# PHYS 413/613 Lasers for Scientists and Engineers

## COURSE INFO

**Course prefix, number(s), and title:** PHYS 413/613 Lasers for Scientists and Engineers
**Number of credits**: 3 (*Undergraduate/Graduate*)
**Prereq**: PHYS 252 or graduate standing
**Term and year**: Spring 2017

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## BULLETIN DESCRIPTION

Lecture and laboratory introduction to lasers. Spontaneous and stimulated transitions, line-broadening, gain, gain saturation, optical resonators, Fabry-Perot interferometers, theory of laser oscillation, rate equations, transverse modes, coherence, and Gaussian beams. Prereq: PHYS 252 or graduate standing.

## REQUIRED TEXTBOOK

B. E. A. Saleh and M. C. Teich, *Fundamentals of Photonics,* 2nd Ed., John Wiley & Sons, 2007.

## COURSE OBJECTIVES

The goal of this course is to provide students with the fundamentals necessary to enable them to successfully apply lasers in their respective disciplines. This will be accomplished through hands-on use of state-of-the-art equipment in conjunction with classroom discussions to experience and understand the basic principles of laser operation and the properties of laser radiation.
**Additional graduate student objective:** graduate students will demonstrate the ability to research a laser topic and present it to the class using terminology and concepts learned in the course.

Lasers and their associated technology are crucial analytical tools in many fields of science and have become ubiquitous in manufacturing and local- and world-communications. Laser applications include communication systems, storage media such as CD-ROM, DVD and Blu-ray Disc readers/writers, laser printers/copiers, medical applications, materials processing, metal cutting/welding, isotope separation, laser induced fusion, etc.

This is a 3 semester-credit-hour senior undergraduate/first year graduate level course with minimum course prerequisites (PHYS 252: University Physics II or graduate standing). Lectures will be based on the text *Fundamentals of Photonics, 2nd ed.*, by Saleh and Teich to provide the background required for performing the experiments. The laboratories will be scheduled in three-hour blocks and each laboratory will replace one lecture period. Students will be paired to maximize their hands-on experience. The topics covered will include optical resonators, Fabry-Perot interferometers, Gaussian beams, spontaneous and stimulated transitions (Einstein coefficients), line-broadening, gain of an optical frequency amplifier, gain saturation, theory of laser oscillation, rate equations, transverse modes, and characteristics of common lasers.

This is a required/suggested course for the undergraduate Physics major, Optical Science and Engineering Option, and the undergraduate ECE major, Optical Engineering Option. Courses in the Optics Sequence are: ECE/PHYS 411/611, Optics for Scientists and Engineers; PHYS 413/613, Lasers for Scientists and Engineers; PHYS 415/615, Elements of Photonics; and ECE 417/617, Optical Signal Transmission.

## GRADING

The final grade will be determined as follows:

| PHYS 413 | | PHYS 613 | |
|---|---|---|---|
| Mid-term Exam | 20% | Mid-term Exam | 20% |
| Final Exam | 25% | Final Exam | 25% |
| Homework | 20% | Homework | 10% |
| Seven labs | 35% | Seven labs | 35% |
| | | Project | 10% |

A total average of 89.5% of the possible points or more ensures an A**,** 75.5 to 89.4% ensures a B**,** 59.5 to 75.4% ensures a C, 49.5 to 59.4 ensures a D and below 49.5 will be an F. Depending on the class average**,** curving may be applied to grades; however the **lowest** passing final grade (C or higher) in the course will always be 50% or higher.

The exams will include conceptual questions requiring short answers and quantitative problems similar to the assigned homework problems. The final exam will consist of problems requiring the application of principles learned throughout the course. The Final Exam is **mandatory**.

