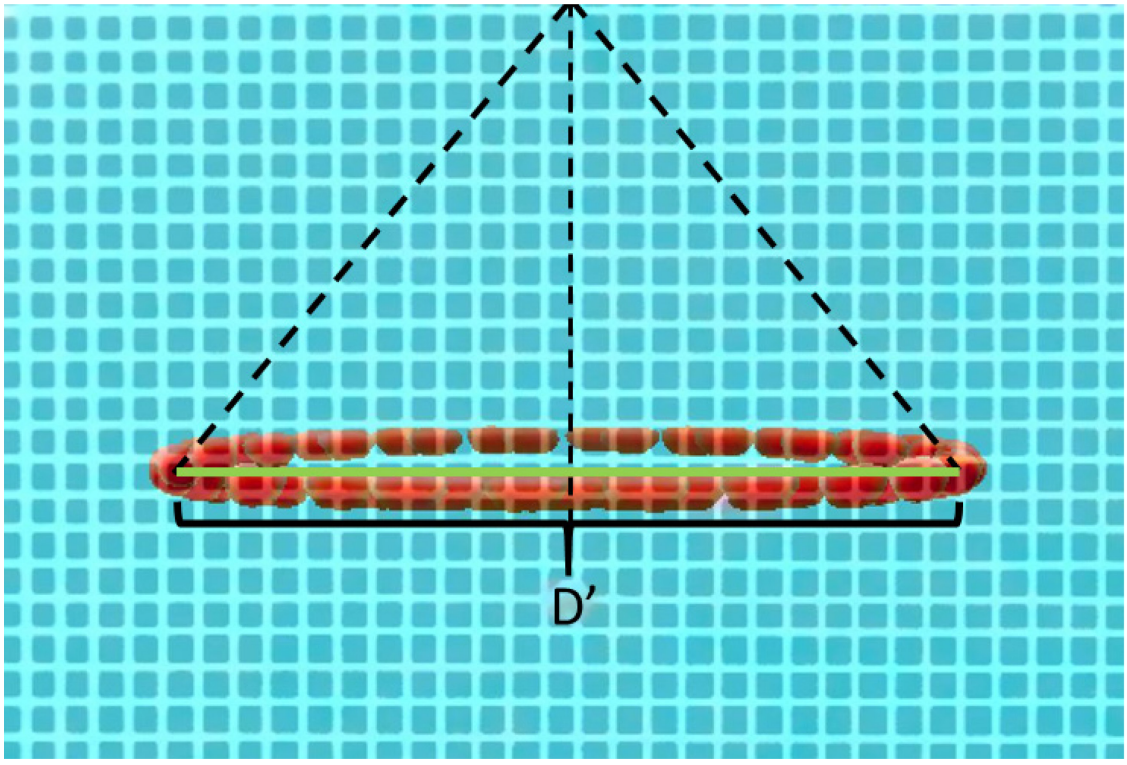
Physics Laboratory Manual - Volume 1: Classical Mechanics, Vibrations, Waves, and Heat



DEPARTMENT OF PHYSICS
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Introduction

What You Need to Bring to the Lab

- This lab manual. It is essential that you have this Fall 2016 version of Volume 1 of the Physics Lab Manual. As of Fall 2016, the manual is only available electronically as a set of PDFs, which you can access from the web by logging on to Expert TA. You may find it easier to print out a copy and bring it to each lab class. New experiments have been introduced and the original experiments have been updated from previous versions of the lab manual.
- A lab notebook for taking notes, making sketches, recording data and doing analysis.
- A pen or pencil.

Policies for Working in the Lab

- Food and drinks are not permitted in the lab.
- Proper attire is required for working in the labs. Tie back long hair.
- Do not leave backpacks or other personal items on the floor where people can trip over them.
- Do not bring a calculator to the lab. Instead, you must use the EXCEL templates provided for all calculations. The spreadsheet template is better than a calculator, you can save all of your work, and you will need to learn to use it for the lab exams.
- Do not bring your laptop to the lab. Instead you must use the computer that is provided at each lab station. In most of the experiments the computer must be connected to the apparatus to take data, there is very little room on the bench for additional equipment, and it is difficult for your lab partner or the TA to view a small and dim laptop screen.
- If you bring a cell phone into the lab, turn it off. The lab computers are only to be used for working on the labs. When you are in class, you should not be talking on your phone, texting, browsing, answering e-mail, watching videos or otherwise distracting yourself and others from the work at hand.
- Follow all safety warnings given in the lab and let your TA know immediately of any broken or damaged equipment.
- At the completion of the lab, turn off all of the equipment except for the computers. Be especially careful to turn off equipment that uses batteries.
- Do not turn off the computers - just close all documents and leave the computer on - the computers will automatically shut down when the day is over.
- If your computer locks-up or a program fails, check with your TA. If all else fails, reboot the computer. No password is required to restart the computer. If the computer demands a password, reboot it using standard shut-down procedures.

