Physics 114 and Physics 214 Lab Manual
Spring 1999

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Preface

This is a first attempt to create a lab manual for second-semester physics at Black Hills State University. This manual was created by collecting the individual labs that were used in Physics 213 in the spring of 1998, making necessary corrections, and then adding new materials to take advantage of equipment that has been purchased recently.

As the first edition of the physics lab manual, there may be many examples of mistakes and/or lack of clarity. I welcome suggestions that could be incorporated into the next version of this manual.

My hope is that the manual will be especially useful in planning future improvements to the physics laboratory. The university has spent several thousand dollars for Pasco computer interface systems that are used extensively in these lab exercises. Hopefully this document will help future instructors make wise choices on where further improvements should be made.

As the equipment base for physics lab has been changing, it has not been possible to describe equipment operation in this manual with the degree of detail that may be necessary. It may be necessary to refer students to the Pasco manuals (available in the physics instructor's office) or other supporting documentation.

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Contents

Lab 1

Electrostatics

1.1 Charge on scotch tape

Scotch tape that is stuck to a surface and then removed acquires a charge. Two pieces of tape that are charged this way will acquire the same sign of charge and, thus, will repel.

1. Make a stand which will allow you two hang two pieces of tape directly across from each other. Before charging the tape strands, hang the strands from the stand to see how much they repel or attract each other already. There probably will be some force as the strands acquire charge when removed from the tape roll.

2. Charge your pieces of tape and attach them to opposite sides of the stand like below:

   .

3. Immediately after putting the tape on the stand, measure the distance between the bottoms of the tape strands using a measuring device that doesn't strongly influence the orientation of the strands (some rulers are strongly attracted to the charged tape strands). It will also help to keep your hands away from the tape strands while obtaining the measurement (*i.e.*, hold a rule by its ends while taking the measurement in the middle).

   Measure this distance every thirty seconds for about three minutes (or longer, if the distance is still changing substantially after this amount of time). Make a table showing distance versus time.

4. What happens to this distance as a function of time? What is your explanation for this?

5. It is also possible to oppositely charge the tape strands so that they attract. To verify this, place one tape strand on a surface and then another tape strand of top of the first piece. Pull the tape off the surface and then pull the strands apart.

   Do the strands act as if they have opposite charge?

1.2 Charge detection

In the following, charged tape strands will be used as detectors of charge. Create a charged piece of tape by applying and then removing the tape from the surface. Periodically repeat this to ensure the tape is always charged.

1. Rub a plastic rod with a piece of cloth. After rubbing, test to see whether the rod has charge by bringing it near a charged piece of tape. What happens? Does the rod have the same or opposite charge as the tape?

2. Try to discharge the plastic rod by rolling it across a metal object. Next, bring the rod near the tape strands. Have you succeeded in reducing the charge on the rod? State your reasoning.

   To make sure that the amount of charge on your strip is low after touching metal, repeat a couple cycles of charging your strip by rubbing, testing the charge, discharging by touching the metal, and testing again.

3. Rub an acetylene (clear) strip with cotton or silk. Test the charge on the strip. Is the charge the same or opposite to the charge on the tape? State your reasoning.

4. Because of a process called induction (which we will talk about on Wednesday), an uncharged metal object will be attracted to an object of either plus or minus charge. To see this, bring a coin near a charged piece of tape. What happens? Discharge the coin by touching it against a large metal object. Does this eliminate the attraction between the tape and the coin?

1.3 Charge on a conducting ball

We will use Newton's and Coulomb's law to determine *approximately* how much charge we can dump on a conducting ball.

The first step is to practice putting charge on a conducting ball. To do this charge a plastic rod. Next, bring a hanging conducting ball towards the rod. It will first be attracted to the strip and stick to it. However, the ball will shortly become charged and will then repel from the rod.

Use the diagram on the board for the following:

1. Charge two conducting balls.

2. Have one member of the group hold the strings for the conducting balls so that the strings come together at the point where they are held.

3. Each ball should hang the same distance from this point.

4. Since the balls are charged, they should push each other apart. If they still are touching, you need to try to charge them more.

5. When they are repelling, estimate with a ruler the center-to-center distance (r) and the length of string from the holder's hand to the ball (l). That's all you need to measure for now.

6. Obtain the mass for each ball on the electronic scale.

7. The board contains a derivation of how to obtain the product $q_1 q_2$ using this information and Newton's laws. Write down your result for $q_1 q_2$.

8. Assume that $q_1 = q_2$, what is the charge on each ball in units of Coulomb's?

9. How many extra (or missing) electrons does this correspond to for each ball?

Lab 2

Equipotential Lines, Electric Fields, and Capacitors

2.1 Introduction

The equipment for this experiment consists of 1) weakly conducting sheets, 2) cardboard holders for these sheets, 3) a DC voltage source (6 V battery, DC power supply, or a Pasco power amplifier), 4) a voltmeter, and 5) graph paper.

Each weakly conducting sheet includes two or three patterns made with highly conducting ink. Voltage is nearly constant over a single, connected conducting pattern. Voltage varies as you move through the rest of the conducting sheet.

The voltage difference between two of the conducting patterns is fixed by attaching the patterns to a DC voltage source. The connection is made with a wire running from a positive or negative terminal of the source to a conducting pattern where it is stuck with a stick pin. The potential difference between the two highly conducting patterns (which you can measure with a voltmeter) is nearly the same as the potential difference between the leads coming from the voltage source.

The conducting sheets have centimeter grids which will allow you to subsequently record your measurements on a normal sheet of paper (don't write on the conducting sheets).

Each of you should turn in a separate lab report with answers to all questions. However, each group may turn in a single set of graphs which includes the group members' names.

2.2 Equipotential Lines

There are three patterns available. Follow these instructions for each of the patterns.

- Connect the plus and minus terminals of the voltage source to conducting patters on the sheet. For groups with a variable voltage source, fix the voltage to be 6 Volts DC.
- Voltages are always defined with respect to a reference. We will use the pattern connected to the negative terminal as the reference. All voltage readings then should be positive. Connect the "minus" terminal of a voltmeter to the reference pattern.
- Connect the other voltmeter lead to a probe wire. As the probe is touched to points on the sheet, you should observe voltage readings between 0 and 6 volts.
- Starting with 1 Volt, locate a reasonable number of points on the graph having that voltage. Mark these points on graph paper (not the conducting sheets). Draw the 1 Volt equipotential line when you have enough data to interpolate between points to make a smooth curve. Equipotential lines form closed curves, although much of your curves may not fit on the sheet of paper.
- Repeat this for 2, 3, 4, and 5 volts.
- Represent the electric field by drawing several electric field lines through the equipotential lines. Be sure to indicate the direction of the field.
- Find the spot on the graph where the equipotential lines are bunched closest together. Estimate the size of the electric field at that spot using

$$E = \frac{-\Delta V}{\Delta l}. \tag{2.1}$$

Please answer the following questions.

1. One pattern consists of two small circles whose potential difference is fixed with the voltage source. Another large conducting pattern is situated near the center. What is the behavior of the voltage both on and inside of the pattern?
2. On this same sheet, another circle has been cut to represent an insulating region. Is the voltage constant on the edge of this region?
3. In class it was stated that the electric field between the plates of a parallel plate capacitor is constant and runs directly between the plates. Is this always true? If not, when is it false? Use your measurements in explaining your answer.

2.3 Charging and Discharging a Capacitor

Connect the terminals of a capacitor to a 6V battery or DC power supply. As long as the capacitance is not too large, the capacitor should charge quickly. After waiting a few seconds, disconnect the capacitor terminals from the battery.

1. Use a voltmeter to obtain the voltage across the capacitor. How does this compare to the source voltage?
2. Repeat this with two more capacitors (having different values of capacitance). What voltage remains across the capacitor terminals after the capacitors are disconnected from the source?
3. Connect the voltmeter to a charged capacitor so that you can continuously monitor the voltage for about three or four minutes. What happens to the voltage reading during that time? Why does this happens?
4. Take a charged capacitor and connect the two terminals to a common ground (some conducting object) for at least a few seconds. What happens to the voltage across the terminals? Why?
5. Once again take a charged capacitor and this time only connect *one* of the terminals to the ground for a few seconds. Now measure the voltage across the terminals. What happens to the voltage? Did the terminal that was attached to ground dump its charge? Why or why not?

