EE 531: Nonlinear Optics

USC Viterbi School of Engineering
4 Units | Wed/Fri, 3:00-4:50pm | Location: Online | Spring 2021

Instructor: Chia Wei (Wade) Hsu, cwhsu@usc.edu
Office Hours: Mon, 3:00-4:55pm | Location: Online

Teaching Assistant: Xingwei Gao, xingweig@usc.edu
Office Hours: Thur, 4:00-6:00pm | Location: Online

Course Webpage: https://blackboard.usc.edu

Final exam time: 8am Monday 5/10 – 8am Tuesday 5/11

Course Description

While the interactions between light and matter are typically linear—twice the input yields twice the output—such linearity breaks down at high intensities. In the nonlinear regime, two light beams can effectively interact with each other (superposition no longer holds), as the optical properties of the material system depends on the presence of light fields. Nonlinear optics involves rich fundamental physics, advanced mathematics and numerical methods, and is used for numerous technologies such as the generation of new frequencies (e.g., green laser pointers and supercontinuum light sources), creation of short laser pulses, electro-optic modulators, laser machining, laser surgery, nonlinear spectroscopies, fiber optical communication with solitons, and optical computing. Nonlinear optics is also an important tool for metrology, sensing, and quantum optics.


Learning Objectives

Upon successful completion of this course a student will be able to

- understand the origin of nonlinear susceptibilities and their properties;
- model frequency generation processes;
- analyze and solve nonlinear wave equations;
- apply phase matching for nonlinear effects to build up coherently;
- model spatial and temporal solitons;
- understand stimulated Raman and Brillouin scattering;
- apply electrooptic effect for modulations

Prerequisite: EE 470. If you have taken an equivalent course elsewhere (i.e., electrodynamics at an upper-undergraduate level or above), please contact the instructor with your USC ID for prerequisite waiver.

Recommended preparation: Maxwell’s equations in differential forms.

Wellness days:
There are university wellness days for the Spring 2021 semester. Therefore, we will not have class on the following days: Friday 3/12, Wednesday 4/7, Friday 4/30.
Main Course Textbooks

Supplementary Materials
5) NPTEL *Nonlinear Optics* Course (2015); online material, available at https://nptel.ac.in/courses/115101008/

Grading Breakdown
40% Problem sets (from 8 out of 9 problem sets with the lowest grade dropped; 5% each)
15% Midterm Exam
20% Project (10% write-up, 10% presentation)
25% Final Exam

Problem Sets Description & Policy
- There will be 9 weekly problem sets. The one with the lowest grade will be dropped automatically.
- **Problem sets will be posted on Blackboard on Fridays and are due at 3:00pm the following Friday, to be submitted on Blackboard under the Assignments tab.** Solution will be posted on Blackboard on the due date, after lecture.
- **No late submission**, since solution will be posted. Late or no submission result in a zero grade.
- Show your work. Problem sets are graded based on the entirety of your solution, not just the final answer.
- You are encouraged to discuss problems and solution strategies with your classmates, the TA, and/or the instructor. However, each person must do all of the problems independently.
- You may not copy the problem solutions from anybody else or from any existing solution. If found doing so, you'll receive zero grade and be reported (see https://viterbischool.usc.edu/academic-integrity).
- For computer-based assignments no code can be shared or copied from the internet. The only exception is code provided to the entire class by the instructor or TA.
- Questions on clarification of the homework problems, if any, must be communicated to the instructor at least 24 hours before the due time.

Final Project Description & Policy
- There will be one final project. The student selects a special topic in nonlinear optics (can be based on research interests and/or recent publications), writes a short overview on the topic, and presents it in class during the last week of class. The goal is for you and for the other students to learn about other topics in nonlinear optics that we do not cover in our lectures. Discuss your selection of topic with the instructor.
- **Project time-line:**
  - Wednesday, March 10: Project description given.
  - Friday, March 26: Project topic picked.
Friday, April 23: Project write-up due by end of day.

Wednesday, April 28 3:00-4:50pm: In-class presentations.
- The write-up and the presentation each count toward 10% of the course grade. As such, the expected amount of work (write-up + presentation) is roughly that of 4 problem sets.
- **The write-up should be 2-4 pages**, in a single-spaced double-column style like a journal paper.
- **Each presentation will be 10 minutes + 2 minutes for questions.**
- The final project will be graded based on (1) whether the topic and the amount of work is appropriate, and (2) clarity and effectiveness of the presentation and write-up. Novelty/originality is not required.
- **If you cannot make the scheduled time of the final project presentation, you must notify and discuss with the instructor before Feb 5 (the last day to drop a class without a W on the transcript).**

**Exam Description & Policy**
- **Midterm Exam**: 8am Friday 3/19 – 8am Saturday 3/20.
- **Final Exam**: 8am Monday 5/10 – 8am Tuesday 5/11.
- The exams will be posted on Blackboard under the Exams tab, available at the starting time of the exam. They will be due 24 hours later, to be submitted by uploading a PDF of your solution under the Exams tab.
- These are open-book exams. You are allowed to use: your note, all materials on Blackboard (includes notes and recordings), Boyd's textbook, and Agrawal's textbook. No searching on the internet, and obviously no working together or asking people for help. You will be asked to sign an honor code.
- The exam durations are made to be 24 hours to accommodate students taking the class from different time zones. They should only take you a few hours to finish.
- The scope of the midterm includes all materials up to the midterm. The scope of the final includes all materials over the semester.
- I will be on Zoom to answer questions; you can also email me.
- **If you cannot make the scheduled time of the midterm or final, you must notify and discuss with the instructor before Feb 5 (the last day to drop a class without a W on the transcript).**
- For requests for accommodations due to disabilities, provide letter from the Office of Disability Services and Programs (DSP) to the instructor and TA.