How To Get a Good Grade in Physics Lab

- Read the lab write-up and watch the short videos of the experiment before coming to class.
- If you do not understand the physics or analysis in an experiment, read the references given in the lab write-up.
- Log onto Expert TA and answer the Pre-lab Questions before coming to class. **Your answers are due before the start of your lab session and are a significant part of your grade.**
- Don't be late for class. During the first five minutes, your instructor may discuss the experiment, give helpful suggestions, and alert you to any changes in procedure.
- Use the EXCEL spreadsheet template provided for each lab.

- Learn how to use EXCEL for calculating and plotting.
- When you make a plot in EXCEL, make sure to **always use an xy-scatter chart**. Also, make sure you always label the axes, include proper units and include a clear chart title.
- These labs generally use SI units (meters, kilograms, seconds ...) for all physical quantities. Use the correct number of significant figures when recording measurements and reporting results. Learn how to use EXCEL to set the number of decimal digits displayed. Learn how to propagate uncertainties and how to correctly fit to data. Don't forget to add units to your spreadsheet template when an open cell is provided for them.
- Stay focused, don't waste time in the lab, and don't skip questions or steps in the procedure. If something does not make sense, ask your lab partner or your TA to explain. You can and should discuss your answers to the questions with your lab partner, but be sure to write your own answers to the questions when you disagree.
- Remember to save your data on the computer at regular intervals. The only place that you can save documents is to the "My Documents" folder. The templates will save a copy for you and your lab partner when you click the save button in the lower right section of each template.
- **Each and every student needs to log in to ELMS Canvas and submit a copy of his or her completed spreadsheet lab report before leaving the lab.** You cannot submit a report after your lab section period ends. You cannot get a grade for a report someone else submitted, even if that someone is your lab partner. It is great that your lab partner turned in a report to their own area in ELMS Canvas, but if you don't want to get a score of zero, you need to submit your report to your own area in ELMS Canvas before your session ends and before you leave the lab.
- In your report, don't forget to include your name, the date, your lab partner's name, your data, analysis, plots and brief answers to the Final Questions. The new templates highlight cells that are missing entries and also provide some feedback when there is a problem - make sure there are no missing entries and that all the issues have been dealt with.
- Get the name and e-mail of your lab partner before you leave the lab.
- You must leave the lab at the end of your scheduled lab period.

Purpose of the lab

The main purpose of this lab is to allow you to study experimentally some of the physical laws, concepts and phenomena covered in the lecture part of your physics courses.

Another purpose of the course is to give you direct experience with measurement instruments and techniques used in the physical sciences and industry.

A third purpose of the lab is to give you a better understanding of measurement uncertainty and its importance in the physical sciences, including the related topics of error propagation and how to compare data to a theory in a meaningful way.

A final aim of the course is to introduce you to accepted scientific standards for recording data, plotting results, and reporting values, including the proper use of units and significant figures.

Philosophy Behind the Labs

In developing these labs, we started from existing experiments but made many changes in an attempt to improve the pedagogy, the apparatus, and the look and feel of the experiments. We did not have unlimited time or budget and numerous compromises had to be made. Two big

constraints we needed to work with were that you will have only two and a half hours to complete a lab and when you do run into trouble, you will have just one TA to assist you in a room with 35 other students. This drove several key decisions. That is why we changed the labs so that they now use EXCEL templates, why we increased the number and power of the macros you will be using in the analysis of your data, and why we incorporated automatic feedback into the templates. This is also why each lab has explicit and clear instructions about what needs to be done. Our aim was to make sure that you and 35 other students can complete complex data taking and analysis without running into easily foreseen problems at every step.

As a student, you should understand that there are some potential **pedagogical problems** with giving you detailed instructions. Critics call this a cook-book approach and argue that students just follow the steps blindly without understanding what they are doing. Instead, some instructors advocate for a minimalist approach with few if any instructions, and correspondingly simple equipment and data analysis, so students have to figure out almost everything. While we have sympathy for minimalist approaches, it is not the approach taken here. It's not just that many engineering students have already had minimalist labs in high-school, but also successful engineering students tend to be smarter than average and don't blindly follow instructions. In reality, you will find that there is an incredible amount you will need to figure out in each lab. The experiments are not simple and the instructions will enable you to use complex equipment in a much more sophisticated and professional manner than would otherwise be possible. Although we hope the instructions are clear enough that anyone can follow them, we know that we are asking a lot of you and you have a limited time to figure it out. Much of what you encounter may well be completely new to you - and you will need to understand it well enough to pass the practical exam at the end of the course. You will need to be well-prepared and on your toes to understand and finish each experiment in the available time.

