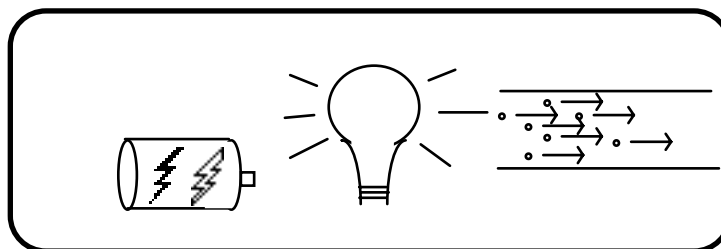


Name _____ Date _____ Partners _____

BATTERIES, BULBS, & CURRENT



OBJECTIVES

- To understand how a potential difference (voltage) can cause an electric current through a conductor.
- To learn to design and construct simple circuits using batteries, bulbs, wires, and switches.
- To learn to draw circuit diagrams using symbols.
- To understand currents at all points in simple circuits.
- To understand the meaning of series and parallel connections in an electric circuit.

OVERVIEW

In the following labs, you are going to discover and extend theories about electric charge and potential difference (voltage), and apply them to electric circuits.

A *battery* is a device that generates an electric potential difference (voltage) from other forms of energy. The type of batteries you will use in these labs are known as chemical batteries because they convert internal chemical energy into electrical energy.

As a result of a potential difference, electric charge is repelled from one terminal of the battery and attracted to the other. However, no charge can flow out of a battery unless there is a conducting material connected between its terminals. If this conductor is the filament in a small light bulb, the flow of charge will cause the light bulb to glow.

In this lab, you are going to explore how charge flows in wires and bulbs when energy has been transferred to it by a battery. You will be asked to develop and explain some models that predict how the charge flows. You will also be asked to devise ways to test your models using current and voltage probes which can measure the rate of flow of

electric charge (current) *through* a circuit element and the potential difference (voltage) *across* a circuit element, respectively, and display these quantities on a computer screen.

Then you will examine more complicated circuits than a single bulb connected to a single battery. You will compare the currents through different parts of these circuits by comparing the brightness of the bulbs, and also by measuring the currents using current probes.

*Some of the activities in this lab have been adapted from those designed by the Physics Education Group at the University of Washington.

The following figure shows the parts of the bulb, some of which may be hidden from view.

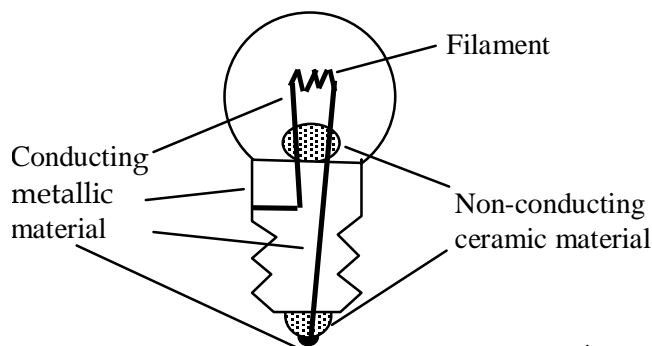


Figure 1-1: Diagram of wiring inside a light bulb.

You will now explore models for current in a simple circuit. In the diagrams below are shown several models that people often propose.

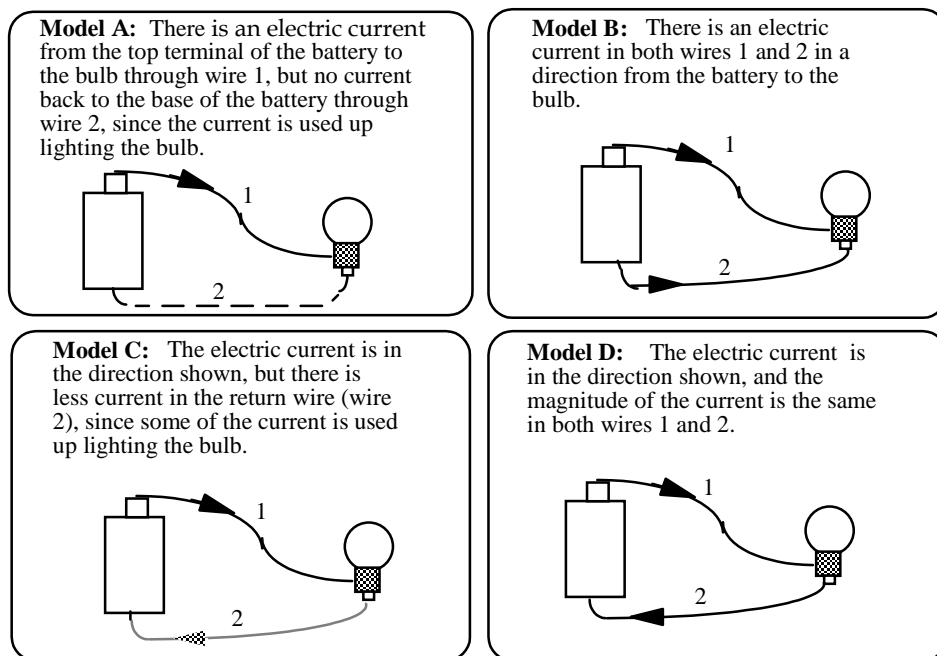


Figure 1-2: Four alternative models for current

Prediction 1-1: Which model do you think best describes the current through the bulb? Explain your reasoning.

