EPFL

PHYS-454 **Quantum optics and quantum information**

Brantut Jean-Philippe

Cursus	Sem.	Type
Electrical and Electronical Engineering	MA2, MA4	Opt.
Ing.-phys	MA2, MA4	Opt.
Photonics minor	E	Opt.
Photonics		Opt.
Physicien	MA2, MA4	Opt.
Physics		Opt.

Language of teaching	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Courses	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This lecture describes advanced developments and applications of quantum optics. It emphasizes the connection with ongoing research, and with the fast growing field of quantum technologies. The topics cover some aspects of quantum information processing, quantum sensing and quantum simulation.

Content

1. Introduction
Exemples of quantum devices. Review of two-level systems and harmonic oscillators.

2. Entanglement, decoherence and measurements
bipartite systems, entanglement, entanglement entropy, generalized measurements, system-meter description and POVMs, completely positive maps and Kraus theorem, quantum channels

3. Open quantum systems
Lindblad master equation, fundamental examples: Optical Bloch equations, damped harmonic oscillator

4. introduction to quantum computing
DiVincenzo criteria and universal quantum computers. Quantum gates, circuit representation. Exemple of algorithms: Deutsch algorithm, quantum teleportation.

5. Structure of real atoms
Quantum defect theory of one electron atoms, fine and hyperfine structure. Interaction with light, selection rules, dark states, closed transitions, qubit states.

6. Collective effects
Dicke states, coherent spin states. Projection noise. Introduction to quantum metrology: quantum Fisher information and quantum limits. Collective light-matter coupling, Tavis-Cummings model, polaritons.

7. Mechanical effects of light and laser cooling
Motional effects on light-matter interactions, Doppler and recoil shifts, semi-classical forces on the two-level atom, Doppler cooling and magneto-optical traps.

8. Trapped ions quantum computer
Lamb-Dicke parameter, motional side-bands, side-band cooling. Schrödinger cat states. Two qubit gates: the Cirac-Zoller gate, geometric phase gate.

Keywords

Quantum technology, quantum computing, quantum simulation, quantum optics, laser cooling, quantum measurement, quantum electrodynamics, quantum devices

Learning Prerequisites

Required courses

Good understanding of basic quantum mechanics
Quantum Electrodynamics and quantum optics (Fall semester)

Recommended courses

Solid state physics III, Optique III, Statistical physics IV

Important concepts to start the course

The two-level system and harmonic oscillator in quantum mechanics, unitary transformations

Learning Outcomes

By the end of the course, the student must be able to:

- Master the calculational techniques
- Read and understand the scientific litterature in quantum optics and quantum information

Teaching methods

Ex-cathaedra, exercise classes. Mini-conference with student presentations

Expected student activities

Weekly problem sheet solving, paper reading and presentation

Assessment methods

Oral examination

Resources

Bibliography

For a review of the basics of quantum optics

- Grynberg, Aspect and Fabre, *Introduction to Quantum Optics*

Core litterature for the course

- Haroche, Raimond, *Exploring the quantum*
- Chuang, Nielsen, *Quantum Computation and Quantum Information*
- Cohen-Tannoudji, Guéry-Odelin, *Advances in Atomic Physics*

Further bibliographic elements on specific topics during the lectures and as exercises.

Ressources en bibliothèque

- Grynberg, Aspect and Fabre, Introduction to Quantum Optics
- Haroche, Raimond, Exploring the quantum
- Chuang, Nielsen, Quantum Computation and Quantum Information
- Cohen-Tannoudji, Dupont-Roc, Grynberg, Atom-Photon Interactions

Prerequisite for

Specialization and Master projects in quantum optics, ultra-cold atoms, cavity quantum-electrodynamics