Physics 316: Optics Lab

Washington University in St.Louis

Tuesday & Thursday, 1:10 – 5:00pm

Instructor: Ryan Ogliore

rogliore@physics.wustl.edu
http://physics.wustl.edu/people/ogliore_ryan
455 Compton
(314) 935-6140

Teaching Assistant: Lindsey Lisalda

lindsey.lisalda@wustl.edu
https://physics.wustl.edu/people/lisalda_lindsey
123 Crow
(314) 935-7426

Lab Coordinator: Scott Handley

smh@wuphys.wustl.edu
https://www.physics.wustl.edu/people/handley_scott-m
167 Compton
(314) 935-7507

1 Course Description

This is an experimental class dedicated to introduce the physics of optics. We will perform experiments on refraction, interference, diffraction, polarization, and coherence properties of waves with emphasis on light. We use statistical methods to analyze and interpret our experimental data.

1.1 Prerequisites

Physics 117 and 118, or Physics 197 and 198.

1.2 Credit

3 units.

1.3 Textbook

Projects in Optics Workbook, Newport Corporation. This textbook will be loaned to each student enrolled in the class, it does not need to be purchased. It should be returned at the end of the semester in good condition, so please do not write notes in the textbook. **It can also be downloaded as a pdf from Blackboard (under Course Documents)** so you can print it off and write notes on that if you wish. (All lecture slides will also be posted on Blackboard.)

1.4 Complementary Material

- https://physics.wustl.edu/classinfo/316/Docs/errorProp2014.pdf (propagation of errors)
- http://phys.columbia.edu/~tutorial/ (a tutorial on error analysis)
- *Optics*, E. Hetcht, 4th edition. Addison-Wesley (2001). (We have a copy available in the lab.)
- *Physics of Light and Optics*, J. Peatross and M. Ware, BYU (2008) (http://optics.byu.edu/BYUOpticsBook_2008.pdf)
- PhET Interactive Simulations from University of Colorado Boulder
- Optics Simulations from Florida State University
- Optics Simulations from University of Hawaiʻi at Mānoa

2 Course Timeline

Week	Experiments	Project	Lab Report Due (11:59pm)
Week 1–2: Jan 16†, 18, 23, 25	Laws of geometrical optics: reflection and refraction	#1	Monday Jan 29
Week 3–4: Jan 30†, Feb 1, 6, 8	Thin lenses and lens combinations	#2	Monday Feb 12
Week 5: Feb 13†, 15	Expanding laser beams	#3	Monday Feb 19
Week 6–7: Feb 20†, 22, 27, Mar 1	Diffraction of circular apertures and single-slit diffraction	#4 , #5	Monday Mar 5
Week 8–10: Mar 6†, 8, 20, 22 (*)	Michelson interferometer and laser coherence	#6 , #7	Monday Mar 26
Week 11–12: Mar 27†, 29, Apr 3, 5	Polarization of light	#8	Monday Apr 9
Week 13: Apr 10†, 12	Birefringence of materials	#9	Monday Apr 16
Week 14–15: Apr 17†, 19, 24, 26	The Abbe theory of imaging	#10	*Friday Apr 27*

† Lecture in Crow 206
(*) Spring break: March 11–17 2018

3 Course Format

Every Tuesday in which we start a new experiment (dates marked with † above) we will meet at 1:10pm in Crow 305 for a brief introduction of the experiment. Following the introduction, we will go to the lab, Crow 306. Other days we will directly meet in Crow 306 from 1:10 to 5pm. In the laboratory, you will work in pairs, but each student should maintain individual lab notes which will provide the basis for preparation of individual written lab reports. Reports need to be submitted for evaluation following completion of each experiment. During the semester you will carry out 7 different experiments. **Seven completed and graded experiments are required to obtain a passing grade in the course.**

4 Course Objectves

1. *Introduction to optics:* To introduce the main concepts and experimental methods in optical physics. We emphasize the physical principles involved in the experiments and the basic physical phenomena such as refraction, polarization, dispersion, interference, diffraction, and image formation. All experiments are quantitative and usually involve observations, measurements, data analysis and interpretation.

