The directions for each experiment are in this booklet. At the start of each lab class, you will also receive an answer sheet to fill out as you do the experiment. Work in pencil so you can erase mistakes. The report you hand in for each experiment is to consist of (1) the completed answer sheet, and (2) a discussion of the experiment, as described below.

For each lab, write a report that would clearly explain the experiment to someone had not done it, but has a knowledge of physics. I will be particularly looking for you to explain how the apparatus works. (I want to be sure you understand that.) The discussion should have the following format:

1) Objective (What you were trying to do.)
2) Apparatus and Procedure (How you did it.)
3) Conclusion (Whether it turned out as expected.)

In the apparatus and procedure section, explain the <u>basic idea</u> as clearly and simply as possible. (Not necessarily all in words; a sketch of the apparatus might be good sometimes.) Again, think of the report being read by someone who wasn't here but knows some physics. You need not repeat what this reader could see by turning the page to the answer sheet. Rather, explain where the numbers on the answer sheet came from and what you did with them. Try to avoid minute detail which distracts from your main points. You are explaining the basic idea, not providing step-by-step instructions. Just explain what was going on, and tie together the other pages you have attached.

Good Example:

Report on Experiment 1C: Acceleration due to Gravity
(Your Name)

The purpose of this experiment was to verify that a freely falling object accelerates at 9.8 m/s^2. One of us dropped a golf ball from near the ceiling. As it fell, its position was periodically recorded by a motion sensor that was on the floor. This sensor works by sending out pulses of sound and timing how long it takes the echoes to return. The sensor was connected to a computer which calculated velocities from the position data, and plotted a graph of velocity versus time.

The acceleration is this graph's slope. The result agrees with the accepted value within our level of uncertainty.

Bad Example:

Report on Experiment 1C: Acceleration due to Gravity
(Your Name)

We connected the interface to the computer with the USB cable. We then connected the motion sensor to the digital inputs on the interface: Yellow to channel 1 and black to channel 2. After turning both the computer and the interface on, (the button at the upper left of the interface should turn blue) we opened PASCO Capstone on the computer. Next, we clicked Hardware Setup at the upper left then clicked the yellow circle by Input 1 on the picture and then click Motion Sensor II. The motion sensor was placed on the floor, aimed upward, somewhat to the side of where the ball would land… (Imagine about two more pages of that.)

Not only does that take longer to write, but it's very easy, in all of that, to never actually get to the point. Don't bore or confuse your reader with a vast amount of trivial detail, even though that might be what took most of your time and attention.

Bad Example:

The purpose was to verify that a freely falling object accelerates at 9.8 m/s^2. We took the apparatus and made the measurements described in the instructions. The measured and calculated values did agree with other.

Your report should stand on its own. Your hypothetical reader does not have the lab manual and could not possibly picture the experiment based on just what you wrote.

Some people like to write the discussion ahead of time so they can get out of the lab sooner. Others feel they can explain the experiment better after they've done it. That's your choice. Also:

- Don't simply copy what your partner wrote or what the instructions say. Similarly, do not copy calculations. Everyone should do the calculations so that everyone understands how, and so you can check each other for mistakes. If everyone in your group has the same arithmetic error, or wrote identical discussions, expect verbal abuse from the instructor.

- A maximum of four students is allowed in each lab group. Except for a few experiments where it's necessary, if your paper is one of more than four with the same data, I'll send you back to do it over. (If yours isn't working, don't use your neighbor's data.)

PHYSICS LABORATORY SAFETY GUIDELINES
Genesee Community College

Although the most dangerous thing you will do for this course is ride in a car to get here, there are hazards involved with working in the physics lab. These will be pointed out as they come up, in the written instructions for each experiment.

It is the student's responsibility to**:**

1. Read the current exercise before coming into the laboratory to be aware of any cautions or warnings. This also helps avoid confusion and wasting time during the lab period. It is your responsibility to be aware of these warnings, to understand them and to take them seriously. Ask the instructor for clarification if necessary.

2. Pay attention to and understand any additional instructions the instructor may give verbally while the experiment is in progress.

3. Inform the instructor if you have a medical condition that could affect your ability to perform laboratory exercises. Reasonable accommodations will be provided.

4. Notify your instructor of any broken glassware so he/she can dispose of it properly. Do not pick up broken glass with your hands. Do not throw broken glass into the wastebaskets.

5. Report all injuries to your instructor regardless of how trivial they may seem.

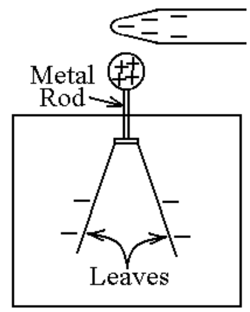
6. Ask, if it is unclear what you should do. On rare occasions, a student may find a novel way of causing injury that was not anticipated in the directions. Have the instructor help you to not be that student.

Experiment 1: Electrostatics

There are only enough part 2 setups for half of the class. If there is a Coulomb's law balance at your table, do part 2 first so it will be free by the time another group wants it.

Part I: Electric charge.

Normally, you will need to write a discussion of the experiment, as described on the lab book's opening page. However, for part I of today's lab, the discussion has been integrated into the answer sheet. Write up part II as usual.



An electroscope is a device used to detect the presence of electric charge. The type used in this experiment consists of two lightweight metal leaves hung from a metal rod with a metal ball on top. The leaves are in a transparent box which protects them from air currents. In the example shown, a negative rod is held near the top of the rod. Since like charges repel, free electrons in the metal are driven out of the ball, down into the leaves. This makes the leaves repel each other, since they have like charges. So, the presence of charge is indicated by seeing the leaves spread away from each other.

A. Charging by friction, and charging by contact. Transferring electrons by rubbing is called charging by friction. You will use this method to charge an insulating rod. Charging an object by touching it to another charged object is called charging by contact. Once you have the rod charged, you will charge the electroscope by touching it. Follow the answer sheet for details of what to do.

B. By chemical reactions. Now you will detect charge with a digital voltmeter instead of an electroscope. Turn its dial into the "DCV" range, to a scale that will read thousandths of a volt.

"DCV" stands for DC volts. For example, pointing the dial at 2 in the area marked DCV turns the meter into a DC voltmeter which reads from 0 to 2 V. If the meter has more than two connectors, you always put one wire in COM, which is negative. Where you put the other wire depends on whether you use the meter to measure volts, amps, or milliamps; the sockets are labeled.

Put a piece of copper, folded up aluminum foil, and enough vinegar to cover them in a beaker. Don't let the foil and copper touch. How the metals react with the acid moves electrons from one metal to the other, making a crude battery. Use your voltmeter to measure the potential difference between the two metals, and to determine which is positive. If the reading is not perfectly steady, just record a typical value.

Part II - Coulomb's Law

Verify that the force between two charges varies as the inverse square of their separation.

APPARATUS: Two balls are charged by touching them to the 5000 V output of a power supply. One ball is mounted on a movable base. The second one is on a plastic rod which sticks out horizontally from a thin vertical wire. Bringing the first ball near the second pushes the second one away. Twisting the wire by turning a dial counterbalances the electric force, bringing the second ball back where it started. You observe the force by how much the wire on this "torsion balance" must be twisted. This force is plotted against the separation of the balls, r, on log-log graph paper. The slope of this plot is equal to n in r^n; that is, the slope is the power r is being raised to. This is compared to what appears in Coulomb's law.

PROCEDURE:

1. Air currents make it hard to get steady readings. They may be somewhat stronger near the center of the room; it won't hurt to have the apparatus near the wall. (But a couple of feet from the wall in case there is charge on it.) Also try to minimize the effect of you moving or breathing.

2. Wires.

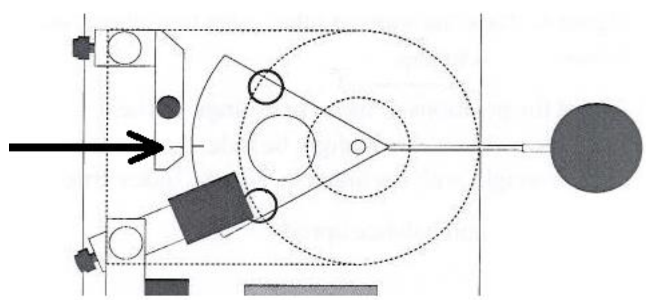
a. Connect the black 0V socket on the power supply to the body of the apparatus. Clipping to the thin piece of metal at the bottom of the torsion wire works well.

b. The red probe should be plugged into the red +5 kV socket.

CAUTION: Do not touch the metal tip of the probe or allow it to touch a ground such as the body of the apparatus. The current is limited to non-lethal values, but it could shock you.

3. If the balance is locked up, loosen the screw pinching the back of the pendulum assembly and turn the arm containing the screw a little so it does not overlap the back of the pendulum.

Check the zero: Put the dial at zero. Put the sliding ball at its maximum distance. The mark on the back of the pendulum assembly should line up with the mark on the arm next to it as shown here. If it does not, slightly rotate the black plastic retainer at the bottom of the torsion wire around a vertical axis. Do NOT turn the screw in the retainer, which would release it from the wire.



4. Turn on the power supply. (Do not touch any metal part of the probe.) Set it for 5 kV. Slide the ball to r = 15 cm on the scale next to its track. Touch one ball then the other with the probe to charge them. It disturbs the balance least if you touch the top or bottom of the one on the wire. Turn the dial, twisting the wire, until the marks line up.

- If doing this on a typical winter day, charge the balls just once at the start of the experiment.
- In warm weather, higher humidity can mean charge slowly leaks off of the balls. To have the same charge for each trial in summer, touch both balls with the 5 kV probe after you think you have adjusted the dial, last thing before recording each reading.

Instead of measuring force in newtons or pounds, it's convenient to make up our own force unit, the amount needed to twist the wire by one unit on the dial.

5. Slide the ball to each of the other distances in the data table and repeat. Recharge the balls last thing before recording each force. (Farther out than 15 cm, the force gets too small. Farther in than 6 cm, the charge on the balls gets too polarized, causing attraction.)

CALCULATIONS & ANALYSIS:

If the q_1 and q_2 remain constant, Coulomb's law reduces to $F = \underbrace{\frac{1}{4\pi\varepsilon_0} q_1 q_2}_{a} \frac{1}{r^2} = ar^{-2}$. Your objective is to measure n in $F = ar^n$ to see if it comes out –2. Notice that if you plot log F as a function of log r, $F = ar^n$ is a straight line whose slope is n:

Take the log of both sides: $\log F = \log (ar^n)$

The log of a product is the sum of the logs: $\log F = \log a + \log r^n$

Since $\log r^n = n \log r$, $\underbrace{\log F}_{y} = \underbrace{n}_{m} \underbrace{\log r}_{x} + \underbrace{\log a}_{b}$

So, you will plot this graph and determine its slope. If Coulomb's law is wrong, the graph will not be a straight line, or its slope will not be –2.

