OPTI 345: Quantum Mechanics and Optical Physics

M/W/F: 11:00 – 11:50 AM

Location: Meinel 422

Description of Course

This course will introduce students to the ideas and methods of quantum theory by building on their knowledge of waves from optics, and developing the tools needed for working with light and matter. After describing the underpinnings of quantum mechanics, some key examples will be worked out in detail including the quantum harmonic oscillator. The quantum theory of atomic structure will then be developed in detail to expose the student to some key techniques and notions for understanding atoms. Next, the interaction between light and matter is explored along with some basic paradigms for understanding optical physics, including Rabi oscillations, spontaneous emission, and the quantum theory of light. Finally, some topics in quantum information science will be explored by building on the basic notions of quantum theory introduced in the class.

Course Prerequisites or Co-requisites

Students must have advanced to at least their junior year and passed all Fall exams with at least a B grade in 210, or with permission of instructor.

Instructor and Contact Information

Kyle Seyler, GCRB 027, klseyler@arizona.edu

Office Hours: Fri 1-2pm (GCRB 027)

Course home page (D2L): https://d2l.arizona.edu/d2l/home/1701496

Course Format and Teaching Methods

Lecture only.

Course Objectives

1. Provide students with a basic background in quantum mechanics
2. Apply quantum theory to atomic structure and its classification
3. Study quantum aspects of light-matter interactions
4. Explore some topics in quantum information science

Expected Learning Outcomes

1. The student will become conversant with the notions of quantum mechanics as a wave theory of matter, and the postulates of quantum mechanics as a basis for applying quantum theory.
2. The student will be able to state and use the solutions of the infinite square well and quantum harmonic oscillator, problems that underpin many physical problems.
3. The student will become conversant with the quantum solutions for the hydrogen atom as a basis for describing and calculating atomic structure and the optical spectra of atoms.
4. The student will be able to use atomic structure to calculate the interaction between atoms and light as a basis for understanding optical physics phenomena such as Rabi oscillations, spontaneous and stimulated emission, and the quantized light field (photons).
5. The student will become familiarized with the basic notions involved in quantum cryptography, quantum information processing using quantum gates, and the idea of quantum algorithms and computers.

Absence and Class Participation Policy

The UA's policy concerning Class Attendance and Participation is available at: https://catalog.arizona.edu/policy/courses-credit/courses/class-attendance-participation.

The UA policy regarding absences for any sincerely held religious belief, observance or practice will be accommodated where reasonable, http://policy.arizona.edu/human-resources/religious-accommodation-policy.

Absences pre-approved by the UA Dean of Students (or Dean Designee) will be honored. See: https://deanofstudents.arizona.edu/policies/attendance-policies-and-practices

Required Texts or Readings

There are no required texts for the class. Class notes will be made available through the course webpage. Alternative reading sources will be referred to throughout the class and made available in the reading room and Science Library.

Required or Special Materials

Students should have access to MATLAB (or Python) and the capability to perform numerical calculations.

Assignments and Examinations: Schedule/Due Dates

The class shall include approximately 10 homework assignments, two in-class midterm exams, and a final exam.

Homework: Homework assignments will be posted on D2L at least 1 week in advance.

- *Due date*: Homework is generally due on Fridays at 11:59 PM and should be turned in on D2L.
- *Late policy*: Students are strongly encouraged to submit their homework on time to keep up with the course material. If the student notifies the instructor via email at least 48 hours before the deadline, they may request to reschedule their deadline. The new deadline must be within 4 days of the original deadline. No credit will be given for homework submitted after the relevant deadline.
- *Scoring*: Graded primarily based on completion. If you make a serious attempt to solve all problems, you receive full credit.
- *Solutions*: Solutions will be posted 5 days after the deadline (or earlier).

Final Examination or Project

The date and time of the final exam or project, along with a link to the Final Exam Regulations and Final Exam Schedule, https://registrar.arizona.edu/faculty-staff-resources/room-class-scheduling/schedule-classes/final-exams

Grading Scale and Policies

The final grade will be based on homework completion, in-class quizzes, two midterm exams, and a final exam.

Homework	20%
Midterm exam 1	25%
Midterm exam 2	25 %
Final exam	30%
Total	100%

The grade will be determined according to the cumulative percentage earned such that 90-100% = A, 80-89% = B, 70-79% = C, 60-69% = D, below 60% = E.

Incomplete (I) or Withdrawal (W):

Requests for incomplete (I) or withdrawal (W) must be made in accordance with University policy, which is available at https://catalog.arizona.edu/policy/courses-credit/grading/grading-system.