Lab 3

Internal resistance of a battery and resistor networks

3.1 Internal resistance of a battery

The voltage across the terminals of a battery decreases as current flow increases:

$$V_b = \mathcal{E} - I\,r, \tag{3.1}$$

where I is the current flow through the battery, r is the battery's internal resistance, and $\mathcal{E}$ is the emf of the battery - the voltage produced in the absence of current flow. In this experiments, we will show that V_b decreases as current increases and estimate the value of r for a battery.

- First measure $\mathcal{E}$ by connecting a voltmeter across the battery terminals when the battery is not driving a current. Use a digital voltmeter to get your result to within 0.01 Volts.
- A resistance box will be connected in a loop with the battery. Before making this connection, dial the resistance to 10,000 Ω so that the current will be low when the circuit is completed. If a large current is drawn from the battery, the battery voltage will drop and you will need to wait several minutes for it to recover before you can proceed.
- With the connections in place, measure V_b, the voltage across the battery terminals while current is drawn.
- Use the data you have so far as the first line in the following table:

R (Ω)	V_b (volts)	$I = V_b/R$ (amps)
10,000	6.23	0.000623

- Continue obtaining data for this table. You should use the following R values (in Ω's) on the resistance box: 1000, 500, 200, 100, 80, 60, 40, 20, 10, and 5. **You must start with large**

R values and progressively work towards the smallest values for this measurement to work. Be careful not to dial through smaller resistances (especially zero!) while bring R down to the desired value.

- You will be plotting and analyzing your results using Maple V. This program is accessible through your lab computer (if it is networked) or through terminals in the physics and math computer lab.

- Start Maple V from your computer. Your worksheet space will open when the program starts. Start by typing in your current and voltage data as follows:

```
> volts := [6.01, 5.95, 5.94, 5.92, 5.90];
> current := [0.1, 0.2, 0.3, 0.32, 0.4];
```

  Of course, you will have more items in each list and your numbers will be different.

- Have Maple V obtain a linear fit of your battery voltage versus current data. To do this type:

```
> with(stats);
> fit[leastsquare[[i,v], v = emf - r*i, {emf,r}]]([current, volts]);
```

  If this has worked then Maple will print your fit:

$$v = \text{emf} - r * i$$

  The number appearing for emf should approximately equal the battery's voltage when there is no current. r, the number multiplying i in the fit, is the estimate for the internal resistant of the battery.

- Produce a plot of your data and fit to the data and then send this to the printer. To do this continue typing in your Maple worksheet.

```
> plots[display]({plot(emf - r * i, i = 0 ..  i_large, color=black)},
{statplots[scatterplot](current, volts, color=black)});
```

  Here you will need to substitute the numerical values you have obtained for "`emf`" and "`r`" when you type the above command. Also, i_{large} should correspond to the largest current in your data set.

  A plot of your data and straight line fit should appear. If it hasn't, make sure that you have typed all the parenthesis, braces, and brackets exactly as they appear in this example. When the plot appears, hit the print button on the Maple V menu to get a printout of your results.

- Put labels on the x and y axis on your printout. Also include the values of emf and r. All members of the group should include in their personal lab reports the values of emf and r that were obtained.

3.2 Network of resistors

A set of three resistors will be provided to each group. The resistance value for each resistor is determined using the color code given on hand-outs provided to each lab group.

- Connect the resistors in series and connect this network to a voltage source.
- Make a sketch of your series network with the resistance given for each resistor. Measure the voltage across each of the resistors. Include these measurements on your sketch.
- Show that your voltage measurements agree (or don't agree) with circuit theory:
  - Calculate $R_{eff} = R_1 + R_2 + R_3$,
  - determine $I = V_{source}/R_{eff}$, and
  - calculate the expected voltage for each resistor, $V_R = I\,R$.
- How close are your measurements to the calculations?
- Calculate the power dissipated by each resistor ($P_R = V_R^2/R$) and the total power used by all three resistors.
- Reconnect the the resistors in parallel and attach them to your source. Make a sketch of this circuit with the resistances labeled.
- Measure the voltage across each resistor and list your result on the graph.
- Calculate the power used by each resistor and the total power used by all resistors.
- Which arrangement uses the most power, the series or parallel arrangement?

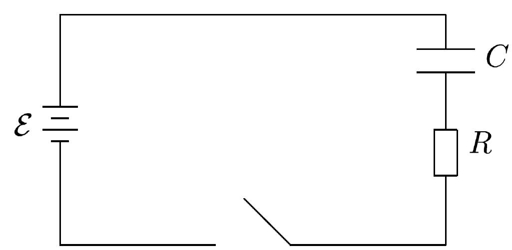
Lab 4

RC circuits and Resistor Networks

4.1 Introduction

Every circuit has some time dependence in its behavior. For circuits containing only resistors and "constant" voltage sources a steady state (*i.e.* a constant current through each loop) is reached quickly after connections are made on the circuit. However, a circuit with both capacitors and resistors has observable time-dependent properties.

In the following diagram, an uncharged capacitor and resistor are connected in series to a DC voltage source. Prior to forming the connections, the capacitor should show a small voltage of zero; to ensure this is the case, periodically discharge the capacitor until you start recording data. Since no current is flowing, the voltage across the resistor is also zero.



When the loop is closed, Kirchoff's Loop Rule states the sum of the potential drops across the capacitor and resistor are equal to the battery voltage, so we have

$$\mathcal{E} = V_R + V_C \quad (4.1)$$

$$\mathcal{E} = I\,R + Q/C. \quad (4.2)$$

Immediately after connection, charge has not had a chance to accumulate on the capacitor, $Q(t = 0) = 0$ and $I(t = 0) = \mathcal{E}/\mathcal{R}$.

The capacitor then begins to charge, taking some of the source voltage and forcing a continuous drop in the current. As shown in class, the time-dependent charge and current are

$$I(t) = (\mathcal{E}/R)\exp(-t/RC) \tag{4.3}$$
$$Q(t) = (C\mathcal{E})\,(1 - \exp(-t/RC)). \tag{4.4}$$

So, for times long compared to RC the capacitor becomes fully charged and accounts for all of the voltage drop. The capacitor and resistor voltages as a function of time are given by

$$V_C(t) = \mathcal{E}(1 - \exp(-t/RC)\,) \tag{4.5}$$
$$V_R(t) = \mathcal{E}\exp(-t/RC) \tag{4.6}$$

After the capacitor is fully charged, the battery is removed from the circuit. The charge remains on the capacitor until the circuit is closed again. If $t = 0$ corresponds to the time when the resistor and capacitor form a closed circuit, then voltage will continually drop across the conductor as charge is able to flow through the resistor. The capacitor and resistor voltage has the following time dependence in this case

$$V_C(t) = \mathcal{E}\exp(-t/RC) \tag{4.7}$$
$$V_R(t) = \mathcal{E}\exp(-t/RC). \tag{4.8}$$

4.2 Charging

1. Choose a resistor and capacitor such that the capacitance is greater than 200μF and RC is about 60 seconds.

2. Connect the resistor and capacitor in series with a power amplifier. Include a switch in the series loop so that current does not begin to flow until you are prepared to record data. The power amplifier will provide 3 volts

3. Start the Science Workshop program on the lab computers.

4. Under the file menu, open “rc_bhsu.swp” This will contain many of the settings you will be using for this experiment.

5. The experiment is set up to record and graph the capacitor and resistor voltages using voltage probes connected to analog channels “A” and “B” respectively. Make the necessary connections with the voltage probes.

6. Check your voltage probe connections to the capacitor and resistor. Make sure that the red wire of the probe is connected to the positive side of each of these circuit elements.

7. Just before closing the switch to start the flow of current, start recording data. When data starts being displayed on the graph, then close the switch. Continue recording for about three minutes.

