Laboratory Manual

Physics 1012/2112 Electricity and Magnetism

Ver. 7.5.22

Table of Contents

PHYSICS 1012/2112 ~ GENERAL GUIDELINES

The Physics 1012 and 2112 labs will be divided into small groups (so you will either be working with one lab partner, or (for the larger classes) in a small group). You and your lab partner(s) will work together, but you each must submit an *individual* lab report, with a discussion of the lab and interpretation of results *in your own words*.

The laboratory classroom is located in the west wing of Benton Hall, Room 336.

Laboratory attendance is mandatory and roll will be taken. At the beginning of each lab, you will sign out a lab kit and your lab instructor will check it in when you finish the lab. If you miss a lab session, it is **your** responsibility to contact the lab instructor to pick up any missed handouts or information for the following week's session.

Always read the experiment before coming to the lab! This is really important, and will help you get the most out of the lab. Bring your calculator to lab, and take good notes when the lab instructor gives detailed information about the experiment and about what s/he expects in the lab report.

Lab reports MUST be typed. If you have trouble finding computer facilities, and don't have a computer at home, see the lab instructors or the course instructor, and we will help you find a computer to work on.

Lab reports should include your name, the name of your lab partner, the lab section (e.g., Tuesday / 2:30), the date the experiment was performed, and the title of the experiment. This is a recommended guideline. The lab instructor has the final say in which details to include and how to format your lab report.

You may find it useful to visit the "Lab Connection" website from the main physics webpage:
http://www.umsl.edu/~physics/Lab%20Connection/index.html

The lab report itself should contain the following sections:

Purpose: State, in your own words, the purpose of the experiment.

Procedure: Describe the procedure in your own words. Describe also any novel approaches you took, difficulties you had, or interesting observations. These descriptions need to be in "scientific" style, as professionally written as if you were going to submit the lab report to a scientific journal. Writing things like "This experiment was fun" is NOT what we are looking for!

Analysis:

Data/graphs: List all data taken in the experiment, in tabular form whenever possible. Make sure that you give the units for all physical quantities. All graphs and tables should be neatly arranged and clearly labeled with titles.

Calculations: Show clearly all the calculations you performed on the data. Show all equations you used.

If calculations are used to get data that is plotted in the graphs, you may want to show the calculations *before* the graphs. For example, you might make some measurements, and plot the raw data. Then you might do some calculations on the raw data, and plot the results. In that case, your results section should show (1) table of original data, (2) graph of original data, (3) calculations (equations and table of calculated results), and (4) graphs of calculated results. Alternately, you might show calculated quantities in columns next to the original measurements. For each experiment, we will give a sample data table that you can copy and paste into your lab report as a guide to how to present the data. **The main point is to have the data and calculations presented clearly. You want the lab instructor to be able to clearly follow your thought process, to be able to see exactly what you measured and what you calculated.**

Questions:

Answer all the questions posed in the lab manual.

Conclusions:

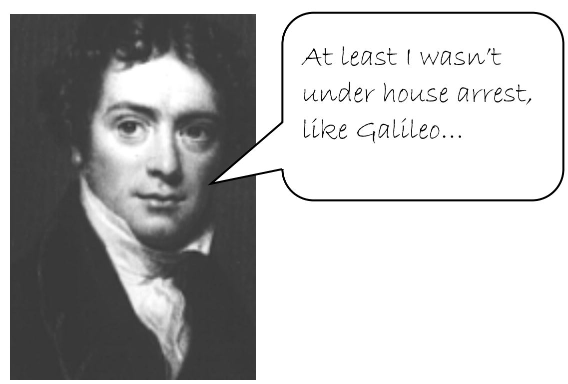
What did you conclude from the experiment? What quantities were measured? Were the results of the measurements what you expected? Describe possible sources and types of error in your measurements. Tie your results back to the original purpose of the experiment.

The lab reports are due at the beginning of the following session unless stated otherwise by your lab instructor.

Graded reports will typically be handed back a week after they are turned in. End-of-semester graded lab reports will be handed back at your lecture.

All measurements taken in the lab should be in SI (Système Internationale) units (formerly known as MKS) units (meters, kilograms, and seconds) unless explicitly stated otherwise by your lab instructor.

And, when you get frustrated, remember that Michael Faraday did all this **without a calculator**!



INTRODUCTION TO STATISTICS, ERROR AND MEASUREMENT

Throughout the semester we will be making measurements. When you do an experiment, it is important to be able to evaluate *how well you can trust your measurements*. For example, the known value of *g*, the acceleration due to gravity, is ≈ 9.81 m/s^2, ("≈" means approximately equal to). If you make a measurement that says g = 10.1 m/s^2, is that measurement "wrong"? How do you compare that measurement to the known value of *g*? Suppose you measure some quantity that is *not* known? You may make a number of measurements, and get several different results. For example, suppose you measure the mass of an object three times, and get three different values, 5 kg, 4.8 kg, and 5.4 kg. Can you evaluate what the *real* mass of the object is from those measurements?

The mathematical tools we will learn in this lab will answer some of these questions. They are some of the most basic methods of statistical analysis; they will allow us to give information about our measurements in a standard, concise way, and to evaluate how "correct" our measurements are. The methods we will cover are used in all areas of science which involve taking any measurements, from popularity polls of politicians, to evaluating the results of a clinical trial, to making precise measurements of basic physical quantities.
Let's start with the basics of the different *kinds* of errors, and how to measure them.

Types of Errors

There are two types of errors encountered in experimental physics: **systematic** errors and **random** errors.

Systematic errors can be introduced

- by the design of the experiment
- by problems with the instruments you are using to take your data
- by your own biases

Consider a very simple experiment designed to measure the dimensions of a particular piece of material precisely. A systematic error of could be introduced if the measuring instrument is calibrated improperly. For example, a scale might be set a little too low, so that what *reads* as "zero" is *really* "-1 kg". Everything you measure on the scale will come out one kilogram lighter than it really is. If a particular observer always tends to overestimate the size of a measurement, that would also be a systematic error, but one related to the personal characteristics of the experimenter.

Random errors are produced by unpredictable and uncontrollable variations in the experiment. These can be due to the limits of the precision of the measuring device, or due to the experimenter's inability to make the same measurement in **precisely** the same way each time. Even if systematic errors can be eliminated by good experimental design, there will always be some uncertainty due to random errors. Numerical values measured in experiments are therefore never **absolutely** precise; there is always some uncertainty.

Accuracy and Precision

The **accuracy** of a measurement describes how close the experimental result comes to the actual value. That is, it is a measure of the "correctness" of the result. For example, if two independent experiments give the values 2.717 and 2.659 for *e* (the base of the natural log), the first value is said to be more accurate because the *actual* value of *e* is 2.718…...

The **precision** of an experiment is a measure of the *reproducibility* of the result. Suppose you measure the same thing three times. The precision would be a measure of how similar all the measurements are to each other. It is a measure of the magnitude of uncertainty in the result. Suppose one person weighs a cat, and comes up with three different masses each time: 10 kg, 12 kg, and 11 kg. Suppose another person weighs the same cat, and comes up with these three masses: 11.1 kg, 11.5 kg, and 11.3 kg. The second person's measurement would be said to be more precise. (Both people are likely to be scratched, though.)

Significant Figures

When reading the value of an experimental measurement from a calibrated scale, only a certain number of figures or digits can be obtained or read. That is, only a certain number of figures are significant. The **significant figures** (sometimes called "**significant digits**") of an experimentally measured value include all the numbers that can be read directly from the instrument scale plus one doubtful or estimated number. For example, if a ruler is graduated in millimeters (mm), you can use that ruler to estimate a length *up to one tenth of a millimeter*. For example, suppose you make a sequence of measurements of the length of some object using this ruler, and get an average value of 318.9811123 mm. The measurement is only accurate to one decimal place, so you would report the number as 319.0 ± 0.1 mm. The "zero" is shown after the decimal point because that digit is the last significant one. All the other digits are meaningless and do not convey any real information about your measurements.

Data Analysis

Percent Error and Percent Difference

How do you measure the *size* of an error? The object of some experiments is to measure the value of a well-known quantity, such as *g*. (You'll be making this measurement yourselves in next week's experiment!) The most accurate value of these quantities (measured by teams of dedicated professional scientists!!) is the value given in your textbooks and tables. In making a comparison between the results of your experiment and the accepted value measured with much more precision in specialized laboratories, you want to cite the **percent error**, a measurement of how much your measurement differs from the "official" value. The **absolute difference** between the experimental value E and the accepted value A is written |E-A|, where the "|" signs mean absolute value. The **fractional error** is the ratio of this **absolute difference** over the accepted value:

$$\text{Fractional error} = \frac{|E - A|}{A}$$

Usually, people convert this fractional error into a percent, and give the percent **error**:

$$\text{Percent error} = \frac{|E - A|}{A} \times 100\%.$$

Sometimes, you need to compare two equally reliable results when an accepted value is *unknown*. This comparison is the **percent difference**, which is the ratio of the **absolute difference** between experimental results E_1 and E_2 to the **average of the two values**, expressed as a percent:

$$\text{Percent difference} = \frac{|E_1 - E_2|}{\left[\frac{(E_1 + E_2)}{2}\right]} \times 100\%.$$

Mean Value

Even if systematic errors can be eliminated from an experiment, the **mean value of a set of measurements of a quantity, x, is a better estimate of the true value of x than is any single measurement**. For this reason, experiments are often repeated a number of times. If we denote $\langle x \rangle$ as the mean value, and there are N measurements x_i (where i varies from 1 to N), then $\langle x \rangle$ is defined by the following equation:

$$\langle x \rangle = \frac{1}{N}\sum_{i=1}^{N} x_i$$

In fact, random errors are distributed according to a Gaussian distribution, which looks like the familiar bell curve. In case you aren't familiar with it, the "Σ" symbol we just used is a capital Greek letter "sigma ". In math, it is called a summation sign. It means "add up everything to the right". So in the equation above, the sigma is a shorthand way of writing

$$\langle x \rangle = \frac{1}{N}(x_1 + x_2 + x_3 + \ldots + x_N).$$

Mean Deviation

To obtain the **mean deviation** of a set of N measurements, the **absolute deviations** of $|\Delta x_i|$ are determined; that is

$|\Delta x_i| = |x_i - \langle x \rangle|$

The **mean deviation** $\langle \Delta x \rangle$ is then

$$\langle \Delta x \rangle = \frac{1}{N}\sum_{i=1}^{N} |\Delta x_i|$$

Example 1.1 What are the mean value and mean deviation of the set of numbers 5.42, 6.18, 5.70, 6.01, and 6.32?

Solution:

The mean is

$$\langle x\rangle = \frac{1}{N}\sum_{i=1}^{N} x_i = \frac{5.42+6.18+5.70+6.01+6.32}{5} = 5.926 = 5.93$$

Note that since the original measurements were only valid to two decimal places, the average can only be valid to two decimal places as well, so we round from 5.926 to 5.93.

The absolute deviations for each measurement are:

$$|\Delta x_1| = |5.42 - 5.93| = 0.51$$
$$|\Delta x_2| = |6.18 - 5.93| = 0.25$$
$$|\Delta x_3| = |5.70 - 5.93| = 0.23$$
$$|\Delta x_4| = |6.01 - 5.93| = 0.08$$
$$|\Delta x_5| = |6.32 - 5.93| = 0.39$$

Then the mean deviation is:

$$\langle \Delta x\rangle = \frac{1}{N}\sum_{i=1}^{N} |\Delta x_i| = \frac{0.51+0.25+0.23+0.08+0.39}{5} = 0.292 = 0.29$$

Usually, people report an experimental measurement as the mean "plus or minus" the mean deviation:

$$E = \langle x\rangle \pm \langle \Delta x\rangle$$

In our example, the value would be reported like this: 5.93 ± 0.29.

Standard Deviation

Statistical theory states that the **precision** of a measurement can be determined using a quantity called the **standard deviation**, σ (called "sigma", this is the Greek lower-case "s"). The standard deviation of a distribution of measurements is defined as follows:

$$\sigma = \sqrt{\frac{1}{\mathrm{N}}\sum_{i=1}^{N}\left(x_{\mathrm{i}} - \langle x\rangle\right)^2}$$

The **standard deviation** is a measure of **spread**. If the standard deviation is *small*, then the **spread in the measured values about the mean** is *small*, and so the **precision** in the measurements is *high*. The standard deviation is always positive and has the same units as the measured values.

It can be shown, for a Gaussian distribution , that 69% of the data points will fall within one standard deviation of $\langle \mathbf{x}\rangle$, $(\langle \mathbf{x}\rangle - \sigma) < x_i < (\langle \mathbf{x}\rangle + \sigma)$; 95% are within two standard deviations, and only 0.3% are farther than 3σ from $\langle \mathbf{x}\rangle$. So, for example, if an experimental data point lies 3σ from a theoretical prediction, there is a strong chance that either the prediction is not correct or there are systematic errors which affect the experiment.

Example 1.2 What is the standard deviation of the set of numbers given in Example 1.1?

Solution:

First, find the square of the deviation of each of the numbers

$$\Delta x_1^2 = (5.42-5.93)^2 = 0.26$$
$$\Delta x_2^2 = (6.18-5.93)^2 = 0.06$$
$$\Delta x_3^2 = (5.70-5.93)^2 = 0.05$$
$$\Delta x_4^2 = (6.01-5.93)^2 = 0.01$$
$$\Delta x_5^2 = (6.32-5.93)^2 = 0.15$$

then

$$\sigma = \sqrt{\frac{1}{\mathrm{N}}\sum_{i=1}^{N}\left(x_{\mathrm{i}} - \langle x\rangle\right)^2} = \sqrt{\frac{0.26+0.06+0.05+0.01+0.15}{5}} = 0.33$$

The result of our measurement of E can also be reported as:

$$\mathrm{E} = \langle \mathbf{x} \rangle \pm \sigma$$

Note that all these statements are valid if **only** random errors are present.

Presenting Data

Data Tables

You should always organize the experimental data which you take into data tables, in order to make the data very clear and easy to understand. The data table will generally have two or more columns which present the values of the controlled (independent) and measured (dependent) variables. The table should contain labels for the various columns, **including units** and **errors**. If some variables are fixed during a particular experiment, the values can be given in the title for the table or in the text; similarly, if the errors are the same for all measurements they can be included in the text or caption. Data tables are usually organized by ascending values of the independent variable.

Example 1.3 For a fixed volume, pressure is proportional to temperature for an ideal gas. A fixed amount (10 moles) of gas is placed in a container having a fixed volume of $1\mathrm{m}^3$ and the temperature is increased from 0°C to 60° C in increments of 10°. The pressure in Newton/m^2 (Pascal) is measured by an apparatus for which the pressure can be read accurately in 100 pascal units with the 10 Pascal digit estimated. The pressure was measured several times and a statistical error determined for each measurement. The independent variable (temperature) is given in the left column of the table on the next page. The measured quantity (a.k.a. the dependent variable) is given, along with the error, in the right column.

