Spring 2024, Phys 721: Atomic and Optical Physics

Instructor: Nathan Schine, PSC 2160, nschine@umd.edu

Room and Time: Toll Physics 4221, Tuesday/Thursday 2:00-3:15. Office hours PSC 2160 or PSC 2148 (depending on attendance) Mondays and Fridays 9:30-10:30 am, with some exceptions.

Course Goals: This course is a broad survey of atomic and optical physics. The content is divided into three main sections focusing on 1) the quantum description of light, 2) atomic structure, and 3) light-matter interactions.

Course Format: This is a lecture-based class for which **in-person attendance is expected**. There is no single textbook for this course (see below), so **your notes taken in class** (or copied from a friend if you are absent) will be your primary reference material.

Grading Policy: Your final grade will be composed of problem sets (40%), class participation (15%), midterm (20%), and final project (25%). The conversion between numerical and letter grades will be determined in response to performance.

Homework Policy:

a) Problem sets will be posted weekly and should be handed in at the beginning of the class in which they are due. Late problem sets will **not** be accepted. Extensions will be granted on a case-by-case basis and only if arranged well ahead of time. *As soon as you know you need an extension, please request it*.
b) Problem set solutions should show all necessary steps and be clearly explained and presented. Students with poor handwriting may need to deliberately rewrite or typeset their solutions using LaTeX.
c) Various problems may require the use of a computer. If you do not know how to approach writing code to accomplish a task, there are many suitable online resources. You can also contact me for advice. I encourage you to use these tools to your advantage, but any use should be noted and any non-trivial and relevant code included in your solutions. I may ask you to email me your code if needed for grading. Mathematica is preferred and python is acceptable.
d) Expect to spend at least 10-15 hours per problem set. If you are spending significantly longer than this, talk with me to discuss strategies for more efficient work.
e) Come to office hours, it will be helpful!

Collaboration Policy: I anticipate ***and strongly encourage(!)*** that you will work together on problem sets. Productive collaboration is an important part of science, and for most questions you should ask a peer before asking me. However, **all work you turn in should be your own**, and all collaborators should be acknowledged. Copying work from any source will result in no credit for all involved.

> Here's what this means in practice: I want you to work together on problem sets and if you come to me having spent a lot of time working by yourself stuck on a problem, my first response will be 'did you ask a peer?'. Working together can result in a peer developing the key idea to solve a problem. You can then write up the solution based on *your* understanding that you developed in conversation with your peer, and write at the top of the solution that you worked with them on the question. It is not acceptable to copy your peers' solution directly or to work with your peer to prepare a single 'joint' solution set.

Communication is key! If you need an accommodation for a religious observance, due to sickness or a personal or family emergency, or a disability, contact me as early as possible, and I will work with you to find a solution.

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Course Content: The course will cover the following topics, time permitting, and according to the interests of the class.

Light (7 lectures):

- Quick review of E&M, modes, momentum, Poynting vector
- Quantization of the electromagnetic field
- Classical theory of coherence, correlation functions
- Quantum theory of coherence, Hanbury Brown and Twiss
- Quantum measurement of light, photon counting, homodyne and heterodyne
- Coherent states, squeezing, Hong Ou Mandel

Atomic structure (7 lectures):

- Spectroscopic notation
- Review of Hydrogen, fine structure, Lamb shift
- Multi-electron atoms with a focus on Helium, Central field approximation, Hartree-Fock, Addition of angular momenta, Clebsch-Gordon coefficients, Wigner-Eckhart theorem
- Effect of the nucleus, hyperfine structure
- Atoms in static DC magnetic and electric fields (Zeeman and Stark effects)

Atom-light interactions (12 lectures)

- Two-level atoms, Einstein A & B coefficients, Rabi oscillations, the Bloch sphere, bare states vs dressed states, AC Stark effect, adiabatic rapid passage and Landau-Zener processes
- Spontaneous emission: Fermi's golden rule and Wigner-Weisskopf
- Review of density matrices, Lindblad master equations, optical Bloch equations
- The saturation parameter, resonance fluorescence: the Mollow triplet
- Multi-level atoms, spherical tensors, polarization and dipole radiation pattern, Wigner 6J symbols
- Atomic polarizability: scalar, vector, and tensor
- Selection rules, higher order processes
- Nonlinear responses and multilevel atoms: Kerr effect, optical pumping, Raman transitions, electromagnetically induced transparency, 4-wave-mixing
- Cavity QED

Atomic motion in light fields (2 lectures)

- Doppler cooling
- Sub-doppler cooling

Text: This course will not use a specific textbook. Instead it will draw from a variety of sources.

For those looking for a more unified foundation

- Atomic Physics [Foot]
- Quantum Optics [Fox]

are two well-written advanced undergraduate textbooks which cover the foundations of the course material.

- Quantum and Atom Optics [Steck, online and unpublished] is a graduate-level textbook which is an excellent resource for going beyond the level of the two advanced-undergraduate texts above.

Additional references are:

- Quantum Optics [Scully & Zubairy]
- The Quantum Theory of Light [Loudon]
- Physics of Atoms and Molecules [Bransden and Joachain]
- Atom-Photon Interactions [Cohen-Tanoudji, Dupont-Roc, Grynberg]
- Laser Cooling and Trapping [Metcalf and van der Straten]