# Physics 201/202/207/208 Instructor Lab Manual

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**NOTE: M=Mechanics, H=Heat, S=Sound/Waves, C=Computerized Experiment**

## Contents



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## Preface

This is a first pass at a Physics 201/202 and 207/208 Laboratory TA manual. The goal is to unify and standardize the manner in which our introductory physics laboratories are conducted and administered. Hopefully it will make teaching of these labs more straightforward than in the recent past. As a first version it is likely that this guide is far from perfect and will require revision. Comments, suggestions, feedback should be mailed to: mwinokur@wisc.edu.

Please use the following format in the **subject** lines of your e-mail so that it can be filed appropriately and then considered in an efficient and effective manner when revisions are made.

**Physics Lab:Course:Experiment:Topic**

The nature of the topic might be, for example: “sample data” or “typo found”. All of these will be considered at subsequent revisions.

## Organization of TA Manual

All of the experiments are organized according to the following scheme:

### Overview

The first page contains a brief overview of the experiment followed by an equipment list detailing what will be used for the specific lab. Also included will be special notes and instructions so that you, as a TA, can make sure than everything will function smoothly.

### 1. Things You Need to Tell Them

This and the next two items should be considered well before scheduled meeting time of the laboratory. If you are not clear on what is it you need to tell them then the laboratory itself is almost certain not to go well. This will diminish the efficacy and educational merit of the lab for your students as well.

### 2. Misconceptions and Pitfalls

The number ways that things can go wrong far exceeds the space allotted for each individual lab. Students have a myriad of different skills and tools at their disposal. Your minimal goal in getting through the lab will be to make sure each and every student learn the essential facts that are experimentally tested or demonstrated.

### 3. What the student are supposed to learn

This is really a continuation of the first step. What is written here represents a working minimum. It will of course enhance these laboratories if you take the initiative do more than the minimum. This all depends on the temperament and style that you project.

### 4. What to expect and sample data

Although you should be aware of what is supposed to happen, please be sensitive to the fact the experimental physics is often best learned if the students are not told explicitly beforehand what the “right answer”.

**5. Pre-lab/Post-lab: Questions and Answers**

As time permits there will series of web accessible quizzes.

## Lab Instructor Duties and Responsibilities

- Read (don't skim) through the lab manual and TA guide before you meet with you class. If this is the first time you have done the laboratory then you are obliged to run through the experiment before you get to class.
- If you have questions about an experiment, direct them to the course instructor, head TA or laboratory staff before meeting with your class.
- Prepare your students properly. If necessary you can use a few minutes of the discussion period.
- Provide a useful introduction for the students. Emphasizing good technique is part of a useful introduction. Remember not to tell them exactly what will happen and what the exact outcome will be. If you do then you will deprive the student of the opportunity of finding out answers for themselves.
- Be friendly and helpful to your students in lab. If you give them clear directions and expectations then they will find the lab far more relevant to the course as a whole.
- Remember that you represent not only yourself but the Department and the University.
- Grade lab work consistently and fairly.

# MC-1a Measurement and Error: TA Notes

## Overview [Est. time: 1 hr]

Students should as a general rule work in groups of three. Be careful to have a good balance of students in the individual groups. Most students have some experience with types of errors and their impact on accuracy and precision. However many will not have developed their critical thinking skill to apply this knowledge in a laboratory setting for assessing results. First and foremost is the recognition that physics is an *experimental* science and so one needs to know what it means to make a measurement and how the process of acquiring data can introduce errors into that particular measurement.

## Equipment

Photogate Sensor, Pasco 700 or 750 interface, Computer Workstation

## Things you need to tell them

- Your students are expected to know and recognize the differences between random and systematic sources of error.
- They should be able to identify these in simple test situations. For example if a wooden meter stick is mismarked at the end then the measurement will always be systematically too large or too small by a constant offset. If the humidity is too high and the meter stick swells then their measurements will be proportionately too short for each and every measurement.
- In this lab a student should always frame his/her measurement in this context. It is essential to understand how one makes a measurement. Without these metrics the efficacy of demonstrating a physical law is rendered almost useless.
- Students need to be reminded about writing *all* their answers with units, appropriate significant digits and, where necessary, an estimate of uncertainty.
- They should know and appreciate the difference between the standard deviation and standard deviation of the mean. Remember that the standard deviation reflects the statistical uncertainty associated with a single measurement. The standard deviation of the mean is a measure of how close your measured mean is to the actual value *assuming* that systematic errors do not contribute.

## What Student are Expected to Learn

- The difference between random and systematic error and recognize these characteristics if present in simple data sets.
- Standard deviation and standard deviation of the mean and their meanings.

## Misconceptions and Pitfalls

Students are likely to have an incomplete understanding of the differences between systematic and random errors. Hence they will often misidentify these two designations.

## What to expect

Generally the range of results will be equal to the number of groups you have in lab and not every contingency can be predicted. In terms of making the simple 2 second time measurement experience suggests that there will be random and systematic sources of error in the data. At first the timing accuracy will be good and the period will start out close to the stated 2 second period with a scatter representative of the random error. Only a large number of measurement can reduce this error. In addition it is likely that there will be a systematic drift in the measured period that will increase or decrease with time.