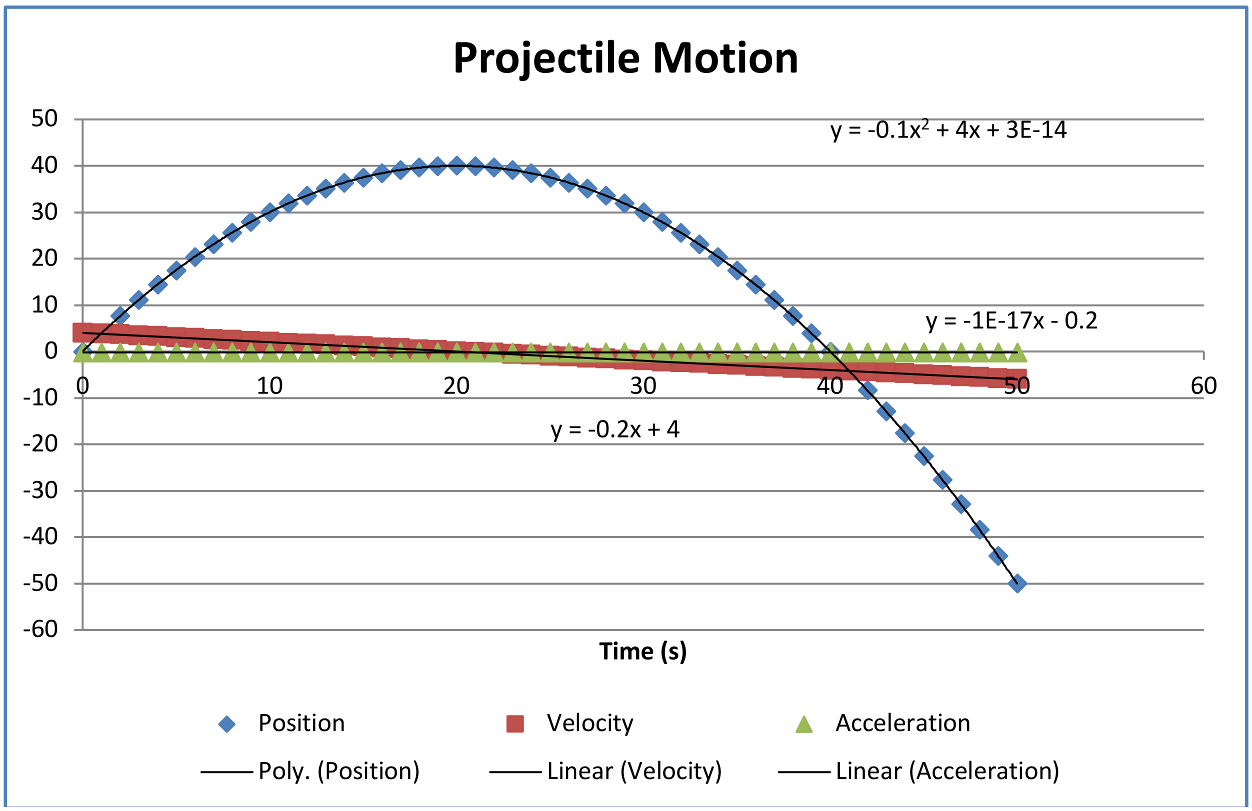
GAS PRESSURE AS A FUNCTION OF TEMPERATURE

$V = 1 m^3$; $n = 10$ moles

Temperature (°C)	Pressure P ± ΔP (Pascals)
0	22700 ± 20
10	23540 ± 20
20	24330 ± 40
30	25210 ± 30
40	26010 ± 30
50	26820 ± 30
60	27730 ± 50

Graphs

It is often useful to visually display your data in the form of a graph. When you are plotting data in a graph, always make it really clear what you are plotting on each axis! Label the axes and show units. We will show you how to do this in the Excel tutorial in the apendix.



EXPERIMENT 1 ~ ELECTROSTATIC FORCE

Introduction:

The electrostatic force is one part of one of the four fundamental forces of nature. One may argue that this force is the most frequently encountered force, being responsible for a range of phenomena, including chemical bonding, repulsion between material objects, and currents in circuits. In fact, this force is much stronger than gravity!

Here, the forces between different types of charges will be studied qualitatively. These forces will act in one of two different directions, either as attraction or repulsion, between the two objects. It is observed that some objects attract, while at the same time other objects can be found to repel the same object. Therefore it is said that there are two types of charge: like charges that repel and unlike charges that attract. These types are referred to as positive and negative.

When dealing with material objects, the charges reside within atoms themselves, having positive charges, or protons, in fixed positions within the atom and negative charges, or electrons, encircling the protons. At this point, it is worth noting that when charges are moved around in materials in the following experiments, electrons are moving, while protons are fixed in the structure of the material. This can be confusing when it is noticed that positive charge is placed on an object. Keep in mind that removing an electron causes a lack of negative charge or an excess of positive charge. In other words, negative charges moving in one direction can be thought of being equivalent to positive charges moving in the opposite direction.

In the following experiments, various objects will be charged and the interaction between the charged objects will be observed. Pay close attention to how different objects interact with each other. Note which are similar and which are different.

Part 1: The Digital Electrometer

Equipment:

This part of the experiment requires wool and polyester cloths, two plastic rods and a glass rod, and the electrometer (USB charge sensor).

Procedure 1a:

Before each part of this lab, the materials will need to be wiped clean of excess charge. This can easily be done by wiping the rods with your hands. The cloths can be cleaned by gathering all cloths at once and continually balling them up or agitating them (like you are washing your hands).

Set up the Faraday ice pail and charge sensor as seen in the following diagram. For this part of the lab you will use the laptop connected to your set up. Save the Data Studio file to the desktop. You will have to change the file formate to all files and save as a .ds file. The file can be downloaded from the Physics lab site at:
http://www.umsl.edu/~physics/lab/electricitylab/electric-mag.html.

Once you have the laptop on and the sensors plugged in you can double click on the saved file to open the Data Studio program. If you need to find it later the program can be found in the 'Education' folder under the programs in the start menu. To start taking measurements, click on the run button on the upper tool bar. The lab TA will provide more instruction. If you make a mistake with the program you can start over by closing the program without saving and opening it again from the Desktop.

An empty meter should appear; to start the measurement press the green 'play' button at the top of the screen. To stop the measurement press the 'stop button' (the same button). Occasionally the sensor will need to be 'zeroed', you can accomplish this by pressing the 'zero' button on the charge sensor. Alternatively, you can ground it by placing your finger on the inner and outer pails, and then removing your finger from the **inner pail first**. The faraday ice pail measures the charge inside of it by lettting the charge carrying electrons move towards the object (positive object), or by forcing the electrons to move to the charge sensor (negative object). For example, in Figure 1 the object is negatively charged, which causes the electrons (negative charges) to move away from the object and twards the charge sensor. The black clip is the ground clip and the sensor measures the difference in charge between the ground and the inner pail.

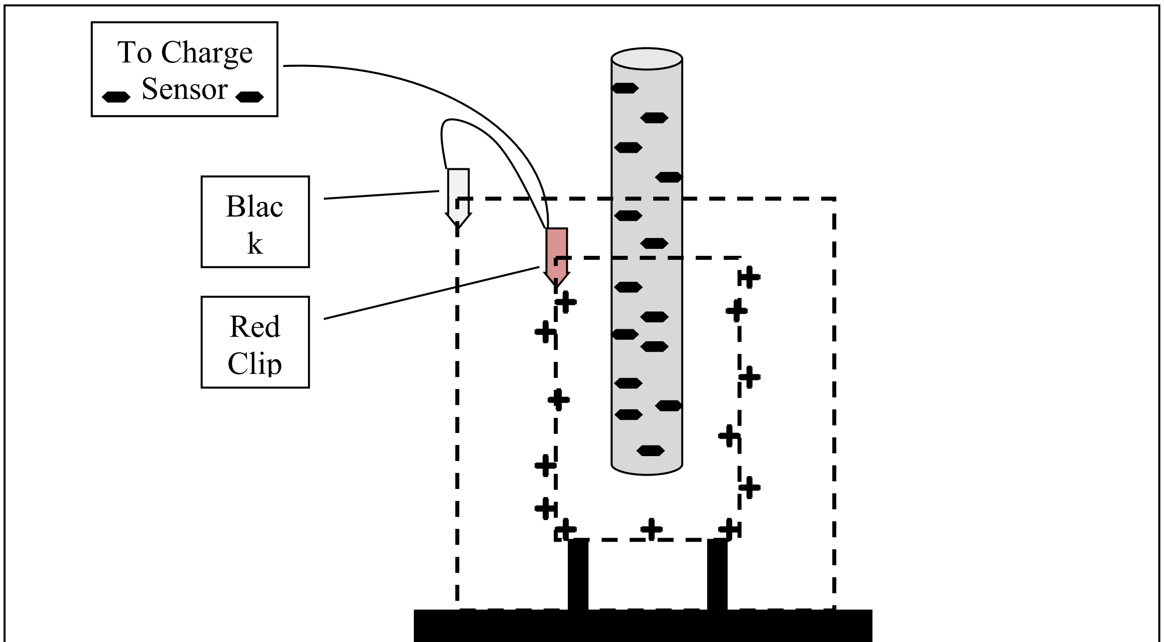


Figure 1: Faraday Ice Pail Sensor Set-up

After wiping the charge from the plastic rod, place it in the faraday cage to make sure there is no charge on it. **When placing objects in the cage it is important that the object does not make contact with the cage.** By making contact with the cage the charge can be passed to it.

Now charge **one** end of the plastic rod, by rubbing one end with the wool cloth, and place it in the cage. **Be careful NOT to touch the cage with the plastic rod.**

1. What kind of charge do you see, (positive, negative, or no charge?)

Now, place the other end of the rod in the cage.

2. What kind of charge do you see now? Can you guess what kind of charge is on the wool cloth?

Repeat the same experiment replacing the plastic rod with the glass rod and the wool cloth with the polyester cloths. Answer the questions above in this new case.

Procedure 1b:

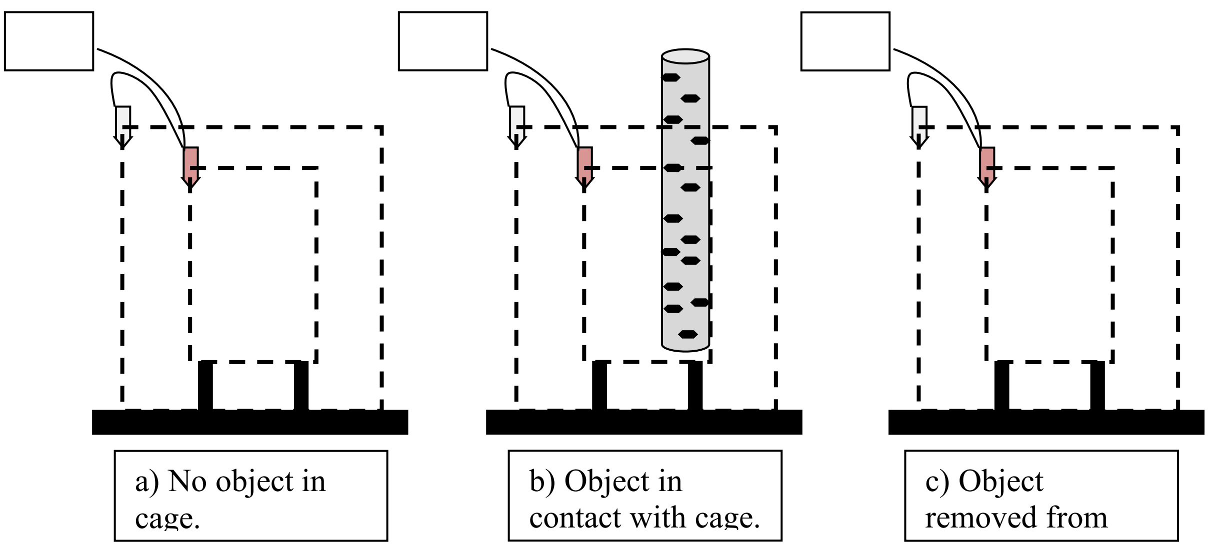
Now, charge the plastic rod and try to **wipe the charge onto the inside of the cage**.

3. What does the electrometer read after you remove the object? Why?

The figure below shows three cages; describe in detail where the charges are and what the electrometer reading should be when:

a) There is nothing in the cage.
b) A negatively charged object is in contact with the inner cage.
c) The charged object is removed from the cage after the charge has been passed to the cage.

The blank box represents the electrometer reading.



Part 2: Electrostatic Force

Theory:

The force between two charged object depends on the charge and the distance between the objects. More precisely, the force varies with the product of the charges and inversely with the square of the distance. This law of nature is known as Coulomb's Law and can be quantified with the proportionality constant, $k = 8.99X10^9 \frac{Nm^2}{C^2}$, giving the equation of electrostatic force,

$$F = \frac{kq_1q_2}{r^2}.$$

If the charges are the same the force is repulsive or positive (- × -, or + × +). If the charges are different the force is attractive or negative (- × +).

Equipment:

The following procedure requires wool cloth, two plastic rods (ABS), and the hanging apparatus.

Procedure:

Wipe the charge from both plastic rods. Charge one end of a plastic rod by rubbing it with the wool. Using the faraday cage check that only one end of the rod is charged, as in part Ia. Without handling it too much, place it horizontally in the wire hooks. Charge the second plastic rod with wool. Bring the charged rod near one end of the hanging rod.

5. What do you observe?

Place the plastic rod near the other end of the suspended rod. Note how this compares to the previous side. Bring the wool used to charge the plastic rod near the suspended rod. Notice how this compares to the plastic rod used previously.

6. Why does the non-charged end of the hanging rod have an attraction to the rod in hand (the answer is in the molecules of the rod)?

Part 3: The Analog Electrometer

Equipment

The following procedure requires an electroscope, wool and silk cloth, plastic and glass rods.

Procedure

Discharge the electroscope by touching the sphere at the top, allowing the charges to move from the electroscope to your body. This procedure allows the net charge of the electrometer to go to zero (equal amounts of positive and negative charge.) After removing the charge from the electroscope, it can be used to study various objects by charging it through induction.

The electroscope can be charged by induction or contact. By bringing a charge near the top sphere, the charges in the electrometer are forced either into the leaves or into the ball at the top (depending on the type of the charge of the object). Touching the sphere with the charged object would be charging by contact, not induction. In this case the net charge in the electrometer is no longer zero. Once the charge in the metal leaves is non-zero, the electrostatic force will cause the leaves to move apart.

First, bring a charged plastic rod (-) close to the sphere, so that the leave move apart. Now that you know there is charge on the rod, try to wipe charge onto the electrometer’s sphere. Move the rod away from the electrometer.

7. What do the leaves do?

Now that the electroscope contains excess charge, *determine whether the charge on a charged glass rod is positive or negative*. You can do this by charging the glass rod as in part I.

8. Explain how you came to this conclusion.

EXPERIMENT 2 ~ ELECTRIC FIELDS AND EQUIPOTENTIAL SURFACES

Objective:

The purpose of this lab is to explore the electric force per unit charge as a function of the distance from various charged electrode configurations.

Equipment:

Multimeter, apparatus for mapping equipotentials, graph paper (provided).