2. *Introduction to experimentation:* To carry out experiments in conjunction with careful data analysis and interpretation. To develop good laboratory practices which, as a rule, are indispensable in any meaningful experimental investigation. These practices include: planning and designing an experiment, adjusting an apparatus for optimum performance, keeping adequate records, carefully analyzing and interpreting data. Finally, good lab practice includes the preparation of a lab report including a clear summary and conclusions section.

3. *Treatment of experimental data:* To analyze experimental data in a more detailed way compared to introductory college-level physics courses. To apply statistical techniques and analysis of data obtained in the lab. In most cases the objective is to calculate the best values of various measured quantities and to determine their uncertainties.

4. *Have fun:* This is supposed to be fun!

5 Grades

The seven graded lab reports are 100% of your final grade. There are no tests or final exam. This course is not graded on a curve. Final grades will be assigned as follows:

Points	**Grade**
90–100%	A
80–89%	B
70–79%	C
60–69%	D
<60%	F

6 Lab Notebooks and Lab Reports

For each experiment, you will take notes in your lab notebook as you proceed through the experiment. This notebook will not be graded. Its only purpose is to allow you to create a formal lab report which you will hand in to be graded. Each person should keep their own notebook, but it is up to you to decide how to structure your notes so that you can accurately describe the experiment and your measurements later. **The formal lab report is due the Monday after the last lab day for that experiment.** See the table under "Course Timeline" for lab report due dates.

6.1 Guideline to Writing Lab Reports

While your lab notebook is for your own use, the lab report should be written so that a third party, not present at the experiment, could clearly understand what you did and replicate the experiment. The lab report should be typed in an editor of your choice, such as Microsoft Word, or even better LaTeX (the document preparation system of choice for professional physicists) for those that are so inclined. Figures can be included in the document itself, or as separate files as long as they have clear filenames which are referred to in the main text.

The lab report should have the following sections:

6.1.1 Objective

In your own words describe briefly the objective of this experiment. Then you should describe what *you* think will happen in the experiement, and what the conclusion will be. This section can be treated as a "thinking aloud" part of the experiment, as it would be performed if it were a gedanken or thought experiment. In other words, your intuitive understanding of how the quantity will be measured should be clearly visible in any description you put down in this section. This section should be brief and in most cases two pages should be sufficient.

To help you in your thought process, you may make a bulleted summary of some of the key steps played out in your mind to carry out the experiment. (At the end of the lab report, you will conclude by comparing the actual steps you took to some of the steps you thought you would take.)

6.1.2 Experimental procedure

Detail the various steps that you feel were necessary to successfully carry out the experiment, with a brief explanation of why the step was required. For example, you may find that leveling of some components was essential and required additional tools, like a liquid level. The steps that you record here need not include the important ones outlined in the experiment handouts. However, if you find that you could or did use an alternate approach, you must record it.

6.1.3 Tabulated list of equipment used

Tabulate the list of items used in the experiment. You do not need to include basic tools like screwdrivers, etc. However, if you find problems or made some modifications to existing tools please record it. It will help us in improving the quality of the tools that we provide.

6.1.4 Schematic sketch of the experimental set-up

Neatly outline a schematic of your experiment. If possible use the notations in the handouts to mark the key dimensions on your drawing. Use similar notations in the collections and analysis of your data to follow. Ensure that the schematic is tidy by using rulers, etc. to make your drawings. A computer drawing program can be used to make the schematics, or you may sketch it by hand, then scan or take a digital picture of the drawing to include in your lab report.

6.1.5 Measurements

Transcribe your data, formulas, derivations, etc. Clearly define the sources of error in your measurement and estimate them. Use metric units, SI/mks or cgs, but be consistent.

6.1.6 Calculations, and analysis

All measurements should be repeated at least 6 times (at least three times by you and three times by your partner). This will aid in estimating errors. For repeated measurements, report the result as the mean $\pm$ the standard error of the mean (error analysis is discussed in the handout, which is also posted on the class website). For calculations that involve multiple such mean values for different variables, the error of the final result will be calculated using the error propagation method. If the values in each measurement differ by more than the associated measurement error, a standard deviation calculation for the repeated measurement results should be performed and used for the error of the final result. The method to obtain the correct number of significant digits for both the final result and its error is also described in the error analysis handout. When your final experimental results disagree with the expected values by more than the propagated error, explain and (even better) quantify possible sources of systematic errors that can contribute to this. Use graph paper or a computer program to plot your data and then digitize the plot for inclusion in your lab report. Use clearly labeled axes (with units) and titles for the graphs. The source and magnitude (e.g. 2σ) of the error bars used must be clearly mentioned. Use the standard error of the mean for error bars of repeated measurements. You can also use least-squares fitting of the data points as described in the error analysis handout.

