6.161 - Modern Optics Project Laboratory
Course Information and Syllabus - Fall 2011

The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them. - Sir William Bragg

1. Overview

6.161 offers an introduction to laboratory optics, optical principles, and optical devices and systems. This course covers a wide range of topics, including: polarization properties of light, reflection and refraction, coherence and interference, Fraunhofer and Fresnel diffraction, holography, imaging and transforming properties of lenses, spatial filtering, two-lens coherent optical processors, optical properties of materials, lasers, electro-optic, acousto-optic and liquid-crystal light modulators, optical detectors, optical waveguides and fiber-optic communication systems.

Most optical systems involve the use of many of the principles and components we will study. The goal is to help the student develop a thorough understanding of the underlying physical principles of modern optical devices and systems through hands-on learning. Lectures are supplemented with weekly laboratory exercises, problem sets and a final laboratory project of the student's choosing. There are 12 design points associated with this subject. Students may use this subject to find an advanced undergraduate project.

In general, there are two lectures and one laboratory period each week for the first eight weeks. During the first several weeks, the lectures will review and develop fundamental principles and concepts in classical optics, and optical and quantum electronics. The remaining lectures address contemporary topics in modern optics.

Since this is a laboratory course, the intent is not to dwell on detailed theoretical treatments of the topics, but to provide a sufficient background for the student to grasp the principles and confirm the associated phenomena in the laboratory. For more theoretical treatments the student is encouraged to enroll in other optics subjects that are specifically designed for this purpose (e.g., 6.630, 6.631, 6.634, and 6.637).

Prerequisites: The prerequisite is 6.003. Exceptions can be made by the Lecturer.
Lecture: Room 34-304, TR 2:00-3:30pm
Laboratory: Optics Lab: 38-633, Time TBA. Optics Lab Phone: x3-4619 (Note: we share the lab phone with 6.115, 6.003, and 6.002).

Course Staff

Lecturer: Prof. Cardinal Warde
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Writing Program Coordinator: Dr. Don Unger; donunger@mit.edu; 12-112; Ext. 4-2371
Course Secretary: Monica Pegis; Room13-3058; Extension 3-3282
Course Website: http://web.mit.edu/6.161

2. Safety

Why put safety at the top? Because it is EXTREMELY important. We strongly urge you to always follow prescribed safety instructions. If you are unsure about anything, especially when dealing with high-intensity light sources (such as lasers) or with high-voltage power supplies (such as those found powering lasers or other laboratory equipment), ask someone who knows (viz., the lab staff). You will receive training on how to deal with lasers and optics, and high voltage sources. However, some basic pointers to remember are listed below. More detailed information is provided in the Laboratory Safety Packet, which will be handed out during the second scheduled class. Additionally, **you will be required to attend a laboratory safety training lecture and take a safety quiz to work in the laboratory**.

Some of the experiments require the use of class 3B and class 4 lasers. For example, the lasers used in the holography lab (3B by output power) and most lasers that you may build as final projects (class 3B/4 by power or wavelength). To meet MIT EHS safety requirements all undergraduates taking the class must complete the laser safety training class. Any graduate student who would like to participate in labs involving our higher-power lasers must also complete the laser safety training class.

To sign up for a class, go to: http://web.mit.edu/sapwebss/PS1/training_home.shtml . The laser safety module can be found under “Radiation safety”. Finally choose the session for which you want to register. The TA will provide more detailed instructions, if necessary.

2.1 Summary of Laser Safety Requirements

1. Never look directly into a laser source, even low-power lasers can blind!
2. Keep track of all stray light (and then block it).
3. Keep all high-intensity light beams at table-level.
4. Always keep your eyes a couple feet above table level. If you violate this exclusion zone, you will be asked to either leave the laboratory for the day, or you will be excluded from working on your project or laboratory exercise.
5. Wear safety glasses when appropriate. You MUST wear them when working with IR and UV laser light, as well as with mercury discharge lamps and strong light sources.
6. Keep your colleagues notified - tell them what you are doing so that they may protect themselves (and you). Always notify them if you turn on a laser or change the direction of the beam. Precautions also include closing the laboratory door, closing the window drapes (if appropriate), as well as turning on the laser warning light (light switch behind the chemical cabinet).
7. Always listen to the suggestions of the laboratory staff and your colleagues.
8. Keep your optics (lenses, mirrors, beam splitters) clean to reduce scattered light
9. Practice good common sense.
10. Institute policy requires that all persons working with high-voltage work in pairs. (see high voltage safety requirements below).
11. No drinking or eating is allowed in the lab. Hands must be washed before handling optics or electronics.
12. You may not work in the lab without supervision of an LA or a TA until final-project time. During final-project time you must work in pairs (only the TA, LA or lecturer may ever be in the lab alone).
13. Cell phones (except for the lab staff) are not allowed to be turned on inside the Modern Optics Lab.

