

Spring 2017

Physics 610

Quantum Optics

Lloyd M. Davis

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Office hours: None—contact me anytime by e-mail or phone



Quantum Optics - 31478 - PHYS 610 - 001

Associated Term: Spring Sem 2017

Registration Dates: 10-Oct-2016 to 20-Jan-2017

Levels: Graduate

UT Space Institute Campus

Lecture Schedule Type

Conventional Methodology Instructional Method

3.000 Credits

[View Catalog Entry](#)

Scheduled Meeting Times

Type	Time	Days	Where	Date Range	Schedule Type	Instructors
Class	12:01 am - 12:02 am	TBA		11-Jan-2017 - 28-Apr-2017	Lecture	Lloyd M Davis (P) 

In this class, we will use Zoom <https://oit.utk.edu/instructional/tools/liveonline/Pages/zoom-getting-started.aspx>, which enables students to attend each class from any location with internet access, e.g., home, office, or lab. However, you must have a PC with a microphone (possibly a smartphone/tablet with a good display) in order to attend interactively, ask questions, etc. On the other hand, each class will be recorded; I do not require that you attend every class—if needed, you can watch the recording at a later time. Also, if you have a schedule conflict, the proposed class time could be changed—on request, I will survey all class members to see if another time slot is preferable.

Proposed Class Time: Tuesdays and Thursdays, 9:00-10:15 Central Time; or 10:00-11:15 Eastern Time

Recommended Prerequisite courses/background:

Quantum Mechanics, Maths Methods, Electrodynamics, Classical Optics, Classical Mechanics

Catalog description:

PHYS 610 - Quantum Optics

Quantum theory of emission and absorption of radiation; frequency-dependent susceptibility; coherence theory; field quantization and coherent photon states; interaction of radiation with atoms; photon optics, counting and higher-order coherence; atomic scattering phenomena.

(DE) Prerequisite(s): 521.

Registration Restriction(s): Minimum student level - graduate.

3.000 Credit hours

3.000 Lecture hours

Levels: Graduate

Schedule Types: [Lecture](#)

Physics and Astronomy Department

Grades:

