• **General information.** The laboratory activities for this course are designed to be of the type that can be performed satisfactorily at home. The main disadvantage is that the activities were meant to be performed in a group setting, allowing discussion of conceptual issues among students. You could perhaps compensate for this by discussing the relevant lab questions with a friend, spouse, or even children. As noted in the syllabus, the main textbook for the lab is McDermott’s *Physics by Inquiry, Vol. II*. A laboratory “kit” will be needed. You’ll rent the kit from the EOU Physics Club. It contains

- A battery holder for the D-cells,
- 6 light bulbs and bulb sockets, and one “different” bulb.
- 6 clip leads with alligator clips
- 6 or so lengths of hook-up wire, stripped on each end.
- Nichrome wire, #30 gauge, 3 30-cm lengths and 1 90-cm length,
- An ammeter and a voltmeter. (The voltmeter is digital and can be used as an ammeter. However, when you need to measure both current and voltage, you’ll need the separate ammeter. The ammeter is calibrated in milliamps from zero to 400 mA or 500 mA)

To complete the kit, you must obtain

- A roll of “Scotch” tape.
- Two D-cells.

• **Format.** We specify no specific format for the lab write-ups. You may answer the questions in the individual labs in “linear” fashion. We do require that questions be answered in *complete sentences*, as opposed to sentence fragments. Labs are graded on clarity of the discussion more than on “correctness” of answers. **Graphs** must be done on graph paper. **See the instructions for making graphs, on the last page of this handout.**
Introduction

This lab will use some simple tools to investigate static electricity. You are asked to put aside your “book knowledge” and observe what you see in these experiments. Your grade will not depend on whether you get a “right” answer, but whether you communicate in a clear, concise fashion what you observe, and make reasonable inferences from the observations. Don’t rush this lab! Some activities may seem almost trivial, but they are not.

Procedure

A basic tool will be Scotch tape. If you stick a strip of tape two or three inches long on virtually any smooth, dry surface and then quickly pull it off, you’ll find the tape has an electric charge. It will be strongly charged when pulled off some materials, and relatively weakly charged when pulled off others. (You’ll want to fold over a small bit of the end to provide a “handle” to make the tape easier to work with.)

1. Pull off another piece of tape from the same surface as your first piece. Do the strips attract or repel each other? Try this again with two pieces of tape pulled off other surfaces. (Be sure to describe the surfaces in your notebook.) Can you make a general rule?

2. Stick a strip of tape on the back of another (parallel, not crossed), and then stick both on some surface. Quickly pull them off the surface, and then pull them apart.

3. Prepare another pair of strips of tape as before, and bring each (in turn) near each of your electroscope leaves. Write down what you observe. Is there always an interaction between charged objects?

4. Stick and pull off pieces of tape from several different surfaces and bring them near each of your electroscope leaves. You are not limited to bits of tape; try rubbing glass and fur together, rub your glasses on your shirt, etc.

5. Do you ever see a charged object that repels both strips of your electroscope? Do you ever see a charged object that attracts both strips?

6. From your observations, what do you conclude about how many kinds of electric charge there are? Defend your conclusion from your observations only, not from any previous knowledge or from textbook material.
7. Does the strength of the attraction or repulsion vary with distance? Can you see Newton’s Third Law in action with strips of tape? **Be very specific in describing how you see the third law manifested.** Can you see it if you bring a charged plastic comb near a strip of tape?

8. Hold a charged object near your arm, or the back of your hand. (A comb or balloon rubbed on your hair works well.) Do you feel anything? What is it you are actually feeling?

9. Can you explain any of your observations with gravitational forces? Do an order-of-magnitude calculation for the gravitational force between a strip of tape and, say, your hand. This kind of calculation is often used in science, and can often eliminate unacceptable hypotheses quickly. Here, we are only interested in a rough estimate, not a precise calculation. Don’t be afraid to guess! You will use Newton’s law of gravitation, which you have seen before:

\[ F = G \frac{M_1 M_2}{r^2} \]

To estimate the mass of the tape, guess the mass of a whole roll and divide by the length of the roll, written on the package. Guess the mass of your hand and use a rough distance, like 10 cm, for the distance between masses. Is the force you calculate enough to cause the bending of the tape you observe? Explain how you know. (Hint: to estimate how much force is required to bend the tape, try estimating how much force would be required to lift a 2-inch or so strip of tape. The force to bend it won’t be different by more than an order of magnitude.)

Reminder: “explaining” something is going to require several well-reasoned English sentences. Sentence fragments are not college-level writing. Your explanation should not be directed at your instructor: a student who has not taken physics should be able to understand your argument.