The "trick" to resolving this systematic error is to reduce the level of random error. To achieve this the only solution is to make a large number of measurements and look at the average value in terms of the mean plus or minus the standard deviation of the mean. If the value of the period agrees with the asked for period within $\overline{\sigma}$ then the measurement is still dominated by random errors (to a 70% certainty if $1\sigma$ used). If not then systematic errors are becoming dominant. This could conceivably due to the computer clock but far more likely at fault is the student.

By splitting up the calculations into to 25 cycle pieces one may be able to see shorted time systematics pertaining to drift. The major point here is to get your students to recognize that each measurement is not truly independent (i.e. uncorrelated) and that, if necessary, one should look for correlations at shorter time scales.

It may be illustrative for each of the groups to compare their with the class as a whole. When they are done the should use the screen graphing tool and print a hard-copy of the DataStudio display. This can be taped onto the wall in a common area. Asking the students to compare and contrast their results with other groups may prove useful.

# MC-1b: Density of a Solid: TA Notes

## Overview[Est. time 1hr]

Reinforcing the idea of random and systematic errors requires that students see them in different settings. Measuring the density of a solid is not always as easy as it seems. In this case we wish to be especially quantitative but, in general, most labs will seem almost qualitative.—

As noted previously your students will necessarily have a multitude of styles and backgrounds. To help those with limited experience develop their lab notebook skills we will use, on occasion, a worksheet. This layout and format should be maintained throughout the rest of the semester.

A possible answer to the question posed on the 1b worksheet: The slope and intercept of the plot are examples of systematic error in terms of offset (from zero) and scaling (a proportional error).
Random errors occur during an individual measurement and these are quantified by the standard deviation calculation.

In addition to the lab itself there will be a short post-lab quiz that further tests their understanding of the differences between systematic and random errors.

## Equipment

Precision micrometer, calibration blocks, digital scale, computer workstation, metal cylinder, worksheet

## Things you need to tell them

- Complex measurements (i.e. density) that have more a single input (i.e., diameter, height, mass) require one to consider multiple factors in assessing a result. They will not do this routinely as this is an introductory lab but these issues must be at least consider in a critical measurement.
- The exact form of a mathematical expression can influence the quality of a result. For example a difference measurement generated from two precision measurements, e.g., $1.0035\pm0.0002$ and $1.0029\pm0.0002$ gives a very limited result.
- Using a vernier scale is a convenient way of extracting one more significant digit. Most digital display devices have this operation internally

## Misconceptions and Pitfalls

Many students cannot use a vernier scale. Make sure you understand its operation and are able to explain to the class.

## What Student are Expected to Learn

- Calibration of a device before conducting an experiment is very important. Most modern electronic devices have an internal calibration scheme.
- Using the same device (i.e., the micrometer) for different measurements can produce correlated systematic errors.
- Record keeping in a notebook requires neat organized tables and results clearly marked with units and, in most instances, uncertainties.

## What to expect

Most student to find this lab exceedingly dull. We have minimized the number of micrometer readings to just twenty or so. If the students learn to use the micrometers well then this will actually go quickly. In the groups of three the should take turns making measurements with the micrometer. An excel spread sheet can also be made available so that all data recording and calculations are streamlined. As if experiment MC-1A it may be useful for the student to compared there results from the different groups.

# Experiment 1b Worksheet

1.

| | | |
|---|---|---|
| CALIBRATION TABLE | | |
| Micrometer Serial # = | ______ | |
| MEASUREMENTS | | |
| Zero gap 1 = | ______ | ± ______ |
| 2 = | ______ | |
| 3 = | ______ | |
| 4 = | ______ | |
| 5 = | ______ | |
| Mean$\pm\sigma$= | ______ | ± ______ |
| Gauge block 6 mm | ______ | |
| 12 mm | ______ | |
| 18 mm | ______ | |
| 24 mm | ______ | |

2. Make a plot of Gauge block thickness (x-axis) versus Micrometer reading.
   Next fit the data to a line; this generates a correction curve where
   Corrected value = actual × slope + intercept
   slope = ______
   intercept = ______

3. Now for the unknown value

| CYLINDER | Height (± ____) | Width (± ____) | Mass (± ____) |
|---|---|---|---|
| 1= | ______ | ______ | ______ |
| 2= | ______ | ______ | ______ |
| 3= | ______ | ______ | ______ |
| 4= | ______ | ______ | ______ |
| 5= | ______ | ______ | ______ |
| Mean$\pm\sigma$ = | ____ ± ____ | ____ ± ____ | ____ ± ____ |
| Corrected Mean$\pm\sigma$= | ____ ± ____ | ____ ± ____ | ____ ± ____ |
| Density = | ______ | | |
| Max. Density = | ______ | | |
| Min. Density = | ______ | | |

4. Final result, density = ____ ± ____

5. Cut and tape this into you lab notebook.

6. Answer the following question in your notebook.
   A. Identify two sources of systematic error and give their magnitude.
   B. Identify two examples of random error and give their magnitude.