Course Syllabus

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Ph/APh 137a: Atoms and Photons
Course Syllabus – Fall 2021
Physics/Applied Physics, California Institute of Technology

Course Instructor

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Course Description

This course will provide an introduction to the interaction of atomic systems with photons. The main emphasis is on laying the foundation for understanding current research that utilizes cold atoms and molecules as well as quantized light fields. First term: resonance phenomena, atomic structure, and the semi-classical interaction of atoms with static and oscillating electromagnetic fields. Techniques such as laser cooling/trapping, coherent manipulation and control of atomic systems.

Prerequisites: Graduate level quantum mechanics, Ph 125 ab or equivalent. We will use angular momentum algebra rather extensively, so quantum mechanics at the Ph 12b level by itself will not be quite enough. It is okay if you are not comfortable with quantum mechanical angular momentum (this course will give you lots of experience and practice!) but if you have not encountered it at all then it might come on a little strong.

Learning Outcomes

By the end of this course, you will be able to:

- Describe the features of coherent quantum systems and their interactions with external perturbations, especially electromagnetic fields.
- Understand atomic structures, along with their physical origins and their effects on properties, spectra, and interactions.
- Relate the response of atoms in static fields to their response in alternating fields, such as lasers and microwaves, and understand how they can be probed and controlled through those means.
- Apply these concepts to understand contemporary research techniques such as laser cooling and trapping, and the science goals that they enable.

Flexibility and Support

This term is wacky! Accordingly, we will be very flexible on our end about all aspects of the course. We appreciate your patience as we navigate this brave (but hopefully temporary) new world.

We intend the course to be challenging but fun, and do not want to compound your stress on top of everything that is going on. Please do not hesitate to reach out if you have any concerns or need any help.

Feedback

You are always welcome to give candid, honest feedback directly to anybody involved in teaching this course. There will also be a formal opportunity to submit feedback around the midterm period. If you prefer an anonymous way to submit feedback, you may use this form: **https://forms.gle/BMUpGABpuZFjNhqs8 (https://forms.gle/BMUpGABpuZFjNhqs8)**

Suggested Books

There are no required books, but here are some to which I will refer often and should be on reserve in the library. Suggested readings, including excerpts from texts, will be posted with the lecture materials. *The first two books will be especially useful for the problem sets*.

- Foot, *Atomic physics*. Good introductory overview, rather inexpensive.
- Budker *et al.*, *Atomic physics*. Not introductory; amazing conceptual discussions.
- Steck, *Quantum and Atom Optics*. Great book, available for free at *http://steck.us*
- Fox, *A Student's Guide to Atomic Physics*. Good introductory overview.
- Weiner and Ho, *Light-matter interaction*. Good, short, introductory overview.
- Metcalf and Van der Straten, *Laser cooling and trapping*. Standard text for atom trappers.
- Metcalf and Van der Straten, *Atoms and Molecules Interacting with Light*. New version of above.

Course Website

All course resources will be posted on Canvas. All course updates and information, including lecture notes, reminders, announcements, etc. will be posted on the page **Weekly Lectures and Updates** under "Modules." We will also use the "Calendar" feature to show due dates, office hours, etc.

Assessment Rubric

Final grades are weighted as 80% problem sets, 20% presentation. We will drop the lowest 12.5% of your problem set points in computing your final grade, but problem sets will still contribute at most 80% of your final grade, according to the following formula:

$$Final\,\% \;=\; 80\% \times Min\left[\frac{Earned\ problem\ set\ points}{87.5\% \times Possible\ problem\ set\ points}, 100\%\right] + 20\% \times \frac{Earned\ presentation\ points}{Possible\ presentation\ points}$$

Minimum grade percentage cutoffs are below. Curves will only be used to increase grades. A grade of D or higher is required to pass the class.

A+	A	A-	B+	B	B-	C+	C	C-	D+	D	F
99	96	92	88	84	80	76	72	68	64	60	<60

Problem Sets

A total of 8 weekly sets, each weighted equally (even if their individual total point values are different). Collaboration is strongly encouraged; see below for details. Please submit the sets using the "Assignments" system on this page. We will not accept physical copies of the homework, but you are free to scan pieces of paper to upload.

The sets will be due on each Thursday before class, with the first set due October 7. There will not be a set due during the week of Thanksgiving (November 25). Due dates can be viewed on the "Assignments" or "Calendar" pages.

Collaboration Policy

Short version: Open everything (really) except for old solution sets. All work must be your own, and you must indicate what/whom you consulted.
Longer version: You are free to consult any textbooks, online resources, people, and so on. This includes things like solution sets and course notes for courses at Caltech and other institutions, online forums, etc. However, everything submitted must be your own work that you understand and show, and you must indicate any resources/people/etc. that you consulted. Include printouts of any computer code that you used. The only exception to the "open everything" rule is that you may not view solution sets for the previous offerings of this course (including the old course number, Ph 103)

Final Presentation

Students will research a topic of their choosing (to be decided later) and present their findings to the class, in the spirit of a journal club. Details and logistics to be decided as we approach the end of the course.

Extensions

Extensions will be granted only for health, family, emergency, or religious reasons. Lots of other homework, preparing for ditch day, *etc*. do not count, but you should always contact us or the deans if you are having trouble. In lieu of extensions, we will drop 12.5% of the homework (equivalent to a full set) as described above.

Course Schedule

All course materials will be posted under the **Weekly Lectures and Updates** module. The "Calendar" contains dates and times for lectures, assignment due dates, and office hours.

Approximate Course Outline

Feel free to suggest additional topics that you would like to see on the list.

Two-level systems and resonance. Classical and quantum magnetic resonance, rotating frames.

Atomic structure. Hydrogenic atoms, electronic structure, fine and hyperfine structure, multi-electron atoms.

Atoms in static fields. Zeeman and Stark effects, angular momentum coupling.

Atoms in alternating fields. Einstein A and B coefficients, dipole approximation, Optical Bloch Equations, saturation, cross-sections, broadening, M1/E2 transitions.

Cooling and trapping. Laser cooling, laser slowing, magneto-optical trapping, dipole trapping, magnetic/electric trapping.

More complex systems. Raman transitions, adiabatic elimination, atomic clocks, STIRAP, EIT/CPT, fundamental symmetry violations and searches for new physics, optical lattices, and synthetic quantum matter.

Academic Integrity

Caltech's Honor Code applies to all aspects of this course: "No member of the Caltech community shall take unfair advantage of any other member of the Caltech community."

Inclusion

Everyone is welcome in this class and at Caltech, and everyone is responsible for creating a welcoming environment. Please contact us with any concerns, or if any accommodations are needed. There are additional resources listed on the **Caltech Resources** page.

Getting Help

If you need any help with anything, contact Nick, Chandler, or Yi. Additionally, there are a large number of resources listed on the **Caltech Resources** page, including those concerning disability accommodations, wellness, counseling, writing assistance, discrimination, inclusion, and more.