Modern Methods of Teaching Physics

Part of **Meeting of Modern Science and School Physics: College for School Teachers of Physics SMR 2234**

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Modern Methods of Teaching Physics

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Research on the Effectiveness of *ILDs* (10 minutes)

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2. Why can you see a test tube in air or in water, but not in the magic fluid? What is special about the magic fluid?

3. What property of transparent media determines whether reflection takes place at the boundary between them? What has to be true about this property for the two materials in order for reflection to take place?

4. What about the light that is transmitted through the test tube? How is it affected when the test tube is in the magic fluid and when the test tube is in air?

Section V

Interactive Lecture Demonstrations

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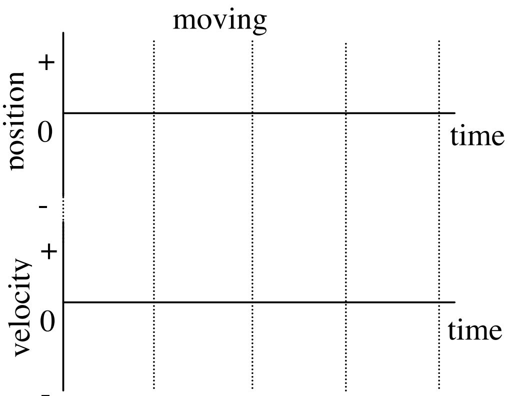
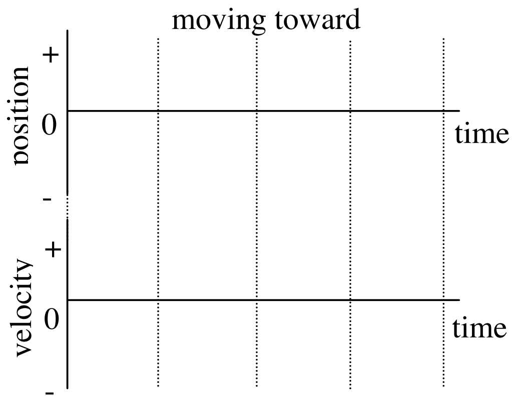
INTERACTIVE LECTURE DEMONSTRATIONS
PREDICTION SHEET—**KINEMATICS 2—MOTION OF CARTS**

Directions: This sheet will be collected. Write your name at the top to record your presence and participation in these demonstrations. Follow your instructor's directions. You may write whatever you wish on the attached Results Sheet and take it with you.

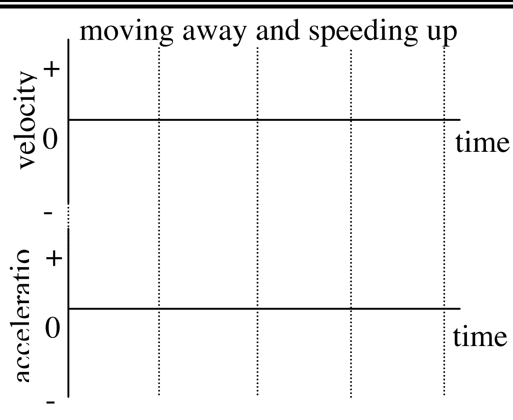
Demonstration 1: On the left velocity axes below sketch your prediction of the *velocity-time* graph of the cart moving away from the motion detector at a steady (constant) velocity. On the left position axes below sketch your prediction of the *position-time* graph for the same motion.



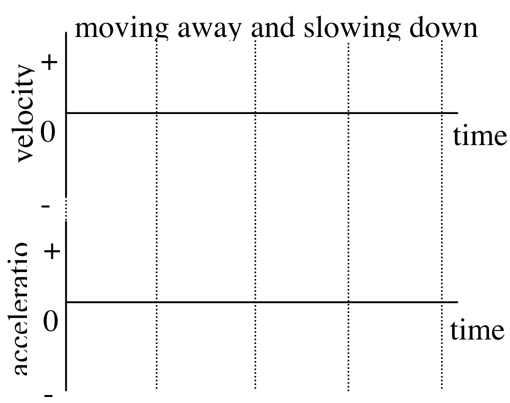


Demonstration 2: On the right velocity axes above sketch your prediction of the *velocity-time* graph for the cart moving toward the motion detector at a steady (constant) velocity. On the right position axes above sketch your prediction of the *position-time* graph for the same motion.

