PHYSICS 100L Lab Manual

Cerritos College

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Most of the labs here are based on labs written by Dr. Robert Buschauer.

If you find any errors, please e-mail the author at tszabo@cerritos.edu with details of your finding.

Contents

Experimental Physics

Why do we perform experiments?

It is possible to think of many different ways to describe how physical systems will behave in nature. Which ways are the best at predicting what nature will actually do? Is there a way to test how accurate our ideas are? The only way to determine if our ideas about nature are correct is to ask directly. An experiment is a carefully designed test to ascertain whether an idea that we have about how nature behaves is true or false.

This informs us how to design an experiment - both a positive outcome and a negative outcome must be possible. Once you formulate an idea that makes testable predictions, you have a *hypothesis.* This is an inherent part of the scientific method. More importantly, a hypothesis must be *falsifiable*. The definitions used to state the hypothesis must be clear. If the experiment gives one set of results, it is evidence in favor of the hypothesis. If the results are outside that set, the experiment shows the hypothesis is false. Of course, one experiment performed only one time is not enough to base this decision upon. The experiment must be *repeatable* by anyone who has access to the same equipment and follows the same procedure.

The Boolean[1] nature of these experimental outcomes is different from "true" or "false" questions in other courses. "An electron has negative charge" is a statement that is true; "a carbon atom has 18 protons" is false. How does this way of thinking apply to our experiments? We need a hypothesis to make a *quantitative* prediction which we can then test. We expect a numerical value and a physical quantity to be associated with the outcome of our experiment. A hypothesis might say we get 5.07 grams of a product, or that an object should rise 1.283 meters above its starting point. It is this quantitative nature that makes physics such an incredibly useful model of nature.

What if our experiment produces a value other than what is expected? What if our object moves 1.288 meters higher, or our product has a mass of 4.98 grams? *Any measurement we make will have an inherent **error range** to it.* This is a critically important part of doing any experiment - evaluating the impact that any errors might have on the outcome. When we consider these errors, we are not talking about making an arithmetic mistake. If you go back through your calculations --- and you *always* should --- you should be able to catch and correct these. There are limits to how well we can measure mass or distance or time. We can take steps to reduce these errors, but we can never eliminate them completely. It is much better to report the range of

[1] "Boolean" refers to the work of George Boole and his mathematical development of logic. You may be more accustomed to thinking about it in terms of computing, where a bit can have a value of 0 or 1, corresponding to a switch that is "off" or "on".

outcomes for an experiment rather than simply producing a single number. The range will take into account all the possible errors that are built into how the experiment is performed.

If we look at the two values mentioned before, we can provide a more useful summary of the experiment if we take errors into account and say that the mass is most likely between 4.93 g and 5.03 g, or that the height is most likely between 1.281 m and 1.295 m. A shorter way of writing these outcomes would be 4.98 ± 0.05 g or 1.288 ± 0.007 m. *If the expected value falls within the error range, we say the experiment provides evidence in support of the hypothesis.* Or, more simply, if the range includes the expected value, our hypothesis is shown to be true for that run of the experiment.

Although we don't know any of the details of the experiments, we can interpret the results based on these values. For the case of the mass, the expected value was 5.07 grams. Our experiment determined:

4.98 ± 0.05 g

Which means the range is from $4.98\ g - 0.05\ g = 4.93\ g$ to $4.98\ g + 0.05\ g = 5.03\ g$. The expected value of 5.07 g is outside this range, so this experiment gives a false result for this hypothesis. In the case of the height, the expected value was 1.283 m. Our measurements gave

1.288 ± 0.007 m

The range is then from $1.288\ m - 0.007\ m = 1.281\ m$ to $1.288\ m + 0.007\ m = 1.295\ m$. Because the expected value falls inside this range, this run of the experiment gives support for the hypothesis.[2]

In addition to paying attention to significant figures, you should also always record and report the precision of any measuring instruments you use. This will allow the reader to determine if the number of significant figures you listed were appropriate. List this with the equipment in your report. See the section on How to Prepare Your Lab Reports for an example.

With enough reinforcing evidence, a hypothesis will become a *theory*. This means that repeated experiments show the hypothesis is true. The hypothesis can then be extended to make additional predictions, which future experiments also show to be true. A well-developed hypothesis that provides a framework for thinking about a set of phenomena and that is continually supported by positive outcomes in experiments is then a theory.

[2] This discussion of numerical or experimental evidence for a hypothesis largely comes from the book, *Probability Theory: The Logic of Science* by E. T. Jaynes (Cambridge University Press, 2003).

In PHYS 100, we do not actually test hypotheses. Everything you explore in this class is a well-established theory. The purposes of doing experiments in this class are:

- to help you develop a physical intuition for how nature behaves,
- to allow you to test assumptions you have made,
- to gain skill in setting up lab equipment and following outlined procedures carefully,
- to evaluate sources of error that are built into the way experiments are conducted, and
- to reinforce the ideas of the lecture portion of the class.

One more point worth noting: if an experiment can be developed that is repeatable that provides a false result for an existing theory, that theory needs to be reworked. Science is not so much something you study as something that you do, and it is never complete. That should not be discouraging if you choose to have a career in the sciences -- it means you will always have something to do. There are always ways to extend even established theories to new predictions, and maybe there is something very subtle in the way that nature behaves hiding in those predictions. A new theory that emerges in response to a negative result still has to encompass all of the ideas that went before, but must be extended to take in the new way that nature shows itself. We may encounter a few cases of this sort in this class, especially if we discuss relativity. The study of nature does not sit still. There will be a lot of new ideas to get comfortable thinking about, and it will pay to be patient and persistent. It is to your benefit to keep asking questions. Each new step brings us to a better approximation of what nature really does.

But do not be fooled -- we only get better and better approximations. The theories, however useful they may be, are not nature itself.

How to Prepare Your Lab Reports

Your lab reports should be a concise but complete summary of your experiment and its results.

- Title page
- Abstract
- Equipment
- Procedure
- Data
- Analysis
- Conclusions

The Title Page - All lab reports need a cover page that states:

- the title of the lab,
- the names of the members of the lab group, and
- the date the experiment was performed.

Abstract - An abstract is a very brief summary of what a lab is ultimately supposed to measure. The abstract should also include a one or two sentence summary of the results which includes values from the conclusion along with percent errors. Abstracts should not include any information about how the experiment was conducted or particulars about the equipment used. The purpose of an abstract is to allow a reader to determine quickly whether the rest of the material in the report is something that will interest them.

Some courses will require an introduction or objective after the abstract. The labs we conduct in PHYS 100L are simple enough that only an abstract is required.

Equipment - Provide a list of all equipment used so that anyone else who wants to replicate the results of the lab has this information. You should also include the limits of precision for any measuring devices used. For example, you should be able to read the triple beam balances to within 0.02 grams. When you list this balance in your equipment, you should state that it is precise to ±0.02 g, or ±0.00002 kg.

Procedure - You do not need to write the entire procedure. Give a brief overview of how to do the lab, and list a reference for where someone could get the full set of instructions. This could be a URL from TalonNet or from my website.

Data - Any values that are directly recorded from a measurement during class count as data. These are not values that typically require any computation. You are getting them from a stopwatch, a balance, a ruler, a thermometer, or other measuring device. They must always have the correct number of significant figures and the proper units. If they are presented in a table, you can include the units in the header of that column of the table rather than repeating them on each measurement. If it is easier to present the data with scientific notation, you can include the power of ten in the header of the table as well. (See the Using Microsoft Excel lab for an example.) There may be computed quantities in the table as well, but you will need to show how you arrived at these in the analysis section.

Analysis - Any computations or graphs that you make with your data should appear in the analysis section. If you have Excel do your computations for you, you should at least list the formula used in your analysis. Any equations that you use should be typed using an equation editor in your analysis. All graphs must have a title, and the axes should be labeled properly. Anyone who reads your lab report should be able to follow your work through the analysis. Explain all of your calculations clearly, either with equations or examples.

Conclusions - Any comparisons with accepted values should occur in the conclusion, as well as percent errors and whether your experiment provides evidence in favor or against the idea to be tested. You should also discuss what in the equipment or procedure could introduce errors. The lab manual will provide a list of points to address in your conclusions for each lab. Remember that the main point or value determined in your conclusion should also appear in your abstract.

Use the ideas that are discussed above, as well as what you learn in the first few labs, and you will do well on your reports. There is a lot of detail to include, but you will get better at it with attention and practice throughout the semester.

Using Microsoft Excel

Objective: Students will gain familiarity with using Excel to record data, display data properly, use built-in formulae to do calculations, and plot and fit data with linear functions. They will also understand the importance of the statistical concepts of the average, the standard deviation, and the idea of *outliers*.

Data analysis in the modern world relies upon computers and program suites to make the process faster and less prone to mistakes. Similarly, this is a much neater way to produce graphs and plots. Additionally, there are built-in functions which can provide statistical analyses that can give us estimates of the sizes of our error ranges. Whenever possible in this lab, we will use Microsoft Excel to help us process data.

Important!!

The laptops in class will not save any new work <u>permanently</u> to the hard drive. *If the machine shuts off, all of your work will be lost.* Make sure your laptop is plugged in to prevent the battery from running out and causing you to lose your work. Be sure to save your work to your own USB drive, save it to a network drive (like Google Drive), or save it and e-mail it to yourself. As long as the computer remains on, your work will be available, and can be saved.

Procedure:

Download the Excel spreadsheet named "Excel_practice_lab" - ask your instructor from where you should get it. Open the spreadsheet, and click to enable editing a file that came from the Internet. Column A lists a reference to each individual run of an experiment, from 1 through 10, for several different experiments. Column B gives you the values measured for that run of the experiment.

You may wonder why we run the experiment so many different times. Why not just five times? Or three times? One of the cornerstones of the scientific method is that results are *repeatable*. How do you know if your values repeat if you perform too few trials of the experiment? This also brings up another element of scientific measurements - the idea of an *outlier*. Repeated measurements, when an experiment is well-designed and executed carefully, should produce results which give about the same value. However, in some cases, you might get a value that is far away from what you expect from the other trials or from the theory. We need to decide if this result is showing us something we did not understand previously, or if it is an outlier. The best way to determine this is to run the experiment more times and do some statistics with the results. There are numerous ways to evaluate a set of data statistically. For this course, we will focus on taking the *average* of a set of data, and its *standard deviation*.

Look at column B in the "Excel_practice_lab" spreadsheet for the trials listed for each experiment. You can most likely get a feel for the average from looking through the list. It has to be higher than the lowest value, but also less than the highest value. The first way to consider it, before doing any calculations, is that it has to be "somewhere in the middle" of the data set. You probably already know how to calculate it, but to review:

- Add up all the values
- Then divide the sum by the number of values that you have.

Look at the temperatures as an example. If you wanted to do this by hand, you would add:

$$95°C + 103°C + 98°C + ... + 97°C + 99°C$$

We should introduce some more general mathematical notation for doing this, so that we can use an equation to represent this sum in the future. First, instead of using the values, we will represent each trial with a variable: T_1 for the first trial, T_2 for the second, up to T_{10}:

$$T_1 + T_2 + \cdots + T_{10},$$

where T_1=95°C, T_2=103°C, and so on, up to T_{10}=99°C. This is better, especially for a computer program, where you want different values assigned to each variable for each time you run the experiment for several trials. You just have as many T_i as you need. What does the *i* stand for that goes with our temperatures? It is an *index*. You see the trials are labeled from 1 to 10 - those are the *indices* to let us know which result comes from which trial. We want to ***sum** the temperatures over their **indices***. The mathematical notation for this is to use a Greek capital letter 'S' to stand for ***sum***. It looks like this:

$$\Sigma$$

and it is pronounced "sigma". The mathematical notation for adding up all the temperatures is

$$\sum T_i.$$

We can add to this notation to let someone else know we are adding from trial 1 up to trial 10:

$$\sum_{i=1}^{10} T_i$$

If there is not enough room to write it this way, you may also see it as $\sum_{i=1}^{10} T_i$.

We do not have the average yet, though. We have to divide by the number of trials, or multiply by the reciprocal of the number of trials:

$$\frac{1}{10}\sum_{i=1}^{10} T_i$$

To write this as generally as possible, we do the following:

$$\frac{1}{n}\sum_{i=1}^{n} T_i$$

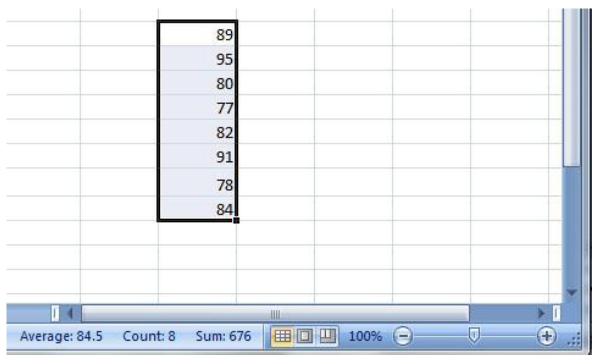
In our case, n=10. We add together the values from all trials, 1 through 10, then divide by 10. If you run the experiment 26 times, then n=26. In some cases, like at the Large Hadron Collider, they are looking for millions or tens of millions of runs of an experiment (or more). The mathematical notation for the average value is a variable with a line above it. For our average temperature, it would be $\bar{T}$. *Any time you see a variable with a bar over it in this course, you should think "average"*. The other name for the average value is the *mean value*. So, *average* and *mean* are interchangeable for our purposes.

