Physics 501: Graduate Quantum Mechanics I

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Web: See Canvas
Class Hours: M/Th 10:20-11:40am
Class Room: SEC 207

Course Description

This is the first semester of a year-long graduate course in quantum mechanics. We rely on each student having already learned the experimental necessity of the theory as well as an undergraduate-level understanding of how it works. This course covers a graduate-level treatment of quantum mechanics, which emphasizes states, operators, eigenvalues, and representations from the beginning and not on a real space wavefunction basis, departing from a "Griffiths like" treatment. This course follows the book of Sakurai and is supplemented heavily from the text of Shankar. This combination allows us to emphasize the fundamental assumptions used in quantum theory that make successful quantitative predictions in experiment, which affects how we think about nature from a fundamental level.

Breakdown of grade contributions

- Homework 34%
- Midterm 33%
- Final 33%

Homework

It is expected you are reading the course material specified in the content below prior to class. We will have homework assignments due at the end of the day (by midnight) to be turned into the grader, **Abay Zhakenov**, **az417@physics.rutgers.edu**, through Canvas or their mail box. Homework assignments will involve both analytic and numerical exercises. In working on the problems, you are encouraged to talk with others in the class, but once you think you know what direction to take in finding a solution you must write up your own work. Always show your

work. You will not receive full credit if you do not show your work. In general, I am not looking for a specific answer; rather, I am always looking for the reasoning behind the answer.

Homework will be **due by midnight on the day specified in the assignment**. Please submit them to the grader **Abay Zhakenov** either via Canvas or to their mailbox. Homework not turned in by the specified time will be considered late. Reasonable requests for extensions can be provided in the appropriate circumstances. The solutions are posted online after the due date. As a result, late homework will receive at most 50% credit.

Grading Rubric: For full points you must show your work in a clear, readable, and logical fashion that someone other then your self can follow. Partial points are given if the answer is incorrect, steps are skipped or not presented, and if only part of the problem is completed. There are several ways to solve a problem, and creativity and ingenuity are praised, not graded negatively.

Rubric for grading homework, and exam questions: Each problem would be graded on a 0 to 10 scale:

- 10 – fully completed problem
- 9-8 fully completed problem with tiny deficiencies
- 7-4 – most of the conceptual steps done correctly, but some errors made
- 3-1 – some essential steps made
- 0 – nothing of value was done

Half points are allowed. The final score for that problem will be converted to the fractional weight of that assignment, where the total assignment would be 100

Grading Scheme

90-100 = A
85-90 = B+
80-85 = B
75-80 = C+
70-75 = C
60-70 = D
below 60 = F

Exams

One in-class midterm will be held on the date specified in the syllabus timeline. The final will be held on **TBD** in room **TBD**. You can bring a scientific calculator for each exam. For the midterm and final, you are allowed one open book.

Policies

The course schedule and guidelines are subject to change. I will communicate any changes promptly and clearly. Still, it is your responsibility to make yourself aware of any and all changes by attending class and maintaining communication with me.

Any questions about a grade received on an exam has to brought to my our the graders attention within one week of completing the exam.

Disability Accommodations

Rutgers University welcomes students with disabilities into all of the University's educational programs. In order to receive consideration for reasonable accommodations, a student with a disability must contact the appropriate disability services office at the campus where you are officially enrolled, participate in an intake interview, and provide documentation: https://ods.rutgers.edu/students/documentation-guidelines. If the documentation supports your request for reasonable accommodations, your campus's disability services office will provide you with a Letter of Accommodations. Please share this letter with your instructors and discuss the accommodations with them as early in your courses as possible. To begin this process, please complete the Registration form on the ODS web site at: https://ods.rutgers.edu/students/getting-registered

Absences

Students are expected to attend all classes; if you expect to miss one or two classes, please use the University absence reporting website to indicate the date and reason for your absence. An email is automatically sent to your instructors. If you have been told to quarantine, or are experiencing symptoms of any transmissable disease, please do not attend in-person class meetings. Contact me to make arrangements for handling such absences.