8. There are two graphs made for the resistance measurements. One is V_R vs. time. The other curve represents $\ln(V_R)$ vs. time. This latter curve is especially usefully as it should nearly be a straight line for an RC circuit:

$$\ln(V_R) = \ln(\mathcal{E}) - t/RC \tag{4.9}$$

   Using the statistics menu on the graph, find the slope of this curve. Make sure that the slope of the curve is obtained using only the part of the graph where current is flowing.

9. Print your graph data ($V_c(t)$, $V_R(t)$ and $\ln(V_R(t))$) from Science Workshop including the statistics window from the regression fit for $\ln(V_R(t))$) .

10. How does the slope you obtained compare to the actual value of $-1/RC$?

4.3 Discharging through a resistor

Your capacitor should have a significant charge at the end of the previous experiments. We will exam the resistor and capacitor voltages as we discharge the capacitor through the resistor.

1. Open the switch in your circuit containing the voltage source, resistor, and capacitor. This will stop the flow of charge until you are prepared to monitor the discharge of the capacitor.

2. You no longer want the voltage source in the circuit. Disconnect the two wires that go to the source. Next, connect the same pair of wires together. You should now have a loop consisting of the capacitor, resistor, and an open switch to stop the flow of charge.

3. Before proceeding, it will be necessary to switch the red and black wires of the voltage probe connected to the resistor. This is necessary since the flow of charge will be in the opposite direction compared to when the capacitor was charging. Switching the wires will allow the resistor voltage reading to be positive (which is necessary for when we look at the natural log of the resistance voltage).

4. Start recording data. Data should immediate appear in your graphs. Once data appears, close the switch to allow the flow of current through your circuit. Continue recording for about three minutes.

5. There are two graphs made for the resistance measurements. One is V_R vs. time. The other curve represents $\ln(V_R)$ vs. time. This latter curve is especially usefully as it should nearly be a straight line for an RC circuit:

$$\ln(V_R) = \ln(\mathcal{E}) - t/RC \tag{4.10}$$

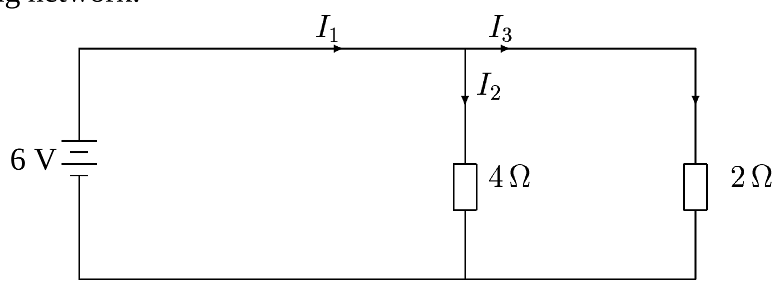
   Using the statistics menu on the graph, find the slope of this curve.

6. Print your graphs and statistics output.

7. How does the slope you obtained compare to the actual value of $-1/RC$?

4.4 Numerical analysis of networks

Consider the following network:



Kirchoff's rules provides the following set of equations for analyzing this network.

$$\begin{aligned} I_1 &= I_2 + I_3 \\ 6\text{ volts} &= 4\Omega\, I_2 \\ 6\text{ volts} &= 2\Omega\, I_3 \end{aligned}$$

Of course, this is a purely parallel circuit for which it is relatively simple to find I_1, I_2 and I_3. However, we will use this simple example to demonstrate how a computer algebra program, Maple V, can be used to solve for the currents. After doing so, we move to a more complicated example where solving without the use of a computer is algebraically tedious.

To solve a set of equations like the above, do the following:

1. Start the Maple program on your computer.

2. Once Maple has started, type in the set of Kirchoff Law equations as follows:
```
> equation1 := I1 = I2 + I3;
> equation2 := 6*volts = 4*ohms*I2;
> equation3 := 6*volts = 2*ohms*I3;
```

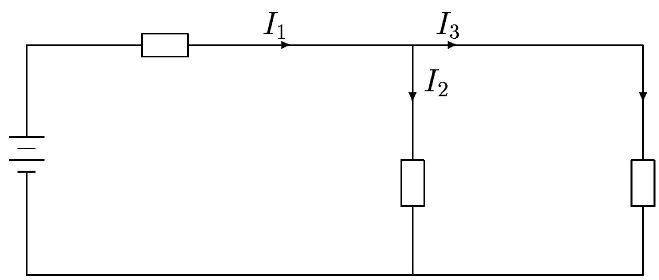
3. Now tell Maple to solve the equations:
```
> solve({equation1,equation2,equation3}, {I1,I2,I3});
```

4. This should produce the correct values of the currents in units of volts/ohms; of course, volts/ohms are just amps.

5. To verify that the results are sensible, draw a diagram of the circuit with the currents listed. Next to each resistor, give the voltage drop across that resistor that is obtained from $V_R = IR$. Do the voltages seem reasonable? Why?

Now consider this slightly more complicated circuit. **Each student's instruction sheet has a circuit of similar structure, but the voltage and resistance values are different. Thus, each**

person will have a different set of results, but you are encouraged to work together. (Note: Numerical R and $\mathcal{E}$ values are to be put in manually by the instructor.)



1. Make a drawing of your circuit with the voltages and resistances labeled.
2. Use Kirchoff's laws to obtain a set of three equations for the three currents that are in your circuit.
3. Use Maple to solve for the currents.
4. List the currents you obtain on your circuit diagram.
5. Compute the voltage drop across each resistor. List the voltages on the graph.
6. Verify (and show your work) that for each loop on your circuit that the sum of the voltage drops equals the voltage gains.

Lab 5

Magnetic Fields and Forces

5.1 Magnetic Field Lines for Magnets

Place a bar magnet on a blank piece of paper. Trace around the magnet so you can ensure that the magnet stays in place. It will also be helpful to place the magnet on the graph paper as symmetrically as possible.

1. For several points on the graph paper determine the direction of the magnetic field with a compass and draw small magnetic field vectors on the graph paper. Make enough vectors to establish the pattern the magnetic field lines make around the magnet.

2. Like the electric field, you can produce magnetic field lines by continually connecting magnetic field vectors along the direction they are pointing. Make several of these. To produce good lines you will probably need to make more magnetic field direction determinations with the compass. A good set of field lines will include some that leave and reenter the graph paper. You can use the compass to trace out these lines as the leave and reenter the paper. It is possible in some case to also make reasonable assumptions about the shape of the field lines (based on symmetry) to determine the relationship between where field lines leave and reenter the graph paper.

3. The electric field for a system with net charge has field field lines extending to infinity. If the system has a net charge of zero, then field lines originate from a positive charge and terminate at a negative charge.

   The corresponding law for magnets is that no lines *ever* go off to infinity. In fact for any closed surface the same number of magnetic field lines enter as go out.

   This means that magnetic field lines form loops. It is difficult to show this with a compass (you might try by passing the compass over the top of the magnet), but the magnetic field continues from the south pole to the north pole through the magnet, thus completing the loops. Draw the "theoretical" lines through the magnet as dashed lines to complete the field line loops.

4. As you you move the compass around in a closed path around the entire magnet, how many times does the compass needle spin around? See if the this number changes if the compass passes outside the north pole as before, but passes through the magnet just above the south pole. Keeping the path near the north pole the same, progressively increase the distance the compass passes above the south pole (moving towards the north pole) through the middle of the magnet while forming a closed path. Note when the number of revolutions the compass needle makes changes. Indicate these points by drawing a line through your outline of the bar magnet on your field line drawing.

   Map the field lines for the horseshoe magnet and the funny-shaped solid magnets.

5.2 Magnetic Field for a Solenoid

1. Map the magnetic field for a solenoid. Place the solenoid symmetrically on a blank sheet of paper. Hold the compass at the level of the solenoid while drawing the magnetic field vectors on the paper.

2. About how far away must you be from the end of solenoid before the Earth's magnetic field becomes stronger than the field from the solenoid?

