OPTI 570 - Quantum Mechanics

Course Description:

This is a one-semester course designed to provide students with a solid understanding of quantum mechanics formalism, techniques, and important example problems. With this background, students will be prepared for subsequent in-depth studies in optical physics, quantum optics, relativistic quantum mechanics and other advanced quantum mechanics topics, condensed matter physics, laser physics, and semiconductor physics and optics. The course emphasizes a formal mathematical treatment of quantum mechanics, and is therefore intended for students who have already completed at least a one-semester introductory course in quantum mechanics where the basic concepts, symbols, and mathematical approaches have been introduced.

Textbook (required):

Cohen-Tannoudji C., Diu B. & Laloë F. (1992). Quantum Mechanics (vol. 1 & 2). Wiley & Sons. ISBN 9780471569527 — A used copy of either the first or second edition is OK. Both volumes will be used in the class.

Course notes (required): available at UA bookstore after start of classes

Grading Policy:

- In-class participation: 5%
- Homework sets: 10%
- First mid-term exam: 15%
- Second mid-term exam: 25%
- Third mid-term exam: 25%
- Final exam: 20%

Each student’s final course grade will be based on the total points accumulated over the semester. A grade of “A” will be given for 90-100 total points, “B” for 80-89 points, “C” for 70-79 points, etc. Extra credit points may be given for the completion of certain assignments, but should not be expected.

OPTI 570 involves required reading assignments (approximately one reading assignment per class period) in which students will be challenged to learn many of the intricate details of quantum mechanics from the required textbook (which will be closely followed throughout the semester). Challenging homework problems, both required and optional, will be assigned approximately weekly.
Class time will be focused on

- discussing and explaining the topics covered in the textbook,
- discussion of concepts that are unclear or difficult to understand
- working example problems
- discussion of material and applications not covered in the textbook.

Students will be expected to fully participate in classroom discussions.

Rerequisites: It is expected that students enrolling in this course have already studied the following topics in an introductory quantum mechanics course:

- deBroglie wavelength of a particle
- Schrödinger’s equation
- energy eigenstates of example potential wells (particle in a box, harmonic oscillator, hydrogen atom)
- Dirac notation (not essential, this is not always covered in a one-semester undergraduate quantum mechanics course) operator algebra and commutators
- Angular momentum in quantum mechanics (spin, electron orbital angular momentum)

It is not necessary that students fully understand these topics, as they will be covered in detail in OPTI 570.

It is also expected that students are familiar with the following mathematical concepts:

- matrix and vector multiplication
- finding the eigenvalues and eigenvectors of simple matrices working with complex numbers
- basic formalism of Fourier transform integrals
- differential equations (although not necessarily the various means to solve a wide range of problems)

Students will be expected to review on their own (as needed) these or similar background topics that will be used in OPTI 570.

Objectives

1. learning formal techniques for solving problems in quantum mechanics (and related areas) for experimental and theoretical research;
2. learning advanced quantum mechanics and quantum optics techniques and concepts, as would be encountered in PHYS 570B and OPTI 544 (for example) or other advanced courses.
**Topics**

OPTI 570 aims to cover the following topics (numbers in parentheses indicate approximate number of 75-minute lectures for each topic):

1. **Mathematical formalism I.** State space and state vectors, scalar product, Dirac notation. Linear operators, Hermitian operators. Representations and bases. Eigenvalue equations, observables, commuting observables. Unitary operators and unitary transformations. (4)

2. **Postulates of quantum mechanics.** Physical implications, interpretations. Time dependence. Time translation (evolution) operator, Schrödinger, Heisenberg and interaction pictures. (2)

3. **Wavepackets:** example to illustrate representations, transformations, translations, other concepts. (1)

4. **The harmonic oscillator.** Creation and annihilation operators, operator algebra. Solution of the eigenvalue problem. Stationary states in position and momentum representations. Quasi-classical states, time evolution of expectation values, comparison to classical harmonic oscillator. (7)


9. **Stationary perturbation theory.** Perturbation equations. Non-degenerate perturbation theory. Degenerate perturbation theory. (2)

10. **Fine and hyperfine structure.** Corrections to hydrogen atom problem: spin-orbit coupling, relativistic effects, Darwin correction. Fine structure of the n=2 shell in hydrogen. Hyperfine structure. (2)

11. **Time-dependent perturbation theory.** Perturbation equations, solution to first order, transitions between discrete states, limits of validity. (4)