PHYS 760 Quantum Physics 2015

Offered:	Semester 2
Credit:	15 points
Pre-/Co-requisites:	None

Description

The nonrelativistic quantum mechanical treatment of light (electromagnetic radiation at microwave to optical frequencies) and its interaction with matter (atoms, quantum dots, superconducting qubits). Photon counting and classical versus nonclassical light; antibunched and squeezed light. Open quantum systems in the Born-Markov limit: master equations, input-output theory, quantum trajectories.

Aims

This course provides an advanced treatment of the nonrelativistic quantum mechanics of photons and their interaction with matter. It aims to bring students with a firm grounding in the Dirac formulation of quantum theory to a level where they are competent to tackle current research papers in the fields of quantum optics and quantum information, as well as related areas of atomic and condensed matter physics.

Skills and knowledge to be gained

Students who pass this course should be able to:

- outline the physics of blackbody radiation as it relates to photons; derive the blackbody spectrum, the photon number mean and variance of thermal light
- explain and apply Einstein A and B theory, e.g., to the absorption/amplification of light
- derive the optical Bloch equations and explain the analogy to a spin-½ in a magnetic field
- explain the dipole and rotating–wave approximations
- outline Dirac quantization of the electromagnetic field
- discuss the quantum mechanics of the harmonic oscillator as it relates to photons: energy spectrum, number, creation and annihilation operators; provide appropriate derivations
- derive the basic properties of coherent states
- define and manipulate the squeezing transformation
- explain the physics/approximations behind the Jaynes-Cummings model; diagonalize it
- review the elements of quantum damping theory: master equation, quantum Langevin equation, inputs and outputs
- derive and use quantum regression formulas
- define the P, Q (Husimi) and Wigner functions and use them to calculate operator averages
- explain the semiclassical approach to photoelectron counting; discuss the quantum extension and how it differs
- contrast classical and nonclassical light, e.g., as it relates to photon antibunching and squeezing
- outline the principles behind quantum trajectory theory
- execute simple quantum trajectory simulations, e.g., for the example of resonance fluorescence

Syllabus

- **Quanta without Quantum Mechanics:** Quanta and the black body spectrum; Fluctuations and thermal-light photon statistics; Einstein A and B theory & rate equations; Saturable absorption, population inversion and gain
- **Semiclassical Optics:** Semiclassical interaction of light and atoms; Rotating wave and dipole approximations; Rabi oscillation and the optical Bloch equations; Pure versus mixed states, density operators and spontaneous emission
- **The Quantized Radiation Field:** Dirac quantization of the EM field; Harmonic oscillator, creation/annihilation and quadrature phase operators; Coherent states
- **Quantum Mechanical Interactions of Light:** Jaynes-Cummings Hamiltonian; Dressed states, quantum collapse and revival; Nonlinear optics and squeezed states
- **Markov Processes and Open Quantum Systems:** Cavity damping, master equations; Quantum Langevin equation and inputs & outputs; Correlation functions and quantum regression; Phase-space representations; Fokker-Planck and stochastic differential equations
- **Photon Counting and Quantum Trajectory Theory:** Photoelectron counting, classical versus nonclassical light; Photon antibunching, homodyne/heterodyne detection and squeezing; Superoperator Dyson expansion and density operator unraveling; Monte Carlo simulation of quantum trajectories; Simple examples: resonance fluorescence, electron shelving, decoherence & measurement

Learning activities and teaching methods

Description	Study time
Lectures 20 × 1-hour	20 hours
Assignments X 4	24 hours
Private study (2 hours/lecture)	40 hours (recommended)

Inclusive learning
Students are urged to discuss privately any impairment-related requirements face-to-face and/or in written form with the course convenor/lecturer and/or tutor

Assessment

Form	Weight	Time	When
Assignments	30% (3of4 ×10%)	6 hours per assignment	weeks 2; 4; 7; 9;
Exam	70%	3 hours	exam period

Academic Integrity
The University of Auckland will not tolerate cheating, or assisting others to cheat, and views cheating in coursework as a serious academic offence. The work that a student submits for grading must be the student's own work, reflecting his or her learning. Where work from other sources is used, it must be properly acknowledged and referenced. This requirement also applies to sources on the world-wide web. A student's assessed work may be reviewed against electronic source material using computerised detection mechanisms. Upon reasonable request, students may be required to provide an electronic version of their work for computerised review. Please visit the below link for further information:
https://www.auckland.ac.nz/en/about/learning-and-teaching/policies-guidelines-and-procedures/academic-integrity-info-for-students.html

Resources

Recommended text:

The Quantum Theory of Light, 3rd edition, R. Loudon (Oxford, 2000)
Optical Coherence and Quantum Optics, L. Mandel and E. Wolf (Cambridge, University Press, Cambridge, 1995)
Quantum Optics, D. F. Walls and G. J. Milburn, 2nd edition (Springer-Verlag, Berlin, 2010)
Elements of Quantum Optics, 4th Edition, P. Meystre and M. Sargent II (Springer-Verlag, Berlin, 2010)
Quantum Optics, M. O. Scully and M. S. Zubairy (Cambridge University Press, Cambridge, 1997)

Lecture notes: Uploaded on Cecil

Feedback

Marked script and model solutions to assignments; marked exam script (if requested)

Enrolment

Typical enrolment Semester 2: 5