PHY 446 Atomic and Molecular Physics
Lehigh University, Spring 2022

Instructor: Ariel Sommer
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Office hours: by appointment (please email)
Class: MW 4:25 – 5:40 pm, Lewis 512

Description:
This course will cover the structure of atoms and their interactions with electromagnetic fields. Atomic physics has a wide range of applications, from interpreting astrophysical spectra, to designing lasers and atomic clocks, building quantum computers, and testing quantum mechanics.

Textbooks (with links to eBooks from Lehigh library and Open Access books)
Primary:
1. C.J. Foot, *Atomic Physics*, Oxford, 2005

Additional references:
1. Fox, *A Student's Guide to Atomic Physics*, Cambridge, 2018
2. Bransden and Joachain, *Physics of Atoms and Molecules* (2nd Ed), Prentice Hall, 2003
3. Cohen-Tannoudji, Dupont-Roc, and Grynberg, *Atom-Photon Interactions*, Wiley, 1998.
4. D.A. Steck, *Quantum and Atom Optics* (Open Access; http://steck.us/teaching)
5. Van der Straten and Metcalf, *Atoms and Molecules Interacting with Light*, Cambridge, 2016

Grading format:
- Homework (50%)
- Midterm (20%): tentatively scheduled for Wed, Mar 23
- Final project (30%)

Homework policies: You may work together on the homework, but make sure that you are able to complete the problems on your own. The work you turn in must be your own. Homework should be turned in on time. Please contact me if you would like to request an extension due to illness or other circumstances.

Final Project: Instead of a final exam, you will explore a topic in atomic, molecular, and optical physics of your choosing. You will write a paper (about 4 pages) and give a presentation with slides (10-15 minutes). The topic can be a current research area or a fundamental topic not covered in class. I encourage you to choose a topic that connects your research area to the course material.

Tentative dates:
Wed, March 9: Topic proposal due
Mon, April 4: Annotated bibliography due
Mon, April 18: Draft of first half of paper due
Wed, April 27: Final paper due
Mon/Wed, May 2/4: Final presentations

Course Outline

1. Atomic structure
    a. Overview of atomic structure
    b. Hydrogen atom and relativistic corrections
    c. Multi-electron atoms
        i. Electron correlation
        ii. Spin-orbit coupling
        iii. LS coupling and Hund's rules; jj coupling
    d. Atoms in static magnetic and electric fields
2. Atom-light interactions
    a. Magnetic resonance
    b. Atom-light interaction Hamiltonian
    c. Quantization of the electromagnetic field
    d. Spontaneous emission
    e. Weak monochromatic light, single-photon transitions
        i. Absorption
        ii. Phase shift
        iii. Radiation force
        iv. AC Stark shift
    f. Strongly driven two level systems
        i. Optical Bloch equations
        ii. Saturation
3. Atomic ensembles
    a. Doppler broadening and saturated absorption spectroscopy
    b. Radiation pressure and laser cooling

Learning Outcomes:

After completing the course, students will be prepared to carry out research in the field of atomic, molecular, and optical physics and related areas. Particular skills gained include:

- Predict the ground state electron configuration and angular momentum quantum numbers of a given atom or ion
- Calculate the energy levels of atoms in static electric and magnetic fields
- Predict the allowed dipole transitions of an atom using selection rules
- Relate light polarization to components of tensor operators for dipole transitions
- Understand spontaneous emission
- Expand the atom-light interaction Hamiltonian as a multipole expansion
- Calculate the absorption and refractive index near an optical resonance
- Understand dipole force and radiation pressure force of light on atoms/molecules
- Predict the time-evolution of a two-level quantum system interacting with radiation
- Describe fluorescence and saturation using optical Bloch equations
- Distinguish between homogeneous and inhomogeneous broadening
- Understand magnetic resonance techniques including spin echo and Ramsey spectroscopy and applications to atomic clocks

- Understand Doppler broadening, hole burning, and applications to Doppler-free spectroscopy

Accommodations for Students with Disabilities: If you have a disability for which you are or may be requesting accommodations, please contact both your instructor and the Office of Academic Support Services, Williams Hall, Suite 301 (610-758-4152) as early as possible in the semester. You must have documentation from the Academic Support Services office before accommodations can be granted.

The Principles of Our Equitable Community: Lehigh University endorses The Principles of Our Equitable Community [http://www.lehigh.edu/~inprv/initiatives/PrinciplesEquity_Sheet_v2_032212.pdf]. We expect each member of this class to acknowledge and practice these Principles. Respect for each other and for differing viewpoints is a vital component of the learning environment inside and outside the classroom.