To put this all together in one equation:

$$\bar{T} = \frac{1}{n}\sum_{i=1}^{n} T_i$$

We can use the same notation for average speed ($\bar{v}$), average mass ($\bar{m}$), or even average florbs ($\overline{florbs}$).

How do you take an average in Excel? Excel has a built-in function for doing this. Go to an empty cell on the spreadsheet and type "=AVERAGE(" then, highlight all of the values you want to average, then close the parenthesis ")". When you hit the "Enter" key, the average value will appear in the cell. There is actually an even easier way to do this: highlight all the values and look in the lower right corner of the window for Excel.



The status area at the bottom displays the average of the values, how many values there are (the "Count"), and the sum of all the values.

Once we have an average value, how do we determine whether a value is an outlier? We have to evaluate how the data is spread out. Does it cover a narrow range of values, or do they go much higher and lower than average? What is most often computed to determine this is the *standard deviation*. This lets another person reading your report know, in one number, a rough idea of how your values were spread out, or distributed.

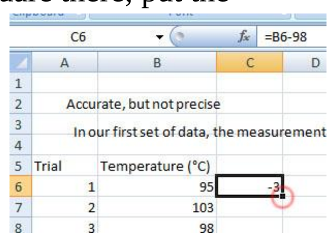
Standard deviations are computed for a set of data by doing the following:

- Find the average (or mean) value of the data
- Subtract the average from the value for each trial
- Square all the differences you got from the previous step
- Sum the squares of the differences
- Divide the sum by one less than the number of trials
- Take the square root of the result

Technically, this is known as the *sample standard deviation* - you could take an entire course on statistics if you want to know more about this. For our purposes, we'll call this our "spread".

Here are the steps for doing this the long way in Excel. Do this for the temperature values in the spreadsheet.

- First, find the average value using one the methods mentioned above - use either the "AVERAGE" function or highlight all the cells.
- In column C on your spreadsheet, do the following:
    - Click on the cell to the right of the first trial
    - Type an equals sign =
    - Click on the value in column B; a reference to that cell should appear next to the equals sign. For example, it should now appear as =B6
    - Type a minus sign - followed by the value for your average. This should now appear as =B6-98.2 (or whatever you got for your average if it was not 98.2°C)
    - Press "Enter" and the difference will appear
    - Instead of repeating this for all the other cells, try this instead:
        - Position the cursor over the lower right corner of the cell where you computed the difference. There is a small black square there; put the cursor directly over that. The square is circled in red in the image at the right.
        - The cursor should change from an open cross to a solid black cross when it is over this square.
        - When the cursor is a solid black cross, click and drag over the cells where you want to computation to be done. The same computation will be automatically repeated over all of the other cells.



- Now that we have the differences, use column D to compute the squares:
    - Click on the cell to the right of the first trial in column C and type an equals sign =
    - Click on the value in column C, then type an asterisk * for multiplication
    - Click on the same value in column C again; the result should look something like =C6*C6
    - Hit "Enter" to get the value squared
    - Use the same trick with clicking and dragging on the little black square in the lower right to repeat the calculation for the other cells
- Find the sum of all values in column D
- Do **not** divide by the number of trials; divide by one less than that number (in this case, 9 instead of 10)
- Take the square root of the result; you can do this in Excel with =SQRT(47.2) (if 47.2 was your result from the last step)

What is produced from the last calculation is what we will use as the standard deviation, denoted by σ (lowercase sigma). The general formula for the standard deviation is:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

This notation may vary slightly from what you learned in a statistics class, but the underlying concept is the same.

Important Excel note:

If you change the formula for one row of a computation, you need to drag that box (using the small black square) over all other computations for it to take effect. Excel does not automatically change the other computations.

Follow along with these steps as we do this for the temperature data, then do these steps on your own with the speed of light data. This will get you more accustomed to using Excel for calculations.

Once these calculations are in your spreadsheet, compare them with the result from the shortcut:

- In an empty cell, type =STDEV(
- Then, drag over the cells that contain the values for the trials
- Close the parentheses) and hit "Enter"

Did you get the same result as you did when you did it the long way? From now on, use the built-in function, but keep in mind what that function is doing with your data.

- Questions to answer in your lab write-up:
  - Why do we square the differences after we subtract the average from each trial? What purpose does this serve?
  - List another example from mathematics where we take the square root of the sum of quantities that are squared.

How should you report these average values with standard deviations in your lab reports? There are two primary ways you may see this done. The first is to use a plus/minus sign, which is what your text uses in the homework from Chapter 1:

The accepted value for the radius of a proton is 0.879±0.008 fm.

The second way is to include the standard deviation in parentheses after the last significant digit:

The accepted value for the radius of a proton is 0.879(8) fm.

The method with the plus/minus (±) sign seems much clearer to me, especially for people who are just learning physics. This is the version you should use. To write this in general for the radius of a proton, we would use:

$$\overline{r_p} \pm \sigma_{r_p}$$

The r_p subscript on the σ reminds us that this is a standard deviation of a measurement of the radius of a proton. (Yes, even subscripts can have subscripts!)

Examine the data for the mass of a mole of bismuth (chemical symbol, Bi) atoms. A mole of something is 602,214,082,000,000,000,000,000 of whatever thing you are counting. This is a bad standard to use for things like books or puppies, but good for things like atoms or molecules. All of those extra zeroes on that number (after the last "2")? Those are not significant. A much better way of writing the most precise value measured[3] for a mole is 6.02214082 x 10^{23}.

- Examine the 10 trials for the mass of bismuth. Can you identify an outlier from looking at the data? Which trial is it? Compute the average mass, $\overline{m}$, and the standard deviation, σ_m, if you include the outlier. Record this value to include in your report.
- Change the ranges on your AVERAGE and STDEV so they do not include the outlier. You can do this by changing =AVERAGE(B78:B87) (or whatever the range is) to =AVERAGE(B78:B79,B81:B87) where the example skips the value in B80 (if that is the outlier). Record the new values for $\overline{m}$ and σ_m.

Be very careful with outliers!

Never assume that because one run of an experiment produces a value that is different from the others that it is automatically an outlier. The best thing to do is run the experiment for additional trials. If the procedure calls for 5 separate measurements, and you suspect one is an outlier, run 6 or 7 (at least) so that you can be sure. Another approach is, once you have run the extra trials, compute the average and standard deviation (σ) without the outlier. If the outlier is more than three standard deviations away from the average, you *may* be safe in omitting it.

In the case of the three data sets we have worked with, there is an accepted value for these quantities. It should only take a little bit of searching to find these accepted values. Since you will have access to a computer during lab, you should get accustomed to using it to look up information from reliable sources. We can compute a percent error for each of the values as follows:

$$\frac{|accepted\ value - experimental\ value|}{accepted\ value} \times 100\%$$

[3] See efforts to redefine the kilogram at www.nist.gov

You may also see "accepted value" listed as "theoretical value", if we have a valid theory (or hypothesis) for determining this value. If there is an accepted or theoretical value for a quantity that you measure in this lab, you should include the percent error.

Something students often get wrong in this course:

When you subtract two values that have a limited number of significant figures, the result often has fewer significant figures than when you start. We will discuss more about this in the next lab, but you should already have done some work with this in class. *This problem arises most often when students are determining percent errors.* Pay close attention to significant figures whenever you subtract two quantities.

The last exercise we will do as part of this lab is to create a plot. Look at the data that represents the altitude of an object falling toward the surface of Mars. First, let's plot the altitude (in meters) vs. the time (in seconds).

1. Click “Insert” at the top, then click the symbol for “Scatter” under “Charts.”
2. Choose the option that shows “Scatter with only markers” – it’s the top left option.
3. You now need to select the data to use. “Chart Tools” should now be highlighted in green. Click the button from the row at the top that says “Select Data.”
4. From the window that appears, click “Remove” on the left side of the window until the area under it is empty.
5. Click the “Add” button.
6. Enter “Altitude vs. time” for the “Series name.”
7. Click on the box for “Series X values,” then drag the cursor over all of your values for the time from your table.
8. Click on the box for “Series Y values,” delete any numbers that are present, then drag the cursor all of your values for altitude from your table.
9. Click OK on this dialog and the one where you originally selected the data. This should complete the data for your graph.

Although this is not the final graph that we want, take a look at what these steps produce.

- What shape would you say the points on the graph make?

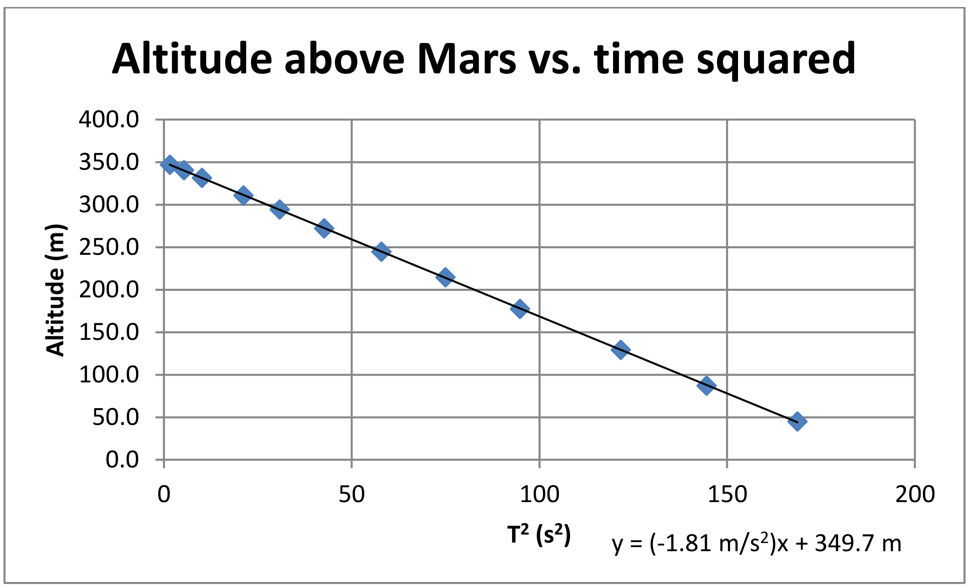
What we would prefer to plot is a *linear graph* - it is easier to determine what relationships are present if the graph is a straight line. To do this, we will plot **altitude vs. time squared (T^2)**. In another column next to the altitude measurements, populate the cells with the square of the time data. You should know how to do this from our practice with standard deviations. Run the steps above to plot altitude vs. time squared.

The last thing you will need to produce for this lab is a copy of the plot shown below. It should have a title, labels on the axes with the proper units, a trend line showing the best line fit to the data, and the equation of the trend line. Here are some guidelines for accomplishing this:

10. “Chart Tools” should still be highlighted in green. Click “Layout” from this highlighted section.

11. Click “Axis Titles”, highlight “Primary Vertical Axis Title,” and choose “Rotated Title.”
12. Click in the “Axis Title” area that appears on your graph and add the appropriate variable and include the units.
13. Click “Axis Titles”, highlight “Primary Horizontal Axis Title,” and choose “Title Below Axis.” Add the appropriate variable and units to the area that appears on your graph.
14. Click on the button that says “Trendline” and choose “Linear Trendline.”
15. Right click on the line that appears on your chart and click “Format Trendline.”
16. Click the box for “Show Equation on Chart.”

You can also use "Gridlines" from the "Layout" menu to add those. To get superscripts or subscripts, right click on the letter or numbers you want to change, then select "Font" from the menu that appears. This will give you the option to change something to a superscript or subscript. You will be graded on how closely your plot resembles the following:



Your report for this lab should include:

- You do not have to write a formal report for this lab. Include a cover sheet, and make sure the following points are addressed.
- Having me sign off on your work in Excel before you leave the lab
- Email your completed Excel file, including your graph, as an attachment to the e-mail address provided by your instructor: ______________________________________
- For all repeated measurements of a single value, such as the boiling point of water or the speed of light, include them in your report in the form:

$$\bar{x} \pm \sigma_x$$

with proper units, scientific notation, and significant figures. Explicitly state what physical quantity the numerical value represents.

- For measurements which are compared with a well-established quantity, compute the percentage error, and include it.
- State whether the accepted value falls within the error range for each measurement.
- The Excel spreadsheet lists the trials as "accurate but not precise", "precise but not accurate", and "precise and accurate." Explain in your own words why each phrase is associated with its set of data.
- Write the radius of a proton in meters (m) rather than in femtometers (fm) by using scientific notation and correctly including the error in the value.
- In the equation in the corner of the "Altitude above Mars vs. time squared" plot above, what is the significance of the y-intercept value? What point in the fall does this refer to?
- Your report should also include using an equation editor to type out the following expressions in the conclusions of your report. This is to get practice with the equation editor.

1) $\dfrac{x_2 - x_1}{t_2 - t_1}$

2) $v_f^2 - v_i^2 = 2a\Delta x$

Measurements and Significant Figures Lab

Even though this lab in particular includes "Significant Figures" in the title, *you should always pay attention to providing the correct significant figures* in every measurement and calculation you make throughout your scientific or engineering career.

Objective:
This lab is designed to give you practice using a micrometer and a Vernier caliper. You will also practice using significant figures correctly. The goal is to find the material of which two objects consist by determining their densities.

Equipment:

Short metal cylinder
Metal rod
Triple beam balance
Micrometer
Vernier calipers
Centimeter ruler

Procedure:

Throughout this experiment, always use the *most precise measuring tool possible* to make your measurements. Remember that you can read the scale on the ruler and micrometer, then estimate one more digit to get the correct number of significant figures.