Theory:

The electric force per unit charge is called the electric field intensity or simply the electric field (E). The electric field is a vector quantity given by

$$\vec{E} = \frac{\vec{F}}{q_o} = k\frac{q}{r^2}\,\hat{r}$$

Like all other vector quantities, it has both magnitude and direction. As discussed in the lecture, electric field lines flow from positively to negatively charged regions (positive to ground in this experiment). From the equation above (Coulomb's Law) you should also realize that the magnitude of the electric field decreases as the inverse square of the distance from the point source (in this experiment, the electrodes). This implies that the density of electric field lines (how close together they are) will decrease as you get further away from the source.

In class, we discussed how the **electrical potential is constant along equipotential surfaces, which are perpendicular to electric field lines. Thus, by mapping experimentally where the potential is constant, you can get a map of the electric field. That is the main point of today's experiment.**

Experiment:

Select two configurations. **Make sure at least one of them is the parallel plate configuration.** Sketch two configurations of the electrodes (the copper shapes on the apparatus) on the graph paper.

Connect the apparatus to the power supply.

Turn the power supply on and set it to 18 volts.

Connect the ground from the voltmeter to the ground from the power supply.

Now, using the positive probe you will mark out some equipotential surfaces around the electrodes. Being careful to not touch the grid with anything other than the probe, locate 10 points each for the following voltages; 3, 6, 9, 12, 15 V. Make sure the points are spread out, so that you can get a good sampling of the space around each electrode.

Connect the points of equal voltage (potential) with a smooth line and label them. These are equipotential surfaces. Now draw the corresponding electric field lines, with arrows to show the direction of the field.

Questions:

1. In your own words, explain why equipotential surfaces are perpendicular to electric field lines. (Hint: Check your book.)
2. What condition must exist to have a region of nearly uniform electric fields? (Hint: think about your parallel plate configuration.)
3. Where are regions of strongest and weakest electric fields located? (Hint: Re-read the introduction.)
4. Can electric field lines ever cross? Explain. (Hint: Remember that the electric field is a vector.

Experiment 3 ~ Ohm's Law, Measurement of Voltage, Current and Resistance

Objective:

In this experiment you will learn to use the multi-meter to measure voltage, current and resistance.

Equipment:

Bread board, variable DC power supply, resistors (15kΩ, 22kΩ, 47kΩ, 68kΩ, and 1MΩ), multi-meter, ammeter.

Theory:

The measurements of voltage, current, and resistance that you will make will be made using direct current (D.C.). D.C. refers to direct current which flows in only one direction down a wire. Usually it is a steady current, meaning that its magnitude is constant in time. "D.C." can also be used to refer to voltage. Of course, unlike current, voltage does not "flow". Instead, "D.C. voltage" (or "D.C. potential") means a constant voltage which has only one polarity. One of the major concepts that will be used in this experiment is Ohm's law, which we discussed in lecture. This law states the relation among the three quantities voltage, current, and resistance:

$$\mathbf{V = IR}$$

where I is the current measured in units of amperes, (I), V is the voltage in units of volts, (V) and R is the resistance in units of Ohms, (Ω).

An easy way to think of this law is to imagine that a "current" flows through a wire just like water flowing through a pipe; the narrower the pipe, the greater the resistance. Figure 1 shows the standard symbols for showing a battery and a resistor in a circuit. Remember that current flows

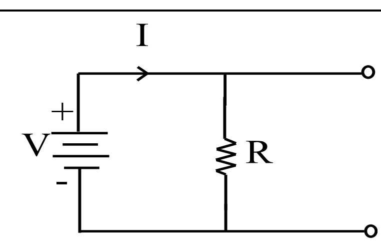
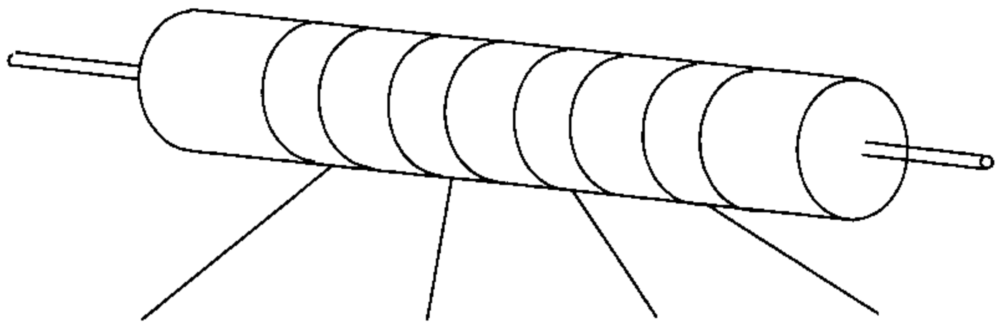


Figure 1: Diagram showing a voltage forcing a current to flow through a resistor.

from positive to negative, representing the flow of positive charge in the wire. (Remember also that it is really the negatively charged electrons that actually do the moving!) In reality, any circuit element (like a light bulb) can act as a resistor. For experiments and for building circuits, small resistors of known resistance can be added to the circuit.

The Resistance Color Code Chart



Color	First Color Band Significant Digit	Second Color Band Significant Digit	Third Color Band Significant Digit	Tolerance Band
Black	0	0	1	--
Brown	1	1	10	--
Red	2	2	100	--
Orange	3	3	1,000	--
Yellow	4	4	10,000	--
Green	5	5	100,000	--
Blue	6	6	1,000,000	--
Violet	7	7	--	--
Gray	8	8	--	--
White	9	9	--	--
Gold	--	--	0.10	±5%
Silver	--	--	0.01	±10%
No color	--	--	--	±20%

EXAMPLE

Yellow / Violet / Orange / Silver (resistor colors)
4 / 7 / ×1,000 / ±10%
47,000 Ω ± 10% or (using engineering notation) 47 KΩ ± 10%

The Experiment

Part 1:

1. Look at several different resistors, which will be passed out to you.

2. There are two ways to find out what the value of any given resistor is.

   a. You can measure the resistance using the function marked Ω on your multi-meter. (kΩ means kilo-ohms or ohms x 1000. MΩ means mega-ohms or ohms x 1,000,000.) **Measure several different resistors with your ohmmeter and record the values in Data Table 1.**

   b. The second way to determine the value of a resistor is to read the color code (see the previous page for the key to the code). **Determine the resistance values from the color code and record these values next to your measured values.**

3. For each resistor, calculate the percent difference between the resistance measured with the ohmmeter and the resistance calculated from the color code chart. Enter the data in Data Table 1.

Part 1 – Analysis:

Data Table 1

Resistor (Colors)	Measured Resistance (Ω)	Resistance from color code chart (Ω)
Resistor 1 ( )		
Resistor 1 ( )		
Resistor 1 ( )		
Resistor 1 ( )		
Resistor 1 ( )		

Calculations

% diff.

Part 2:

1. Connect the circuit as shown by the diagram in Fig. 2. Use the variable power supply and a 15KΩ resistor. **Adjust the power supply voltage to 5 volts.**

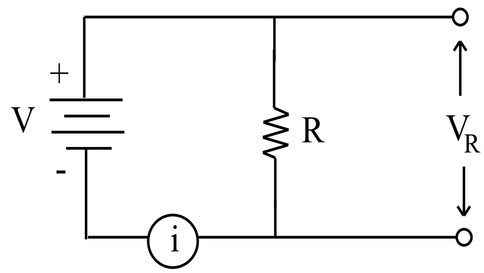


Figure 2A

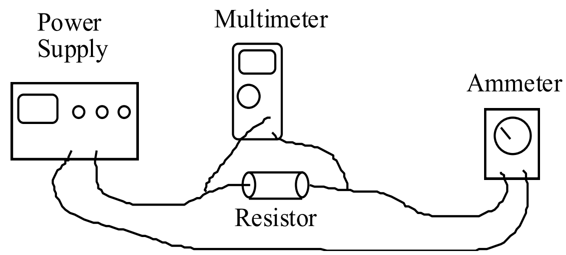


Figure 2B

Figure 2 - A: Circuit diagrams, B: Actual connections for the circuit shown on the left

2. Use the multi-meter to measure the voltage across the resistor (V_R).
3. Use the ammeter to measure the current through the resistor (I).
4. Record your measurements of voltage and current in Data Table 2.
5. Repeat steps 2 through 4 for 10 different values of voltage, in steps of 1V. Record all measurements in your table.

Part 2 – Analysis:

1. Enter the data from Table 2 into Excel, and plot it with current on the x-axis and voltage on the y-axis. As you may have noticed, Ohm's law is an equation in the form of a straight line:

   $$\mathbf{V = RI} \qquad \rightarrow \qquad \mathbf{y = mx + b}$$

   In the case of Ohm's law, we have (ideally) the slope m = R and the y-intercept b = 0. Fit a straight line to the data. What value do you get for the resistance? (Important: in order to get your slope (R) in units of Ohms, you must have current in units of Amperes and voltage in units of Volts. If you originally recorded your current data in units of milliamps, or some other unit, be careful to convert back to Amps!)

2. Measure the resistor you used with the ohmmeter. Is the value similar to the value you calculated from the slope of your line? Calculate the percent difference between the two values of R.

Data Table 2

Power Supply Voltage, V (V)	Voltage Across Resistor, V_R, (V)	Current, I (A)

Trendline equation (y=): ____________________

Slope = ______________

R from color code chart = ___________

Percent difference of Slope and R= _________________

Questions:

1. In Part 1 of the experiment, are the measured values of resistance within the tolerance given by the resistor's color code? (Look at the percent difference.) Explain.

2. In Part 2 of the experiment, was the value of the resistance you obtained from your graph within the tolerance given by the resistor’s color code? Explain.

3. List some possible sources of error that might have affected your measurements in Part 2 of the experiment.

4. Is a plot of current vs. voltage ALWAYS a straight line? Explain why or why not.

5. Sometimes, people might plot I on the y-axis and V on the x-axis. (In this case, the slope will be 1/R.) Why might a scientist want to plot the data that way?

EXPERIMENT 4 ~
RESISTORS IN SERIES & PARALLEL

Objective:

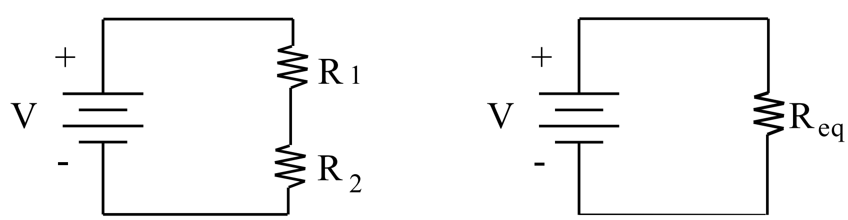
In this experiment you will set up three circuits: one with resistors in series, one with resistors in parallel, and one with some of each. You will be building circuits similar to the ones you will be working with in homework and exam problems. *This experiment should show you the difference between resistors in series and parallel. If you understand what we are doing in this experiment, you will be all set to do well on the midterm questions about circuits!*

Equipment:

Resistors (R_1 = 2.2 kΩ, R_2 = 6.8 kΩ, and R_3 = 4.7 kΩ), multimeter, and DC power supply.

Theory:

In the first part of this experiment we will study the properties of resistors, which are connected "in series". Figure 1 shows two resistors connected in series (a) and the equivalent circuit with the two resistors replaced by an equivalent single resistor (b), as we discussed in the lecture. Remember from lecture that, when resistors are connected in series, each one "sees" the same current. Recall the water analogy: If you have two pipes that have different diameters but are



(a) The actual circuit. *(b) The equivalent circuit*

Figure 1. Resistors connected in series.

connected in series and you send water through them, each receives the same amount of water, there are no branches into which the water can split. In lecture, we showed that the equivalent resistance for resistors in series is

$$\mathbf{R_{eq} = R_1 + R_2}.$$

Of course, this equation can be extend to any number of resistors in series, so that for N resistors the equivalent resistance is given by

$$\mathbf{R_{eq} = \Sigma\, R_i} \quad \text{(for i=1,2,3,...,N)}$$

or

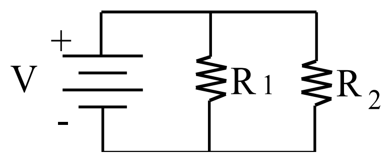


Figure 2: Two resistors in parallel

$$\mathbf{R_{eq} = R_1 + R_2 + R_3 + \ldots + R_N.}$$

You (hopefully!) remember from lecture this isn't the only way to hook up resistors in a circuit. In the second part of this lab we'll hook them together as in Figure 2.

We say these resistors are connected in parallel. In series they were connected one after the other, but in parallel, as the name suggests, they are 'side by side' in the circuit. When resistors are in parallel, the current flowing from the battery will come to a junction where it has a "choice" as to which branch to take. Therefore, they "see" different amounts of current, just the way water branching into two different pipes will flow more through the larger pipe (lower resistance) than through the narrower pipe (greater resistance). Resistors in parallel "see" different currents, but they each experience the same potential difference (voltage). In lecture, we used this property of resistors in parallel to derive an equation for calculating the equivalent resistance. In this case, the equation is a bit more complicated than for resistors in series. Instead of the resistances adding directly, we calculate

$$\mathbf{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}}$$

It's important to remember that after you do this calculation, you will have gotten $\mathbf{1/R_{eq}}$. You have to flip that over in order to get $\mathbf{R_{eq}}$! Here's an example: If we have $\mathbf{R_1}$ = 270Ω and $\mathbf{R_2}$ = 330Ω we would find $\mathbf{R_{eq}}$ as follows:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{270\Omega} + \frac{1}{330\Omega}$$

$$= .0037037\Omega^{-1} + .003030\Omega^{-1}$$

$$= .006734\Omega^{-1}$$

So, $R_{eq} \approx 148\Omega$

We can generalize this equation to any number of resistors, just the way we did for resistors in series. As in the case for series we can generalize this law to any number of resistors:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_N} = \sum_{i=1}^{N} \frac{\mathbf{1}}{\mathbf{R_i}}$$

The Experiment

Part 1

1. Take three resistors. Measure the resistance of each resistor individually using the ohmmeter (i.e., the multimeter). Record the values in Data Table 1.
2. Determine the resistance of each resistor, using the Resistor Color Code Chart on page 17. Record the values and the colors in Data Table 1.
3. Now, connect the resistors in series, as shown in Figure 3a, and connect them to the power supply that is set at 12 V. Record the voltage across each resistor, using the multimeter. Record the measured values in Data Table 1.

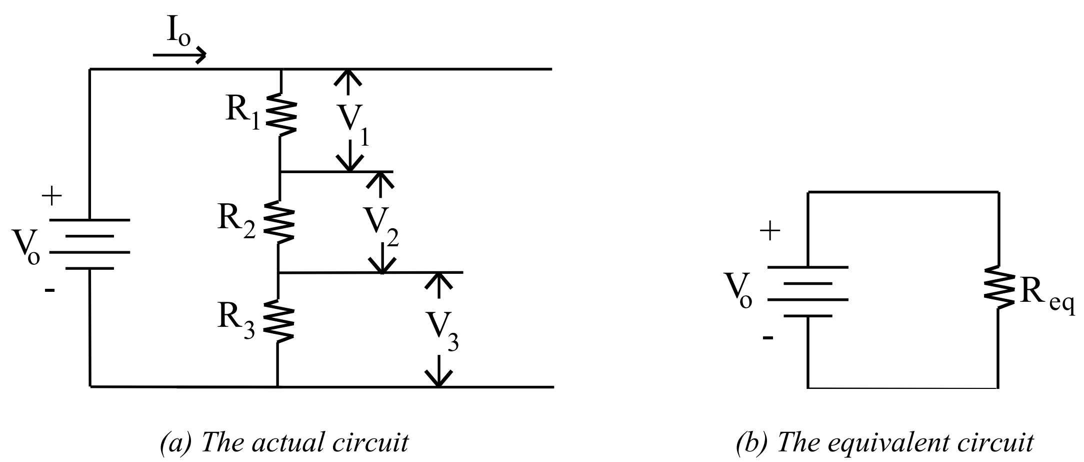


Figure 3 : The voltages across series resistors.