14. Always inspect optical fiber carefully - bare fiber can easily puncture your skin or eye!

2.2 Summary of High Voltage Safety Requirements

1. **SHIELDING**: Live parts of all electrical equipment must be completely enclosed or otherwise guarded against accidental contact.
2. **INTERLOCKING**: Where continual maintenance or adjustments must be performed, enclosing shields must be provided with interlocks which will disconnect all power to conductors and short out capacitors when the shield is removed or opened.
3. **DISCONNECTS**: Provide an accessible, labeled main power disconnect switch.
4. **GROUNDING**: Ground all exposed non-current carrying parts. (Metallic optical table tops should be grounded to the nearest water pipe.)
5. **BONDING**: All grounded parts must be bonded to each other to keep them at the same grounded electrical potential.
6. **INSULATORS**: Adjustment mechanisms must be insulated from live electrical parts or be made of nonconductive material.
7. **SPACE**: A minimum of 30 inches width should be maintained on all working sides of equipment operating at 600 volts or less; 36 inches if over 600 volts.
8. **WORKING ALONE**: Working alone at any time is contrary to Institute policy.
9. **CPR**: It is recommended that all persons working with high voltage have training in cardiopulmonary resuscitation, available through the Safety Office, through the American Red Cross or through the American Heart Association.

Note: Violation of safety rules, if severe enough, may lead to automatic dismissal from the class. Such dismissible offenses include roughhousing, as well as moderate or serious injury due to careless action. Severe safety violations may lead to an automatic failing grade as well as possible action by the Institute or even possible criminal liability. Some general rules follow:

For minor safety violations, you will receive a warning. After two warnings, you will be asked to leave the lab and come back on the next lab day (if it exists). If you are asked to leave due to an accumulation of minor safety violations (more than twice), you will receive an incomplete for the current lab, and therefore will not be able to receive a passing grade for the class.

Safety violations can be caused by a lack of sleep, drug use (antihistamines, pain killers, alcohol, etc.), or emotional strife (daydreaming, family illness, etc.). Therefore, temporary dismissal from the lab is not meant to be punishment, but rather an opportunity for you to remedy what ails you. You may discuss your temporary dismissal with the lab staff AFTER the lab day. However, no excuses or arguments will be accepted at the time of dismissal - arguing will only result in disciplinary measures. So far, we have never had to dismiss a student for safety violations... please don't be the first.

3. Course Content

3.1 Laboratory Exercises

There are seven laboratory exercises concerned with the measurement and observation of basic optical and quantum phenomena. Each laboratory exercise consists of pre-lab exercises (to be completed before entering the lab) and several experiments dealing with the same theme, designed to complement the lecture material. The course staff will set up each laboratory exercise for one week only, and you must complete each laboratory exercise sometime during the week that it is set up. Some of the laboratory exercises require a considerable amount of setup time, and once taken apart, will not be set up again.

To make the laboratory exercises flow smoothly, please arrive on time for your assigned lab sessions. Additionally, please come prepared: this means that you will have: (1) read the lab material before arriving, (2) completed the pre-lab, and (3) brought your questions with you. As part of the pre-lab, you must find and review the material necessary to complete the lab before you begin. In order to ensure that you will have all the data you need for your write-ups, **you will be required to take notes in a laboratory notebook.** More information as to laboratory write-up specifics will become available during the first week of the term.

For all labs, write your answers in your lab notebook, and be prepared to discuss them in your oral presentations to the TA. **Be sure to include derivations, solutions, graphs, diagrams, data, and physical explanation when answering the lab questions. Be sure to include copies of any computer print-outs.** These notebooks may be checked at any time by the TA or professor to make sure they contain all necessary information. A well-kept notebook will help ensure that you not fail to gather all the necessary data for your write-up (as you may not be able to come back and retrieve the data before the apparatus for a given laboratory exercise has been dismantled). Additionally, short oral quizzes may be given in the lab to test your comprehension of the current laboratory material -- these quizzes or notebook checks can count toward your laboratory grade in borderline cases.