**Homework Assignments**

Problem solving is the primary learning method for this course. Homework will be emphasized and assigned in groups. You will be assigned to a homework group, optimally 4 members, for the semester. One legible problem solution set per group will be turned in on 8 1/2" x 11" paper ONE SIDE ONLY. SHOW all work. The students in the group may be asked to present and/or discuss their solutions in class. Each group needs to decide on their group rules such as when you will meet, what the consequences are for members that don't show up/contribute, rotation for preparing the solutions to hand in, rotation for presenting solutions in class, etc.

**Lab Reports**

Lab reports are required for all labs except Lab 1. The grading of Labs 1 and 2 will be combined and you will receive the same grade for both.

The laboratories do not correspond to the material covered in the lecture portion of the course but provide an alternative approach to learn complementary material. This hands-on learning approach requires you to also investigate additional parts of the text and other sources.

Lab reports will be submitted using BlackBoard Assignment. Reports are due 1 week after the lab is scheduled to be completed. **Late reports will not be accepted and will result in no credit** (except for exceptional excused delays such as medical or blizzards).

Each student must submit their own report. All students must have a lab notebook, with the pages numbered consecutively, in which all notes and experimental data, including graphs and tables, will

be entered. Think of this as a diary of your work. The suggested notebook is Lab Book Large, 43-581, available in the NDSU Bookstore.

Lab Report Grading Rubric

| Criteria | A | B | C | D |
|---|---|---|---|---|
| Lab notebook | **9 to 10 points** Information entered neatly in ink. Corrections crossed out with a single line. Notes clearly describe what was done as it was accomplished. Graphics or tables generated by computer neatly taped into notebook. | **8 to 8 points** Most information is provided. Neatness could use improvement. | **7 to 7 points** At least one major component is missing or notes are not legible. | **6 to 6 points** Notes have been copied into notebook. They should be entered directly as you work. |
| Lab instructions followed | **18 to 20 points** A clear and correct understanding of the purpose and physics of the experiment is demonstrated. | **16 to 17 points** Some significant aspect of the experiment or theory is incorrect or missing. | **14 to 15 points** Only partial understanding of the purpose and physics of the experiment is demonstrated. | **12 to 13 points** Little understanding of the purpose and physics of the experiment is demonstrated. |
| Data and images | **18 to 20 points** Data/images for every measurement are provided. Data/images are clearly presented. | **16 to 17 points** Data sets are not clearly presented. Images are distorted. | **14 to 15 points** Data sets are incomplete. Images are missing. | **12 to 13 points** Data sets/images are inadequate for determining results. |
| Plotting and fitting data | **18 to 20 points** Best-fit functions are properly chosen and presented as solid lines in your plots. Experimental points are plotted as individual points on the same graph. Axes and legends are properly labeled. Images include a clear caption. | **16 to 17 points** Fits are provided but not fully described. Labeling is not complete. | **14 to 15 points** Labeling and legends are missing. | **12 to 13 points** Fits are not appropriate for data. Images are mislabeled. |
| Lab report questions | **18 to 20 points** Answers are clearly presented. | **16 to 17 points** Some answers are inconsistent or incorrect for the collected data/images. | **14 to 15 points** Significant aspects of the experiment and theory are discussed incorrectly. | **12 to 13 points** Answers are missing. |
| Composition and grammar | **9 to 10 points** Prose is clear and in a logical styles. Words are correctly spelled. Punctuation is correct. | **8 to 8 points** Prose is mostly clear but parts seem out of place or are unsupported. A few misspelled words and/or incorrect punctuation. | **7 to 7 points** Numerous misspellings and words used inappropriately. Sentences are incomplete. | **6 to 6 points** Sentences don't make sense. |

## Additional Requirement for Graduate Students

Graduate student exams and homework will be graded separately. In addition, graduate students will research a laser topic of their choice (that is not covered in class) such as quantum-confined lasers, microcavity lasers, or ultrafast lasers. They will present their topic to the class during the last week of the course and will provide notes to be posted on BlackBoard for distribution to the other students. Their presentation and notes will be graded. Satisfactory completion of this task is mandatory.

