Fall 2025 **Syllabus**

Physics 430 / Physics 631: Quantum Optics & Atomics

TTh 12:30-13:50 pm in Small Hall room 122

Undergraduate pre/co-requisites: PHYS 313 and 314 (Intro to Quantum Physics)

Instructors

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Course Objectives

The primary purpose of this course is to teach the basic physics, theory, current research topics, and applications of Atomic Physics and Quantum Optics.

a. Topics:

The course will cover the following topics:

- Classical and quantum coherence.
- 2-level atoms, atom-light interactions, Bloch sphere.
- Spontaneous emission, decoherence.
- Schrödinger equation, density matrix, quantum Monte Carlo.
- Angular momentum of light and atoms.
- Multi-level quantum systems.
- Laser cooling and trapping.
- Quantum theory of light, dressed atoms, squeezing.
- Bose-Einstein condensation, degenerate Fermi gases.
- Spin squeezing, entanglement.
- Grad: Quantum information, quantum Fourier transform (Shor's alg.)

b. Demonstrations

An important objective of the course is the experimental demonstration of course concepts and theory with in-class and research lab proof-of-principle experiments. Demonstration topics will include laser cooling and trapping, Doppler broadening, saturation spectroscopy, spatial and temporal coherence, particle behavior of light, etc ...

c. Scientific Articles

A central component of the course is the reading and writing of scientific articles. Roughly every week, we will read a historically important physics paper that shows the discovery of an important physics idea, so that you can develop the ability to distill its essential physics. **Graduate student readings will cover additional course materials. At the end of the course, undergraduate students will write a term paper in the form of a scientific article.**

Course Materials

There is no official textbook for the course. The lecture notes will be based on original physics papers and the following texts:

Cold Atoms and Molecules, edited by M. Weidemüller and C. Zimmerman
Laser Cooling and Trapping, by H. J. Metcalf and P. van der Straten
Quantum Theory of Light, by R. Loudon
Optical Coherence and Quantum Optics, by L. Mandel and E. Wolf
Atomic Physics, by C. Foot
Bose-Einstein Condensation in Dilute Gases, by C. J. Pethick and H. Smith
Quantum Mechanics, by C. Cohen-Tannoudji, B. Diu, F. Laloë
Atomic Physics, by D. Budker, D. F. Kimball, and D. P. DeMille
Introduction to Quantum Optics, by G. Grynberg, A. Aspect, and C. Fabre

Quantum and Atom Optics, by D. Steck
https://atomoptics.uoregon.edu/~dsteck/teaching/quantum-optics/quantum-optics-notes.pdf

Evaluations

Your final grade for the course will be determined from the following grading weight distribution:

Undergraduate students

Problem sets:	30%
Participation:	10%
Midterm:	25%
Final paper:	**20%**
Oral presentation:	**15%**

Graduate students

Problem sets:	35%
Participation:	10%
Midterm:	25%
Final Exam:	**30%**

Problem sets: The problem sets are the main evaluation of learning for the course and also serve as significant means of learning the material. At the undergraduate level, the problem sets will serve primarily to review material seen in class and will not go too far beyond the classroom material. **Graduate students will do the same problem sets as the undergraduate students, but with one or two additional harder problems each week.**

Participation: The classroom presentation of course material will involve a significant amount of in-class discussion. All students are expected to participate in these discussions, since they will help elucidate the course material. Participation also reflects class attendance.

Midterm: The midterm will cover course material from the first half of the course. It is the only undergraduate examination of the course.

Final paper and oral presentation (undergraduates only): Undergraduate teams of 2 will write a final paper presenting an atomic physics or quantum optics calculation and its context. The paper will have a maximum length of 4 single space pages in the format of an article in *Physical Review Letters*. Each student team will also make a 20-30 minute oral presentation of their calculation and its context.

Final exam (graduate students only): Graduate students will take a final exam covering all course topics.

E-mail policy

Feel free to communicate with S. Aubin or M. Jamil via e-mail. We cannot guarantee that we will read e-mails sent in the evening until the next day.

Student Accessibility Services

William & Mary accommodates students with disabilities in accordance with federal laws and university policy. Any student who feels that's/he/they may need an accommodation based on the impact of a learning, psychiatric, physical, or chronic health diagnosis should contact Student Accessibility Services staff at 757-221-2512 or at sas@wm.edu to determine if accommodations are warranted and to obtain an official letter of accommodation. For more information, please see www.wm.edu/sas.

Honor Code (from W&M website)

William & Mary has had an honor code since at least 1779. Academic integrity is at the heart of the university, and we all are responsible for upholding the ideals of honor and integrity. The student-led honor system is responsible for resolving any suspected violations of the Honor Code, and I will report all suspected instances of academic dishonesty to the honor system. The Student Handbook (www.wm.edu/studenthandbook) includes your responsibilities as a student. Your full participation and observance of the Honor Code is expected. To read the Honor Code, see www.wm.edu/honor.

Academic dishonesty includes cheating, plagiarism, unauthorized collaboration, and the use of unauthorized materials and artificial intelligence systems (e.g., ChatGPT).

Important academic deadlines

Add/drop deadline: Monday, September 8, 2025
Withdraw deadline: Monday, October 27, 2025

Weekly Schedule (tentative)

Week 0: 8/28 **Intro to Atomic Physics and Quantum Optics**
Introduction to atom-light interactions, semi-classical atomic physics.

Week 1: 9/2-4 **Coherence**
Interference, first and second order coherence, correlation functions.

Week 2: 9/9-11 **Quantum atomic physics: 2-level atoms**
2-level systems, Rabi Flopping, Bloch sphere, Landau-Zener transitions.

Week 3: 9/16-18 **AC Stark shift**
Dressed atom picture, optical dipole trapping, optical tweezers.

Week 4: 9/23-25 **Density Matrix**
Decoherence, spontaneous emission, optical Bloch equations.

Week 5: 9/30-10/2 **Monte Carlo numerical methods**
Classical Monte Carlo, Quantum Monte Carlo, quantum jumps.

Week 6: 10/7 **Multi-level atoms**
Selection rules, fine and hyperfine structure, Zeeman effect, Rydberg atoms.

------------------------------- Fall Break --------------------------------

Week 7: 10/14-16 **3-level atoms**
Saturation spectroscopy, electromagnetically-induced transparency.

Week 8: 10/21-23 **Laser cooling and trapping I**
Doppler cooling, optical molasses, Sisyphus cooling.

Week 9: 10/28-30 **Laser cooling and trapping II**
Resolved sideband cooling of ions, magnetic trapping, RF evaporation.

Week 10: 11/4-6 **Photons I: Quantization of the electromagnetic field**
Introduction to field theory: quantization of the electromagnetic field.

Week 11: 11/11-13 **Photons II: Quantization of the electromagnetic field**
Atom-photon interactions, photon squeezing, Casimir force.

Week 12: 11/18-20 **Quantum gases**
2nd quantization of QM, atom interactions, Bose-Einstein condensation, Thomas-Fermi.

------------------------------- Thanksgiving Break --------------------------------

Week 13: 11/25 **Atom interferometry & quantum sensing**
Superpositions of position and momentum states, atomic shot noise. **Draft due on 11/25.**

Week 14: 12/2-4 **Spin squeezing & quantum information**
Heisenberg limit, spin squeezing, entanglement, quantum Fourier transform. **Undergraduate oral presentations on 12/2. Final papers due on 12/4.**

December 11, 2025, 9 am-noon **Final Exam (graduate students only)**