For the **odd-numbered laboratory exercises (1, 3 and 5) the laboratory report will be in oral form**. The same amount of care and preparation must go into these oral reports as if the reports were written. For each of these oral reports, each student will prepare a 10-minute Power-Point Presentation that addresses all of the topics that would have been covered in a fully written report. These oral reports will be scheduled by appointment with the TA and they must be completed within one week after the laboratory work is done.

The written laboratory exercise reports for the even-numbered exercises (2, 4 and 6) **must** be turned in to the Teaching Assistant (TA) one week after the exercise was scheduled. In the event the report is due on a day when the Institute is closed, the report should be turned in to the TA by 5:00 pm on the first day that classes resume whether or not the Laboratory is open on that day. This may be a day when 6.161 does not meet. Late laboratory exercise reports should be handed directly to the TA.

3.2 Homework Problems

One homework problem set will be handed out each week for the first 8 weeks of the term. The homework problems are designed to encourage outside reading, and to strengthen your grasp of the fundamentals. How you got to your answer is very important. Show your work! The grader will deduct points for answers which lack justification. Problem sets will not be accepted after the solutions are handed out. Points will be deducted for late problem sets. Late homework should be placed in the bin outside 13-3102 or handed directly to the TA.

3.3 Quizzes

There will be two quizzes during the term. The quizzes will be given during the regular class period (see class calendar). These quizzes will cover broad ideas, as presented in lecture, lab, and homework. The quizzes will consist of short questions intended to test your knowledge of basic optical principles and laboratory optics. These quizzes will be open book (Prof. Warde's class notes). If you have done the reading, attended the lecture, completed the homework, and worked the labs, you should be well prepared for the quizzes. **The quizzes will count for approximately 20 % of your grade (10 % each).** These quizzes will enable the teaching staff to diagnose both our teaching and your comprehension.

3.4 Final Project

To make all the final projects roughly equal in difficulty and time requirement, we will provide you with several possible final projects (which will still allow for, and require, innovation). Additionally, we will allow students to start the final project as soon as they want, hopefully reducing end-of-the-term stress. We will provide the necessary lab equipment and all the technical help we can to ensure that your experience is both educational and rewarding. Of course, if you still want to find your own project, or have a hankering to do something different, just tell us and we will try to accommodate you (in such a case, we would encourage you to look around MIT for groups that may have projects that interest you). Many final projects found outside of class turn into RAships and M.Eng. theses. Additional information will be distributed around the sixth week of the term. The written report (see *CIM requirement*) for the final project should not exceed 30 pages in length.

4. CIM Requirement

4.1 Specifics

There are three special assignments for which formal write-ups are required: Laboratory exercise No. 2 (interferometry), laboratory exercise No. 4 (holography) and the final project report. Laboratory report No. 2 will be graded for its technical merit by the MOL staff and then it will be submitted to the Writing Program staff who will read it for its communication effectiveness and provide feedback to you. No grade for the writing component of the report will be assigned. Thus you can practice your writing skills without penalty.

Laboratory exercise No. 4 will be graded by both the MOL staff (for technical content) and the Writing Program staff (for communication effectiveness) and feedback will be given. **Your Lab 4 report must then be revised and resubmitted** to the Writing Program. The Writing Program staff will assign a final grade based on the revised report.

The final project report will also be graded for its clarity and completeness, but there will be no opportunity to rewrite the final project report. Further, all students must give an oral presentation on their final project towards the end of the course. This oral presentation will be graded for its communication effectiveness, as part of the final project report grade. The communication intensive portion of this subject counts for about 20% of the overall grade (see grade distribution table in Section 4).

A suggested format for writing the formal reports is given below. Alternatively, you can follow the guidelines provided by the Writing Program. In both cases, the lab exercise reports should be limited to a maximum of 15 single-spaced pages with fonts no smaller than 10 point. The final project report should not exceed 30 pages.

4.2 Writing the Formal Reports

The three formal reports must be written in accordance with the outline provided below, or that provided by the Writing Program. Alternatively, you may use the outline followed by most professional journals in the field (e.g., Applied Optics or Journal of the Optical Society of America). Your laboratory exercises and project reports must therefore contain, at the very least, the following information:

