OPTI 570: Quantum Mechanics

Graduate Course Syllabus

Semester and Year this Document Covers
Fall 2024 to present (this syllabus remains in effect until replaced)

Course Number and Title
OPTI 570: Quantum Mechanics

Course Description
This one-semester course is designed to provide students with an understanding of the formalism, techniques, and important example problems of quantum mechanics. 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. The course emphasizes a formal mathematical treatment of quantum mechanics, and is therefore intended for students who have already completed at least one semester-long introductory course in quantum mechanics where the basic concepts, symbols, and mathematical approaches have been discussed.

Instructor Information
Instructor: Professor Brian P. Anderson
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Teaching Assistant (TA): TA information is announced at the beginning of each semester

Course Format
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 primary required textbook (which will be closely followed throughout the semester). Challenging homework problems will be assigned approximately weekly. Students will be expected to fully participate in classroom discussions. **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.

Prerequisites
It is expected that students enrolling in this course have already studied the following topics in an introductory quantum mechanics course (one or two semesters, such as OPTI 345 or OPTI 511R or equivalent):

- deBroglie wavelength of a particle
- Schrodinger's equation
- energy eigenstates of example potential wells (free particle, particle in a box, harmonic oscillator, hydrogen atom)
- Dirac notation (preferred but not essential)
- operator algebra and commutators
- angular momentum in quantum mechanics (spin, electron orbital angular momentum)

It is not necessary that the topics above be fully understood, as they will be covered in detail in OPTI 570. It is also **essential** that students are familiar with and can utilize 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
- interpreting and using differential equations (being able to solve challenging differential equations is not expected)

Students will be expected to review on their own (as needed) these or other introductory or background topics that will be used in OPTI 570 but not covered in detail. Students may also be expected to incorporate (alone or with a partner) computer-based work with Matlab (or similar) into their homework assignments, exams, or projects.

Permissions
The instructor's permission is needed to take this class, and is especially needed for students who do not have a previous quantum mechanics course with a passing grade on a college/university course transcript, non-degree-seeking students, and off-campus students.

Recitation Sections

On most Wednesday afternoons/evenings, the TA for the course will hold an ***optional*** help session for about 1.5 hours. These are offered for your benefit, and are a chance for you to ask questions about material that is not making sense to you, and especially to discuss difficulties that you might be having with that week's problem set. Problem sets will usually be due on Thursdays. Although attendance is optional, recitation sections are strongly recommended: most students usually end up attending most help sessions. Additionally, 2 or 3 Wednesday afternoon/evening sessions during the semester will be utilized for exams. ***These particular sessions are not optional; your attendance at these times is required.*** Each in class exam will be two hours, starting at the typical time of the recitation section. Exam dates and times will be announced near the beginning of each semester. One of these exams may be take-home instead, with a longer duration.

Learning Outcomes

Upon completion of this course, it is expected that students will be able to:

- interpret and assign physical meaning to the notation and symbols of quantum mechanics when encountering new quantum mechanics problems or reading quantum mechanics literature;
- construct equations using the formalism of quantum mechanics that directly correspond with a wide variety of scenarios and processes of the physical world;
- solve a wide variety of equations and systems of equations using the formalism of quantum mechanics in order to reach conclusions about physical problems and make predictions about the outcomes of possible measurements;
- be prepared to take more advanced courses involving quantum mechanics and quantum physics, such as UA courses OPTI 544, OPTI 646, PHYS 570B, and OPTI 561.

Required Texts and Materials

Required: The primary required course textbook is a hardcopy or electronic copy of Volumes 1 and 2 of *Quantum Mechanics* by C. Cohen-Tannoudji, B. Diu, & F. Laloe, published by Wiley & Sons. The 3rd edition of this classic textbook (printed in 2019) has three volumes. The earlier 1st and 2nd editions each have two volumes, and are no longer in print. New or used copies of Volumes 1 and 2 of *any* edition are required. **The 3rd volume of the 3rd edition is not used and does not need to be purchased.**

Required: *Field Guide to Quantum Mechanics*, by Brian P. Anderson, published by SPIE Press, 2019. UA students can obtain a free PDF copy from the SPIE Digital Library website via a subscription held by the UA Libraries. From the UA Libraries main website (library.arizona.edu) perform a **Library Search** with the **title** "Field Guide to Quantum Mechanics" (including quotes makes the search results easier to navigate). The book should be the only result. Select the book, then select the link for **SPIE Digital Library eBooks**. If you are logged in with your UA NetID, you will then be able to download the entire PDF. You may also purchase a hardcopy of the book through SPIE press.

Required: OPTI 570 handwritten class notes. A free PDF copy will be available to all students. Bound copies may be available for purchase through UA FastCopy (this option will be discussed in class at the beginning of the semester) or borrowed from a student who previously took OPTI 570 (printed versions of these notes used to be required). These class notes contain content presented in lectures, expanded discussions of the content of the *Field Guide to Quantum Mechanics*, and required reading.

Schedule of Topics and Activities

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 and Heisenberg 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 (coherent) states, time evolution of expectation values, comparison to classical harmonic oscillator. (7)
5. Angular momentum. Commutation relations. Angular momentum ladder operators, operator algebra. Solution of the eigenvalue problem (operator approach). Pauli matrices. Stern-Gerlach experiment. Spin 1/2 problem. Two-level systems. Bloch sphere. (4)
6. Eigenvalue problem for the central potential, separation in angular and radial equations. Hydrogen atom. Orbital angular momentum, spherical harmonics. Addition of angular momentum, Clebsch-Gordan coefficients. (4)
7. Stationary perturbation theory. Perturbation equations. Non-degenerate perturbation theory. Degenerate perturbation theory. (2)
8. 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. Atomic Structure. (2)
9. Time-dependent perturbation theory. Interaction picture. Perturbation equations, solutions to first and second order, transitions between discrete states, limits of validity. (4)

Grading Scale and Policies

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. For this course, A is interpreted as "Excellent – has demonstrated a more than acceptable understanding of the material; exceptional performance; exceeds expectations," B is interpreted as "Good – has demonstrated an acceptable understanding of the material; adequate performance; meets expectations," C is interpreted as "Average – has not demonstrated an acceptable understanding of the material; inadequate performance; does not meet expectations," D is interpreted as "Poor – little to no demonstrated understanding of the material; exceptionally weak performance.", and E is interpreted as "Failure – usually reserved for non-attendance."

Extra credit points may be given for the completion of certain assignments or available on exams to students who scored below the B/C threshold, but should not be expected. Students who obtain a low grade on an exam may also be given a chance to bring their grade up by completing an extra assignment.

Assessments

The following assessments and their percentages (weight of final grade) are used to calculate grades for this course.

Assessments	Percentage of final
Participation, including attendance, asking and answering questions in class, asking questions during office hours when struggling with a topic,	5%
Completing and turning in homework	11%
First mid-term exam (written)	21%
Second mid-term exam (written)	21%
Third mid-term exam (written or oral)	21%
Final exam OR final project OR final homework	21%

Attendance and Participation Policies

OPTI 570 follows the Class Attendance and Participation Policies described at http://www.optics.arizona.edu/academics/course/grading-policies, and the University of Arizona academic policies available at https://academicaffairs.arizona.edu/syllabus-policies.

Subject-To-Change Notice

Information contained in the course syllabus, other than the Grading Scale and Policies and Absence Policies, may be subject to change with reasonable advance notice, as deemed appropriate by the instructor of this course.

Graduate Student Resources

The University of Arizona's Basic Needs Initiative is comprised of programs and resources that can be found at: http://basicneeds.arizona.edu/index.html