Data Table 1

R_1 (measured)		R_1 (from color code)		V_1 (measured)		I_1 (calculated)	
R_2 (measured)		R_2 (from color code)		V_2 (measured)		I_2 (calculated)	
R_3 (measured)		R_3 (from color code)		V_3 (measured)		I_3 (calculated)	

Questions: Part 1

1. Are the voltages V_1, V_2 and V_3 equal to each other? Why or why not?

2. Calculate the total voltage $V = V_1 + V_2 + V_3$. Explain why it has the value it does.

3. Use Ohm's law to calculate the current through each resistor. (e.g., $V_1=I_1*R_1$, so $I_1=V_1/R_1$). For this calculation, use the measured value of the resistances. Record these calculated values in the table above. Is the result what you expected? Why?

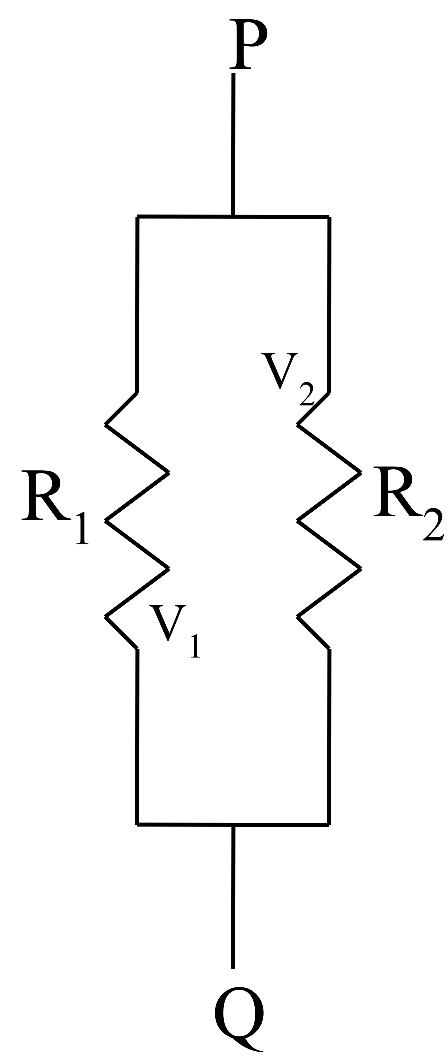


Figure 4: Two resistors attached in parallel

Part 2

In this part of the experiment, you will experimentally test the addition law for resistors in parallel.

1. Take two resistors. Measure the resistance of each resistor individually using the ohmmeter (i.e., the multimeter). Record the values in Data Table 2.

2. Calculate the resistance of each resistor, using the Resistor Color Code Chart on page 17. Record the values in Data Table 2.

3. Now, connect the resistors in parallel, as shown in Figure 4, and connect them to the power supply that is set at 12 V. Record the voltage across each resistor, using the multimeter. Record the measured values in Data Table 2.

4. Calculate the equivalent resistance ($\mathbf{R_{eq}}$) of the circuit, based on your *measured* values of R_1 and R_2. Enter the value at the top of Data Table 2.

5. Measure the equivalent resistance of the circuit using the ohmmeter. This is the resistance between points **P** and **Q** in Figure 4a. Record the value at the top of Data Table 2.

6. Use Ohm's law, with your *measured* value of R_{eq}, to calculate the total current in the circuit. Enter the value at the top of Data Table 2.

Data Table 2 follows on the next page →

Data Table 2

R_1 (measured)		R_1 (from color code)		V_1 (measured)		I_1 (calculated)	
R_2 (measured)		R_2 (from color code)		V_2 (measured)		I_2 (calculated)	

R_{eq} (measured) ________ R_{eq} (from color code) ________ I_{total}_________

Questions: Part 2

4. Are the measured values of R_1 and R_2 equal to the values calculated using the color code chart? How much do they differ (calculate percent error)? Is this within the specified tolerance?
5. Is your measured value of R_{eq} similar to your calculated value? Explain.
6. Are V_1 and V_2 equal to each other? Explain.
7. Are I_1 and I_2 equal to each other? Explain.
8. Compare I_{total} to the I_1 and I_2. What do you notice?

Part 3

Now for the grand conclusion. We are going to use our techniques on a circuit that has resistors in **both series and parallel** connections. Below we have a circuit with three resistors. The two which are connected in parallel, R_1 and R_3, are in series with R_1.

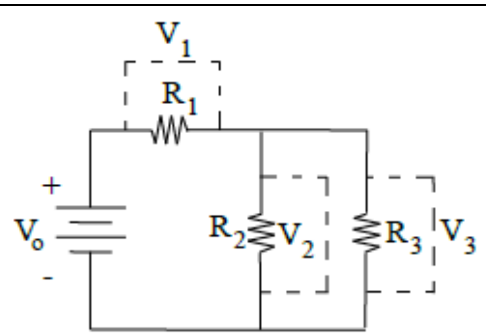


Figure 5: A series/parallel combination

1. Write down the resistor values from their color codes in Table 3.
2. Measure their individual resistances using your multimeter and record these values in Table 3.
3. Calculate the equivalent resistance, R_{eq}, for the three resistors hooked up as in Figure 5, first using your measured resistances (record as Measured R_{eq} in Table 3), and then using the values from the color code chart (record as Color Code R_{eq} in Table 3).
4. Now connect them to the power supply that is set at 12V.
5. Measure the voltage across R_1 and then across R_2 and R_3.

Data Table 3

				V_0 (measured)	
R_1 (measured)		R_1 (from color code)		V_1 (measured)	
R_2 (measured)		R_2 (from color code)		V_2 (measured)	
R_3 (measured)		R_3 (from color code)		V_3 (measured)	
R_{eq} (measured)		R_{eq} (from color code)		V_1+V_2	

Questions: Part 3

9. Are the voltages V_1, V_2 and V_3 equal to each other? Why or why not?

10. Calculate the total voltage $V = V_1 + V_2$. Explain why it has the value it does. How does this sum compare with V_0? Is it the same as $V_1 + V_3$? Why or why not?

11. Use Ohm's law to calculate the current through each resistor. (e.g., $V_1=I_1*R_1$, so $I_1=V_1/R_1$). For this calculation, use the measured value of the resistances. Record these calculated values in the table above. Is the result what you expected? Why?

Experiment 5 ~ Kirchhoff's Laws

Objective:

To verify Kirchhoff's Laws by comparing voltages obtained from a real circuit to those predicted by Kirchhoff's Laws.

Introduction:

A simple circuit is one that can be reduced to an equivalent circuit containing a single resistance and a single voltage source. Many circuits are not simple and require the use of Kirchhoff's Laws to determine voltage, current, or resistance values. Kirchhoff's Laws for current and voltage are given by equations 1 and 2.

$$Equation\ 1:\ \sum_{Junction} I = 0,\ \ Junction\ Law$$

$$Equation\ 2:\ \sum_{Loop} \Delta V = 0,\ \ Loop\ Law$$

In this experiment, we will construct two circuits with 4 resistors and a voltage source. These circuits will not be simple, thus Kirchhoff's Laws will be required to determine the current in each resistor. We will then use a digital multi-meter to obtain an experimental value for the voltage across each resistor in the circuits. Kirchhoff's Laws will then be applied to the circuits to obtain theoretical values for the current in each resistor. By applying Ohm's Law, we can then obtain a theoretical value for the voltage across each resistor. The experimental and theoretical voltages can then be compared by means of % error.

Equipment:

- Proto-board
- 4 resistors: (R_1=68 kΩ, R_2=47 kΩ, R_3=15 kΩ, R_4=1000 kΩ)
- *Please be consistent with this numbering of the resistors in every part of the experiment to make things clearer when you are analyzing your data, and for your TA while they are grading!*
- Digital multi-meter
- Variable power supply
- Wire leads and alligator clips

Experimental Procedure Part 1:

1. Using the proto-board, the 4 resistors, the variable power supply, and the wire leads and alligator clips; construct the circuit shown in Figure 2.

2. Turn on the power supply. Connect the multi-meter across the power supply and adjust the voltage to 8.0 volts.

3. Connect the multi-meter across each of the 4 resistors. Record these 4 values of voltage in the data table.

4. Turn the power supply off and disconnect the circuit.

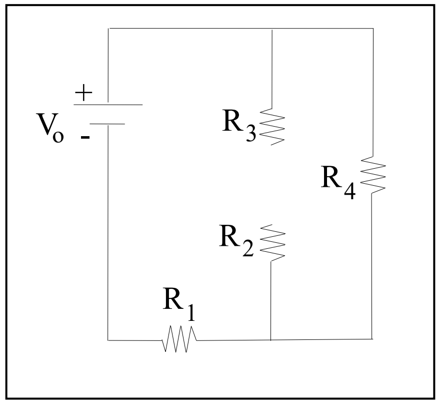


Figure 2

Experimental Procedure Part 2 (1012 labs will typically skip this part):

1. Add a second power supply to the circuit as shown in Figure 3.

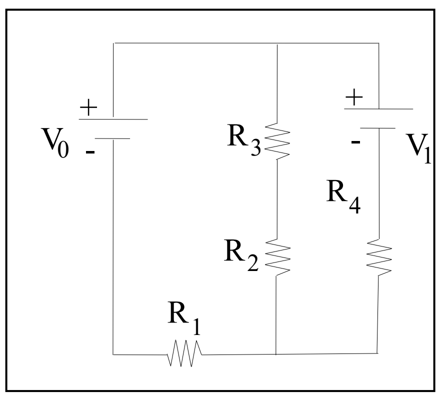


Figure 3

2. Turn on the power supplies. Adjust the voltages V_0 and V_1 to 4.0 volts.
3. Connect the multi-meter across each of the 4 resistors. Record these 4 values of voltage in the data table.
4. Turn the power supply off and disconnect the circuit.

Analysis:

1. For the first circuit, use equations 1 and 2 to write a system of linear equations that may be solved for the current in each branch of the circuit. Then, solve the system to obtain a theoretical value for each current. Show your work! (*For 1012 students, you can also use*

the method discussed in class, where you find R_{eq} first, then the total current, and then use Kirchhoff's Loop Rule and Junction Rule to find the currents in each branch.)

2. Using the currents obtained in step 1 of the analysis; apply Ohm's Law to determine the theoretical voltage across each resistor.
3. Compare the theoretical voltages obtained in step 2 of the analysis to those measured in the actual circuit.
4. Repeat steps 1 to 3 for the second circuit.
5. Record the theoretical voltages, the experimental voltages, and the % errors in the results table.

Results:

Part #1	**V (theoretical)**	**V (experimental)**	**% error**
R_1=			
R_2=			
R_3=			
R_4=			

Part #2	**V (theoretical)**	**V (experimental)**	**% error**
R_1=			
R_2=			
R_3=			
R_4=			

Challenge (1012 labs will typically skip this part, and 2112 labs may do this as extra credit; see your Lab Instructor for specific instructions)):

Repeat experimental steps 1-4 and the analysis for the circuit in Figure 4 with 5 resistors and a power supply:

(R_1=68 kΩ, R_2=47 kΩ, R_3=22 kΩ, R_4=15 kΩ, R_5=1000 kΩ)

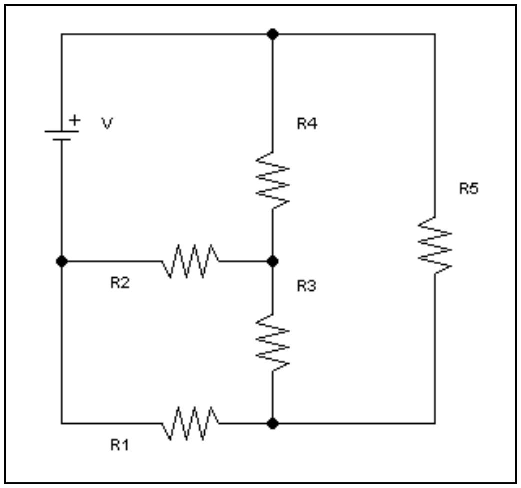


Figure 4

Challenge Results:

Trial #1	V (theoretical)	V (experimental)	% error
R_1=			
R_2=			
R_3=			
R_4=			
R_5=			

EXPERIMENT 6 ~ AC VOLTAGES, FREQUENCY AND THE USE OF THE OSCILLOSCOPE

Objective:

After completing this experiment, you will be able to use the oscilloscope to measure unknown voltages and frequencies. There is a worksheet available on the lab webpage at: **http://www.umsl.edu/~physics/lab/electricitylab/electric-mag.html.**

Equipment:

Oscilloscope, signal generator, connecting wires

Note:

Buttons or markings on the oscilloscope are in bold.

These instructions are written for the 'blue' oscilloscopes. Differences for the 'gray' oscilloscopes are noted.

Experimental Procedure and Questions:

Part 1

In the first part of this experiment, we'll try a few different things with the oscilloscope to help you become more familiar with it. Turn your oscilloscope on and let it warm up for a few seconds. While it's warming up check the following switches to make sure they're set correctly. Look for the area marked **Trigger**. There is a switch marked **Mode** which should be set to **Auto**. There's also a switch here marked **Source**. This switch should be all the way up, (it will be set on **line**). We will also be using **Channel 1** throughout this lab, unless otherwise directed, so any switches marked **CH1** or **CH2** should be set to **CH1**. For the gray oscilloscope, leave the Source set to **CH1**.

By now your oscilloscope should be warmed up. If you don't see something on the screen, try pushing the **Beam Find** button and use the **Position** knobs to move the trace back to the center of the screen. If you still see nothing, try turning the **Intensity** up a little. If you still can't see anything, ask your TA for help.

You'll notice the screen is divided into squares. Each square is called a division. This is important to know because you'll notice the 3 largest knobs are marked **sec/div** or **volts/div**. So when we see that something has moved say 3 divisions, we'll be able to convert that to Volts or seconds. This is how we'll make our measurements.

Now, look for the knob marked **sec/div**. This knob controls the 'Time base'. Turn this knob to .1 sec/div. For the grey oscilloscope you may need different values for this knob.You can now see the trace move across the screen from left to right. You'll notice it takes about a second to cross the screen. Actually it takes exactly a second to cross the screen. We can calculate this because the time base knob is on .1 sec/div and the grid on the screen is divided into 10 divisions horizontally and 8 divisions vertically. Multiplying gives:

$$.1\frac{\text{sec}}{\text{div}} \text{ x } 10 \text{ div} = 1 \text{ second.}$$

If you now set the time base knob to something smaller like 1ms/div, (Remember, m stands for milli = 10-3), you'll see the trace move so fast that it's hard or impossible to see.

<u>**Question 1:**</u> How many seconds does it take the trace to go across 1/2 the screen at the 1 ms/div setting?