Demonstration 3: Sketch on the axes on the right your predictions for the *velocity-time* and *acceleration-time* graphs of the cart moving away from the motion detector and speeding up at a steady rate.



Demonstration 4: Sketch on the axes on the right your predictions for the *velocity-time* and *acceleration-time* graphs of the cart moving away from the motion detector and slowing down at a steady rate.



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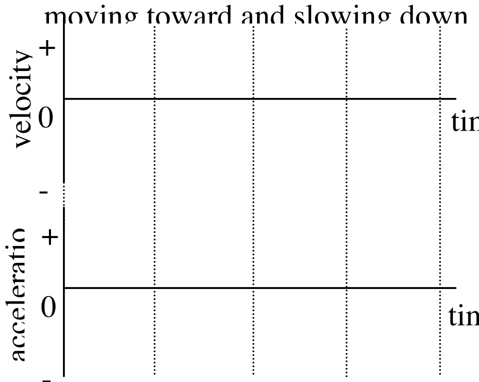

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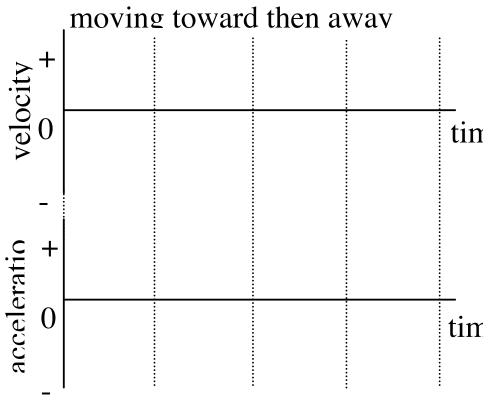
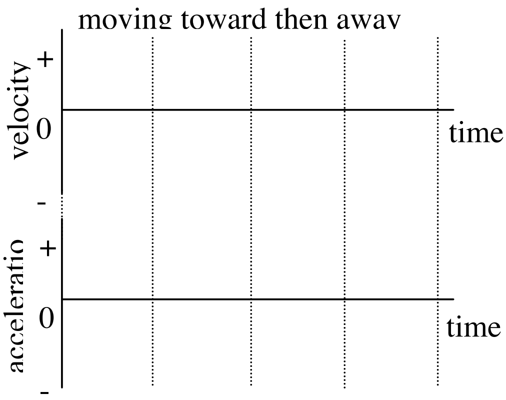
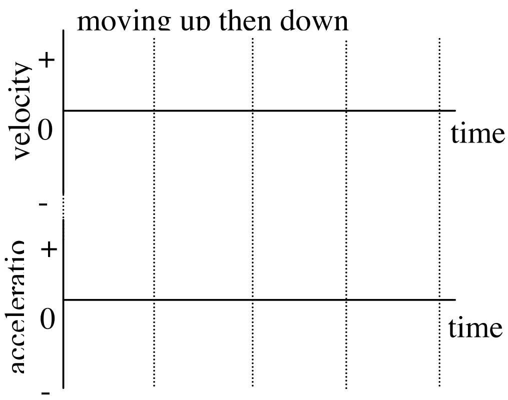


Demonstration 7: Sketch below your predictions for the *velocity-time* and *acceleration-time* graphs for the cart which is given a short push up the inclined ramp toward the motion detector (and is released) Sketch the graph as the cart slows down moving toward the detector, comes *momentarily* to rest and then speeds up moving away from the detector.



Demonstration 8: The origin of the coordinate system is on the floor, and the positive direction is upward. A ball is thrown upward. It moves upward, slowing down, reaches its highest point and falls back downward speeding up as it falls. Sketch on the axes on the right your predictions for the *velocity-time* and *acceleration-time* graphs of the ball from the moment just after it is released until the moment just before it hits the floor.