6.1.7 Results

Succinctly state the main results of the experiment.

6.1.8 Discussion and conclusions

End the report with a brief summary of your experiment and its results. A good format to follow for this section is that of a widely circulated journal like one published by the AIP, for example the Applied Physics Letters. Also add a discussion of your understanding of the experiment. Ideally, you would like to compare the experiment to your original thought and put down the various aspects of it, especially the physics related ones, that you found to be interesting or unanticipated. Add a brief comment or two about any serious problems you had (if any) in performing the experiments.

6.2 Grading Lab Reports

100 points total:

20 pts: *Understanding of the relevant physics*
Write up your understanding of the physics principles of each experiment in the Objective section of the lab report. Use these principles throughout the experiment for data analysis, interpretation, and problem solving.

20 pts: *Laboratory procedures and quality of measurements*
Clearly describe each step of the experiment. You should write your report assuming that someone is going to repeat your work with the same apparatus. Be sure to note everything that could have affected your results or caused problems.

20 pts: *Presentation treatment and interpretation*
Include clear presentation of tables, units and error estimates on all data. If you are calculating a quantity or converting measured values to something else, show an example of the full calculation once.

10 pts: *Error analyses:*
Report all your measurements with uncertainties using either of the methods described in the Lecture #1 slides.

10 pts: *Conciseness and clarity of the laboratory report*
Do not include details that are not relevant to the experiment. Use simple and clear language.

20 pts: *Provide answers to the questions in the text* ***and from the in-class lecture slides (last slide)*** *in the report of each experiment*

-5 pts: *Each day the lab report is overdue*
The lab report is due one week after the last lab day for that experiment.

-10pts: *If equipment is not returned to the original location and stored properly at the end of each experiment*

Meaningful originality and extra work will be taken into account, as will constructive ideas and contributions beyond the requirements. Suggestions for improving the course notes are welcome.

7 Course Policies

7.1 Lab rules

1. No smoking, food or drinks in the laboratory.
2. The laboratory equipment is new and sensitive and *expensive*, please treat it with care.
3. Handle the optical equipment with gloves, in particular, optical surfaces like lenses and mirrors.
4. Please no talking/messaging on your phone during lab, but you may use phones for, e.g., photodocumentation of the experiment.
5. Return all optical elements and equipment to proper storage locations. Points will be deducted if equipment is not returned to storage location and stored properly. For example, if an optical element is removed from a package, it must be returned to that package.

7.2 Lab Safety

1. **NEVER LOOK DIRECTLY INTO A LASER BEAM OR INTO ITS STRONG REFLECTION.** Ordinary low-power, classroom lasers produce optical irradiance which can be about 1000 times greater than a safe level if viewed directly or in specular reflection. A "safe" level recommended by the American Conference of Government Industrial Hygienists (1968) for daylight illumination is 5 $\times 10^5$ watts/cm^2. A 1-milliwatt laser with a beam diameter of 1.5 mm at the aperture produces about 6 $\times 10^2$ watts/cm^2 at the aperture, a value about 1000 times greater than this "safe" value. Even 40 feet away such a laser may produce about 6 $\times 10^4$ watts/cm^2 in the direct beam, a value 10 times greater than the proposed safe level. Therefore, use great caution with lasers. It is almost always unsafe to view an unfiltered or undiverged laser beam, either directly or in specular reflection. Otherwise, permanent damage to the eye may result.

2. Remove reflective objects (e.g. jewelry) when operating a laser for your and your partners safety.

3. Take adequate precautions to avoid unnecessary exposure of eyes to high-intensity lamps.

4. Some experiments may require the use of high-voltage power supplies. Ensure that proper precautions are taken in the use of cables and connectors for these supplies. Never open the covers to make modifications or correct problems. Please report any problems with the supplies to the TA or instructor.