Physics 115L

Wave Motion and Optics

Laboratory Manual

Spring 2018

Dept. of Physics

The University of Texas at Austin

Acknowledgements

For many years prior to his retirement in 2004, Prof. Mel Oakes taught this course and its associated lecture course Physics 315. Prof. Oakes was one of the department's finest instructors, and developed this course into an excellent teaching laboratory.

After ten years without significant changes, the department decided in 2014 that it was time to revamp the lab, and I have taken on that job. Although I am revamping this course, I am retaining many of Prof. Oakes' experiments in whole or part, along with material from his lab manual. I am indebted to Prof. Oakes for providing such a firm foundation to build on. In addition, a number of changes to the manual have been made by the teaching assistants over the years, and some of these changes have also been retained. I did retire a few experiments and add a few new ones. Recent and current TAs, including J. Elliott Ortmann, Bangguo Xiong, Zhongping Chen, Xiaoyu Wu, Stefan Eccles, Rotem Kupfer, Andy Lin, and Kemal Sobotkiewich provided valuable comment on the new experiments and the revised laboratory manual. Finally, I've gotten useful feedback on changes to the lab from my "AMO" colleagues Manfred Fink, Mike Downer, Greg Sitz, and John Keto.

Daniel Heinzen, Jan. 2018

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0. Introduction

A. Motivation for this course.

This is the manual for Physics 115L, the laboratory course for Phys. 315, Wave Motion and Optics. In this course you will carry out a number of basic experiments on vibratory and wave phenomena.

Measurement is the foundation of science. Every scientist needs a general understanding of what kinds of experimental hardware are used, what its limitations are, how it produces observable signals, how those signals are recorded and analyzed, the kinds of errors that are present, and how to estimate errors. The only effective way to learn these things is by actually carrying out experiments, and courses like 115L are the only place in your required curriculum where you'll do this. Hopefully you will also gain experimental experience outside of your required coursework.

Experimental work helps to develop conceptual understanding. When you actually see a phenomenon for yourself and are able to experiment with it, you learn about that phenomenon in a way that is complementary to and generally more memorable than pencil-and-paper theory. You'll also see that experiments tend to behave in unexpected ways, or to give results that deviate from ideal theory. Sometimes this occurs because of defects in the experimental design or procedure, and other times because something has been left out of the theory. Having some experience of the resulting interplay between theory and experiment, as you try to understand what is happening, gives you a better understanding of both the physics and its experimental foundation.

Experimental coursework is also useful preparation for later experimental research, or for later work at applied research and development jobs. In this course, you'll gain experience with equipment for the study of acoustics and vibrations, lasers and optics, atomic spectroscopy, radio-frequency electronics, digital oscilloscopes, and computer data acquisition and analysis. These can provide a useful foundation for later work.

Even those who will ultimately become theoretical physicists should have some understanding of experiment, in order to better understand the results of previous experiments, to understand what might be possible with new experiments, and to be able to more effectively interact with experimentalists.

B. Course requirements and procedures

Note about the pace of this course

In this course, it is normal for the physics content of the lab course to run ahead of the content of the lecture course. That is because it takes quite a bit of time in the lecture course to introduce the required concepts and mathematics. For this reason, in most weeks the lab manual will contain an introduction to the physics of the experiment. This will hopefully allow you to understand the physics well enough to appreciate the experiment, in case you haven't gotten that far in the lecture course yet.

Preparation for lab

The lab manual section for each lab will be posted sometime the week prior to each lab. **You are required to read over this material in advance of your scheduled lab time.** This requirement is especially important in this lab, due to the fact that we're running ahead of the lecture course in our physics content. In most weeks, we will also post pre-lab assignments. **Pre-lab assignments are due at the start of your appointed lab time.**

Students should arrive at their lab sessions on time and ready to start lab work. You should plan to work in groups of two. Sections with an odd number of students will normally have one group of three; in addition we may form groups of three if we lack enough equipment to make up the required number of set-ups.