Scheduled Topics/Activities

The intended topics to be included are as follows:

1. Review of linear algebra
2. Introduction to quantum mechanics, wave/particle duality, uncertainty principle
3. Quantum mechanics of free and bound particles, wave packets
4. Schrodinger equation, wave functions, eigenvalue equations
5. Postulates of quantum mechanics
6. Measurements in quantum mechanics, expectation values
7. Quantum harmonic oscillator
8. Hydrogen atom, quantum mechanics of the real hydrogen atom
9. Dirac notation, matrix formulation of quantum mechanics
10. Spin angular momentum, Pauli exclusion principle
11. Optical physics, Hamiltonian for light/matter interaction
12. Electric dipole and rotating wave approximations
13. Two-level atom approximation, Rabi oscillations
14. Collisional decay and spontaneous emission, rate equations
15. Blackbody radiation, Einstein A and B coefficients
16. Steady-state absorption coefficient, saturation, optical properties of gases
17. Quantization of the electromagnetic field, number states, and vacuum field fluctuations
18. Jaynes-Cummings model for the interaction between a single-mode and a two-level atom
19. Photon number distributions, quantum collapses and revivals
20. Multi-mode quantum fields, Jones calculus, beam splitter, random number generator
21. Topics in quantum information, classical and quantum cryptography
22. Quantum key distribution using single photons or qubits
23. BB84 protocol, quantum security, quantum uncertainty as a resource
24. Quantum information processing, universal sets of classical and quantum gates
25. Quantum gates and their realization using polarization optics
26. Universal quantum computers, survey of quantum algorithms
27. Quantum primacy and the challenges of realizing quantum computers

The final exam date will be on the date set by the UA, and the midterms will approximately follow topics 10 and 18 above.

Classroom Behavior Policy

To foster a positive learning environment, students and instructors have a shared responsibility. We want a safe, welcoming, and inclusive environment where all of us feel comfortable with each other and where we can challenge ourselves to succeed. To that end, our focus is on the tasks at hand and not on extraneous activities (e.g., texting, chatting, reading a newspaper, making phone calls, web surfing, etc.).

Threatening Behavior Policy

The UA Threatening Behavior by Students Policy prohibits threats of physical harm to any member of the University community, including to oneself. See http://policy.arizona.edu/education-and-student-affairs/threatening-behavior-students.

Accessibility and Accommodations

At the University of Arizona, we strive to make learning experiences as accessible as possible. If you anticipate or experience barriers based on disability or pregnancy, please contact the Disability Resource Center (520-621-3268, https://drc.arizona.edu/) to establish reasonable accommodations.

Generative AI Policy

Use of AI on homework is permitted as long as proper acknowledgement is given. However, physics is often best learned by struggling through problem solving. I strongly recommend that you seriously attempt to solve every problem on your own without assistance first. If you rely on AI to generate answers you do not fully understand, the exams will likely be challenging. Use these tools to deepen your understanding, not to bypass the learning process.

If you use generative AI to help you complete a homework assignment, you must add a short "Acknowledgement" section at the end of your homework submission that states the model(s) (e.g., "ChatGPT 5.2") and how they were used (e.g., "AI Use: ChatGPT 5.2 helped identify a sign error in my derivation for Problem 3.")

Code of Academic Integrity

Students are encouraged to share intellectual views and discuss freely the principles and applications of course materials. However, graded work/exercises must be the product of independent effort unless otherwise instructed. Students are expected to adhere to the UA Code of Academic Integrity as described in the UA General Catalog. See: https://deanofstudents.arizona.edu/student-rights-responsibilities/academic-integrity.

Nondiscrimination and Anti-harassment Policy

The University of Arizona is committed to creating and maintaining an environment free of discrimination. In support of this commitment, the University prohibits discrimination, including harassment and retaliation, based on a protected classification, including race, color, religion, sex (including pregnancy), national origin, age, disability, veteran status, sexual orientation, gender identity, or genetic information. For more information, including how to report a concern, please see https://policy.arizona.edu/employment-human-resources/nondiscrimination-and-anti-harassment-policy

Additional Resources for Students

UA Academic policies and procedures are available at http://catalog.arizona.edu/policies

Campus Health
http://www.health.arizona.edu/
Campus Health provides quality medical and mental health care services through virtual and in-person care.
Phone: 520-621-9202

Counseling and Psych Services (CAPS)
https://health.arizona.edu/counseling-psych-services
CAPS provides mental health care, including short-term counseling services.
Phone: 520-621-3334

The Dean of Students Office's Student Assistance Program
https://deanofstudents.arizona.edu/support/student-assistance
Student Assistance helps students manage crises, life traumas, and other barriers that impede success. The staff addresses the needs of students who experience issues related to social adjustment, academic challenges, psychological health, physical health, victimization, and relationship issues, through a variety of interventions, referrals, and follow up services.
Email: DOS-deanofstudents@arizona.edu
Phone: 520-621-7057

Survivor Advocacy Program
https://survivoradvocacy.arizona.edu/
The Survivor Advocacy Program provides confidential support and advocacy services to student survivors of sexual and gender-based violence. The Program can also advise students about relevant non-UA resources available within the local community for support.
Email: survivoradvocacy@arizona.edu
Phone: 520-621-5767

Safety on Campus and in the Classroom

For a list of emergency procedures for all types of incidents, please visit the website of the Critical Incident Response Team (CIRT): https://cirt.arizona.edu/case-emergency/overview

Also watch the video available at https://arizona.sabacloud.com/Saba/Web_spf/NA7P1PRD161/common/learningeventdetail/crtfy0000000000003560

Subject to Change Statement

Information contained in the course syllabus, other than the grade and absence policy, may be subject to change with advance notice, as deemed appropriate by the instructor.