Remember, the horizontal axis of the screen is where we measure time, so you just have to count the divisions between any two points you're interested in and multiply by the scale on the sec/div knob. So now you can (or will soon be able to) find how long it takes the trace to move between any two points on the screen.

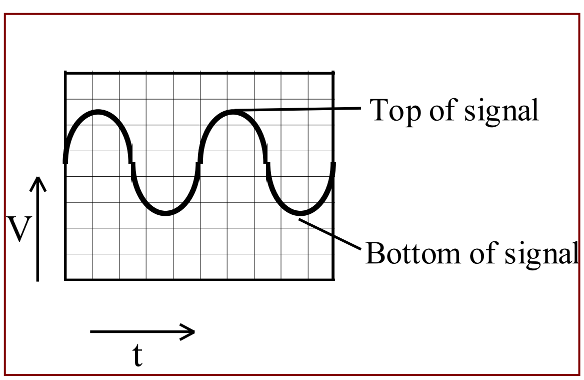


Figure 4:Example of a signal on an oscilloscope.

The vertical axis works the same way, except we use it to measure volts rather than time. Looking at Figure 1 as an example, we can see that there are 4 divisions between the bottom of the wave and the top of the wave. If our volts/div knob is set on 1 volt/div, then we would have:

$$1\frac{\text{volt}}{\text{div}} \text{ x } 4 \text{ div} = 4 \text{ volts}$$

A helpful way to think about these knobs is that changing the setting is like changing which units you can use on a ruler; if you're measuring a piece of paper you can use centimeters or millimeters or whatever. But the object you're measuring doesn't change as you switch between scales. Or you might imagine you're zooming in or out with a variable magnifying glass; changing the knobs just changes the magnification, and the numbers tell you what the magnification scale is.

Part 2

Remember, the vertical scale factor (the number of volts/div) is controlled by the two knobs marked volts/div. There are two inputs on this scope so that two voltages may be viewed simultaneously, but for now we will use only one input, Channel 1. Look for the switch by the volts/div knob marked AC-GND-DC and set this to GND. This grounds the input to the scope; the vertical scale is at zero volts. Now use the vertical position knob to move the trace to the center of the screen. Once the line is centered, set the switch to AC (DC voltages will be eliminated at the input of the scope.) For the gray oscilloscope, push in the GND button and then center the trace. Then return the GND button to its original position. Check that the AC/DC button is out.

Connect a triangular wave of about 1 KHz frequency from the signal generator to CH 1 of the scope.

Since we are measuring a wave whose frequency is in the 1 kHz range, the typical period will be in the ms range. Set the time base knob to 1 ms/div. Make sure the cal knob is all the way clockwise.

Set the volts/div switch to 2 volts/div. Check that the small knob marked cal on the volts/div knob is turned all the way clockwise, i.e. in its calibrated position. If this knob is not in the calibrated position, your measurements will be incorrect.

Adjust the amplitude of the signal generator using the output level knob to give you a +/- 6 volt wave (12 volts peak to peak). Be sure that the DC offset knob on the generator has the white dot pointed up, i.e. zero volts DC offset. You should see a triangular wave which has a positive maximum three divisions above the middle line across the screen and a negative minimum three divisions below.

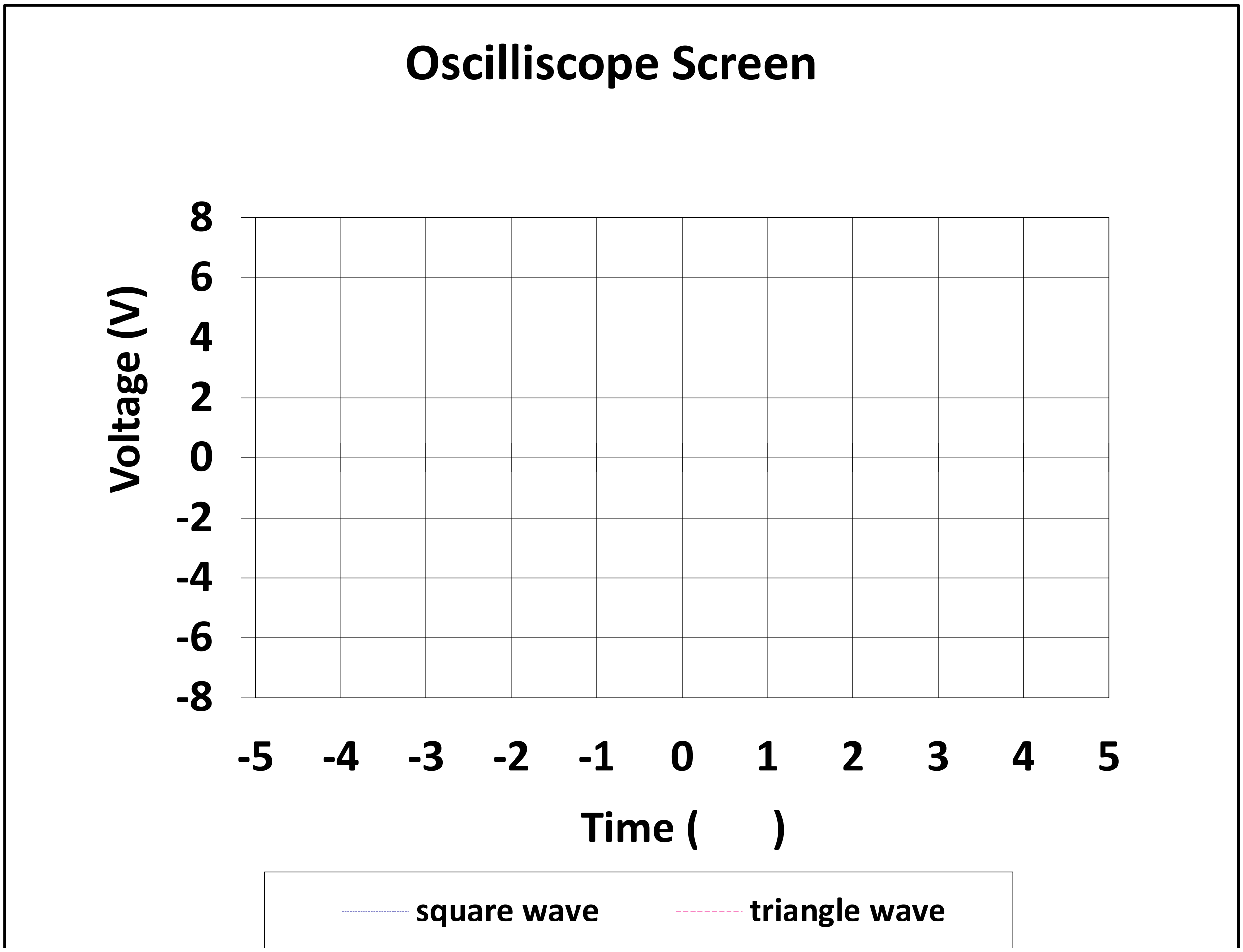
The sweep (i.e. the movement of the dot across the screen) is "triggered" when the voltage crosses the threshold set with the level control. The point at which this crossing takes place then becomes the "origin" of the graph. The threshold is controlled with the small knob marked level. Use the horizontal position knob to move the whole trace to the right so you can see the beginning. Explore what happens when the level knob is rotated. Note that you can change the location of the origin of your graph.

Now look at the button or switch right by the level control marked slope. This controls the polarity of the voltage for which the triggering takes place. Both positive triggering and negative triggering are possible. Explore what happens when this button is both up and down or in and out for the gray oscilloscope. You may have to adjust the level to get stable triggering after this.
Now make an accurate measurement of the frequency of the triangular wave. You will measure the period, T, the time between any two repeating points on the wave. For example, count accurately the divisions between the two maxima, and then use the information about sec/div from the time base knob setting to find T. The frequency is given by:

$$f = 1 / T$$

Question 2: Is the signal generator frequency knob very accurate? Sketch the triangular wave in your notebook. Compare your measured value with the settings on the signal generator.
The scope is capable of looking at two waves simultaneously. Look for the switch marked CH1-both-CH2. Push this switch to both. When you do this, you will activate the capability to look at

both inputs. Leaving the triangular wave connected to CH 1, connect the TTL pulse to CH 2. Make sure to set the sec/div switch to same value as you are using on CH 1. Use the two vertical position knobs to adjust the two waveforms for a convenient display. Make a sketch of them in your notebook. Note that the amplitude of the TTL wave is not adjustable on the signal generator. Measure its amplitude in volts and label your sketch accordingly.



EXPERIMENT 7 ~ MAGNETIC FIELD INDUCED BY A CURRENT-CARRYING WIRE

Objective:
In this experiment you will investigate the interaction between current and magnetic fields. You will

(1) Determine the direction of the B field surrounding a long straight wire using a compass (Oersted's experiment),

(2) Find the induced voltage in a small inductor coil, and show that the magnitude of the B field decreases as 1/r.

(3) Determine the permeability of free space using a Hall probe and the constant magnetic field near a long straight wire.

Equipment:
DC power supply, function generator, oscilloscope, inductor coil, small compass, and long straight wire apparatus.

Theory:
When a current I exists in a long straight wire, a magnetic field B is generated around the wire. The field lines are concentric circles surrounding the wire, as shown in Figure 1.

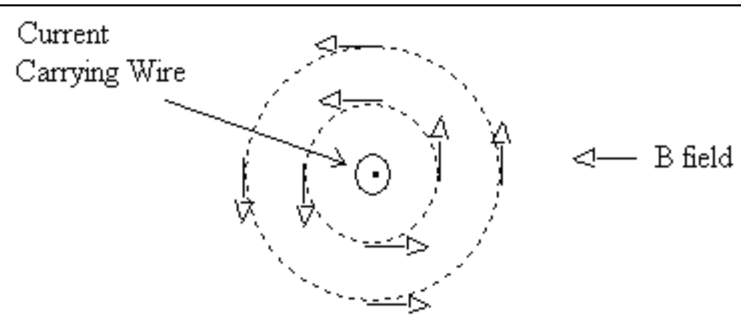


Figure 1: B field near a current-carrying wire.

In Figure 1, the current I is shown coming out of the page toward you. The magnitude of the magnetic field (B) as a function of I and the distance (r) away from the wire is given by:

$$B = \frac{\mu_0 I}{2\pi r},$$

where $\mu_0 = 4\pi \times 10^{-7}$ Tm/A, I is in Amperes, r is in meters, and B is in Tesla. (The direction of B, of course, is given by the right hand rule. (Note that this equation is actually derived assuming that the long straight wire is actually infinitely long!!)

If the current in the long straight wire is constant in time, the B field created by that current will also be constant in time. In this case, the direction of the B field can be determined by observing its effect on a small compass placed in the vicinity of the long straight wire. This is basically Oersted's experiment.

If the current in the long straight wire is an alternating current produced by a sine wave generator, the B field surrounding the wire will also be time-varying. A changing magnetic field can induce a current in a wire, because it induces an electromotive force. This is Faraday's law, and is part of the endless hall of mirrors of reciprocal interactions between electricity and magnetism that we have been emphasizing in class. Faraday's law states that the induced emf in a coil of wire (in this case, that's the "inductor coil") placed near the long straight wire is

$$\varepsilon = \frac{\Delta\Phi}{\Delta t},$$

where $\Delta\Phi$ is the magnetic flux, which can be changed by changing the magnetic field. (The flux can be changed by a few other things too, which we will discuss in class!) So, if the magnetic field going through the inductor coil is changing, alternating in magnitude and direction because of the sine-wave generator, an alternating voltage will be induced in the wire. In other words: The current in the long wire oscillates because it is coming from a sine wave generator….which makes the B field around the wire oscillate….which makes the induced emf in the small "inductor coil" oscillate too! (Which makes an oscillating current in the inductor coil…And yes, the current in the inductor coil will generate a tiny little B field of its own…)

According to Faraday's law, this induced voltage in the coil is proportional to the rate of change of the magnetic flux through the coil, and hence to the magnitude of the time-varying B field. Therefore, a measurement of the voltage induced in the coil, as the coil is placed at different distances from the wire, provides a relative measure of the magnitude of the B field at different distances from the wire. Note that the quantity actually measured is an alternating electric voltage, but its magnitude is proportional to the B field and will be taken to be a relative measurement of the B field at a given point. In other words, we are not measuring B directly. We are measuring the emf caused by B, and by measuring the emf at different distances r, we can infer how B changes as a function of distance.

The Experiment

Part 1: Determination of the Direction of the B Field around a Current-Carrying Wire:

1. Connect the circuit shown in Fig. 2 using the direct current power supply. Stand the long wire apparatus on its end so that the long wire is vertical.

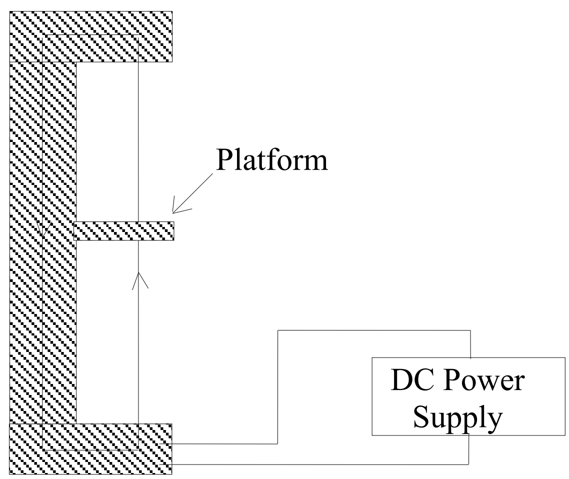
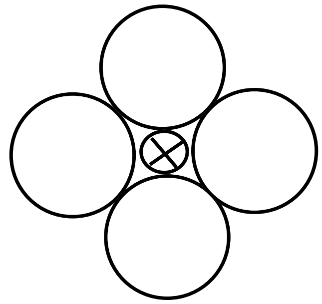


Fig. 2 Long wire apparatus connected to the Direct Current Power Supply.

2. Turn on the power supply. (Notes: the DC power supply you will use for this experiment is the same as the one you used before; the power supply needs to be set to the maximum voltage).

3. Place the compass on the platform at various positions around the wire, and record the direction of the compass needle at each position. Record your measurements in Data "Table" 1.

Indicate the compass direction at the positions shown. The X in the center is showing the direction of the current in the wire (into page). A dot indicates current flowing perpendicularly out of the page. (See Question 2 below) is this direction correct for your experimental set up? If the direction is wrong, change it to the correct direction by swapping the wires from the power supply.



Data "Table" 1

Part 2: Determination of Magnitude of the B Field as a Function of Distance from the Wire

1. Connect the circuit shown in Fig. 3 using the long wire apparatus and the sine wave generator. Turn the generator to maximum amplitude.