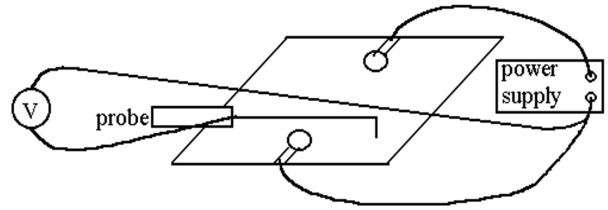
1. Graph the data on the log-log graph paper provided. Don't calculate any logs; the graph paper does the logs for you. Draw what appears to be a best fit line through your data.

2. Find its slope, measuring the rise and run <u>with a ruler</u>, not from your data or the scale of the graph. Measuring the logarithmic graph with the linear ruler is what takes the logs of F and r. Indicate which points on the line you measured between.

3. Round n to the nearest integer - it's only good to one significant figure. In your conclusion, state whether your result agrees with Coulomb's.

Experiment 2: Field Mapping/ Capacitors

Part 1 - Electric Field Mapping



BACKGROUND: A DC power supply charges two electrodes printed on a sheet which is coated with a poor electrical conductor. The current through this coating is large enough to give a voltmeter something to measure, but small enough that conditions are approximately static. You will use the voltmeter to find several curves of constant potential. The direction of the field vector, $\vec{E}$, is perpendicular to these equipotentials. So, you will sketch field lines by drawing them perpendicular to the equipotentials.

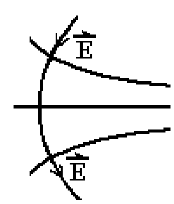
PROCEDURE:

1. Hook up two wires, one from each electrode on the sheet, to the DC terminals of a power supply. (Red and black.) Hook up two more wires: One from minus on the digital voltmeter to minus on the power supply, and one from plus on the meter to the probe. (The thing with the black handle.)

2. Start with the power supply turned all the way down (knob fully counterclockwise) because its maximum output can damage the sheet. With the probe touching the sheet's positive electrode, turn up the power supply until the meter reads 6.0 V.

3. Move the probe around the sheet to find points where the potential is 1.0 V. Plot enough on the answer sheet to accurately sketch a curve of constant potential all the way across the picture. (Maybe 2 or 3 cm apart; closer where the curve bends sharply.)

4 Repeat, obtaining equipotentials at 2, 3, 4 and 5 V.



5. Draw in some approximate lines of force by sketching smooth curves that cross all equipotentials at right angles. The edges of the printed electrodes are your equipotentials for 0 V and 6 V. Include arrowheads, and label which are the positive and negative electrodes. Draw enough to show the field in all areas of the picture.

(Comparing to a gravitational field, equipotentials would be like lines of constant elevation on a map: 100 feet above sea level, 200 ft, 300 ft and so on. Field lines point in the direction water would flow – the direction where the potential changes fastest.)

All you did was draw a picture, so there is no conclusion. Just describe the apparatus and procedure.

Part 2 – Parallel Plate Capacitors

Two parallel plate capacitors are known to have the same voltage between their plates. The plates are twice as far apart in one capacitor as in the other. You will predict how the capacitors' charge is affected by the distance, then take measurements to see if you are right.

Theory: Combine the formula for the capacitance of parallel plates with the formula that defines capacitance in general to obtain an expression relating charge to the distance between the plates. According to this, what should doubling the distance (at the same voltage) do to the amount of charge stored?

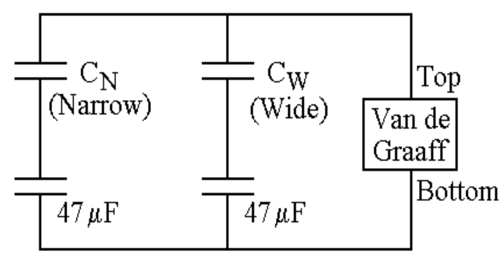
Experiment: Since the capacitance of the parallel plates is small, a large voltage is needed to deposit much charge. Therefore, a Van de Graaff static generator capable of producing around 100 000 V will be used. This is much too high for a normal voltmeter to measure, so a 47 μF capacitor will be placed in series with each set of plates because the voltage across that will be measurable. Knowing C and V gives q on the 47 μF from C = q/V. q on the parallel plates is the same as on the 47 μF because capacitors in series have the same charge. Having determined q in this way, you compare it to the distance between the plates.

Cautions: Although its voltage is quite high, the Van de Graaff can only throw a small amount of charge through you, so it is not normally dangerous. However,

1. Anyone with a pacemaker should keep back from it.

2. Electronic devices such as computers, cell phones or calculators should be at least a meter away, due to the sensitivity of miniaturized parts to sparks. (If you follow the directions, sparks are only possible between the capacitor plates. But in case you don't, keep those things back.)

3. A shock from the Van de Graaff is not otherwise dangerous, but it's unpleasant, so avoid it.

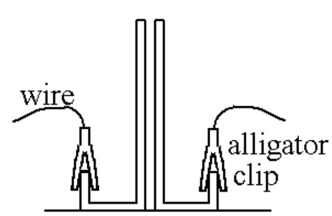


Van de Graaffs with blue base are (–) on top. All others are (+) on top.

Get two identical capacitors around 47 μF, and connect this circuit. A wire goes from the top of the Van de Graaff to one plate of C_W. Another wire goes from the other plate of C_W to the 47 μF. And a third wire goes from the other side of the 47 μF to the bottom of the Van de Graaff. Likewise, use three more wires to make the other path from the top to the bottom of the Van de Graaff, through the other two capacitors.

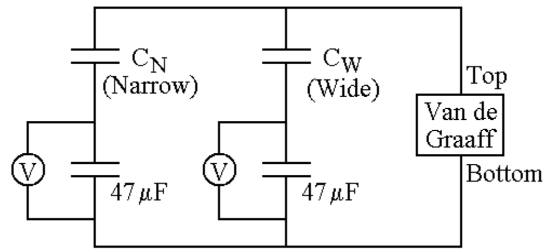
- For the top connection, lift the dome off the Van de Graaff, and attach an alligator clip to the dome's support or clip to a paperclip taped to the dome. For the bottom, the blue ones have a ground connector on top of the base, the green ones have a grounding tag near the power cord, just clip to the metal base on a gray one.

- C_N and C_W are parallel-plate capacitors you will make out of metal plates which stand on the counter. To start with, put each pair of plates a few millimeters apart without touching. Don't worry about exactly how far - it's not going to work at this point anyhow.)



- You must observe correct + and – polarity with the 47 μF capacitors.

Once all of that is done, put two wires on each meter, and run those to opposite sides of the 47 μF capacitors. Set the meters to a scale which will read thousandths of a DC volt.



Notice that both C_N and C_W will have essentially the same voltage across them, as you assumed under "theory." Both have one plate connected to the top of the Van de Graaff, and, with only a fraction of a volt across the 47 μF capacitors, both have the other plate pretty much at the potential of the bottom of the Van de Graaff.

Have the instructor approve your wiring, then try to charge the capacitors by running the Van de Graaff. Turn it off. Describe what happened.

Touch the ends of a wire to the parallel plates, one end to each plate, to discharge them. If you leave them charged, there could be a nasty surprise if you touch them.

A dielectric between the capacitor plates will solve the problem. Old transparencies work pretty well. Put one sheet between the plates of C_N and two sheets in C_W.

Both meters should read zero when you start. If not, discharge both the parallel plate capacitors and the 47μF capacitors through a wire until they do.

Run the Van de Graaff until the meters read something like a tenth of a volt. If you go higher than a few tenths, a spark may jump between the parallel plates and you will have to start over.

As soon as you turn off the Van de Graaff, the readings begin to slowly drop, as the capacitors discharge through the voltmeters. Take your readings immediately after turning off the Van de Graaff, at the same time.

Calculations: Ccalculate the charge on each 47μF capacitor from the measured voltages. As will soon be covered in class, capacitors in series have the same charge so these numbers are also the charges on the parallel plate capacitors.

Conclusion: How do the charges you determined compare to your prediction?

Experiment 3: Ohm's Law; Electric Power.

How to use the digital meters:

You have already used these for DC volts. Turn the dial to "A" or "mA" to get amps or milliamps. If the meter has more than two connectors, you always put one wire in COM, which is negative. Where you put the other wire depends on whether you use the meter to measure volts, amps, or milliamps; the sockets are labeled. On the yellow meters, notice that the dial goes in the same place for the 10 A scale and for the 20 mA scale; which you are using depends on which socket the + wire is in.

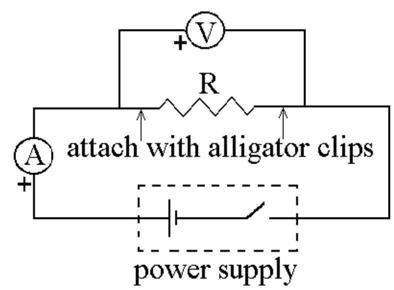
We usually don't get through this lab without blowing the fuse in a meter because someone hooked it up wrong. Voltmeters go in **parallel**, ammeters in **series**. Start with the least sensitive scale (such as 0 to 10 A), then change scales (such as milliamps) once you know the approximate reading.

Don't take circuits apart until the instructor says you don't need to double-check anything.

Part 1: Ohm's Law.

In part a, a resistor is connected to a DC power supply and some meters. (The resistor has a coiled up piece of fine wire inside; a more common type contains graphite.) Different voltages are applied to it by adjusting the power supply, and the resulting current is observed. You then see if the results are consistent with Ohm's law. In part b, this is repeated using a light bulb as the resistor.

Part 1a, Resistor:



Select a resistor of 100 to 1000 Ω. Connect a circuit as shown. (R is the resistor, V is the voltmeter, and A is the ammeter.) Start with the ammeter reading amps, not milliamps; switch to milliamps if it turns out that the current is small enough.

As you try to follow the diagram, it may be helpful to follow the path of the current: (Almost no current goes through the voltmeter since its resistance is very high, so ignore that for now.) The current leaves the + (red) terminal of the power supply, and travels to the + connector on the ammeter. So run a wire between those points. After flowing through the ammeter, the current goes through another wire to the resistor. So add that wire. Then the current goes from the resistor to – on the power supply, completing the circuit. Put that wire in place. Finally, run wires from the voltmeter to opposite ends of the resistor (the points you want to know the potential difference between.)