For the Investigations in this lab, you will need the following:

- two current probes
- D cell battery
- push (contact) switch
- 8 wires with alligator clips
- 3 bulbs (#14) and holders
- two voltage probes
- 2 resistors (10 Ω)
- knife switch
- battery holder

The current probe is a device that measures current and displays it as a function of time on the computer screen. It will allow you to explore the current at different locations and under different conditions in your electric circuits.

To measure the current *through* a part of the circuit, you must break open the circuit at the point where you want to measure the current, and insert the current probe. That is, disconnect the circuit, put in the current probe, and reconnect with the probe in place.

Note that the current probe measures both the *magnitude* and *direction* of the current. A current *in* through the “+” terminal and *out* through the “-“ terminal (in the direction of the arrow) will be displayed as a positive current. Thus, if the current measured by the probe is positive, you know that the current must be counterclockwise in Figure 1-3 from the “+” terminal of the battery, through the bulb, through the switch, and toward the “-“ terminal of the battery. On the other hand, if the probe measures a negative current, then the current must be clockwise in Figure 1-3 (into the “-“ terminal and out of the “+” terminal of the probe).

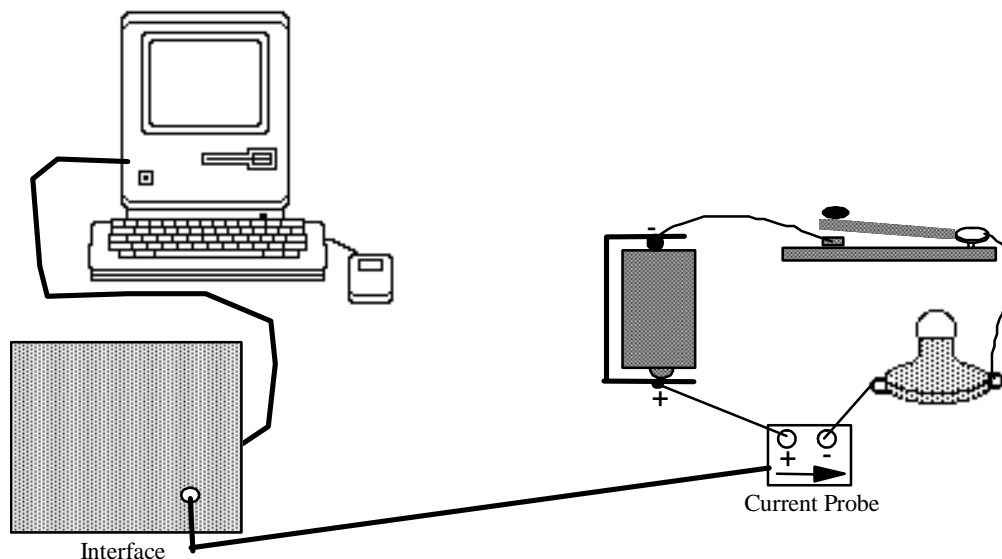


Figure 1-3: A circuit with a battery, bulb, switch, and current probe connected to the computer interface.

Figure 1-4(a) below, shows a simplified diagram representing a current probe connected as shown in Figure 1-3.

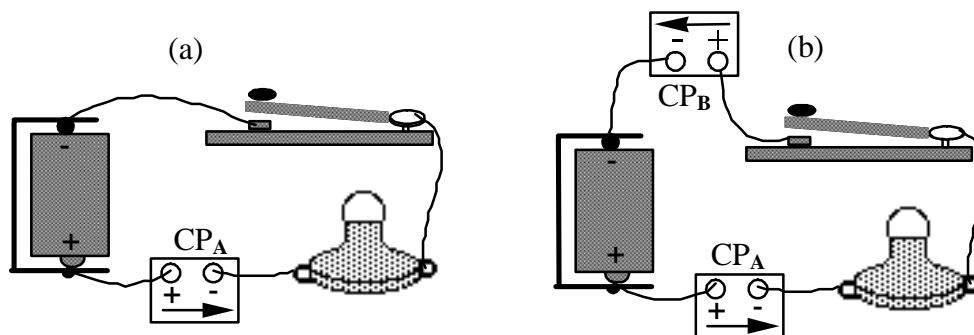


Figure 1-4 (a) current probe connected to measure the current out of the + terminal of the battery and into the bulb; (b) Two current probes, one connected as in (a) and the other connected to measure the current out of the switch and into the - terminal of the battery.

Look at Figure 1-4(b) and convince yourself that if the currents measured by current probes CP_A and CP_B are both positive, this shows that the current is in a counterclockwise direction around all parts of the circuit.

INVESTIGATION 1: MODELS DESCRIBING CURRENT

Activity 1-1: Developing a Model for Current in a Circuit

1. Be sure that current probes CP_A and CP_B are plugged into the interface.
2. In *DataStudio*, open the experiment file called **Current Model**. Current for two probes versus time should appear on the screen.

The top axes display the current through CP_A and the bottom the current through CP_B . The amount of current through each probe is also displayed digitally on the screen.

3. To begin, set up the circuit in Figure 1-4(b). **Begin graphing**, and try closing the switch for a couple of seconds and then opening it for a couple of seconds. Repeat this a few times during the time when you are graphing.
4. **Print** one set of graphs for your group.

