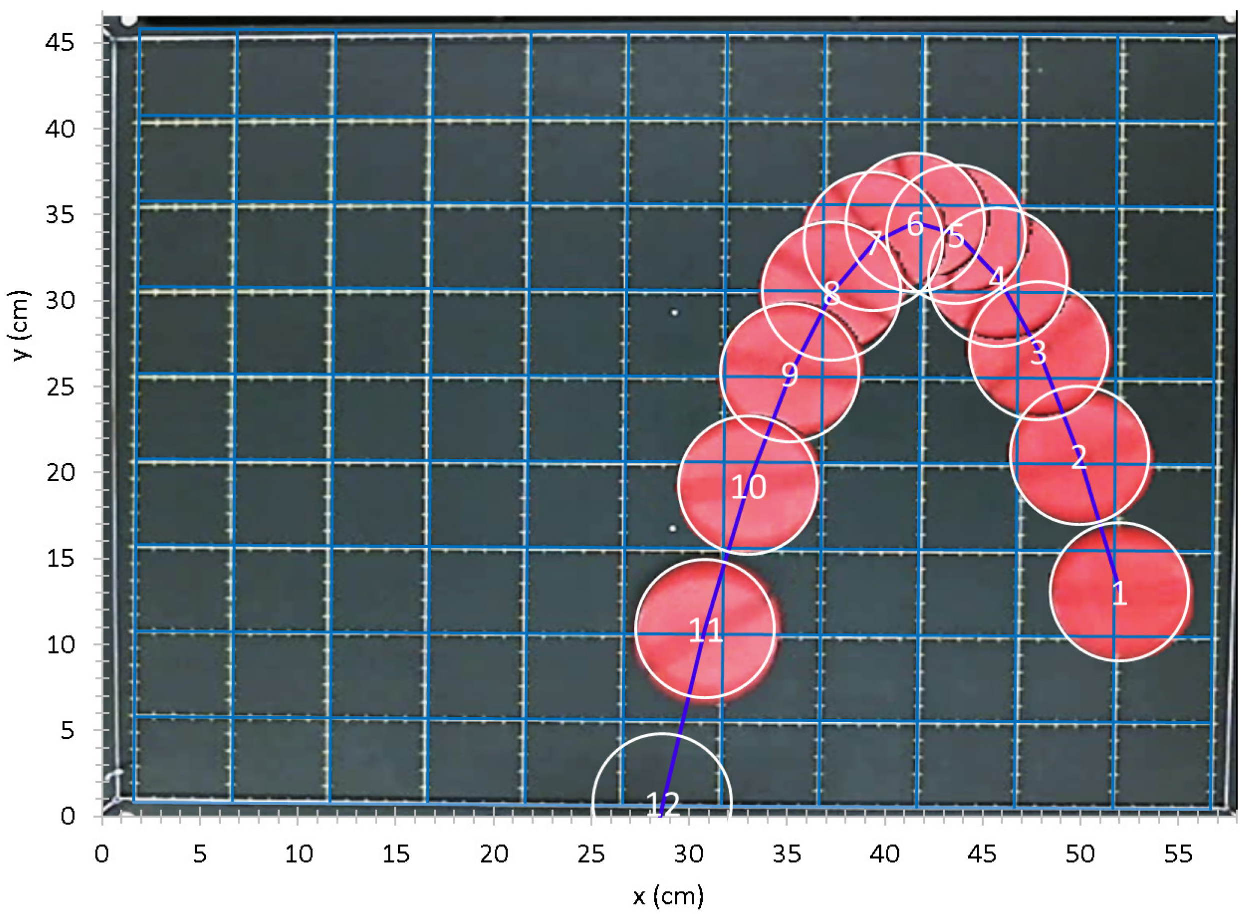
Fundamentals of Physics Laboratory Manual - Volume 1



Spring 2020 edition

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Revised by F. C. Wellstood and N. Boroujeni from June 2016 Edition Physics 121 Lab Manual
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Introduction to the Lab

Purpose of the Labs

The purpose of this laboratory is to help you learn about physics and physical phenomena by making your own measurements of phenomena on real experimental setups.