Books: required and suggested

- (Sakurai) *Modern Quantum Mechanics*, Third Edition by J. J. Sakurai and Jim Napolitano, ISBN:1108473229. This is the **required textbook** for the class.
- (Shankar) *Principles of Quantum Mechanics* by R. Shankar, ISBN:0306447908. We will supplement Sakurai constantly with this text.
- (Izaac&Wang) *Computational Quantum Mechanics*, by Joshua Izaac and Jingbo Wang, ISBN:978-3-319-99929-6. This will be used for homework assignments and will be very good additional reading for the course.
- (Feynman) *Feynman's Thesis: A New Approach to Quantum Theory* by Richard Feynman (Author), Laurie M. Brown (Editor), ISBN:9812563806. This is worth reading during this semester when we study path integrals.

Prerequisites

Prerequisites: Physics 750:417 Intermediate Quantum Mechanics.

Learning Goals

This class builds a deep understanding of quantum mechanics from a strong mathematical foundation. The learning goals of this semester are:

- *Linear vector spaces and Dirac notation*: Understanding the state of a quantum system as a vector in Hilbert space. The mathematical notation and operations one can perform on vectors and matrices in these spaces.
- *Postulates of quantum mechanics*: The students will be exposed to the postulates of quantum mechanics and their implications. We while aim for this to be learned from an empirical perspective, as this is not mathematics, its physics.
- *Schrödinger's equation and Pictures of QM*: Solutions in one-dimension, time evolution, and the path integral representation of quantum mechanics.
- *Theory of angular momentum*: Rotations, symmetries, eigenvalues and eigenstates, addition of, Schrodingers equation.
- *Symmetry, conservation laws, and degeneracies in QM*: The meaning of symmetries through operator relations and the meaning of conservation laws. The origin of degeneracies in QM.

Schedule

The schedule is tentative and subject to change. Reading is meant to supplement the course lectures and is a required component of the class.

Week 01 (Labor day so only one class this week) , 09/01 - 09/05:

- Fundamental Concepts: Linear Vector spaces, Dirac notation.
- Reading: Sakurai 1.1-1.2; Shankar 1.1-1.3

Week 02, 09/08 - 09/12:

- Fundamental Concepts: Operators, matrices, diagonalization, measurements.
- Reading: Sakurai 1.3-1.5 ; Shankar 1.4-1.6

Week 03, 09/15 - 09/19:

- Compatible and not compatible observables, change of basis, operators with continuous spectra, states in real and momentum space, Wavepackets
- Reading: Sakurai 1.6-1.8, Shankar 1.7-1.10

Week 04, 09/22 - 09/26:

- Postulates of quantum mechanics and their implications. Schrödinger's equation and dynamics: time evolution operator, pictures of QM, meaning of the wavefunction
- Reading: Shankar 4.1-4.2; Sakurai 2.1-2.2; Start Shankar Chapter 5

Week 05, 09/29 - 10/03:

- Schrödinger's equation and dynamics: Solutions in 1D (including the harmonic oscillator).
- Reading: Sakurai 2.3-2.4; Finish Shankar Chapter 5 and go through Shankar Chapter 7

Week 06, 10/06 - 10/10:

- Solutions in 1D. Propagators and Feynman path integrals.
- Reading: Sakurai 2.6; Shankar Chapters 6 and 8, Feynman's PhD Thesis

Week 07, 10/13 - 10/17:

- Gauge transformations, gravity, E&M, Aharnov Bohm Effect, and the magnetic monopole.
- Reading: Sakurai 2.7; Shankar 18.4

Week 08, 10/20 - 10/24:

- Gauge transformations (contd) Aharnov Bohm Effect, and the magnetic monopole. Angular momentum: rotations, spin-1/2.
- Reading: Sakurai 3.1-3.2; Shankar 12.1-12.3

Week 09, 10/27 - 10/31:

- Midterm week
- Angular momentum: SU(2), SO(3), Euler rotations, eigenvalues and eigenvectors of angular momentum
- Reading: Sakurai 3.3,3.5, skipping 3.4; Shankar 12.4-12.5

Week 10, 11/03 - 11/07:

- Angular momentum: Orbital angular momentum and Schrödinger's equation in a central potential
- Reading: Sakurai 3.6,3.7.1-3.7.3; Shankar 12.6

Week 11, 11/10 - 11/14:

- The hydrogen atom
- Reading: Sakurai 3.7.4; Shankar 12.6

Week 12, 11/17 - 11/21:

- Addition of angular momentum
- Reading: Sakurai 3.8.1; Shankar 15.1-15.2
- **Thanksgiving break**

Week 13, 11/24 - 11/28:

