PHYS 330L, Optics Laboratory

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Office hours

My official office hours are Tuesdays and Thursdays, from 11:30am - 12:30pm. In addition, I will be in the PHYS330L Optics Labs on Tuesdays and Thursdays from 1:00 - 5:15 pm. Please feel free to call or e-mail me to set up an appointment for discussions at any other times, or simply drop by my office to see if I'm available.

Laboratory times and location

PHYS330L, Section 0101: Tuesdays, 1:00-5:15 pm (Physics 213/214)
PHYS330L, Section 0102: Thursdays, 1:00-5:15 pm (Physics 213/214)

Course overview

Optics is one of the most exciting and rapidly developing areas of experimental physics. Recent discoveries in optics have led to dramatic advances in areas ranging from astronomical observations to cutting-edge academic-research in quantum information. In addition, optics continues to enhance our lives through more practical applications such as advances in medicine, and bringing the internet to our homes and dorms.

Despite the growing complexity of these applications, optics remains rooted in beautiful basic principles and ideas. In this course, we will perform 9 experiments that will provide hands-on experience as a way of learning much of the basic physics of optics. This should provide a solid foundation for future growth, learning, and contributions to the world through your own innovations in optics. The course will also help to develop your technical writing skills and your ability to verbally communicate scientific information.

In my opinion, one of the best perks of being a Physics student at UMBC is the ability to participate in laboratory courses. This is *your lab*…please take full advantage of all that it has to offer. Tinkering, exploring, and thinking outside-of-the-box are highly encouraged! Who knows…perhaps you'll make a new discovery in the lab and win the Nobel prize!

Learning outcomes assessment

There are a number of specific educational objectives for physics students at UMBC. The two specific educational objectives that will be assessed in 330L are:

1. The ability to design and carry out experiments using modern equipment, and analyze and interpret experimental data

2. The ability to communicate scientific information effectively, both verbally and in writing

Writing intensive program

PHYS 330L has been designated as the Writing Intensive (WI) course in the standard Physics curriculum. The basic idea is to give you an opportunity to learn technical writing skills for scholarly research in experimental physics. The primary mechanism for learning these skills is through writing up lab reports for all the experiments that you will perform throughout the semester.

We will spend time during our class lectures discussing technical writing in physics, and you will be given feedback on each of your reports. Due to the fact that the general structure of the reports will be fairly similar, this feedback will give you a chance to revise and improve your technical writing skills as the semester progresses. You will also have specific opportunities to rewrite two of the lab reports in an effort to increase your grade. As outlined in the grading section your lab reports are worth 80% of your course grade.

Course logistics

The course is divided into two *Sessions*:

First Session Experiments	Second Session Experiments
1. Lenses	6. Diffraction and Gratings
2. Index of Refraction	7. Polarized Light
3. Speed of Light	*8. Holography*
4. Michelson Interferometer	9. Laser Gyro
5. Interference in Thin Films	

On the first day of class, we will establish research teams for the First Session. Each team will consist of 2 or 3 students. Each research team will perform one experiment each week. It is important to prepare for the experiments by reading the relevant lab manual and reference material and to complete your pre-lab summaries *before arriving at the lab each week*. This will allow you to dive right in and maximize your enjoyment of the laboratory experience.

At the end of the First Session, *we will establish new research teams for the Second Session.* In other words, your "lab partners'" will change. This has the potential drawback of dissolving enjoyable and fruitful teams, but will reduce the probability of someone being stuck in a dud team for the entire semester. In any event, the ability to work in research teams with a variety of people and personalities is a valuable skill to develop for real-world research.

At the end of the First Session, we will have a make-up week. At the end of the Second Session, we will have two make-up weeks. The make-up week is a chance to repeat the experiment and lab report associated with your lowest grade, or you feel unhappy about it. Even if you are satisfied with your grades, I would encourage you to attend the make-up week and repeat the experiments which you found most interesting. This can be a great chance to tweak things in a different way, and try to develop new methods for improving results, or investigating new aspects of the equipment and underlying physics.

