functions from Young tableaux](#)

E Second quantization

- 1 Classical field theory and quantum wave mechanics
- 2 Quantizing a classical field
- 3 Fock space, creation and annihilation operators
- 4 Statistics
- 5 One particle and two particle operators
- 6 The propagator in 2nd quantization
- 7 Application to the degenerate Fermi gas
 - A. Density of states of a Fermi gas
 - B. Surface energy of nuclei
- [8 Thomas Fermi approximation for high \$Z\$ atoms](#)
- [9 Thomas Fermi for a conducting surface](#)

IV Scattering theory

- A Elementary kinematics of scattering theory: Cross section, scattering amplitude, unitarity and the optical theorem
- B Partial waves, spherical Bessel's functions, phase shifts, partial wave unitarity
- C Calculating phase shifts: scattering length and effective range.
- D Formal scattering theory:
 - 1 Scattering states and the Lippmann Schwinger equation
 - 2 Potential scattering
 - 3 T -matrix, S -matrix and the Born approximation
 - 4 Phase shifts reconsidered.
- E Striking phenomena at low energies: bound states, resonances, virtual states
- F Analytic properties of scattering amplitudes.
- [G Extended example: The separable potential: bound states, scattering resonances, convergence of the Born Approximation.](#)
- [H Multichannel scattering and Fano-Feshbach Resonances.](#)

V Time dependent perturbation theory, radiation

- A Interaction representation
- B The Dyson series
- C The transition rate in first order: Fermi's Golden Rule
- D Elementary treatment of radiation — emission and absorption and the dipole approximation

- E Quantization of the EM field
- F The Casimir Effect
- G Multipole radiation