5.3 Force on a stream of electrons

Activate the electron gun in the e/m apparatus by supplying 6.3 volts the heater (which boils electrons off a metal surface) and then applying about 150 volts to the accelerator plates. This should produce a straight, glowing stream as electrons collide with helium gas in the apparatus.

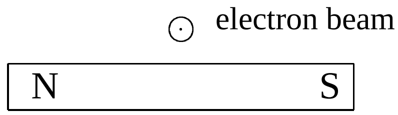
1. We will try to verify that the magnetic force applied to the electrons obeys the right hand rule. First, determine the pole structure of a permanent magnet (don't rule on the "N" and "S" on the two ends).

   To do this, first test a compass by having it respond to the Earth's magnetic field. The field lines for the Earth point in the geographic north direction. This will tell you how the compass needle aligns in a magnetic field.

   Now bring the compass to the pole marked "N" on your magnet. Verify whether or not it really is a north pole.

2. Once you have determine the North pole of the magnet, verify that off the side edge of the magnet, about half-way between the poles, the field points from north to south.

3. Place the magnet underneath the electron beam so that the north pole of the magnet is to the left as you look at the oncoming beam:



4. Which direction is the beam deflected? Does this agree with the right hand rule?

5.4 q/m for electrons

As current is sent to the Helmholtz coils, a nearly uniform magnetic field results near the center. As a result, the electrons begin to follow circular paths. The radius of the path is given by

$$r = \frac{m\,v}{q\,B} \tag{5.1}$$

where m is the electron mass, v is the electron velocity, q is the electron charge, and B is the magnetic field. B can be increased by the stepping up the current going into the coils (verify that this decreases r). v can be increased by stepping up the acceleration voltage (verify this increases r).

Equation (5.1) can be manipulated to isolate the ratio of charge to mass:

$$q/m = \frac{v}{B\,r}. \tag{5.2}$$

The electron velocity, v, can be obtained from the acceleration voltage using:

$$\frac{1}{2}mv^2 = qV, \tag{5.3}$$

or

$$v = (2qV/m)^{1/2}. \tag{5.4}$$

The field produce at the center of the Helmholtz coils is determined by the current through the relation:

$$B = \frac{N\mu_o I}{(5/4)^{3/2}a}\,, \tag{5.5}$$

where N is the number of turns in each coil (130 for our coils) and a is the radius of the Helmholtz coils.

Substituting Eqs. (5.4,5.5) into Eq. (5.2) gives

$$q/m = \frac{(2qV/m)^{1/2}\,(5/4)^{3/2}a}{N\mu_o I\,r}. \tag{5.6}$$

Solving for q/m gives

$$q/m = \frac{2V(5/4)^3 a^2}{(N\mu_o I r)^2}. \tag{5.7}$$

1. Obtain q/m for electrons by measuring r for a circular path, the radius a of the Helmholtz coils, and the current, I, and voltage, V, used. Substitute these values in Eq. (5.7).

2. Compare your experimental value to q/m obtained using the known values for q and m.

3. The base of the tube containing the electrodes can turn. Turn this 90^o so that electron beam is initially directed on a line going through the center of the coils. What does this due to the magnetic force on the electrons? Why does this happen?

Lab 6

Lenz's Law, Faraday's Law, and LR Circuits

6.1 Lenz's Law

This first part of the lab is qualitative. The main purpose is to see Lenz's Law in action and understand how it works.

1. Use a compass to determine the direction of the magnetic field between the poles of the large horseshoe magnet. Make a sketch of the top view of the magnet with a single arrow showing the direction of the field between the poles.

2. Connect the coil containing approximately 10 turns in series to the green mechanical ammeter. If an emf is generated in the coil, then a current will be produced in the loop which will be detected by the ammeter.

   It is essential to recognize the convention for the "+" and "—" terminals of the ammeter:

   - When current comes into the "+" terminal, the current reading is positive.
   - When current comes into the "—" terminal, the current reading is negative.

   Move the coil in and and out of the center of the horseshoe magnet. You should see both positive and negative currents.

3. Hold the coil far away from the magnet. Examine the winding of the loops and how the wires are connected to the ammeter.

   Knowing that the induced current in the loop tries to oppose the change in flux through the loop, predict whether the ammeter will register a positive or negative current when the loop is inserted into the magnet.

4. Once all members understand completely the behavior of the current as the loop moves into the magnet, then predict (on the basis of Lenz's law) what the sign of the current will be when the loop is pulled away from the magnet.

5. Turn the magnet upside down, what happens to the direction of the currents with respect to the original orientation of the magnet? Explain why this is the case.

6. Before proceeding to the next section, have your group demonstrate to the instructor how this exercise validates Lenz's law.

6.2 Faraday's Law, magnetic field strength

Construct the following circuit:

The coil is the set of loops from the previous experiment. The resistor is a resistance box set to 1000 Ω. The voltmeter is the voltage probe from the Pasco computer station.

The idea here is that you will use the computer to record the time-dependent voltage induced as the coil is rapidly brought towards and into the large magnet. Using Faraday's Law, we can use the voltage vs. time curve to estimate the magnetic field strength between the poles of the large magnet. First I provide the mathematical steps to show how the measurement ideally works. After that, I provide specific instructions on how to set up the computer to make the measurement work okay.

Faraday's law states that the voltage or emf induced in the loop is given by

$$\mathcal{E}(t) = -N_{\text{loops}} \frac{d\Phi_M}{dt} \tag{6.1}$$

where $d\Phi_M/dt$ is the rate of change of the magnetic flux through each of the loops.

If the voltage produced by the loops is integrated over time we have

$$\int_{\text{start}}^{\text{end}} \mathcal{E}(t)\, dt = -N_{\text{loops}} \int_{\text{start}}^{\text{end}} \frac{d\Phi_M}{dt} dt \tag{6.2}$$

$$= -N_{\text{loops}} \int_{\text{start}}^{\text{end}} d\Phi_M \tag{6.3}$$

$$= -N_{\text{loops}} (\Phi_M(\text{end}) - \Phi_M(\text{start})\,). \tag{6.4}$$

For those of you who have not had calculus, Eq. (6.2) is interpreted as follows: if you sum up the induced voltage over time, the sum is proportional to the change in the magnetic flux through the loop during that time.

If the coil starts far away from the magnet, then $\Phi_M(\text{start}) = 0$. Also, if we assume that the magnetic field is constant over the area of the loops when the coil is between the poles of the magnet, then $\Phi_M(\text{end}) = BA$ where B is the magnetic field between the poles of the magnet and A is the area of the loops.

Finally, we end up with the equation

$$\int_{\text{start}}^{\text{end}} \mathcal{E}(t)\, dt = -N_{\text{loops}} BA. \tag{6.5}$$

The integral will be measured with the computer, you can count the the number of loops on the coil, and you can estimate A by using a ruler to measure the loop radius. B is the only unknown, so you will be able to make an estimate for B using the above equation.

1. Initialize the Science Workshop software on the computer.

2. Put a voltage probe into analogue channel A. Set up the software so a graph is produced for this channel.

3. This experiment will need to be done rapidly, so some special settings must be made. Under the experiments menu, set the sampling rate to at least 1000 Hz (1000 voltage samples are taken each second).

4. Now the fun begins. You are going to record voltage versus time as the loop is inserted between the poles of the magnet. However, this will have to be fast! Otherwise the voltage induced in the loops will not be larger than the electronic noise of the Pasco system.

   It will be best to start and stop recording by working from the “experiment menu” rather than the buttons on the screen. Have one group member start recording and, after recording starts, another group member should quickly jam the coil between the poles of the magnet and hold the coil in place while another group member stops the recording.

   The start and stopping times for recording *do not* need to be perfectly synchronized with the motion of the coil. The relevant part of the recorded data can be selected after the experiment is completed.

5. Display the voltage versus time data you just obtained. You should see alot of noise with one strong peak having to do with the motion of the loop. Zoom in on the the part of the graph where the peak is found.

