Spring 2011 **Syllabus**

Physics 404 / Physics 690-3: Atomic Physics and Quantum Optics

MWF 1:00-1:50 pm in Millington Hall room 123

Undergraduate prerequisites: PHYS 313 and 314 (Intro to Quantum Physics)

Instructor

Prof. Seth Aubin
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Office hours: Thursday, 5-6 pm.

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.

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. At the end of the course, you 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 base 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

Evaluations

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

Undergraduate students

Problem sets:	40%
Participation:	10%
Midterm:	15%
Final paper:	20%
Oral presentation:	15%

Graduate students

Problem sets:	50%
Participation:	10%
Midterm:	15%
Final Exam:	25%

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 problem each week. For the undergraduates, if you hand in all problem sets, then I will drop the one with the lowest grade.

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. ***The instructor expects that undergraduate seniors who have applied for employment and graduate schools will need to be absent for several classes in order to visit prospective graduate schools and employers. Please notify the instructor as early as possible prior to these absences.***

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 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.

Weekly Schedule

Week 0: 1/19-21 **Intro to Atomic Physics**
Introduction to atom-light interactions, semi-classical atomic physics.

Week 1: 1/24-28 **Coherence**
Interference, first and second order coherence, correlation functions.

Week 2: 1/31-2/4 **Quantum atomic physics: 2-level atoms**
2-level systems, Rabi Flopping, Bloch sphere, Landau-Zener transitions.

Week 3: 2/7-11 **AC Stark Shift**
Dressed atom picture, optical dipole trapping, optical tweezers.

Week 4: 2/14-18 **Density Matrix**
Decoherence, spontaneous emission, optical Bloch equations.

Week 5: 2/21-25 **Monte Carlo numerical methods**
Classical Monte Carlo, Quantum Monte Carlo.

Week 6: 2/28-3/4 **Multi-level atoms**
Selection rules, fine and hyperfine structure, Zeeman effect.

------------------------------- Spring Break --------------------------------

Week 7: 3/14-18 **3-level atoms**
Saturation spectroscopy, electromagnetically-induced transparency.

Week 8: 3/21-25 **Laser Cooling and Trapping I**
Doppler cooling, optical molasses, Sysiphus cooling.

Week 9: 3/28-4/1 **Laser Cooling and Trapping II**
Resolved sideband cooling of ions, magnetic trapping, RF evaporation.

Week 10: 4/4-8 **Photons I: Quantization of the Electromagnetic Field**
Introduction to field theory: quantization of the electromagnetic field.

Week 11: 4/11-15 **Photons II: Quantization of the Electromagnetic Field**
Atom-photon interactions, photon squeezing, Casimir force.

Week 12: 4/18-22 **Bose-Einstein Condensation I**
2nd quantization of QM, atom-atom interactions, Bose-Einstein condensation. Final papers due on 4/22. Undergraduate oral presentations.

Week 13: 4/25-29 **Bose-Einstein Condensation II**
Gross-Pitaevskii equation, Thomas-Fermi, vortices, Bogoliubov excitation spectrum.

May 5, 2011, 2-5pm **Final Exam (graduate students only)**