OPTI 596-006: Elements of Nonlinear Optics
Effective Spring 2025
Course Modality: In-person

Course Description:

The course introduces the student to the basics of nonlinear optics and the zoology of phenomena produced by optical nonlinearities for very intense laser fields propagating in dielectric media. The treatment is centered on the classical Lorentz electron oscillator, but a quantum perspective is also given for many of the phenomena discussed. The class project requires students to have some computational skills. This class can serve as a companion class to OPTI 553 Nonlinear Photonics that provides a more detailed treatment of nonlinear optics, integrated optics, materials, and device applications.

Pre-requisites:

The class should be accessible to students who has taken and passed OPTI 501 or equivalent. A working knowledge of MATLAB or similar simulation software will be advantageous but not essential.

Number of Units/component:

Number of units: 3

Class component: Two 75 min lectures each week.

- **Class meetings:** In-person
  - Each MW from 9:30-10:45 in Meinel Rm. 305

- **Classroom attendance:**
  - If you feel sick, or may have been in contact with someone who is infectious, stay home. Except for seeking medical care, avoid contact with others and do not travel.
  - Notify your instructor(s) if you will be missing a course meeting or an assignment deadline.
  - Non-attendance for any reason does **not** guarantee an automatic extension of due date or rescheduling of examinations/assessments.
    - Please communicate and coordinate any request directly with your instructor.
  - If you must miss the equivalent of more than one week of class, you should contact the Dean of Students Office DOS-deanofstudents@email.arizona.edu to share documentation about the challenges you are facing.
  - Voluntary, free, and convenient COVID-19 testing is available for students on Main Campus.
  - COVID-19 vaccine is available for all students at Campus Health.
  - Visit the UArizona COVID-19 page for regular updates.

- **Academic advising:** If you have questions about your academic progress this semester, please reach out to your academic advisor.

- **Life challenges:** If you are experiencing unexpected barriers to your success in your courses, please note the Dean of Students Office is a central support resource for all students and may be helpful. The Dean of Students Office can be reached at (520) 621-2057 or DOS-deanofstudents@email.arizona.edu.

- **Physical and mental-health challenges**: If you are facing physical or mental health challenges this semester, please note that Campus Health provides quality medical and mental health care. For medical appointments, call (520) 621-9202. For After Hours care, call (520) 570-7898. For the Counseling & Psych Services (CAPS) 24/7 hotline, call (520) 621-3334.

- **Exams and Assessments**: Grades for this class will be based entirely upon weekly computational laboratory assignments. There is no final exam.

- **Staying current:** You are required to complete the required (2) and your selected (typically 2-3) computer assignments in a timely manner to complete the requirements for this lab class.

Instructor Information:

The course instructor is:

Prof. Ewan M. Wright
Meinel 636
621-2406
ewan.wright@optics.arizona.edu

Expected Learning Outcomes:

After completion of this course, it is expected that students will be able to (i) recognize and manipulate the basic equations of nonlinear optics; (ii) identify and discuss the key phenomena underpinning nonlinear effects at high intensities; (iii) be able to discuss and research classic papers from the field of nonlinear optics; (iv) be able to address and advanced topic of their own choosing by carrying out a numerical project and/or literature search. In this way students will gain a broad appreciation of the field of nonlinear optics plus an in-depth study of one topic. For some students this may be what they require whereas for others they may seek a more in-depth class, eg. OPTI 553.

Required Texts:

There are no required texts, and class notes will be made available. An optional source book is

R. W. Boyd: Nonlinear Optics (Academic Press)

Topics and/or general calendar:

The topics to be covered are

1. **Review**
   Linear optical properties, Maxwell's equations, plane-wave solutions, paraxial wave equation and Gaussian beam propagation, Lorentz electron oscillator model in the time and frequency domains, crystal optics basics.

2. **Introduction**
   Introduction to nonlinear optics, nonlinear response function and optical susceptibility, classes of nonlinear optical interactions, tensorial properties of the nonlinear susceptibility.

