Lab 11

DC Circuits

Continuing Objectives

4. Be able to make careful measurements to ensure reproducible results.

5. Know how to keep a clear and organized record, including an introduction (with purpose of lab and appropriate laws or equations), apparatus sketch, table of raw data and calculated quantities, and a good conclusion or summary.

Introduction

All electrical and electronic appliances (for example: toasters, computers, headphones, radios, telephones, refrigerators) use electric circuits. In this lab, you will learn how to build a circuit, read and draw schematic circuit diagrams, and measure voltages and currents in a circuit. Also, you will apply two very important conservation laws: conservation of charge and conservation of energy. The ideas of current, potential difference, resistance, and Ohm's law that you will see in this lab play an important role in your study of electricity and magnetism, and you will see them elsewhere in the course. Your main exposure to circuits, ammeters and voltmeters, and Kirchhoff's rules will be during this lab. Because this lab introduces new concepts, the instructions are more directed than some other labs.

Part I: Lighting a Light Bulb & Simple Circuits

The behavior of any electric circuit can be understood in terms of electric charges moving through the circuit. It is conventional, but not essential, to consider positive charges flowing from the positive to the negative terminal of the battery. The bulbs will only light up when charges flow through it. This is analogous to the flow of water

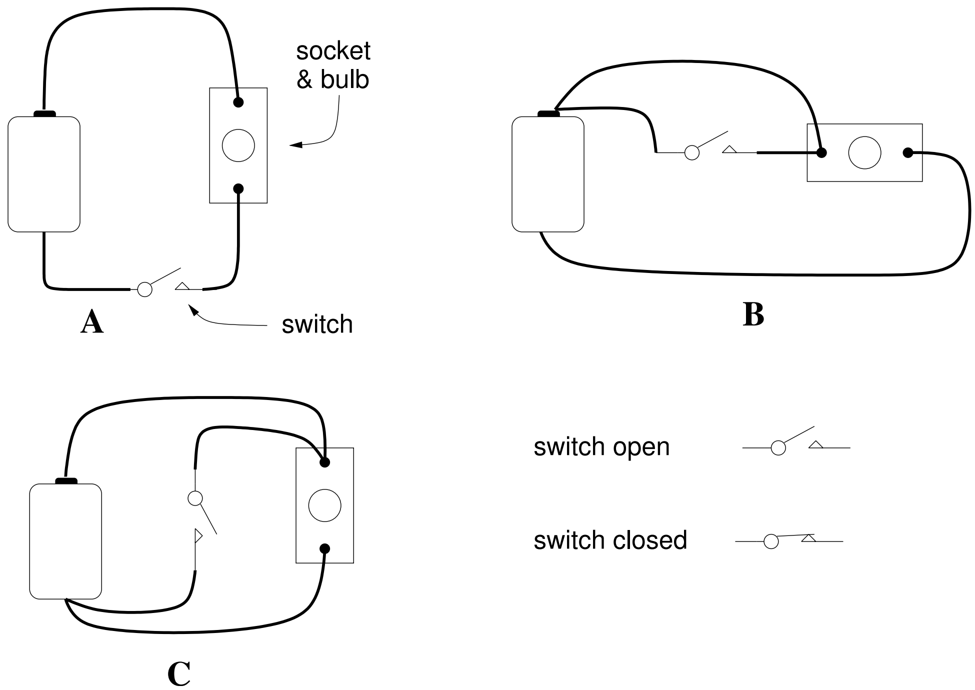


Figure 11.1: Connecting a bulb, battery, and switch.

around a closed network of pipes with a pump taking the place of the battery; here each connecting wire corresponds to a very wide pipe and the bulb a resistive paddle wheel.

You will use the notion of circulating charge to predict what happens in each circuit of Figure 11.1. Once you have made your predictions, you will connect the circuit elements on your bench in the same way to test your predictions. Do not build any circuits until you have made *and justified* all predictions.

You will use the red and black banana plug wires to connect circuit elements to each other. Each circuit element block has a connection port on either side. The colors of the wires and the colors of the ports do NOT correspond to each other. You may connect any wire to any port. **Do not connect batteries positive-to-positive or negative-to-negative!** The plugs may also be "stacked" in a single port, as you can see in circuits **B** and **C** of 11.1. The knife switch on the yellow block is closed when the arm is touching the far side, and open when the arm is in the air. Make sure you are using the smaller threaded bulbs for this part.

1. Record your predictions for whether the bulb will light for both the open and closed positions of the switch in each of the three circuits in 11.1.

