PHY 355
Nonlinear Optics

Tuesdays and Tursdays, 2:35-3:50pm LL 514

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 the light-matter interaction effects collectively known as nonlinear optics.

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. We will study the origin, symmetry, and definitions of the nonlinear optical susceptibilities that are associated to multi-photon interactions mediated by matter and that can be used to relate the complex amplitudes of interacting electromagnetic waves. We will then use these basic tools to describe and understand nonlinear optical effects, discussing in depth 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 and discussion of the pitfalls arising from the inconsistent definitions found in the literature; Molecular hyperpolarizabilities and macroscopic nonlinearities; 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.

We will also touch several current topics of interest related to the material in the course. 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 are critical for the understanding and optimization of information-transmission in optical fibers and elsewhere.

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 and that are of the second order and of the third order in the optical electric field. 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:

30%: Short Quizzes
20% Homeworks
50% Exams

Quizzes are simple, 5-minute questions that you will answer in writing in class, from time to time. Quizzes will be graded from 0 (if you are not there or do not write anything) to 3 (if everything is perfect). Only the top 70% will contribute to the final grade.

Homework assignments are due every week and complement the material in the lecture.
There will be a new homework assignment each week that counts 6 points. New assignments are distributed on Tuesdays, discussed on Thursdays, and must be handed in the next Tuesday. The grading of the homework is mostly based on effort, not on correctness. This is how it works:

- You hand in an initial solution
- I look at it, and give it back to you, assigning a number of points between 0 (no effort) to 2 (complete attempt at a solution)
- I provide a solution, either in writing or we derive it in class.
- You then use what you have written before, any comments from me, and the solutions I provided to look at your initial solution again. You then hand it in again, with corrections and comments describing why your approach was wrong. You may add some paper with new work when you do this.
- I look at your final solution and again I assign a number of points between 0 (initial solution was incomplete, and there has been no attempt to improve on it) and 2 (all errors where caught and fixed, or maybe there were none in the first place).
- Finally, I assign a number of additional of points, between 0 and 2, that depend on the general quality of the work in both iterations.

This gives a final tally of 6 points for every homework assignment. A total of 50 points at the end of the semester maximizes the homework contribution to the final grade

Homework problems are an essential part of the course. To achieve the expected learning outcomes you must seriously attempt to understand them and solve them. 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 (they are qualitatively different from exam questions and quiz questions). Many homework assignments will be structured as a different way to learn the material, in addition to what I am presenting in class. Because of this it is important that you not only attempt to do the homework assignments the first time, but that you also review the solution, discuss any differences between how you approached a problem, and how it was treated in the solution (both may be valid), and analyze any new material presented in a solution, asking questions in case of doubts.

Also, understanding homework assignments will give you the tools and the abilities to easily answer quiz questions and exam questions. It is the same as athletics, without exercise you cannot be good. Also Important: try to make an attempt to first solve the homework assignments alone. It is tempting to do it by committee all together from the start, 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. Come to me if you have questions.

Exams. There will be a mid-term exam and a comprehensive final exam. The mid-term exam is only counted for the final grade if its grade was better than the grade in the final exam. If both exams are counted, 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 a bit longer than quiz questions, but are more similar to the quizzes than to homework assignment, which are designed to teach the material.

Accommodations for Students with Disabilities: If you have a disability for which you are or may be requesting accommodations, please contact both your instructor and the Office of Academic Support Services, Williams Hall, Suite 301 (610-758-4152) as early as possible in the semester. You must have documentation from the Academic Support Services office before accommodations can be granted.

The Principles of Our Equitable Community: Lehigh University endorses The Principles of Our Equitable Community [http://www.lehigh.edu/~inprv/initiatives/PrinciplesEquity_Sheet_v2_032212.pdf]. 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.