10. You ought to have noticed that a piece of metal, or even your hand by itself, attracts both strips of your electrostatic force. This is due to “induced charge” in the conducting material (the metal or your hand). Draw a diagram illustrating how this happens. Show a neutral object attracting a positively charged strip and another diagram for a negatively charge strip.

11. Make a list of the similarities and differences between the electrostatic and gravitational forces.

END Part 3 Lab
Notes on lab activities in the McDermott book.

Since the McDermott activities were designed to be done in a university physics lab, we will occasionally have to modify the activities. What follows here is

1. Modifications to the McDermott lab descriptions. There are activities which we cannot duplicate (for lack of equipment or a “staff member”), so I am making note of that.

2. A specific list of McDermott activities you are to mail in to me. In order that your write-ups not be tedious and lengthy, I am not requiring that all of the lab activities be mailed in.

3. There are a few activities that I am modifying and asking that you complete.

**Part 4 Laboratory** McDermott Part A, sections 1 and 2.

- In Experiment 1.1 you are NOT to use a socket.
- Exercise 1.4 refers to Volume I of this text. Ignore the exercise.
- Experiment 1.8: you will not be able to check with a “staff member,” of course.
- Experiment 1.9 and following:
  - Sockets may be connected together with wires inserted into the “Fahnestock clips” on the sockets. Some lengths of wire were so connected in the kit, to give you the idea. However, the alligator clips will still be necessary for hooking the batteries to the bulbs.
  - Often you can do without using switches. In the newer kits we supply some single-pole switches with Fahnestock clips.
  - Experiment 2.4 and following. Unless otherwise noted, a single “battery” symbol will represent two cells in series. We need about three volts to make many of the circuits work, so we will use two “D” cells in series as a battery. Just hook a clip lead between the cells.

Mail in the following: Exercises 2.2, 2.3, 2.4, 2.5, and 2.7. You may e-mail these to tom.herrmann@eou.edu.

**Part 5 Laboratory** McDermott Part A, Sections 3-4.

- Experiment 4.5. You may skip this. I do not find the exercise very helpful.
- Exercise 4.14 – skip this since there is no “staff member.”
- Pages 416 and 417 deal with switches. If you wish, you may make an SPDT switch just by pounding three nails partially into a block of wood. The nails will be terminals A, B, and C, and an alligator clip can provide the C-A or C-B connection. But this is not necessary for hooking up the circuit of Experiment 4.12. It might make the set-up more stable (fewer clips lying on the table), so do it if you wish.
Mail in the following: Experiment 3.3, Exercise 3.4, Experiment 3.7, and Experiment 3.10. Exercise 4.3, 4.6, 4.10, 4.11, and 4.12. You may e-mail these to tom.herrmann@eou.edu.

Part 6 Laboratory McDermott Part B, Sections 5-6.

- In Experiment 5.2, you need to measure the current fairly precisely. This is one place where I would suggest you use the ammeter function of the digital multimeter. You may have to use the “10A” (10-ampere) scale on the multimeter, since the maximum current on the next lowest scale might be 200 mA and your current for a single 30-cm wire may exceed that. (It depends on which meter you have.)

- In Experiment 5.3, you are asked to use two 15-cm lengths of nichrome wire. This produces too much current; it is off-scale with your ammeter. Use two 30-cm pieces instead.

- Experiment 6.1 A — as the instructions say, DON’T hook up the top circuit. It could ruin your ammeter.

- Experiment 6.1 B — To have two ammeters, you will have to use your digital multimeter as an ammeter. Be careful with it, as it is easy to burn out the internal fuse!

- Experiment 6.2. Your operational definition should have something about measuring current and voltage in it. Suppose there are two wires with identical voltages across them. One wire A carries twice the current of wire B. How does the resistance of wire A compare to that of wire B? (Wire A’s resistance is NOT twice that of wire B.)

- Experiment 6.3.A. You are making actual measurements here, not just making predictions of some sort. Again, 5-cm lengths are too short. Use at least 15-cm lengths of nichrome wire.

- Experiment 6.3.B. Modify the experiment as follows: circuit (1) is a single 30-cm length of wire. In circuit (2), use 30-cm lengths instead of 20-cm lengths. Circuit (3) is OK as it is.

- Exercise 6.4.A. Note that you are not making actual measurements here.

- Exercise 6.4.B. You must use full 5-cm lengths! No fair using shorter wires.

Mail in the following: Exercises 5.6, 5.7, 5.8, and 5.9. Exercise 6.4, A and B. (Again, you may e-mail these.)

Part 7 Laboratory McDermott Part C, Sections 7-8.