Physics 613 Graduate Student Presentation Rubric

| Criteria | A | B | C | D |
|---|---|---|---|---|
| Content | **18 to 20 points** Content appropriate for the course. Detailed content reflecting significant research. Well-integrated citations. May be from course textbook. | **16 to 17 points** Content was mostly appropriate for the course. Content reflecting adequate research. Used appropriate citations. May be from course textbook. | **14 to 15 points** Content was somewhat appropriate for the course. A few significant content errors but general ideas are correct. No appropriate citations. May be from course textbook. | **12 to 13 points** Content had little correlation with the course. |
| Planning & Preparation | **18 to 20 points** Manages time well, presentation lasts 20-40 min. Smooth transitions, ideas flow effectively, topic presented in a logical order. Appropriate topic and level for class. Little or no use of technical jargon, all technical words appropriately defined. | **16 to 17 points** Manages time fairly well, presentation slightly outside of 20-40 min. Fair transitions, ideas flow reasonably effectively, fairly easy to follow. Somewhat appropriate topic and level for class. Some use of technical jargon, all technical words defined. | **14 to 15 points** Presentation well outside of 20-40 min. Choppy transitions, somewhat difficult to follow. Topic too simple or complex for class. Use of technical jargon, technical words not defined. | **12 to 13 points** Hard to understand presentation. Preparation was incomplete or hastily done. |
| Subject Knowledge | **18 to 20 points** Clear, complete and accurate explanation of physics concepts. | **16 to 17 points** Parts of explanations had gaps in clarity, completeness or accuracy. | **14 to 15 points** Much of explanations had gaps in clarity, completeness or accuracy. | **12 to 13 points** Did not understand topic. |
| Lesson Notes | **9 to 10 points** Comprehensible to average 413/613 student. Sufficient information for students to follow presentation. | **8 to 8 points** Somewhat disorganized but contains necessary details for students to follow presentation. | **7 to 7 points** Descriptive but too much or too little information is presented. | **6 to 6 points** Notes delivered too late to post on BlackBoard before presentation. |
| Use of Visual Aids | **9 to 10 points** All visual aids (PowerPoint and blackboard) are relevant to the topic or support the presentation. Easy to read and understand. | **8 to 8 points** Most visual aids (PowerPoint and blackboard) are relevant to the topic or support the presentation. Most are easy to read and understand. | **7 to 7 points** Visual aids (PowerPoint and blackboard) are not very relevant to the topic. | **6 to 6 points** Missing or difficult to read and understand. |
| Delivery | **9 to 10 points** Clear and engaging. Nearly continual use of direct eye contact with audience, seldom used notes. Easy to hear. | **8 to 8 points** Relied heavily on notes. Some direct eye contact. | **7 to 7 points** Parts of the presentation were difficult to hear or understand. Occasional eye contact with audience. | **6 to 6 points** Entire presentation was difficult to hear or understand. Not much eye contact with the audience. |
| Answering Questions | **9 to 10 points** Answered all questions clearly and completely. | **8 to 8 points** Answered nearly all questions clearly and completely. | **7 to 7 points** Had trouble answering questions. | **6 to 6 points** Did not answer questions. |