Homework assignments: 50 %

Midterm test 1: 10 %

Midterm test 2: 15 %

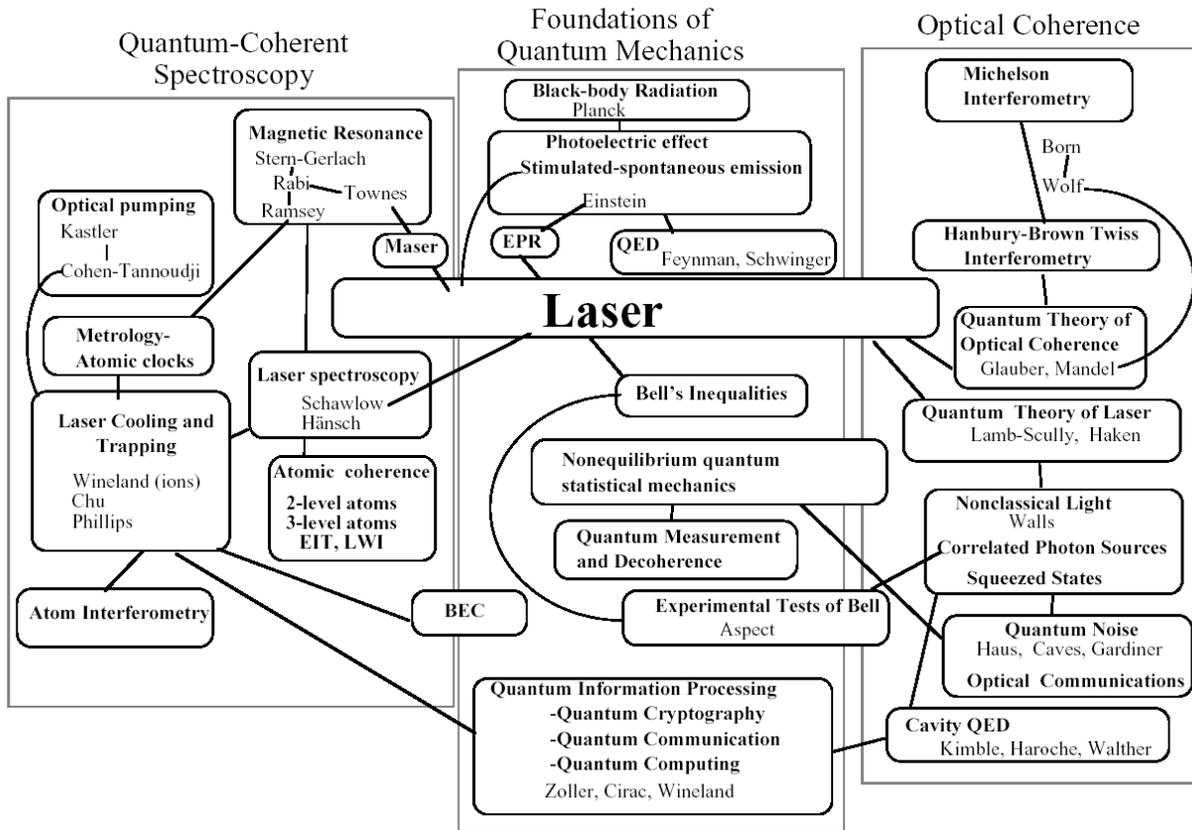
Final exam: 25 %

(Midterms and final will be open book take home.)

Course Content and Texts:

Quantum Optics studies the nature and effects of light as quantized photons. The field is ever evolving, has become quite extensive (see “Map of Quantum Optics” given below), and has become pervasive into many other areas of modern physics.

Map of Quantum Optics



Several Nobel prizes have been awarded for developments in quantum optics:

- 1921: Albert Einstein; "for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect". http://www.nobelprize.org/nobel_prizes/physics/laureates/1921/
- 1997: Steven Chu, Claude Cohen-Tannoudji, and William Daniel Phillips; "for development of methods to cool and trap atoms with laser light". http://www.nobelprize.org/nobel_prizes/physics/laureates/1997/
- 2001, Wolfgang Ketterle, Eric Allin Cornell and Carl Wieman; "for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates". http://www.nobelprize.org/nobel_prizes/physics/laureates/2001/
- 2005, Theodor W. Hänsch, Roy J. Glauber and John L. Hall; one half awarded to Roy J. Glauber "for his contribution to the quantum theory of optical coherence", the other half jointly to John L. Hall and Theodor W. Hänsch "for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique". http://www.nobelprize.org/nobel_prizes/physics/laureates/2005/
- 2012, Serge Haroche and David J. Wineland; "for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems". http://www.nobelprize.org/nobel_prizes/physics/laureates/2012/

And several Nobel prizes have been awarded for applications of photonics and quantum optics:

- 1930: http://www.nobelprize.org/nobel_prizes/physics/laureates/1930/
- 1944: http://www.nobelprize.org/nobel_prizes/physics/laureates/1944/

- 1953: http://www.nobelprize.org/nobel_prizes/physics/laureates/1953/
- 1964: http://www.nobelprize.org/nobel_prizes/physics/laureates/1964/
- 1966: http://www.nobelprize.org/nobel_prizes/physics/laureates/1966/
- 1971: http://www.nobelprize.org/nobel_prizes/physics/laureates/1971/
- 1981: http://www.nobelprize.org/nobel_prizes/physics/laureates/1981/
- 2009: http://www.nobelprize.org/nobel_prizes/physics/laureates/2009/
- 2014: http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/
- 2014: http://www.nobelprize.org/nobel_prizes/physics/laureates/2014/

In this course we will not follow any one text but I will provide class notes and material drawn from a number of texts, which are listed below, as well as some papers from the literature. However, we will begin the course by following text book No. 1—Optical Coherence and Quantum Optics, by Mandel and Wolf, which you are recommended to purchase (available on Kindle).

In October 1995, Leonard Mandel (1927-2001) and Emil Wolf (born 1922) from the University of Rochester published a treatise that encompasses a very broad range of topics, both in the classical and quantum theories of light. Topics on the classical theory of light propagation and on the classical theory of coherence of light, the research specialty of Wolf, are treated in detail in the first 9 chapters. In this course, we will touch only briefly on classical coherence theory. Most of the lectures will cover material on the fully-quantum mechanical description of the radiation field and its interaction with matter, as treated in the later chapters. We begin at chapter 10, in which Maxwell's equations are quantized, and we then proceed to consider various properties, measurements, and physical states of the quantized radiation field, including states that have no classical counterpart. A particular interest in quantum optics, and in fundamental quantum theory, relates to "entangled two-photon states", and Bell's inequality. Mandel was an expert in this area, and his chapter 10 on the quantization of Maxwell's equations seems to be slanted towards giving a very thorough foundation for covering such topics.