You should bring the following to each lab:

- A USB memory stick
- A lab notebook

If you take data with the computer, you must save it to your USB stick before leaving the lab. The lab computers are restored to the same state each night, which means that all student data is deleted from the computers once each day.

The best type of lab book is a composition-style book with quad ruling that you can use for hand-drawn graphs. But you are not required to use any particular kind of book. You can use a spiral notebook or something similar if you like.

Lab work

Each week, the lab manual will list the goals of the experiment. Your primary focus should be to realize these goals. The manual will also contain a detailed procedure to guide your work. You may do more than is listed in this procedure, but be sure to at least carry out all the measurements that are listed. The procedure will also give questions related to the measurements. Think about these questions as you go, and be sure to take the measurements that are needed to answer them.

You should **carry out a preliminary analysis of data (e.g. plotting, fitting) as you go.** The reason is that such preliminary analysis may reveal a problem with your measurements, such as unexpected irregularity. If you wait to do this until after you leave the lab, and then find a problem, it will be too late to correct your experimental procedure.

Please **read the manual and follow directions.** Please also **follow the directions of your laboratory instructor.** Many problems happen because students are not following the directions of the lab manual or the instructor.

Your lab instructor is there to help. There is a balance to be struck here. On the one hand, we would like to see some initiative on your part, and that you begin to develop the ability to diagnose and solve experimental problems on your own. On the other hand, it sometimes happens that students are too slow to ask for help, and spin their wheels on some problem for a half-hour, an hour, or more. We don't want that. If you seem to be really stuck, ask for help.

You should **take good notes in your lab notebook.** Things to include would be drawings of the set-up, experimental parameters, graphs of data, questions that come up and possible answers, *etc.* A good rule of thumb is that if someone came along six months later and asked you what the experimental set-up was, what the parameters of that set-up were, how you carried out the measurements, and what the results were, you should be able to answer those questions working from your lab book.

There is a printer in the lab that you can use to print out paper copies of graphs, spreadsheets, etc.

In experimental work, **always write numbers with correct units.** The units are just as much a part of the result as the number. A reported measurement without the units is just plain wrong. **Always in science, both axes on any graph should be clearly labelled with the plotted quantity, including correct units.**

Reported experimental measurements should generally include uncertainties. If, for instance, the purpose of the lab is to measure the speed of sound in air, then you will want to quote your result for that quantity with an uncertainty – something like $v_s = 347 \pm 35$ m/s. Unless otherwise specified, the presumption is that the error is one standard deviation. In practice one often doesn't have purely statistical error, and so it's a little difficult to determine the size of a standard deviation. Nevertheless you should make a reasonable stab at estimating how large one standard deviation would be. Remember the rule is that a measurement will lie within one standard deviation of the true result about 68% of the time.

If the experimental result is obtained from a calculation involving more than one measured quantity, then you'll also need to record the error for each measured quantity, and then calculate the error in the calculated quantity with propagation of errors. A brief introduction to propagation of errors will be posted.

In some cases you can omit the uncertainty on numbers in your lab book or report. Mainly, this will apply if the key result you are trying to obtain does not depend on a specific measured quantity. For example, the speed of sound in an experiment will not depend on the amplitude of a driver for the sound wave (*e.g.* the current in a speaker coil) or on the amplitude of the recorded sound wave (*e.g.* the amplitude of a microphone output). You may want to write these amplitudes down, but it would be OK to write them down without an uncertainty.

In experimental work, you only write down significant digits. Therefore, **do not write down more digits than is justified by the precision of your measurement.** It is normal to write down something like one extra digit, just to be sure you're not losing accuracy from the truncation of the number. But writing down two or more extra digits that are not significant is wrong, since it implies an accuracy that is far greater than the true accuracy. The only exception would be if you want to keep track of small changes in a measured number, where it is the changes in the last digits, and not the digits themselves, that are significant.