2. Build each circuit using the wires and elements on your bench. Record your observations for both positions of the switch. Compare these observations to

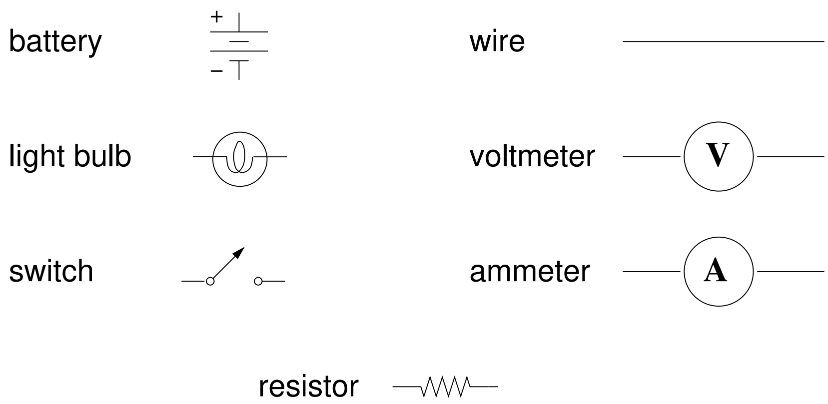
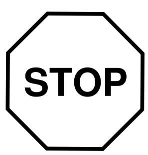


Figure 11.2: Symbolic representation of circuit elements.

your predictions. **For this and every following part, only connect the battery when you are actively making observations.** Disconnect the battery each time you are finished observing the circuit.



Discuss your predictions and results with your instructor or TA.

3. When working with electric circuits, it is often quicker to utilize a *schematic diagram* of the circuit. This uses simplified symbols to represent each element as seen in Figure 11.2, rather than a more detailed true-to-life drawing as in Figure 11.1. **Draw** schematic diagrams for each of the three circuits you just built. Figure 11.3 later in the lab shows a simple schematic diagram.

Part II: Characterizing Circuit Elements

We will characterize the behavior of electrical circuits and the charges flowing through them in terms of two physical quantities: *current* and *potential difference*.

The *current* at any point in the circuit or within any single circuit element, denoted I, is the rate at which electric charge passes that point. This is analogous to the rate of flow of the water through a system of pipes. Current is measured in Coulombs/second, or Amperes (A). It is not necessarily the same at *two different points* in the circuit (although it may be in special cases).

Current is measured by an *ammeter*. There are two yellow boxes on your desk; the ammeter is labeled **DCA**. An ideal measuring device should not disturb the circuit that is being measured. In the next few steps, you will use the brightness of a light

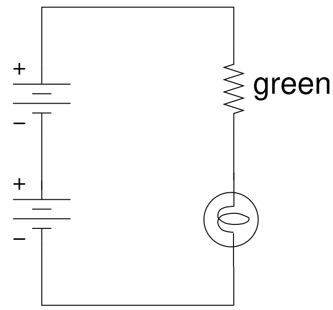


Figure 11.3: Series circuit.

bulb as a visual check to determine how to use an ammeter to measure current in a circuit.

Measuring current

1. Set the switch on the left side of your ammeter to the **5 A** setting. Insert one banana plug lead into the hole/port/socket labeled **COM** (the middle port at the top); insert a different banana plug lead into the port labeled **5A** (the left port). The on/off switch is on the right side of the ammeter.

2. Connect the circuit in Figure 11.3 using the mounted circuit elements, but *do not connect the ammeter yet.* Note the brightness of the light. This will be your reference level.

3. There are many ways to insert the ammeter into your basic circuit; the correct one will not affect the current. You will use the brightness of the light bulb to determine whether or not you have affected the circuit. Each circuit in Figure 11.4 includes an ammeter (and a switch). In configuration A, we would say that the ammeter is *in parallel* with the light bulb. Do you see why we would use the term *parallel* to describe this arrangement? For configuration B, we would say that the ammeter is *in series* with the light bulb (in fact, for this configuration, the green resistor, the light bulb, and the ammeter are all in series).

4. Connect each circuit of Figure 11.4. Note that for circuit A you won't need to break the circuit, but for B, you will need to open the circuit to insert the ammeter. For both switch positions, record in a table:

   (a) whether or not the bulb lights,

   (b) the ammeter reading, and

   (c) the bulb brightness (compared to the circuit of Figure 11.3).