6. Use the statistics menu to integrate the part of the curve corresponding to the loop motion. The computer should give you a result in units of volt-seconds. List your result for this integral. Also determine the number of loops on your coil and estimate the area of a loop. List those values as well.

7. Use these results in Eq. (6.5) to obtain an estimate for the magnitude of the magnetic field, in Teslas.

8. What is the ratio of this estimate of the magnetic field strength to the Earth's magnetic field (approximately 4×10^{-5} Tesla)? How does this field compared to that used in magnetic resonance image (approximately 1 Tesla)?

6.3 LR Circuits

Create an LR circuit by connecting the copper-colored inductor in series with a variable resistor (set at 10 Ω) and the Pasco power supply. Also attach a voltage probe across the variable resistor.

When a switch is thrown and voltage is produced by the power supply, then the current gradually rises as it overcomes the back emf of the inductor. As a consequence, the voltage across the resistor (which is proportional to the current), has a time-dependent behavior that is given by,

$$v_R(t) = V_{R,M}[1 - \exp\{-t/(L/R)\}]. \quad (6.6)$$

L/R determines how quickly the resistance voltage reaches its maximum value. When $t = L/R$, then the resistance voltage will have reached 63% of its maximum value. So, if we graph the resistance voltage versus time, we can estimate the value of L/R.

1. First set up the voltage source.
   - Set the voltage level to be as high as possible (about 10 V).
   - The type of signal we want to use is one that starts at zero, jumps to its maximum, goes back to zero, etc. Press the button for that type of signal.
   - Set the frequency of the signal to 100 Hz.
   - Select "auto mode." With this mode, the source starts producing voltage when the record button is pushed and stops when recording stops.
2. Set up the voltage probe.
   - Configure the voltage probe to produce a graph as output.

- On the graph, there is a button for including other graphs along with the probe voltage. Enable a second graph which shows the output voltage.

3. Set the sampling frequency.

   - Under the experiment menu, choose “sampling options.”
   - Under the dialog box this produces, several parameters must be set:
     - Set the sampling frequency to 10,000 Hz
     - For the “start condition” select “channel.” Choose to have the output channel start recording when its voltage reaches 4 Volts.
     - For the “stop condition” choose “time.” Have recording stop 0.02 seconds after it starts.

4. You are ready to proceed. Under the experiment menu, select the record button. Recording should automatically stop almost instantly. However, it will take some time for the computer to assemble and display the 0.02 seconds of data.

5. On the graph, you should see the step-voltages of the source displayed along with the “slowly” rising voltage of the resistor.

   Use this graph to estimate the time it takes for the resistance voltage to go from 0 V to 63% of its maximum value. You can use the zoom button on the graph to help you estimate where this occurs.

   List the time that you obtain.

6. This time value is your estimate of L/R for your circuit. With a value of R for the circuit, you can estimate of L for the inductor. However, you can’t use just 10Ω for R since the inductor has a substantial amount of resistance that must be included.

   Use the digital multimeter to obtain the resistance of the inductor coil and add this value to 10Ω to obtain the total resistance of the circuit. Use this R value to estimate L for the inductor.

7. Compare the L value you obtain to the theoretical value for a solenoid,

$$L = \frac{\mu_o N^2 A}{l}. \tag{6.7}$$

   According to the manufacturer of the solenoid, l =10.6 cm, A = 5.7 cm^2, and N = 2920.

8. When the power supply voltage drops to zero, the voltage across the resistor does not immediately drop to zero. What is supplying the current to produce this residual voltage?

Lab 7

AC Circuits

7.1 Introduction to Oscilloscopes

In this lab you will use the oscilloscope mode of the Science Workshop program to analyze properties of AC circuits. The first part of the lab is designed to help you learn how to operate an oscilloscope and interpret the oscilloscope traces.

1. Set up the power supply
   - Physically connect the power supply into analog channel A. On the computer screen, drag an analog plug onto channel A and set the plug to be a power supply. (Note: The Science Workshop 750 interface has a built-in power supply that operates in the $\pm$ 5V range. The built-in power supply had not been tested as of this writing - 4/1/99, J.D.- presumably it is possible to perform this lab using this power supply.)
   - A signal generator window should pop up. Select the button to produce sinusoidal voltages. The signal generator window is also where you can change the source voltage frequency and amplitude. Set these to 100 Hz and 5 Volts respectively. You can change these settings at any time during the experiment; nothing needs to be turned off to change the signal generator parameters. Oh, ensure that the "on" button is depressed on the signal generator window.
   - Now drag an oscilloscope icon on top of the channel A plug on the computer screen. This will allow you to continually monitor the oscillating voltage source for small snapshots of time. Double click on the monitor button in the main window to start monitoring voltages on the oscilloscope window.
2. You can monitor up to three voltage sources at a time on the oscilloscope window. It is probably set up at the moment to only monitor a single voltage. On the right hand side of the oscilloscope window, you can separately configure each of the three voltages to be

monitored. Make sure that *output voltage* is the one being monitored in channel A of the oscilloscope window.

3. The time and voltage scales that are set on your computer may not be appropriate for examining the output voltage. First adjust the "time per division" (sweep time) using the buttons on the lower part of the oscilloscope window. Since a 100 Hz signal repeats 100 times per second, a reasonable time scale to use is 2 millisecond (ms) per division.

4. The voltage scale for each of the three voltage channels to be monitored can be adjusted separately on the right hand of the oscilloscope screen. Adjust the scale for the output voltage channel to be 1 V /division.

   - What is the wave period, τ, you obtain for the voltage source on the basis of estimating the repeat time observed on the oscilloscope screen? What is the corresponding frequency ($f = 1/\tau$)? Does this agree with the setting made in the signal generator window?
   - Read the maximum and minimum voltages on the oscilloscope window. Do they agree with your settings made on the signal generator?

5. If everything works so far, then practice using the frequency and time settings. The settings that you should vary are:

   - the frequency of the power source; this runs between .1 Hertz and 20000 Hertz (You can change frequency with the mouse or by typing in the number you want) and
   - the sweep time of your display; when the frequency of the source is increased, you will want to shrink the sweep time on the oscilloscope display.
   - Scan through both of the above settings until you are comfortable with being able to both produce and display signals of arbitrary frequency.

6. Turn off the monitor button in the main window before proceeding to the next step.

7. Using two resistance boxes, connect a 1000 Ω resistor and a 2000 Ω resistor in series with the AC source.

8. Connect voltage probes across each of these resistances. Plug the probes into analog channels B and C on the interface box and set the software to recognize the probes.

9. On the oscilloscope window, set the two remaining free channels to read the voltages coming from analog channels B and C.

10. Double click on the monitor button to re-activate the oscilloscope display.

11. Obtain the peak voltages for each resistor from the oscilloscope window. How do resistance voltage amplitudes compare to the source voltage amplitude?

7.2 LRC Circuits

Connect an inductor, a 100 ohm resistor (use the resistance box), and a variable capacitor (set to $1\mu F$) in series with the voltage source to make an LRC circuit.

Once you have verified that you are still able to monitor the source voltage on channel A, attach a voltage probe across the resistance box and set this to be channel B on the oscilloscope. The voltage probe for channel C will be used to measure both the inductor and capacitor voltages.

1. Fix the source voltage amplitude ($V_{s,M}$) at about 5 volts.

2. Next, you will measure the resistance voltage amplitude ($V_{R,M}$), the inductance voltage amplitude ($V_{L,M}$), and the capacitor voltage amplitude ($V_{C,M}$), all as a function of frequency. Make a table like the sample that appears below. Your table should include measurements for the following set of frequencies: $f =$ 100 Hz, 200 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 700 Hz, 800 Hz, 900 Hz, 1000 Hz, 1100 Hz, and 1200 Hz.