Note: you should observe carefully whether the current through both probes is essentially the same or if there is a *significant* difference (more than a few percent). Write your observation:

Question 1-1: You will notice after closing the switch that the current through the circuit is not constant in time. This is because the electrical resistance of a light bulb changes as it heats up, quickly reaching a steady-state condition. When is the current through the bulb the largest---just after the switch has been closed, or when the bulb reaches equilibrium? About how long does it take for the bulb to reach equilibrium?

Question 1-2: Based on your observations, which of the four models in Figure 1-2 seems to correctly describe the behavior of the current in your circuit? Explain based on your observations. Is the current “used up” by the bulb?

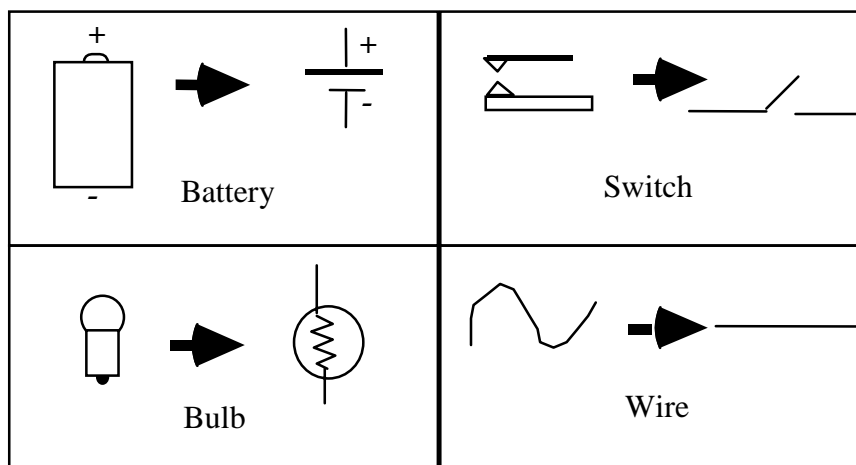
INVESTIGATION 2: CURRENT AND POTENTIAL DIFFERENCE

Figure 2-1: Some common circuit symbols

Using these symbols, the circuit with a switch, bulb, wires, and battery can be sketched as on the right in Figure 2-2.

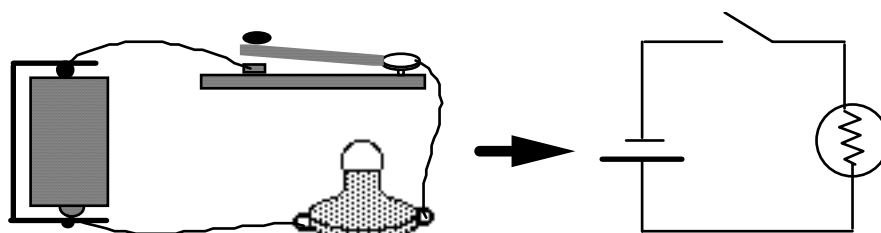


Figure 2-2: A circuit sketch and corresponding circuit diagram

There are two important quantities to consider in describing the operation of electric circuits. One is *current*, which is the flow of charges (usually electrons) *through* circuit elements. The other is *potential difference*, often referred to as *voltage*. Let's actually measure *both current and voltage* in a familiar circuit.

Figure 2-3 shows the symbols we will use to indicate a current probe or a voltage probe.



Figure 2-3 Symbols for current probe and voltage probe.

Figure 2-4(a) shows our simple circuit with voltage probes connected to measure the voltage *across* the battery and the voltage *across* the bulb. The circuit is drawn again symbolically in Figure 2-4(b). Note

that the word *across* is very descriptive of how the voltage probes are connected.

Activity 2-1: Measuring Potential Difference (Voltage)

1. To set up the voltage probes, first unplug the current probes from the interface and plug in the voltage probes.

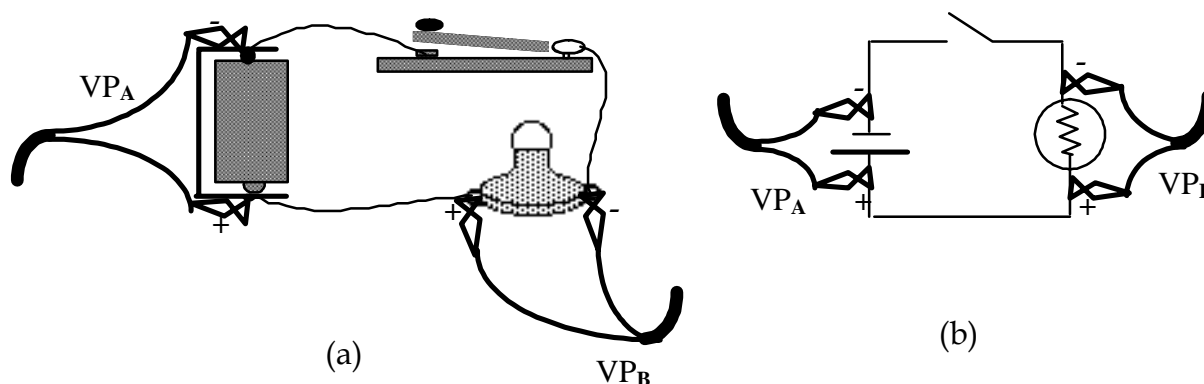


Figure 2-4: Two voltage probes connected to measure the voltages across the battery and the bulb.