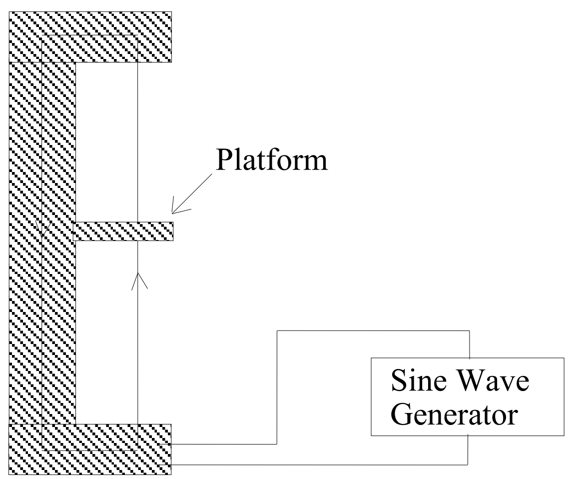


Fig. 3 Long wire apparatus connected to the Sine Wave Generator.

2. Connect the inductor coil to the oscilloscope. Place the inductor coil on the platform as shown in Fig. 4. Line up the coil with the ruler attached to the platform.

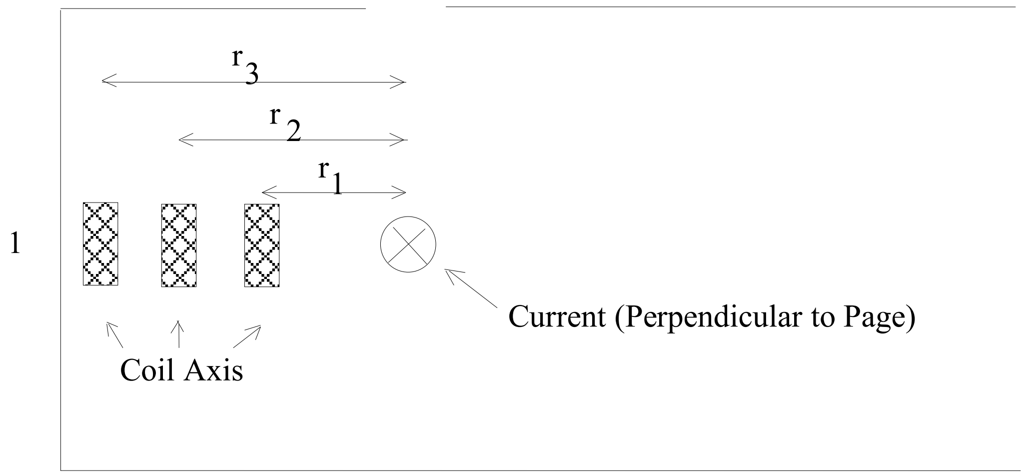


Fig. 4 View of the platform looking down from above. The current is perpendicular to the page alternating into and out of the page.

3. The amplitude of the induced voltage on the oscilloscope will depend upon the frequency of the generator sine wave. Adjust the frequency until you get a large amplitude voltage signal (about 2 Volts peak-to-peak).

4. Measure the voltage induced in the inductor coil as a function of *r*. The quantity *r* is the distance from the center of the coil to the center of the wire. Take data from $r = 2.0$ cm to $r = 9.0$ cm in increments of 1 cm. The reason that data is not taken for *r* less than 2 cm is the fact that at distances close to the wire, the *B* field is not even approximately uniform over the cross-section. Record the values of the voltage in the Data Table 2 under the column labeled *B* (trial 1). If this were a true measure of the *B* field, the units would be Tesla. The measured quantity is really a voltage which is proportional to *B*.

5. Repeat step 4 two more times measuring the induced voltage as a function of distance and recording the values in the Data Table 2 under Trial 2 and Trial 3.

6. Calculate the average "*B*" from Trials 1, 2 and 3.

7. Plot the average value of *B* as a function of $1/r$.

Data Table 2

r (cm)	*1/r* (cm^{-1})	*B* Trial 1	*B* Trial 2	*B* Trial 3	*B* (Average)
2.0					
3.0					
4.0					
5.0					
6.0					
7.0					
8.0					
9.0					

Part 3: Direct Measurement of the B Field as a Function of the Current in the Wire

For this part of the lab you will use the laptop connected to your set up. Save the Data Studio file to the desktop. The file can be downloaded from the Physics lab site at: **http://www.umsl.edu/~physics/lab/electricitylab/electric-mag.html.**

Once you have the laptop on and the sensors plugged in you can double click on the saved file to open the Data Studio program. If you need to find it later the program can be found in the 'Education' folder under the programs in the start menu. To start taking measurements, click on the run button on the upper tool bar. The lab TA will provide more instruction. If you make a mistake with the program you can start over by closing the program without saving and opening it again from the Desktop. **An empty graph should appear; to start the measurement press the green 'play' button at the top of the screen. To stop the measurement press the 'stop button' (the same button).**

The magnetic field sensor is a two axis field probe. One axis is parallel to the probe (axial) and the other axis is perpendicular to the probe. The approxiamate axis of the sensor is indicated by a white dot on the end of the probe. The field strength is measured using a Hall probe in the sensor. To find out more on Hall probes you can visit wikipedia at: http://en.wikipedia.org/wiki/Hall_probe#Hall_probe.

This experiment will attempt to determine the magnetic permeability of free space μ_0; using the hall probe and the DC power supply. Using the same set up from part 1 (Figure 2):

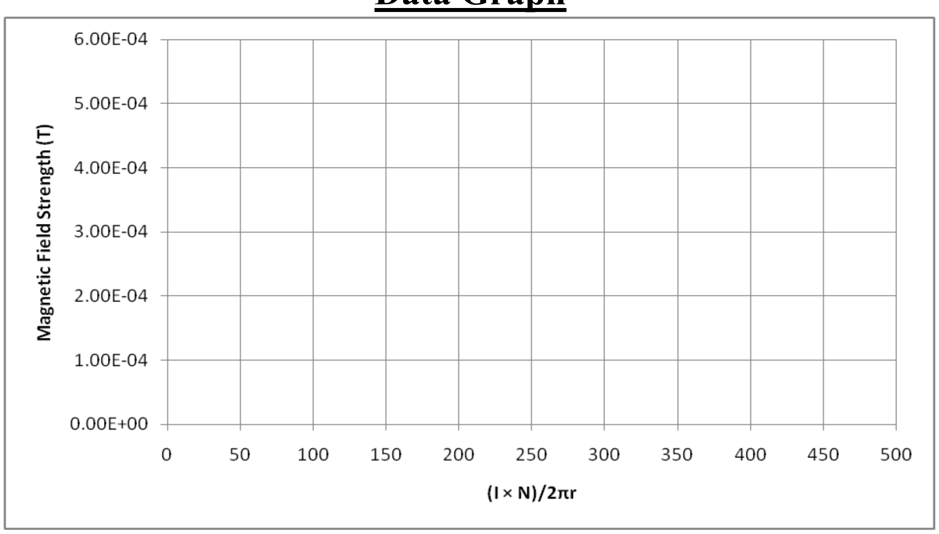
1. Place and hold the axis of the probe at 2 cm (r=0.02m).
2. The power supply needs to be set at the maximum voltage and the current should be set at 1.75 A. When the direct current is 1.75 A in a single wire of the bundle of N wires, the total current in the bundle of wire that approximates the long straight wire is N x *1.75 A*. This total current is used in the calculation of column 2 of Data Table 3.
3. Record the field strength.
4. Reduce the current by .25 A and repeat steps 3 & 4 until you reach a current of .25 A.

Data Table 3

Current (A)	$\frac{N * I}{2\pi r}$	Axial Magnetic Field Strength (G)
1.75		
1.50		
1.25		
1.00		
0.75		
0.50		
0.25		

Create a graph of B on the y-axis and $(I*N)/(2\pi r)$ on the x-axis. The slope of this line should be equal to the magnetic permeability of free space μ_0. Discuss your results in the conclusion.

Data Graph



Questions:

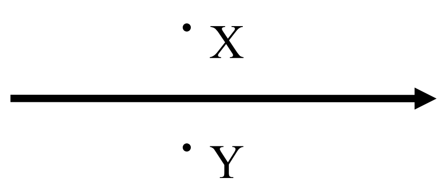
1. Explain how the earth's magnetic field could affect your results in Part 1. Based only on your data in Data Table 1 above, can you tell what side of the laboratory is facing (geographic) North?

2. In Part 1, use the direction of the compass needles and the right hand rule to determine whether the current in the wire is going up or down.

3. Why does the plot of "B" vs. 1/r look like a straight line?

4. When the direct current is 2.00 A in a single wire of the bundle of 10 wires, the total current in the bundle of wire that approximates the long straight wire is 20.0 A. What is the magnitude of the B field 3.00 cm from this long straight wire carrying a current of 20.0 A? What is the magnitude of the B field 9.00 cm from the wire carrying 20.0 A?

5. A constant current is in a long straight wire in the plane of the paper in the direction shown below by the arrow. Point X is in the plane of the paper above the wire, and point Y is in the plane of the paper but below the wire. What is the direction of the B field at point X? What is the direction of the B field at point Y?



Direction at X =________________________

Direction at Y= ________________________

Experiment 8 ~ RC Circuits

Objective:

This experiment will introduce you to the properties of circuits that contain both resistors AND capacitors.

Equipment:

18 volt power supply, resistor (2.2 MΩ), two capacitors (8 μF, 20 μF, or other value), multimeter, stopwatch.

Theory:

In this experiment, you will work with a circuit where a resistor is combined in series with a capacitor. This is called an RC circuit. Remember from lecture that capacitors are devices which store charge. In the lecture, we talked about a simple, "idealized" kind of capacitor, a parallel plate capacitor, which consists of two metal sheets separated by a dielectric. In practice, real capacitors are usually made up of thin metal sheets ("plates"), separated by a thin plastic insulator and rolled up. The two plates are not in electrical contact, and charge can be stored on them with the + charge on one, and the - charge on the other. There is a voltage difference between the two plates of a capacitor, and the capacitance C (with units of Farads) is defined as the amount of charge (Q) stored on the plates per unit potential difference (V):

$$C=Q/V \qquad (1)$$

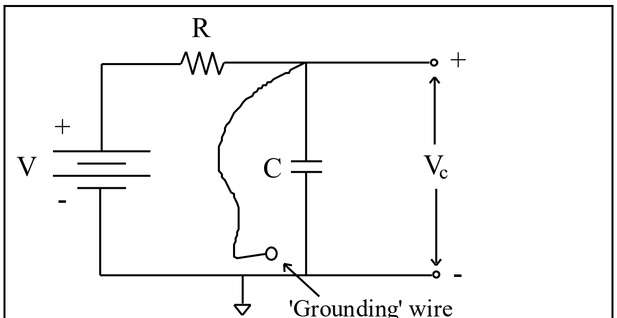


Figure 1. An RC circuit with power supply showing a "grounding" wire.

In practice, you will never see a capacitance as large as 1 F. Most capacitances you might encounter in real life can be measured in microfarads (1 μF = 1 x 10^{-6} F). Therefore, as you can see from the above equation, charges found in the laboratory will usually be of the order of microcoulombs (μC) in order to have voltages in the range of a few volts.

An RC circuit is shown in Figure 1. The grounding wire shown in the figure is equivalent to having a switch in the circuit. When the wire is connected to ground, no current will flow. What happens when the grounding wire is removed and current is allowed to flow in the circuit? Current will flow from the power supply through the resistor onto the + plate of the capacitor (the top plate in the figure), and a net + charge will collect on the plate. An equal - charge will collect on the other plate (the bottom one in the figure).

Why does this happen? Essentially, positive charge will flow through the circuit, trying to get from the positive terminal of the battery to the negative terminal (flowing from positive to negative, as we have said in class). But it can't cross the capacitor, because there is an insulator between the plates, so positive charge will collect on the top plate of the capacitor. Like passengers collecting at Lambert Airport when flights are cancelled: more and more charges waiting, with no place to go. The same thing will happen at the negative plate (imagine more and more people waiting to pick up their relatives at O'Hare, but no planes are landing).

As the charge accumulates on the plates of the capacitor, the voltage across the capacitor, V_c, slowly builds up, approaching a maximum value, the voltage of the power supply, V.

Once the voltage has reached its maximum, no more current can flow (the airport terminals are full to bursting). Why is $V_c = V$? Recall Kirchhoff's first law. $V_c = V$ because the sum of the potential differences around a closed circuit has to equal zero. In lecture, we used calculus to show that V_c changes with time according to the equation below:

$$V_c = V\,(1 - e^{-t/RC}) \qquad (2)$$

Where e is 2.71828…, and t is the time since the circuit switch was closed (or the grounding wire removed), i.e., the time since current began to flow. To review what we discussed in class, you can get an idea of what this function should look like by thinking what will happen in the limits of $t \rightarrow 0$ and $t \rightarrow \infty$. As $t \rightarrow 0$, the exponential term approaches 1 (since $e^0 = 1$). Thus, $V_c = 0$ when $t = 0$. Likewise, when $t \rightarrow \infty$, the exponential term is zero, since $e^{-\infty} = 0$. Thus $V_c = V$ when $t = \infty$. The rate at which this buildup occurs is governed by the time constant RC. Note that the exponent in equation (2) must be dimensionless. Therefore the product RC has units of seconds when R is in Ohms and C in Farads.

One final thing to review from lecture: a charged capacitor can store an amount of energy equal to

$$U = \frac{Q^2}{2C} = \frac{1}{2}QV = \frac{1}{2}CV^2 \qquad (3)$$

<u>The Experiment:</u>

1. Connect the resistor and the 8 μF capacitor as shown in Figure 1. Set the power supply voltage to 10 volts D.C.
2. Attach a grounding wire to the node where the capacitor and resistor are connected, as shown in the figure. When you connect this wire to ground, it will remove any excess charge from the capacitor, so that you will know you are starting with a capacitor that is initially free of charge. (Think about it: why is it important that q=0 at t=0?)
3. Now, connect your voltmeter between the node and the ground so that you are measuring the voltage across the capacitor. What voltage do you see on the voltmeter? Why?
4. Disconnect the grounding wire from the ground. What happens to the voltage?

Once current can flow in the circuit, the voltage will increase according to Equation 2. To verify this, measure the potential difference across the capacitor, V_c, at different time intervals. This will allow you to plot V_c as a function of time, to see if the measured curve looks like the curve predicted in Equation 2. The voltage sensor will record the voltage across the capacitor. Call out the times at 5 second intervals, and note the values of V_c in the following table. It is essential to make sure that the stopwatch is started at exactly the moment when current begins to flow.

Before you start your measurements, reconnect the grounding wire to ground (to discharge the capacitor). When the person with the stopwatch says "go", remove the grounding wire, and start recording V_c every 5 seconds. Keep collecting data until V_c reaches a steady-state (constant) value. Enter the time points and the measured V_c values in the first two columns of Data Table 1.

5. Repeat the experiment using the 20 μF capacitor. Record your data in Data Table 2.

Data tables follow starting on the next page →

Data Table 1

R: __2.2 x 10^6___ (Ω)   C: ______8 x 10^{-6}_______ (F)
V (battery) :___________(V)
Time Constant _________ (=RC)

Time (sec)	V_c (Volts) measured	V_c (Volts) calculated
0		
5		
10		
15		
20		
25		
30		
35		
40		
45		
50		
55		
60		
65		
70		
75		
80		
85		
90		

Data Table 2

R: __2.2 x 10^6___ (Ω) C: ______20 x 10^{-6}________ (F)
V (battery) :____________(V)
Time Constant __________ (=RC)

Time (sec)	V_c (Volts) measured	V_c (Volts) calculated
0		
5		
10		
15		
20		
25		
30		
35		
40		
45		
50		
55		
60		
65		
70		
75		
80		
85		
90		

Time (sec)	V_c (Volts) measured	V_c (Volts) calculated
95		
100		
105		
110		
115		
120		
125		
130		
135		
140		
145		
150		
155		
160		
165		
170		
175		
180		
185		

Analysis and Questions

1. For each data set, plot your measured data using Excel. Plot time on the x axis and V_c on the y axis.

2. Plot your calculated results using Excel for each data set. Plot time on the x axis and your calculated values of V_c on the y axis. Show this plot overlaid on the plot of the measured data.