   You will also use your measurements to obtain the current amplitude and impedance. (Note: The following is fake data. Perform all measurements to fill the table.)

f	$V_{s,M}$	$V_{R,M}$	$I_M = V_{R,M}/(100\Omega)$	$Z = V_{s,M}/I_M$	$V_{C,M}$	$V_{L,M}$	
100 Hz	5 V	0.06 V	.0006 amps	8333 Ω	6.6 V	1.5 V	
200 Hz	5 V	0.21 V	.0021 amps	2380 Ω	6.0 V	2.0 V	
300 Hz	5 V	0.61 V	0.0061 amps	820 Ω	5.0 V	3.0 V	
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
1100 Hz	5 V	0.22 V	0.0022 amps	2272 Ω	1.0 V	5.5 V	
1200 Hz	5 V	0.06 V	0.0006 amps	8333 Ω	0.8 V	6.0 V	

3. Make a plot of impedance, Z, versus frequency, f, using Maple V. Start the program using either your computer or one of the computers in the physics lab or math computer lab.

4. Input your frequency and impedance lists into the maple worksheet (again, the input is just an example, use all of your actual data):

```
> frequency := [100,200,300,1100,1200];
> impedance := [8333,2380,820,2272,8333];
```

5. Along with a scatter plot of your data, include a plot of the predicted impedance curve. To place these together type

   ```
   > with(stats);
   > plots[display]({statplots[scatterplot](frequency, impedance,
   color = black)},
   {plot(sqrt((2.0 * 3.14 * L * f - 1 / (2.0 * 3.14 * C *f))**2 +
   R**2),
   f=0..1200)});
   ```

   In the above expression, you should substitute the actual values for L, C, and R that you are using in the circuit. C is obtained from the capacitance box, R from the resistance box, and L is obtained from the theoretical value for a solenoid:

   $$L = \frac{\mu_o N^2 A}{l}. \tag{7.1}$$

   According to the manufacturer, the number of loops, N, for your solenoid is 2920, the length, l, is 10.6 cm = 0.106 m, and the area of the loops, A, is 5.7 cm^2 = 0.00057 m^2. The magnetic permeability of vacuum, μ_o is $4\pi \times 10^{-7}$Tesla · meters/amp.

6. Chances are the curve fit to the experimental data is not perfect. The reasons for this are primarily (1) there are sources of resistance (like the coil) in the circuit that need to be accounted for by increasing the value of R and (2) some of the assumptions used in forming the L value in Eq. (7.1) are not perfectly valid.

   Try adjusting the values of L and R in the maple plot command until you obtain a curve that is a good fit to your experimental data. Once you have obtained such a fit, send the plot to the printer to include in your lab report.

7. The resonant frequency, f_o, is the frequency value for which Z is smallest. Use your plot to estimate f_o.

8. Return to the experimental setup. Set the signal generator frequency to f_o. What is the relative phase between the source (oscilloscope channel A) and resistance voltage (oscilloscope channel B) at f_o?

9. As you lower f below f_o, what happens to this phase?

10. As f goes above f_o, what happens to this phase?

Lab 8

Polarization, Color, and Refraction

8.1 Polarization

As light travels on a straight line from an object towards your eyes, the electric field can oscillate in the two directions perpendicular to the line. As you look at the object, if the oscillation of the electric field is in the left and right directions, then we say that the polarization of the electric field is horizontal. If the oscillations are up and down, the polarization is said to be vertical.

It is often the case that light emanating from an object is *unpolarized*; there is just as much horizontally polarized light as there is vertically polarized light. However, in certain situations there is significant polarization.

A polarizer is an object that allows light to pass through only if the electric field is polarized in a certain direction. Thus, for example, if a polarizer is oriented so that only vertically polarized light passes through, then horizontally polarized light is completely blocked.

Several polarizers are available to perform the following set of experiments.

1. Determine whether or not light coming from an overhead fluorescent bulb is unpolarized. To do this, examine the fluorescent bulb's light through a single polarizer. Rotate the polarizer and see if the amount of light passing through the polarizer changes as the polarizer is turned.

2. Verify that it is possible to completely block the light coming from the fluorescent bulb when you view the light through two polarizers (you will need to turn the two polarizers with respect to each other). Explain why you are able to block the light with two polarizers.

3. Light reflected from a dielectric surface is polarized. Verify that the glare from the ceiling light reflected off the floor is polarized by rotating a single polarizer and observing that

the glare is eliminated for certain orientations of the polarizer, but is unaffected at other orientations.

Repeat this in a long hallway where a glare streak appears over a long distance. Is the entire glare streak eliminated by the polarizer?

Summarize your findings.

4. If the sun does manage to come out, determine whether or not blue sky light is polarized. Do not examine the sun's direct rays as, of course, this is bad for your eyes. Compare the polarization of sky light in directions close to the sun versus sky light far way from the sun, *i.e.* from the north.

5. Scattered Light. Put a bulb over a container of water. When you stand in front of the container, you should see a reflected image of the bulb coming from the water. Examine the bulb through the polarizer so you can see both the bulb and its reflected image at the same time. Is the light from the bulb itself polarized? How about the light from the reflection? Summarize your findings.

6. FYI. High quality sun glasses use polarized lenses. These lenses eliminate the glare coming from surface reflections. In contrast, cheaper sun glasses filter light without regard to polarization; glare is not eliminated. You can determine whether or not sun glasses have polarizing lenses by observing whether surface glare appears and disappears as the lenses are turned.

7. Send a laser beam into a container with water. Unless there is a lot of junk in the water, the scattering of laser light by the water is so weak that you can't see the beam passing through the water. It is simple to verify, though, the light beam is passing through the liquid.

   Add some material (provided) to induce some scattering. Hopefully the beam will start to appear in the container as the added material scatters the laser light. If you view the beam from the side of the container, you should see that the light coming towards you is polarized.

8.2 Spectrometers

Spectrometers are used to measure the wavelength of light from a source. Most sources contain light with more than one wavelength (a laser has essentially a single wavelength).

Table top and hand held spectrometers are available. The table top models are better for getting values for the wavelengths, but hand held spectrometers are fine for making qualitative comparisons between two sources.

Be sure that the slit on the spectrometer is facing the source. Light passes through the slit and then through a diffraction grating to resolve the light into components.

1. Use a spectrometer to resolve light from a lamp. Light from a lamp contains visible light of all wavelengths. Make a table listing the wavelength range for red, orange, yellow, etc. as given by your spectrometer. Compare this to a standard table for color wavelengths.

2. Use a hand held spectrometer to compare light from a lamp to light from a fluorescent bulb. Describe the difference between the two.

8.3 Atomic Spectral Lines

Atoms and molecules have characteristic energy levels, E_n, where n is a label for the state of the atom or molecule. When a transition is made from a high energy level to a lower level, radiation is emitted.

Since the energy levels of atoms and molecules are unique, the radiation they emit is distinct. It is possible to use the light radiated by an object to determine its atomic and molecular constituents.

1. Use a spectrometer to obtain some of the characteristic wave lengths for the following atomic and molecular discharge tubes: Hydrogen, Helium, and Mercury. (Be careful that the spectral lines you observe are from the light from the discharge tube and not from an overhead fluorescent light.)

2. Compare the wave lengths you obtain to those listed on the chart in the room. The chart will contain more lines than you are able to see, but you should be able to find the line on the chart which corresponds to each spectral line you observe.

   For each of these elements, produce a table containing the wave length you obtained versus the wave length listed on the chart.

8.4 Index of Refraction for Glass

Use a laser and a square piece of glass to measure the index of refraction for glass. Begin by setting a laser on a flat table. Next, place a sheet of paper on book that is just below the height of the laser beam. Now place the the square piece of glass on the paper. A top view of your setup should look something like this:

The glass is just at the right height so that the laser beam strikes one edge, making a red spot on the edge of the glass. Part of the beam is reflected and the rest is transmitted. The exit point of the transmitted beam can be located with the help of a red spot found at the exit point for the beam.

Note: *Use an angle of incidence of at least 45^o. The measurement is increasingly inaccurate for smaller angles.*

1. Once this set-up is operational, trace the square glass on the sheet of paper. Mark the points where the beam enters and exits the glass. Also draw a line indicating the laser beam path as it enters the glass.

2. Remove the glass from the paper and draw a line from the enter and exit points. Assuming that light travels in a straight line through the glass, this is the beam path through the glass.