2. Open the experiment file called **Two Voltages** to display graphs for two voltage probes as a function of time.
3. Connect the circuit shown in Figure 2-4.

Prediction 2-1: In the circuit in Figure 2-4, how would you expect the voltage across the battery to compare to the voltage across the bulb with the switch open and closed? Explain.

4. Now test your prediction. Connect the voltage probes to measure the voltage *across* the battery and the voltage *across* the bulb simultaneously.
5. Click on **Start**, and close and open the switch a few times.
6. **Print** one set of graphs for your group.

Question 2-1: Did your observations agree with your **Prediction 2-1**? If not, explain.

Question 2-2: Does the voltage across the battery change as the switch is opened and closed? What is the "open circuit" battery voltage, and what is the battery voltage with a "load" on it (i.e. when it's powering the light bulb)?

Activity 2-2: Measuring Potential Difference (Voltage) and Current

1. Connect a voltage and a current probe so that you are measuring the voltage *across* the battery and the current *through* the battery at the same time. (See Figure 2-5.)
2. Open the experiment file called **Current and Voltage** to display the current CP_B and voltage VP_A as a function of time.

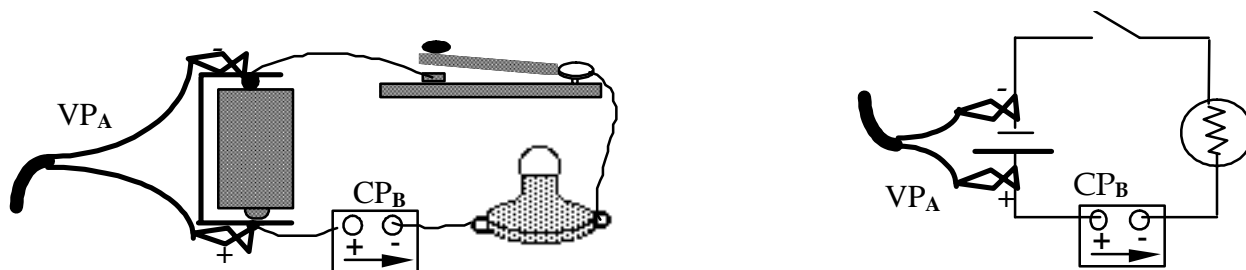


Figure 2-5: Probes connected to measure the voltage across the battery and the current through it.

3. Click on **Start**, and close and open the switch a few times, as before.
4. **Print** one set of graphs for your group.

Question 2-3: Explain the appearance of your current and voltage graphs. What happens to the current through the battery as the switch is closed and opened? What happens to the voltage across the battery?

5. Find the voltage across, and the current through, the battery when the switch is closed, the bulb is lit, and the values are constant. Use the **Smart Tool** and/or the **Statistics** feature.

Average voltage: _____ Average current: _____

Prediction 2-2: Now suppose you connect a second bulb in the circuit, as shown in Figure 2-6. How do you think the voltage across the battery will compare to that with only one bulb? Will it change significantly? What about the current in the circuit and the brightness of the bulbs? Explain.

Comment: These activities assume identical bulbs. Differences in brightness may arise if the bulbs are not exactly identical. To determine whether a difference in brightness is caused by a difference in the currents through the bulbs or by a difference in the bulbs, you should exchange the bulbs.

Sometimes a bulb will not light noticeably, even if there is a small but significant current through it. If a bulb is really off, that is, if there is no current through it, then unscrewing the bulb will not affect the rest of the circuit. To verify whether a non-glowing bulb actually has a current through it, unscrew the bulb and see if anything else in the circuit changes.

6. Connect the circuit with two bulbs, and test your prediction. Take data. Again measure the voltage across and the current through the battery with the switch closed.

Average voltage: _____ Average current: _____

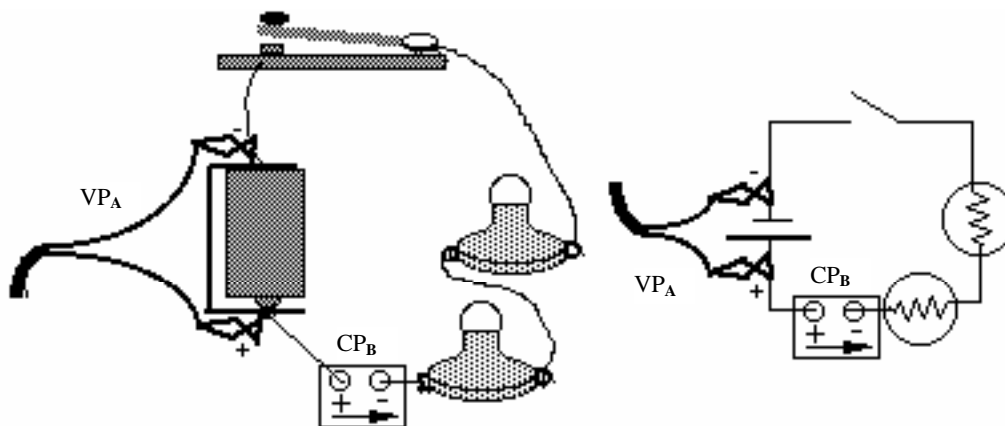


Figure 2-6: Two bulbs connected with voltage and current probes.