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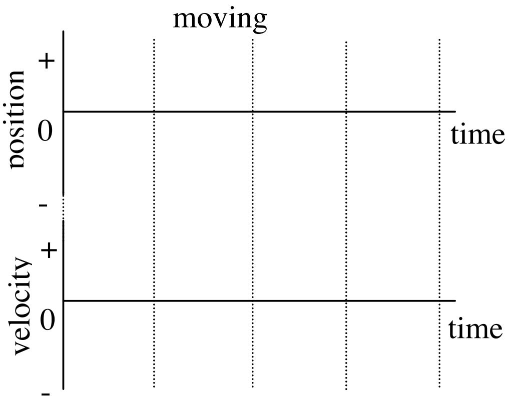

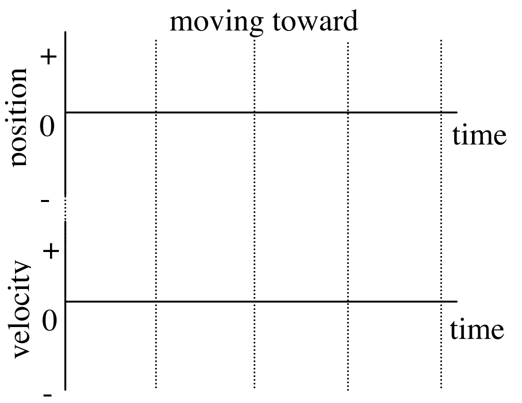

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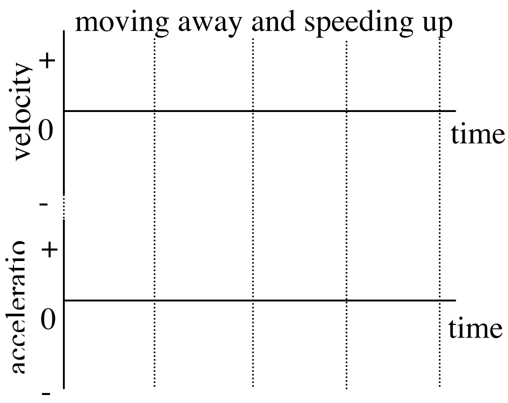

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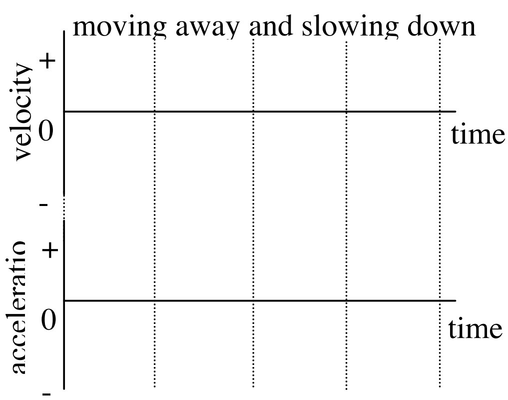

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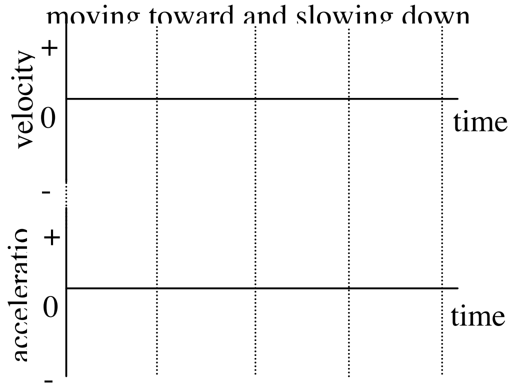

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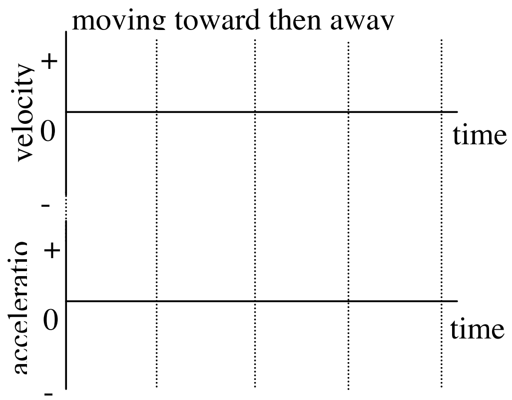

