

EE222/223: Applied Quantum Mechanics

Fall/Winter 2005/2006

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Syllabus (*tentative*)

Note: DABM refers to the course reader, and CCT to Quantum Mechanics by Claude Cohen Tannoudji et al.

Part 1 (1 hw)

Fundamental ideas of quantum mechanics

(DABM chapters 1, 2; CCT chapter 1)

- History of quantum mechanics
- Double-slit experiment
- Wave-particle duality
- Wavefunctions
- Time independent Schrödinger equation (TISE)
- Exact solutions of the TISE for simple problems
 - Particle in an infinitely deep potential well
 - Particle and an infinitely thick finite potential barrier
 - Particle in a finite potential well

Part 2 (1 hw)

Fundamental ideas of quantum mechanics – continued

(DABM chapters 3; CCT chapter 1)

- Time dependent Schrödinger equation (TDSE)
- Probability current
- Exact solutions of the TDSE for simple problems
- Wavepackets
- Heisenberg uncertainty principle

Part 3 (2 hws)

Mathematical tools of quantum mechanics

(DABM chapter 4; CCT chapter 2)

- Wavefunction (state) space
- Linear operators
 - Eigenvalue equation
 - Expectation value
 - Commutator
 - Special types of linear operators (Hermitian, unitary, inverse) and their properties
 - Examples of linear operators in quantum mechanics: Hamiltonian, momentum, position operators.
- Orthonormal basis of the state space
- Dirac notation

- Closure relation
- Representations in the state space and change of representation

The postulates of quantum mechanics and applications

(DABM chapter 5; CCT chapter 3)

- Formulation of the postulates: quantum state, observable, measurement, and the evolution of a quantum state
- Commuting observables
- Density operator and density matrix
- Time evolution of the mean value of an observable
- Evolution operator
- The Schrödinger and Heisenberg pictures
- General form of the uncertainty principle

Part 4 (1 hw)

Two-particle states

- Separable states
- Entangled states
- Single and two-qubit states; Bell states
- Quantum key distribution, teleportation, superdense coding.

Harmonic oscillator

(DABM chapters 2,3; CCT chapter 5)

- Review of the classical harmonic oscillator
- Quantum harmonic oscillator (QHO) – 1D case
- Time evolution of the 1D QHO
- Coherent states
- Annihilation and creation operators

Part 5 (2 hws)

Approximation methods in quantum mechanics

(DABM chapters 6-7; CCT chapters 11,13)

- Finite basis subsets
- Time-independent nondegenerate perturbation theory
- Time-independent degenerate perturbation theory
- Variational method
- Time-dependent perturbation theory and applications
 - Fermi's golden rule
 - Refractive index
 - Nonlinear optical coefficients

Part 6 (1 hw)

Methods for one-dimensional problems

(DABM chapter 11)

- Transfer matrix method
- WKB method

- Electron emission with a potential barrier

Part x

Other topics in applied quantum mechanics

(Lecture notes, DABM chapter 17, other sources)

- Pure vs. mixed states in quantum mechanics, density matrices
- Bell's inequality

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Part 7 (1 hw)

Quantum mechanics in crystalline materials

(DABM chapter 8; CCT chapter 11 – complement F)

- Bloch theorem
- k.p method
- Effective mass approximation
- Density of states
- Optical absorption

Part 8 (1 hw)

Angular momentum in quantum mechanics

(DABM chapters 9,12; CCT chapters 4, 6)

- Orbital angular momentum
- Angular momentum operators and commutation relations
- General theory of angular momentum in quantum mechanics
- Eigenvalues and eigenstates of orbital angular momentum; spherical harmonics
- Spin angular momentum

Part 9 (1 hw)

The hydrogen atom

(DABM chapter 10; CCT chapter 7)

- Particle in a central potential
- Solution of the hydrogen atom problem

Part 10 (1 hw)

Systems of identical particles

(DABM chapter 13; CCT chapter 14)

- Identical particles in quantum vs. classical mechanics
- Systems of two identical particles
- Bosons and fermions
- System of an arbitrary number of identical particles
 - Permutation operators; symmetrizer and antisymmetrizer
 - Symmetrization postulate and construction of physical states for systems of identical particles
 - Construction of basis for a system of identical particles

- Differences between bosons and fermions
 - Pauli exclusion principle
 - Thermal distribution functions (Bose-Einstein and Fermi-Dirac)
- Direct and exchange terms
- The consequences of particle indistinguishability: quantum interference; bunching, antibunching

Part 11 (1-2 hws)

Introductory quantum optics

(DABM chapter 14; CCT chapter 5 - complements G, K)

- Quantization of the electromagnetic field
 - Finite one-dimensional cavity case;
 - Free space case;
 - General approach (for lossless medium).
- Electric and magnetic field operators
- Uncertainty principle for electric and magnetic fields in a mode
- Multimode fields
- Fock (number) states
- Coherent states
- Squeezed states

Part 12 (1 hw)

Quantum mechanics of fermions

(DABM chapters 15)

- Fermion annihilation and creation operators
- Fermion wavefunction operator
- Fermion Hamiltonians (for noninteracting particles)
- General form of a single-particle fermion operator
- Hamiltonian for two interacting fermions

Part 13 (1 hw)

Interaction of different kinds of particles

(DABM chapter 16)

- Electron-photon interaction
- Stimulated emission
- Spontaneous emission
- Optical absorption

Part 14

Other topics in applied quantum mechanics

(DABM chapter 17, other sources)

- Quantum computation
- Interpretations of quantum mechanics