PHYS-470 **Nonlinear optics for quantum technologies**

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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	Written
Workload	120h
Weeks	14
Hours	**4 weekly**
Courses	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This course provides the fundamental knowledge and theoretical tools needed to deal with nonlinear optical interactions, covering both classical and quantum theory of nonlinear optics.

Content

Nonlinear optics is used for the generation and conversion of quantum states of light, with numerous applications in 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 spectroscopy on molecules and nanomaterials is a power ful tool to probe their electronic and vibrational properties. This course covers the fundamental knowledge needed to understand these contemporary developments.

Fundamentals of nonlinear optics

- Reminders: wave propagation in a linear medium with dispersion
- Wave propagation in a nonlinear medium and phase matching conditions
- The nonlinear susceptibility tensor and crystal symmetries
- Generation of coherent states at new frequencies (second harmonic, sum- and difference frequency, etc.)

Quantum theory of nonlinear optics and its applications

- Quantum theory of the nonlinear susceptibility (first quantisation, semi-classical treatment). Particular case of the two-level system.
- Quantization of the electromagnetic field
- Effective Hamiltonian of nonlinear interactions
- Generation of nonclassical states of light: the case of parametric down conversion
- The joint spectral amplitude and the two-mode squeezed state
- Integrated nonlinear optics in waveguides and cavities
- Application to quantum frequency conversion, quantum networks, etc.

Invited seminars and tutorials from researchers active in some of these fields (quantum frequency conversion, integrated quantum optics, etc.) will enrich the course with practical examples from contemporary research.

Keywords

Nonlinear optics, quantum optics, photonics, quantum technologies, integrated optics, optical spectroscopy

Learning Prerequisites

Required courses

Classical electrodynamics (or any equivalent introduction to optical waves in a medium)
Quantum mechanics (perturbation theory and the harmonic oscillator)

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

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

Final written exam.

Supervision

Office hours	Yes
Assistant.e.s	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

- Find the references at the Library

Notes/Handbook

Hand-written notes recorded on the tablet + slides.

Moodle Link

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