In this course we will not follow section by section through Mandel and Wolf's text, but instead we will attempt to present a broad perspective by skipping some of the more specialized sections and embedding material from other texts and articles from the literature. In particular, some of the lecture notes and some problems will be drawn from Loudon's texts "The Quantum Theory of Light", now in its third edition, and from other texts listed below. Also, some use will be made of Eberly and Allen's short treatise on the two-level atom, first published in 1975 and now available on Kindle, and of other now-classic texts.

Some classes will include problems that will be performed as worked examples. There will also be problems set for homework each class. Your solutions to the problems are due to be scanned and e-mailed to me generally before the next class (for full credit), unless otherwise specified. If needed, ask for hints or more time. Model answers will be provided together with your graded solutions. The midterm and final exams will be comprised of problems selected from the homework and the worked examples. References from the texts and the literature will be given for background reading.

A course outline is given below. This will probably be adjusted depending on students' progress and interests, and we may incorporate material from recent texts by Garrison and Chiao (No. 3, below), Agrawal (No. 15, below), Haroche (No. 16, below), and Orzag (No. 16, below).

Texts:

1. MW=Mandel and Wolf (1995) "Optical Coherence and Quantum Optics" (*Recommended to purchase)
http://www.amazon.com/Optical-Coherence-Quantum-Optics-Leonard/dp/0521417112/ref=sr_1_1?ie=UTF8&s=books&qid=1241028296&sr=1-1
2. FX=Fox (2006) "Quantum Optics: An Introduction" (Undergraduate level; Recommended for summer reading)
http://www.amazon.com/Quantum-Optics-Introduction-Oxford-Physics/dp/0198566735/ref=sr_1_2?ie=UTF8&s=books&qid=1241032576&sr=1-2
3. GC=Garrison and Chiao (2008) "Quantum Optics"
http://www.amazon.com/Quantum-Optics-Oxford-Graduate-Texts/dp/0198508867/ref=sr_1_1?ie=UTF8&s=books&qid=1241031018&sr=1-1
4. WM=Walls and Milburn (a:1994, b:2008) "Quantum Optics"
http://www.amazon.com/Quantum-Optics-D-F-Walls/dp/3540285733/ref=sr_1_1?ie=UTF8&s=books&qid=1241031075&sr=1-1
5. SZ=Scully and Zubairy (1997) "Quantum Optics"
http://www.amazon.com/Quantum-Optics-Marian-O-Scully/dp/0521435951/ref=sr_1_1?ie=UTF8&s=books&qid=1241030904&sr=1-1
6. MS=Meystre and Sargent (1990,2007) "Elements of Quantum Optics"
http://www.amazon.com/Elements-Quantum-Optics-Pierre-Meystre/dp/3540742093/ref=sr_1_1?ie=UTF8&s=books&qid=1241032140&sr=1-1#
7. BR=Bachor and Ralph (2004) "A Guide to Experiments in Quantum Optics"
http://www.amazon.com/Guide-Experiments-Quantum-Optics/dp/3527403930/ref=sr_1_1?ie=UTF8&s=books&qid=1241032689&sr=1-1
8. NC=Nielsen and Chuang (2000) "Quantum Computation and Quantum Information"
http://www.amazon.com/Quantum-Computation-Information-Michael-Nielsen/dp/0521635039/ref=sr_1_1?ie=UTF8&s=books&qid=1241035387&sr=1-1
9. L3=Loudon, 3rd edn (2000) "The Quantum Theory of Light"
http://www.amazon.com/Quantum-Theory-Oxford-Science-Publications/dp/0198501765/ref=sr_1_1?ie=UTF8&s=books&qid=1241035436&sr=1-1
10. L2=Loudon, 2nd edn (1983) "The Quantum Theory of Light"
11. L1=Loudon, 1st edn (1973) "The Quantum Theory of Light"
12. EA=Eberly and Allen (1975; now on kindle) "Optical Resonance and Two-Level Atoms"
http://www.amazon.com/Optical-Resonance-Two-Level-Atoms-Physics-ebook/dp/B00A73J1W8/ref=dp_kinw_strp_1
13. KS=Klauder & Sudarshan (1968; reprinted 2006) "Fundamentals of Quantum Optics"
http://www.amazon.com/Fundamentals-Quantum-Optics-Dover-Physics/dp/0486450082/ref=ja_B001HPJSZ0_1_1?s=books&ie=UTF8&qid=1426782416&sr=1-1
14. GK=Gerry and Knight (2005) "Introductory Quantum Optics"
http://www.amazon.com/Introductory-Quantum-Optics-Christopher-Gerry/dp/052152735X/ref=sr_1_5?ie=UTF8&s=books&qid=1241035672&sr=1-5#
15. GA=Girish Agrawal (Dec 28, 2012) "Quantum Optics"
http://www.amazon.com/Quantum-Optics-Girish-S-Agarwal/dp/1107006406/ref=sr_1_1?s=books&ie=UTF8&qid=1426782937&sr=1-1
16. SH=Serge Haroche (2006) "Exploring the Quantum: Atoms, Cavities, and Photons"
<http://www.amazon.com/Exploring-Quantum-Cavities-Photons-Graduate/dp/0198509146>
17. MO=Miguel Orzag (2016; third edition) "Quantum Optics"
https://www.amazon.com/Quantum-Optics-Including-Trajectories-Decoherence-ebook/dp/B01EV0GOOY/ref=sr_1_1?s=digital-text&ie=UTF8&qid=1483722199&sr=1-1