1. Record the zero reading of the micrometer in mm. This is the reading it has when it is closed. ***Only use the small knob at the end of the micrometer to close it!***
2. Measure the diameter of the object at least six times in six different places along the length of the object. Alternate between you and your lab partner. Average the results of the measurements. Subtract the zero reading to get the corrected average diameter.
3. Record the zero reading of the Vernier calipers in cm.
4. Measure the length of the object at least six times using the most precise tool possible. Alternate between you and your lab partner. Average the results. If you used the Vernier caliper, subtract the zero reading from your average.
5. Zero the triple beam balance. Determine the mass of the object in grams (g) to the correct precision and record it.

6. Convert all corrected average length and diameter measurements to cm. Use the mass you found in step 5 to calculate the density of the object in g/cm^3. Record your answer to the correct number of significant figures.
7. Compare your calculated density from step 6 with the actual density of the object. Look at the densities in the table in this lab. If there are any other properties that help you identify the substance it is made of (such as its color), take this into account. Calculate a percent error between your experimental value and the accepted value, and report it with the correct number of significant figures. If your error is greater than 7%, find the problem and correct it.

   Do the above steps for both cylinders and record them on your answer sheet.

Equation for density: $\rho = \frac{M}{V}$ (We use the Greek letter, ρ -- pronounced *rho* -- for density because *d* is used for distance or diameter. Using the same variable for too many things gets confusing.)

Volume of a cylinder: $V = \pi r^2 h$
$D = 2r$

Combine these equations to solve for density, ρ, in terms of mass, m, height, h, and diameter, D. Show your work on your data sheet.

Definition of percent error:

$$\frac{|experimental - theoretical|}{theoretical} \times 100\%$$

Rules to keep in mind when using significant figures:

- Multiply or divide? Use the least precise value (smallest number of s.f.) to limit your final expression.
- Add or subtract? Make sure all measurements have the same units and the same power of 10, then use the least precise measurement (tenths? Hundredths? Millionths?) to limit your final answer. ***Subtraction can reduce the number of sig figs.***
- Powers? 2.45^2 or $18.42^{1/2}$ – answer has same number of sig figs as original value.
- 0.1444 x 100% = 14.44 %
- 0.0001444 = 1.444 x 10^{-4}
- sin(15.83°) = 0.2728 – Keep same number of sig figs as the argument in your answer.
- Exact numerical constants **never** change the number of sig figs.
- The speed of light (c = 2.99792458 x 10^8 *m/s*) is defined as an exact numerical constant.

Table of densities

Material	Density (ρ) in g/cm^3
Lithium (Li)	0.535
Aluminum (Al)	2.70
Zinc (Zn)	7.14
Steel	7.86
Brass	8.44
Copper(Cu)	8.92
Silver (Ag)	10.49
Uranium (U)	19.05
Gold (Au)	19.3

There are some additional problems on the data sheet to test your ability with significant figures and scientific notation. Please complete these as well.

Your report for this lab should include:

- Your derivation for ρ in terms of m, h, and D. This should be typed using an equation editor, showing each step of your derivation.
- Your densities for each of the materials.
- Your guess for what materials they are. You can include additional supporting details, but your guess should be mostly based on the density you computed.
- Your % error (with correct sig figs) based on the provided densities of those materials. Use the provided density as the theoretical value.
- Solutions to the following problems to demonstrate that you know how to work with significant figures:

1) $6.105\left(\frac{3.228}{0.0020}\right)^3 =$

2) $\frac{2.3842\left[\tan 12.38^\circ - \sin 12.382^\circ\right]}{\sqrt{42.19}} =$

3) $\frac{|9.78-9.806|}{9.806} \times 100\% =$

- You do not need to type a formal lab report. You can use the data sheet provided, but type your measurements and formulae into it. Please attach the written version of your measurements (that you did by hand in lab) to the back.

Vector Addition Lab

Objective:
To confirm experimentally that forces obey the laws of vector addition and to practice the techniques involved with vector addition and subtraction, both algebraically and graphically.

Procedure:

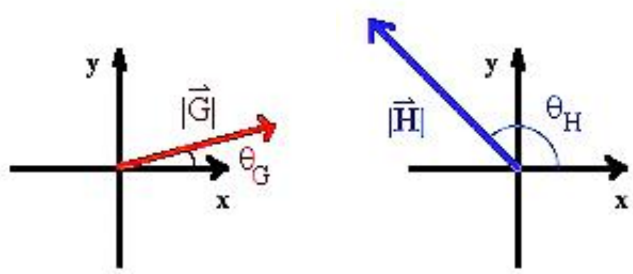
1. Level the force table. Then attach the following masses to the ring on the force table. Don't forget to include the mass of the hanger. Notice that the ring is NOT in equilibrium under the action of the three forces alone. If you removed the peg (which applies a force to the ring), the ring would accelerate.

   2.00×10^2 grams at an angle of 0.0 degrees.....This provides force $\vec{A}$.
   1.00×10^2 grams at an angle of 70.0 degrees....This provides force $\vec{B}$.
   1.50×10^2 grams at an angle of 150.0 degrees...This provides force $\vec{C}$.

Convert all three masses to weights in newtons for use in the calculations below. Keep in mind that the magnitudes of these forces are always in newtons, **not** grams or kilograms.

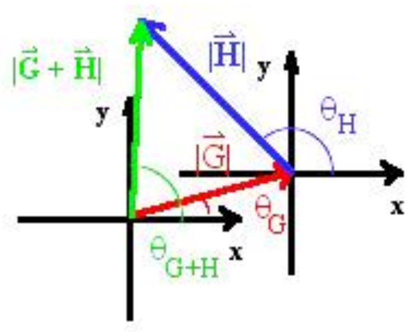
2. Graphically construct the sum $\vec{A} + \vec{B} + \vec{C}$ to scale on a piece of paper using the tip to tail method. That is, draw $\vec{A}$ to scale. Choose a scale of 3.50 cm = 1.00 N. Then, using the tip to tail method add $\vec{B}$ to $\vec{A}$ (also drawn to scale). Then add $\vec{C}$ to $\vec{A} + \vec{B}$. Finally, draw a vector from the tail of $\vec{A}$ to the tip of $\vec{C}$ and call it $\vec{R}$ for *resultant*. Measure the length of $\vec{R}$ with a ruler in cm, and convert it to N (newtons). Also, measure the angle in degrees that $\vec{R}$ makes with the positive x axis using a protractor. Write down these numbers (magnitude of $\vec{R}$ in N and the angle it makes with the positive x axis) on the diagram and enclose them clearly in a box.

As an example, let's say you have two vectors, $\vec{G}$ and $\vec{H}$, as shown below.



There are coordinate axes with each vector to help you visualize the angles associated with them. Note that the x- and y-axes point in the same directions for both vectors. *Once you assign the directions of the x- and y-axes, those must remain consistent throughout the problem.* You are allowed to move vectors around by repositioning the beginning (the tail) of each vector, but you cannot change the rotation of the axes, *or the direction that the vector points*. Note that the angle of each vector, θ_G and θ_H, are both measured from the positive x-axis.

To continue with adding the vectors graphically, move the tail of one vector so it is at the tip of the other vector. In the diagram below, we moved vector $\vec{H}$ so that its tail is at the tip of vector $\vec{G}$. This is allowed, because the coordinate axes and the vectors still have the same angles; we did not rotate either one.



Vector $\vec{G}$ is still shown in red, and vector $\vec{H}$ in blue. Now, there is a new vector, $\vec{G}+\vec{H}$, shown in green. This was constructed by drawing a new vector from the beginning (tail) of vector $\vec{G}$ to the end (tip) of vector $\vec{H}$. This new vector is the sum of the two vectors, and its magnitude, $\left|\vec{G}+\vec{H}\right|$, and angle, θ_{G+H}, are shown in the diagram.

Note: You do not draw the coordinate axes with each vector when you graphically add vectors. They are shown to help you get the right idea of how to do it.

3. Using the component method calculate $\vec{R}$ above. That is, calculate its magnitude(in N), and the angle in degrees that $\vec{R}$ makes with the **positive x axis**.

Remember that:

$$\left|\vec{R}\right| = \sqrt{R_x^2 + R_y^2}$$

$\theta = \tan^{-1}\frac{R_y}{R_x}$ but, be careful to adjust the angle to the correct quadrant.

$$R_x = \left|\vec{R}\right|\cos\theta$$
$$R_y = \left|\vec{R}\right|\sin\theta$$

If you use $0° \leq \theta < 360°$, you automatically get the correct sign for R_x and R_y.

Clearly write these numbers and a box around the result. Compare these results for the magnitude and angle of $\vec{R}$ with those in Step #2 by calculating a percent error for the magnitude, and report the difference in the values for the angles. Compute the absolute difference in θ_R between step 2 and step 3. Make sure your absolute difference has the correct number of significant figures. If either difference is large, figure out why and correct the problem.

Remember: you can only add x-components to other x-components, and y-components to other y-components. *Be careful not to mix them when adding!*

4. Now we wish to put the ring in equilibrium. To do so we need to add another force to $\vec{A}$, $\vec{B}$, and $\vec{C}$ which is the opposite of $\vec{R}$. Call it $\vec{E}$ for *equilibrant*. $\vec{E}$ will have the same magnitude as $\vec{R}$ but will point in the opposite direction. Set up all the forces $\vec{A}$, $\vec{B}$, $\vec{C}$, and $\vec{E}$ on the force table. Is the ring in equilibrium? If not, figure out why not. CALL ME OVER AT THIS TIME to verify the equilibrium and to record the number of your mass set.

5. As in step #3 use components to calculate the magnitude of vector $\vec{D} = \vec{C} - 2\vec{A}$. Also, calculate the angle in degrees that $\vec{D}$ makes with the positive x axis. Write these numbers and indicate your answers in a clear manner.

Consider these questions as you work on step 5:

- What does multiplying a vector by -1 do to the vector? How would $\vec{B}$ and $-\vec{B}$ be related?
- What does multiplying a vector by a positive number do? Does the magnitude change? What about the direction?

You should look at step 5 as follows:

$\vec{D} = \vec{C} - 2\vec{A}$ is actually two equations:

- $D_x = C_x - 2A_x$
- $D_y = C_y - 2A_y$

You will always have as many equations as you have *dimensions* for your vectors. This is part of what makes one-dimensional problems easier.

6. As in step #2 draw $\vec{A}$, $\vec{C}$, and $\vec{D}$ to scale on a diagram; use the same scale of 3.50 cm = 1.00 N. Measure the length of $\vec{D}$ in cm and convert to N. Also, measure the angle that $\vec{D}$ makes with the positive x-axis. Write down these numbers clearly and box in the result. Finally, calculate a percent error between the component calculations (taken to be the true, theoretical values) and your measured (experimental) values for $\vec{D}$ (in N). Calculate an absolute difference between the θ_D values.

Your report for this lab should include:

- Make sure all vector diagrams are drawn neatly, to scale, and are clearly labeled as Step 2 and Step 6.
- Type at least one example (either step 3 or step 5) for combining vectors by the component method. Your data sheets from lab should show all your calculations.
- What is the precision with which you can read the ruler, the protractor, and the angles on the force table? The errors on the hanging masses should be taken as ±0.5g.
- When writing your conclusions, state whether you were able to get the ring in equilibrium in step 4. Find the percent difference between the magnitude of the theoretical equilibrium vector from step 3 and the experimental equilibrium vector for step 4. Do not find the percent difference in angle – only provide the actual difference in degrees.
- Include percent error in magnitude between step 5 (theoretical) and step 6 (experimental), and the difference (not percent difference) in angle.

Friction Lab

Objective: To determine the coefficients of static and kinetic friction between a block and a surface by two separate methods

Procedure:

In this lab, it will always be easier to determine the coefficient of kinetic friction than to determine the coefficient of static friction. *Always do kinetic friction first so you have a baseline for comparison.*

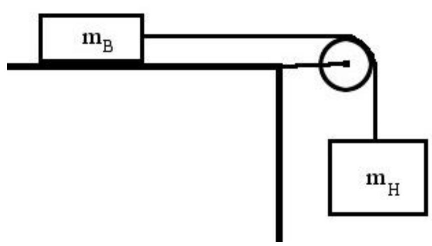
The *coefficient of friction* is a ratio of two forces: a force perpendicular to a surface (most often this is the weight of the object, or a portion of it), and a force needed to hold the object in place or to resist its motion. Coefficients of friction never have any units - the units cancel. We use the lowercase Greek letter μ for coefficients of friction. Thus, μ_s is for ***s***tatic friction, and μ_k is for ***k***inetic friction.

- From lecture, how are μ_s and μ_k always related?

Before beginning your other measurements, record the number of the wooden block you used and which side will be in contact with the surface. Use the triple beam balance to get the mass of the block. Keep in mind the precision of the triple beam balance when recording your value.

<u>Using a horizontal surface to determine coefficients of friction</u>

In the diagram below, m_B refers to the mass of the block, and m_H refers to the amount of mass hanging vertically.



To determine the coefficient of kinetic friction between block and surface using a horizontal surface.

1. (a) Put the block on the inclined plane set to zero degrees, run a cord parallel to the plane over the pulley and attach a mass hanger at the end. Add mass to the hanger until the system moves with constant speed when given a small push to overcome static friction.

(b) The coefficient of kinetic friction, μ_k, is the ratio of the mass hung from the string (m_H) to the mass of the block (m_B): $\mu_k = m_H/m_B$. As part of your lab report, you will need to draw free body diagrams for each block and show how to derive that this is the general expression for the coefficient of kinetic friction. Remember that the mass of the hanger counts as part of m_H.