Check that the knob on the power supply is turned all the way down (counterclockwise). As you slowly turn up the voltage, be careful that the meters don't go off scale. (When a digital meter goes off scale, the display goes blank.) Put the meter on a less sensitive scale if necessary. On the other hand, don't use a scale which isn't sensitive enough. Get as many decimal places as possible.

Get several pairs of values for potential difference and current, covering as wide a range of values as possible (0 to 23 V.). Include (0,0) as one of your data points. Graph the potential difference as a function of current. Neatly draw the best average line or smooth curve through the data.

Pick a point that lies right on your line, and use it to compute the resistance. The data points that lie somewhat off the line presumably contain random errors due to your experimental uncertainty.

In your conclusion,

1. Compare the value you obtain to the value printed on the resistor. Do they agree within the uncertainty printed on the resistor?

2. Comment on the shape of your graph. (The graph of $V = IR$, where R is a constant, is a straight line. A linear voltage-current relationship is called ohmic behavior because it's what Ohm's Law leads you to expect. Say whether the resistor is ohmic or nonohmic.)

Part 1b, Light Bulb:

Replace the resistor with a light bulb, leaving the circuit the same otherwise. Start again with an ammeter, not a milliammeter, since the current might be larger now.

Get several pairs of values for V and I covering as wide a range as possible (all the way up to 23 V). Include a few readings under 2 V. Include (0,0) as one of your data points, too. Nothing is wrong if the bulb doesn't glow; it's just because of the low voltages you are using.

Graph the potential difference against the current as before.

Pick two points, one near each end of the graph, and compute the resistance from each of them.

In your conclusion,

1. State whether the bulb is ohmic or nonohmic. (The graph of $V = IR$, where R is a constant, is a straight line.)

2. Ohm's law implies that R is related to the slope of this graph. What happens to the resistance as the bulb gets hotter?

Part Two: Power.

An electric heating element is immersed in water, and runs for a time t, producing a temperature change ΔT. You will calculate its power from the formula covered in class, and see if it matches the rate you observe energy being delivered as heat.

Procedure:

1. In the same circuit from part 1, replace the light bulb with the heating coil. The meters should be able to handle around 3 A and 15 V.

2. Remove the inner aluminum cup, and measure its mass empty. Measure the mass again with at least enough water to cover the heating coil. Subtract to obtain the water's mass.

3. Hang the inner cup through the ring in the top of the outer cup, and put on the lid which includes the heating coil. (The stagnant air between the cups makes good insulation.) Insert the thermometer through the hole in the lid, and record the initial temperature, T_i.

4. Turn the power supply's knob all the way up (clockwise), then
   - Start the current and the stopwatch at the same time. (The power supply will hum because of the heavy load, but it's fine.)
   - Keep the water stirred. The best way is to pick the apparatus up and swirl it frequently. (Not so hard you spill the water.)
   - Record the voltage and current.
   - Go until the temperature changes by 10°C or so then turn off the current and stop the watch at the same time. Record the time, t.
   - Stir thoroughly. The temperature will rise a little more as the last of the heat flows through the water. Record the highest temperature reached, T_f.

Calculations:

1. Compute the heater's power from the voltage and current.

2. Compute the rate heat energy was delivered to the cup:

   a. From PHY 121, heat = m c ΔT, where m = mass (in kg), c is a property of the material called its specific heat, and ΔT = temperature change. The specific heat of water is 4186 J/kg·°C; calculate how much heat was added to the water. The specific heat of aluminum is 900 J/kg·°C; calculate how much heat was added to the cup. Add to obtain the total thermal energy produced.

   b. Power is energy delivered per unit time. (A watt is a joule per second.) So, divide the energy by the time spent putting it there.

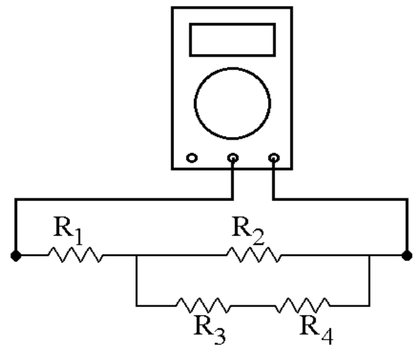
Conclusion: Does the power calculated from I and V match the rate you observed energy being delivered? (Expect a difference of 10% or so. The rate heat was added to the cup might be just a little low, because some heat escapes into the surrounding room.)

When you're sure nothing needs to be rechecked, please dump the water and leave the lid off so things will dry.

Experiment 4: Resistance and Kirchhoff's Laws

Part 1 – Equivalent Resistance.

Select four different resistors in the range 100 Ω through 1000 Ω. Arrange them as in this diagram. Calculate the equivalent resistance of the group, showing the complete calculation in the space on the answer sheet.



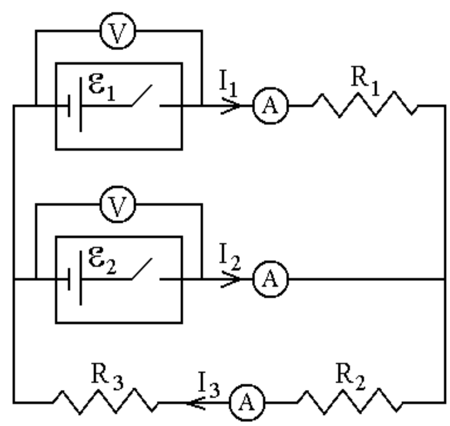
To check your answer, set a digital multimeter to read resistance and measure across the entire group. In your conclusion, say whether this matches what you calculated.

Part 2 – Kirchhoff's Laws.

To check whether Kirchhoff's Laws actually work, you will set up the circuit shown, predict what the currents ought to be, then measure the currents to see if your prediction was right.

Meters: The wires from a voltmeter should go to the two points you are finding the potential difference between. That is, put it in parallel with the emf source. An ammeter should be in series, so the current to be measured flows through it. Never connect an ammeter in parallel; its resistance is practically zero, so this would create a "short circuit" and overload the meter.

Set up this circuit, using two power supplies, three different resistors between 250 Ω and 1000 Ω and five multimeters. If possible, use Elenco M-1750 meters for the currents; they work a little better due to their lower internal resistance. Decide on two different values to use for $\mathcal{E}_1$ and $\mathcal{E}_2$ in the range 3 V to 6 V. Get the circuit approved by the instructor, but do not turn it on yet.



Use Kirchhoff's laws to calculate I_1, I_2 and I_3. Hint: Start by looking for a loop which gives an equation with only one variable in it. Calculating the uncertainties in the answers would be complicated. As a rough estimate, let's say each I might be off by 5% or .01 mA, whichever is larger.

Set two of the meters to read DC volts and the other three to read DC milliamperes. Starting with their knobs all the way down (counterclockwise), turn on the power supplies then adjust them as closely as possible to the $\mathcal{E}_1$ and $\mathcal{E}_2$ you chose. Record the currents. A current whose direction is opposite that shown in the picture should be recorded as negative.

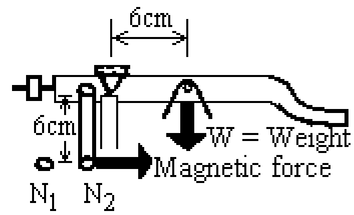
Don't take the circuit apart before the instructor accepts your paper, so you can double-check data if necessary.

In your conclusion, state whether what theory predicts matched observation.

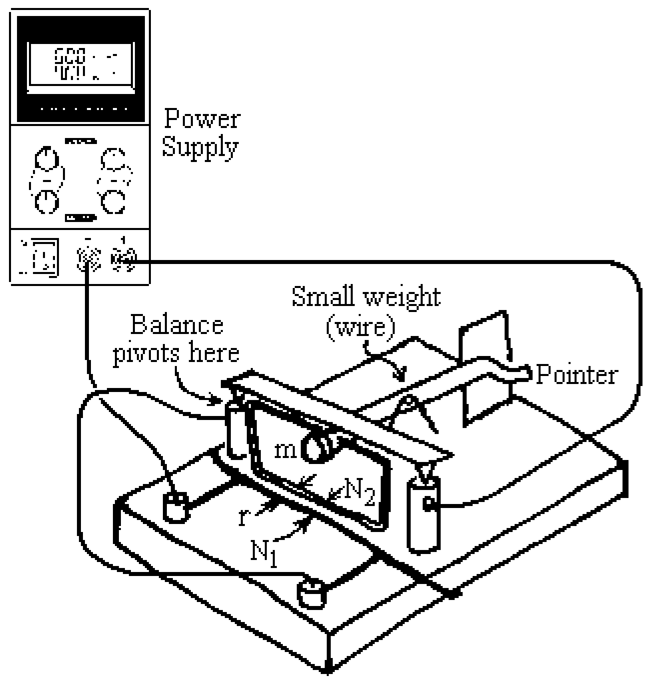
Experiment 5: The Current Balance

Object: To see if the measured magnetic force between current carrying wires matches that predicted by theory.

Apparatus: A current carrying bundle of N_1 wires creates a magnetic field around itself. Another bundle of N_2 wires hanging from a balance feels a force from this field, pushing the balance upward. A known weight (the small wire on the peg) pulls the balance back down. The current is adjusted, varying the magnetic force, until the balance balances. The magnetic force is then just equal to the weight since they have equal moment arms. (The sum of the torques is zero, so (6 cm)(F_{mag}) = (6 cm)(W).) This observed force is compared to what the equations predict.



Procedure: Have the bundle of N_2 wires along a north-south line so that Earth's field will not push it up or down. (The blackboard is at the north end of the room.) Connect this circuit using a power supply which can provide at least 5 amps. Current leaves the power supply, goes through both bundles of wires, N_1, and N_2, in series and then returns to the power supply.



With the wire off the peg, check that

- the pointer does not rub on the scale.
- the wires under the base run directly under the balance.
- the counterweight, m, is adjusted so that the pointer is somewhere in the middle of the scale. (It does not have to be at 0.)
- bundle 2 on the balance is not resting against bundle 1 on the base.
- the balance moves freely. If you blow on it, it should bob up and down a few times.
- the pointer goes up not down when you turn the current on. If down, switch the current's direction in one set of wires

Measure the mass of the little wire (approximately .2 gram) on a balance which can be read to the nearest hundredth of a gram. To obtain its weight in newtons, convert the mass to kilograms and multiply by 9.8. (As explained in PHY 121, mass is the amount of matter in the wire; weight is the gravitational force on it. 9.8 m/s^2 is the strength of Earth's gravitational field.)