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.
- 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 any safety warnings given in the lab.
- 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.

Submit Your Answers to the Pre-Lab Questions Before You Get to the Lab

Before you do each lab, you need to read the write-up for that week's lab.

In addition, before your lab sessions starts you will need to submit your answers to the pre-lab questions. Answers to pre-lab questions must be submitted on-line using **Expert TA.** The purpose of the pre-lab questions is to make sure that you prepare before you try doing the lab and that is why they are due before your section meets. You should not be surprised that you will get no credit if you try to turn in your pre-lab questions after your lab section starts.

The Expert TA system has several advantages compared to the old system of turning in answers on a piece of paper. Grading of each question is automatic and nothing can get misplaced. Another nice feature of this system is that if you give a wrong answer to a question with multiple choices or a numerical answer, you will typically be allowed additional attempts, with the number of attempts being set by your instructor and the amount you lose for each wrong answer. In addition, Expert TA is also distributing the lab manuals electronically and next to each question is a link that will take you to the write-up for that week's experiment. Typically, all of the answers to the pre-lab questions can be found by reading the write-up. Consult the course syllabus for instructions on how to **enroll in Expert TA**.

What You Need to Bring to the Lab

Before you go to your first lab you need to purchase access to the Lab Manual. As of Fall 2016, the Lab Manual is only available electronically as a set of PDFs that are distributed on-line via **Expert TA**. After you enroll in **Expert TA,** you can access the manual anywhere you have a web connection. In the lab, each station has a computer that you can use to log in to your Expert TA account and view the manual. If you prefer, you can also print out a copy of the manual at home and bring it to each lab class. Earlier printed editions of the manual as many of the experiments are new or have been updated.

Doing the Labs and and Your Lab Partner

While you are working through each lab, be sure to work closely with your lab partner and discuss all aspects of the experiment with her or him. The data you take together will be the same, but you will each need to turn in your own lab report. 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 your lab partner always operate the equipment while you look on. 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 your lab partner try to measure the same quantity and then check if the answer is the same. Because of the limited bench space and the importance of allowing each student to work on all aspects of each experiment, your instructor should never permit more than two students to work on one set-up.

Your Lab Reports

During the lab, make sure you follow the procedure and record your calculations and observations about the experiment as you go. If you need make a plot, it is smart to do this while you are in the lab. Similarly, it is smart to complete the analysis and write up explanations while you are in the lab. Every semester there are students that rush out of the lab without making plots or analysis or trying to answer the questions. When they finally get around to doing the work they should have done in the lab, there is no TA to discuss with and if they made any mistake in taking the data, there is no way to go back and correct the mistake.

After each lab you will need to prepare a **Lab Report.** The due date for each lab report is given in the course syllabus - typically lab reports are due before the start of your next lab but check the course syllabus. In a section below there is a detailed set of guidelines for preparing your lab reports. As of Spring 2016, paper copies of Lab Reports were still being accepted. However, it should be expected that the Labs will eventually to move to only accepting electronic reports (MS Word or PDFs), collected via ELMS. Consult the course syllabus for how your instructor has set things up.

Your report will be graded and should be returned to you the next week. Your overall course grade will be determined by your scores on the pre-lab questions and your lab reports, but may also include participation in the actual laboratory experience. You will not be graded on the length of your lab reports, but accuracy, clarity and completeness are important parts of the grade. Consult the course syllabus for details on the grading.

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. Don't be afraid to ask questions. 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 walking 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.

Make-up Labs

Your instructor will schedule make-up labs during the semester to allow for completion of work missed due to absences recognized by the University. Check the course syllabus for rules regarding make-ups labs and when they are scheduled. Failure to perform all of the experiments will result in a decrease of your course grade.