Safety and care of equipment

Generally speaking the safety hazards in this lab are modest. However, please adhere to all written instructions in the lab manual, follow the directions of your instructor, and please use common sense to stay safe. For instance, when a laser beam is on, don't put your face down to the level of the beam. Don't make a connection to AC power that is not insulated. *Etc.*

The lab contains equipment that can be broken and in some cases is fairly expensive. **You are expected to handle the equipment with care.** Follow all directions in the manual. When in doubt about proper operating procedure, ask the instructor. Obviously, anything fragile should be handled carefully so as not to break it. Avoid getting fingerprints on optics. A good general rule is to make electrical connections with the equipment power turned off, and to double check that everything is connected properly before turning power on. It is also good practice to turn equipment like power supplies on with the output levels set to zero, and then to slowly increase the voltage or current to the correct level.

If a piece of equipment is broken or appears not to be operating properly, please inform your instructor.

Lab reports

Each week, you will write a lab report. **Even though you work in groups, each student must turn in his or her own report.** You are expected to analyze the data, formulate conclusions, and write up your result independently. **Each student should be sure to take his or her own copy of the data from the lab.** If you don't, you might find it hard to get it from your lab partner later on.

The basic elements of a lab report are a statement of the objectives of the experiment, a brief description of the apparatus and procedure, a compilation of the results, including error analysis, and a summary with conclusions. It is appropriate to include an illustration of the apparatus, and summaries of key results in the form of tables or graphs. You may copy figures from this manual to save time. For this course, your lab report should specifically address the questions that were raised in the lab manual. The primary focus of your report should be on your results and on what those results say about physics.

You will sometimes need to fit data, make graphs, or determine errors in fitted data. There are a number of software packages you can use to do this, including Excel, Mathematica, Matlab, PASCO Capstone, or KaleidaGraph. Some of these are installed in the computers in the lab and/or in the Physics Microcomputer Lab down the hall. Scientific calculators can also perform some of these functions. Unless otherwise specified by your instructor, you may use whichever software you prefer.

The report can and should be brief. In order to reduce the length of the report, your description of the apparatus and procedure can be very short, since that is mostly just reproducing material in the lab manual. You should focus mainly on your results and analysis. An appropriate length is a few pages, not including illustrations and graphs. You might include several pages of illustrations and graphs for some labs.

In your report, you may only include data that you took in the lab while working on the experiment. Your instructor may take specific steps to enforce this rule, but you must follow it even if he or she doesn't take such steps. If you include data that you did not take as an active member of a lab group, include analysis that you did not do yourself, or otherwise copy material from someone else's lab report, that is cheating. Possible consequences of cheating are discussed at the Dean of Students' Judicial Services website (here).

Policies on grading, absences, and make-up labs

Grades will be determined on the basis of (i) pre-lab grades, (ii) lab report grades, and (iii) instructor assessment of laboratory performance, with more weight going to lab reports. Your lab instructor will give the precise grading policy for your section on his or her syllabus.

There will be one lab session per section each week, according to the calendar below. The last regular lab sessions for this course will be held April 24-25. The lab will be open at its regularly scheduled time May 1-2 to allow for make-up labs. Generally speaking **unexcused absences are not allowed in this course.** Your instructor will set a policy for excused absences and make-up labs, which will be announced on his or her syllabus. *Labs can be made up only if you meet the requirements of an excused absence, as determined by your instructor (TA).*

Calendar

This semester we have sections meeting on Monday and Tuesday, according to the following schedule. It is possible the schedule of experiments may be revised if I feel the course will benefit from the revision.

Lab dates	Experiment
Jan. 29-30	1: Vibrations of strings
Feb. 5-6	2: Speed of sound in air, and vibrations of a solid bar
Feb. 12-13	3: Mechanical resonance
Feb. 19-20	4: Coupled oscillations
Feb. 26-27	5: Polarization
Mar. 5-6	6: Refraction
Mar. 19-20	7: Lenses
Mar. 26-27	8: Radio frequency electronics
Apr. 2-3	9: Interference and diffraction I
Apr. 9-10	10: Interference and diffraction II
Apr. 16-17	11: Diffraction grating spectroscopy
Apr. 23-34	12: Michelson interferometer
Apr. 30 - May 1	Make-up labs