PHYS-470

Nonlinear optics for quantum technologies

Galland Christophe

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Microtechnics	MA2, MA4	Opt.
Minor in Quantum Science and Engineering	E	Opt.
Photonics minor	E	Opt.
Photonics		Opt.
Physicien	MA2, MA4	Opt.
Quantum Science and Engineering	MA2, MA4	Opt.

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

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 micro/nano-cavities 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.

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:

- Compute wave propagation in linear and nonlinear media, in waveguides and low-dimensional geometries
- Formulate quantum models of nonlinear optical interactions
- Describe applications of nonlinear optics in classical and quantum technologies
- Predict the quantum state of light generated by a specific nonlinear process

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.

Assessment methods

The grade will be given based on a final oral exam (60-70%) and the level of participation during the semester, including exercise sessions (30-40%)

Resources

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
- Introduction to nanophotonics / Henri Benisty, Jean-Jacques Greffet, Philippe Lalanne. - 2022
- B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics
- J. D. Jackson, Classical electrodynamics
- P. N. Butcher and D. Cotter, The elements of nonlinear optics
- François Hache: Optique Non Linéaire
- Robert Boyd: Nonlinear Optics
- J. Vanderlinde, Classical Electromagnetic Theory

Moodle Link

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