Measure r, the distance between the centers of bundle 1 and bundle 2. A good way to do this is to measure left to left, then right to right, then average. (Trying to measure r between these wiggly bunches of wires is the largest source of error in this experiment.) After this be careful not to move where the pivot points rest on their supports or you could change r.

Also measure the length of bundle 2, the wires along the bottom of the balance, and count the number of strands in both bundles.

With the little wire still off the arm, notice the position of the pointer.

<u>CAUTION</u>: The pivot points or other loose connections could get hot.

Put the wire on the peg. Turn on the power supply and use the “coarse current” knob at the lower right to adjust the current. If the reading does not respond when turning this up, increase the voltage a little using the knob at upper right. (The knobs on the left do the same thing but more slowly.) Find I, the current that brings the pointer back where it was before. Be sure you are looking at the number on the bottom of the display when you record it. (After several minutes of operation, you may see the current decrease because warm connections have more resistance. Compensate by turning up the power supply. If necessary, turn it off a few minutes to let things cool.)

This device doesn’t give particularly consistent results, so recheck your value for I a few times. (The balance can stick a little. It doesn’t take much with such small forces.) Without bumping anything that changes r, take the wire off the peg between each trial and recheck the original position of the pointer. If it was at 1.4 before the first trial but at 1.3 before the second trial, find the current that brings it to 1.4 during the first trial and the current that brings it to 1.3 during the second trial. Average the trials for I.

When you're done, stick your piece of wire to the base with some scotch tape so it won't get lost.

<u>CALCULATIONS</u>:

1. Find the magnetic field which one wire on the base creates at the bottom of the balance.

2. Multiply this by the number of strands on the base to obtain the total field.

3. From the total field, find the force on a single wire on the balance.

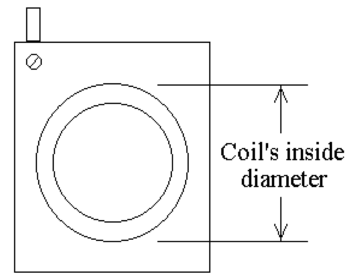
4. From the total number of wires, find the total force. (Ignore the other three sides of the coil on the balance.) This is your theoretical value for the magnetic force. It could be off by as much as 20%, due especially due to the uncertainty in measuring r between the wiggly bunches of wires. Express your answer as in this example: F = 3.0 $\pm$ .6 mN. (20% of 3.0 is .6.)

In your conclusion, state whether the observed force (the weight of the wire) and the theoretical force agree.

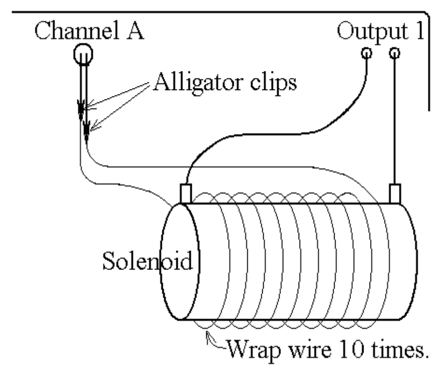
Experiment 6: Induction

Part 1. Faraday's Law.

You will send a current which changes at a known rate through a solenoid. From this and the solenoid's dimensions you can determine the rate the flux through it changes. Putting this into Faraday's law tells you how many volts should be induced in some wire wound around the outside of the solenoid. You then use a computer with a voltage sensor to obtain a graph of the induced voltage which shows whether Faraday's law predicted correctly.



1. Measure the solenoid's outside diameter. (The nearest millimeter is good enough, but closer is better.) If you need help with the vernier caliper, ask. Notice that you can see the tube around which the coil is wound protruding through the end pieces. Use this to measure the coil's inside diameter. Find the average diameter then the average radius from that. Also measure the coil's length.



2. Wrap a piece of insulated wire around the solenoid ten times and connect it to a voltage sensor plugged into channel A of the computer interface. Connect the solenoid to Output 1 of the interface.

3. Connect the interface to the computer with a USB cable and turn both on. (The button at the upper left of the interface should turn blue.) Open PASCO Capstone on the computer.

4. On the computer screen, click signal generator at the bottom of the column on the left. Click 850 Output 1. Set the frequency at 50 Hz and the amplitude at 5 V. Set the wave form for Positive Ramp. Click On.

5. Click Hardware Setup at the upper left. Click the yellow circle by Channel A on the picture then on Voltage Sensor. Click the yellow circle by Output 1 on the picture then on Output Voltage-Current Sensor. Click Hardware Setup again to hide that window.

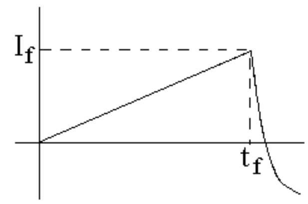
6. To have the computer show graphs of the current in the solenoid and the voltage induced in the 10 loops of wire,

a. In the column on the right, double click Scope, which is second from the top. Click <Select measurement> by the vertical axis and select Output Current, Ch 01 (A).

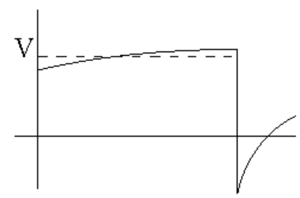
b. In the toolbar at the top, click on ↑✳ (Add new y axis to scope display.) By the vertical axis which appears on the right, click <Select measurement> and select Voltage, Ch A (V).

c. Click where it says Continuous Mode near the lower left. Click Fast Monitor Mode on the menu which appears. Click Monitor at bottom left. Two curves should appear. The voltage probably looks like a horizontal line because only a small fraction of a volt is induced. Stretch the scale on the right until it shows up by dragging the numbers along the axis away from the origin. Also adjust the other axes as needed for a clear view of what is going on.

d. Near the left of the toolbar at the top, click (Activate and Control Scope Trigger) to stabilize the display.



7. The graph of the current should rise fairly steadily for a few milliseconds and then it should suddenly drop and become curvy. Record the highest current reached and the time to get there. The best way is to click on then drag the crosshairs to the point you want the coordinates of. Right click on the box containing the coordinates. Click Tool Properties, then Numerical Format then Horizontal Coordinate. Check the box by Override default number format and under Number Style select Significant Figures. Click OK.



8. The voltage graph should be fairly constant and then suddenly drop. (If the wires are connected the other way, it will be a fairly constant negative voltage which suddenly jumps up.) While taking this reading, have the ten loops bunched up around the middle of the solenoid; its field is weaker near the ends. The graph may vary a little. Record what looks like a good average voltage.

9. Calculations. For the time interval between $t = 0$ and $t = t_f$,

a. What is the final magnetic field in the solenoid, B_f?

b. What is the final flux through the solenoid, Φ_f?

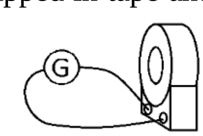
c. The flux through the ten loop coil you made is the same as through the solenoid. Calculate the emf induced in the ten loop coil.

10. In your conclusion, compare the measured and calculated voltages.

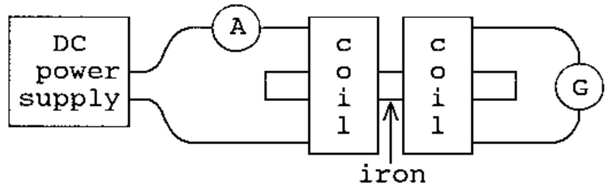
<u>Parts 2 through 4</u> are a series of short demonstrations. The "write up" for them has been integrated into the answer sheet. You only need to attach a discussion for part 1.

<u>Part 2. Coil and Magnet.</u>

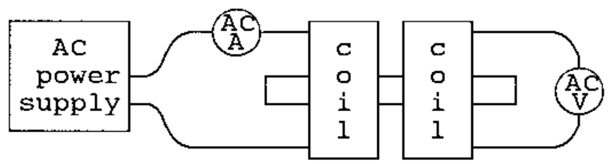
Obtain a neodymium magnet from the instructor. <u>Caution</u>: Keep the magnet wrapped in tape and cardboard, as you found it. Without this padding, they have pinched people's fingers, and also gotten chipped. Connect a coil to a galvanometer (a sensitive ammeter). Do the things described on the answer sheet, record your observations and answer the questions.



Part 3. Transformer.

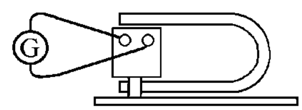


1. DC: Instead of using a magnet, use another coil as an electromagnet to produce the magnetic field. Include an ammeter in the circuit with the electromagnet and keep the current in it around one amp (Don't go much higher). The two coils should be placed against each other with a piece of iron through their centers. Investigate these questions: Do transformers work on steady DC? Do transformers work on DC if you chop it (turn it off and on)?



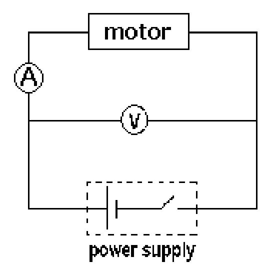
2. AC: Replace the DC meters with an AC ammeter and voltmeter as shown. Switch the primary coil from the DC to the AC terminals of your power supply. Do transformers work on AC?

Part 4. DC generator and DC motor.



a. Generator. You have a device in which a coil is between the poles of a horseshoe magnet. Connect a galvanometer, then spin the coil. Answer the questions.

b. Motor. A DC motor and a DC generator are basically the same device. In one case you put mechanical work in and get electricity out. In the other, you put electricity in and get mechanical work out.



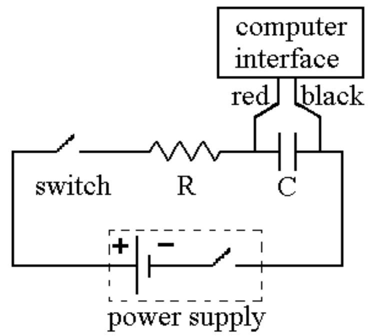
Get rid of the galvanometer and connect to the DC terminals of the power supply. Meters with a needle are better because digital meters might not be steady enough to read. Use scales suitable for 1 A or more and 3 V. Before switching on the power supply, set its knob at the second mark on the left. You'll probably have to push the motor to get it started. Adjust the power supply so the motor isn't running it too fast. Record the meter readings, and answer the questions on the answer sheet.

Experiment 7: RC and LC Circuits

Part I: RC Circuits

You will check whether the time constant and voltage observed for an RC circuit match those predicted by theory. These will be observed on a graph of capacitor voltage versus time produced by a computer monitoring the circuit shown.

Select a capacitor somewhere around 1 μF. Calculate the resistance needed with it to make the time constant at least 20 ms. Obtain a resistor at least that large but under a hundred thousand ohms. Do not trust the label on the drawer the resistor was in; check the resistance with a multimeter. Record R and C.