## COURSE SCHEDULE

Tentative Course Outline

| Lesson | Saleh/Teich | |
|---|---|---|
| 1 | 10.1 | Resonator modes |
| 2 | 10.1 | Losses and resonance spectra width |
| 3 | 1.4 | Matrix Optics |
| 4 | 10.2 | Spherical-mirror resonators |
| 5 | 3.1 | The Gaussian beam |
| 6 | 3.1B | Properties of the Gaussian beam |
| 7 | 3.2 | Transmission through a thin lens |
| 8 | 3.3 | Hermite-Gaussian beams |
| 9 | 10.3 | Two- and three-dimensional resonators |
| 10 | 10.4 | Microresonators |
| 11 | 13.1 | Energy levels |
| 12 | 13.2 | Occupation of energy levels |
| 13 | 13.3 | Interactions of photons with atoms |
| 14 | 13.4 | Thermal light |
| 15 | 13.5 | Luminescence and light scattering |
| 16 | 14.1 | Theory of laser amplification |
| 17 | 14.2 | Amplifier pumping |
| | | Mid-term exam |
| 18 | 14.3 | Common laser amplifiers |
| 19 | 14.4 | Amplifier nonlinearity |
| 20 | 15.1 | Theory of laser oscillation |
| 21 | 15.2A | Characteristics of the laser output: Power |
| 22 | 15.2B | Characteristics of the laser output: Spectral distribution |
| 23 | 15.3 | Common lasers |
| 24 | 15.4AB | Pulsed lasers |
| 25 | 15.4CD | Q-switching and mode locking |
| 26 | 16.1AB | Semiconductor physics background |
| 27 | 16.1CD | Electron and hole concentrations, generation, recombination, injection |
| 28 | 16.1E | Junctions |
| 29 | 16.2AB | Photon interactions in bulk semiconductors |
| 30 | 16.2C | Absorption, emission, and gain in bulk semiconductors |
| 31 | 17.1 | Light-emitting diodes |
| 32 | 17.2 | Semiconductor optical amplifiers |
| 33 | 17.3 | Laser diodes |
| 34 | | Graduate student presentations |
| | | Laser safety |
| | | Final Monday May 8, 10:30 am to 12:30 pm |

Tentative Laboratory Schedule

| Lab Number | Topic |
|---|---|
| 1 | Setting up an open cavity HeNe laser (no report) |
| 2 | Characterization of open cavity HeNe laser |
| 3 | Gaussian optics with beam profiler |
| 4 | Laser beam expansion |
| 5 | Spectral characterization of light sources |
| 6 | Laser diode/LED characteristics |
| 7 | Scanning Fabry-Perot interferometer |

## ATTENDANCE STATEMENT

According to NDSU Policy 333 (www.ndsu.edu/fileadmin/policy/333.pdf), attendance in classes is expected.

Veterans and student service members with special circumstances or who are activated are encouraged to notify the instructor as soon as possible and are encouraged to provide Activation Orders.

Students are expected to attend all class sessions except for valid excuses such as medical situations. Active participation in lectures is essential. Students are expected to read the lesson prior to coming to class and to be prepared to discuss it in class. Material may be presented that is not in the text or it may be presented in a different way. Students are responsible for all material presented in class including that missed during excused absences. Attendance at exams is mandatory unless excused for a valid University approved reason.

## BLACKBOARD

Course assignments, lesson notes, information, and messages will be posted to Blackboard: http://bb.ndsu.nodak.edu/.

## GRADUATE SCHOOL STATEMENT

The 613-level version of this class is a graduate level course and is subject to the General Policies of the Graduate School: https://bulletin.ndsu.edu/graduate/graduate-school-policies/#supervisorycommitteeplanofstudytext.

## AMERICANS WITH DISABILITIES ACT FOR STUDENTS WITH SPECIAL NEEDS

Any students with disabilities or other special needs, who need special accommodations in this course, are invited to share these concerns or requests with the instructor and contact the Disability Services Office (www.ndsu.edu/disabilityservices) as soon as possible.

## ACADEMIC HONESTY STATEMENT

The academic community is operated on the basis of honesty, integrity, and fair play. NDSU Policy 335: Code of Academic Responsibility and Conduct applies to cases in which cheating, plagiarism, or other academic misconduct have occurred in an instructional context. Students found guilty of academic misconduct are subject to penalties, up to and possibly including suspension and/or expulsion. Student academic misconduct records are maintained by the Office of Registration and Records. Informational resources about academic honesty for students and instructional staff members can be found at www.ndsu.edu/academichonesty.