

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	6
Session	Summer
Semester	Spring
Exam	Written
Workload	180h
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. Example 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. Chosen topics among:

- Trapped ions quantum logic
- Rydberg quantum logic
- Digital and analogue quantum simulation

Keywords

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

Learning Prerequisites**Required courses**

Quantum Electrodynamics and quantum optics (Fall semester)

Recommended courses

Solid state physics, Statistical physics

Important concepts to start the course

Good understanding of the two-level system and the 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 literature in quantum optics and quantum information

Teaching methods

Ex-cathedra, tutorials and exercise classes. Mini-conferences with student presentations of research papers.

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 literature 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](#)
- [Cohen-Tannoudji, Dupont-Roc, Grynberg, Atom-Photon Interactions](#)
- [Chuang, Nielsen, Quantum Computation and Quantum Information](#)
- [Haroche, Raimond, Exploring the quantum](#)

Prerequisite for

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

