AEP 4400/5400: Nonlinear and Quantum Optics (Spring 2026)

Instructor: Prof. Nicholas Rivera
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Credits and recommended study hours: 3 credits; 9 hours per week outside of class.

Lecture Meeting Time & Location: MWF 9:05am – 9:55am, Rockefeller 122
Office Hours: W 2-3pm, Clark 206

Course Description: The course develops classical electrodynamics in nonlinear media – starting with nonlinear susceptibilities and nonlinear phenomena in transparent dielectric media resulting from second- and third-order nonlinearities. The second part of the course covers the quantized treatment of electromagnetic fields in dielectric media, the quantum theory of nonlinear optics, and its applications in quantum information science.

After this course, students will have the fundamental grounding in nonlinear and quantum optics to understand and make contributions to modern research in the field.

Course Textbooks:

- (Required) Nonlinear Optics by Robert Boyd.
- (Required) Course lecture notes [to be distributed prior to relevant lectures].
- (Optional) The Quantum Theory of Nonlinear Optics; Mark Hillery and Peter Drummond
- (Optional) Quantum Noise and Electromagnetic Measurements; Hermann Haus
- (Optional) Quantum Electronics; Amnon Yariv
- (Optional) Waves and Fields in Optoelectronics; Hermann Haus
- (Optional) Quantum Optics; Marlan Scully and M. Suhail Zubairy

Prerequisites: AEP 3560 (Intermediate Electrodynamics II), AEP 3620 (Intermediate Quantum Mechanics), and AEP 4200 (Intermediate Mathematical Physics) or equivalent, or permission of instructor.

Grading:

- Midterm 1: 15%,
- Midterm 2: 15%
- Final exam: 30%
- Homework: 25%
- Attendance and participation: 10%
- In-class mini-quizzes: 5%

Homework: 6 problem sets throughout the course, due approximately every two weeks. Submit online on Canvas. Feel free to collaborate with other students. You should write up your own solutions in your own words to convince yourself that you understand the problems.

Homework policy: Late homework submissions will be accepted. If they are submitted within 24 hours of the due date, 25 points will be deducted from your grade. Every additional day, another 25 points is subtracted (if the PSet was due at 11:59 PM on Friday, and is submitted after Sunday 11:59 PM, it cannot receive credit (and it will not be graded)). I cannot grant longer extensions, as solutions will be released by the end of the week.

Collaboration policy: I have no issue with you discussing the homework problems with other students in the course, but you should write up your solutions independently, to ensure that you understand the logic behind each solution.

Exams: Two midterms each worth 15% of the total grade. One final exam worth 30% of the grade.

Exam dates (tentative): TBA, will be announced on Canvas.

Attendance and participation: Worth 10% of the total grade: full points are achieved by attending class regularly, asking questions frequently, contributing positively to in-class discussions, and attending office hours.

Mini-quizzes: Occasionally (largely without warning), I will ask you to answer a question and turn in your answer. Worth 5% of total grade.

AI policy I have no issue with you using AI tools such as large language models (LLM) to help your learning, but you must not use it to generate full solutions to homework problems. For each problem set, you must at the end describe how you used AI tools in doing the problem set. Nevertheless, your best bet on doing well is attending lecture and discussion sections, and writing up solutions to all homework problems by yourself (even if you collaborate with other students).

Course topics (subject to modification; modifications likely):

1. **Introduction to classical nonlinear optics:** Nonlinear polarization, classical anharmonic oscillator model of nonlinear susceptibility, frequency generation and modification of the refractive index by light, typical magnitude of nonlinear response coefficients, formal properties of nonlinear susceptibilities, energy in lossless nonlinear media.

2. **Nonlinear optics in second-order nonlinear media:** Sum-frequency generation, phase matching, second-harmonic generation, difference-frequency generation, parametric amplification and oscillation, nonlinear optics for focused beams, nonlinear optics at an interface. Electro-optic and Pockels effect and electro-optic modulators.

3. **Nonlinear optics in third-order nonlinear media:** Nonlinear refractive index, self- and cross-phase modulation, phase conjugation and holography. Nonlinear polarization coupling. Bistability. Kerr effect in ultrafast optics: temporal and spatial solitons. Supercontinuum generation. Vibrational contribution to Kerr nonlinearity.

4. **Quantum optics and electrodynamics:** Canonical quantization of the electromagnetic field. Quantum states of light such as Fock states, entangled photon states, coherent states and squeezed states. Characterizing and measuring quantum noise and correlations. Open system dynamics and quantum Langevin equations.

5. **Quantum treatment of linear optical phenomena:** Scattering and attenuation of quantum states of light. Amplification of quantum states of light: phase-sensitive and phase-insensitive amplifiers and Caves limits.

6. **Quantum treatment of nonlinear optical phenomena:** Quantum noise picture of quantum nonlinear optics. Linearization and quantum sensitivity analysis. Quantum statistics of parametric amplifiers and oscillators. Kerr squeezing. Quantum nonlinear ultrafast optics. Metrology with squeezed states.

**** Information can be out of date and course topics are subject to change, please confirm with instructor if you are not sure of something!**

Key Dates (these are subject to change!)

Jan. 21 – Instructor travel; class cancelled
Jan. 23 – First day of AEP 4400/5400.
Feb. 6 – PS1 due
Feb. 16 – No class (winter break)
Feb. 20 – PS2 due
Mar. 13 – PS3 due
Mar. 27 – PS4 due
Mar. 30 – No class (spring break)
Apr. 1 – No class (spring break)
Apr. 3 – No class (spring break)
Apr. 6 – Instructor travel; class cancelled
Apr. 20 – PS5 due
May 4 – PS6 due
May 9-16 Final exam TBA