Connect them to a power supply, a switch and your computer's voltage sensor as shown. Plug the voltage sensor (which is just some wires) into channel A on the interface. The grounds (black wires) of the voltage sensor and power supply must be together. Connect the interface to the computer with a USB cable and turn both on. (The button at the upper left of the interface should turn blue.) Open PASCO Capstone on the computer.

Get a graph showing how voltage builds up after you close the switch:

Click Hardware Setup at the upper left. Click the yellow circle by Channel A on the picture. Select Voltage Sensor. Click Hardware Setup again to hide that window.

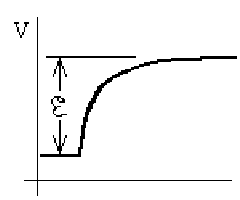
The sampling rate is at the bottom center. It probably says 20 Hz now. Click the up arrow until it says 1.00 kHz.

In the column on the right, double click Graph, which is at the top. Click <Select measurement> by the vertical axis and select Voltage (V). Adjust the vertical scale so that it goes from 0 to around 5 or 10 V and the horizontal scale to run from 0 to roughly 10 or 20 seconds. To move the graph up or down, click on it and drag it. To change the scale, click on a number by one of the axes and drag it toward or away from the origin.

Put the knob on the power supply one notch clockwise from its off position. (Off is fully counter clockwise.) With the switch off, turn on the power supply.

Click Record at the lower left of the screen. Right after that, close the switch. After a second or two, click Stop. Open the switch back up and turn off the power supply.

Change the scale of the graph to get a better look at the voltage building up right after the switch was closed, like this. You don't need a hard copy, but have the instructor approve your data before deleting the graph.



On this graph, observe the following:

(To measure differences in voltage or differences in time between two points on graph, click on at the top of the graph. Move the crosshairs to the point at the start of your interval. Right click then select Show Delta. A rectangle appears. Move its opposite corner to the point at the end of the interval. Δx, written above the rectangle, is the difference in time. Δy, written beside it, is the difference in voltage.)

Right click on the box with Δx. Click Tool Properties then Numerical Format then Horizontal Coordinate. Check the box for Override default number format. Next to Number Style, select Significant Figures. Click OK.

1. Emf: The capacitor might have started out with a little charge on it. Observe the <u>difference</u> between its voltage just before the switch was closed and the final voltage it builds up to after a long time. Record this as $\mathcal{E}$, the full-charge voltage on the capacitor.

2. The time constant. (Remember what the time constant <u>means</u>: Read how much time passes from the closing of the switch until the voltage is 63% of its final value.)

3. The voltage (above the initial) when t = half the measured time constant.

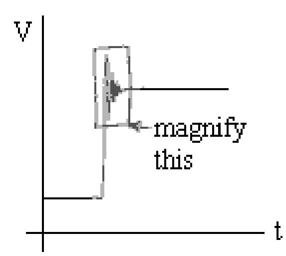
Calculate these last two things, and compare to the measured values. Taking the calculated values as exact, and the measured values as 10% uncertain, do they agree?

(When you write your discussion: Include how to read $\mathcal{E}$ from the graph. Include how to read the time constant from the graph.)

<u>Part II: LC Circuit:</u>

Use the same circuit, except replace the resistor with a 5 mH coil. Change the sampling rate to 10.00 kHz. Turn on the power supply and click Record. As soon as dots start appearing on the graph, close the switch immediately. As soon as the voltage on the graph pops up, click stop.

Stretch the graph horizontally (quite a lot) until you can see the oscillations right after the switch was closed. When you close the switch, the pulse of voltage hits the circuit like striking a bell; it makes the circuit "ring" for a little while. So, the curve should suddenly spike up when you closed the switch, then briefly oscillate around the final voltage with decreasing amplitude. If the oscillations damp out before a couple of periods are completed, try turning up the power supply somewhat. (Hit the bell harder.)



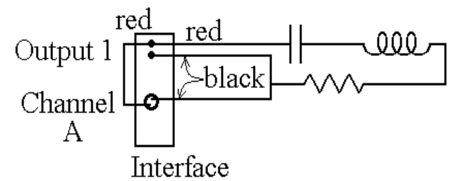
Read the period from the graph. For best accuracy, measure across several periods using the Show Delta feature, then divide. To get three significant figures, the format used by Show Delta might need changing by right clicking on it. Have the instructor help with this.

Calculate what the circuit's period ought to be from its capacitance and inductance. (Find the frequency, then get the period from T = 1/f.) Does this agree with what you saw within 10%?

Experiment 8: An AC Circuit

PART ONE: AC Voltages.

Set up this circuit. Use R = 500 Ω, L = 5.0 mH and C = .01 μF. A signal generator built into the interface provides the emf to run the circuit from Output 1. The voltage sensor plugged into channel A will measure this output voltage and the computer will display it on a graph.



Connect the interface to the computer with the USB cable and turn them both on. (The button on the interface should turn blue.) Open PASCO Capstone. Click Signal Generator at the bottom left. Click 850 Output 1. Set the frequency at 60 Hz and the amplitude at 10.0 V. Click On. Click Signal Generator again to get that out of the way.

Click Hardware Setup at the upper left. Click channel A, near the center. Click Voltage Sensor. Click Hardware Setup again.

To have the computer display the voltage on channel A,

a. In the column on the right, double click Scope, which is second from the top. Click <Select measurement> by the vertical axis. Select Voltage (V).

b. Click the arrow where it says Continuous Mode near the bottom left. On the menu, click Fast Monitor mode.

c. Click Monitor at bottom left. A sine wave should appear. Near the left of the toolbar at the top, click to stabilize the display. Change the scale of the graph as needed by dragging the numbers along the axes as in last week's lab.

Record the amplitude of the voltage, which may actually be a little less than the 10.0 V you put in the box. The best way to read the graph is to click on at the top of the graph then move the crosshairs to the top of a peak.

Connect a meter set for AC volts (most have a DC/AC button at the upper right) to the same signal from output 1. Record the reading. In your conclusion, say why this is different from what you read off the graph.

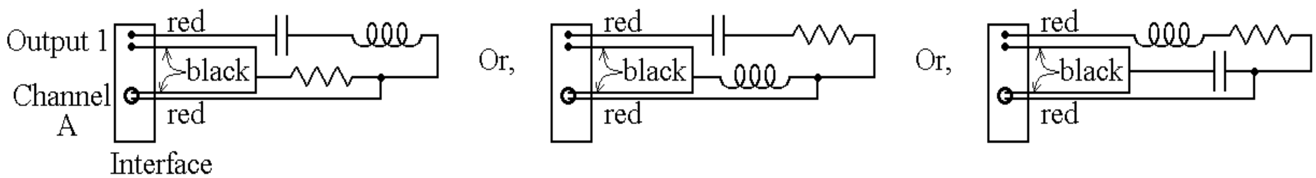
PART TWO: RLC Series Circuit.

In an AC circuit, we wish to see if calculated and observed voltages match, and if the phases of the voltages are as predicted. A resistor, inductor and capacitor are connected in series across a signal generator. A computer with current and voltage sensors displays the amplitude and phase of the voltage across each of these.

Calculations. The same R = 500 Ω, L = 5.0 mH and C = .01 μF from part one will be placed in series with a V_{max} = 10.0 volt, 15,000 Hz emf. Find the impedance of the circuit, the current, and the potential difference across each of the three circuit elements: the capacitor, resistor and inductor. (Solve this problem mathematically.)

Experimental Procedure. Now, check your results. Just remove the meter and otherwise it is the same circuit from part one. Click on Signal Generator and set the frequency at 15 000 Hz. Do a lot of stretching on the horizontal axis until the graph shows just one or two periods. Adjust the number in the signal generator's Amplitude box until the graph actually shows an amplitude of 10.0 V. The number in the box will probably need to be around 10.2 V. Click Stop.

Remove the red wire of the voltage sensor from Output 1 and connect it to the un-grounded end of the resistor as in the picture on the left. Click Hardware Setup at the upper left. Click Output 1 at the top right of the picture. Click Output Voltage Current Sensor. Click Hardware Setup again.



To include the current as well as the voltage in the computer display,

a. In the toolbar at the top, click on ↑✳ (Add new y axis to scope display.) By the vertical axis which appears on the right, click <Select measurement>. Select Output Current, Ch 01 (A).

b. Click Monitor. Another sine wave should appear, which probably looks like a horizontal line at the moment. Stretch it vertically. Numbers on the left go with the voltage and those on the right go with the current. You have to adjust each separately.

- Record the amplitudes of the voltage and current.

- Sketch the graphs in the little boxes on the answer sheet. (The one for I is kind of messy. Just sketch a sine wave without all the little spikes.) Be careful to show the phase difference between V and I accurately. Label which curve is V and which is I.

Next, switch the resistor with the inductor to set things up as in the center picture. Keep the wires arranged the same way; just unclip R and L and put them in each other's places. Record the voltage. (I should still be the same.) Repeat for the last of the three. Get the instructor's approval of your sketches before going on; there are often problems.

In your conclusion,

1. Comment on whether your measured and computed values for the current and three voltages agree with each other if the measured values have a 10% uncertainty. (A typical tolerance when components like these are manufactured.)

2. Comment on the phases:
   a. Should V_R lead or lag I? Is this what you see?
   b. Should V_L lead or lag I? Is this what you see?
   c. Should V_C lead or lag I? Is this what you see?

PART THREE: Resonance

You will see if a circuit's calculated resonant frequency matches the observed resonant frequency.

Switch to a 47 Ω resistor. (Less resistance means more current around the resonant frequency, making the effect stand out better.) There is no other change in the circuit. For various frequencies, read the current from the display you set up before. Ignore the voltage curve. You will use this data to make a graph of current as a function of frequency.

a. Click Signal Generator at the bottom left. Scroll through different frequencies with the arrow keys and find where the current is largest. When you get close, change f by just 100 Hz at a time. Record f and the amplitude of I.

b. Record the same information for a frequency just 2 or 3 kHz above this, and again about 2 or 3 kHz below. We want this part of the graph to be clearly defined.

c. Take data at more widely spaced frequencies to fill out the range 5 kHz to 40 kHz. You will have to adjust the display's scale to get some of the readings.

Plot your data on a graph with f in the horizontal axis and I on the vertical axis. Read the resonant frequency from it. Also, calculate the resonant frequency from L and C. If your observed (graph) value has a 10% uncertainty, do these agree?

Experiment 9: Sound Waves

Part One: Audible Sound.

Caution: Keep your feet out from under the kilogram for part C in case the wire slips.

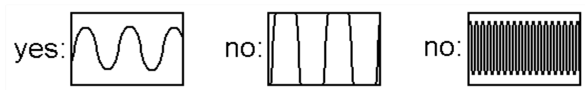
Connect the interface and computer with the USB cable and turn them on. Open PASCO Capstone.

A. Loudness and pitch:

1. Click Hardware Setup at the upper left. Click Output 1 at the picture's upper right. Click Output Voltage Current Sensor. Click Hardware Setup again to make it go away.

2. Click signal generator at the bottom of the column on the left. Click 850 Output 1. Put .15 in the Amplitude box and set the frequency for a few hundred hertz. Click On.

3. In the column on the right, double click Scope, second from the top. Click by the vertical axis and select Output Voltage (V). Click Continuous Mode at the bottom near the left then click Fast Monitor Mode. Click Monitor at bottom left. Near the top left, click to stabilize the display. You may have to move the cursor to the top for this toolbar to appear. To change the graph's scale, click on a number by one of the axes and drag that number toward or away from the origin. Adjust the graph like this:



4. Connect a speaker to Output 1 at the upper right of the interface, red to red and black to black.

5. Try different amplitudes and frequencies: Do not make the amplitude more than .25 V or it gets really annoying. Highlight a digit in either box and then you can scroll that digit up or down with the up or down arrows on the screen or keyboard. Hold the key down to scroll faster. Draw pictures to show the difference between loud and soft sounds, with the same pitch. Draw two more to show the difference between high and low pitches, with the same loudness. Don't change the graph's scale between pictures.

6. Turn off the signal generator and unplug the speaker. Click Stop at the lower left.

B. Frequency of your voice:

1. Plug the sound sensor into Channel A of the interface.

2. Have the computer display the input from channel A:

   a. Click Hardware Setup at the upper left. To disconnect from the signal generator, click the lightning bolt by output 1 then press delete on the keyboard, then click yes. Click on Channel A then on Sound Sensor. Click Hardware Setup again.

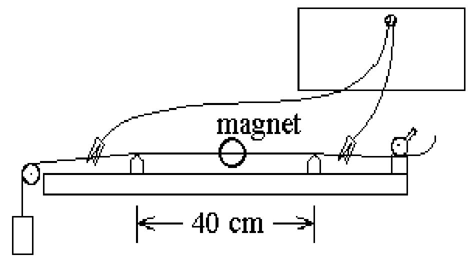
   b. Click <Select Measurement> by the vertical axis. Click Sound Intensity (V).

c. Click Monitor at lower left. Hum into the sound sensor. As before, adjust the scale of the graph so that it shows just a few periods and the amplitude takes up most of the vertical space.
While humming, click Stop to freeze the picture.

3. To read the period from the graph, click -¦- at the top of the graph. Move the crosshairs to a point at the start of the interval. Right click, select Show Delta, then move the opposite corner of the rectangle to a point at the end of the interval. Right click on Δx then click Tool Properties to get more decimal places. Calculate the frequency from the period

C. Period of a vibrating wire.

1. The wire should run from a clamp on one side of the table over a pulley on the other side of the table to a 1 kg mass that keeps it under tension. Put the wooden supports 40 cm apart. Put a neodymium magnet close to the wire about halfway between them, on top of something so its center is at about the height of the wire.



2. Plug the voltage sensor into channel A of the interface. Using alligator clips, attach it to the piano wire as shown. Click Hardware Setup at the upper left. Delete the sound sensor. Click Input A and select Voltage Sensor. Click Hardware Setup again.

3. Click <Select Measurement> by the vertical axis. Click Voltage (V). The amplitude will be just a few thousandths of a volt; stretch out the vertical axis. The computer should still be in Fast Monitor Mode. Click Monitor at bottom left.

4. Pluck the wire and click Stop while it is vibrating. You need to be quick. (The signal is an induced voltage due to the wire moving through the magnetic field. This isn't exactly how an electric guitar pickup works, but it's pretty similar.) Measure the period. The best accuracy comes from measuring the time for several periods, ten for example, and then dividing.

5. As a comparison, calculate the period from theory. As covered in our next class, there is a <u>standing wave</u> on the wire whose wavelength is twice the length of the part which vibrates. So,

a. Measure the exact distance from the point on top of one wooden support to the other.

b. Double this to get the wavelength.

c. When this amount of tension is put on these particular wires, waves on them travel at about 115 m/s. Use this and the wavelength to calculate what the frequency should be.

d. Find the period from the frequency.

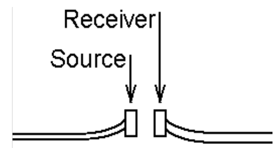
6. Comment on how well the measured and calculated periods match.

<u>Part two</u>: Ultrasound.

You will determine the speed of sound, by finding a sound's frequency and wavelength. For a more pleasant environment, you will use a frequency above your range of hearing.

You have two crystals, encased in little cans, which transduce electrical signals into mechanical vibrations and mechanical vibrations into electrical signals. You will use one as a "loudspeaker" (source) and the other as a "microphone" (receiver).

1. Clip the voltage sensor from channel A to a transducer, red to red, black to black. This will act as a microphone Connect the other transducer to output channel 1, using wires with alligator clips. This is the speaker. Place the cans on the counter, facing each other.



2. Click Hardware Setup at the upper left. Click Output 1 and select Output Voltage Current Sensor. Click Hardware Setup.

3. Click Signal Generator. Put 10 V in the Amplitude box and 40 000 Hz in the frequency box. Click On. Click Signal Generator.

4. Click by the vertical axis on the left and select Output Voltage Ch 01 (V). At the top, click on ↑✳ (Add new y axis to scope display.) Click by the vertical axis which appears on the right and select Voltage, Ch A. Adjust the scale of both graphs.

There are now two sine curves on the graph: Channel 1 is the signal driving the "speaker," channel A is the signal from the "microphone." Just ignore the speaker's.

5. Near the top left, click (Activate and Control Scope Trigger) to stabilize the display.

6. Now, if you move the receiver, you see the waves go by on the screen. Measure the wavelength:

a. Start with the source and receiver a few centimeters apart. (Standing waves form between them if they're too close.) Have a ruler under the receiver with the receiver at 0 cm. Be sure the ruler doesn't move after this.

b. Move the receiver ten wavelengths along the ruler by counting the number of waves that go by on the computer. Record the distance moved by the receiver. (Not the distance between crests on the screen. The graph shows you the wave's <u>period</u>, not its wavelength.)

c. Divide by ten. (This is more accurate than measuring just one wavelength.)

7. Record the frequency from the signal generator.

8. From the wave's frequency and wavelength, calculate its speed.

9. If your result has a 10% uncertainty, does it agree with the accepted value?

Please shut down the computer before you leave.

Experiment 10: Standing Waves and the Speed of Sound

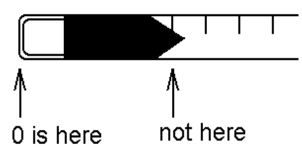
(If some of you do part two first, it's easier to hear your tuning fork if there aren't five others going at the same time.)

PART I: Standing Waves on a String.

You will calculate what theory predicts for the resonant frequencies of a "string," then observe the frequencies to see if they match. (Actually, a long spring is used because its mass makes the waves go slower.) The frequencies can be predicted from speed and wavelength. The speed is found from observing the time for a transverse pulse to cover a known distance. The wavelength is determined from the length of the spring. The observed frequencies come from setting up the standing waves, and counting the number of cycles in a certain number of seconds.

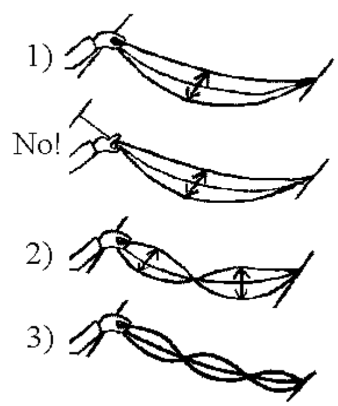
1. One end of the spring goes on the hook on the wall, the other in the clamp on the pole.

2. Find the waves' speed: Give one end of the spring a quick push to the side or hit it with your finger. Measure the time the pulse takes to go back and forth for as many times as you can make the pulse out, hopefully 8 or 10. You might be able to feel the pulse with a finger resting lightly on the spring more clearly than you can see it. Get the spring's length from the tape measure. The picture shows a common mistake. Another is recording, for example, 3.46 m as .46m: Notice where 1m, 2m and 3m are on the tape measure. The total distance covered divided by the time is the speed.



3. From the spring's length and the wave speed, find the three lowest resonant frequencies. Calculate 10% of these numbers for their uncertainties. (Most of this uncertainty is from your reaction time with the stopwatch.)

4. Set up each of the standing waves shown by shaking the spring at the appropriate frequency with your hand. **Rough treatment will damage the spring. Keep the amplitude down to a foot or two.** Don't cut off part of the vibrating length, like fingering a guitar string. Measure the frequency of each by counting the number of vibrations in 30 seconds. (Cycles per second = cycles ÷ seconds.) Assume the uncertainty is 5% in these numbers. (Since the clock ran longer, the amount you might be off is a smaller percent.)



5. Compare the calculated to the actual resonant frequencies.

PART II: Sound Resonance.

Note: Once in a while, the apparatus gets tipped over, which is kind of messy. When not in use, please put it somewhere it's not likely to be bumped into.

You will use resonance to measure the speed of sound. The speed of a wave can be found from its frequency and wavelength. You get the frequency by simply reading it off the tuning fork making the sound. The wavelength can be determined from the length of a resonating air column.

Sound from the tuning fork goes down a plastic tube partly filled with water. The water is there so you can adjust the length of the air column; water is added or removed through a hose which leads to a cup. The sound reflects off the water and comes back up the tube; the waves going through each other in opposite directions make a standing wave. If the length of the air column is just right, this standing wave will resonate. Resonance means the buildup of a large amplitude, and the amplitude of a sound is its loudness, so you can hear when this happens because it gets louder. The resonating length is related to the wavelength, which in turn is related to the speed of sound.

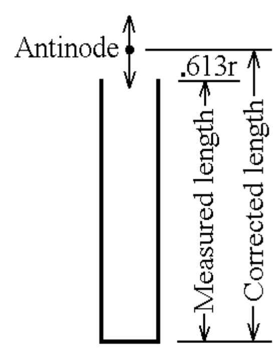
Record the frequency stamped on the tuning fork.

Stand the apparatus on the floor, with the counter where it will block it if it starts to tip. Fill it to near the top with water. Holding the cup on the hose in your hand, you can change the water level in the tube by raising or lowering the cup. Use the large plastic beaker to add or remove water from the cup as necessary.