Question 2-4: Did the current through the battery change significantly when you added the second bulb to the circuit (by more than 5%)?

Question 2-5: Did the voltage across the battery change significantly when you added the second bulb to the circuit (by more than 5%)?

Question 2-6: Does the battery appear to be a source of constant current, constant voltage, or neither when different elements are added to a circuit?

INVESTIGATION 3: CURRENT IN SERIES CIRCUITS

In the next series of activities you will be asked to make a number of predictions about the current in various circuits, and then to compare your predictions with actual observations. Whenever your experimental observations disagree with your predictions you should try to develop new concepts about how circuits with batteries and bulbs actually work.

Hint: Helpful symbols are ($>$ "is greater than", $<$ "is less than", $=$ "is equal to"), for example $B > C > A$

Prediction 3-1: What would you predict about the relative amount of current going through each bulb in Figures 3-1 (a) and (b)? Write down your predicted order of the amount of current passing through bulbs A, B and C.

Activity 3-1: Current in a Simple Circuit with Bulbs

We continue to see which model in Figure 1-2 accurately represents what is happening. You can test your Prediction 3-1 by using current

probes. Convince yourself that the current probes shown in Figure 3-1 measure the currents described in the figure caption.

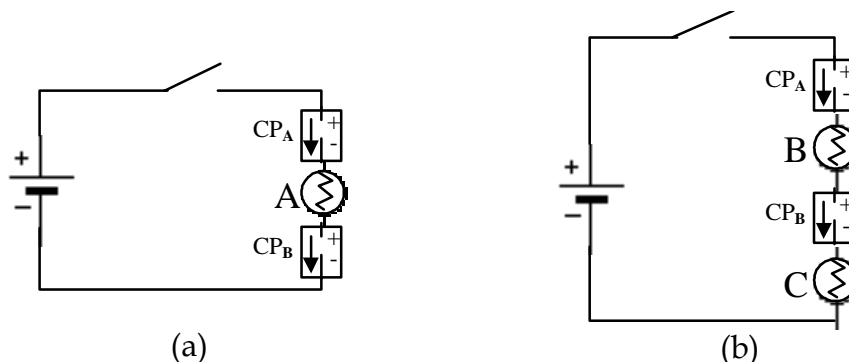


Figure 3-1: Current probes connected to measure the current through bulbs. In circuit (a), CP_A measures the current into bulb A, and CP_B measures the current out of bulb A. In circuit (b), CP_A measures the current into bulb B while CP_B measures the current out of bulb B and the current into bulb C.

1. Open the experiment file **Two Currents** to display the two sets of current axes versus time.
2. Connect circuit (a) in Figure 3-1.
3. **Begin graphing**, close the switch for a second or so, open it for a second or so and then close it again.
4. **Print** one set of graphs for your group.
5. Use the **Smart Tool** to measure the currents into and out of bulb A when the switch is closed:

Current into bulb A: _____ Current out of bulb A: _____

Question 3-1: Are the currents into and out of bulb A equal or is one significantly larger (do they differ by more than a few percent)? What can you say about the directions of the currents? Is this what you expected?

6. Connect circuit (b) in Figure 3-1. **Begin graphing** current as above, and record the measured values of the currents.
Current through bulb B: _____ Current through bulb C: _____
7. **Print** one set of graphs for your group.

Question 3-2: Consider your observation of the circuit in Figure 3-1b with bulbs B and C in it. Is current "used up" in the first bulb or is it the same in both bulbs?

Question 3-3: Is the ranking of the currents in bulbs A, B and C what you predicted? If not, can you explain what assumptions you were making that now seem false?

Question 3-4: Based on your observations, how is the brightness of a bulb related to the current through it?

Question 3-5: Formulate a qualitative rule (in words, not an equation) for predicting whether current increases or decreases as the total resistance of the circuit is increased.

Comment: The rule you have formulated based on your observations with bulbs may be *qualitatively* correct--correctly predicting an increase or decrease in current--but it won't be *quantitatively* correct. That is, it won't allow you to predict the exact sizes of the currents correctly. This is because the electrical resistance of a bulb changes as the current through the bulb changes.

Another common circuit element is a *resistor*. A resistor has a constant resistance to current regardless of how large the current is through it (unless it gets quite hot). In the next activity you will reformulate your rule using resistors.

Prediction 3-2: Consider the circuit diagrams in Figure 3-2 in which the light bulbs in Figure 3-1 have been replaced by identical resistors.

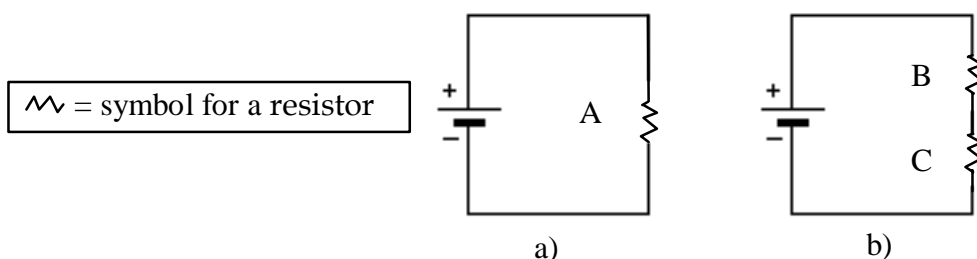


Figure 3-2: Two different circuits: (a) a battery with a single resistor, and (b) an identical battery with two resistors identical to the one in (a).