Finally, as a prospective engineer, you should understand that real engineers do have to figure some things out from scratch, but they also have to know how to follow instructions and how to interpret numerous codes, rules and laws. There is a good reason why engineers in particular write and follow explicit instructions and codes - it makes it possible to plan and accomplish complex, technically challenging and sometimes dangerous work in a well-thought out, reproducible, cost-effective, efficient and safe manner. It is "good practice" and learning to follow good practice is a key part of every engineer's training.

Analytical Tools for the Lab

In the laboratory you will need to use two analytical tools: a computer spreadsheet and error analysis. You should not bring a calculator to the lab.

By using a computer spreadsheet, you will save yourself a lot of time and trouble when it comes to analyzing data and making plots. At this point in your classes, you should already be familiar with the spreadsheet program EXCEL, which is what you will use in the lab. If you don't know how to use EXCEL, it really is time to learn. During the first week of classes, there is a lab tutorial that will introduce you to the EXCEL. This is Experiment 1 and everyone must complete it. In most semesters, students do the exercise on their own outside the lab - however, make sure to check the syllabus to see if you need to come into the lab the first week or if you must complete Experiment 1 on your own.

Many students begin these labs without knowing anything about error analysis or have learned some things that are not correct about error bars and statistics. Because of this,

Experiment 2 was developed as an introduction to data analysis. This is a large and challenging subject that includes techniques for estimating uncertainties in measured quantities, propagation of errors, least square fitting, χ^2 fitting, determining the error in fitted quantities, and determining in a statistically meaningful way whether a theory is in agreement with a data set. You should think of Experiment 2 as a starting point rather than the final word and later experiments will go over and build on the ideas developed there.

As you work on these labs, you may wonder: **what is the point of error analysis?** In some of the experiments, the reason you need to do error analysis is to determine whether a given result or law of physics is actually obeyed or whether your measurement agrees with an accepted result. One soon finds that this is not so easy to do. The problem is that a measurement of a physical quantity, such as mass or velocity, can only be made to a certain precision. We say that a measurement has an uncertainty and it turns out that one cannot prove with mathematical rigor that a physical law is true by doing experiments. The best you can do is show that a measurement agrees with theory to within the experimental uncertainty, or that it does not. Thus, it is essential to understand measurement errors before you can decide whether a result agrees with a theory. By the end of the lab course, you should know how to estimate the uncertainty in a measurement and understand what it means to prove something experimentally. As engineers who will soon be entering the job market, you should also understand that simulations and more advanced data analysis techniques, which go beyond simple error analysis, are very important because of their application to design, quality control and process control in manufacturing.

About the Equipment

Most of the equipment used in the lab is fairly simple and durable. However, treat all the equipment with care. Do not push or pull forcefully on any of the equipment, and make sure that you don't bang chairs or your knees into the computers, cords and wires. Deliberately damaging the equipment, or other state property, harms other students and can get you expelled - don't do it. On the other hand, if something is bent, broken, leaking, smoking or otherwise misbehaving, let your TA know and they will call in a lab technician to take a look. Not only will the students who follow you be grateful, but you will have fewer problems and get better results. Finally,

Lab Safety

Always be aware of potential dangers when using tools or other equipment in an experiment. The write-up for each experiment includes a section on known hazards. **Be sure to heed all safety warnings. If you find something that is hazardous, let your instructor or the lab technicians know immediately.** You also need to be aware of common hazards such as tripping over a backpack someone has carelessly left on the floor.

Your Lab Partner

In order for every student to have a chance to operate the equipment and take data, it is not permitted for more than two students to work together at one set up. Your TA cannot make an exception for you, or anyone else, and if you see a TA allow this, report the TA to the lab technicians and your course instructor. You should ordinarily expect that you will work with one other student. If there are an odd number of students in a section you may find you are in luck and have a set-up all to yourself.

Be sure to work closely with your lab partner, and discuss all aspects of the experiment

with her or him. Your data will be the same, but you will each need to turn in your own lab report to ELMS. If there is some part of the lab that does not make sense to you, by all means ask your lab partner. Also, make sure that you both have a chance to operate the equipment. Do not let one person always operate the equipment while the other person always works on the computer. Letting everyone work on the different parts of an experiment is not only the fair way to do it, but it also is the best way to catch mistakes before it is too late. An easy way to find if you are measuring something wrong is to have another person try to measure the same quantity and then check if the answer is the same. Also, each person needs to be able to demonstrate that he or she understands the data on their spreadsheet. The TA or course instructor may come by and ask that you explain the calculations you and your lab partner are doing - if you can't explain, the instructor may deduct points from your lab grade.