**Grading Timeline**
Problem sets, exams, and project write-up will be graded within two weeks of collection.
**Course Schedule** (28 classes, including 1 for midterm and 1 for final project presentation)

<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
<th>Reading</th>
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<tbody>
<tr>
<td>Week 0</td>
<td>Course info, objectives, and overview. Linear vs nonlinear optics. Superposition principle &amp; light-light interaction. Coupling/decoupling of frequencies.</td>
<td>Boyd 2.1, 1.1</td>
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<td>1/15</td>
<td>Drude-Lorentz model. Anharmonic oscillator. Overview of nonlinear processes. HW 1 assigned.</td>
<td>Boyd 1.4.1, 1.2</td>
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<tr>
<td>Week 1</td>
<td>Susceptibility tensors. Spatial symmetries of $\chi^{(1)}$ and $\chi^{(2)}$. Permutation symmetries. Contracted notation. HW 1 due. HW 2 assigned.</td>
<td>Boyd 1.3, 1.5  Butcher 5.3</td>
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<td>1/20, 1/22</td>
<td>Effective nonlinear coefficients. Maxwell’s equations with nonlinear polarizability. Sum frequency generation (SFG) without pump depletion. Phase matching concept. HW 2 due. HW 3 assigned.</td>
<td>Dmitriev 2.10 Butoy 2.1, 2.2</td>
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<td>1/27, 1/29</td>
<td>Coupled nonlinear wave equations. Manley-Rowe relations. SFG with partial pump depletion. Second harmonic generation with pump depletion. HW 4 due. HW 5 assigned.</td>
<td>Boyd 2.5, 2.6, 2.7</td>
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<td>Week 3</td>
<td>Tensor nature of $\chi^{(3)}$. Intensity dependent refractive index and its polarization dependence. $\chi^{(3)}$ from bound electrons, thermal effects, and in semiconductors. HW 5 due. HW 6 assigned.</td>
<td>Boyd 4.1, 4.2, 4.3, 4.5, 4.6</td>
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<td>2/3, 2/5</td>
<td>Nonlinear Schrodinger equation (NLSE), Gaussian beams. Self-focusing v.s. diffraction. Spatial soliton: qualitative picture, solution in 1+1D and 1+2D, and stability. HW 6 due. HW 7 assigned.</td>
<td>Boyd 2.10, 7.1 Agrawal 3.1, 5.2.2</td>
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<td>2/10, 2/12</td>
<td>Review. Midterm Exam: 8am Friday 3/19 – 8am Saturday 3/20</td>
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<td>Week 6</td>
<td>4/7: USC Wellness Day; no class Raman gain and its threshold. Electrostriction. HW 9 due.</td>
<td>Agrawal 8.1.2 Boyd 9,2</td>
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<td>Week 7</td>
<td>Stimulated Brillouin scattering (SBS). Brillouin gain, its threshold, and effect on fiber optic communications. Raman</td>
<td>Boyd 9.3, 11.1 Agrawal 9.2.1</td>
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<td>3/31, 4/2</td>
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<td>Week 11</td>
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<td>4/14, 4/16</td>
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<td>Week 15</td>
<td>4/28</td>
<td>In-class project presentations on Wed 4/28. 4/30: USC Wellness Day; no class</td>
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<td>Final Week</td>
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<td>Final Exam: 8am Monday 5/10 – 8am Tuesday 5/11.</td>
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**Statement on Academic Conduct and Support Systems**

**Academic Conduct:**

Plagiarism – presenting someone else’s ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in SCampus in Part B, Section 11, “Behavior Violating University Standards” policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on scientific misconduct, policy.usc.edu/scientific-misconduct.

**Support Systems:**

*Counseling and Mental Health* - (213) 740-9355 – 24/7 on call studenthealth.usc.edu/counseling
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

*National Suicide Prevention Lifeline* - 1 (800) 273-8255 – 24/7 on call suicidepreventionlifeline.org
Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.

*Relationship and Sexual Violence Prevention and Services (RSVP)* - (213) 740-9355(WELL), press “0” after hours – 24/7 on call studenthealth.usc.edu/sexual-assault
Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

*Office of Equity and Diversity (OED)* - (213) 740-5086 l Title IX – (213) 821-8298 equity.usc.edu, titleix.usc.edu
Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants. The university prohibits discrimination or harassment based on the following protected characteristics: race, color, national origin, ancestry, religion, sex, gender, gender identity, gender expression, sexual orientation, age, physical disability, medical condition, mental disability, marital status, pregnancy, veteran status, genetic information, and any other characteristic which may be specified in applicable laws and governmental regulations. The university also prohibits sexual assault, non-consensual sexual contact, sexual misconduct, intimate partner violence, stalking, malicious dissuasion, retaliation, and violation of interim measures.

*Reporting Incidents of Bias or Harassment* - (213) 740-5086 or (213) 821-8298 usc-advocate.symplicity.com/care_report
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office of Equity and Diversity lTitle IX for appropriate investigation, supportive measures, and response.
The Office of Disability Services and Programs - (213) 740-0776
dsp.usc.edu
Support and accommodations for students with disabilities. Services include assistance in providing readers/notetakers/interpreters, special accommodations for test taking needs, assistance with architectural barriers, assistive technology, and support for individual needs.

USC Support and Advocacy - (213) 821-4710
uscsa.usc.edu
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

Diversity at USC - (213) 740-2101
diversity.usc.edu
Information on events, programs and training, the Provost’s Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
dps.usc.edu, emergency.usc.edu
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-120 – 24/7 on call
dps.usc.edu
Non-emergency assistance or information.