Significant Figures

In these labs and your lab reports you will need to record results from the measurements you make. Any real measurement that you make will have a limited precision and accuracy, no matter what measuring instrument is used. When you record the result from a measurement, you should only record the digits that are reliably known; these are referred to as ***significant figures*.**

For example, suppose you are using a meter stick to measure a wooden block. If the meter stick is marked with 1 mm intervals, then typically it would be straight-forward to measure the length, width, or height of the block to the nearest mm mark and this will correspond to the smallest digit that you can report. If the block measures 348 mm in length, our measurement has 3 significant figures. The block's length may also be stated as 0.348 m or 348 mm. The decimal point has been moved with the change of units, but the number of significant figures remains the same. Note that the position of the decimal point has no effect on the number of significant figures.

When considering significant figures, leading zeros in a value are ignored (because they are merely place holders showing where the decimal point goes). For example, 23.45 and 0.02345 both have 4 significant figures. However, interpretation of trailing zeros may be ambiguous. Consider the number 80, for example. Are there 1 or 2 significant figures? If we say it is *about* 80 km between two cities, there is only 1 significant figure (the 8) since the zero is merely a place holder. If it is *precisely* 80 km within an accuracy of ±1 km, then the 80 has 2 significant figures. In such a case some people prefer to write it 80., with a decimal point. This is not always (or even usually) done, so the number of significant figures in 80 can be ambiguous unless something is said about it, such as "about" or "precisely".

In order to clearly indicate the number of significant figures, you can record values using ***scientific notation*.** In this format, a value will be presented as a number of digits, showing the correct number of significant figures, times a power of ten. Thus, if the value 43,600 has only 3 significant figures, it should be written as 4.36×10^4. If the number has 4 significant figures, because the 0 following the 6 has been determined by measurement, then the number should be written as 4.360×10^4.

When recording measurements or doing calculations, do not keep more digits in the final answer than is justified. For example, to calculate the area of a rectangle 11.3 cm by 6.8 cm, the result of multiplication would be 76.84 cm^2. But this answer is clearly not accurate to ±0.01 cm^2, since (using the outer limits of the assumed uncertainty for each measurement) the result could be between $11.2\times6.7 = 75.04$ cm^2 and $11.4\times6.9 = 78.66$ cm^2. At best, we can quote the answer as 77 cm^2, which implies an uncertainty of about ±1 cm^2. The other two digits (8 and 4 in the number 76.84 cm^2) must be dropped since they are not significant. As a rough general rule, (i.e., in the absence of a detailed consideration of uncertainties), we can say that: *the final result of a multiplication or division should have only as many digits as the number with the least number of significant figures used in the calculation*. In our example, 6.8 cm has the least number of significant figures, namely 2. Thus the result 76.84 cm^2 needs to be rounded off to 77 cm^2.

For addition and subtraction, the final result will have the same number of decimal places as the addend having the least number of decimal places. For example, the result of subtracting 0.57 from 30.6 is 30.0 (and not 30.03). Note that the subtrahend has only 2 significant figures, but the result has 3.

Sometimes, quantities are assumed to be known exactly, i.e. with an *infinite* number of significant figures. Such are natural integers 1, 2, 3,… and mathematical constants like π. Numbers like 12 inch in 1 foot, 100 centimeters in 1 meter, or 60 minutes in 1 hour are also exact quantities by virtue of their definition. Exact quantities do not affect the accuracy of your calculations that is determined by the quantities with *finite* number of significant figures.

Keep in mind when you use a calculator that all the digits it produces may not be significant. When you divide 2.0 by 3.0, the proper answer is 0.67 and not some such thing as 0.66666666. Note also that calculators sometimes give too few significant figures. For example, when you multiply 2.5×3.2, a calculator may give the answer as simply 8. But the answer is good to two significant figures, so the proper answer is 8.0.

Digits should not be quoted (or written down) in a result, unless they are truly significant figures. However, to obtain the most accurate result, you should normally keep an extra significant figure or two throughout a calculation, and round off only in the final result. When rounding, if the figure beyond the last significant figure is greater than 5 or equal 5, drop it and add 1 to the previous figure. If it is less than 5, just drop it.

