OPTI 549: Atom Optics

Graduate Course Syllabus

Semester and Year this Syllabus Covers

Spring 2024 to present (this syllabus remains in effect until replaced)

Course Number and Title

OPTI 549: Atom Optics

Course Description

This course presents an introduction to experiments and theoretical concepts of atom optics and matter-wave optics in order to develop a better understanding the wave nature of matter and the similarities and differences between the physics of light and matter. In atom and matter-wave optics studies, the wave-like properties of matter are emphasized and may be utilized for the manipulation and control of states of matter (often by laser light), and are centrally important for an understanding of physics at the atomic level and for modern quantum optics applications. This course will primarily cover foundational and groundbreaking ideas and experimental results related to the wave nature of matter, beginning with the early development of quantum mechanics. An emphasis will be placed on reading, evaluating, and discussing published scientific papers. Throughout the course, links between conventional optics, quantum optics, and the wave nature of matter will also be discussed. This course will be suitable for students who have covered the formalism of quantum mechanics, atomic structure, and light-matter interaction in a graduate-level quantum mechanics course. Prereq: OPTI 570 or equivalent. Strongly recommended: OPTI 544 (previous or concurrent enrollment).

Instructor Information

Instructor: Prof. Brian Anderson and Prof. Ewan M. Wright
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Course Format

OPTI 549 involves required reading assignments (a few papers, typically published journal articles), and some preparation of brief summaries of the main points of articles read. Students will be expected to fully participate in classroom discussions about the articles. Class time will be focused on

- discussing and explaining the topics covered in the articles
- discussion of concepts that are unclear or difficult to understand
- working through some of the technical details and physics covered in the articles
- discussion of material and applications not covered in directly in the articles
- discussing the broader contexts into which the articles fall

Prerequisites

A graduate-level course in quantum mechanics is the only prerequisite. Discussions will involve concepts covered in a formal mathematics-based treatment of quantum mechanics, including terminology, and an understanding of atomic structure will be important for proper interpretation of papers covered in the second half of the semester. A graduate-level course in quantum optics (concurrent or previous) is strongly recommended.

Permissions

The instructor's permission is needed to take this class for students who have not taken a previous graduate-level quantum mechanics course with a grade of A or B.

Learning Outcomes

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

- be able to more efficiently read, interpret, and discuss scientific journal articles
- have developed an understanding of important elements of technical writing to include in articles and proposals
- be able to interpret and assign physical meaning to the notation and symbols of quantum mechanics based on realistic, experimental contexts, and to discuss such meaning with others
- better understand the timeline of historical progress in science, and in quantum mechanics fields specifically, and see how an understanding of such progress can be beneficial to their own scientific careers

Required Texts and Materials

Required: There are no required textbooks. All required reading materials will be provided in the form of articles and handouts posted online via D2L.

Schedule of Topics and Activities

The schedule of topics covered will be loosely based on the sequence of topics below. Depending on how class discussions go, our timing and choice of topics to cover may be modified.

A. **Concepts and Foundations *(~3 weeks)***

1. Beginnings and Photons
2. Planck and Einstein
3. deBroglie's relations
4. Bose and Einstein (again, or still?)
5. Schrodinger's equation
6. The first matter-wave experiments and their limitations

B. **Enabling technologies *(~2 weeks)***

1. Development of our understanding of light and of the laser
2. Review of the 2-level atom
3. Light forces on real atoms
4. Magnetic forces on atoms
5. Atom cooling and trapping

C. **Linear Atom Optics and Atom-optical elements*. (~4 weeks)***

1. The Schrodinger equation revisited
2. Atom-optical lenses: collimation and focusing
3. Atom diffraction
4. Atom-optical mirrors
5. Atom traps and cavities

Additional reading and discussion topics will be selected from the following list:

6. Optical Lattices
7. Atom waveguides
8. Atom and molecule interferometry
9. Atom holography

D. **Quantum and Nonlinear Atom Optics*. (~4 weeks)***

1. Bose-Einstein condensation: the matter equivalent of laser light
2. Atomic interactions
3. Nonlinear Schrodinger Equation

Additional reading and discussion topics will be selected from the following list:

4. Phase imprinting
5. Bragg diffraction
6. Atom lasers
7. Matter-wave solitons
8. Angular momentum and quantized vortices
9. Nonlinear wave mixing and matter-wave amplification
10. Squeezed states

E. **Advanced and related concepts *(~2 weeks)***

Grading Scale and Policies

Each student's final course grade will be based on attendance and class participation (50%), project 1 (20%), and project 2 (30%). Project 1 will be a mid-semester review of brief notes/summaries of some of the papers assigned, and a discussion with the course instructors regarding progress in learning outcomes and feedback to the student, as will be described in more detail on the first day of class. Project 2 will consist of either (1) summaries of papers for the remainder of the semester, or (2) a detailed report of a few papers not covered in class, or (3) a short (approx. 5 minute) class presentation covering a few papers not discussed in class. Additional details will be covered in class. Grades will be mostly based on effort to do good work and to participate in the activities of the class. Since attendance and participation is so crucial to this course, students will be expected to inform the instructors of absences ahead of time, and excessive absence (30% or more of lectures missed) may result in either a grade of C or lower, or additional work assigned to earn a grade of A or B.

Attendance and Participation Policies

OPTI 570 follows the Class Attendance and Participation Policies described at https://www.optics.arizona.edu/osc-students/grading-attendance-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