(c) Repeat adding masses to the hanger, starting with just the hanger, a few more times to get several values of the coefficient. Average them as above to obtain a final result. Be sure to check for outliers, and run additional trials if you encounter any. Call your average coefficient:

$\mu_{k_{horizontal}}$

2. To determine the coefficient of static friction between a wood block and a surface using a horizontal surface, follow the same procedure as for step 1, except now you will add mass to the hanger until the block slips on its own. As it does, it will accelerate. *Be very careful not to bump the table. Do not allow the hanging mass to swing or spin. Add masses very gently so you do not provide the jolt that might break static friction.*

$$\mu_s = m_H/m_B$$

Use the equation above to find μ_s. Repeat the measurement at least 5 more times, and check for outliers as you do so. *Keep in mind the relationship between μ_s and μ_k.* After you have enough data, take the average of your coefficients and call it:

$\mu_{s_{horizontal}}$

<u>Using an inclined surface to determine coefficients of friction</u>

3. (a) Put the block on the plane and slowly raise the plane. Raise the plane only until the block slides at constant speed when given a small push to overcome static friction. The coefficient of kinetic friction is the tangent of the angle at which it slides at constant speed.

- To how many significant figures can you read the angle on the incline? Remember that the tangent of that angle will have the same number of significant figures.

(b) Repeat at least four more times alternating between you and your lab partner. Check for outliers. Average the values of μ_k to obtain a final result, which you will call:

$\mu_{k_{inclined}}$

4. To determine the coefficient of static friction between block and surface using a non-horizontal surface.

(a) Place the block on the plane. Very slowly increase the angle of the plane until the block is on the verge of slipping. The coefficient of static friction is the tangent of the angle made by the plane with the horizontal. *Raise the ramp very gently; do not jolt or jar it, or move it very suddenly. Using a soft cloth or folded paper towel can dampen vibrations that you might otherwise pass from your hand to the plane.*

(b) Repeat at least four more times. Alternate between you and your lab partner, and check for outliers. Average the values of the coefficient (**not** the angles) and call the final result:

$\mu_{s_{inclined}}$

5. Check that all of your values for μ_s and μ_k make sense. How can you tell?

6. There is no theoretical value for making comparisons, so find the average μ_s and average μ_k :

$$\overline{\mu_s} = \frac{\mu_{s_{horizontal}} + \mu_{s_{inclined}}}{2}$$

$$\overline{\mu_k} = \frac{\mu_{k_{horizontal}} + \mu_{k_{inclined}}}{2}$$

7. Compute a percentage difference between $\mu_{s_{horizontal}}$ and $\mu_{s_{inclined}}$. Use $\overline{\mu_s}$ as the denominator. Do the same for your μ_k values. Make sure that no percentage difference is greater than 20% (to 2 s.f.). If any percentage differences exceed 20%, determine what in your methods led to this result and redo that part of the experiment.

Your report for this lab should include:

- Your values of $\overline{\mu_s}$ and $\overline{\mu_k}$ along with their percent differences should appear in the abstract and the conclusions.
- A free-body diagram and the equations of motion derived from them for the horizontal case to show that, when the system is in equilibrium (refer to lecture notes):
$$\mu_k = m_H / m_B$$
- Values for $\mu_{k_{horizontal}}$, $\mu_{s_{horizontal}}$, $\mu_{k_{inclined}}$, and $\mu_{s_{inclined}}$, along with their standard deviations. Use the form that was emphasized in the Excel lab.

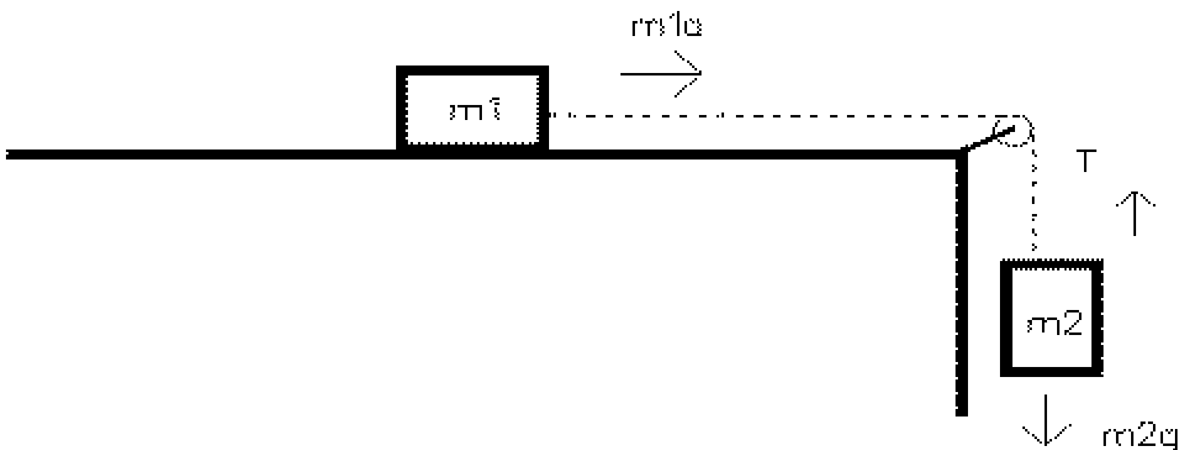
Newton's Second Law Lab

(Written by Prof. Carlos Mera)

Objective:

To examine Newton's second law for connected masses.

THEORY: As you know by now, Isaac Newton was a great physicist who derived $\vec{F} = m\vec{a}$. This means a system of masses will undergo acceleration when subjected to a force, in this case a weight hanging off the lab bench. The system of masses means all the mass that moves due to the net applied force. In this lab we will examine specifically the consequences of $\vec{F} = m\vec{a}$. Consider the standard connected masses diagram below:



The force which causes the system to move is the force of gravity on m_2, the hanging mass. Gravity causes no motion directly in m_1, although it does play a part in the friction between m_1 and the surface. Let the string that connects m_1 and m_2 be very light and not stretchable. This means that the accelerations for both masses is the same. Examining all the forces on m_1 we see that the tension T in the wire equals (neglecting friction) m_1***a**. T is the only force which causes acceleration in m_1. On the other hand, m_2 has two forces working on it. Gravity is pulling down and tension T is pulling up. The net force on m_2 is the difference between m_2*g and T. Putting these ideas together and solving for **a** we have:

$$|\vec{a}| = \frac{m_2 g}{(m_2 + m_1)}$$

(Equation 1)

We will use equation 1 to calculate the **theoretical value of a**.

Also, by knowing the distance m_2 falls, and the time of descent, one can use fundamental kinematic equations to also determine **a**.

$$|\vec{a}| = \frac{2h}{t_{avg.}^2}$$

(Equation 2)

We will use equation 2 above to calculate the **experimental value of a.**

Think about the consequences of making $m_1 >> m_2$. Disregarding friction for the moment, will m_1 ever become big enough for the acceleration to equal zero? Will acceleration ever equal g ($9.8 m/s^2$)? Will keeping the total mass constant but changing the distribution of the mass affect the acceleration? Suppose the string that connected the two masses was very heavy — how would the acceleration be affected? These are the questions you can answer by carefully observing the outcome of the experiment, and you should address them in your conclusions.

Equipment:

- Air track
- Cart
- Pasco Interface and Photo gates
- meter stick
- foam landing pad
- masses
- 5g mass hanger
- PC and spreadsheet

Procedure:

1. Set up the air track and cart as shown at the front desk.

** **<u>Do NOT move the cart while the air is off!</u>** Make sure once the air is on that the cart doesn't move. (The mass hanger should not be attached to the string in this step.) This means the track is level. **

2. Set the height of the hanger to a distance greater than 70 cm.
3. Mass the cart, and record this value in Kg.
4. The cart will represent m_1 and the hanging mass (the hanger plus any other mass on it) will be m_2.

<u>Interface and Software Initial Setup:</u>

1. **Carefully position the photo gates so that the distance between the gates is the same distance the mass hanger falls.** ***<u>Use 70 cm for this distance. This is the same value that you will use for h in your calculations</u>***
2. Connect the PASCO Interface to the computer by using the USB cord.
3. **Plug the photo gate near the blower into the digital input #1 and the other photo gate into the digital input #2 on the interface box (1/4" phone plugs)**.
4. Make sure that the cart can block the photo gate and that the string in not triggering the photo gates. **You will use the leading edge of the cart to trigger the photo gates**.
5. Double Click the "PASCO Capstone" shortcut on the desktop to start the program.

6. On the left side of the screen click on the "Hardware Setup" icon that is under the tools menu. The hardware setup window will open with a picture of the interface.
7. Move your mouse cursor over Digital Input # 1 and right click. Select Photo gate from the drop down menu. A picture of a photo gate connected to the input will appear.
8. Repeat step 7 for the Digital Input # 2.
9. Click on the "Timer Setup" icon on the left side under the Tool group. The Timers Setup window will open.
10. Select "Built your own timer" from the drop down menu.
11. Select both photo gates by checking the boxes next to their names. Click next.
12. Set the timing sequence to Photo gate ch1 "Block" and Photo gate ch2 "Block" by using the pull down menus next to each photo gate name. Click next.
13. Click Finish.
14. Click the Timer Setup Icon under tools to close the window.
15. Double click the table icon that is under the displays group on the right side of the screen. A table with two columns will open.
16. On the table's left column click the "Select Measurement" button. Then select "Custom timer (s)" from the drop down menu. You are ready to start taking data.
17. Click the "Record" button (big red button) on the lower left side of the screen to start collecting data. The timer will start as soon as the cart crosses the first gate and stop when the cart crosses the second gate.
18. Click the stop button after every run. To see previous runs, click on the "Run #" button and select the run you wish to see.

Make sure that the hanger does not hit the ground before the cart has passed the second photo gate. Turn off the blower once the car passes the second gate. Your table should now display the time of travel between photo gates.

<u>Experiment</u> : During this part of the experiment both the values of m_1 and m_2 will change.
<u>Do NOT move the cart while the air is off!</u>

1. Add 40 grams to your cart (use a combinations of 5 and 10 grams masses)
2. With m_1 on the air track (cart + 40 grams) and 10 grams (the mass hanger + 5 g) as m_2, time the descent of the mass hanger **five times**. Record the time values.
3. Decrease m_1 by 5 grams and increase m_2 by 5 grams (just transfer 5 grams from the cart to the hanger). Time five descents and record all values.
4. Repeat step 3 until m_2 = 50 grams (remember to account for the hanger's mass). Each occasion time five descents. **Record all values.**

Calculations:

1. On a spreadsheet make columns for m_1 (kg), m_2 (kg), the total mass ($m_1 + m_2$) (kg), $m_2/(m_1+m_2)$, times 1, 2, 3, 4 & 5, the average time, the experimental acceleration from kinematics, the theoretical acceleration (our working equation), and the accelerating force **(m_2*g)**. **<u>Be sure to label all columns, and include units!</u>**
2. Next you are going to make eight different charts using your data:

1. **Chart 1:** Using markers only, graph the experimental acceleration vs. the Mass Ratio $m_2/(m_1+m_2)$. **Add a trend line with a (0,0) intercept. Include the equation of the line.**
2. **Chart 2:** Using markers only, graph the theoretical acceleration vs. the Mass Ratio $m_2/(m_1+m_2)$. **Add a trend line with a (0,0) intercept. Include the equation of the line.**
3. **Chart 3:** Using markers only, graph the experimental acceleration vs. M_1 **Add a trend line do not cross it through (0,0) intercept. Include the equation of the line.**
4. **Chart 4:** Using markers only, graph the theoretical acceleration vs. M_1 **Add a trend line do not cross it through (0,0) intercept. Include the equation of the line.**
5. **Chart 5:** Using markers only, graph the experimental acceleration vs. M_2 **Add a trend line with a (0,0) intercept. Include the equation of the line.**
6. **Chart 6:** Using markers only, graph the theoretical acceleration vs. M_2 **Add a trend line with a (0,0) intercept. Include the equation of the line.**
7. **Chart 7:** Make a graph **(using markers only)** of the accelerating force (Y-axis) vs. the experimental acceleration (X-axis). **Add a trend line with a (0,0) intercept. Include the equation of the line.**
8. **Chart 8:** Make a graph **(using markers only)** of the accelerating force (Y-axis) vs. the theoretical acceleration (X-axis). **Add a trend line with a (0,0) intercept. Include the equation of the line.**

Percent Error:

1. Compare the slopes of chart 2 **(theoretical)** and the slope of chart 1 **(experimental)** by calculating the percent error.
2. Compare the slope of chart 8 **(theoretical)** and the slope of chart 7 **(experimental)** by calculating the percent error.

Your report for this lab should include:

- Check with instructor.

Simple Machines Lab

Objective: Setup and examine the operation of three different types of simple machines. Measure the actual mechanical advantage and compute the efficiency of each machine to determine which one is most efficient.

Introduction

A simple machine is a force multiplier. It allows us to exert a greater force than would otherwise be possible. Pliers, a car jack and a wrench are common examples. In this experiment we shall use three different simple machines to lift an object vertically. Here are some definitions.

F_0 = output force. In this experiment the output force is the same as the weight of the object (in N) that we are lifting vertically.
S_0 = output distance. This is the vertical distance that the object is lifted.
F_I = input force. This is the force that we must exert to lift the object when using the machine.
S_I = input distance. This is the distance through which the input force acts.