1. A cover page which states the title of experiment, your name, subject number, the date, and the name of the person who supervised your work.
2. A one-paragraph **Abstract** that states the problem being addressed or the goals of the research, the procedures used to solve or analyze the problem, and the salient findings, conclusions or implications of the work.
3. An **Introduction** that contains a brief description of the problem being investigated as well as brief background information to familiarize the reader with the significance or importance of the work to the field. Be sure to define all uncommon terms.
4. A section describing the **Approach** used. This section should briefly describe the general techniques or methods used to explore the phenomena being investigated. It may, therefore, include a brief theoretical formulation or modeling of the problem. For brevity, you should cover the principles at a level such that one with a similar educational background (MIT junior or senior) can follow your reasoning. Do not rederive complicated equations. Instead you should state the equation, cite the reference (see 8 below) where one can find the derivation, but interpret each term in the equation so the reader can understand the physical concepts involved.
5. A brief description of the apparatus used, followed by your **Experimental Procedure**. Use as many diagrams as you need to describe the apparatus and its operating principles, and how the data were taken.
6. A section describing your **Experimental Results and Analysis**. Present raw data, whenever possible, in tabular form, and derived results or analysis, whenever possible, in graphical form.
7. A section summarizing your **Conclusions** with comments on the errors in your measurements, and recommendations for improving the measurements or the experiment. Your conclusions should also tie in to the stated objectives of the experiment so that the reader gets your opinion of the overall success of the work. This is also a good place to speculate on the potential applications of your work.
8. A list of **References** that support claims made in your report.

If still in doubt, use the bold-face words above as section headings in your reports.

5. General Policies

5.1 Grades and Grading

The laboratory exercises are an integral part of 6.161, constitute the majority of your learning, and thus the final grade. Homework problem sets make up a significant portion of the final grade. The two quizzes are obviously important since they represent 20% of the grade. Your performance on the Final Project is also a very important portion of our evaluation of your overall performance. The approximate percentage values are as follows: **40% Labs (includes active participation in lab, performance on pre-lab, good laboratory notes, and the communication component), 20% Homework, 20% for the in-Class Quizzes, and 20% Final Project (including the communication component)**. The table below summarizes the grading algorithm. We will take into account participation in the classroom and in the laboratory as well as attendance when deciding borderline final grades.

<table>
<tr><th rowspan="2">Assignment</th><th colspan="5">% of Grade</th></tr>
<tr><td colspan="2">Technical</td><td colspan="2">Written</td><td>Oral</td></tr>
<tr><td>Lab 1</td><td colspan="2">5</td><td colspan="2">0</td><td>1</td></tr>
<tr><td>Lab 2</td><td colspan="2">6</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>Lab 3</td><td colspan="2">5</td><td colspan="2">0</td><td>1</td></tr>
<tr><td>Lab 4</td><td>3</td><td>3</td><td>2</td><td>2</td><td>0</td></tr>
<tr><td>Lab 5</td><td colspan="2">5</td><td colspan="2">0</td><td>1</td></tr>
<tr><td>Lab 6</td><td colspan="2">6</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>Lab 7 (in class)</td><td colspan="2">0</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>Homework</td><td colspan="2">20</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>Quizzes</td><td colspan="2">20</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>Final Project</td><td colspan="2">12</td><td colspan="2">5</td><td>3</td></tr>
</table>

Please note: To earn a passing grade (A, B, C) in this subject, you must complete and either write up or present each of the six laboratory exercises within the prescribed time period. Thus, at the end of the term no incompletes will be given due to incomplete lab reports! Also, since most students do well on both the labs and the Final Project, performance on both the problems sets and quizzes become an extremely important factor in determining the final grades.

Note from the TA: Please do not become discouraged if your score on the first lab seems low. Lab 1, while it does count as part of the final grade, should be viewed as a steppingstone into the course. Just do the best you can on this Lab. Assume nothing, and be very thorough! Do not assume that the TA knows how you arrived at your answers. Assume the TA has never taken this class, and thus needs a full and detailed explanation. While you may have the correct answer, how you got there is more important! **You will not receive credit for answers without explanation.** The TA will only grade your lab report if you showed up to lab and actively participated in the lab experiments.

5.2 Neatness and Clarity

To ensure that you get the maximum number of points on each Lab and homework assignment, make sure to be neat! The TA or grader will not grade messy work. Additionally, messy work will delay turnaround on both problem sets and homework. Questions on both problems sets and labs must be answered clearly and succinctly. The TA will be looking for demonstrated understanding. It is preferred that you explain in words when possible; this will ensure that you get the maximum number of points for your effort. However, do not neglect mathematical rigor. When math is needed, it must have the proper units and be clearly written. The TA and a grader grade all labs and homework; the more clear and succinct your answers, the better. However, do not compromise important details. The grader will not accept numerical answers without their derivation. Likewise, the grader will not accept written answers, without appropriate reasoning.