- Experiment 7.1. You have been using two “D” cells all along before this. The two cells in series make a “battery.” To set up the circuit in 7.1.B, use only ONE cell to make a “battery.” Thus, the circuit on page 430 uses two cells. Hopefully you can borrow a “D” cell from a spare flashlight to complete 7.1.C.
- Experiment 7.2 – take very seriously the instruction not to keep the bulb lit very long with three cells. It will burn out if you keep it lit too long.

- In Experiment 7.8, use a 60-cm length of wire, not at 15-cm length. (Put the clip leads 60 cm apart on your 90-cm length of wire.)

- In Experiment 7.10, use 30-cm and 60-cm lengths instead of 15-cm and 30-cm lengths. This keeps the current lower.

- Exercise 7.12. Note that the resistors 1 and 2 have different values: they are not identical resistors!

- In experiment 8.1, the battery shown is a 3-V (nominal) battery, consisting of two cells in your battery holder.

- In Experiment 8.5, you must use a 3-V battery (two cells) instead of a 1.5-V cell as it shows. This is because your light bulbs are made for the higher voltages.

- In Experiment 8.7, we are back to using only a single cell for each of the “battery” symbols. Each circuit on page 450 has two cells.

- The circuits on page 453 (Experiments 8.11 and 8.12) need a 3-V battery (two cells.)

Mail in the following: Experiment 7.9, Exercise 7.12, Exercise 7.14, Exercise 7.15, Exercise 7.16, Experiment 8.1, Exercise 8.2, and Exercise 8.9.

Part 8 Laboratory McDermott Part C, Section 9.

- Experiment 9.6. Use 30-cm lengths of nichrome wire instead of the 10-cm lengths specified.

- Your voltmeter has a black lead and a red lead. The text does not make really clear what a “positive” voltage is. Voltages (or electrical potential) is a relative quantity, just like gravitational potential energy. We can pick the bottom of a building or the top of the same building to be the reference for “zero” gravitational potential energy, and all other potential energies are \(mgh\) measured relative to our reference point. Similarly, we can pick any place in a circuit to have zero voltage, and measure all voltages relative to it. When we measure the voltage drop across a resistor, we are measuring the difference in voltage between the two ends.

If we obtain a positive reading on the meter, the red lead is positive relative to the black lead. A negative reading means the red lead is negative relative to the black lead. In a circuit, current flows from the positive end of a resistor toward the negative end. (Electrons flow the other way, and this can be confusing. Blame Benjamin Franklin for his choice of the convention.)

In answering 9.6.B, you must measure the voltage drops across all 5 elements, and state: “the voltage at point \(A\) relative to \(B\) is _____, the voltage at point \(B\) relative to point \(C\) is _____,” etc.
• When you sum the voltages along a path, as the diagram on page 461 shows, you must determine if the voltage is rising or falling as you go from one end of a resistor to the other.

• **Question D (in Experiment 9.6) is badly worded.** You must say “Point B is positive relative to point C” or vice versa. To merely say the voltage across a circuit element is negative is not descriptive enough to be of any use.

**Mail in the following:** Experiment 9.6, Exercise 9.8, Exercise 9.9, and Exercise 9.10.

**Part 9 Laboratory** McDermott Part C, Section 10.

• **Experiment 10.1. MODIFY THIS COMPLETELY AS FOLLOWS:** Hook up a 30-cm piece of nichrome wire and a 90-cm piece as follows:

![Diagram](image)

The object here is to find out how the current through the 30-cm resistor is related to the voltage across it. We are going to change the current by changing the point where we hook the clip lead to the 90-cm wire. Complete a table like this:

<table>
<thead>
<tr>
<th>Voltage reading (V)</th>
<th>Current reading (A)</th>
<th>length along 90-cm wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.53</td>
<td>0.29 A</td>
<td>0 cm</td>
</tr>
<tr>
<td>1.46</td>
<td>0.24 A</td>
<td>10 cm</td>
</tr>
<tr>
<td>:</td>
<td>:</td>
<td>:</td>
</tr>
</tbody>
</table>

The data filled in is just hypothetical. Complete this table, varying the length along the 90-cm wire from zero to 90 cm, in steps of about 10 cm. *The distances do NOT have to be exact; you can just guess!* We are trying to find a relationship between current and voltage. So all we really need are some pairs of current-voltage readings over a decent range. The exact values don’t matter as long as the range is wide enough. You should end up with 10 pairs of current-voltage readings.

Plot these data on a piece of graph paper. **Before** doing the graph, review the instructions for graphing which is at the end of this handout. **Plot current on the vertical axis and voltage on the horizontal axis.**
What do you conclude about the relationship between current and voltage? What happens to the current through the wire if you double the voltage? What would your plot look like if we had used a 15-cm wire instead of a 30-cm wire?