In addition, at the beginning of each Session, we will have a Lecture class. In the Lecture class, I'll be giving you a brief tour of the five experiments in that Session, as well as mini-lectures describing each experiment. We will also spend a significant amount of time discussing effective technical writing, and specific guidelines for writing your lab reports. You will not be performing the experiments on these days.

Course schedule

Section 0101

Tues 9/5	Session 1 Lectures
Tues 9/12	Session 1 Experiment
Tues 9/19	Session 1 Experiment
Tues 9/26	Session 1 Experiment
Tues 10/3	Session 1 Experiment
Tues 10/10	Session 1 Experiment
Tues 10/17	*Session 1 Make-Up*
Tues 10/24	Session 2 Lectures
Tues 10/31	Session 2 Experiment
Tues 11/7	Session 2 Experiment
Tues 11/14	Session 2 Experiment
Tues 11/21	Session 2 Experiment
Tues 11/28	Session 2 *Make-Up*
Thes 12/5	Session 1, 2 *Make-Up*

Section 0102

Thurs 8/31	Session 1 Lectures
Thurs 9/7	Session 1 Experiment
Thurs 9/14	Session 1 Experiment
Thurs 9/21	Session 1 Experiment
Thurs 9/28	Session 1 Experiment
Thurs 10/5	Session 1 Experiment
Thurs 10/12	*Session 1 Make-Up*
Thurs 10/19	Session 2 Lectures
Thurs 10/26	Session 2 Experiment
Thurs 11/2	Session 2 Experiment
Thurs 11/9	Session 2 Experiment
Thurs 11/16	Session 2 Experiment
Thurs 11/23	No class
Thurs 11/30	Session 2 *Make-Up*
Thurs 12/7	Session 1, 2 *Make-Up*

Course grading

20% of your course grade will based on "class participation", which includes your level of participation in the experimental work, the quality of the experimental work, your pre-lab summaries and lab notebook practices.

80% of your grade will be based on the average of your lab report scores. During the first Lecture, we will spend time going over the grading scale for the lab reports. The grade will be based on a rubric which assigns points to each of the relevant aspects of the lab reports. If you are still struggling with your lab reports after a few weeks, a sample of a well-written lab report can be provided to help you develop a feel for what is required.

Lab Manuals

The laboratory manuals should serve as a guide to your experimental work for each of the experiments. *One of the keys to success in these labs is to pre-read the manual for the experiment you will be performing each week and complete your pre-lab summary*. For consistency, the manuals are all organized as follows:

1. Reference Material: This provides a brief list of recommended reading associated with the experiment. These are listed in order of importance. This list is only a start…there are many other resources which may help you prepare for the lab and write your report. I highly recommend reading at least some of the reference material *before* showing up for the lab.

2. Purpose: This is typically a one or two sentence statement of the primary objective of the experiment. It typically describes the "result" you will try to obtain.

3. Overview and Theory: This section provides the big picture of the experiment. It typically includes a figure or drawing that provides an overview of the apparatus. A theory is then outlined which highlights the physics behind the effects that will be studied and measured. Be sure you fully understand and can derive the equations. If not, ask the TA or instructor for help. The theory will typically end up with an equation relating the desired "result" in terms of parameters you will measure in the lab.

4. Equipment: This provides a list of key equipment to be used in the experiments. However, it is important to emphasize that there are a lot of tools and other equipment that you should feel free to use. If you can devise an alternative way to make a measurement, please try it! If you find yourself thinking "I could do this better/differently if I had this type of wrench, or that type of lens, etc.", please ask. We have lots of stuff in the lab...we've probably got what you are looking for!

5. Procedure: This section provides a *guide* to what actually needs to be done in the lab.

6. Calculations and Questions: This final section asks you to make calculations based on the theoretical equations in the *Theory* section, and the measurements you have made in the *Procedure* section. These will typically be the "results" of your experiment. There are also a series of questions that should be addressed in your lab reports.