- Addition of angular momentum
- Reading: Sakurai 3.8.2-3.8.4; Shankar 15.3-15.4

Week 14, 12/01 - 12/05:

- Symmetry in quantum mechanics
- Reading: Sakurai 4; Shankar 11

Week 15, 12/08 - 12/12:

- Symmetry in quantum mechanics
- Reading: Sakurai 4; Shankar 11
- Last class 12/10

Resources for Students

The faculty and staff at Rutgers are committed to your success. Students who are successful tend to seek out resources that enable them to excel academically, maintain their health and wellness, prepare for future careers, navigate college life and finances, and connect with the RU community. Helpful resources include the Rutgers Learning Centers and school-based advising (for SAS, SOE, SEBS, and RBS). Additional resources that can help you succeed and connect with the Rutgers community can be found at https://success.rutgers.edu.

Please visit the Rutgers Student Tech Guide for resources available to all students. If you do not have the appropriate technology for financial reasons, please email the Dean of Students (deanofstudents@echo.rutgers.edu) for assistance. If you are facing other financial hardships please visit the Office of Financial Aid.

Academic Integrity

Rutgers University takes academic dishonesty very seriously. By enrolling in this course, you assume responsibility for familiarizing yourself with the Academic Integrity Policy and the possible penalties (including suspension and expulsion) for violating the policy. Using ChatGPT or other AI to generate written work is also a violation of academic integrity, unless explicitly allowed by the instructor in a specific course. As per the policy, all suspected violations will be reported to the Office of Student Conduct. Academic dishonesty includes (but is not limited to):

1. Cheating
2. Plagiarism
3. Aiding others in committing a violation or allowing others to use your work
4. Failure to cite sources correctly
5. Fabrication
6. Using another person's ideas or words without attribution–re-using a previous assignment Unauthorized collaboration
7. Sabotaging another student's work

If in doubt, please contact me. Also review the Academic Integrity Policy and Academic Integrity Resources for Students. Use of external website resources (such as Chegg.com or others) to obtain solutions to homework assignments or exams is cheating and a violation of the University Academic Integrity policy. Cheating in the course may result in grade penalties, disciplinary sanctions or educational sanctions. Posting homework assignments or exams to external sites without the instructor's permission may be a violation of copyright and may constitute the facilitation of dishonesty, which may result in the same penalties as cheating.

The Rutgers honor pledge will be included on all major assignments for you to sign: *On my honor, I have neither received nor given any unauthorized assistance on this examination/assignment.*

Almost all original work is the intellectual property of its authors. This includes not just books and articles, but the syllabi, lectures, slides, recordings, course materials, presentations, homework problems, exams, and other materials used in this course, in either printed or electronic form. **You may not copy this work, post it online, or disseminate it in any way without the explicit permission of the instructor**. Respect for an author's efforts and intellectual property rights is an important value that members of the university community are expected to take seriously.

Student Wellness Services

Student Wellness Services

The university provides a number of resources to support your physical and mental well-being. Several valuable resources and listed here and you are encouraged to contact the Professor for more guidance about university resources.

- Student Success Essentials: https://success.rutgers.edu
- Student Support Services: https://www.rutgers.edu/academics/student-support
- The Learning Centers: https://rlc.rutgers.edu/
- Rutgers Libraries: https://www.libraries.rutgers.edu/
- Bias Incident Reporting: https://studentaffairs.rutgers.edu/bias-incident-reporting

- Dean of Students – Student Support Office: https://success.rutgers.edu/resource/dean-students-student-support-office
- Office of Veteran and Military Programs and Services: https://veterans.rutgers.edu
- Student Health Services: http://health.rutgers.edu/
- Counseling, Alcohol and Other Drug Assistance Program & Psychiatric Services (CAPS): http://health.rutgers.edu/medical-counseling-services/counseling/
- UWill: free immediate access to teletherapy; you can choose a therapist based on your preferences including issue, gender, language, ethnicity. http://health.rutgers.edu/uwill/
- Office for Violence Prevention and Victim Assistance: vpva.rutgers.edu/
- Office of Disability Services: https://ods.rutgers.edu/
- Basic Needs Assistance (food, housing, and other essentials): https://ruoffcampus.rutgers.edu/basic-needs
- Rutgers Student Food Pantry: https://ruoffcampus.rutgers.edu/food-pantry