- **Experiment 10.2. MODIFY THIS COMPLETELY AS FOLLOWS:**

  A. You will hook up circuits as follows:

  ![Circuit Diagram](image)

  Again, the object is to determine how current varies as a function of voltage, for a light bulb. We have to obtain a wide variety of currents and voltages, so using one cell will give us some low readings, and using two cells will give the higher readings. **Pay special attention to getting some readings in the low range, below 60 mA.**

  Plot the data (voltage on the horizontal scale, current on the vertical scale) and look at the distribution of points. If there are “holes,” try to get more readings to fill them in.

  It should be quite clear that a light bulb does not follow Ohm’s law! Sometimes we define what is called “dynamic resistance,” defined as

  \[
  \frac{\text{change in voltage}}{\text{change in current}} \quad \text{or} \quad \frac{\Delta V}{\Delta I}
  \]

  For instance, from your graph it should be clear that when the filament is cold, a small change in voltage will give you a big change in the current: the resistance is small. But when the filament is hot, the same change in voltage (say, a 0.2...
volt change) will not give much of a change in current; the dynamic resistance is large.

B. Sketch a graph of $V$ vs. $I$ for a hypothetical device which has a large dynamic resistance when the voltage is low and a smaller dynamic resistance when the voltage is high.

- Do all the exercises in Section 10.

Mail in the following: Experiments 10.1 and 10.2 (described above), Exercises 10.3, 10.4, 10.6, 10.8, 10.9, 10.10, 10.11, 10.12, and 10.13.

**Part 10 Laboratory** McDermott Part D, Sections 11 and 12.

- Experiment 11.1. This experiment will work better if you an find an “old” flashlight battery. Fresh batteries have small internal resistance, which is harder to measure. Also, alkaline-type cells have smaller internal resistance than ordinary cells. (The latter are often labeled “heavy-duty,” but do not contain the word “alkaline.”) A fresh “heavy-duty” cell may have enough internal resistance to be easily measurable. The bottom line: don’t use an alkaline cell. Find an old flashlight cell if you can. However, a really dead battery will not work well either, since the voltage across the terminals will drop to a very low (and changing) value when you connect it to the nichrome wire.

- Exercise 11.6. This is too much work for the amount of learning that may happen! Basically, if the shorting wire has a resistance of $0.1\ \Omega$, its voltage drop will be close to $1.5\ \text{V}$ (since $0.1\ \Omega$ is quite a bit bigger than the battery’s internal resistance) and the light bulb gets very little current. (Actually the wire’s voltage drop is $1.36\ \text{V}$). When the wire’s resistance is $0.01\ \Omega$, this is the same as that of the battery’s internal resistance, so you would expect that half of the EMF will be across the wire and half across the battery’s internal $r$: $0.75$ volts each. When the wire has $0.001\ \Omega$, most of the voltage drop occurs inside the battery. Just make sure you understand this concept.

- **Skip** Exercise 11.7. It is more confusing than enlightening.

- Exercise 11.8. Neither of the explanations are incorrect. But Student 1’s explanation is incomplete. Student 2’s explanation is correct but very wordy!

- Experiment 12.1. Most of your bulbs are round. In your kit, there is one bulb which is “long” in comparison. For this experiment, use one “round” bulb and one “long” bulb.

- **Experiment 12.2. Don’t do Part C.** You don’t have enough bulbs or batteries, and besides, this activity will wear out the batteries. However, do the prediction for the relative lifetimes of the batteries.

Complete and mail in: Exercises 12.3, 12.4, 12.6, and 12.10; Exercises 11.3, 11.4, and 11.5.
Summary of good graphical technique

1. Use graph paper. A graph on ruled notebook paper is NOT college-level work. You may use spreadsheet such as Excel. If you do, be sure to format it so that gridlines are included on both axes.

2. Make your graph large, not tiny. The size should be a half-page, minimum.

3. Your graph must be based on data that is already organized in a table. The table must be included in your write-up.

4. Before plotting any points, choose appropriate scales on the two axes, so that the points are spread out, not “bunched up.” DO NOT choose some “odd” number of squares per unit, like 3 or 7. Doing this would make it impossible to accurately plot your points.

5. Label each axis, including the units.

6. After making a point, put a circle or some other symbol around the point.

7. Do not “connect the dots.” When appropriate, draw a “best” straight line through (not connecting) the points, or perhaps draw a smooth curve.

8. Put a title somewhere in your graph.

9. Graphs are important parts of your write-up, and your write-up should contain comments concerning what you can infer or learn from each graph. What relationship does it show or not show? How reliable is your data, based on the “scatter” you see in the graph?

10. Illustration:

In this case we have drawn a smooth curve through the points. Often, one draws a “best” straight line through the points. NEVER connect the dots.