Quantum Optics Spring 2017 Approximate Course Outline

Lecture Date Topics

States of the Quantized Radiation Field

- 1 1-12 Quantization of Maxwell's equations (MW 10.1-3)
- 2 1-17 Fock states, linear and angular momentum (MW 10.4-6)
- 3 1-19 Phase in quantum optics (MW 10.7)
- 4 1-24 Coherent states (MW 11.1-4)
- 5 1-26 Quantum dynamics; Squeezed states (MW 11.5, 21.0-7; L3 4.7)
 Take-home midterm exam 1 (Covers lectures 1-5) (Due: 2-6)
- 1-31 No class due to conference
- 2-2 No class due to conference
- 6 2-7 Mixed States; Chaotic State (L3 4.6; MW 13.1-3)
- 7 2-9 Coherent state representation (MW 11.6-9; WMa 4.2)

Coherence

- 8 2-14 Young's experiment; First order coherence (WMa 3.1-5; MW 12.1-3; L2 6.1-2)
- 9 2-16 Higher order coherence (MW 12.4; L2 6.3-5)
- 10 2-21 Cross-spectral density; Hanbury-Brown Twiss (L2 6.4, 6.5; MW 4.3.2, 8.3, 2.4.4)
- 11 2-23 Propagation of coherence; Spectral change with propagation (MW 4.4, 5.3, 5.4, 5.8)
- 12 2-28 Photon counting (MW 12.10, 13.2; L2 3.6, 6.6-6.8)

Interaction of light with matter

- 13 3-2 Einstein A&B; Semiclassical theory; Field Commutators (M&W 9.1, 9.2, 9.3; L2 Ch1&2, 4.7)
- 14 3-7 Atom-radiation interaction ; Minimal coupling; Atomic second quantization (M&W 14.1; L2 5.1)
- 15 3-9 Schrodinger rep; Perturbative rates; Heisenberg Rep (L2 5.8, 5.9)
 Take-home midterm exam 2 (Covers lectures 6-15) (Due: 3-20)
- 3-14 Spring Break
- 3-16 Spring Break
- 16 3-21 Interaction picture calculations; Superfluorescence (MW 15.5, L2 5.11, 5.12, 5.14)
- 17 3-23 Derivation of optical Bloch equations
- 18 3-28 Damping mechanisms; Power broadening; Linewidths
- 19 3-30 Motion on the Bloch sphere; Pulse propagation; Maxwell-Bloch equations; Solitons
- 20 4-4 Photon echoes; Super fluorescence; Superradiance; Optical bistability
- 21 4-6 Resonance fluorescence
- 22 4-11 Introduction to Quantum theory of damping
- 23 4-13 Master equation in number state basis; Fokker Planck equation; Langevin equation

Entanglement

- 24 4-18 Einstein-Podolsky-Rosen paradox; Bell's inequality; Transactional interpretation
- 25 4-20 Beam splitters; Interferometers
- 26 4-25 Hong-Ou-Mandel & Franson experiments
- 27 4-27 Introduction to Quantum Cryptography and Teleportation; Quantum Computing
- 5-2 **Final Exam** (Covers lectures 16-28)

Value Proposition:

Quantum Optics provides a valuable underlying base for research in many other areas of modern physics, including quantum information theory, condensed matter physics, and optical, laser, and device physics.

Student Learning Outcomes/Objectives:

By the end of the course, students should have an in depth knowledge of the Quantum theory of light, including coherence and the interaction of light with matter. Students should be able to solve problems in these areas, understand the literature, and apply their knowledge to research in optical physics and in related areas of physics.