What would you predict about the relative amount of current going through each resistor in Figures 3-2 (a) and (b)? Write down your

predicted rankings of the currents through resistors A, B and C. (Remember that a resistor has a constant resistance to current regardless of the current through it.)

Activity 3-2: Current in a Simple Circuit with Resistors

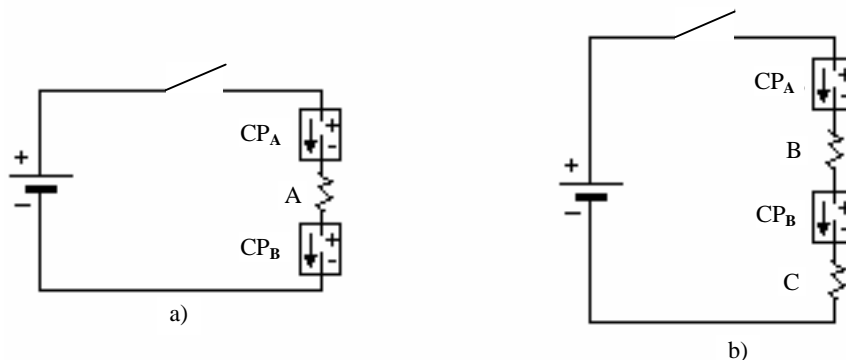


Figure 3-3: Current probes connected to measure the current through resistors. In circuit (a), CP_A measures the current into resistor A, and CP_B measures the current out of resistor A. In circuit (b), CP_A measures the current into resistor B while CP_B measures the current out of resistor B and into resistor C.

1. Continue to use the experiment file **Two Currents** (but clear the old data).
2. Connect circuit (a) in Figure 3-3 using the $10\ \Omega$ resistor.
3. Use the current probes and the **Smart Tool** to measure the current through resistor A in circuit 3-3 (a), then connect circuit 3-3 (b) and measure the currents through resistors B and C:

Current through resistor A: _____

Current through resistor B: _____ resistor C: _____

Question 3-6: Is the ranking of the currents in resistors A, B and C what you predicted? If not, can you explain what assumptions you were making that now seem false?

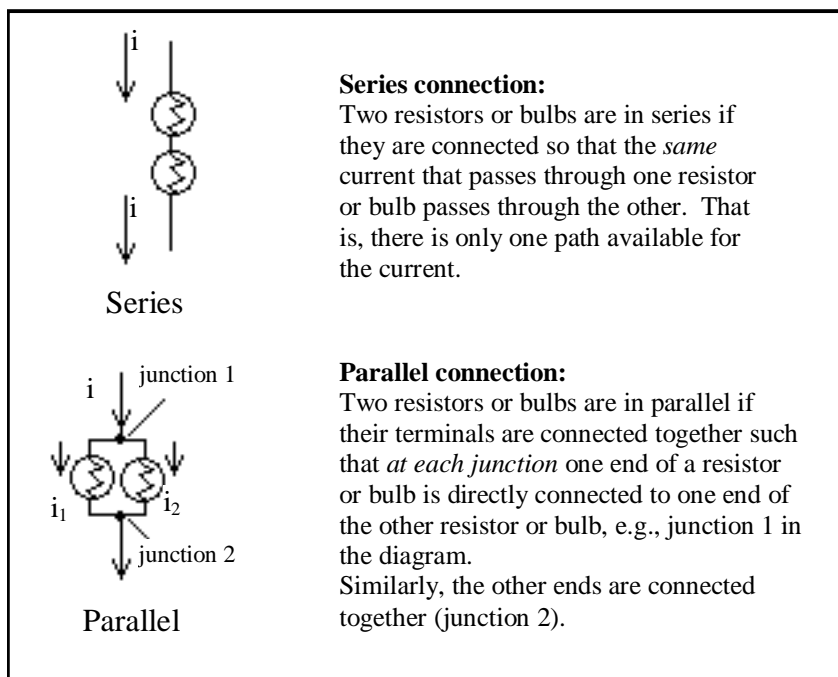
Question 3-7: How does the amount of current produced by the battery in the single resistor circuit — Figure 3-3(a) — compare to that produced by the battery with two resistors connected as in Figure 3-

3(b)? Does the addition of this second resistor in this manner affect the current through the original resistor? Explain.

Question 3-8: Re-formulate a more quantitative rule for predicting how the current supplied by the battery decreases as more resistors are connected in the circuit as in Figure 3-3(b).

INVESTIGATION 4: CURRENT IN PARALLEL CIRCUITS

There are two basic ways to connect resistors, bulbs or other elements in a circuit--*series* and *parallel*. So far you have been connecting bulbs and resistors *in series*. To make predictions involving more complicated circuits we need to have a more precise definition of series and parallel. These are summarized in the box below.



It is important to keep in mind that in more complex circuits, say with three or more elements, not every element is necessarily connected in series or parallel with other elements.

Let's compare the behavior of a circuit with two bulbs wired in parallel to the circuit with a single bulb. (See Figure 4-1.)