5. Compared to the circuit of Figure 11.3, which circuit in Figure 11.4 disturbs the original circuit's behavior noticeably when the ammeter is inserted into the

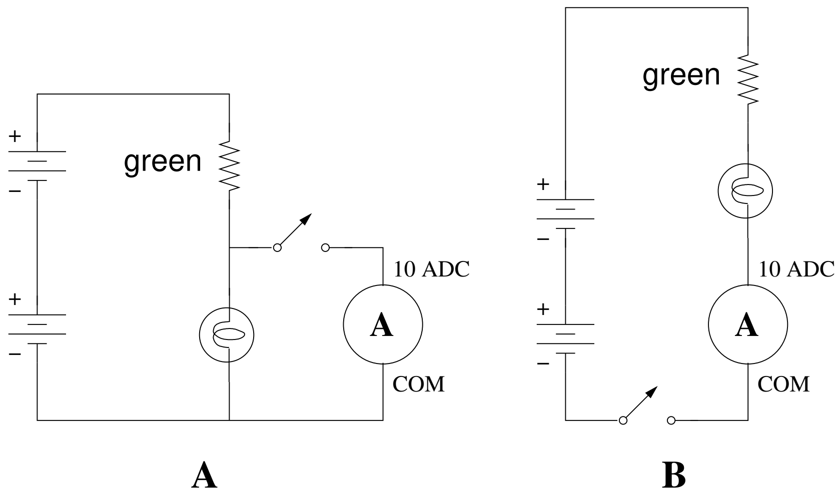


Figure 11.4: Inserting an ammeter into a simple series circuit.

circuit? Which is closest to an ideal current measurement? In order to properly measure current through the bulb, would you place the ammeter in parallel or in series with the bulb?

6. Consider the configuration that measures current correctly. What happens if you reverse the order of the leads on the ammeter? The easiest way to do this is to switch the leads at the ammeter sockets. Describe the difference that this causes in the reading and **explain this** in terms of the flow of charge.

Measuring potential difference

The *potential difference* or voltage difference *between two points* in a circuit, denoted ΔV or V, is the energy required to move one unit of charge between those points. This is analogous to the water pressure difference between two points in a pipe system. Potential difference is measured in Joules/Coulomb, or Volts (V). For example, it requires energy to move charge through a light bulb; $\Delta V = 3\,\mathrm{V}$ across the bulb means that 3 J of energy is needed to move 1 C of charge from one end of the bulb to the other. The energy lost by this charge may manifest itself as heat and light.

7. You will now measure the potential difference across the bulb. Reconnect the circuit of Figure 11.3 and note the brightness of the bulb. The other yellow box on your desk, labeled **DCV**, is your voltmeter. Set the switch on the left side to **20 V**, connect one lead to the **-** port and the other to the + port.

8. For each circuit of Figure 11.5, insert the voltmeter as indicated and, for both switch positions, record in a table:

   (a) whether or not the bulb lights,

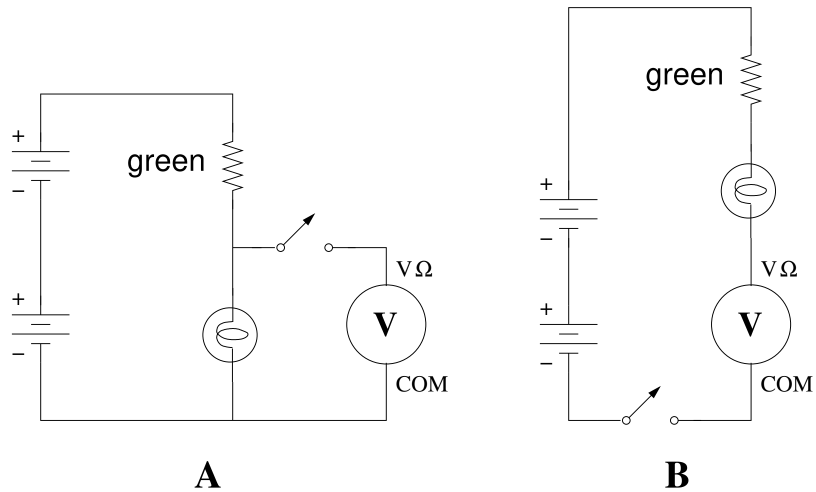


Figure 11.5: Inserting a voltmeter into a simple series circuit.

(b) the voltmeter reading, and

(c) the bulb brightness (compared to the circuit of Figure 11.3).

9. Which circuit from Figure 11.5 creates the most noticeable disturbance compared to that of Figure 11.3? Which is closest to an ideal potential difference measurement? In order to properly measure potential difference across the bulb, would you place the voltmeter in parallel or in series with the light bulb?

10. Reconnect circuit A of Figure 11.5, reversing the connections to the voltmeter. Describe the difference that this causes in the reading and **explain this** in terms of the relative energy of the charges on either side of the bulb. Consider the motion of positive charges circulating from the positive to the negative battery terminal. On which side of the bulb would you expect the energy of each positive charge to be higher? Given that the energy of each charge changes as it passes through the bulb, explain what happens to the energy that each charge loses.

11. The voltmeter can measure voltage across a circuit element by diverting a small fraction of the current that would otherwise flow through the element. Into which voltmeter port must this diverted current flow in order to get a positive reading?

12. Now consider the possible source of energy that propels the charges around the circuit: the battery. **Predict** the sign of the voltmeter reading if the voltmeter is connected in parallel across one of the batteries with the + lead at the negative end of the battery and the **-** lead at the positive end of the battery. **Verify** your prediction.

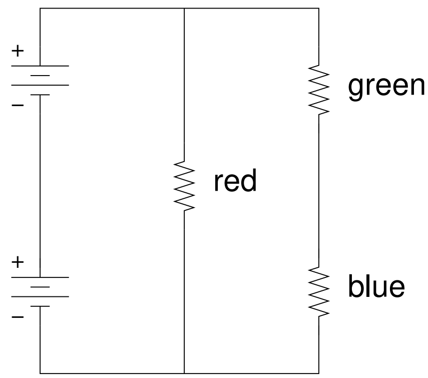
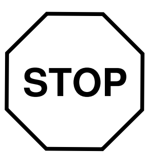


Figure 11.6: Resistors in series and parallel.

Measuring current and voltage in complex circuits

13. Now consider a more complicated circuit, such as that of Figure 11.6. Where would you place an ammeter or a voltmeter in order to determine the **current flowing through each element** (battery or resistor) and the **potential difference across each element**? Which is easier to build into your circuit, an ammeter or a voltmeter? Why?



BEFORE connecting the circuit of Figure 11.6, show your instructor or TA where you would place an ammeter and a voltmeter to make a correct measurement.

14. Sketch a copy of Fig. 11.6 in your lab notebook. Using the ammeter and voltmeter, measure the following:

    (a) the current flowing **through each element** (battery or resistor), ensuring that you connect the ammeter such that the **5A** port is connected to the side of the element where the current enters;

    (b) the potential difference **across each element** (battery or resistor). Connect the voltmeter to your circuit in the way you determined in the previous section (so as not to disrupt the circuit) and include the sign of the potential difference.

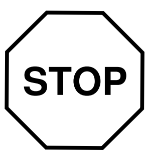
Note these values and label your sketch of the circuit with the voltages and currents you measured. You will need these measurments for the next part.

Part III: Conservation of Charge & Energy (Kirchhoff's Rules)

Two fundamental principles, conservation of charge and conservation of energy, determine circuit behavior. When applied to circuits, these are called Kirchhoff's rules.

1. *Kirchhoff's junction rule* states that, *at any point in a circuit*, the sum of the currents entering the point equals the sum of the currents leaving that point. This is a consequence of charge conservation. **Explain** why this is a consequence of the conservation of charge. Using the currents you measured above, **verify** Kirchhoff's junction rule for one of the junctions where three wires meet for the circuit of Figure 11.6.

2. *Kirchhoff's loop rule* states that, *in any closed loop around a circuit*, the sum of the potential differences across each circuit element is zero. **Explain** why this is a consequence of the conservation of energy. (Note: This is because the electrical force is a conservative force like the gravitational force.) Using the potential differences you measured above, **verify** Kirchhoff's loop rule for one of the loops of the circuit of Figure 11.6.



Discuss your results with your instructor or TA.

Part IV: Current, Voltage, and Resistance (Ohm's Law)

For many circuit elements, the current I through the element and the voltage difference ΔV across the element are related by *Ohm's Law*:

$$I = \frac{1}{R}\Delta V, \tag{11.1}$$

where R is the resistance of the circuit element. Ohm's Law is not a fundamental physical principle, but rather an experimentally observed relationship that holds approximately for many circuit elements. The units of resistance are Ohms ($\Omega =$V/A).

1. **Design** an experiment to determine if the blue mounted resistor obeys Ohm's Law, using **up to four** of the batteries. (Using more than four may damage the resistor.)

STOP Before beginning measurements, discuss your experimental design with your instructor or TA

2. **Execute** the experiment. Does the blue resistor obey Ohm's Law and, if so, what is its resistance? How could you determine an uncertainty for this experimental value?

3. Take the small bulb out of the mounted socket and replace it with the larger threaded bulb. **Design and execute** an experiment similar to your previous one to determine whether this bulb obeys Ohm's Law. Again, use only up to four batteries, because more may burn out the light bulb.

STOP Discuss your experimental results with your instructor or TA.

Please replace the small bulb in the socket after completing this experiment.

Write a conclusion about this lab, including a discussion of how to use ammeters and voltmeters, and what you learned about Kirchhoff's rules and Ohm's Law.