V. Units

Measurements of physical quantities are always made in terms of certain quantities called units. If we say that a force had a strength of 5 N, we are saying that it has a strength that is five times the SI unit of force which is 1 newton or 1 N. There are many different possible units that can be used, but in this lab you should use the metric or SI system of units. In the SI system of units, distance is measured in meters, time in seconds, force is measured in newtons, electric current is measured in amperes, and so on. Sometimes you may need to convert to the English system because it is commonly used in the US. Some common conversions are listed below:

1 inch	=	2.54 cm
1 meter	=	39.37 in
1 mile	=	5280 ft.
1 km	=	0.62 mi
1 mile	=	1.61 km
9.8 newton	=	2.2 lb -----> 1 N = 0.224 lb

Weight and mass are frequently confused by students. Weight has units of force, so it is expressed in units of newtons (N) in the SI system and pounds (lb) in the English system. Mass is expressed in units of slugs in the English system, and it is fair to say that no one uses this unit. Mass in the SI system is in units of kilograms (kg). Now you might have seen an equation like:

$$1 \text{ lb} = (1/2.2) \text{ kg} = 0.454 \text{ kg} = 454 \text{ g}$$

because a mass of 455 grams has a weight of 1 pound. However, this "equation" is physically nonsense because lb is a unit of force and kg and g are units of mass. Since force and mass are completely different units, the left side cannot be equal to the right side. Fortunately the "weight" scales in the lab are actually report the mass in SI units of kg or grams, and you will not need to use English system units for mass.

One very nice feature of the SI system of unit lies in its use of powers of 10 and prefixes to keep track of how many powers of 10 prefix. The following prefixes are the most common ones used and you should make yourself familiar with them, if you have not already done so.

Table 1. Common prefixes used in science.

Power	Prefix	Abbreviation
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
10^{-2}	centi	c
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T

<u>About this Edition of the Lab Manual</u>

This January 2020 edition of the Physics 121 Lab Manual was prepared by F. C. Wellstood and N. Boroujeni. The main change is the addition of a new Experiment 5 on projectile motion. The new experiment uses video processing software developed by Dr. Alex Jeffers for Experiment 8 in 2016, which in turn was based on video processing software created several years prior by Dr. Steve Cowen for the Physics 261 lab. We also took the opportunity to fix typos and make some other small updates. Special thanks to our lab technicians Allen Monroe, Omar Torres and Cathy Owens for modifying the air-tables so they could be tilted, for sorting through other issues and for setting up apparatus as we developed and tested experiments.

The Fall 2016 version of the manual was revised by F. C. Wellstood to allow on-line distribution via Expert TA, going paperless in the lab and to update changes in the equipment and procedure. We would like to give special thanks to Donna Hammer for her continuing strong support for the labs, to Bill Norwood for keeping track of updates and all the equipment changes, and to Allen for advice on handling many of the issues that arose in this revision. This version was based closely on the Spring 2016 edition of the Physics 121 Lab Manual by Dr. Matt Severson who did a major revision to the previous version with the introduction of many new experiments and updated equipment and procedures. The Fall 2016 version included a new lab, Experiment 8 Conservation of Linear Momentum that used a camera to record collisions between two pucks on an air-table. This lab was developed by Dr. Alex Jeffers, who modified a Matlab and Excel based routines created by Dr. Steve Cowen for the Physics 261 lab.

One of the biggest changes from earlier versions of this manual is that it will generally only be available as an electronic file via **Expert TA**. There are some significant advantages to electronic distribution, including being able to distribute updated versions, being able to show high-resolution color photographs and being able to access the manual anywhere. Of course it is still possible for you to print out the manual on your own if that is what you prefer. Electronic distribution of the lab manuals is one step in trying to go paperless in the lab.