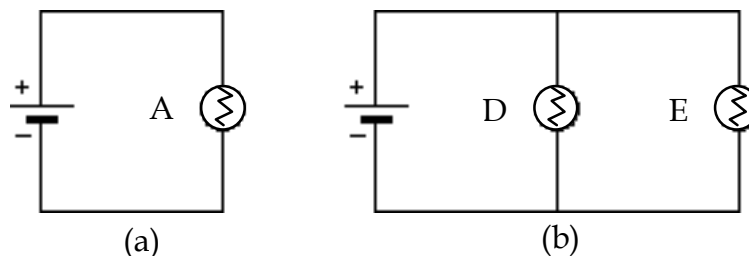


Figure 4-1: Two different circuits: (a) a single bulb circuit and (b) a circuit with two bulbs identical to the one in (a) connected *in parallel* to each other and *in parallel* to the battery.

Note that if bulbs A, D and E are identical, then the circuit in Figure 4-2 is equivalent to circuit 4-1(a) when the switch S_2 is open (as shown) and equivalent to circuit 4-1(b) when the switch S_2 is closed. Switch S_1 is always closed when taking data and open when not. Switch S_1 is used to prolong the life of the battery.

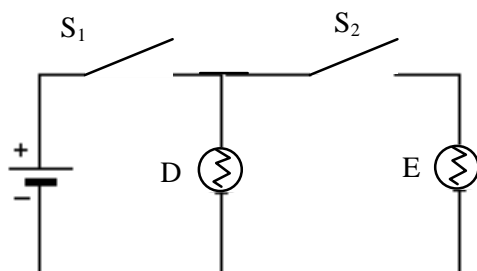


Figure 4-2: When the switch S_2 is open (S_1 is closed), only bulb D is connected to the battery. When the switch S_2 is closed, bulbs D and E are connected *in parallel* to each other and *in parallel* to the battery.

Prediction 4-1: What do you predict about the relative amount of current through each bulb in a parallel connection, i.e., compare the current through bulbs D and E in Figure 4-1 (b)?

Prediction 4-2: How do you think that closing the switch S_2 in Figure 4-2 affects the current through bulb D (while S_1 is closed)?

Activity 4-1: Current in Parallel Branches

You can test Predictions 4-1 and 4-2 by connecting current probes to measure the currents through bulbs D and E.

1. Continue to use the experiment file called **Two Currents**. Clear the old data.
2. Connect the circuit shown below in Figure 4-3. **Add a knife switch S_1 to the left side to save the battery.**

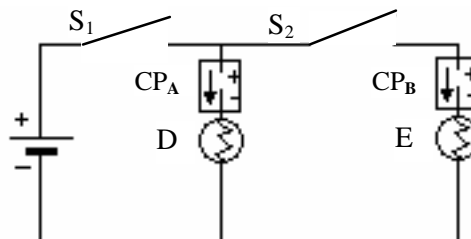


Figure 4-3: Current probes connected to measure the current through bulb D and the current through bulb E.

3. **Begin graphing** the currents through both probes with S_1 closed then close the switch S_2 for a second or so, open it for a second or so, and then close it again.
4. **Print** one set of graphs for your group. The knife switch S_1 will be left open to save the battery.
5. Use the **Smart Tool** to measure both currents.

Switch S_2 open:

Current through bulb D: _____ Current through bulb E: _____

Switch S_2 closed:

Current through bulb D: _____ Current through bulb E: _____

Question 4-1: Did closing the switch S_2 and connecting bulb E *in parallel* with bulb D significantly affect the current through bulb D? How do you know? (**Note:** you are making a very significant change in the circuit. Think about whether the new current through D when the switch is closed reflects this.)

You have already seen that the voltage maintained by a battery doesn't change appreciably when changes are made to the circuit (i.e. an ideal battery is a constant voltage source). But what about the current through the battery? Is it always the same no matter what is connected to it, or does it change depending on the circuit? This is what you will investigate next.

Prediction 4-3: What do you predict about the amount of current through the battery in the parallel bulb circuit--Figure 4-1 (b)--

compared to that through the single bulb circuit--Figure 4-1 (a)? Explain.

Activity 4-2: Current Through the Battery

1. Test your prediction with the circuit shown in Figure 4-4. Use the same experiment file, **Two Currents**, as in the previous activities. **Add a switch S_1 in the left hand circuit below to save the battery.**

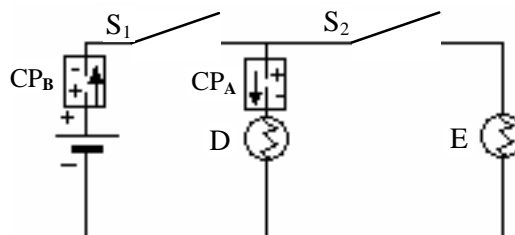


Figure 4-4: Current probes connected to measure the current through the battery and the current through bulb D.

2. Clear any old data. **Begin graphing** while closing and opening the switch S_2 as before.
3. **Print** one set of graphs for your group
4. Label on your graphs when the switch S_2 is open and when it is closed. Remember that switch S_1 is always closed when taking data, but open when not in order to save the battery.
5. Measure the currents through the battery and through bulb D:
Switch S_2 open:
Current through battery: _____ Current through bulb D: _____
Switch S_2 closed:
Current through battery: _____ Current through bulb D: _____

Question 4-2: Does the current through the battery change as you predicted? If not, why not?