Strike the tuning fork with the rubber hammer. (Don't beat the daylights out of the poor tuning fork. You might try hitting it on your head once, instead of with the hammer, to see what it's supposed to sound like. Never strike it on anything hard, like the counter.) Hold it above the tube horizontally, close to the tube, with the vibrating ends going all the way across the tube but not much beyond. Strike it every ten seconds or so to keep it vibrating.

Lower the water level from near the top of the tube until you hear resonance. It should be no more than half way down the tube; resonances below this are from a different standing wave pattern. Mark this level with a rubber band. Run the water level back and forth across it a few times to make sure you have it exactly right. Measure the length of the resonant air column, from the top of the water to the top of the tube.

A more detailed analysis of resonating air columns shows that the antinode is not exactly at the open end, but beyond it at a distance of .613 times the tube's inside radius. To obtain the correct wavelength of the sound, this "end correction" must be added to your measured air column length.



Compute the wavelength of the sound from the (corrected) length of the resonant air column. Compute the speed of sound from the wavelength and frequency. Its uncertainty is about 5%.

Compute a theoretical value for the speed of sound from the formula on your formula sheet. (There is a thermometer at the front of the room.)

Do the two values for the speed of sound agree within the uncertainty?

Experiment 11: Reflection and Refraction

Part one:

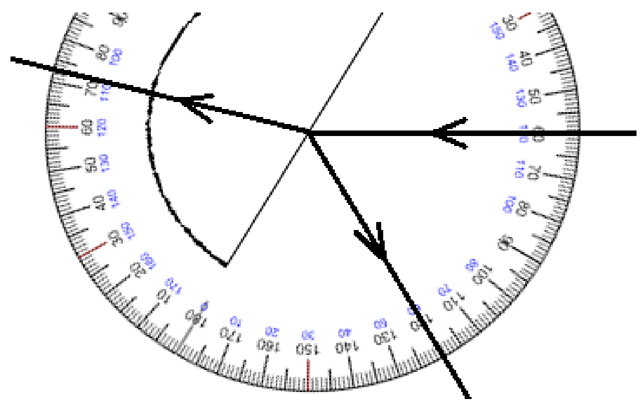
You will test the law of reflection, and also measure the index of refraction of a piece of plastic. To do this, you shoot a laser at the flat side of a plastic semicircle. The angles of incidence, reflection and refraction are measured using protractors which are attached. The results are compared to the law of reflection, and used in Snell's law to obtain n.

CAUTION: THE LASER CAN DAMAGE YOUR EYES IF IT ENTERS THEM. Its intensity is similar to looking at the sun.

Leave the clamp on base of the semicircle loose enough to turn it to different angles, but tight enough that it will stay when you let go.

Aim the laser at the mark at the center of the plastic's flat side. Move the clamp up or down the pole as a coarse adjustment, adjust the screws under the laser to tilt it for a fine adjustment. After that, turn the semicircle to different angles to see if the law of reflection is working. If not, adjust this further.

When the beam hits the plastic, part of it reflects back into the air, and part refracts into the plastic. Record the angle of incidence, θ_i, the angle of reflection, θ_a, (a for "air"), and the angle of refraction θ_p (p for "plastic") for four different values of θ_i of over 10°. (Small angles give large percent uncertainties.) To observe these, you can move the stand holding the plastic toward or away from you to make the beam hit the numbers on the protractor. Do not change its distance from the laser, or it may affect the aim of the beam.



Example: $\theta_i = 30°$, $\theta_a = 30°$, $\theta_p = 17°$

Remember these are all **acute** angles measured from a **normal** (perpendicular) to the surface, so you must subtract the protractor's reading from 90°.

Compute n_p, the plastic's index of refraction. n= 1.00 for air. Average the results. Show the details of these calculations for at least one trial. (Note that you are experimentally determining n_p: do not look it up in a table.)

In conclusion, state (1) whether your results agree with the law of reflection assuming the angles are good to ±1°, and (2) your result for the plastic's index of refraction.

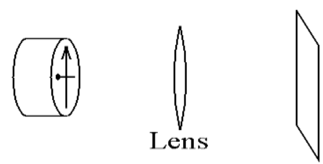
Part two:

You will make two predictions of the position, size and character of the image from a lens (one from equations, the other from a ray diagram), then observe the image to see if you were right. The image from a concave mirror will also be briefly observed. An electric lamp with an arrow painted on it is used as the object. Holders for the lens and screen fit on a meter stick with legs attached. First, to determine the lens's focal length, the lens is placed fairly far from the object, and the image is located. The focal length is calculated from the object and image distances. The object distance is then changed, and the focal length is used to predict what the image will be like now. The screen is moved until the image is sharp, and the result compared to the predictions. Finally, the focal length and radius of curvature of a mirror are determined from the location of the image it projects.

Convex Lens:

1. Set things up: Mount the meter stick on its feet and place the lens on it. Clamp the light we use for an object to the ring stand from part one, about the same height above the counter as the lens. (Be sure you don't want to recheck anything before you disassemble part one.)

2. Determine the lens's focal length: Place the object 40 to 80 cm from the lens. On a card, locate the image it forms. Measure the object distance and the image distance. Use them to find the focal length of the lens.



3. Change things around and predict what will happen now:

a. Move the object closer to the lens, making d_o about 5 or 10 cm more than f. Measure d_o and h_o. (Note that h_o is the length of the arrow, not its height above the counter.)

b. Calculate the distance of the image from the lens d_i, and calculate the height of the image h_i. Also, decide whether the image should be erect or inverted.

c. Solve the problem again, this time by measurement on a ray diagram drawn to scale, instead of using equations.

4. Move the card along the meter stick to locate the actual image. Record its position, size, and character.

In your conclusion,

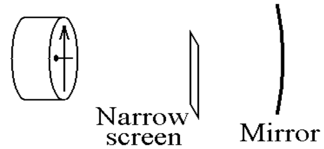
a. State whether the position, size and character you calculated for the image agrees with what you observed.

b. State whether the position, size and character you predicted with the ray diagram agrees with what you observed.

Consider all numbers to have 10% uncertainties.

Concave Mirror:

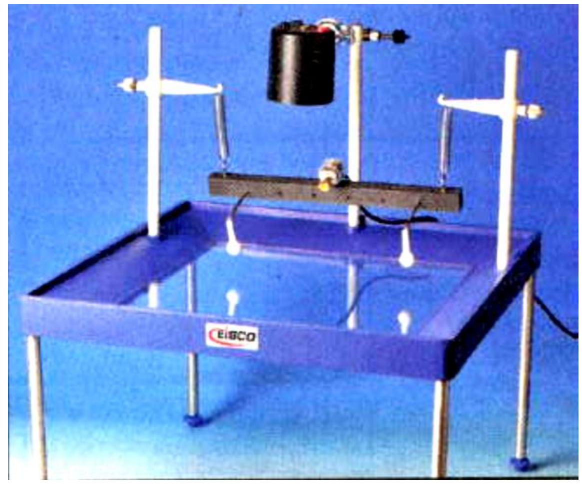
Place the object 10 to 20 cm from the mirror. Fold a small piece of paper to make a screen about the width of a pencil, so it doesn't block all the light. Measure the object and image distances.



Compute the focal length and radius of curvature of the mirror. (No comparison this time.)

Experiment 12: Interference and Diffraction

Part I: Diffraction and Interference of Water Waves.



A) Part A's objective is to see how the amount of diffraction depends on the wavelength as waves pass through an opening. The apparatus is a ripple tank: A glass-bottomed tank of water is between a light above and a screen below. A horizontal bar in the tank, hung from springs, bounces as a motor on it shakes, creating waves. Each wave acts as a lens, focusing light into a bright area on the screen, where it is observed. In part A, waves pass through an opening between two metal barriers.

Before adding water, place the tank on an 18" by 24" sheet of paper with the extra few inches extending beyond the side opposite the vibrating bar.
The light on the tank uses a 12 volt bulb. Use it only with the 12 V power source which should have been provided.

Start up the ripple tank and use the metal barriers to build a wall across it with an opening about 2 cm wide. The two balls on the ripple bar should be turned up out of the way or removed. If the image isn't clear, try rubbing dirt and bubbles off the tank's glass bottom with your fingers, dissolving the dirt in the water.

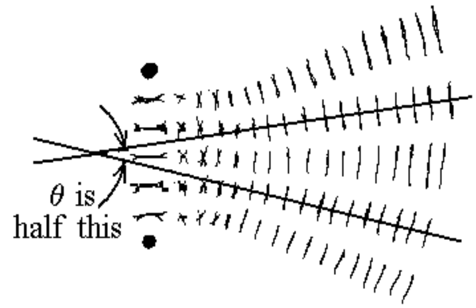
Vary the wavelength to compare the behavior of waves whose wavelength is larger than the opening to waves which are a good deal smaller than the opening. If you don't see enough of a difference, you can vary the size of the opening too. Sketch what you see.

As your conclusion for this part, state under what conditions waves more or less reach all places behind the wall, and under what conditions they don't.

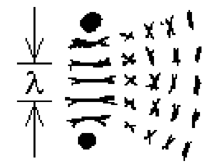
B) You will verify that $m\lambda = d \sin\theta$ correctly describes the maxima of a "double slit" interference pattern. You use the ripple tank again, this time with waves from two balls hung from the bar. Waves from these pointlike sources interfere the same way light from two slits would. The interference pattern on the screen is traced. λ is measured from the standing wave between the two sources, d and θ are measured from the tracing with a ruler and a protractor. $m\lambda$ and $d \sin\theta$ are each calculated, and compared to see if they match.

Take out the barriers. Raise the bar and turn down the two plastic balls so they are all that touch the water, about half submerged. Having the centers of the balls 4.5 to 6 cm apart, so that their images on the screen are 10 to 15 cm apart, works best. Rotate the bar supports to get the balls as close as possible to the back edge of the tank.

Start it up. Notice that the maxima curve near the sources; $m\lambda = d \sin\theta$ is invalid there. Using a ruler, draw lines through the centers of the first order maxima out where they are straight. Extend the lines behind the sources to where they meet. Measure the angle formed and divide by 2 to get θ measured from the center. Repeat for second order; these lines may not cross at the same point as first order.



Notice the standing wave along the line between the two sources formed by the identical waves traveling in opposite directions. This is the easiest place to measure the wavelength. Each flickering bright spot is an antinode; mark as many of them as you can clearly see. Measure across them and divide to get λ. Also measure d, the distance between the two sources. Measure d on the screen, not at the balls themselves, to be consistent with your other measurements.