3. How does your measured steady-state value (constant voltage) of V_c compare to your calculated value for the 8 μF capacitor? What about for the 20 μF? How do your measured and calculated values compare overall?

4. Calculate the time constant RC for each of the two capacitors, and enter the value at the top of each table. Do the time constants make sense with your data? Explain.

5. How many time points do you need to take before V_c reaches a constant value? A typical rule is that you should record data until t=3RC. Why?

6. For this experiment, what would a plot of Q vs. t look like, where Q is the charge on the capacitor? Draw a sketch by hand. How would this plot be different for the 8 μF vs. the 20 μF capacitor?

7. For this experiment, what would a plot of I vs. t look like, where I is the current in the circuit? Draw a sketch by hand. How would this plot be different for the 8 uF vs. the 20 uF capacitor?

8. List some possible sources of error in your measurements and calculations, and classify them as random or systematic errors.

Experiment 9 ~ Reflection and Refraction

Purpose:

The purpose of this experiment is to investigate two of the basic laws of optics, namely the law of reflection and Snell's law.

Theory:

Reflection and refraction are two commonly observed optical properties of light. Whenever a light strikes the surface of some material at an angle, part of the wave is reflected and part is transmitted (or absorbed). Due to refraction, the velocity of transmitted light is less than the velocity before it entered the medium. The denser the medium, the more the light is slowed down. This is due to interaction between the light and the orbiting electrons in the atoms comprising the material.
The law of reflection is stated in your text. It says that the angle of incidence equals the angle of reflection, as shown in Figure 1.

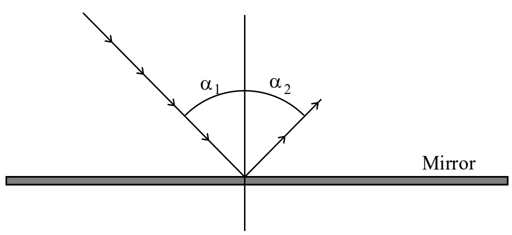


Figure 1

$\alpha_1 = \alpha_2$

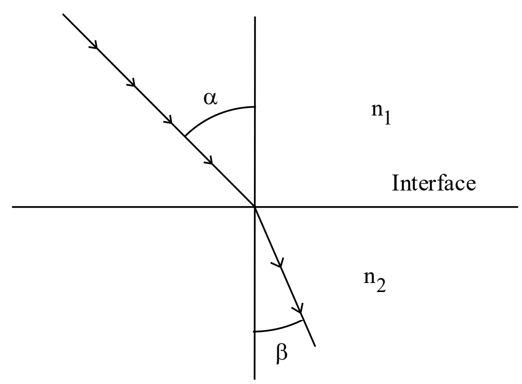


Figure 2

When light travels from one material into another, it not only may change velocity, but it may be bent at a different angle in the new medium than the angle at which it entered (Figure 2). Snell's law states the relationship between the indices of refraction of the two materials, and the light's angle of incidence and angle of refraction:

$$\mathbf{n_1 \sin \alpha = n_2 \sin \beta}$$

Equipment:

- ray box
- semicircular solid block
- semicircular hollow plastic block
- polar graph paper
- tape

Experiment: Part 1

1. Block off all slits on the ray box with masking tape, except for the center slit.
2. Place the solid semicircular block so that it is centered on the polar graph paper with its flat edge facing the ray box. Secure the block to the graph paper with tape so that the flat side lies along the center line (parallel to the short side of the paper). The center of the block should be aligned with the center of the coordinate system.
3. Angles will be measured with respect to the zero degree line on the polar graph paper. Note that all angle measurements will be in the range $0° \leq \theta \leq 90°$.
4. Starting with the light ray at normal incidence (perpendicular) to the flat edge of the block, rotate the graph paper from 0° to 90° in 10° increments, each time recording the angle of reflection and the angle of refraction as the light exits the block through its curved side. Be sure that the light enters the block at the center point. Record your measurements in Table 1. (Note: the amount of reflected light may be very small, so the reflected trace may be very faint. You will need to dim the room lights to record the angle of reflection.)

Table 1

Angle of Incidence α_1	Angle or Reflection α_2	Angle of Refraction β		Index of Refraction n
0°				
10°				
20°				
30°				
40°				
50°				
60°				
70°				
80°				

Average index of refraction: ________________

Part 2:

Starting with the light ray at normal incidence (perpendicular) to the curved edge of the block, rotate the graph paper from 0° to 90°, each time noting the angle of reflection and the angle of refraction as the light exits the block through its flat side. Be sure that the light exits the block at the center point. Find the angle at which the refracted ray totally disappears. This is the angle at which total internal reflection occurs.

Total internal reflection observed at angle: _________________
Calculated critical angle: ___________________

Part 3:

Repeat Part 1 and 2, but using the hollow semicircular block filled with water. Enter your measurements in Table 2. Be careful not to get the graph paper wet!

Table 2

Angle of Incidence α_1	Angle or Reflection α_2	Angle of Refraction β		Index of Refraction n
0°				
10°				
20°				
30°				
40°				
50°				
60°				
70°				
80°				

Average index of refraction: ________________
Total internal reflection observed at angle: _________________
Calculated critical angle: ___________________

Analysis and Questions: Part 1 and Part 2

1. Using Snell's Law, compute the value of the index of refraction of the block. For the refractive index of air, use the value of 1.0. Compute n for the block for each 10° increment from 10 to 80 degrees, and compute the average value. Enter your calculated values in the fourth column of each table.

2. Compare your calculated value of the average index of refraction from Table 1 with the value you obtained in Table 2. Are the values different? Would you expect them to be?

3. Why do you need to make sure that the light enters the block normal to the curved side, and exits the flat side at the center point?

4. In the second orientation of the block (curved edge facing the light box) at what observed angle does the refracted light ray disappear? Is this angle the same for Part 1 of the experiment (air) as for Part 2 (water)? This is the critical angle at which total internal reflection occurs, and is given by the equation $\theta_{critical}=\sin^{-1}(n_2/n_1)$, where n_1 is the index of refraction of the medium the light is leaving (in our experiment, either plastic or water), and n_2 is the index of refraction of the medium the light is entering (in our case, this is air, and you can assume that $n_2=1$). Compute $\theta_{critical}$ using your average values of n in Table 1 and Table 2. How does your calculated value compare with your measured value?

EXPERIMENT 10 ~ DIFFRACTION, WAVELENGTH, AND ATOMIC LINE SPECTRA

Part 1

1.1. Atomic Line Spectra.

In this experiment, we will look at the diffraction of light, and how wavelengths can be calculated from diffraction. We'll also look at atomic line spectra, which actually relate to the quantum-mechanical energy levels that electrons occupy around the nucleus of an atom; the wavelengths of emitted light from an atom relates to these energy levels. The wavelengths of the emission lines in the spectrum are given by the Rydberg formula:

$$\frac{1}{\lambda} = RZ^2\left(\frac{1}{n^2{}_{final}} - \frac{1}{n^2{}_{initial}}\right)$$

where R=1.097 x 10^7 m^{-1}, Z is the atomic number of the atom, n_{final} is the principal quantum number of the final (lowest) energy state of the electron, and $n_{initial}$ is the principal quantum number of the initial (highest) energy level of the electron. For various values of n_{final}, different "series" of spectral lines occur. Specifically, for hydrogen, n_{final} =1, 2, 3, 4 gives the Lyman, Balmer, Paschen and Brackett series, respectively. The energy of a photon is related to the corresponding wavelength of light as follows $E=hf=h(c/\lambda)$.

The shortest wavelengths of light emitted correspond to the greatest loss of energy and occur when the electron falls the greatest possible number of energy levels. This will happen when the initial energy level is the highest one possible, or $n_{initial} = \infty$. The longest wavelengths of light emitted corresponds to the smallest loss of energy and occur when the electron falls the least possible number of energy levels. This will happen when the initial energy level is just one principal quantum number above the final level.

1.2 Atomic Transitions: The Demonstration

For this part of the lab, the TA will show you various gas tubes. Each tube contains a different element that, after being excited by running high voltage through it, will emit different spectral lines, which you can view through the diffraction gratings. This happens because the high voltage makes the electrons in the gas jump up to higher energy levels; light is emitted when the electrons "fall" back down again, emitting photons as they fall.

Your task is to draw the lines you see in the demo in the boxes in Table 1, at the locations where they are observed. Once you have been shown all the gas tubes and sketched the spectra you observe, compare your drawing to the diagrams provided in order to identify which element was in each tube element in each tube. Remember that 400 nm is UV light, and 700 nm is infrared.

NOTE: Since this part of the experiment, as well as part 3, involve very high voltages, it is VERY important not to change the tubes yourself; let the TA do it. Also, don't touch any of the light bulbs with your fingers – you can damage them, and you can burn yourself – the tubes get hot enough to fry an egg.

Table 1

	400 nm 700 nm	
Gas		Element: ________
Gas		Element: ________
Gas		Element: ________
Gas		Element: ________

Analysis and Questions

1. Calculate the longest and shortest wavelengths for the hydrogen Lyman transitions.

2. Calculate the longest and shortest wavelengths for the hydrogen Balmer transitions.

3. Calculate the longest and shortest wavelengths for the hydrogen Paschen transitions.

4. Based on your calculations for questions 1-3, which series (Lyman, Balmer or Paschen) are you observing when you looked at the visible part of the spectrum for atomic hydrogen in Part 1 of the experiment? EXPLAIN!

APPENDIX A: EXCEL, THE BASICS!

Note: This tutorial was originally written for Excel 2003. There are a few additional instructions for the Excel 2007 and later versions. As it does not fit all versions of Excel, see the Excel help files or ask a lab instructor if you need additional help.

We are going to walk through a few steps to practice (or learn) some important features in Excel. We are going to:

- define some Excel terminology
- learn how to enter data into a spreadsheet
- learn how to calculate mean and standard deviation from the data
- learn how to enter equations into a spreadsheet
- learn how to graph the data in the spreadsheet
- learn how to analyze the data based on the graph

First, the terminology:

When you create a new spread sheet in Excel, a page will show up with a grid on it. To the left of the grid, there are numbers designating which rows and to the top of the grid, there are capitol letters designating columns. Each box is referred to as a 'Cell' and we will consider the upper left cell to be the home cell. So, if you move 4 cells down and 3 cells to the right you would be in cell D5. Cell designations will be important when using equations.

Entering data:

The first task will be to type in some information. All you have to do for this is select a cell and start typing! A good thing to do first is to set up column headers. Simply go to cell 'A1' and type 'L1', cell 'B1' and type 'L2', cell ‘C1’ and type L2-L1. You can move between cells either by clicking on the new cell where you want to enter information, or by hitting the tab key or up/down/left/right arrows.

Now it is time to enter some data. Type your measurements of l_1 into one column, and l_2 into the next column.

Now, we want to calculate the difference between the two measurements, in order to calculate the length. Excel will do this for you! Select cell C2. Type the following:

=B2-A2

Notice that as you type “B2”, cell B2 is highlighted, and as you type “A2”, cell “A2” is highlighted! Also notice that as you type in the cell, the equation appears in the formula bar at the top. Now, hit enter, and the difference between the values in cells B2 and A2 will appear…in cell C2!

Now, you want to calculate the difference for each of your pairs of measurements. You could repeat the method we just described, for every row of your data, a very tedious method, but Excel does have way to speed up this process. The first step to unlock this secret is to select cell

C2. Then hit "control C" on the keyboard to select this cell. (You are actually selecting the equation associated with the cell.) Now select cells C2 through C10 (or however many rows of data you have), and hit "control V" on the keyboard. You have just pasted the equation into all the rows! Each cell in column C now contains the difference between the corresponding rows in column B and column A!

What about calculating the average (mean) and standard deviation? Do this by hand, with your calculator (you can do that at home). It is annoying and tedious, but we want you to do it … just this once. The easier way is with Excel, of course. Suppose you want to put the average value of your measured lengths in cell C11 (or whatever is your first empty cell in column C). Select this cell. Now type this:

=AVERAGE(C2:C10)

and hit Enter. The average (mean) of cells C2 through C10 will appear in cell C11! (Another trick: instead of typing "C2:C10", you can select cells C2 through C10, and the cell numbers will automatically appear in your equation!)

What about the standard deviation? Select the cell where you want the standard deviation to appear. Go up to the formula bar, and type:

=STDEV(C2:C10)

Now hit Enter, and the standard deviation of the numbers in cells C2 through C10 will appear!

You may want to set up your data tables so that they display the correct number of significant digits. To do this, select the cells you want to change. Right click on the selection, and choose 'Format Cells'. Under the 'Number' tab, choose 'number', and choose the number of decimal places you want to keep.

Also, you can set up your table with borders. Again, select all the cells you want to put a border around. Right click in the selection, and choose the 'border' tab. Click the 'outline' and and 'inside' buttons, then ok.

Practice Creating a Graph (Using Pretend Data):

Now, let's do something a bit more complicated. Let's enter some "pretend" data. Suppose a ball is rolling down an inclined plane. You measure its position at various different time points. Suppose you measure time from 0 seconds to 50 seconds, in increments of 1 second. Let's enter that data in column D. First, set up column headers. Go to cell D1 and enter "Time". Go to cell E1 and enter "Position". Go to cell F1 and enter "Velocity". Go to cell G1 and enter "Acceleration".

There are 2 ways to enter the time data. The obvious one would be to go to cell 'D2' and type 0, then cell 'D3' and type 1, etc… Again, a very tedious method, especially at the end of a long day when you want to go home! Again, Excel does have way to speed up things up. Enter 0 in 'D2' and 1 in 'D3'. Next highlight cells 'D2' and 'D3' (do this by clicking on one cell and dragging over to the other). Once you have selected the two cells, let go of the mouse buttons. You will notice in the lower right corner of cell 'B4' there is a small black square. Move the mouse over this square and you will notice that your cursor changes from a white thick plus sign to a black thin plus sign. Once the cursor changes to this black plus sign you can click and drag straight down about 50 cells. You should notice to the right of the mouse a box with a number in it appears. This number represents the value that Excel will enter into the cell for you. When you see that number reach 50, you can let go of the mouse and, like magic, all the cells will be filled with the values you would have otherwise had to type in yourself. This process is known as **autofilling**.

Now, let's work with an equation. Just like what we did for the length data before, to enter an equation, you simply have to choose a cell and hit the '=' key. This tells Excel that you want to use an equation in that cell. The equation you are typing will appear in the function bar as you type it in the cell.