Ideal mechanical advantage (IMA) is defined as

$$IMA = \frac{S_I}{S_O}$$

Actual mechanical advantage is defined as

$$AMA = \frac{F_O}{F_I}$$

Efficiency, ε, is defined as

$$\varepsilon = \frac{AMA}{IMA}$$

It is not possible to have a machine that is 100% efficient, thus $\varepsilon < 1$ for all simple machines.

- What force acts within real systems that makes the efficiency less than one?

Equipment

- Inclined plane with adjustable angles
- Mass set
- Wooden block
- Triple beam balance
- Wheel and axle assembly - should have three different diameter wheels on one axis
- Two sets of triple pulley apparati
- Miscellaneous clamps and rods

Procedure

Inclined Plane (wedge, ramp, etc).

1. Set the inclined plane at 30.0°. (How many significant figures does this measurement have?)

2. Attach a string to the block, run it over the pulley parallel to the inclined plane, and attach a mass hanger. Slowly add slotted masses to the hanger until the block slides up the incline at a constant speed when given a small push to overcome static friction. Record the mass hung from the string (including the mass hanger) and the mass of the block. The weight of the block is the output force, and the weight of the mass hung from the string is the input force.

- Draw the free-body diagrams that go with this setup. From your diagrams, write the equations of motion for each block assuming the system is in equilibrium. You will have three (3) equations when you are finished.

3. AMA, IMA and Efficiency
   a) Calculate the AMA of the machine. Note, that when you setup these relations, AMA is defined as a ratio of *forces* (not masses).
   b) Calculate the IMA as the cosecant of the angle made by the plane with the horizontal — pay close attention to significant figures.
   c) Calculate the efficiency of the machine.

Wheel and Axle (lever).

1. Wrap a length of string around the smallest diameter wheel (this is the axle) several times and hang 550 grams from it using the mass hanger and slotted masses. Use one of the little holes near the axle to secure the string to the axle.

2. Wrap string around the largest wheel and use a hole to secure the string. This string should be wound in the opposite direction of the first string. For example, if the string was wound around the small wheel counterclockwise, this one should be would clockwise. This means that, as the wheel and axle spin, one mass will rise while the other one lowers. Hang a mass hanger and slotted masses from the end of the string until the 550 gram mass rises at constant speed when given a small start. The weight hung from the wheel is the input force and the weight hung from the axle is the output force.

3. AMA, IMA and Efficiency
   a) Calculate the AMA.
   b) Calculate the IMA. This is simply the ratio of the diameter of the wheel to the diameter of the axle. You should measure these diameters with the most precise tool possible, and you may need to be creative with how to do it.
   c) Calculate the efficiency.

Block and Tackle

1. Set up the two sets of triple tandem pulleys as shown at the front of the room. The output mass is again 550 grams. Attach enough mass to the other end of the string so that the output mass rises at a constant speed when given a small push.

- Draw the free-body diagrams for the small mass and for the pulley assembly that is free to move. Show what the equations of motion are for the equilibrium case. There should only be two (2) equations this time.

2. A useful technique for dealing with the block and tackle is to pick a distance for the large mass to move – for example, 10.0 cm. Move the large mass by hand and measure how far the small mass moves in response. S_I is the distance the small mass moves, and S_O is the distance the large mass moves.

3. AMA, IMA and Efficiency

   a) Calculate the AMA.
   b) Calculate the IMA. This is simply the distance the input mass moves divided the distance the output mass moves. Once you determine what the masses are for the AMA, you can move the small mass and see how much the large mass and pulley system move in response. The ratio of the large distance to the small distance is the IMA.
   c) Calculate the efficiency of the machine.

Make sure that all calculations are clear and clearly labeled. The equations should always be written in symbols first, reasonable significant figures must be used, and the results must make sense. Use the equation editor for typing equations in your final draft.

Your report for this lab should include:

- Answers to any questions that have a bullet point in front of them;
- Average values and standard deviations for any measurement that was repeated;
- The AMA, IMA, and efficiency for each machine; and
- A statement about which machine was most efficient and which was least efficient, supported by the values determined in your lab.

Ballistic Pendulum Lab

Objective: Use both the ideas of conservation of mechanical energy and conservation of momentum to determine the initial velocity of a projectile. Use kinematics in 2-D to determine the initial velocity of the same projectile. Compare the results from both methods, and determine the energy lost in a perfectly inelastic collision.

PART I

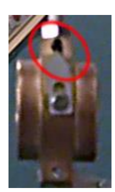
1. Clamp the frame of the apparatus to the laboratory table. Do not tighten the clamp too much or it will actually bend the frame enough so that the apparatus will not function properly. You also need to make sure the apparatus is level for it to work properly.

2. With the pendulum resting on the notched rack, place the ball on the end of the firing rod and compress the spring thereby cocking the spring gun.

3. Release the pendulum from the notched rack and allow it to hang vertically at rest. Please handle the pendulum gently because the pivot is delicate, and it can easily go out of adjustment. For example, NEVER move the pendulum side to side; only directly back and forth. Shoot the ball into the pendulum by squeezing the trigger. Record the number of the notch that captures the pawl on the pendulum.

4. Repeat at least 5 more times to get a minimum of six notch numbers. Average them to get a single notch number. ***Remember:*** *you cannot make an average more precise than the least precise place of the individual measurements.*

5. Engage the pawl in the notch that most closely matches the average number and measure the vertical distance h_f from the base of the apparatus to the center of mass of the pendulum. Release the pendulum, and when it is hanging at rest, measure the distance from the base to the center of mass; call it h_0. Then calculate $h = h_f - h_0$. This is the vertical distance that the bullet/pendulum rises. The center of mass is indicated by the tip of the metal point attached to the side of the brass cup that catches the ball.



The tip is circled in red in the picture above.

6. Mass the ball. Also, the mass of the pendulum is written on the apparatus. Record these values. Never remove the pendulum from its pivot because it takes a lot of work to get it back into adjustment.

7. Use conservation of momentum (for the collision) and conservation of mechanical energy (for the swing of the pendulum) to calculate the speed of the bullet as it leaves the gun. If *M* is the

mass of the pendulum, *m* is the mass of the ball, $\vec{v_i}$ is the intial velocity of the ball as it leaves the gun, and $\vec{v_c}$ is the velocity immediately after the ball is caught by the pendulum:

Conservation of momentum:

$$m\vec{v_i} = (M+m)\vec{v_c}$$

Conservation of energy:

$$E_{start} = PE_{start} + KE_{start}$$

$$E_{start} = (M+m)gh_0 + \frac{1}{2}(M+m)v_c^2$$

$$E_{end} = PE_{end} + KE_{end}$$

$$E_{end} = (M+m)gh_f$$

$$E_{start} = E_{end}$$

(All forces are conservative as the pendulum swings upward.)

PART II

1. To start the projectile motion phase of the experiment, clamp the frame of the apparatus near the edge of the lab table and aim the bullet toward a part of the room free of obstructions for about three meters. Move the pendulum up onto the notched rack, out of the path of the ball, and fire the bullet horizontally once to determine the approximate point of impact on the floor. Position a wooden box to stop the ball from rolling after it hits the floor.

2. Tape a sheet of paper to the floor with a sheet of carbon paper over it. Fire the bullet at least six times to produce 6 spots on the paper. These spots should be clustered together quite closely--over a distance of a couple inches or less. Estimate the center of the pattern by eye and mark it on the paper.

3. Measure the horizontal range, *R*, which is the horizontal distance from where the ball becomes a free projectile to the center of the pattern on the floor.

4. Measure the vertical distance of fall of the bullet during this projectile phase of the experiment; call it *H*.

5. Use kinematics equations in 2-D to calculate the speed of the bullet as it leaves the gun:

$$H = \frac{1}{2}gt^2$$

$$R = v_i t$$

ANALYSIS AND QUESTION

1. Using the two values for the initial speed of the bullet found above, calculate a percent error. Use the average of the two values for the accepted value. This percent error should be less than 6%. If it is not, then figure out why and fix the problem.

2. From Part I, calculate the fraction of the bullets kinetic energy that is lost during the collision with the pendulum bob. In other words, calculate the initial KE of the bullet before impact and the KE of the bullet/pendulum combination right after the impact. Subtract these and divide the initial KE of the bullet. This shows that Mechanical Energy is definitely NOT conserved during the collision, but momentum is. Where does the "lost" energy go?

$$KE_i = \frac{1}{2}mv_i^2 + \frac{1}{2}M(0)^2$$

$$KE_i = \frac{1}{2}mv_i^2$$

$$KE_f = \frac{1}{2}(M+m)v_c^2$$

$$\%KE_{lost} = \frac{|KE_i - KE_f|}{KE_i} \times 100\%$$

Your report for this lab should include:

- The piece of paper showing the pattern of impacts of the ball from Part II;
- A derivation to show how to get v_i for Part I in terms of m, M, g, h_0, and h_f ;
- A derivation to show how to get v_i for Part II in terms of g, R, and H;
- Your average value for v_i from both methods;
- Your percent difference in v_i when compared with the average;
- Your calculation for the percent of kinetic energy lost;
- A brief but detailed discussion of where this kinetic energy went.

Be sure to include standard deviations for any repeated measurements, as well as the precision of any measuring devices used.

Terminal Speed Lab

Objective:
To study the concept of terminal speed (sometimes called terminal velocity) and fluid resistance.

Procedure:

1. Measure the diameters, D, of five of the steel spheres (the steel spheres are the larger ones). From this calculate the average diameter, D_{avg}, of a single sphere.

2. Determine the density of the liquid soap, ρ_L, in the following way. Mass an empty graduated cylinder. Then add soap to near the 25 ml line. Mass the cylinder again. Using the mass of the soap and its volume (1 mL = 1 cm^3) calculate the density of the liquid, ρ_L.

3. Drop one of the steel spheres into the soap from a very small height. It will achieve terminal speed almost immediately upon entering the fluid, and therefore falls at terminal speed throughout the fluid. Measure the time, t, required for the sphere to fall a premeasured distance, d, through the fluid. Repeat 9 more times to obtain 10 values for t. Find the average and standard deviation of your time measurements. Divide the fall distance, d, by the fall time, t_{avg}, to obtain a value for the terminal speed. ($v = d/t_{avg}$)

4. Use the following formula to calculate the viscosity of the soap at room temperature in units of $N \cdot s/m^2$.

$$\eta = \frac{D_{avg}^2 g(\rho_S - \rho_L)}{9v}$$

Here v is the terminal speed, g is the acceleration of gravity, D_{avg} is the average diameter of a sphere, ρ_S is the density of the steel spheres (7900 kg/m^3), and ρ_L is the density of the liquid.

5. Drop a tiny lead sphere into the soap. Note that the terminal speed is much lower. Can you see why from the formula?

6. When you are finished, drop the graduated cylinder containing soap and bb's into the water bucket at the front of the room. Also, please clean up any mess at your station.

7. Work the following problem. If the terminal speed of a sphere in some fluid is 0.50 mm/s, what is the terminal speed of a sphere of the same material as the first one, but whose diameter is four times as large in the same fluid? You do not need to know any densities or the viscosity of the fluid.

Your report for this lab should include:

- Your raw data, and your calculation for the viscosity, η;
- Any additional calculations or analysis listed in the instructions.

Simple Harmonic Motion Lab

(Written by Prof. Carlos Mera)

Objective: Find the constant for a spring from its equilibrium positions under load, as well as the spring constant by observing simple harmonic motion for the mass-spring system. Also, find the acceleration due to gravity by measuring the simple harmonic motion of a pendulum.

Theory:
Periodic motion is motion of an object that regularly returns to a given position in a fixed time interval. A special kind of periodic motion occurs in mechanical systems when the force acting on an object is proportional to the position of the object relative to some equilibrium point. If this force is always directed toward the equilibrium position, the motion is called Simple Harmonic Motion. The net force acting in a Simple Harmonic System always obeys Hooke's Law.

The following three concepts are important in discussing any kind of periodic motion:

1. **Amplitude(A):** is the maximum distance of the object from its equilibrium position. In the absence of friction, an object in simple harmonic motion oscillates between the positions -A and +A.
2. **Period (T):** is the time it takes the object to move through one complete cycle of motion, from +A to -A and back to +A. The units of period are seconds.
3. **Frequency (f):** is the number of complete cycles or vibrations per unit time, and is the reciprocal of the period (f= 1/T). The units of frequency are Hertz (Hz).

We will study two types of harmonic motion systems in this lab: A Mass-Spring system and a pendulum system. For the Mass-Spring system we will find the constant of the spring by using hook's law and study the relation between the Period and the k. Finally, we will look at the SHM behavior of a Simple Pendulum and determine the local value of gravity.