One point is worth repeating here. Each and every student needs to log in to ELMS Canvas and submit a copy of their own lab report before leaving the lab. There are no exceptions to this policy. It is great that your lab partner turned in a report, but if you want to get a grade for doing the lab, you need to turn in a report to your own area in ELMS.

Your Teaching Assistant

Your Teaching Assistant is in the lab to help you succeed, help sort out problems and explain things that you don't understand. Your TA should always be in the lab during your session. Your TA should respond promptly when you raise your hand because you are stuck or have a question, unless he or she is already dealing with a student. You should understand that TA's are also students, they are still learning and they have their own classes and homework to deal with. However, your TA should not spend his or her time sitting at the front of the lab working on the computer, doing homework or grading lab reports. Instead your TA should continually be working their way around the lab, checking how students are doing, talking to students to see if they are getting it, letting you know if something looks wrong, and watching out for everyone's safety. If you have a great TA, let your Physics course instructor know. Similarly, if your TA is not doing their job, let your Physics course instructor know.

One last thing concerning your TA - he or she cannot make exceptions to the course rules. As you read through the labs, you will notice some serious repeated reminders: for each lab each student needs to turn in a spreadsheet report to their own area in ELMS before they leave the lab, the Pre-Lab Questions are due before your lab session starts, and the Review and Exam are required and graded labs. These are part of the course rules and the TA cannot make exceptions to them.

The Spreadsheet Templates

One of the biggest changes from versions of the lab prior to 2014 is that each lab now comes with an EXCEL spreadsheet template that is available on the lab computers. You must use these templates. The templates provide a standardized common layout for recording your data, doing analysis and answering questions. This helps your TA understand what you have done and grade your work efficiently and consistently. The templates also have custom macros for doing analysis and providing automated feedback - the template can let you know when you left something out and alert you to some problems in your data or analysis.

Acknowledgements to the 2016 edition

This version of the General Physics Lab Manual - Volume 1, was put together in the Spring 2016 semester by Fred Wellstood. The version corrects a few minor problems in the Fall 2015 edition. The 2015 edition was an updated version of the Physics 261 Lab Manual that was put together in the Spring 2014 semester by Drs. Steve Cowen and Fred Wellstood.

Acknowledgements to the 2014 edition

In the 2014 edition, we made many changes and would like to thank the people that have made this possible. The Physics Lab Staff (Allen Monroe, Bill Norwood, Tom Baldwin and Rory Finneren) was critical to the development of the new labs. We would like to especially thank Allen Monroe for making this all possible by applying for, getting and managing the STEM money from the College for expanding and upgrading the equipment. Allen, along with Tom McMullen and Sean Davis from the College, was responsible for managing the construction to expand and renovate the lab room itself, including installing new lights, new lab benches, new flooring and fresh paint. Allen was also responsible for ordering most of the equipment you will be using and for converting our crazy prototypes into equipment that you could use. Allen, Bill, Tom and Rory provided many fresh ideas, pointed out problems with existing equipment, suggested replacements, dug out odd parts and test equipment from their supplies, and let us duct tape things together to create prototypes. They helped us in a hundred other ways during the development process, all while keeping the labs running for a couple of thousands students during the semester. They not only made our job fun but we would not have succeeded without their ideas, enthusiasm, support, criticism and deep knowledge of the labs. We would also like to acknowledge technical help from two other staff members, Tuck Owens in OIT for helping us with numerous computer related issues and Clay Daetwyler in Physics Lecture Demonstrations for equipment and ideas.

While some of the experiments are completely new, most have been adapted from earlier versions. In fact, some of these labs existed in a recognizable form twenty years ago when computers were first introduced into the engineering sequence physics labs by Jordan Goodman and one of us (FW). Within the last decade, Derek Boyd upgraded many of the experiments, not only fixing many mistakes but also increasing the sophistication of the data analysis, creating custom EXCEL macros for fitting the data and developing greatly improved hardware, particularly for the labs on Centripetal Force, the Pendulum and The Ideal Gas Law. While many other faculty and staff have worked on the labs, the present version of the manual would not have been possible without Derek's creativity and hard work. His insight and dedication to improving the Physics Labs has been a real inspiration.

Finally, we would like to thank Donna Hammer, the Director of Education Services in the Physics Department, and Tom Cohen, the Associate Chair for Undergraduate Education. They understood the need to make changes and the risks involved in doing so in such a short time. Our effort would not have been possible without their continuing support and commitment.

Steve Cowen and Fred Wellstood
June 15, 2014