Guidelines for Writing Your Lab Reports

Your lab report should be concise. Do your best to be clear, thorough, and brief. Make sure you include written explanations of the procedure or analysis as you did them. Consult your course syllabus for the due date and due time and don't miss the deadline. Also check with your instructor on whether electronic copies must be submitted to ELMS Canvas or whether printed hardcopies are required. One last bit of advice. After you are all done writing your report, go back and read it before you submit it. You will be surprised by how many simple mistakes you find - correct them and then don't forget to submit your report.

The following gives a template with five parts (A-E) that you should use for preparing your Lab Reports.

A. Title and Author Information

Experiment #
Experiment Title
Your name
Your lab partner's name
Date the lab was done
Your lab section number

B. Purpose and Introduction

Write one or two sentences giving what, from your perspective, is the purpose of the experiment. Try to be specific rather general. For example, it would be much better to write "In this lab we observed how the position of an object that is traveling with uniform acceleration varies as a function of time". Examples of badly written purposes would be "to study motion" or "to take data and see that it fits the theory", because they are so general as to be meaningless.

C. Data and Analysis

Present your data in tables or plots as often as is feasible. Make sure that data tables have a title and that you include clear labels and units. As an example, Table 1 on page 6 shows some of the most common prefixes used in the sciences. Notice that each column is labelled and the Table itself is named (Table 1) and it has a caption that briefly explains what the table is showing. Again, be sure to present your data in a well-defined tabular format as is appropriate.

In many cases you will need to include a plot of some measured results. Such plots are most easily made using a spreadsheet such as Excel. Make sure you label axes on all plots, identify what each curve is if there is more than one on a plot, and give each plot a title. Figure 1(a) shows an example of a bad plot and Figure 1(b) shows an example of a good plot.

Also include your original data sheet and any sketches, photographs or diagrams done as part of the experiment. Label these extra parts clearly and include your name and partner.

In labs where Excel spreadsheets are used and your instructor wants a printed hard copy, hand in a reasonably-formatted printout. Landscape orientation is often helpful. Use the Print Preview and Page Layout options to create appropriate page breaks whenever possible. Avoid pages of single stray rows or columns. If your instructor is accepting lab reports electronically, just copy and paste your Excel plots into your report. For any plot, make sure you have a title on the plot and label the axes, including units. Also include a legend when multiple data sets are plotted on a single chart. Data should almost always be plotted as disconnected points, and fit curves should be plotted as smooth continuous lines. Go back to Experiment 1 if you need a refresher on how to do any of this in Excel.

In many of the labs you will need to use your data as input for additional calculations so that you can compare your results to theory, or known values or fundamental constants. When reporting your analysis, begin every calculation with the pertinent formula you used. Show your work, and clearly state the quantity obtained from the data with units. Never report numbers without identifying the variable. Include uncertainties when pertinent.

D. Sources of Uncertainty

Clearly and concisely state any significant sources of uncertainty. This is one of the most important parts of your report, as it reflects rather accurately how well you understood the experiment and apparatus. Experiment #2 in this manual is an introduction to uncertainty and you may want to refer back to this as you write your reports since it has much information about how to estimate uncertainties in your measurements.

The main point of an uncertainty is to quantify the precision of the result. In many cases you will find that your results disagree with your expectations. This may be because the experiment has additional random or systematic errors that weren't properly accounted for. It can also be that the theory left out some key factors or was overly simplified. In this case, the theory really does disagree with your results and you need to say so. You should put some effort into thinking back through the experimental procedure to try to discover sources of disagreement. If you were actually sloppy, saying so is better than not, but you may still lose credit elsewhere. If you include flippant or meaningless statements about "human error" or how "we weren't careful enough", don't be surprised if it cost you points.

E. Conclusions

Write a few sentences summarizing your key results and their significance. If your key result was a measured value of a physical quantity, be sure to state the value and include the uncertainty and units. Include any requested comparison to measured or actual values and comment on the statistical agreement. Report χ^2 values where pertinent - if you are not sure what that is then you haven't done Experiment #3 yet or you need to go back and review it! Be sure you have addressed any questions explicitly posed during the procedure or analysis.