Go to cell 'E2' and hit the '=' key. After the '=' you are free to enter any equation into the cell. For our purposes, we will use the equation "-.1*t^2+4*t", where '^' designates the use of a power. This equation may seem strange, but you will see it in class in a few days. It shows **how position changes as a function of time for something that is moving at a constant acceleration**. Since our times are in column D, the equation we need, in terms that Excel will understand, is

=-0.1*D2^2+4*D2

Now hit Enter, and a number will appear in cell E2. Excel has taken the value in cell 'D2' and entered it into your equation. Does the value that showed up make sense? Check it with a calculator.

Now that you have your equation, you can manually type it into each cell or you can use the method for autofilling described before. The only difference is that this time you will not select multiple cells. The reason you selected multiple cells in the previous step was so that Excel could **determine the pattern of the values you wanted**. This time, you have an equation in cell E2, which *already* specifies a pattern. Simply click on the cell with the equation, move the mouse over to the lower right corner and click and drag until you will fill all the cells you have times for.

Do the same thing in column F (velocity) with the equation starting with '=-.2*D2+4' in cell 'F2', and autofill the data into the rest of the columns.

Do the same thing in column G (acceleration) with the equation starting with '=-.2' in cell 'G2' and autofill the data into the rest of the columns.

The 'manual' method of making a scatter plot of data (Vista version):

First, select any blank cell on the Excel spreadsheet to which you want to add a graph. Next, select the "Insert" tab near the top left of the Excel window. A row of new options will appear just below the tabs row. Near the middle of the row of options, you'll see a box labeled "Scatter". Select this and a drop down menu should appear with various scatter graph options. Select the "Scatter with only Markers" option (The options aren't labeled by name, but the associated picture looks like graphed polka dots. You can check the option by scrolling over the pictures and letting your mouse cursor sit for a second or two). After selecting the desired plot, a blank rectangle will pop up over some of your Excel worksheet, and a new row of options will appear just below the row of tabs.

The blank rectangle will house your plot, but to do so you'll need to first select your data. Select from the options row, "Select Data". A pop-up window "Select Data Source" will appear. Under the section labeled "Legend Entries (Series)" you'll have the choice to "Add", "Edit", "Remove", and two series ordering buttons (up and down arrows). Since no data was selected before opening "Select Data", no series will appear under "Legend Entries (Series)" (this is how the 'manual' method contrasts to the 'automatic' method).

To add a data series, select the "Add" button. A new pop-up window will appear, "Edit Series". Here, you can label your series by clicking in the blank space under "Series name:". Now you can enter what data you want to plot along your x axis and what data you want along your y axis. Your y values should always be your **dependent** variable while your x values should be the **independent** variable. In our case, time is the independent variable. Position, velocity, etc. are CALCULATED FROM TIME, and therefore they are dependent variables ("dependent" on time).

To choose the time column as the for the x axis, select the white space under "**Series X values**:". After clicking in the white box, you need to select the data from your spreadsheet. Simply click on the first value you want plotted and drag down to the last (select all 50 of your time values). When you let go of the mouse button the appropriate code will be entered into the box for you. (Excel won't know what to do if you select multiple rows or columns, so it may fuss at you). Once your desired row OR column is selected, you'll notice that the white space under "Series X values:" is filled in. Next do the same procedure for the box next to **'Y Values:'** To do so, select the white space under "Series Y values:". Delete{1} from this space. Now, you may click and drag over a row OR column on your worksheet which you want to plot along the y-axis, for example, position data. The white space under "series Y values:" will be filled in after you've made your selection, which SHOULD mean you are done selecting some data. Click the "OK" button on the "Edit Series" pop-up window to return to the "Select Data Source" window. Notice that the series you just selected from the worksheet is now under "Legend Entries (Series)".

We now want to add more series to the graph, one for time vs. velocity, and another for time vs. acceleration. To do this simply, **right-click on the chart and select 'Source Data' from the menu.** This will bring up the window we saw in the previous steps. You can rename or select alternative data for a series you have created by selecting your series first and then selecting "Edit". *Make sure you are on the series tab.* Next add a new series and follow the same procedure to add the next columns. Your graph should end up with 3 series on it (i.e., 3 data plots). **An example of what the graph should look like is shown on the following page.**

The 'automatic' method of making a scatter plot of data (2007 version):

First, make sure the cell above each column of data is labeled (for example: above time values, make the cell just above the time data cells say "Time (*you insert appropriate units here*)". Then, with your x-axis values on the left side of your data table (this should be the time values for this example 'experiment'), select ALL columns of data you'd like to plot. The rows to the right of the time column should be position, velocity, and acceleration for this example. Now, while this data table is selected, click the "Insert" tab from near the top left corner of the Excel window. Look for the "Scatter" button near the middle of the row of options. Then select the polka dots of data picture which should represent "Scatter with only Markers". Once you have selected this plot type, a graph should appear over your worksheet with your data series automatically plotted. And that's it besides adding a label for your x-axis and a plot title.

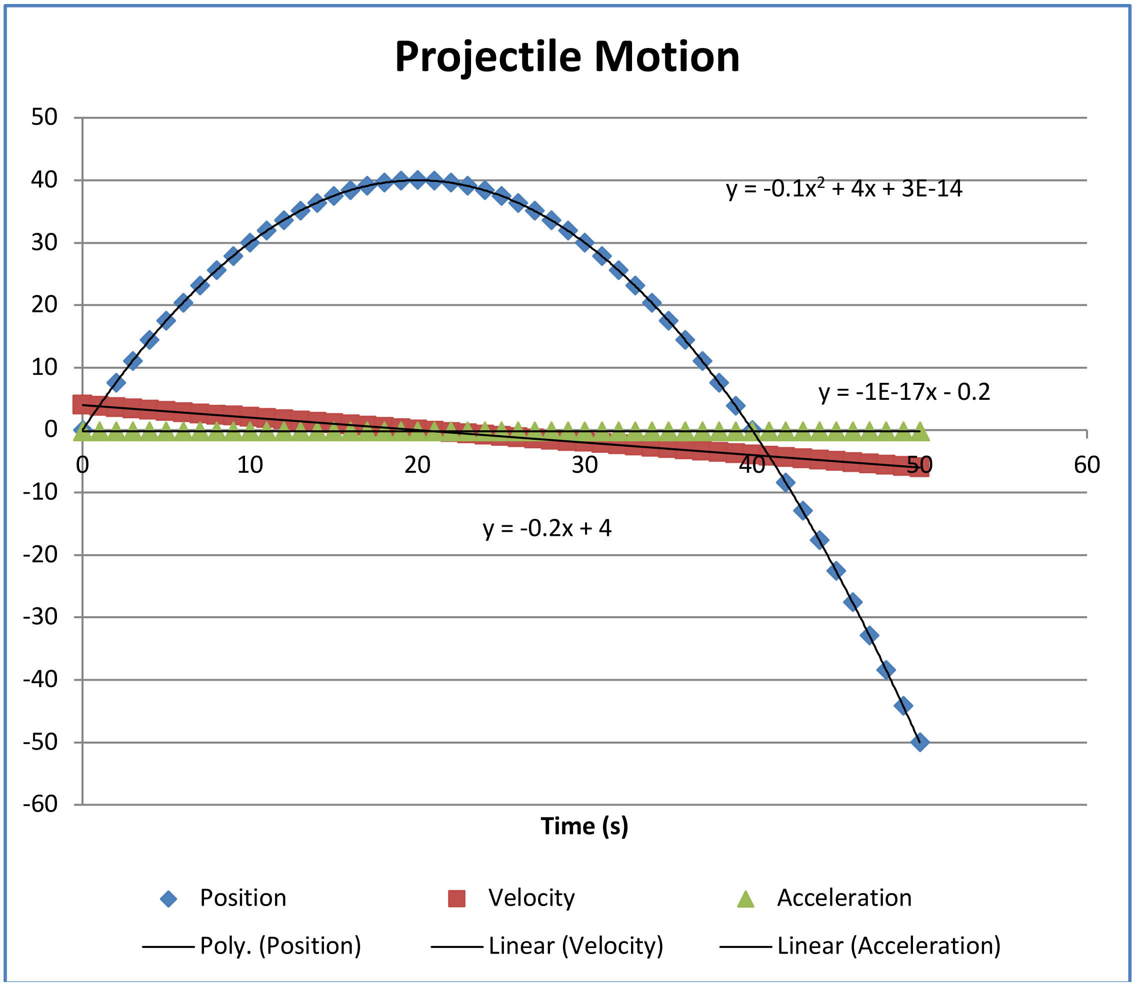
To add axis labels and a chart title (2007 Version):

First select your graph by clicking somewhere in the white space around the legend. Next, select the “Layout” tab. Near the mid left of the options row, the “Chart Title” option will allow you to input a chart title, and the “Axis Titles” option will allow you to input horizontal and vertical axis titles. Once you’ve selected your desired title(s), you can edit them by clicking on them in your graph.

Our final task, before you get to go home, is to add **trendlines** to the data. Trendlines are useful because they allow us to figure out an equation for data if we do not already know it.

To add a trendline, **right-click on any one of the data points** from the data set you want to add a trendline to. To add a trendline to the position data, right-click on any one of the position data points and a drop-down menu should appear. Select **'Add Trendline'** from the list and a dialog box will appear. The screen that comes up should have a number of boxes with different types of equations you can fit to the data. Depending on which series you clicked on you will have to select the correct type of equation to fit to the data (parabola for position, straight line for velocity and acceleration). Once you have made this selection, click on the '**Options'** tab at the top. Check the box next to **'Display equation on chart'** so that you can actually see the equation Excel used to make the trendline. Click “ok”, and your graph should now have a trendline on it with a handy equation.

One more trick you can use is to add error bars to your data. To do this, click on any point in the data set you are interested in. Go to the Format menu, and click “Selected Data Series”. A menu will appear where you can select the error bars you want to add. This way you can plot data points and show their standard deviation on the same plot. Your plots should look something like the following graph:


Projectile Motion
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0
10
20
30
40
50
60
y = -0.1x² + 4x + 3E-14
y = -1E-17x - 0.2
y = -0.2x + 4
Time (s)
Position
Velocity
Acceleration
Poly. (Position)
Linear (Velocity)
Linear (Acceleration)

APPENDIX B: DATASTUDIO INSTRUCTIONS

General Procedure:

- Turn on computer and log in
- Plug in sensor
- Go to **http://www.umsl.edu/~physics/lab**
- Download DataStudio file to desktop (make sure to save as .ds file)
- To begin/end data taking click Start/Stop button

If data is already present:

- Go to Experiment
- Click Delete Last Data Run

To get statistics on data:

- Highlight data you are interested in
- Click ∑ button and select type of statistics you need

To Create a New Activity:

- Open DataStudio – located in All Programs-Education-DataStudio
- Click "New Activity"

Graphs:

- Add types of graphs you desire
- Clicking "Scale to Fit" gives a nice graph
- To zoom in and out, place the cursor on the number on the graph until a squiggle with two arrows on either side appears, then left click and hold, moving cursor will Zoom
- Axis can be moved by grabbing zero axis with cursor (a hand will appear) and moving cursor.

To fit a curve to your data:

- Click "Fit" – select type
- Highlight data to be fit

To go from Graph format to Table format:

- In top sidebar click on the run and drag down to lower side table

Import/Export data:

Export:

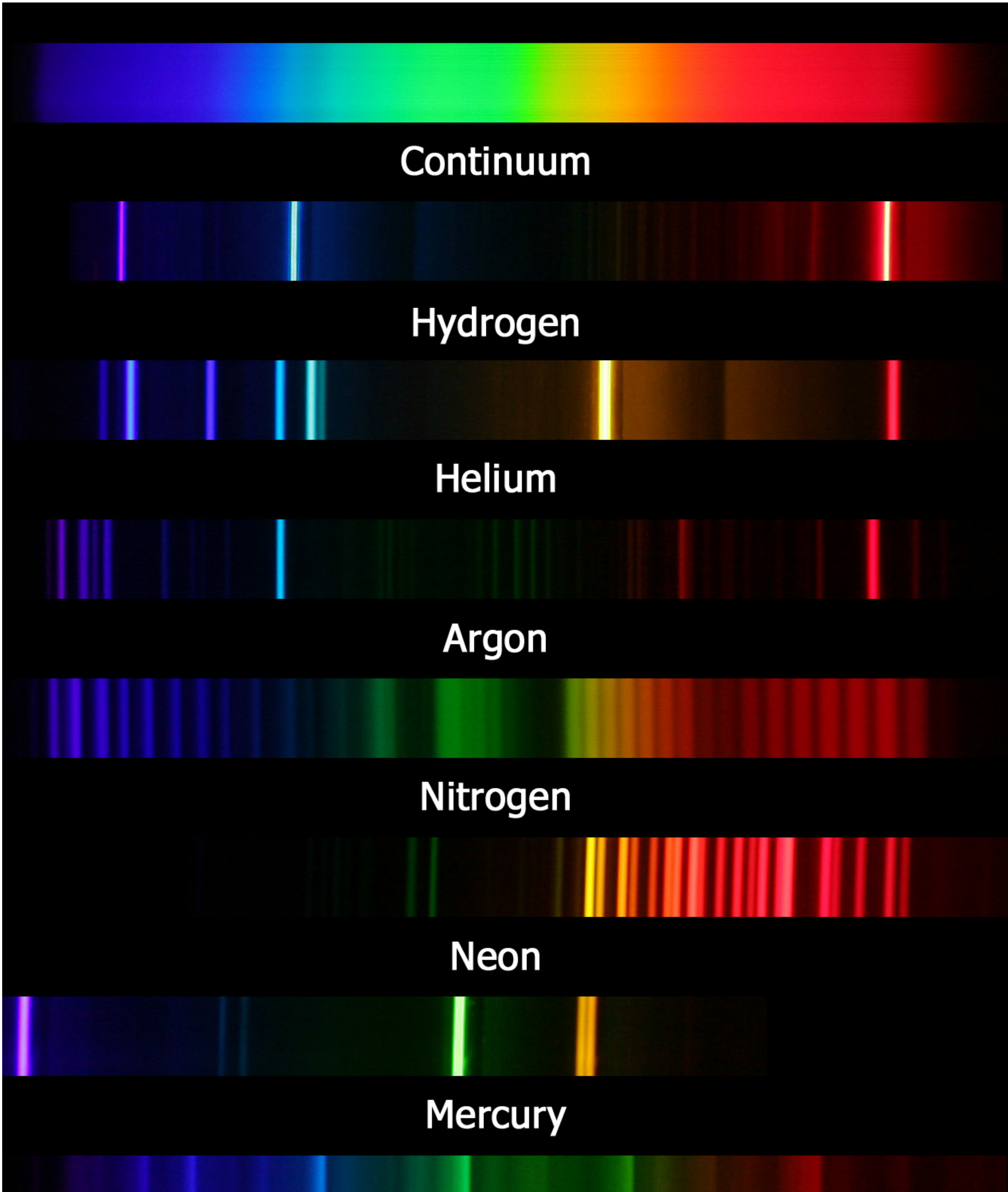
- Go to File
- Click "Export Data"
- Choose "Run"
- Save to desktop as .txt file

Import:

- Open DataStudio
- Click “Enter Data”
- Click “Import Data”
- Select data to be imported

<u>MISC. Details:</u>

- Clicking “Summary” button will give you view of all open windows
- To delete data, highlight data and hit delete


Continuum
Hydrogen
Helium
Argon
Nitrogen
Neon
Mercury