<u>Mass-Spring System</u>
This is called a simple harmonic oscillator and it consists of a mass couple to an ideal, mass-less spring which obeys Hook's Law. One end of the spring is attached to the mass and the other is held fixed. When such a spring is stretched a distance x (for a compressed spring, x is negative), the restoring force exerted by the spring is:

$$\vec{\boldsymbol{F}} = -\boldsymbol{k}\boldsymbol{\Delta}\vec{\boldsymbol{x}}$$

The minus sign indicates that the restoring force is always opposite in direction to the distortion. The spring constant k has units of N/m and is a measure of the stiffness of the spring.
For the first phase of the experiment we will investigate an example of simple harmonic motion, or SHM: a weight on a spring. Let's hang the system vertically, so that a mass on the spring stretches it some amount. The point of rest for the system is called the equilibrium point, and we will measure all displacements relative to this point. First we need the spring constant, that quality of a spring which describes its stiffness. Since $F = -k\Delta x$ (see above equation) for a spring and $\vec{F} = m\vec{g}$ for the mass on the spring, each added mass will produce an extension of the spring. If we assume a linear relationship (which it is to a good approximation) we can solve for k:

$$\boldsymbol{k = \frac{mg}{\Delta x}}.$$

Where:
k is the spring constant in N/m
g is the value of gravity of 9.81 m/s^2
m is the value hanging mass in kilograms
Δx is the stretched distance in meters ($x_n - x_o$)

In the second part of the spring mass experiment we will study the relation between the value of k and the period of oscillation of the spring mass system.
For a spring mass system the period T is given by:

$$\boldsymbol{T = 2\pi\sqrt{\frac{m}{k}}}$$

Where:
T is the Mass-Spring system's period in seconds
m is the value hanging mass in kilograms
k is the spring constant in N/m

Procedure for the Mass-Spring System:
Part I

1. Record the vertical position of the spring with no load other than the 5g mass hanger.
2. Add a total of 50g to the spring in increments of 5g each time. Remember to account for the hanger mass.
3. Using Excel graph the values of the *weight* in the X-axis **(<u>remember you have to multiply your mass by g</u>**) and the stretch values **(Δx)** in the Y-axis. **(Use markers only. You should have 10 points on your plot.)**
4. Plot the best fit line using Excel's built in function (trendline). Display the equation of the line on your graph.

Part II

1. Start with the 5 g mass hanger alone loaded on the spring.
2. Pull the spring down enough for you to be able to see an oscillation.
3. **Remember a complete oscillation requires the spring to go down and come back to the same initial point.**
4. Release the spring and record the time for ten oscillations
5. Divide the total time by ten to find the period of oscillation.
6. Repeat steps 1 through 4 for mass increments of 5 g until you have 50 g total (45 g plus 5 g of the hanger). You should have ten values of T at the end.
7. Graph the square of the period, T^2 (Y axis), versus the values of the mass (x axis) using Excel **(Use markers only; you should have 10 points of data)**.
8. Plot the best fit line using excel's built in function (trendline). Display the equation of the line on your graph.

Calculations:

1. Determine the value of the spring constant **k in N/m** from the value of the slope of the graph in Part I, using the fact that:
$$slope = \frac{1}{k}$$
2. Determine the value of the spring constant **k in N/m** from the value of the slope of the graph in part II, using the fact that:
$$slope = \frac{4\pi^2}{k}$$
3. Find the percent difference between the values of k in part I and part II. Since the theoretical value is unknown, use the average of the two values of *k* for the denominator.

Simple Pendulum

A simple pendulum is a device that exhibits Simple Harmonic Motion. A simple pendulum consists of a small bob suspended from a fixed point by a string or a rod. The bob is assumed to behave like a point- like particle of mass m, and the string is assumed mass less. Gravity acting on the bob provides the restoring force. When in equilibrium, the pendulum hangs vertically. When released at some angle with the vertical, the pendulum will swing back and forth along an arc of circle in a fixed vertical plane containing the equilibrium position and the initial position of the string.

The period of a simple pendulum is given by:

$$\boldsymbol{T = 2\pi\sqrt{\frac{L}{g}}}$$

Where:
T is the Pendulum's period in seconds
L is the Pendulum's length in meters
g is the value of gravity m/s^2

This is equation is only valid when the amplitude of oscillation is much less than a radian.

Procedure for the Simple Pendulum:

1. Setup a simple pendulum. Use the spherical steel ball as the bob.
2. Start with a pendulum length of 10 cm. The length L of the pendulum is from the point of support to the center of mass of the bob.
3. Displace the pendulum by about 10 degrees from the equilibrium position and release.
4. Measure the time of 10 oscillations; then divide by ten to obtain the period T.
5. **Remember a complete oscillation requires the pendulum to go from the initial point back to that same initial point.**
6. Repeat steps 1 to 3 for values of L in increments of 10 cm until L is equal to 100 cm.
7. Use Excel to plot the square of the period (T^2) in seconds squared on the vertical axis, and the length in meters in the horizontal axis. **(Use markers only; you should have 10 data points.)**
8. Plot the best fit line using Excel's built in function (trendine). Display the equation of the line on the graph.

Calculations:

1. Determine the local value of gravity in m/s^2 from the slope of the graph
2. Find the percent error by using 9.81 m/s^2 as the theoretical value of g.

Your report for this lab should include:

- Your three graphs — one from each section of the lab;
- Your two separate calculations for the value of the spring constant, k;
- Your average value for the spring constant, $\bar{k}$, and the percent difference between your two values;
- Your experimental value for the acceleration due to gravity, $|\vec{g}|$, and the percent error for it.

Ideal Gas Law Lab

Objective: Determine the number of moles of air in a sealed container, as well as its mass; extrapolate from the data to determine the temperature (in Kelvins) at zero pressure.

Equipment:

- Gay-Lussac apparatus (metal ball with pressure gauge attached)
- 2000 mL beaker
- Bunsen burner
- Metal stand
- Thermometer
- Various clamps and rods for supporting the apparatus

Procedure:

1. Immerse the bulb completely in a bath of room temperature water. Clamp the bulb in place with its bottom about a centimeter or so above the bottom of the beaker. When the pressure stabilizes, record both the temperature of the bath in Celsius and gauge pressure of air in the bulb in lb/in^2.

2. Start heating the bath. CAUTION—THE BUNSEN BURNER FLAME IS ALMOST INVISIBLE. DO NOT BURN YOURSELF. The thermometer should NOT be resting on the bottom of the beaker, and it should not be used as a stirring rod. Gently stir the water with the stirring rod to keep the temperature uniform as you are heating it.

3. As the system is heating, take pressure and temperature measurements every 10 degrees or so until the temperature reaches about 65 degrees, or so. Shut off the flame and let everything cool while you do the following steps. THE METAL STAND MAY STAY HOT FOR A LONG TIME.

4. Record the temperature in °C and gauge pressure in lbs. per square inch (psi) on a piece of paper.

5. Set up an Excel spreadsheet that will allow you to enter your data. Use the spreadsheet to calculate:

   - Temperature in Kelvins
   - Gauge pressure in N/m^2
   - Absolute pressure in N/m^2
   - Number of moles of gas in the bulb.

The volume of the bulb is 535 cm^3. Do not forget to convert this to SI units. Make sure your Excel spreadsheet displays all values with the correct significant figures.

6. Calculate the average and standard deviation for the number of moles of air in the bulb.

7. Calculate one value of the mass of air in the bulb (in grams) from the average number of moles. The molar mass of air is 28.8 grams per mole. It is important that you get the right answer. As

always do a reality check to make sure that your calculation makes sense.

8. Plot absolute pressure, P (in pascals), vs. absolute temperature, T (in Kelvins); fit a linear function to this data and determine what the temperature should be for P = 0.0 Pa. Compare your value with the accepted value for absolute zero.

Your report for this lab should include:

- Your spreadsheet with all values and calculations; each column should be clearly labeled and list the correct units;
- The plot of P vs. T, with the best fit line and its equation;
- Your value of T for P = 0.0 Pa, based on the equation of your best fit line, along with an explanation for any difference from 0 K.

Speed of Sound Lab

Objective: Use the concept of resonance to determine the speed of sound in air experimentally and compare it to the theoretical value.

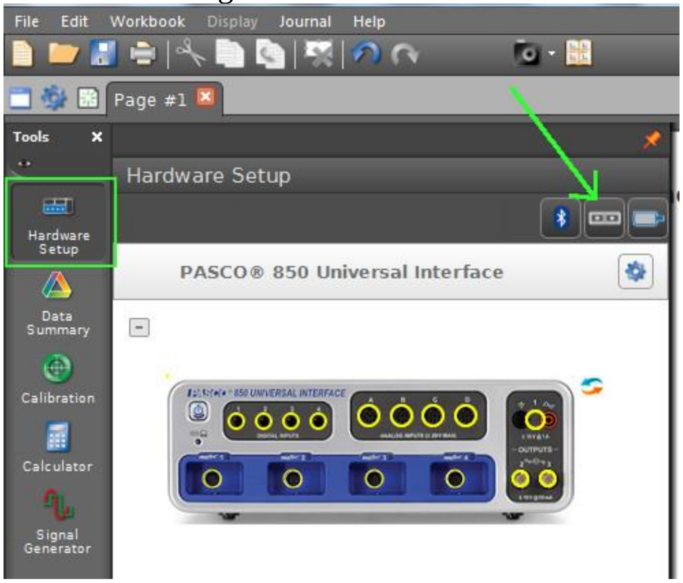
Equipment:

- Laptop computer
- Pasco Capstone Interface (PCI)
- Speaker
- Graduated cylinder
- Large glass beaker
- Small (50 mL) glass beaker
- Sound intensity meter
- Various electrical connectors

Procedure:

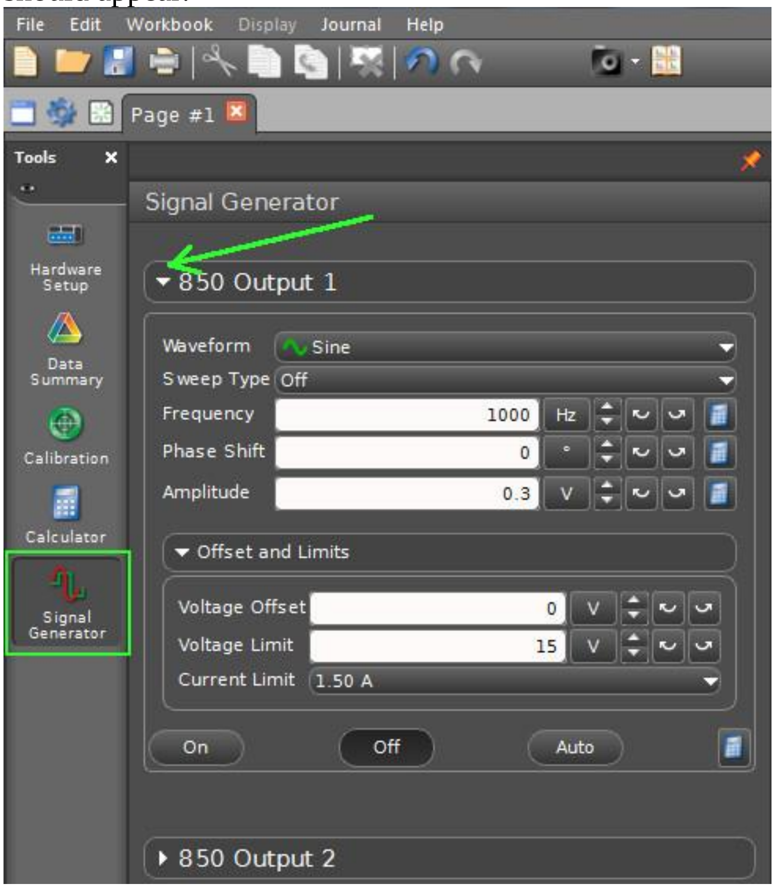
1. Plug in the Capstone Pasco Interface (PCI) and connect it to your laptop with the USB cable. Turn on the PCI.
2. On the laptop, look for "Pasco Capstone". There should be an icon for it on the desktop that looks like this:

3. Click on the "Hardware Setup" button in the left margin (outlined in green in the figure below). If the PASCO 850 Universal Interface does not show to its right, click the button at the end of the green arrow and select this interface.



4. Connect the banana plug connectors to the red and black outputs on the front of the PCI, at the right side. Clip the other end of these wires to the wires on the speaker.

5. Click the button at the left margin for “Signal Generator” (outlined in green in the figure below). Then click the drop down menu for “850 Output 1.” The interface shown below should appear.



6. In the interface shown above, set the amplitude to 0.3 V or less. ***A voltage greater than this will make a sound that is painfully loud when you achieve resonance.*** Set the frequency to one of the following values:
   - 440 Hz
   - 523 Hz
   - 698 Hz
   - 784 Hz
   - 880 Hz
   - 1046 Hz

   Consult with people near you to make sure you are not using the same frequency as them, otherwise it will be hard to hear when you are on resonance. Make a note of the frequency you are using.
7. Clamp the speaker to the sound apparatus so that it is a few millimeters above the end of the pipe. Put water in the pipe and set the water level about 3 cm below the end of the pipe.
8. Lower the aluminum can thereby dropping the water level. Listen to the sound intensity. At resonance you will hear a louder sound. Now carefully determine the level of the meniscus where the resonance occurs and record this reading to the nearest millimeter.

9. Lower the can further and locate the position of the next resonance. Record its position to the nearest millimeter.

The apparatus is a closed pipe, and has resonances for frequencies that correspond to the following wavelengths:

$$\frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}, \text{etc.}$$

where L is the length of the column of air above the water. Thus, the first resonance occurs for

$$L_1 = \frac{\lambda}{4}$$

and the second resonance occurs for when we add another half-wavelength:

$$L_2 = \frac{3\lambda}{4}$$

However, L_1 and L_2 will include air that extends above the region that can be measured by the graduated cylinder.

Thus, to get the correct wavelength for the sound in air, we need to use

$$L_2 - L_1 = \frac{\lambda}{2}$$

Use the relationship between frequency, wavelength, and speed for a wave to get the experimental value of the speed of sound:

$$v_{exp} = \lambda f$$

To get the theoretical value of the speed of sound, take the temperature (in °C) of the air in the room. Convert this temperature to the Kelvin scale (add 273.15). Then use this relation to get the theoretical value for the speed:

$$v_{th} = (331\ m/s)\sqrt{\frac{T_{air}}{273.15}}$$

Calculate a percent error using the formula value as the theoretical value. This error should be less than 5%. If not find the problem and fix it.