Calculate mλ and d sinθ for the first two orders. For your conclusion, say whether the equation mλ = d sinθ seems to be correct. (Assume 10% uncertainty in both mλ and d sinθ.)

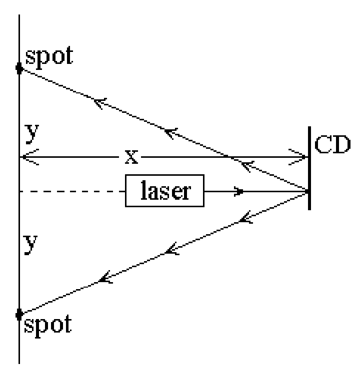
After the instructor approves your results, please drain the tank. If the water level is low enough to carry it there without sloshing some out, pour from a corner into the sink. Otherwise, use a large sponge to remove some first.

Part II: Track spacing on a CD

Caution: Looking directly into the laser beam is dangerous like looking at the sun. Keep the beam and its reflections down at table-top level and keep your eyes above this level.

The objective is to measure the distance from one track to the next on a compact disk. You shine a laser on a CD. The way the light scatters from the equally spaced "lines" of pits is equivalent to having many parallel slits, so it acts like a diffraction grating. By measuring the angle for first order reflection, you can calculate the spacing from the grating equation.

Mount the CD in the holder at least 8 cm from the laser, with a small piece of folded paper between the CD and the screw. The laser should hit at about the same height as the CD's hole, where the tracks are fairly vertical. The incoming beam should be normal to the CD, so arrange for the 0^{th} order reflection to land on the laser's aperture. Behind the laser and parallel to the CD should be a wall or some other fixed, rigid screen.

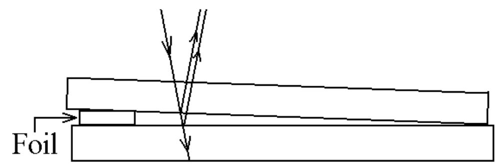


Locate the first order maxima. If you have trouble finding them, place a sheet of paper a few inches from the CD, where you can find them easily, then follow them out. Measure the distance from one first order spot to the other, then divide by 2 to get y, the distance from the central maximum. The central maximum won't show on the screen because the laser blocks it. Measure x, the distance from the CD to center of the screen. (You won't use them for anything, but also notice the second order maxima, more than twice as far to the side.)

Find θ using trigonometry. The wavelength of a helium-neon laser is 632.8 nm. Calculate the distance between the tracks.

Part III. Thin film interference.

CAUTION. Mercury lamps give off ultraviolet radiation which is bad for your eyes. Do not look at the bulb if the lamp does not have a filter on it.



You will use thin film interference to measure the thickness of a piece of aluminum foil. The thin film in this case is made of air, sandwiched between a pair of glass plates. Rubber bands clamp the plates in contact at one end, while the foil holds their other ends slightly apart, making a wedge-shaped air space. This is viewed with monochromatic light from a mercury lamp, which is reflected from both the top and bottom of the air gap. Where the plates touch, the path difference between these rays is zero, and they interfere destructively there. (One of them undergoes a phase reversal on reflection.) That would be m = 0 in the equation for thin film interference. As you go toward the foil, the next dark band is m = 1, where the gap is λ/2 thick giving a path difference of (1)λ. If you count dark bands from the contact point to the edge of the foil, this tells you m at the edge of the foil. Putting this into the equation tells you how thick the gap is there, which is the thickness of the foil.

Please do not take the apparatus apart, as the glass will then probably have to be cleaned before the experiment will work again.

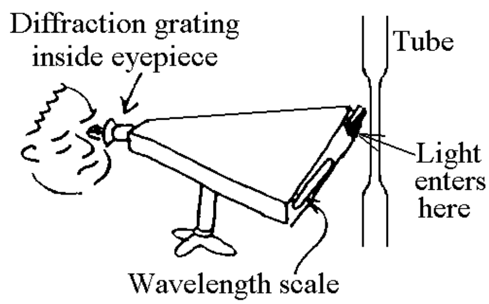
Observe interference fringes by looking at the reflection of the mercury lamp. With its green filter, this lamp radiates light with a single wavelength, 546 nm. Count (as accurately as you can) the dark interference fringes along the length of the air wedge. Moving some sharp pointer, such as a pencil, along the glass will help you keep track of where you are as you count. You will have to move the lamp to see them. Use this number to compute the thickness of the foil. Don't be concerned if you are not getting quite the same thing as the group next to you; a little dust or a wrinkle in the foil could hold the glass farther apart than for another group.

Experiment13: The Atom

Part 1: The hydrogen spectrum.

You will compare observed and theoretical wavelengths for the three most prominent visible lines in hydrogen. Hydrogen in a glass tube is excited by an electric current, making it glow. The light enters a spectroscope, which is a device containing a diffraction grating and a wavelength scale. The grating bends different colors into different directions, making them appear at different points on the scale. You then calculate the wavelengths from the Bohr model, and see if its predictions match what you saw.

CAUTION: The spectrum tube operates at 5000 volts. The metal connections are not normally exposed, but be careful if you do something abnormal. Also, turn the tube off when not in use.



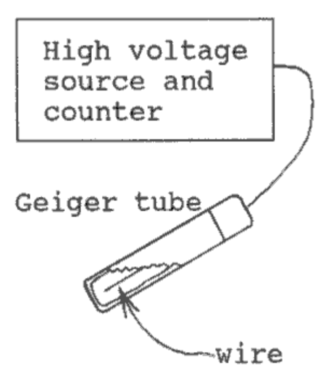
1. Put the spectroscope on books to get it the same height as the narrow middle part of the glass tube. Check that the opening where light enters the spectroscope isn't all the way shut. Put the opening about an inch from the tube, then while looking in the spectroscope, slowly turn it one way or the other until you see bright colored lines appear.

2. There should be three bright lines, and maybe some fainter stuff you can ignore. Record the colors and wavelengths, which are given in nanometers. If they're too hard to see with the overhead lights on, turn them off. If you do that, ask for a light to shine on the white part of the spectroscope labeled "wavelength scale" on the diagram, so you can see the numbers.

3. As explained in class, the Bohr model predicts that the wavelengths ought to be given by $1/\lambda = R(1/n_f^2 - 1/n_o^2)$. Use this to calculate the wavelengths given off when an electron drops from n = 3 to 2, from 4 to 2 and from 5 to 2.

4. Compare the wavelengths you saw through the spectroscope to what you calculated.

Part 2: Radioactivity.



We detect radiation with a Geiger tube. In the center of the tube is a wire charged to a high electric potential. An alpha, beta, or gamma ray entering the tube can break apart atoms of gas or atoms in the walls of the tube, into free electrons and ions. The electrons rush toward the charged wire, ionizing more gas atoms on the way by hitting them, so that an avalanche of electrons crashes into the wire. The electrical pulse produced is counted by an electronic device. Instead of using a traditional counter, it is more economical to simulate one with a computer. The number of pulses registered in some time interval measures the amount of radiation entering the Geiger tube.

CAUTION: The radiation sources are embedded in green and orange plastic discs. They are weak enough to be handled without special precautions, but avoid unnecessary contact: Don't play with them. Don't put them in your pocket.

Setup:

1. Mount the Geiger-Muller Counter on a ring stand, with the bottom of the tube about one centimeter above the table. Do NOT remove the cap from the end of the tube or you will expose a delicate, easily broken part.

2. Plug the counter into channel 1 of the interface. Connect the interface to the computer and turn them both on. Open PASCO Capstone. (Traditional Geiger counters click every time they register ionizing radiation. This one makes an annoying beep instead. The only way to stop it is to pull the plug out of channel 1 when not in use.)

3. Click Hardware Setup at the upper left. Click channel 1 on the picture of the interface. Click Geiger Counter on the menu. Click Hardware Setup again to get that out of the way.

4. Double click "Digits" about halfway down on the right. Click <Select measurement> at the upper left. Click Geiger Counts (counts/ sample).

5. It probably says 1.0 Hz at the bottom of the screen. With the down arrow, change it to 1.00 min.

A) Background radiation.

With no radioactive disk nearby, click Record near the bottom left. Nothing will appear for a minute, then it will show the number of pulses it counted. Write it down and leave the counter running. At 2.00 minutes, it will display the number it counted during the second minute. Record that and also the number of pulses during the third minute. Click Stop. Average.

The efficiency of a Geiger tube varies for different kinds of radiation and can be as low as 1%. Your body is thick and dense enough to absorb a much higher percentage. Multiply the average number of counts per minute by 100 to compensate for this. Also, you are quite a bit larger than the tube. Multiply by 100 again to account for this. You now have a crude estimate for how many times per minute natural radiation interacts with (causes ionization in) your body. Kinda scary, isn't it?

B) Penetrating ability and shielding.

1. Obtain a beta ray source (Sr-90 in a green disk) and place it below the detector.

2. Temporarily change from 1 minute to 10 seconds at the bottom of the screen. Make short data runs to see if you get a stronger signal from the disk when the side with writing on it is up or down.

(They aren't all the same.) Use it the way that gives a stronger signal.

3. Make four 30 s runs. Add and divide by 2 to get average counts per minute.

Notice that the decay rate goes up and down at random. The shorter the time interval, the more significant the variation is. This is why you need to collect data for a couple of minutes each time, to average this out. Now that you have seen this, just do 2 minute runs and divide by 2.

4. Measure the counting rate with two pieces of lead stacked between the source and detector. Repeat with the same thickness of aluminum, and then cardboard.

5. Replace the beta source with a gamma source (Cobalt-60, orange disk). Do not use one that says "old"; that's for part (C). It makes less difference which side of the disk is up. Let's go with writing side on the bottom. Repeat what you did with the beta source.

6. Conclusions:
    a. Compare the penetrating ability of beta to gamma rays. That is, for which kind of rays does a larger fraction of the rays get through a material?
    b. Compare the effectiveness of these three materials in blocking out radiation.

C) <u>Radioactive dating</u>.

You will determine the age of an old Co-60 sample by comparing its activity to the newer one you just measured.

1. Put the old gamma ray source under the tube. Have it the same way you had the other one: Manufacturer's label on the bottom, handwritten paper tag on top.

2. Determine the counts per minute, as before.

3. The half-life of Co-60 is printed on the disk. Calculate the time it would take for the newer sample to decay down to the activity of the older sample. (The samples were not made very precisely; some were more radioactive than others when new. So, which ones you happened to pick up can affect your answer. What you get may differ from other groups by a few years.)

4. The year the newer one was made is printed on it. According to your measurements, in what year was the old one made?