Course textbooks

Aside from this laboratory manual, there is no assigned course textbook for PHYS330L. There are, however, 4 textbooks which are highly recommended as resources for the course (they on reserve in the AOK library):

- *Optics* by Hecht
- *Introduction to Optics* by Pedrotti and Pedrotti
- *Fundamentals of Optics* by Jenkins and White
- *Modern Optics* by Guenther.

Lab Notebooks

You are required to obtain a standard laboratory notebook for this course. There are several varieties, but the best ones typically have a brown hard-paper cover, and roughly 100 sheets of ~ 9 1/4 X 11 3/4 inch graph paper. Notebooks without graph paper are unacceptable. *The UMBC bookstore sells these laboratory notebooks for ~$16*; they can also be obtained at many office-supply stores.

These notebooks are an essential part of modern experimental research, and this course will emphasize developing the skills and habits necessary to document original scientific work. It's not easy to get in the habit of writing everything down, but it's incredibly worthwhile. You'll learn this first-hand when you sit down a few days later to write up your lab reports. *Before leaving each week, Your TA need to sign-off on your lab notebooks. What I see is a big part of the "class participation" grade.*

You should make every effort to record and describe everything you are doing (a good model is to assume you will not see the notebook for 10 years, and then want to reproduce your results!). Write down anything and everything that seems important…and even some stuff that doesn't seem important.

At the end of an experiment, your lab notebook should be full of notes, numbers, data, *and lots and lots of figures*. Draw pictures of everything! Some people have even begun to take pictures with a digital camera, print them out and tape them in. The same goes for plots made with mathematics software etc. Figure 1. shows a typical lab notebook, and it's contents.

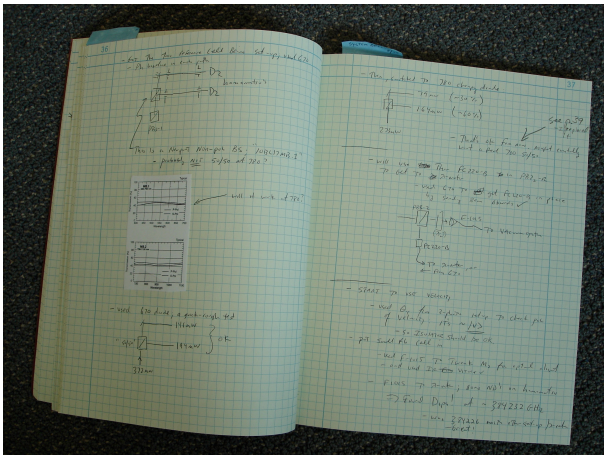

Figure 1. Photograph of a good lab notebook. Note that there are lots of figures, data, and plots. Learning good lab-notebook techniques is an important part of the course!

Pre-Lab summaries

You will write a brief pre-lab summary for all experiments. There is no formal length requirement for these pre-lab summaries, one or two pages long are typical.

*You **must** turn in your pre-lab summary to your Teaching Assistant before starting each experiment. No late summary is accepted. You should keep a copy of your pre-lab summary for yourself. Basically, your pre-lab summary should give yourself a clear guidance about the experiment and the experimental procedure.*

Lab reports

You will write a lab report for all experiments. *Recall that 80% of your grade in the class will be determined based on the average score of these reports.* The Teaching Assistant will be grading the lab reports, and we will both be providing you with extensive feedback. The grading will be based on both the quality of the experimental work, as well as the technical writing. Whereas it is not always necessary to get the "right answer" to receive a high grade, poorly written lab reports will ensure a poor grade. Specific details of the grading method can be seen in the Lab Report Guidelines for PHYS 330L.

You will turn in your lab reports at the beginning of class each week. Late reports will be accepted, but their score will be reduced by 1 letter grade (10 pts) per day.

There is no formal length requirement for these reports, although they will typically be on the order of 3 - 5 pages long. The laboratory reports are to be written for an audience that is assumed to have some scientific background, but has never heard of this particular experiment or ideas.

In addition to a title page, the reports will consist of 4 main sections. The exact titles of the sections, and how you break them into subsections, may depend on the particular experiment you are describing, and the results you are trying to convey. Be sure that the end result is a coherent, and somewhat self-contained document. *Keep in mind that an average reader from your intended audience should be able to understand what is going on solely based on your lab report*. Your writing will need to be extremely clear and concise in order to accomplish this in something like 3 - 5 pages!

The 4 main sections of your lab reports can be loosely described as follows:

1. *Purpose:* This should typically be a one or two sentence statement of the main objective of your work. For example, if your experiment involved measuring the volume of a tennis ball, the Purpose might be something like, "A tennis ball can essentially be thought of as a spheroidal object. In this experiment, we determined the volume of a tennis ball by measuring it's diameter".

2. *Introduction, overview, & theory*: This section of the lab report provides the background and theory needed to understand what you are trying to do in the lab. It may resemble the analogous section in the lab manual, but should typically be much shorter. For example, it is not necessary to entirely re-derive the key equations, unless it seems appropriate. Statements of the kind, "It can be shown that the volume of tennis ball is given by $4/3\ \pi\ r^3$…" are usually

suitable. Nonetheless, it is important to emphasize that the intended audience needs to be able to comprehend the analysis. In many cases, it may be better to provide a simple derivation of key equations. Figures are typically required in this section.

3. *Procedure, experimental details, & results*: This section is the chance to show-off your experimental work. A list of equipment is not necessary, or advised. Rather, describe your equipment and arrangement in the context of the overview and theory. In other words, how did you build something up that let you test the theory and/or make the measurements you needed? For example, statements of the following tone are appropriate: "In order to measure the radius of the tennis ball, we developed a caliper made of rulers and hinges. This allowed us to measure the diameter of the ball, and the radius was determined by dividing this result in half. A graph of our results, as a function of caliper pressure, is shown in Figure 5. We found that the tighter we squeezed the caliper, the smaller the ball appeared. This introduced error into our measurements…''.

   This section should contain also contain the main results of your experiment: "… we measured the volume of the tennis ball to be $(1.51 \pm 0.12)\text{x}10^{-4}$ m^3 ''. Plots of data, analysis, etc. should be included in this section. *Make sure that any tables and figures are clearly labeled, and related to the text.*

4. Discussion and Conclusions: This will typically be a two or three paragraph summary of your work. Keep in mind that a *Conclusion* is typically not the same as a *Result*. For example, a discussion and conclusions might be in the spirit of, "Based on…, we conclude that measuring the volume of a tennis ball with calipers can provide a rough estimate of the actual volume. Our approach could be improved by incorporating a pressure sensor…. A better method might involve submerging the ball and weighing the displaced water…''. (Note: hopefully your conclusions will be much more positive!)

Safety

Although our experiments are very well tested, and we do not anticipate any problems, it is important to realize that we will be working in an active laboratory environment which poses certain risks. **Our primary goal is to ensure our safety in the lab.** Some of the equipment relies on high voltages and current, and proper precautions must be taken at all times. If you are unsure about the operation of *any equipment or tools*, please ask the instructor or TA for help. The basic rule is to be over-careful.

Many of our experiments will involve the use of lasers. **These lasers can cause serious damage to the human eye. Never look directly into a laser beam, no matter how many times it has been reflected. Always wear laser goggles when they are needed. Do not take shortcuts with laser safety**.

1. When using a laser, be sure to turn on the "Laser In Use" sign that hangs outside the lab. This will alert visitors to the fact that a laser is turned on inside the laboratory.

2. Familiarize yourself with the location and contents of the first aid kit. It is mounted on a wall in the Foyer area of Rooms 213 & 214, and contains bandages, cleansers, etc.

3. The labs are equipped with a master "kill switch'". Familiarize yourself with the location of these switches. They are the big red buttons located just inside the laboratory doors. Pushing this button cuts off all power to the room. Don't worry …they do not shut down the entire building! In the event of an emergency, please use the "kill switch'" if appropriate.

Error analysis

Error analysis is a key part of this lab. We will be trying to reduce errors and get the most accurate results that we can. Often times, this means repeating measurements multiple times to reduce statistical error. You are expected to perform error analysis for your results. Results should always be stated in forms like, "my lab partner is (2.0 ± 0.2) meters tall", rather than "my lab partner is about 2 meters tall'".

Understand the difference between instrumental errors, systematic errors, and statistical errors in your experiments. You should use the methods of propagation of error*s* introduced in earlier courses such as PHYS122L. If you are not familiar with these ideas, please ask for help. We have handouts that may be of assistance. In addition, many students find the text *Introduction to Error Analysis*, by John R. Taylor, to be very helpful. A copy of this text is available in the Alvin Meckler reading room in the Physics Building.

Academic Integrity

As with all courses, Academic Integrity is required in PHYS330L:

By enrolling in this course, each student assumes the responsibilities of an active participant in UMBC's scholarly community in which everyone's academic work and behavior are held to the highest standards of honesty. Cheating, fabrication, plagiarism, and helping others to commit these acts are all forms of academic dishonesty, and they are wrong. Academic misconduct could result in disciplinary action that may include, but is not limited to, suspension or dismissal. To read the full Student Academic Conduct Policy, consult the UMBC Student Handbook, the Faculty Handbook, or the UMBC Policies section of the UMBC Directory.

The issue of academic integrity, particularly with regards to plagiarism, can be confusing in writing up lab reports. This is primarily due to the fact that the expectations can be different for different courses.

In this course, I encourage you to work together as a team as much as possible on everything except the actual writing of the lab reports. The lab reports should be written entirely by you.

In other words, I encourage team members to meet and discuss their methods, calculations, and results outside of the lab. Working together on the analysis can be just as important and fulfilling as working together on the actual experiment. In almost all cases, the members of a team will have the same data in their lab

notebooks; It is therefore entirely reasonable that the members of a team will have the same "results". Working together in obtaining these results is encouraged. However, I emphasize that the team members must not share in the writing of the lab reports. Each person must write up her or his lab report by themselves. This is a key part of your educational experience in PHYS330L.

It is also important to include adequate references in your lab reports. If textbooks, journal articles, etc., are mentioned in your report, you should reference these sources. Proper referencing will be an emphasis during the second Session of the course.

Six tips for success in PHYS 330L

Because your grade is primarily based upon your lab reports, your success in the class is only limited by the effort you are willing to give. Some tips for succeeding in this regard are:

1. *Read the lab manual and reference material before you arrive each week.* The experiments can be overwhelming if you are thinking about them for the first time when you arrive in the lab. You should have a good understanding of the basic idea of the lab, as well as a solid grasp of the theory involved. In almost all of the labs, the theory derives a result in terms of a few quantities that you will measure in the lab. If you are comfortable with this before you arrive, you will be able to spend much more time on the precision of your measurements and the quality of your results. This is probably the biggest tip for success in PHYS 330L.

2. *Don't leave too soon*. Often times students will be in a rush to make their measurements, and flee the lab as soon as they are done. Later in the week, they analyze their data and realize that their results are way off! It is a good idea to perform at least a brief analysis of your results *before* you leave. That way, if your results are terrible or don't make any sense, you can debug your methods and re-take the data. Complete error analysis is not really necessary here; just get a quick idea if you did it right or not.

3. *Ask lots of questions*! Take full advantage of the TA and instructor. If something is not clear, do not it slip by. Ask as many questions as you can think of...we appreciate it!

4. *Don't rely on the make-up session*. Chances are you will need the make-up session to repeat an experiment that just didn't work out. Please don't skip a lab thinking you can just make it up. You only get one make-up session…save it for something you really need!

5. *Have fun!* Optics experiments can be extremely rewarding, but also extremely frustrating. Keep a good attitude alive when things aren't going well. Sometimes its just a simple tweak of a single knob that is needed to get back on track.

6. *Tinker and explore.* You'll get a great educational experience even by doing the minimum of what's "required" in the lab manual. However, this lab really is a great opportunity for exploration. We have a lot of equipment lying around; please use it all! Try to develop new methods; tinker and take things apart when appropriate!