The purpose of the 50 ml beaker is to scoop water out of the aluminum can when it gets too full.

Your report for this lab should include:

- Any measurements of lengths or temperatures;
- Your calculations for the experimental and theoretical speed of sound;
- Your percent error, using the speed determined from the temperature as the theoretical value.

Calorimetry Lab

Objective:
To determine the specific heat of copper by using calorimetry.

Equipment:

Copper cylinder
Calorimetry cup
Aluminum can
Bunsen burner
Bunsen burner stand
Wooden dowel
String
Triple beam balance (with precision of ±0.02 g)
Thermometers (with precision of ±0.1°C)

Procedure:
1. Mass the inner calorimeter cup and copper cylinder.
2. Put just enough tap water into the inner calorimeter cup to cover the copper cylinder when the cylinder is lying in the cup. Mass the cup and water combination to determine the mass of water in the cup.
3. Place this inner cup into the large aluminum can using the fiber spacer to hold it in place.
4. Place a thermometer in the water and allow it to equilibrate with the water. After this has happened, record the temperature of the water/cup combination. Note that the temperature of the water may not be the same as that of the air. Keep the thermometer in the water. You will need it there soon.
5. Tie one end of a piece of string around the cylinder and tie the other end of the string to the wood dowel. The cylinder should rest horizontally when suspended from the string. Adjust the length of the string so that the cylinder is just barely suspended off the bottom of the can when the dowel is resting on the rim of the can.
6. Put enough water into the large can so that it completely covers the cylinder when the cylinder is suspended by its string.
7. Place the large can with water and suspended copper cylinder on the ring stand and start heating it with the Bunsen burner. The flame should be blue, not yellow. BE CAREFUL TO NOT BURN YOURSELF. It should take about 6 minutes for the water to start boiling. Once it starts boiling take its temperature and record this value.
8. After the water has been boiling for about a minute, transfer the cylinder to the inner calorimeter cup, cut the string, and cover the can with the plastic cap that is provided. Do this quickly AND safely.
9. Stir the contents. Watch the temperature rise. When the temperature reaches its maximum value, record this temperature.
10. Shut off the Bunsen burner and let the hot stuff cool. THE RING STAND STAYS HOT FOR A LONG TIME, SO USE GLOVES TO HANDLE IT.
11. Using calorimetry, determine the specific heat of copper.

12. Compare this to the accepted value by calculating a percent error. If you follow instructions and do the experiment carefully, the error should be under 20%. If it is not, then you need to redo it. Call me over before you do this.

Analysis:

In the following equations:

- m_{Al}, m_{H2O}, and m_{Cu} represent the mass of aluminum, water, and copper,
- cAl, cH2O, and cCu represent the specific heat of aluminum, water, and copper,
- and Th, Tc, and Te represent the initial temperature of the copper, the initial temperature of the water and aluminum, and the final temperature of the system, respectively.

  Use what you have learned about solving calorimetry problems to show, symbolically, that:

$$c_{Cu} = \frac{(m_{Al}c_{Al} + m_{H2O}c_{H2O})(T_e - T_c)}{m_{Cu}(T_h - T_e)}$$

Question:

What are the greatest sources of error in this experiment? Be as precise and quantitative as possible. Most importantly, state whether these error sources would *raise* or *lower* your value for the specific heat of copper. To test these ideas, try different numbers in the equation above, and explain your reasoning for choosing to test that value.

Your report for this lab should include:

- Your derivation of the formula for the specific heat of copper, starting from first principles,
- your value for the specific heat of copper and the percent error,
- and your analysis of the sources of error in the experiment and their quantitative effects. Apply this error analysis to your own results if you initially had an error in excess of the specified limit.

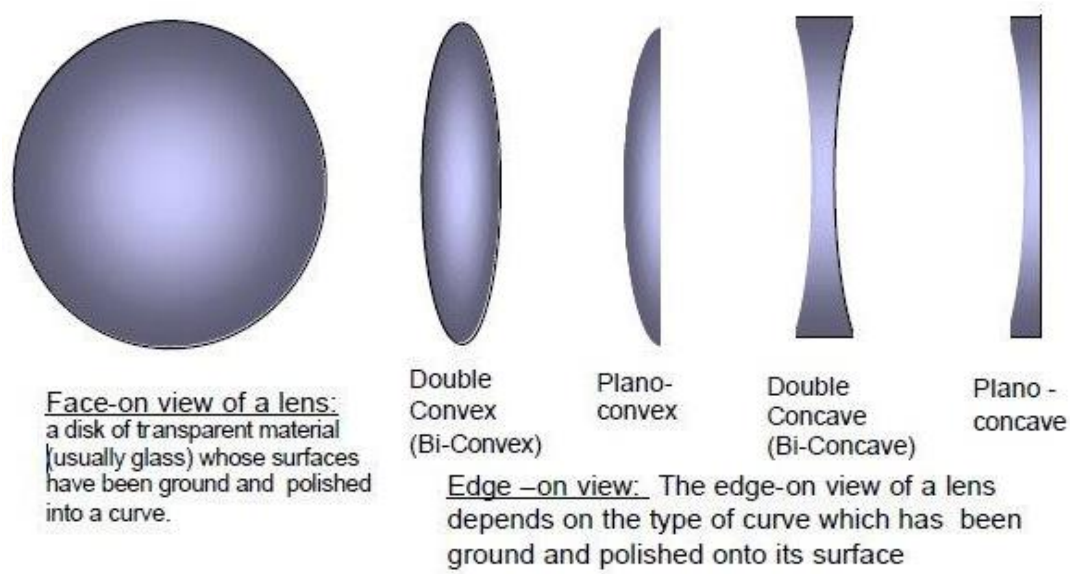
Image Formation Lab

Objective:

- Determine the focal length of two convex lenses by two separate methods
- Determine the focal length of a concave mirror
- Determine the focal length of a concave lens in combination with a convex lens
- Show that there are two equivalent ways of determining the magnification of an optical system

Mirrors and lenses can be flat or curved. If they are curved, they can be used to focus light and possibly produce an image. If the curve of the mirror or lens brings light rays together, the mirror or lens is *convergent*. If the curve of the mirror or lens spreads light rays apart, it is *divergent*.

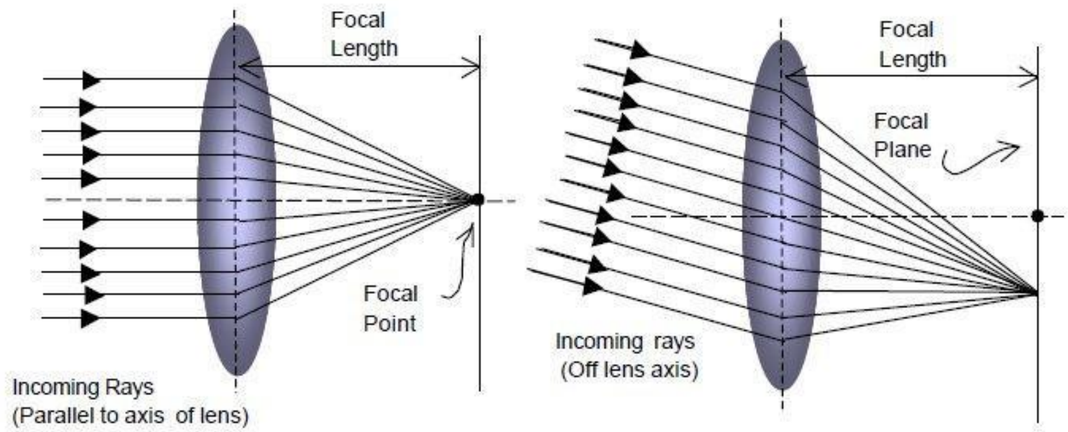
The curvatures of lenses and mirrors can be either *convex* or *concave.* See the pictures below for examples of each.



To make light rays converge, use a convex lens or a concave mirror. To make light rays diverge, use a concave lens or convex mirror. Since we want to concentrate the light that comes into a telescope, the primary optical element is either a convex lens or a concave mirror.

If light rays are parallel when they are incident on a lens or mirror, we say the light source is at infinity. Light that comes from astronomical sources is always so far away that this is a good approximation.

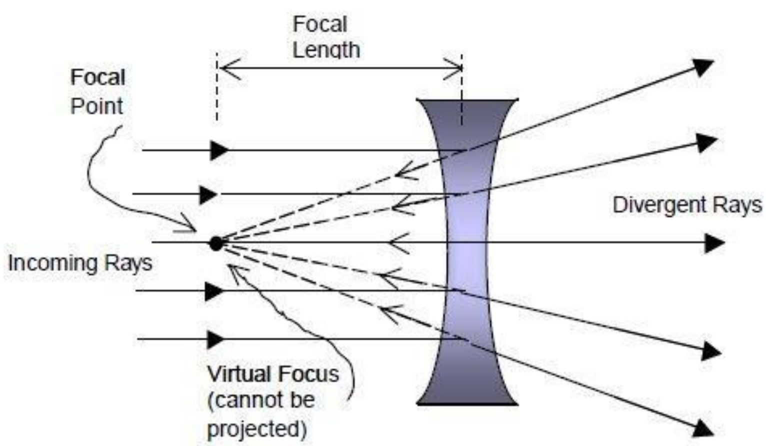
The diagram below shows what happens when parallel rays pass through a convergent lens:



Convergent Lens

Convex lenses are ***convergent*** that is to say, after passing through the glass, light rays are brought together (I.e., come to a ***focus***). Rays from distant objects are always parallel and parallel rays always come to a focus at the ***focal plane*** of the lens.

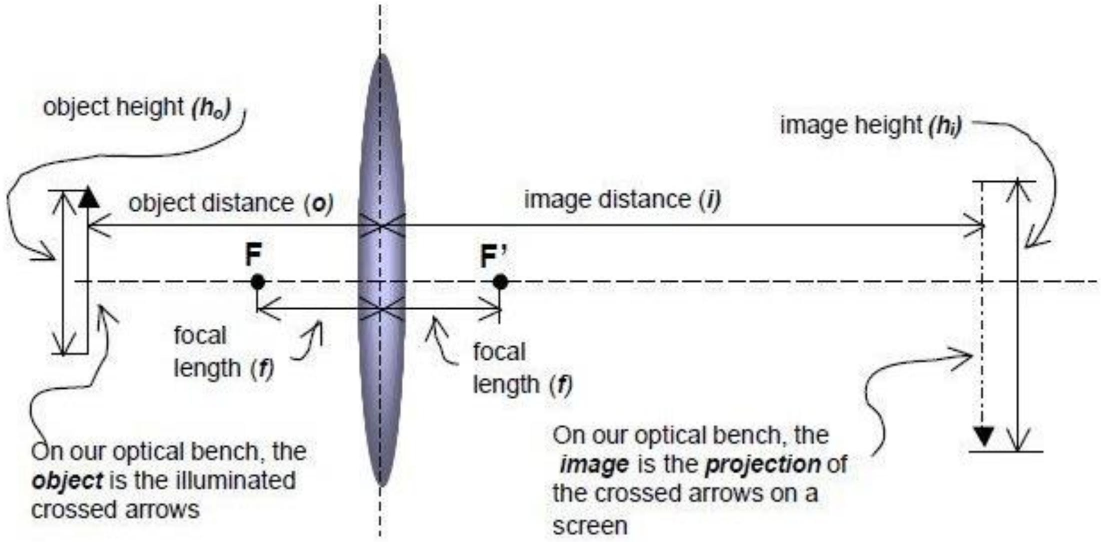
The diagram below shows the behavior of parallel light rays when they pass through a divergent lens:



Divergent Lens

The lens is ***concave*** on both sides. Light rays which have passed through the lens ***diverge*** (spread out) and will not produce a real image. This type of lens has a ***virtual*** focal point on the same side as the object.

If an object is not infinitely far away, the rays will not be parallel. We need a different way of evaluating this optical system. See the diagram below.



Object and Image distances

The distance from the object to the lens (or mirror) is labeled as ***o*** (on the left side of the diagram above) – this is called the *object distance*. The distance from the lens (or mirror) to where a clear image forms is labeled ***i*** (on the right side of the diagram above) – this is the *image distance*. The focal length for the lens in the diagram is ***f***. For the lenses in our experiment, ***f*** is the same distance on both sides of the lens. The relationship between the values of *o*, *i*, and *f* is given by the **<u>lens equation</u>**:

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$

We can also compute the magnification of our optical setup. This is a comparison of the size of the image to the size of the object. If you can measure the height of the object (h_o) and the height of the image (h_i), you can compute the magnification (M) with:

$M = \frac{h_i}{h_o}$ (**Note:** if an image is upside-down, the height of the image is negative.)

If it is easier to measure the object distance, *o*, and image distance, *i*, you can also get the magnification using:

$$M = -\frac{i}{o}$$

The minus sign indicates that the image is inverted, or flipped upside-down. The main point to keep in mind with magnification is that you always divide the value from the image by the value for the object.

<u>Equipment</u>:

- Optical bench
- Lens holders

- Lamp (which will act as the object)
- Cardboard screen
- Thin converging lens (not so curvy)
- Thick converging lens (more curvy)
- Converging mirror
- Concave (diverging) lens

Procedure:

Step 1:

Place the *thin converging lens* in one of the lens holders. Secure it to the optical bench near the middle. It will be easier to do computations if it is at the 50 cm mark. Turn the optical bench so that it is pointed at either the projector screen at the front of the room or the lamp at the back of the room – use whichever object is farther away from you. Move the cardboard screen back and forth until you get a clear image on the cardboard screen. Record the position of the screen by seeing where it lines up with the optical bench. Be careful to hold the screen perpendicular to the optical bench so that the position of the top and bottom of the screen match. Since the object is so distant, the rays from it are nearly parallel. In this case, the focal length of the lens equals the distance between the center of the lens and the screen. Find the focal length from your values. It should be a positive number.