Question 4-3: Does the addition of more bulbs in parallel increase, decrease or not change the total *resistance* of the circuit?

INVESTIGATION 5: MORE COMPLEX SERIES AND PARALLEL CIRCUITS

Now you can apply your knowledge to some more complex circuits. Consider the circuit consisting of a battery and two bulbs, A and B, in series shown in Figure 5-1(a). What will happen if you add a third bulb, C, in parallel with bulb B as shown in Figure 5-1(b)? You should be able to predict the relative brightness of A, B, and C based on previous observations. We will address tough questions such as: How does the brightness of A change when C is connected in parallel to B?

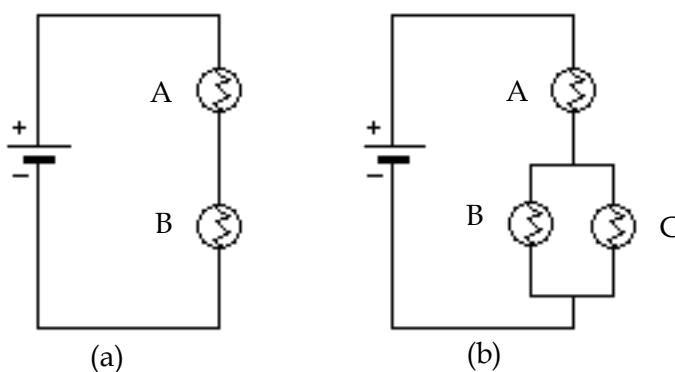


Figure 5-1: Two circuits with identical components

Question 5-1: In Figure 5-1 (b) is bulb A in series with bulb B? with bulb C? or with a combination of bulbs B and C? (You may want to go back to the definitions of series and parallel connections.)

Question 5-2: In Figure 5-1 (b) are bulbs B and C connected in series or in parallel with each other, or neither?

Question 5-3: Is the resistance of the combination A, B and C in Figure 5-1 (b) larger than, smaller than or the same as the combination of A and B in Figure 5-1 (a)?

Prediction 5-1: Predict how the current through bulb A will change, if at all, when circuit 5-1 (a) is changed to 5-1 (b) (when bulb C is added in parallel to bulb B). What will happen to the brightness of bulb A? Explain the reasons for your predictions.

Prediction 5-2: Predict how the current through bulb B will change, if at all, when circuit 5-1 (a) is changed to 5-1 (b) (when bulb C is added in parallel to bulb B). What will happen to the brightness of bulb B? Explain the reasons for your predictions. (This is difficult to do without a calculation, but at least explain your considerations.)

Activity 5-1: A More Complex Circuit

1. Set up the circuit shown in Figure 5-2(a). **Add a knife switch to the left side to save the battery.** Convince yourself that this circuit is identical to Figure 5-1 (a) when the switch, S, is open, and to Figure 5-1 (b) when the switch is closed.
2. Connect the two current probes as shown in Figure 5-2(b). **Be sure you added a switch next to the battery to save the battery.** Open the experiment file **Two Currents**, if it is not already opened. Clear any old data.

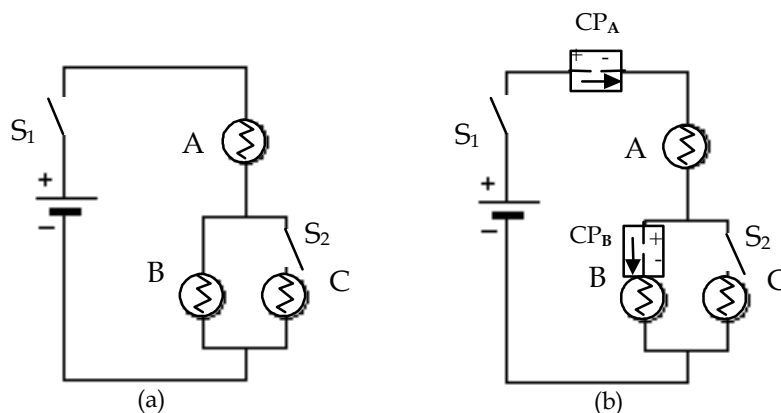


Figure 5-2: (a) Circuit equivalent to Figure 5-1 (a) when the switch S_2 is open and to Figure 5-1 (b) when the switch S_2 is closed. (b) Same circuit with current probes connected to measure the current through bulb A (CP_A) and the current through bulb B (CP_B). Switch S_1 is always closed when taking data.

- Close the battery switch S_1 and **begin graphing**. Observe what happens to the current through bulb A (i.e. through the battery) and the current through bulb B when the switch S_2 to bulb C is opened and closed.
- Open** the battery switch S_1 .
- Print** one set of graphs for your group.
- Use the **Smart Tool** to find the following information:

Without bulb C in the circuit:

current through A: _____ current through B: _____

With bulb C in the circuit:

current through A: _____ current through B: _____

Question 5-4: What happened to the brightness of bulbs A and B as the switch to bulb C was opened and closed? Compare to your predictions.

Question 5-5: What happens to the current through the battery when bulb C is added into the circuit? What do you conclude happens to the total resistance in the circuit?