PHY 355
Nonlinear Optics

Tuesdays and Thursdays, 10:45 AM - 12:00 PM LL 512

Prof. I. Biaggio, Lewis Lab 407

Course Description. This course is designed for advanced undergraduate and graduate students having some previous exposure to the field of optics and electromagnetism, and wishing to become knowledgeable in the basic principles that govern multi-photon interactions mediated by matter, meaning photons being destroyed to create other photons, while conserving energy. These effects are relevant for optical telecommunication, optical computing and data processing, and photonics in general.

Learning Outcomes

Initial Competences required for this course: Students should be familiar with electricity and magnetism and some physical optics, in particular Maxwell equations and the propagation of electromagnetic waves, and properties such as light polarization, intensity, wavevector, and Poynting vector. Some knowledge of lasers and laser beams is useful.

Course contents: The course focuses on the fundamental building blocks that are used to describe the nonlinear interaction of laser light with transparent materials, important for various aspects of photonics and in general light-matter interaction. We will study the origin, symmetry, and definitions of the nonlinear optical susceptibilities that are used to relate the complex amplitudes of interacting electromagnetic waves. We will then use these basic tools to describe and understand nonlinear optical effects, in particular second- and third-order effects. The emphasis here will be on the presentation and discussion of the analysis tools that allow the description and the understanding of any nonlinear optical effects, not just standard examples such as second harmonic generation or self-phase modulation. In addition, the course will cover the following topics: Measurement of nonlinear optical properties; Molecular hyperpolarizabilities and macroscopic nonlinear optical susceptibilities; Second and third harmonic generation; Frequency conversion and parametric interactions; Wave interaction in anisotropic crystals; Phase matching; Optical Kerr effect; All optical switching; Four-wave mixing.

In fundamental research, lasers and nonlinear optical techniques can deliver information on the symmetry of materials and interfaces, on the excited states of matter, and on the workings of a multitude of material excitations. In technology, nonlinear optical effects are used to change the color of laser beams, to create short laser pulses, to build “optical transistors”, and to transfer information from electrical to optical signals.

Competencies expected after this course: After this course you will be able to understand and analyze the nonlinear optical effects that laser beams induce in transparent materials. If faced with a new phenomenon or effect, you will be able to analyze it with the tools presented in this course, understand its origins and implications, and quantitatively relate it to material properties such as the linear and nonlinear optical susceptibilities.

Required coursework and grading distribution:

20%: Homework and term paper
20% Quizzes about homework and reading assignments
60% Exams

Reading assignments and quizzes

Full lecture notes will be provided. There will generally be material that must be read before class, with a short quiz about that material at the beginning of class. This is to make sure that we can then discuss the material efficiently in class.

Homework

Homework assignments are an essential complement to the material in the lecture, and will be provided each week. The idea is that you get the homework, we discuss it in the next meeting, and then you turn it in the week after. In a move to which you might not be accustomed to, I will *not mark up your homework* to identify mistakes for you. I will instead provide you with full solutions and I will evaluate your homework mainly based on the effort you put into it and the criteria listed below. You will be responsible for studying the detailed solutions to the weekly homework, and to compare them with what you did. In this way you will identify any mistakes you might have made. We then discuss any additional details in our class meetings.

Rules for a good homework assignment.

- Write an introduction at the beginning of each problem: This is a paragraph to introduce your work and explain in words how you will go about solving the problem.
- Your written work must mimic what you would see in a book: Not just numbers or equations, but subtitles and full sentences that incorporate equations and numbers.
- Write a conclusion at the end of each problem. This is a paragraph that summarizes anything that your learned while doing the homework. You can also add questions for me to your solutions.

To achieve the expected learning outcomes you must seriously attempt to understand and solve the homework problems. Start working on them as soon as you get them. The problems are designed to lead you towards a better understanding of the material of the course. Many homework assignments will be structured as a different way to learn the material, in addition to what we do in class.

Also Important: try to make an attempt to first think about the homework assignments alone. It is tempting to do them by committee all together from the start, or to find a pre-canned solution somewhere, but this more or less destructs the purpose of the homework, and it is especially unhelpful if you feel you are having difficulties in understanding the material. If you work on the homework with others, make sure to make it a brainstorming competition, where you first discuss the problem together, trying to win an argument about what the best strategy towards a solution is. Come to me if you have questions.

Class participation and attendance:

Class discussions are important. The aim is that students come to class prepared and contribute to the conversation in class with questions or comments based on past and present class material or the reading assignments. Classes will be flexible, and I can adapt the contents depending on questions and student interest. Coming to class prepared means having read and studied the class notes or other material (such as homework solutions), and being ready to discuss them or to ask questions. It doesn't necessarily mean having understood everything already.

Term paper
After the middle of the semester we will determine topics for every student, and everyone will pick a topic. You will then write a short paper about your findings, which we will then discuss in class.

Exams.
There will be a mid-term exam and a comprehensive final exam. The total grade will be given by $(m + 2f)/3$, where m is the grade of the mid-term, and f the grade of the final. Exam questions are designed to test your knowledge in the field while requiring only little mathematical calculations. They are shorter than what you find in homework assignment, which are designed to teach the material.

Accommodations for Students with Disabilities.
Lehigh University is committed to maintaining an equitable and inclusive community and welcomes students with disabilities into all of the University's educational programs. In order to receive consideration for reasonable accommodations, a student with a disability must contact Disability Support Services (DSS), provide documentation, and participate in an interactive review process. If the documentation supports a request for reasonable accommodations, DSS will provide students with a Letter of Accommodations. Students who are approved for accommodations at Lehigh should share this letter and discuss their accommodations and learning needs with instructors as early in the semester as possible. For more information or to request services, please contact Disability Support Services in person in Williams Hall, Suite 301, via phone at 610-758-4152, via email at indss@lehigh.edu, or online at https://studentaffairs.lehigh.edu/disabilities.

The principles of our equitable community.
Lehigh University endorses The Principles of Our Equitable Community. We expect each member of this class to acknowledge and practice these Principles. Respect for each other and for differing viewpoints is a vital component of the learning environment inside and outside the classroom.
[http://www.lehigh.edu/~inprv/initiatives/PrinciplesEquity_Sheet_v2_032212.pdf]

Academic Integrity.
The office of the provost says that the improper use of platforms such as Chegg, Bartleby, and other homework and note-sharing websites can be very problematic and may be a violation of Lehigh's Code of Conduct. I would add to that that looking up a homework solution online almost completely destroys any usefulness a homework assignment might have. First, because the solution you find on-line may be wrong or worse than what you would do yourself, second, because it is the fact of struggling to find a solution of the homework that creates skills and understanding. It's not even important that you get at a final result, it's the fact of working on it and of looking up things. Here a leak to the vignettes on academic dishonesty: http://www.lehigh.edu/lts/official/Academic_Integrity_Vignettes.pdf