Step 2:

Repeat Step 1 for the *thick converging lens*.

Step 3:

Replace the thick converging lens with the *converging mirror*. The mirror will have two sides. If you look at it, you will see your image is larger and inverted on one side, and smaller and upright on the other side. You want the side where you appear upside-down facing the screen or lamp in the room (again, whichever is farther away from you). Move the screen back and forth until you get a clear image of the object. You will have to hold the screen so that it does not block all the light coming from the object. Record the position of the mirror and the screen (in centimeters), and use these to find the focal length of the concave mirror.

Step 4:

Place the concave (diverging) lens in the holder. Hold the thick converging lens directly in front of the concave lens so that it is between your distant object and the concave lens. Record the position of the concave lens and the cardboard screen when the image on the cardboard screen is in sharp focus.

Step 5:

Turn the optical bench again so that it does not extend beyond the edges of your table. Get the lamp with the arrows on it and secure it at the 10 cm mark on the bench with the side with the arrows facing the distant end of the optical bench. Place a lens holder at the 40 cm mark on the optical bench and place the *thin converging lens* in it. The arrows on the lamp will act as your object, so the *object distance, o,* is 40 cm – 10 cm = 30 cm.

Move the screen back and forth on the side of the lens opposite where you put the lamp until you get a clear image of the arrows on your screen. Be careful to hold the screen vertically. If it is tilted, you will get the wrong value for the position of the screen. The distance from the lens to the screen is your *image distance, i*. Record the value on the table.

Step 6:

Repeat step 5 using the *thick converging lens*.

Step 7:

Use the *thin converging lens*. Change the *object distance* so that it is 20 cm. Be as careful as possible to place the lamp and lens exactly 20 cm apart. Find the new *image distance* using the same method from steps 5 and 6, and record this (in cm). Next, measure the size of one of the arrows on the lamp. Record this as your *object size*. Then, while keeping the screen in place where the image is clear, measure the size of the corresponding arrow **on the image**. Record this value as your *image size*.

Analysis:

In steps 1-3, you find the focal length by subtracting the two positions. Record the focal lengths you get from these steps.

In step 4, we use the combination of the two lenses to get the focal length of the diverging lens. In the equation below, q is the distance from the diverging lens to the screen, f_b is the focal length of the diverging lens, and f_a is the focal length of the thick converging lens minus the distance between the centers of the thick converging and the diverging lenses. Use f_a = 3.5 cm.

$$\frac{1}{f_a} + \frac{1}{f_b} = \frac{1}{q}$$

Solve for f_b. Your answer should be negative, since the lens is a diverging lens.

In steps 5 and 6, you must use the *lens formula* to find the focal length of each lens. Show an example of how you found the focal lengths this way, and record the focal lengths you get.

From step 7, you can get the magnification two different ways. Use the *image distance* and the *object distance* to find the magnification first. Then, use the *image size* and *object size* to get the magnification. Show your work and record your values.

<u>Conclusions</u>:

In step 1 and step 5, you measure the focal length of the same lens using two different methods. What is the difference in the focal length from the two measurements? The actual focal length is 15 cm. Which method was more accurate? Since step 2 and step 6 apply to the other lens, answer these questions for the values for that lens as well. The actual focal length for this lens is 5.0 cm.

How does the curvature of the lens affects the focal length? Do you think this relationship also is true for mirrors?

Can you focus light rays onto a screen with a *concave lens*? Why or why not?

Compare your two magnifications from step 7. Did you get the same value from both methods? Divide the magnification you got from the distances by the magnification you got from the sizes; what value should you get? How close was your value to the value you should get (report the difference)?

Describe the main source of error in this experiment and how you would reduce the effects of that error. "Human error" is not an answer. You are a human – figure out specifically what the error is and discuss it. Address something specific in either the procedure or from the equipment.

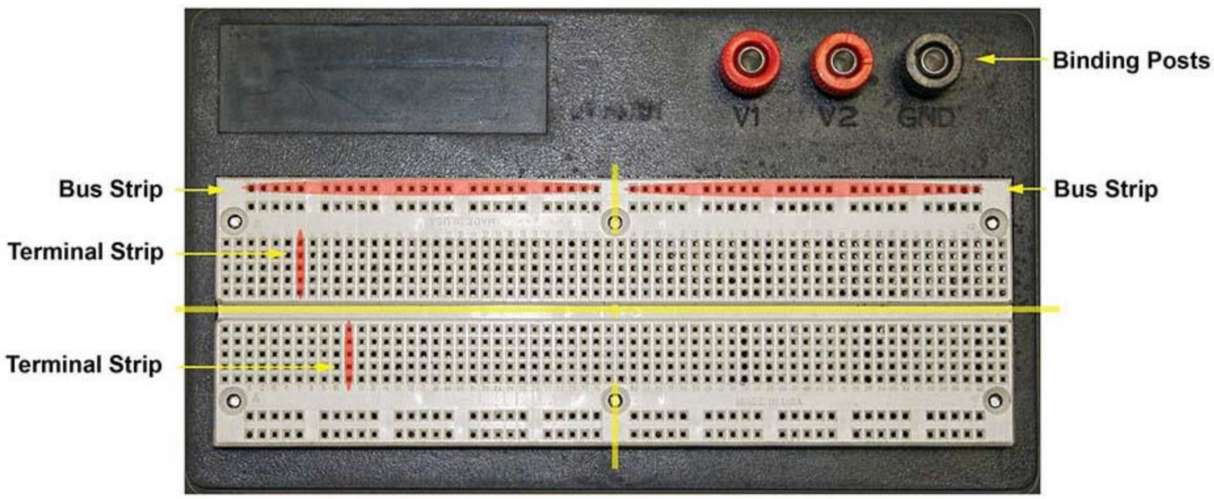
Your report for this lab should include:

- A typed version of your completed data sheet;
- Calculations showing proper use of the formulae for steps 4-6;
- Calculations for each method of finding the magnification;
- A summary of focal lengths and magnifications with percentage errors in the abstract;
- And answers to all conclusion questions.

Implementing and Measuring Electric Circuits

The most important point to remember when constructing an electrical circuit is that there needs to be a continuous path for the electricity to flow through. ***All wires and electrical elements must be connected in a way to allow electrical current to flow both into and out of each part of the circuit.*** If the connection is not made on both ends of every element of a circuit, the electrical current will not flow the way that you need. If the path is broken at any point, the experiment or device will not work at all.

Use of the Breadboard for Wiring Circuits



Solderless Connection Breadboard

In the picture above, all electrical leads plugged into a terminal strip will be connected. If you have a wiring diagram that shows a connection between two or more electrical elements, that means that one lead from each of those elements must be plugged into the same terminal strip. The maximum number of leads that can be on a terminal strip on these breadboards is five, but different terminal strips can be bridged together with wires.

Bus strips allow you to connect many leads to a particular voltage source. You can feed connectors that provide voltage into one of the holes in the bus strip. The end of any electrical elements that you plug into the same bus strip will then be at that voltage.

Mapping Electric Fields and Equipotentials Lab

Objective:

To get a visual picture of what electric field and equipotential lines look like for at least one simple source geometry.

It is *highly* recommended that you practice with the following simulation to get an idea of what you should expect for a result for this lab:

PhET Interactive Simulations, University of Colorado, Boulder: Charges and Fields

PROCEDURE:

1. Put about a centimeter of tap water in the clear glass tray.
2. Mark a coordinate system on a piece of graph paper. The origin of coordinates can be anywhere on the paper, but it might be best to put the origin at the position of one of the sources, as described below. If your Instructor allows you to do so, you may use the template included with the lab manual.
3. Place the tray on the paper in a symmetric way. Then place two sources in the tray. One of the sources should be a small circular source and it should lie at the origin. The other source should be a line source and the x axis should be its perpendicular bisector.
4. On a second piece of graph paper, set up another coordinate system just like the one on the paper that's under the tray. Also, copy the outlines of the sources on your second paper.
5. Connect the two sources to the two terminals of the power supply using the wires provided. Set the supply to 6 volts. Connect the positive terminal of the power supply to the point source and the negative terminal to the line source.
6. Attach the "com" terminal of the DMM to the line source. Turn the DMM on to DC volts.
7. Turn on the power supply. Immerse the second DMM probe in the water somewhere between the sources and note its reading. It should read about 3V. Now move the probe near the positive terminal. The DMM should read close to 6V. Finally, move the probe near the negative terminal. The probe should read close to zero. When taking data, try to look straight down into the water to avoid refraction effects. If all this works, then you are ready to start taking data.
8. Move the probe to a location on the x axis where it reads 3.0 volts. Record the coordinates of this point on your second piece of graph paper. Also, label that point with the 3V potential. Set the probe at (0, 3). Move the probe to your right along the line y = 3 until your DMM reads 3.0 V again. Record these coordinates on the other sheet of paper and label the point with 3V. Move the probe to (0, 6) and then move horizontally to find another 3V point. Repeat until you have about 5 points on and above the x axis. Make sure that the points are spread out, not bunched up close together. Connect the points with a smooth curve. This is your 3V equipotential line.
9. Now choose another potential, maybe 4.0V, and generate another equipotential line. Keep going till you get a total of 5 lines between the sources. To make sure that the lines are spread sufficiently far apart, you might want to choose potentials like 1,2,3,4,5 volts, and draw one line for each.
10. Then, using a different color pen or pencil (if possible), draw lines perpendicular to the equipotential lines. These will be the electric field lines. At the surface of the sources, the electric field lines are always perpendicular to the surface. Use this fact when attaching the e-field lines to the sources. Draw enough e-field lines (maybe 5 above the x axis) so that you can clearly see the structure of the field.

11. Label the sources with their polarity (+/-). Also, indicate the directions of the field lines by putting arrows on them. The arrows point from positive to negative.

Your report for this lab should include:

- Your complete and correctly labeled sketch of the sources, electric field lines, and equipotentials.

Simple DC Circuits Lab

(Note: the instructions for this lab are not complete yet.)

Objective:

To learn about the current/voltage relationships in simple Series and Parallel DC circuits.

PROCEDURE:

1. Check the continuity of all wires using the digital multimeter (DMM). The Instructor will explain how to do this.
2. Determine the exact resistance of the two resistors in your cup using the DMM. The resistance of one of them will be around 100 ohms; call this resistor R_1. The resistance of the other one will be around 220 ohms; call it R_2. Notice that they have colored bands so that you can tell them apart (and read the resistance).
3. Set up the series circuit shown below. The resistors should be mounted on the breadboard. The Instructor will explain how the breadboard is wired. Set the voltage of the black power supply to 9 or 12 volts. However, keep the power off until you are ready to start taking data.

4. Set the analog ammeter to the 0-50 mA range. You will now make several current measurements on that circuit. The Instructor will demonstrate the method.

Measure the current between the positive terminal of the power supply and R_1; call this I_a.
Measure the current between R_1 and R_2; call it I_b
Measure the current between R_2 and the negative power supply terminal; call it I_c.
Record your measurements here:

I_a = __________ mA I_b = __________ mA I_c = __________ mA

5. Now you will take several voltage measurements on this circuit using the DMM set to DC volts.

Measure the potential difference across R_1; call it V_{ab}
Measure the potential difference across R_2; call it V_{bc}
Measure the potential difference across the terminals of the power supply; call it V_{ac}.
Record your measurements on the next page:

V_{ab} = __________ volts V_{bc} = __________ volts V_{ac} = __________ volts

6. Take apart the series circuit and set up the parallel circuit shown below.

7. Reduce the voltage on the power supply to 3.0 volts. You will now make several current measurements with the analog ammeter.

Measure the current through resistor R_1; Call it I_{ab}
Measure the current through resistor R_2; Call it I_{cd}
Measure the current leaving the positive terminal of the power supply; Call it I
Record your measurements here:

I_{ab} = __________ mA I_{cd} = __________ mA I = __________ mA

8. Using the DMM set on DC volts, make the following voltage measurements.

Measure the voltage across R_1; Call it V_{ab}
Measure the voltage across R_2: Call it V_{cd}
Measure the voltage across the terminals of the power supply; Call it V
Record your measurements here:

V_{ab} = __________ volts V_{cd} = __________ volts V = __________ volts

<u>CALCULATIONS</u>

1. From step #4 compare the three current measurements. Within experimental errors they should be the same.

2. From step #5 add the V_{ab} to V_{bc} and compare this sum to V_{ac} by calculating a percent error. The error should be small because, within experimental errors, they should be the same.

3. From step #7 add current I_{ab} to I_{cd} and compare this sum to I by calculating a percent error. Again the error should be small because, in principle, these quantities should alike.

4. From step #8 compare the three voltage measurements. In principle they should be the same.

5. From step #4 of the Procedure, average the three currents recorded there, and call them I. Then using Ohm's Law calculate the voltage across R1 and R2:

$V_1 = IR_1 =$ __________ volts $V_2 = IR_2 =$ ___________ volts

Add V_1 to V_2 and compare this sum to the voltage across the power supply terminals by calculating a percent error.

6. From step #7 of the Procedure calculate the voltage across the two resistors using Ohm's law. Then compare to the voltages that were measured across these resistors directly in step #8 by calculating a percent error. This error should be small.

Your report for this lab should include: