PHYS 495/595: Special Topics in Physics: Quantum Atomic & Optical Physics

Winter 2018
Lecture B04
M W F 13:00 - 13:50
CCIS L1-029

Instructor: Dr. Lindsay J. LeBlanc
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Recommended Texts: Christopher J. Foot, Atomic Physics (Oxford University Press, 2005).
Mark Fox, Quantum Optics: An Introduction (Oxford University Press, 2006).

Scully and Zubairy, Quantum Optics (Cambridge, 1997).

Course website: All course material will be made available online via eClass.

Office Hours: TBD

Evaluation: Assignments 30% (≈ 6)
Midterm examination 25%
Final examination 45%

Course description
Introduction to quantum atomic and optical physics, with a focus on the quantum light-matter interaction. Topics include: a detailed study of the two-level problem using both semiclassical and quantum optics (Rabi flopping, AC Stark shift, optical Bloch equations); the fundamentals of atomic structure (fine, hyperfine, Zeeman interactions); quantization of the electromagnetic field (Jaynes-Cummings model, quantum states of light); applications to current research topics (laser cooling and trapping, cavity QED, quantum information). Prerequisite: Phys 472 or Phys 511 or equivalent.

Prerequisites
PHYS 472 or 511 or equivalent
It is important to prepare yourself for this course through a review of the prerequisite material. Students who do not have the required prerequisites at the time of taking this course should not expect supplementary professorial tutoring from the instructor. Topics to review include:

Course objectives
By the end of the course, students should be able to:

- Understand the basic electronic structure of atoms, including the fine, hyperfine and Zeeman effects
- Be able to use selection rules to determine which transitions can be made between different electronic levels
- Understand the semiclassical light-matter interaction for a two-level system and derive the Rabi oscillation from the Schrödinger equation
- Apply the results of semiclassical light-matter interactions to various applications including lasers, laser cooling, and optical trapping
- Understand the quantum nature of light, and when the photon description is appropriate
- Understand why and how optical cavities are used to increase the atom-light interaction
- Describe the basic advantages of quantum information applications, especially their optical implementations.
Proposed Syllabus

This schedule is subject to change; we may add or drop topics depending on time and interest. There is likely too much to cover listed here, but this is the aspiration.

<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
<th>Text</th>
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<tbody>
<tr>
<td>8-Jan-2018</td>
<td>Introduction, review outline, establish notation</td>
<td>Fox Ch. 3</td>
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<td></td>
<td><strong>Section 1: Atomic Physics</strong></td>
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<tr>
<td>10-Jan-2018</td>
<td>Review hydrogen atom: angular and radial integrals</td>
<td>Foot Ch. 2.1, 2.2</td>
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<td>12-Jan-2018</td>
<td>Hydrogen atom: level transitions, selection rules</td>
<td>Foot Ch. 2.2</td>
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<td>15-Jan-2018</td>
<td>Hydrogen atom: fine structure, spin-orbit coupling</td>
<td>Foot Ch. 2.3</td>
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<td>17-Jan-2018</td>
<td>Helium: brief overview of how to solve, fine structure</td>
<td>Foot Ch. 3</td>
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<tr>
<td>19-Jan-2018</td>
<td>Other atoms (esp. alkalis): brief overview of how to solve, fine structure</td>
<td>Foot Ch. 4</td>
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<td>22-Jan-2018</td>
<td>L-S coupling scheme</td>
<td>Foot Ch. 5.1 - 5.3</td>
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<tr>
<td>24-Jan-2018</td>
<td>Zeeman splitting, more selection rules</td>
<td>Foot Ch. 5.4, 5.5</td>
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<td>26-Jan-2018</td>
<td>Hyperfine structure</td>
<td>Foot Ch 6.1, 6.2</td>
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<td>29-Jan-2018</td>
<td>Zeeman structure, magnetic transitions</td>
<td>Foot Ch 6.3, Appendix C</td>
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<td><strong>Section 2: Light-matter interactions a semiclassical approach</strong></td>
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<td>31-Jan-2018</td>
<td>Semiclassical interactions between radiation and atoms: TDSE and 2-level atom Hamiltonian, dipole operator, rotating-wave approximation (RWA)</td>
<td>Foot Ch. 7.1, 7.2, Fox Ch. 9.1-9.4</td>
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<tr>
<td>2-Feb-2018</td>
<td>Semiclassical interactions between radiation and atoms: Monochromatic radiation, Rabi oscillations</td>
<td>Foot Ch. 7.3, Fox Ch. 9.5</td>
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<td>5-Feb-2018</td>
<td>Semiclassical interactions between radiation and atoms: Bloch equations, Bloch sphere</td>
<td>Fox Ch. 9.6</td>
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<td>7-Feb-2018</td>
<td>Ramsey fringes, damping, modified Bloch equations</td>
<td>Foot Ch. 7.4, 7.5</td>
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<td>9-Feb-2018</td>
<td>Optical absorption, ac Stark effect</td>
<td>Foot Ch. 7.6, 7.7</td>
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<td>12-Feb-2018</td>
<td>Connections to Einstein A, B coefficients, laser operation</td>
<td>Foot Ch. 7.2, Fox Ch. 4</td>
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<td>16-Feb-2018</td>
<td>Applications: Bose-Einstein condensation</td>
<td>Foot 10.3 - 10.6</td>
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<td>19-Feb-2018</td>
<td><strong>Reading Week</strong></td>
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<td>21-Feb-2018</td>
<td><strong>Reading Week</strong></td>
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<td>23-Feb-2018</td>
<td><strong>Reading Week</strong></td>
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26-Feb-2018 Buffer
28-Feb-2018 Midterm?