3. Use this drawing and a protractor to estimate the incident angle, θ_i, and the transmitted angle, θ_t.

4. Use Snell's law,

$$n_{\text{air}} \sin(\theta_i) = n_{\text{glass}} \sin(\theta_t), \tag{8.1}$$

   to estimate n_{glass} (assume $n_{\text{air}} = 1$).

8.5 Index of Refraction for Water

Use an inclined plane to angle a laser beam downward towards a container of water. The angle the laser beam makes with the vertical axis (θ_i) can be determined from the scale on inclined plane. Use a protractor to estimate the angle of the refracted beam of light in water.

1. Make these measurements for at least three non-zero angles of incidence and produce a table something like the following:

θ_i	$\sin(\theta_i)$	θ_t	$\sin(\theta_t)$
0	0	0	0
45	? 0.707 ?	?	
60	? 0.866 ?	?	
75	? 0.966 ?	?	

2. Make a computer plot of $\sin(\theta_i)$ (*y*-axis) vs. $\sin(\theta_t)$ (*x*-axis). Perform a linear regression to obtain the slope of the line.

   - Maple V can be used to obtain a regression fit of $\sin(\theta_i)$ vs. $\sin(\theta_t)$. In the example below, the data is fake. You need to substitute the values you obtain experimentally. Here are the required maple commands.

     ```
     > sin_theta_i := [0.0, 0.707, 0.866, 0.966];
     > sin_theta_t := [0.0, 0.642, 0.732, 0.815];

     > with(stats);
     > fit[leastsquare[[sin_i,sin_t], sin_i = n * sin_t, {n}]]
     ([sin_theta_i, sin_theta_t]);
     ```

     If this has worked then Maple will print your fit:

     $$sin\_i = n\ sin\_t$$

     The number appearing for n is the linear regression estimate for the index of refraction for water.

   - Produce a plot of your data and fit to the data and then send this to the printer. To do this continue typing in your Maple worksheet (place your value for n in the following command).

     ```
     > plots[display]({plot( n * sin_t, sin_t = 0 ..  1, color=black)},
     {statplots[scatterplot](sin_theta_t, sin_theta_i, color=black)});
     ```

3. According to Snell's law,

   $$\sin(\theta_i) = n_{\text{water}} \sin(\theta_t), \tag{8.2}$$

   so the slope of the regression line provides an estimate for n_{water}. Compare the number you get to the known value of 1.33.

Lab 9

Lenses

9.1 Focal length

9.1.1 Lens maker's equation estimate of the focal length

The focal length, *f*, for a thin spherical lens is given by

$$\frac{1}{f} = (n-1)(\frac{1}{R_1} - \frac{1}{R_2}). \tag{9.1}$$

Thus, the focal length can be determined from the physical properties of the lens.

1. Use a spherometer to obtain R_1 and R_2 for a large converging lens (the spherometer is too big to measure the curvature for smaller lenses).

    - First place the spherometer on a flat surface and adjust the center post until all posts are in contact with the surface. Measure s, the average distance from the center post to the outside post.
    - Before proceeding, note the current reading for the post height on the spherometer. Now place the spherometer on the lens and raise the center post until all four posts are in contact with the lens surface. Determine the vertical displacement, h, of the center post.
    - The radius of curvature for the surface is given by

    $$R = \frac{h^2 + s^2}{2h}. \tag{9.2}$$

2. Assume that the glass you are using has an index of refraction of $n = 1.5$ to estimate the focal length of the lens.

9.1.2 Optical determination of the focal length

The image and object locations for a single lens obey the equation

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}. \tag{9.3}$$

The converging lens is placed on an optical bench with a lit source (with a cross-shaped pattern) in front of the lens and a screen behind the lens. The screen position can be adjusted until a converged image appears. The object (p) and image distances (q) can be measured and Eq. (9.3) used to determine f.

1. The optical determination works best when a set of image and object distances are obtained and a fit is performed to Eq. (9.3). However, we will try to do as best we can to obtain a decent result with a single measurement. The most accurate single measurement results will occur when p is approximately $2f$. Use the focal length determined in the previous section to set the initial object location.

2. Adjust the screen position until a converged image appears.

3. Measure the values of p and q. Use these to find f using Eq. (9.3).

4. Describe how your optically determined value compares with the result obtained from the Lens maker's equation.

5. You will need to know the focal length for at least two converging lenses to complete the rest of the lab. For those using the new Pasco optics bench, you will need to determine the focal length of two smaller lenses that fit in the lens holders (yes, you have to measure the focal length even if the lenses are labeled).

   Use the optical method to determine the focal length for the two converging lenses you will use.

6. Why doesn't the optical method allow you to obtain the focal length for a diverging lens?

9.2 A single converging lens

1. You should have already obtained the focal length (optically) for the lens you will use.

2. Measure p, the distance from the source to the lens, and q, the distance from the lens to the converged image location.

3. The magnification, M, is defined as the height of the image, h', divided by the height of the object, h,

$$M = \frac{h'}{h}. \tag{9.4}$$

Measure h' and h and evaluate M.

4. According to the theory for geometrical optics,

$$M = -\frac{q}{p}. \tag{9.5}$$

Use your values for s_i and s_o in this equation and compare the value to your measurement for M.

5. According to Eq. (9.3), if we move the lens position so that the values for p and q are exchanged, then we should once again obtain a converged image on the screen. Verify that this is true. Does this change the magnification compared to the original converged image?

9.3 Combination of diverging and converging lenses

1. Arrange the source, a converging lens, and the screen so that a converged image appears on the screen. Measure the height of the converged image, y_i.

2. Now move the source 15 cm further away from the lens, leaving a mark to indicate the original position of the source.

3. There no longer should be a converged image on the screen. One way to obtain a converged image would be to move the screen. However, in this case we will leave the screen fixed at its original position. To obtain a converged image we can also produce a virtual image at the original position of the source. To do this, place a *diverging* lens between the source and converging lens. Adjust the position of the diverging lens until a converged image appears on the screen.

4. Measure the dimensions of the converged image. Are they the same as the dimensions of the original converged image?

5. Make a sketch indicating the positions of the 1) screen, 2) converging lens, 3) diverging lens, 4) original position of the source, and 5) final position of the source. Indicate the distances between optical elements.

9.4 Combinations of converging lenses

1. Place a converging lens at a distance of approximately half of its focal length from the source. Verify that no real, focused image appears anywhere behind the lens.

2. Use Eq. (9.3) and your previously determined value for f to determine the position of the virtual image.

3. Place your second converging lens behind the first lens. The lens separation should be at least equal to the focal length of the second lens.

4. Make a sketch of the set-up indicating 1) the source, 2) the first lens, 3) the position of the virtual image produced by the first lens, and 4) the position of the second lens.

5. Use Eq. (9.3) to predict how far behind the second lens a converged image should appear. Remember that the *effective* source for the second lens is the virtual image produced by the first lens.

6. Move the screen behind the second lens until a converged image appears. Measure the distance between the second lens and the screen. How does the value compare to your prediction?

7. Is the converged image inverted or upright?

Lab 10

Wave Optics

10.1 Single-slit diffraction

Much of the text for this lab is adapted from the ***Instruction Manual and Experiment Guide for the PASCO scientific model OS-8523****. The copyright notice of the manual states "...permission is granted to non-profit educational institutions for reproduction of any part of the Slit Accessory manual providing the reproductions are used only for their laboratories and are not sold for profit."*

When monochromatic light passes through a narrow slit, the angle to the *minima* in the diffraction pattern is given by

$$a \sin(\theta) = m\lambda \quad (m = 1,\ 2,\ 3\ \cdots). \tag{10.1}$$

Here, a is the slit width, θ is the angle from the center of the pattern to the m^{th} minimum, λ is the wavelength of light, and m is the order (1 for the first minimum, 2 for the second minimum, ... counting from the center out). A schematic representation appears below.