Programmatic Outcomes / Department Goals:

This course provides 3 credit hours at the 600-level for the doctoral program in physics with the University of Tennessee Knoxville. While it satisfies this requirement for students pursuing any area of specialization in the doctoral program, for students who are specializing in optical physics, this course provides a worthwhile initial base for other 600-level physics courses, notably Physics 606 Nonlinear Optics and Physics 605 Laser Spectroscopy. For example, a detailed understanding of most phenomena in non-linear optics and spectroscopy demands the application of a fully quantum mechanical model of the radiation field.

Learning Environment:

I envision that all students in the class are self-motivated by a genuine desire to become knowledgeable in the current physical understanding of the quantum theory of light so that they may use this knowledge in their research and future careers. Hence I expect each student to actively participate in class activities and in timely communications with me on their progress and/or questions. I respect that graduate students must balance coursework demands with other responsibilities so I'm willing to make accommodations in individual student schedules (e.g., for conference attendance) if provided with advanced warning. I understand that graduate students must maintain a 3.0 GPA; hence if you are really struggling in this course, be proactive and communicate that to me in a timely manner so that there will be time to make arrangements for an opportunity to remedy your situation.

Course Communications:

Best to communicate with me by e-mail. Please put "Quantum Optics" in the subject line. Send me a test e-mail if you have not already communicated with me. I should respond within a day or less, except when I am away on travel, when it may take a couple of days. Also, feel free to call my office line 931-393-7335 if this is simpler. For technical issues, contact OIT (<http://help.utk.edu/footprints/contact>)]

How to Be Successful In This Course:

Come to each class well prepared, having read the assigned pages from the texts, reviewed notes that are posted before the class, and having made a vigorous attempt to complete the assigned homework problems from previous classes. If you cannot complete a homework problem, hand in your attempt and seek help in completing the problem for partial credit. In the process, learn how to solve problems. The material in each class builds on previous material, so it is important to keep up with prior material. Ask questions in class if you do not understand something. Do not just rely on the distributed notes, but take notes in class and review your notes and your understanding after class. Revise the course material and homework problems to study for the exams. Abide by the UT Honor Code: do not seek or accept help in completing assignments or exams, except from me, the course instructor.

Course Resources:

The course material will be posted on the UTK Canvas Site. Recordings of lectures on zoom will be posted on a site yet to be determined.

University Policies:

Dear Student,

The purpose of this Campus Syllabus is to provide you with important information that is common across courses at UT. Please observe the following policies and familiarize yourself with the university resources listed below. At UT, we are committed to providing you with a high quality learning experience.

I wish you the best for a successful and productive semester.

Interim Provost John Zomchick

Academic Integrity:

“An essential feature of the University of Tennessee, Knoxville is a commitment to maintaining an atmosphere of intellectual integrity and academic honesty. As a student of the university, I pledge that I will neither knowingly give nor receive any inappropriate assistance in academic work, thus affirming my own personal commitment to honor and integrity.”

University Civility Statement:

Civility is genuine respect and regard for others: politeness, consideration, tact, good manners, graciousness, cordiality, affability, amiability and courteousness. Civility enhances academic freedom and integrity, and is a prerequisite to the free exchange of ideas and knowledge in the learning community. Our community consists of students, faculty, staff, alumni, and campus visitors. Community members affect each other’s well-being and have a shared interest in creating and sustaining an environment where all community members and their points of view are valued and respected. Affirming the value of each member of the university community, the campus asks that all its members adhere to the principles of civility and community adopted by the campus: <http://civility.utk.edu/>.

Disability Services:

“Any student who feels he or she may need an accommodation based on the impact of a disability should contact the Office of Disability Services (ODS) at 865-974-6087 in 100 Dunford Hall to document their eligibility for services. ODS will work with students and faculty to coordinate reasonable accommodations for students with documented disabilities.”

Your Role in Improving Teaching and Learning Through Course Assessment:

At UT, it is our collective responsibility to improve the state of teaching and learning. During the semester, you may be requested to assess aspects of this course either during class or at the completion of the class. You are encouraged to respond to these various forms of assessment as a means of continuing to improve the quality of the UT learning experience.

Key Campus Resources for Students:

- [Undergraduate Catalog](#): (Listing of academic programs, courses, and policies)
- [Graduate Catalog](#)
- [Hilltopics](#): (Campus and academic policies, procedures and standards of conduct)
- [Course Timetable](#): (Schedule of classes)
- [Academic Planning](#): (Advising resources, course requirements, and major guides)
- [Student Success Center](#): (Academic support resources)
- [Library](#): (Access to library resources, databases, course reserves, and services)
- [Career Services](#): (Career counseling and resources; HIRE-A-VOL job search system)
- [Student Health Center](#) (visit the site for a list of services)
- OIT Help Desk: **(865) 974-9900**