**Section 3: Quantum optics**

2-Mar-2018 Photons: Coherent light, super- and sub-Poissonian statistics
5-Mar-2018 Photons: Theory of detection, shot noise
7-Mar-2018 Intensity interferometry, Hanbury Brown-Twiss
9-Mar-2018 Second-order correlations, photon antibunching
12-Mar-2018 Light as a harmonic oscillator
14-Mar-2018 Vacuum field, squeezed states
16-Mar-2018 Quantum atom-field interaction: quantizing the EM field
19-Mar-2018 Quantum atom-field interaction: quantizing the EM field
21-Mar-2018 Quantum atom-field interaction: absorption, stimulated emission and spontaneous emission
26-Mar-2018 Atoms in cavities: Purcell effect, strong coupling
28-Mar-2018 Quantum optics descriptions of photon counting statistics
30-Mar-2018 Beam splitter operations, quantum picture

**Section 4: Overview of quantum information applications**

2-Apr-2018 Qubits, gate operations
4-Apr-2018 Error correction, algorithms
6-Apr-2018 Photons as qubits, entanglement, single photons
9-Apr-2018 No-cloning, Bell Inequalities, teleportation
11-Apr-2018 Other physical implementations of qubits
13-Apr-2018 Other physical implementations of qubits

**Assignments**

Assignments and solutions will be posted on eClass. The goal of the assignments is for students to develop skills in the process of solving problems – not just in finding the right answer. Students are encouraged to discuss their work with others and with me, but all submitted work must be produced independently. A good indication of this independence is that, after any discussion with others, students should be able to work a problem from start to finish without talking to anyone else or looking at another solution.
Assignments will be posted two weeks ahead of their due date, and material (should) be covered one week prior to due date. All assignments will each carry equal weight. Also, see “Missed midterm examination and assignments” section below.

Exams
Exams will be open book/open notes. Students’ photo I.D. is required at exams to verify identity. Students will not be allowed to begin an examination after it has been in progress for 30 minutes. Students must remain in the exam room until at least 30 minutes has elapsed. Electronic equipment other than calculators cannot be brought into examination rooms. Exams will consist of problems similar to those found on regular assignments.

Past/representative evaluative material: A sample examination from a previous year will be provided prior to both the midterm and final exams, and will be posted on eClass before each examination.