5.3 Labeling and Formatting

Whenever a problem asks for a graph, the student must create computer-generated graphs. All graphs must be labeled and titled - a copy of the graph must be transferred to your lab notebook or your homework problem solution. Use callouts to point out important regions of your graphs. Any written answers exceeding one page must be typed. It is suggested that you format all your answers using LaTeX or a comparable typesetting package.

Label your answers clearly; the grader will not search extensively for an answer. Circle your answers, and underline key portions of your work which directly aid in the creation of the answer. Points may not be given back if an answer is skipped in the grading process because the answer was difficult to find.

5.4 Matlab, Mathematica, LabView and Maple

When computer-based problems are presented, please use Matlab, Mathematica, LabView or Maple to do your work. If you feel much more comfortable with other math packages, that is okay, but please put the code in your public directory along with instructions on its execution. You can download homework-specific Matlab scripts and Matlab notebooks from the website for this class. Please include any code and graphs you use in your solutions. Often, unless stated, graphical solutions may be used, especially if they show that you really understand the material. To use Matlab, Mathematica or Maple on Athena, type: `add matlab`, `add math`, and `add maple` at the Athena% prompt.

5.5 Late-Work Policy

Having been an undergraduate once, your TA knows that many of you have obligations which inhibit your ability (on rare occasions) to turn in work on time. If such an emergency arises, notify the TA before the homework is due (if possible). In order to be fair to your classmates, we must still penalize late work (unless the tardiness was due to medical or similarly urgent reasons). Additionally, an incomplete problem set will not be accepted. We expect you to make an effort on ALL parts of ALL problems. This gives us the chance to see where you are having problems, if any. If you need additional time, ask for it. You will always receive more points for a completed late problem set than an on-time incomplete one (assuming you turn it in before solutions are handed out). If tardiness becomes a chronic problem, it will significantly degrade our final evaluation of your performance.

5.6 Collaboration

Collaboration is encouraged. Talking with peers about problems helps everyone ("*To teach is to learn twice*." – Joseph Joubert). However, blatant copying and other forms of cheating will not be tolerated. Always acknowledge your collaborators. This will not hurt your grade. In fact, it may help. We care that you learn the material. If you learn it best from a friend, that is fine.

5.7 Plagiarism

While collaboration is encouraged, plagiarism will not be tolerated. Please become familiar with the various forms of plagiarism so that you avoid making embarrassing and perhaps costly mistakes. Here are two MIT websites where you can learn more about plagiarism:
http://web.mit.edu/writing/Citation/plagiarism.html

http://web.mit.edu/academicintegrity/handbook/handbook.pdf

5.8 Office Hours

Group office hours will be conducted weekly in Prof. Warde's office. Office hours will address questions from the laboratory exercises, quizzes, and problem sets. Office hours may also include hands-on demonstrations of applied concepts. While office hours are not mandatory (except to deliver oral presentations of your laboratory exercises) they may cover concepts and material that may show up on quizzes, homework and labs. Students are expected to ask questions and come to office hours prepared.

6. Textbooks and Reading Materials

A combination of class notes and lecture slides will be provided on each topic we will cover. However, several of the basic concepts are covered in the following textbooks:

1. J. W. Goodman, *Fourier Optics*, 3rd Edition, Roberts & Co., 2005
2. A. Yariv, Optical Electronics in Modern Communications, 5th Edition, Oxford University Press, 1997.
3. B. Saleh and M. Teich, *Fundamentals of Photonics*, Wiley, 1991.
4. E. Hecht, *Optics*, 4th Edition, Addison Wesley, 2002.
5. M. Born and E. Wolf, *Principles of Optics*, 5th, 6th, or 7th Edition, Pergamon Press, 1980.
6. F.A. Jenkins and H.E. White, *Fundamentals of Optics*, 4th Edition, McGraw Hill, 1976.

We recommend you purchase the book by Hecht. Hecht's *Optics* can be purchased at the Coop or Quantum books (Quantum sometimes offers lower prices). Purchase of the other textbooks is not essential. These books are on reserve in the Barker Library - but occasionally disappear during the term (especially when problem sets are due). They are intended for use as reference material. Please note that Hecht is a required book for 8.03, and Saleh is recommended for 6.631.

Portions of the material we will cover can also be found scattered throughout a number of journals and conference proceedings that include:

Journal of the Optical Society of America
Applied Optics
Optics Letters
Applied Physics Letters
Optics Communications
Optical Engineering
Proceedings of the SPIE (Society of Photo-Optical Instrumentation Engineers).

Occasionally, students will be expected to read and apply material covered in articles selected from these journals.