Since the angles are usually small, it can be assumed that

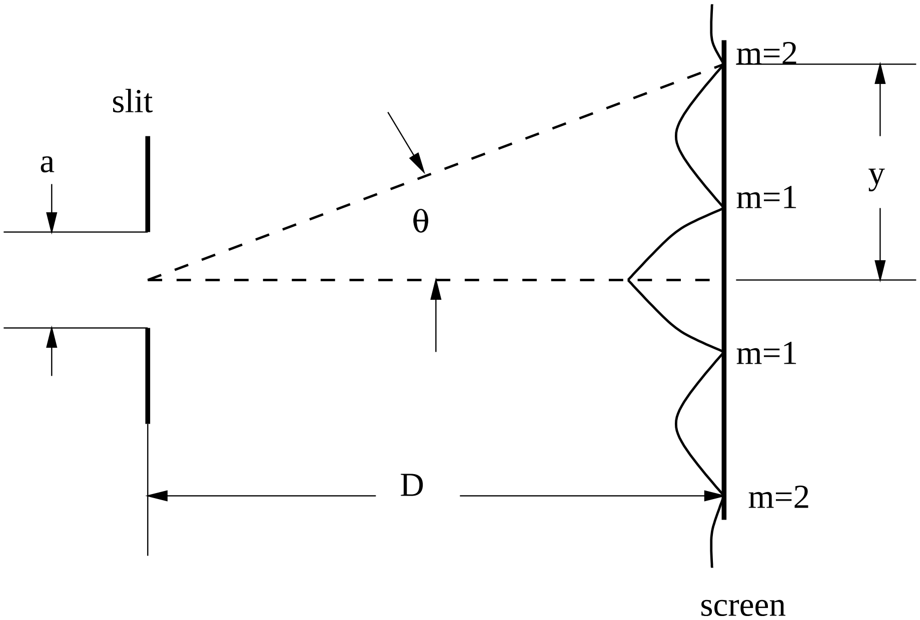
$$\sin(\theta) \simeq \tan(\theta). \tag{10.2}$$

The standard definition for the tangent function gives

$$\tan(\theta) = \frac{y}{D} \tag{10.3}$$

where y is the distance on the screen from the center of the pattern to the m^{th} minimum and D is the distance from the slit to the screen. As a consequence, Eq. (10.1) can be written as

$$a = \frac{m\lambda D}{y} \quad (m = 1,\ 2,\ 3\ \cdots). \tag{10.4}$$



1. Set up the laser at one end of the optics bench and place the Single Slit Disk in its holder about 3 cm in front of the laser. The diode laser used in these experiments has a wavelength, λ, of 670 nm.

2. Cover the screen with a sheet of paper and attach it to the other end of the bench so that the paper faces the laser.

3. Select the 0.04 mm slit by rotating the slit disk until the 0.04 mm slit is centered in the slit holder. Adjust the position of the laser beam from left-to-right and up-and-down until the beam is centered on the slit.

4. Determine the distance, D, from the slit to the screen.

5. Turn off the lights and mark the positions of the minima in the diffraction pattern on the screen. Also mark the central bright spot on the paper.

6. Turn on the room lights. Each group member should sketch the diffraction pattern *to scale*. Rulers will be available to make the sketch.

7. Measure the distance between the first order ($m = 1$) marks. Also measure the distance between the two second order ($m = 2$) marks. Construct a table like the following.

	First order ($m = 1$)	Second order ($m = 2$)
Distance between side orders ($2y$)		
y		
Calculated slit width: $a = m\lambda D/y$		
actual a		
% difference		

8. Repeat this exercise for slit widths of 0.02 mm and 0.08 mm. Be sure to make a sketch of the diffraction pattern and a table for each of these cases.

9. How does the diffraction pattern change as the slit width is increased? Are diffraction effects most evident for large or narrow slits?

10.2 Interference from a double-slit

When light passes through two slits, the two light rays emerging from the slits interfere with each other and produce interference fringes. The angle to the maxima (bright fringes) in the interference pattern is given by

$$d \sin(\theta) = m\lambda \quad (m = 0,\ 1,\ 2,\ 3,\ \cdots) \tag{10.5}$$

where d is the slit separation, θ is the angle from the center of the pattern to the m^{th} maximum, λ is the wavelength of the light, and m is the order (0 for the central maximum, 1 for the first side maximum, 2 for the second side maximum, ..., counting from the center out). See the figure below.

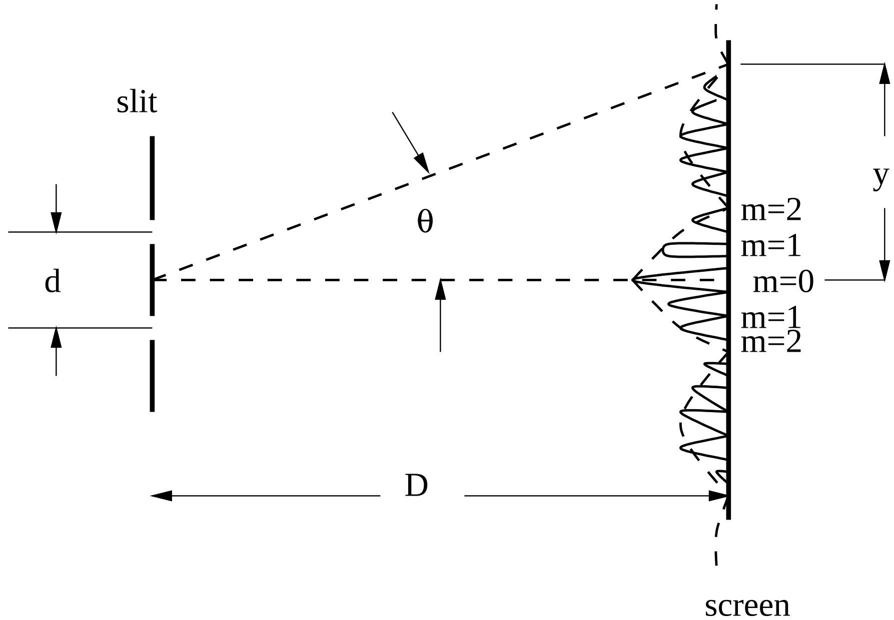
Once again, since angles are small, it is assumed that Eq. (10.3) is valid. Since

$$\tan(\theta) = \frac{y}{D} \tag{10.6}$$

where y is the distance on the screen from the center of the pattern to the m^{th} maximum and D is the distance from the slits to the screen. Thus, Eq. (10.5) can be written as:

$$d = \frac{m\lambda D}{y} \quad (m = 0,\ 1,\ 2,\ cdots) \tag{10.7}$$

While the interference fringes are created by the interference of light coming from the two slits, there is also a diffraction effect occurring at the each slit due to Single Slit diffraction. This causes the envelope of oscillating maximum intensities that is shown in the figure.



1. Set up the laser at one end of the optics bench and place the Multiple Slit Disk in its holder about 3 cm in front of the laser.

2. Cover the screen with a sheet of paper and attach it to the other end of the bench so that the paper faces the laser.

3. Select the double-slit with 0.04 mm slit width and 0.25 mm slit separation by rotating the slit disk until the desired double slit is centered in the slit holder. Adjust the position of the laser from left-to-right and up-and-down until the beam is centered on the double slit.

4. Determine the distance, D, from the slits to the screen.

5. Turn off the room lights and mark the positions of the maxima in the interference pattern on the screen.

6. Turn on the room lights. Each group member should sketch the interference pattern *to scale*.

7. Measure the distance between the first order ($m = 1$) marks. Also measure the distance between the two second order ($m = 2$) marks. Construct a table like the following.

	First order ($m = 1$)	Second order ($m = 2$)
Distance between side orders ($2y$)		
y		
Calculated slit separation: $d = m\lambda D/y$		
actual d		
% difference		

8. Repeat this exercise using the same slit width (0.04 mm), but with a different slit separation (0.5 mm).
9. Repeat this exercise with a slit width of 0.08 mm and the original slit separation (0.25 mm).
10. Does the distance between maxima increase, decrease, or stay the same when the slit separation is increased?
11. Does the distance between maxima increase, decrease, or stay the same when the slit width is increased?