3. **Second-order Nonlinear Optics**
   Second-harmonic generation, sum and frequency generation, propagation effects, phase matching methods, quasi-phase matching, parametric processes, parametric amplifiers and oscillators.

4. **Third-order Nonlinear Optics**
   Third-harmonic generation, Kerr-type nonlinearities and self-phase modulation, two-photon absorption, four-wave mixing. Applications including spectral broadening due to SPM, nonlinear pulse compression, and optical phase-conjugation.

5. **Self-focusing collapse and optical solitons**
   The nonlinear Schrodinger equation, self-focusing collapse in a bulk nonlinear medium, aberrationless approximation and the critical power, spatial solitons in one-dimensional waveguides, higher-order solitons, cascaded nonlinearities in second-order media, spatial solitons in second-order nonlinear media. modulational instability of a plane-wave and filamentation. The nonlinear Beam Propagation Method.

6. **Optical breakdown in transparent materials**
   Multi-photon ionization and avalanche ionization, optical breakdown for > ps pulses, plasma defocusing and arrest of collapse for short pulses, plasma blue-shifting, supercontinuum or white light generation due to collapse of fs pulses.

7. **Temporal solitons and space-time collapse**
   Group velocity dispersion in optical fibers, temporal optical solitons, modulational instability, short pulse lasers. Space-time collapse in transparent dielectric media, light bullets, collapse arrest via pulse-splitting due to group velocity dispersion, long distance propagation of fs pulses in air.

8. **Stimulated Scattering**
   Stimulated Raman and Rayleigh wing scattering, two-wave coupling, Raman amplification and oscillation.

9. **Contemporary topics in nonlinear optics**
   Potential topics include high-harmonic generation, attosecond pulse generation, extreme nonlinear optics and vacuum nonlinear optics, photon fluids, and analogue gravity systems.

Number of Exams and Papers:

There will be two class papers and no written exams.

Course Policies:

Grading Policy

Grading will be based on a combination of homework, keeping a log of research papers, a midterm paper and a nonlinear optics project that is due before the final class. Grades will be determined based on the timeliness of completing the assignments, participation in the class, and the quality of the papers. The grade will be determined according to the cumulative percentage earned such that 90-100% = A, 80-89% = B, 70-79% = C, 60-69% = D, below 60% = E.

Academic Integrity (http://web.arizona.edu/~studpubs/policies/cacaint.htm)

According to the Arizona Code of Academic Integrity, "Integrity is expected of every student in all academic work. The guiding principle of academic integrity is that a student's submitted work must be the student's own." Unless otherwise noted by the instructor, work for all assignments in this course must be conducted independently by each student. Co-authored work of any kind is unacceptable. Misappropriation of exams before or after they are given will be considered academics misconduct.

Misconduct of any kind will be prosecuted and may result in any or all of the following:

- Reduction of grade
- Failing grade
- Referral to the Dean of Students for consideration of additional penalty, i.e. notation on a student's transcript re. academic integrity violation, etc.

Attendance Policy

It is important to attend all classes, as what is discussed in class is pertinent to adequate performance on assignments and exams. If you must be absent, it is your responsibility to obtain and review the information you missed. This is especially important in this course where a substantial amount of course material will emerge through class discussion.

"All holidays or special events observed by organized religions will be honored for those students who show affiliation with that particular religion. Absences pre-approved by the UA Dean of Students (or Dean's designee) will be honored."

Classroom Behavior

The Arizona Board of Regents' Student Code of Conduct, ABOR Policy 5-308, prohibits threats of physical harm to any member of the University community, including to one's self. See: http://policy.web.arizona.edu/threatening-behavior-students.

Students with Disabilities

If a student is registered with the Disability Resource Center, he/she must submit appropriate documentation to the instructor if he/she is requesting reasonable accommodations. (http://drc.arizona.edu/instructor/syllabus-statement.shtml).

The information contained in this syllabus, other than the grade and absence policies, may be subject to change with reasonable advance notice, as deemed appropriate by the instructor.