PHYS-470

Nonlinear optics for quantum technologies

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Microtechnics	MA1, MA3	Opt.
Minor in Quantum Science and Engineering	H	Opt.
Photonics minor	H	Opt.
Photonics		Opt.
Physicien	MA1, MA3	Opt.
Quantum Science and Engineering	MA1, MA3	Opt.

Language of teaching	English
Credits	4
Session	Winter
Semester	Fall
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Remark

pas donné en 2023-24

Summary

This course provides the fundamental knowledge and theoretical tools needed to treat nonlinear optical interactions, covering both classical and quantum theory of nonlinear optics. It presents applications such as nonclassical state generation and coherent frequency conversion.

Content

Nonlinear optics is continuously gaining in impact and relevance for the generation and conversion of quantum states of light, with numerous applications to quantum technologies. In parallel, the development of photonic integrated circuits and plasmonic nanocavities offers new opportunities to boost and tailor nonlinear effects. Finally, nonlinear optics offers unlimited possibilities to perform spectroscopy on molecules and nanomaterials and study their electronic and vibrational properties. This course gives an introduction to these contemporary developments.

Block 1. Fundamentals of nonlinear optics

- Introduction: corpuscular view on nonlinear optical phenomena
- Reminders: wave propagation in linear medium with dispersion; paraxial optics
- Nonlinear susceptibility and wave propagation in a nonlinear medium
- The nonlinear susceptibility tensor. Crystal symmetries, phase matching conditions
- Generation of coherent states at new frequencies (OPO, Raman laser, etc.)

Block 2. Quantum theory of nonlinear optics and its applications

- Quantum theory of nonlinear susceptibility (quantisation of matter). Particular case of the two-level approximation.
- Quantum nonlinear optics: quantisation of light in a nonlinear medium
- Effective Hamiltonian of nonlinear interactions
- Generation of nonclassical states of light and their applications in quantum technologies
- Quantum coherent frequency conversion for quantum networks
- Nonlinear optics in low-dimensional structures (waveguids, micro/nano-cavities)

Invited seminars and tutorials from researchers active in some of these fields (quantum frequency conversion, integrated quantum optics, etc.) will complement the lectures and exercises to enrich the course with practical example of ongoing scientific developments.

Keywords

Nonlinear optics, quantum optics, electromagnetism, electrodynamics, spectroscopy, quantum technology, lasers, oscillators, crystals, molecules, nanostructures, quantum correlations, entanglement, photonic integrated circuits, waveguides, optical cavities, plasmonics, photonics

Learning Prerequisites

Recommended courses

A solid background in the following areas is highly recommended: Classical Electromagnetism and Electrodynamics (Maxwell equations, light-matter interaction), Wave mechanics, Fundamentals of Optics.

Important concepts to start the course

Classical Electromagnetism and Electrodynamics (Maxwell equations, light-matter interaction), Wave mechanics, Fundamentals of Optics.

Learning Outcomes

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

- Define the different types of nonlinear interactions of light with a medium
- Describe the macroscopic manifestation and microscopic origin of nonlinear susceptibility
- Model wave propagation in linear and nonlinear media, in waveguides and low-dimensional geometries
- Predict the efficiency of different nonlinear effects in different geometries
- Explain how to derive a quantum theory of nonlinear optics
- Develop models of nonclassical state generation based on nonlinear optics

Transversal skills

- Use a work methodology appropriate to the task.
- Demonstrate a capacity for creativity.
- Take feedback (critique) and respond in an appropriate manner.
- Use both general and domain specific IT resources and tools
- Continue to work through difficulties or initial failure to find optimal solutions.
- Make an oral presentation.
- Summarize an article or a technical report.

Teaching methods

The course will be interactive, with an alternance of blackboard and slide lecturing, hands-on student exercises, questions and discussions. Active participation is expected.
Research seminars by external experts will establish a closer connection to contemporary research and illustrate the concepts seen in the course.

Expected student activities

Self-study before/after the lecture, active participation, asking questions, solving exercises, studying and presenting research papers

Assessment methods

Active participation during the semester including an oral presentation on a research topic (30%); final oral exam (70%)

Supervision

Office hours	Yes
Assistants	Yes
Forum	Yes

Resources

Virtual desktop infrastructure (VDI)

No

Bibliography

- P. N. Butcher and D. Cotter, *The elements of nonlinear optics*
- Robert Boyd: *Nonlinear Optics*
- François Hache: *Optique Non Linéaire*
- G Grynberg, A Aspect and C Fabre, *Introduction to Quantum Optics*
- J. D. Jackson, *Classical electrodynamics*
- J. Vanderlinde, *Classical Electromagnetic Theory*
- B. E. A. Saleh and M. C. Teich, *Fundamentals of Photonics*

Ressources en bibliothèque

- G Grynberg, A Aspect and C Fabre, Introduction to Quantum Optics
- B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics
- J. Vanderlinde, Classical Electromagnetic Theory
- J. D. Jackson, Classical electrodynamics
- François Hache: Optique Non Linéaire
- Robert Boyd: Nonlinear Optics
- P. N. Butcher and D. Cotter, The elements of nonlinear optics

Notes/Handbook

Hand-written lecture notes will be provided

Moodle Link

- https://go.epfl.ch/PHYS-470