Light Bulb Circuits

Pre-Lab: Thomas Edison and Physics with PhET

A Bit of History

In this lab you will spend quite a bit of time working with little incandescent light bulbs that probably don't seem especially impressive. But consider this: the telegraph, telephone, photograph, and steam engine were all ubiquitous before Thomas Edison introduced the first commercially viable incandescent lighting system. It is worth taking a brief look at the steps that led to Edison's great innovation.

Up until the year 1800, the study of electricity was limited almost entirely to electrostatics. Large static charges could be produced with relative ease, but extremely limited usefulness. Imagine shuffling across a carpet in your socks. That wouldn't have been too far from the state of the art. The charges produced could be stored in devices called Leyden jars, which were the forerunners of capacitors, a device that we will study in the second part of this lab. But, once again, there were no practical uses for this stored charge.

But in that first year of the nineteenth century (or last of the eighteenth?), Italian physicist Alessandro Volta invented the first battery. This was a monumental achievement as it was the first time in the history of man that a steady electrical current could be produced. Less than a decade after the battery was introduced, English scientist Sir Humphrey Davy used an absolutely huge one to power the first ever arc light. In this light, two charcoal rods were placed nearly end-to-end, separated by only a few centimeters of air. When the rods were each connected to a terminal of the battery, the tremendous potential difference caused a very bright, continuous electrical discharge across the gap. Davy also demonstrated the incandescence of a platinum wire, showing that it became so hot when carrying a large current that it actually glowed. Sir Humphrey was not interested in developing either lighting technique any further (he was too busy discovering most of the alkaline earth metals). It was up to others to improve upon his demonstrations and make electric light commercially viable.

Many decades later, following the invention of the first practical electrical generators (c. 1870), there were real successes in the development of the arc light. A few streets in Paris and New York were lit using many arc lights connected one after the other. In addition, some theatres and high-end retailers employed the arc light indoors. But although the arc light did not emit fumes like a gas lantern, it was still less than ideal. For one, they were so tremendously bright that one could not comfortably look in the direction of an arc light. Further, they were fairly unreliable and required dangerously high voltages. (Arc lights have come a long way since then: fluorescent bulbs are highly evolved descendants.)

After viewing an exhibition of arc lights in 1878, Thomas Edison was sure that the electric light was the way of the future. However, he believed that incandescent light could be made to provide a more useful illumination than the arc light. When Edison began his work on the electric light, incandescent bulbs already existed, but they were nowhere near practical. Edison and his team made significant improvements to filaments, vacuum pumps, electrical generators, and electrical wiring, among other things. Four years and lots of money later, Edison proved that his faith in incandescence was well-placed when he gave electric light to a large section of Lower Manhattan (this required him to build and install all the necessary generators and wiring!). Do the little bulbs seem more impressive now?

(Most of the history in this lab comes from *Age of Edison* by Ernest Freeberg and *Empire of Light* by Jill Jonnes. There's more good stuff in there!)

Simulated Circuits

Before coming to lab and working with some real circuits, here's a chance to spend some time with some simulated circuits.

Do This: Begin by reading Appendix B concerning voltmeters and ammeters.

Do This: Find the PhET DC Circuit applet on the *Pre-Lab* links on the course website to download the virtual lab software from the University of Colorado Boulder. A file called *CircuitsPreLab* will also be downloaded.

Do This: Open the applet. In the top-right corner there is a button labeled *Load*. Click the *Load* button and open the *CircuitsPreLab* file. You should see a circuit with a battery, a switch, three light bulbs, and three ammeters. The switch is open so nothing should be happening.

Do This: Close the switch using the mouse. You should see electrons within the wires start moving.

PL1. Is the current moving in the same direction that the electrons are moving? Explain.

PL2. Draw a diagram of the circuit that includes the current readings next to the ammeters. Use the standard symbols for each circuit element. (You may consider the light bulb to be a resistor.)

PL3. Explain how the current readings support Kirchhoff's Junction Rule? (This is also sometimes known as Kirchhoff's Current Rule. And the word *Law* is sometimes used in place of *Rule*. See Appendix C for more information on Kirchhoff's Rules.)

Read This: In this week's lab, you will build several circuits very much like the one you are simulating. The basic goal will be to understand the brightness of the bulbs in each circuit. Increasing the current through a bulb will make it brighter. Equivalently, increasing the voltage across a bulb will make it brighter. Sometimes current might be easier to think about. Other times, considering voltage will make a problem easier to solve. Here you'll be asked to explain the brightness of the bulbs both ways.

PL4. By considering the current readings given by the ammeters, why are the bottom two bulbs dimmer than the top bulb?

PL5. Why *is* it that less current goes through the bottom two bulbs? Your response does not necessarily require a lot of math.

Do This: To measure voltages, we need a voltmeter. If you haven't read Appendix B yet, please do so now.

Do This: You can make a virtual voltmeter appear by clicking the checkbox next to the voltmeter in the *Tools* menu on the bar at the right of the window. This voltmeter will give you the potential difference between the red lead and the black lead.

PL6. Use the voltmeter to measure the voltage across each light bulb and write that value next to each bulb in the diagram you drew for PL2. As your response to PL6 you can just write *Done!*

PL7. By considering the voltage readings given by the voltmeter, why are the bottom two bulbs dimmer than the top bulb?

PL8. Why *is* it that there is a smaller voltage across each of the bottom two bulbs? Explain using Kirchhoff's Loop Rule. (This is also sometimes called Kirchhoff's Voltage Rule. And the word *Law* is sometimes used in place of *Rule*. See Appendix C for more information on Kirchhoff's Rules.)

Part I: Just Light Bulbs

The Story

There's an interesting part of the Edison tale that was left out of the Bit of History. When arc lights were used to light a street, they tended to be connected to each other in *series*. When Edison began exhibiting his incandescent bulbs to investors and the interested public, he connected the lights in *parallel*, an alternative to series connections.

Why was Edison so concerned about how his lights were connected?

It's up to you to do some detective work so that you can solve this historical mystery as completely as possible. In Part I, you will explore several ways in which you can connect light bulbs to a power supply. After you've discovered how the geometry of the connection affects the operation of the bulbs, you'll understand Edison's dilemma. Finally, you will apply your knowledge to a strand of Christmas lights.

Equipment

- Three light bulbs in holders
- Four white connectors (used to connect light bulbs to each other)
- Test leads (one red, one black, one green)
- DC power supply
- Strand of 100 lights (for Section 6)

1. Bulbs in Series

Two light bulbs are connected in series if a charge flowing through the first bulb must also flow through the second bulb. An equivalent definition is that two bulbs are in series if they share exactly one wire and they share that wire with no other circuit elements. Here you will characterize a series connection of bulbs and explain your observations.

Read This: The power supply is easy to use if you know a few simple things. There are two knobs. The top knob adjusts the voltage of the supply. This is the knob that you will turn as you are doing the experiment. The bottom knob is a current limiter. You do not need to adjust this knob during lab. Just make sure that it is turned all the way up (clockwise) and leave it there. The other thing to know is that the blue terminal on the supply is referred to as the *black* terminal throughout this manual since black is usually used to denote the negative terminal.

Figure 1: How to use the power supply during lab. Check that the bottom knob is turned all the way up and leave it there.

Do This: First things first. Examine a single bulb connected to the supply. Begin with the supply voltage turned all the way down (counterclockwise). Connect the bulb to the supply using the red and black leads and switch it on. Slowly raise the voltage. Do not raise the voltage past 6.0 V or you risk damaging the bulb.

1.1. Describe how the brightness of the bulb changes as you raise the voltage on the supply.

Read This: In the rest of Part I, we will be talking about the brightness of bulbs. You will be asked to discuss relative brightness and absolute brightness. When discussing *relative* brightness, consider how a bulb compares to other bulbs within the same circuit. When discussing *absolute* brightness, you will be answering the question, "How does the brightness of a bulb compare to the brightness of a single bulb connected to a power supply that is set at 5.0 V." This single bulb with 5.0 V across it could be called our standard candle.

Do This: Set the power supply to 5.0 V and take note of the brightness of the bulb (our standard candle). Then remove the red and black leads from the power supply. Get a second bulb and connect it in series with the first. That is, construct the circuit that is depicted in Figure 2. In this lab, **use the short white connectors to connect light bulbs to each other.** Don't plug the red and black leads back in quite yet.

1.2. Before powering up the circuit, *predict* both the relative brightness and the absolute brightness of the two bulbs. (By *absolute* we mean compare it to a single bulb connected to the power supply at 5.0 V.) See Appendix A for information about predictions. Please support your predictions with a sentence or two.

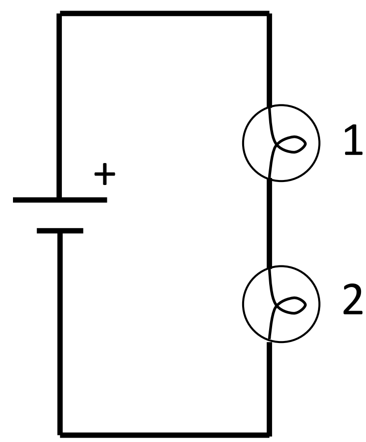

Figure 2: Two bulbs in series.

Do This: Plug the red and black leads into the power supply.

1.3. Were your predictions correct? If not, explain where your reasoning failed.

1.4. *Predict* what will happen if you unscrew Bulb 1 and remove it from the holder. Support your prediction with a sentence or two.

Do This: Unscrew Bulb 1 and remove it from the holder.

1.5. Were your predictions correct? If not, explain where your reasoning failed.

Do This: Screw Bulb 1 back into the holder.

1.6. *Predict* what will happen if you unscrew Bulb 2 and remove it from the holder. Support your prediction with a sentence or two.

Do This: Unscrew Bulb 2 and remove it from the holder.

1.7. Were your predictions correct? If not, explain where your reasoning failed.

Do This: Screw Bulb 2 back into the holder.

1.8. *Predict* what will happen to the brightness of each bulb if you connect one end of your green lead to the red terminal of Bulb 2 and the other end of the green lead to the black terminal of Bulb 2. Support your prediction with a sentence or two.

Do This: Connect the green lead as described in Step 1.8.

1.9. Were your predictions correct? If not, explain where your reasoning failed.

Read This: We say that the green wire has created a *short circuit* around Bulb 2.

Do This: Disconnect the green lead.

1.10. *Predict* what will happen if you connect a third bulb in series. Support your prediction with a sentence or two.

Do This: Add a third bulb in series.

1.11. Were your predictions correct? If not, explain where your reasoning failed.

2. Bulbs in Parallel

A set of bulbs are connected in parallel if a given charge carrier flowing through the set flows though only one of its elements and the voltage drop across each element is the same for the entire set. Another way to say this is that two bulbs are connected in parallel if they share both of their wires with each other. Here you will characterize bulbs connected in parallel and explain your observations.

2.1. Draw the circuit diagram for two bulbs connected in parallel connected to a battery.

Do This: Label the bulb that is closer to the battery *Bulb 1*. Label the bulb that is farther from the battery *Bulb 2*.

2.2. *Predict* the relative and absolute brightness of the bulbs in the circuit you just drew. (By *absolute* we mean compare it to a single bulb connected to the power supply at 5.0 V.) Support your prediction with a sentence or two.

Do This: Build the circuit you drew in Step 2.1 and power it up. (Check that it's still at 5.0 V.)

2.3. Were your predictions correct? If not, explain where your reasoning failed.

2.4. *Predict* what will happen if you unscrew Bulb 1 and remove it from the holder. Support your prediction with a sentence or two.

Do This: Unscrew Bulb 1 and remove it from the holder.

2.5. Were your predictions correct? If not, explain where your reasoning failed.

Do This: Screw Bulb 1 back into its holder.

2.6. *Predict* what will happen if you add a third bulb in parallel. Support your prediction with a sentence or two.

Do This: Add a third bulb in parallel.

2.7. Were your predictions correct? If not, explain where your reasoning failed.

2.8. Do you suspect the headlights of a car are connected in series or in parallel? Explain.

3. Three-Bulb Circuit

Many circuits will have certain sets of elements that are connected in series while other sets of elements are connected in parallel. In Section 3, you'll look at another way that three bulbs can be connected to a power supply.

3.1. Look at Figure 3. Draw the corresponding circuit diagram. Be sure to label the bulbs in your diagram using the same numbers that are used in the figure.

3.2. *Predict* the relative and absolute brightness of the bulbs. Support your prediction with a sentence or two.

Do This: Build the circuit and set the supply voltage to 5.0 V. Your circuit may look different from the photo. There's more than one way to construct the same circuit.

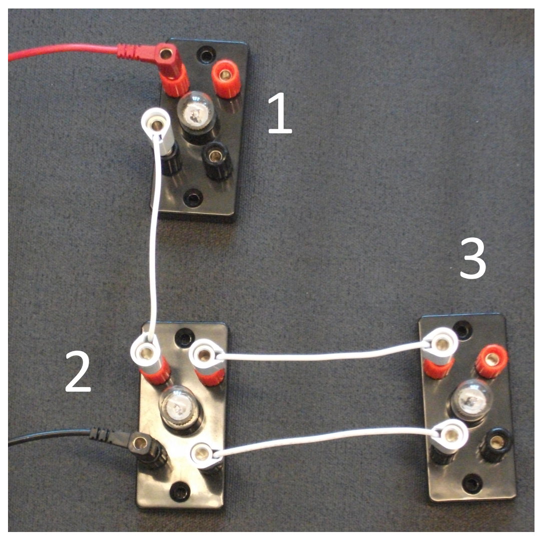

Figure 3: Three-bulb circuit for Section 3.

3.3. Were your predictions correct? If not, explain where your reasoning failed.

3.4. *Predict* what will happen if you unscrew Bulb 1 and remove it from the holder. Support your prediction with a sentence or two.

Do This: Unscrew Bulb 1 and remove it from the holder.

3.5. Were your predictions correct? If not, explain where your reasoning failed.

Do This: Screw Bulb 1 back into its holder.

3.6. *Predict* what will happen if you unscrew Bulb 2 and remove it from the holder. Support your prediction with a sentence or two.

Do This: Unscrew Bulb 2 and remove it from the holder.

3.7. Were your predictions correct? If not, explain where your reasoning failed.

Do This: Screw Bulb 2 back into its holder.

3.8. *Predict* what will happen if you unscrew Bulb 3 and remove it from the holder. Support your prediction with a sentence or two.

Do This: Unscrew Bulb 3 and remove it from the holder.

3.9. Were your predictions correct? If not, explain where your reasoning failed.

Do This: Screw Bulb 3 back into its holder.

3.10. TA Challenge! Call your TA over to your circuit. He or she will ask you what will happen if you connect your green lead between two points in your circuit. You will make predictions, support your predictions, and then test them. If your TA is satisfied, you will get a signature. Nothing else needs to be recorded.

4. The Edison Mystery Solved

It's time to see how good of a detective you were.

4.1. As mentioned in the story, Thomas Edison would hold exhibitions of his latest bulbs for investors. These gatherings would take place at night at his Menlo Park laboratory, lit only by his electric bulbs. Explain why Thomas Edison was right to be concerned with the details of how his light bulbs were connected during his exhibitions. There should be **at least two advantages** that parallel connections would have had over series connections.

5. Christmas Lights

Edison's light shows weren't too different from modern-day Christmas light displays. As such, you can use the skills you developed as you analyzed Edison's dilemma to do a little reverse engineering of Christmas lights.

Do This: In the following experiment you will be removing bulbs from a strand of Christmas lights. If you do this incorrectly, you can break the lights. To avoid damaging the lights, go to the In-Lab Links page and watch the video that demonstrates the proper and improper ways to remove the lights. The proper method uses the little screwdriver that can be found in the pillbox inside the box of Christmas lights.

Do This: After watching the video, plug your strand of lights into the power strip on top of the lab table. If your strand does not light up, please notify your TA so that you can get a new strand of lights. If your lights work, continue on.

5.1. Now that you're an expert on the basics of wiring light bulbs, figure out how your strand of Christmas lights is wired by removing bulbs and noting the results. (Please remove the bulbs using the method shown in the online video.) Record and analyze your observations. Then draw a circuit diagram for the strand of lights. (You don't need to draw all 100 bulbs. Just make sure it's clear how they're wired.)

Do This: Replace any bulbs that you have removed from the strand of lights.

Do This: Remove one of the bulbs and replace it with the red-tipped bulb that can be found in the pill bottle where you found the screwdriver.

5.2. What do you observe? Be as specific as possible. (If nothing interesting happens, please consult your TA.)

Do This: When you are done observing the red-tipped bulb, remove it and replace it with a regular bulb. Put the red-tipped bulb back in the pillbox.

Read This: Let's try to understand the physics of the red-tipped bulb. If you were to look closely at the red-tipped bulb while it is not plugged in, you would notice that it looks different from the other bulbs. Inside a normal bulb you can see two conductors connected by a very thin wire called the filament. The red-tipped bulb has an extra component called a bimetallic strip. (See Figure 4.)

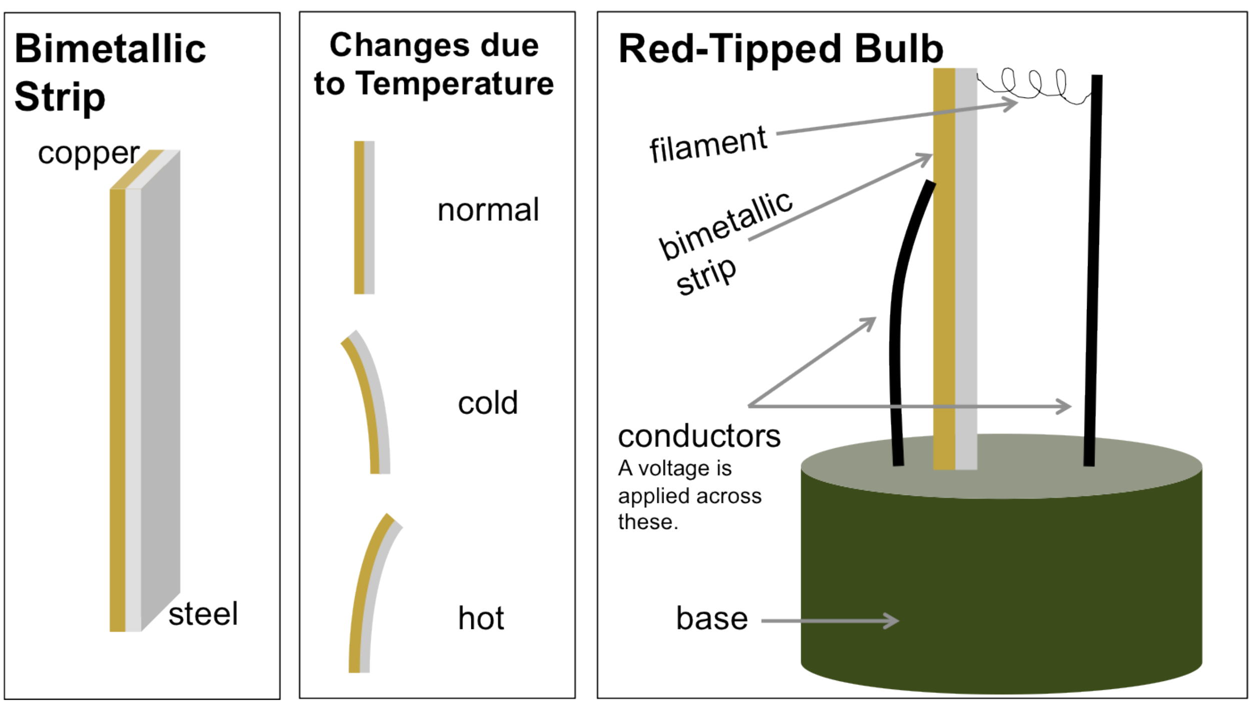

Figure 4: Bimetallic strips and the red-tipped bulb.

Read This: To understand a bimetallic strip, we must know that when metals heat up, they expand. Different metals expand at different rates. Copper expands faster than steel given the same change in temperature. So if you couple a strip of copper to a strip of steel, the resulting bimetallic strip will bend as it changes temperature as shown in Figure 4.

5.3. Knowing what you know about circuits and bimetallic strips, explain the observations that you recorded in Step 5.2.

Read This: Here's a final interesting fact about these particular Christmas lights. It turns out that removing one of these bulbs does not have the same effect as if one of the bulbs burns out. These are special bulbs that are equipped with an *antifuse* that completes the circuit if the filament happens to break. (A *fuse* acts in the opposite way. It is designed to break a circuit under certain conditions.) However, most light bulbs do not contain an antifuse, and current will *not* flow through most bulbs with a broken filament.

Part II: Light Bulbs and Capacitors

The Story

Leyden jars, the ancestors of the modern capacitor, were able to store charge, and in that charge, energy. The energy wasn't all that practical, although Benjamin Franklin is said to have used a Leyden jar to kill a turkey for a dinner party at one point.

In the days that Thomas Edison was trying to wow investors, capacitors like the ones you will use today didn't exist. Were they available, however, there is little doubt that he would have employed them to make his light shows even more impressive. But how?

Equipment

- Two light bulbs in holders with connectors
- One 1-F capacitor
- DC power supply
- Test leads (one red, one black)

6. Storing Energy in a Capacitor

The particular capacitors that you will use in Part II have a capacitance of 1 farad, which is an absolutely tremendous capacitance. But this high capacitance comes with two drawbacks.

Drawback 1: The maximum voltage that the capacitor can handle is 5.5 volts. Just to be safe, do not put more than 5 volts across the capacitor at any time.

Drawback 2: The capacitor is polarized. ***The black terminal on the capacitor should always be connected to the black terminal of the power supply***. The capacitor could be irreparably damaged if you are careless about the polarity.

For us, these drawbacks are worth the benefits of large capacitance. We start the foray into the world of capacitance by showing that they can store energy.

Do This: Set the voltage on the power supply to 5.0 V.

Do This: Connect the negative terminal of the power supply to the black terminal of the capacitor. Then connect the positive terminal of the power supply to the red terminal of the capacitor. The capacitor is now charging. (You should see a digital readout of the current on the power supply. If that meter reads zero, alert your TA.) Let the capacitor charge for about 20 seconds.

Do This: Remove the leads from the power supply and connect the capacitor to one of your light bulbs.

6.1. What happens? What does this say about a capacitor's ability to store energy?

Do This: Discharge your capacitor by connecting its two terminals with a test lead for 10 seconds. **Remember to discharge your capacitor like this after each experiment in which you use it.**

In the following two experiments you will connect a capacitor and a light bulb to the power supply at the same time. The way these circuits evolve with time should be interesting to observe.

7. Capacitor and Bulb in Series

When a resistor and a capacitor are connected to a power supply in series, we refer to the setup as an *RC circuit*. In this experiment, a light bulb will act as your resistor.

7.1. Draw the circuit diagram that shows a light bulb and a capacitor connected in series hooked up to a power supply.

7.2. If the capacitor begins uncharged, *predict* how the brightness of the bulb will change in time after turning on the supply. Support your response with a sentence or two.

Do This: Set the supply voltage to 5.0 V. Build the circuit you drew in Step 7.1 and test your prediction.

7.3. Were you right? If not, explain where your reasoning failed.

Read This: Here's a nice rule of thumb. DC circuits with resistors and capacitors tend to settle into a steady state if given enough time. Initially, capacitors act like wires (if they begin uncharged). When steady state is reached, a capacitor acts like a gap in the circuit. Sometimes the details of how steady state is reached are complicated; however, predicting the initial and final behavior of the circuit is often manageable, even in a complicated circuit.

7.4. *Predict* what will happen if you disconnect the leads from the power supply. Support your response with a sentence or two.

Do This: Disconnect the leads from the power supply and observe.

7.5. Evaluate the prediction you made in Step 7.4. Were you right? If not, explain where your reasoning failed.

7.6. *Predict* what will happen if you connect the free ends of the test leads (that is, the ends that were in the power supply). Support your answer with a sentence or two.

Do This: Connect the free ends of the leads to test your prediction.

7.7. Evaluate the prediction you made in Step 7.6. Were you right? If not, explain where your reasoning failed.

Do This: Discharge your capacitor by connecting its two terminals with a test lead for at least 10 seconds.

8. Capacitor and Bulb in Parallel

Let's see what happens when a capacitor and a light bulb are connected in parallel.

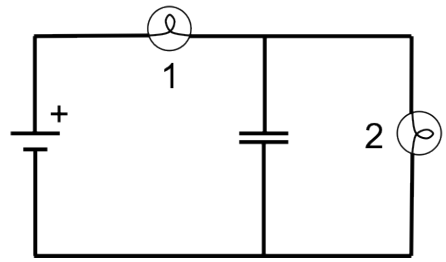

Figure 5: The circuit used in Section 9.

8.1. Take a look at the circuit diagram in Figure 5. If the capacitor begins uncharged, *predict* how the brightness of Bulb 2 will change in time after powering up the supply. Support your prediction with a sentence or two. (You might want to think back to the most recent "**Read This"**.)

Do This: Set the supply to 5.0 V. Build the circuit and test your prediction. Remember that the black terminal of the capacitor should be connected directly to the black terminal of the power supply.

8.2. Evaluate the prediction you made in Step 8.1. Were you right? If not, explain where your reasoning failed.

8.3. *Predict* what will happen if you disconnect the leads from the power supply. Make a prediction for both Bulb 1 and Bulb 2. Support your prediction with a sentence or two.

Do This: Disconnect the leads from the power supply.

8.4. Evaluate the prediction you made in Step 8.3. Were you right? If not, explain where your reasoning failed.

Read This: The circuit you just built demonstrates how one might use a capacitor to protect an electrical device against power outages. Even if the power supply gets unplugged, there is stored energy in the capacitor that can keep things running (for awhile anyway). This works well for devices that don't require much power.

9. Improving Edison's Light Shows with Capacitors

9.1. How do you think Edison could have improved his light shows if he had these capacitors available to him? Detail **at least two functions** that the capacitors could have had.

Part III: Using Voltmeters and Ammeters

We must leave behind the Edison angle in order to get a little experience using some modern laboratory equipment. Using the brightness of a bulb as a proxy for the voltage across it or the current through it is an excellent way to get more comfortable with circuits. However, it's also important to be able to accurately quantify voltages and currents in a circuit. In the final part of this lab, you will make measurements in a circuit that you have already analyzed qualitatively.

Equipment

- Three light bulbs
- DC power supply
- Test leads (one red, one black)
- Two Extech multimeters with test leads (two leads for each multimeter)

10. Measuring Voltages and Currents in a Three-Bulb Circuit

Take a look at Appendix B if you need to be refreshed about the ins and outs of voltmeters, ammeters, and multimeters. For this lab, ***measure currents using the 10 A setting*** on the multimeter.

Do This: Build the circuit that you drew in Step 3.1. But this final experiment will be easier if you connect Bulb 3 to Bulb 1 instead of connecting Bulb 3 to Bulb 2. Set the voltage on the power supply to 5.0 V.

10.1. Draw the diagram of a circuit where you are measuring the current through Bulb 1 and the voltage across Bulb 1 at the same time.

Do This: Construct the circuit that you drew in Step 10.1. Remember to measure current using the *10 A* setting. You should be using both multimeters.

10.2. Record the current through Bulb 1 and the voltage across Bulb 1.

10.3. Draw the diagram of a circuit where you are measuring the current through Bulb 2 and the voltage across Bulb 2.

Do This: Construct the circuit that you drew in Step 10.3.

10.4. Record the current through Bulb 2 and the voltage across Bulb 2.

10.5. Draw the diagram of a circuit where you are measuring the current through Bulb 3 and the voltage across Bulb 3.

Do This: Construct the circuit that you drew in Step 10.5.

10.6. Record the current through Bulb 3 and the voltage across Bulb 3.

10.7. Do your data indicate that light bulbs are ohmic? Explain, making sure to define that term and to show at least a little math.

Head-Scratchers

Don't forget to complete the following problems. They should be at the end of your lab report. If you want to work on them during lab, start a new page in your lab notebook.

- 2.8
- 4.1
- 5.3
- 9.1
- 10.7

Appendix A: Making Predictions

In this lab, you are asked to make many predictions, after which you test your predictions. It's okay if your predictions are wrong! Do not erase predictions that you discover were incorrect. Incorrect predictions will receive full credit as long as you "support your prediction with a sentence or two" as requested. On the other hand, correct predictions will receive little or no credit if you do not explain how you made your prediction.

After you test your predictions, you are asked whether or not you were correct. If your prediction was correct and complete, just draw a smiley face. If your prediction was incorrect or incomplete, you must explain where your reasoning failed. Make it clear that you understand what went wrong. Learning what your misconceptions are is the best way to fix them! As mentioned previously, do not erase incorrect predictions.

Appendix B: Voltmeters, Ammeters, and Multimeters

Voltmeters

A voltmeter is used to measure the voltage drop across a circuit element or set of circuit elements. For our purposes, we will just consider measuring the voltage across a single light bulb. The most important thing to remember is that the ***voltmeter should be connected in parallel*** with the light bulb. That means you can always connect the voltmeter last. You do not have to disconnect any cables in order to properly add the voltmeter to a circuit. A voltmeter is designed to have a very high resistance so that it does not affect the rest of the circuit. (What would happen in your circuit if you incorrectly connected a bulb and a voltmeter in series? You should be able to answer this question by the time you complete this lab.)

In a circuit diagram, a voltmeter is represented by a circle with a “V” inside as shown in Figure 6.

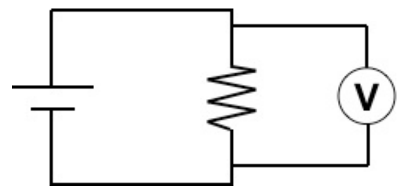

Figure 6: Measuring the voltage across a resistor.

Ammeters

An ammeter is used to measure the current through a circuit element. (Once again, we will consider a light bulb.) The most important thing to remember is that an ***ammeter must be connected in series*** with the light bulb. This means that you must break the circuit in order to add an ammeter. That is, you must disconnect a lead or two in order to use an ammeter in a circuit. If you add an ammeter without disconnecting anything, you have added it incorrectly.

Ammeters are designed to have very low resistance. That means that connecting an ammeter in parallel with a circuit element will cause a short circuit, possibly blowing a fuse in the ammeter. (You should understand why this would happen by the time you complete this lab.) You must be *very careful* with ammeters. Always feel free to ask your TA for help if you are unsure about the use of an ammeter.

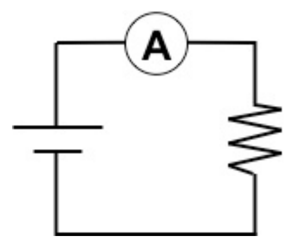

Figure 7: Measuring the current through a resistor.

In a circuit diagram, an ammeter is represented by a circle with an “A” in it as shown in Figure 7.

Multimeters

A multimeter is a digital instrument that can function as a voltmeter, ammeter, ohmmeter, and possibly several other instruments. (An ohmmeter measures resistance.) The versatility of a multimeter makes them very useful. However, the versatility also makes multimeters notoriously confusing. Here are some tips that should help you out.

Picking the correct input jacks: You must take care when connecting leads to a multimeter. One lead should always be connected to the “COM” input jack. Where the second lead goes depends on how you are using the multimeter. If you are using it as a voltmeter, plug the second lead into the terminal that has a “V” next to it. If you are using the multimeter as an ammeter, then your choice depends on how large your currents will be. Plug the second lead into the jack that has “10 A” next to it if you are expecting to measure large currents or if you are unsure about how big the current will be. For smaller currents, use the jack labeled with “µA” and “mA”. Current is displayed as positive if current flows out of the COM jack. If your multimeter is not giving you the reading you expect, the first thing you should check is that your leads are in the proper jacks.

Selecting the range: Many multimeters (like this one) have multiple settings, or ranges, for a given function. For example, when using the Extech meter as an ammeter, we can choose from:

- µA - use this range for currents up to 4000 µA.
- mA - use this range for currents up to 400 mA.
- 10A - use this range for currents up to 10 A.

AC vs. DC: Many multimeters can measure both AC and DC quantities. The DC voltmeter/ammeter is often a separate setting from the AC voltmeter/ammeter. For these multimeters, the “Mode” button switches between AC and DC measurements. In this lab, we will only measure DC quantities.

Appendix C: Kirchhoff's Rules

In 1845, the Prussian physicist Gustov Kirchhoff wrote down two rules that describe how the current and potential difference changes throughout a circuit. Although we won't do much with these laws, they offer a handy way to understand circuits. They are particularly invaluable for electrical engineers!

Kirchhoff's Junction Rule

The junction rule states that at any circuit junction (in other words, at any point where wires meet in a circuit), the total current that flows into the junction must equal the total current flowing out of the junction. This is really just another way of saying that charge is conserved – you can't add charges or take them away just because some wires meet.

Convention says that charge flowing into a wire junction gets a positive sign and charge flowing out of a wire junction gets a negative sign. That means that for any junction, Kirchhoff's Junction Rule can be written as $\sum I = 0$.

For example, in Figure 8, the current flowing into Junction 1 splits into the two currents flowing out of Junction 1. Kirchhoff's Junction Rule tells us that $I_A = I_B + I_C$.

Kirchhoff's Loop Rule

The loop rule states that the potential difference across each circuit element in a closed loop must add up to zero. Figure 9 provides a simple example. The battery has a potential difference between its terminals, called its EMF. The potential difference across Resistor 1 plus the potential difference across Resistor 2 will always equal the battery's EMF. For any closed loop, Kirchhoff's Loop Rule can be written as $\sum V = 0$. This is particularly helpful when investigating complicated circuits since the Loop Rule applies to each of the closed loops. Figure 10 shows the three closed loops present in Figure 8's circuit.

The loop rule is really just another way of saying that energy is conserved. Energy can't be created or destroyed, but it can change forms. In Figure 9, the battery converts chemical energy into electrical potential energy, then each resistor converts part of this electrical potential energy into thermal energy. After the current has flowed through both resistors, all of the electrical potential energy created by the battery has been converted into other forms, leaving the net change in voltage (the energy per unit charge) as zero.

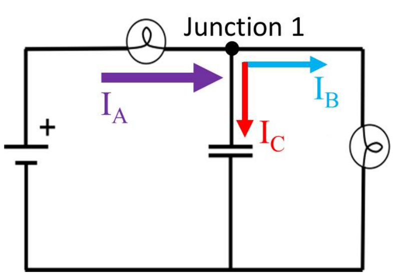

Figure 8: Current at a wire junction

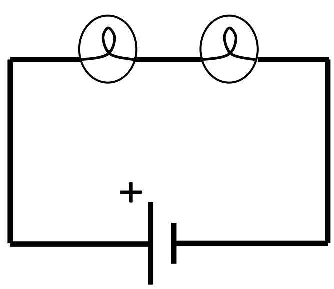

Figure 9: A closed loop

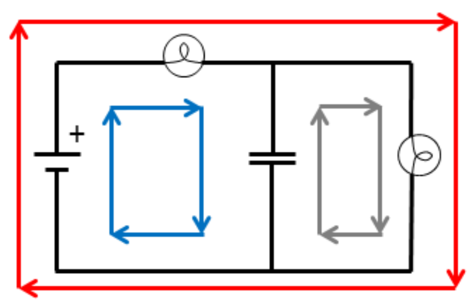

Figure 10: The same circuit as Figure 8. There are three closed loops to analyze: the outer loop; the left loop; the right loop.