Missed midterm examination and assignments: A student who cannot write the midterm examination or complete a special assignment due to incapacitating illness, severe domestic affliction or other compelling reasons can apply to defer the weight of the missed midterm examination/assignment to the final examination. Late regular assignments will not be accepted and will result in a mark of zero (note: only the seven best grades of the eight regular assignments are included in the final assignment grade). Deferral of term work is a privilege and not a right; there is no guarantee that a deferred examination will be granted. Misrepresentation of Facts to gain a deferred examination is a serious breach of the Code of Student Behaviour.

Final examination deferrals: A student who cannot write the final examination due to incapacitating illness, severe domestic affliction or other compelling reasons can apply for a deferred final examination. Such an application must be made to the student’s Faculty office within two working days of the missed examination and must be supported by a Statutory Declaration or other appropriate documentation (Calendar §23.5.6). Deferred examinations are a privilege and not a right; there is no guarantee that a deferred examination will be granted. Misrepresentation of Facts to gain a deferred examination is a serious breach of the Code of Student Behaviour. Any deferred final examinations will be held on XXXX at 9:00am.

Final reexaminations: A student who writes the final examination and fails the course may apply for a reexamination. Reexaminations are rarely granted in the Faculty of Science. These exams are governed by University (Calendar §23.5.5) and Faculty of Science Regulations (Calendar §192.5.9). Misrepresentation of Facts to gain a reexamination is a serious breach of the Code of Student Behaviour.

Final grades
Final grades will be determined based on a combination of absolute marks (according to the grade distribution given above) and the class distribution. Grades are unofficial until approved by the Department and/or Faculty offering the course.

Student Responsibilities

Academic integrity: The University of Alberta is committed to the highest standards of academic integrity and honesty. Students are expected to be familiar with these standards regarding academic honesty and to uphold the policies of the University in this respect. Students are particularly urged to familiarize themselves with the provisions of the Code of Student Behaviour (online at http://www.governance.ualberta.ca/) and avoid any behaviour which could potentially result in suspicions of cheating, plagiarism, misrepresentation of facts and/or participation in an offence. Academic dishonesty is a serious offence and can result in suspension or expulsion from the University.

All forms of dishonesty are unacceptable at the University. Any offence will be reported to the Senior Associate Dean of Science who will determine the disciplinary action to be taken. Cheating, plagiarism and misrepresentation of facts are serious offences. Anyone who engages in these practices will receive at minimum a grade of zero for the exam or paper in question and no opportunity will be given to replace the grade or redistribute the weights. As well, in the Faculty of Science the sanction for cheating on any examination will include a disciplinary failing grade (no exceptions) and senior students should expect a period of suspension or expulsion from the University of Alberta.
**Mobile devices:** Mobile devices are to be turned off during lectures. Mobile devices are not to be brought to exams.

**Students eligible for accessibility-related accommodations:** (Students registered with Specialized Support and Disability Services - SDSS) Eligible students have both rights and responsibilities with regard to accessibility-related accommodations. Consequently, scheduling exam accommodations in accordance with SSDS deadlines and procedures is essential. Please note adherence to procedures and deadlines is required for U of A to provide accommodations. Contact SDSS (www.ssds.ualberta.ca) for further information.

**Student Success Centre:** Students who require additional help in developing strategies for better time management, study skills, or examination skills should contact the Student Success Centre (2-300 Students' Union Building).

**Audio or Video Recording and Digital Content:** Audio or video recording, digital or otherwise, of lectures, labs, seminars or any other teaching environment by students is allowed only with the prior written consent of the instructor or as a part of an approved accommodation plan. Student or instructor content, digital or otherwise, created and/or used within the context of the course is to be used solely for personal study, and is not to be used or distributed for any other purpose without prior written consent from the content author(s).

Policy about course outlines can be found in §23.4(2) of the University Calendar.

**Disclaimer:** Any typographical errors in this Course Outline are subject to change and will be announced in class. The date of the final examination is set by the Registrar and takes precedence over the final examination date reported in this syllabus.