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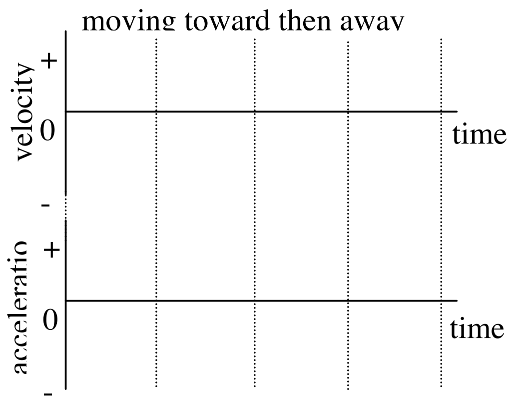

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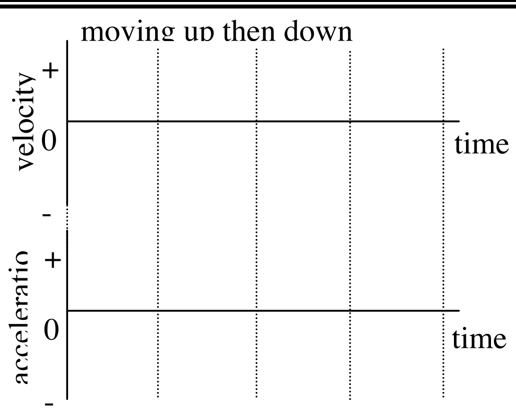

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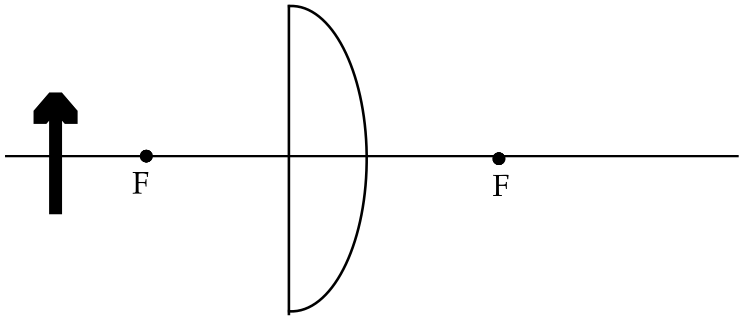
INTERACTIVE LECTURE DEMONSTRATIONS
PREDICTION SHEET—**IMAGE FORMATION WITH LENSES**

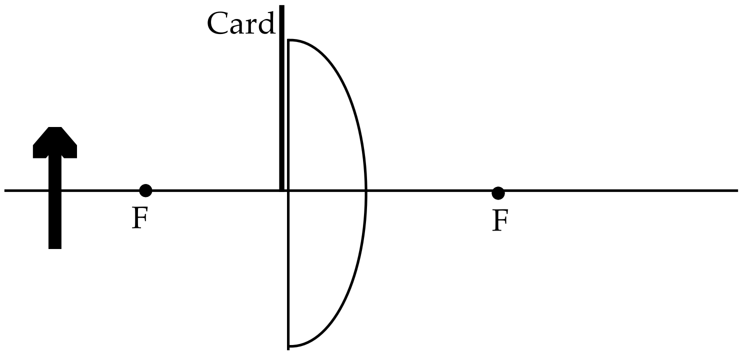
Directions: This sheet will be collected. Write your name at the top to record your presence and participation in these demonstrations. Follow your instructor's directions. You may write whatever you wish on the attached Results Sheet and take it with you.

Demonstration 1: You have a converging lens. An object in the shape of an arrow is positioned a distance larger than the focal length to the left of the lens, as shown in the diagram on the right. Draw several rays from the head of the arrow and several rays from the foot of the arrow to show how the image of the arrow is formed by the lens.

Is this a real or a virtual image?



Demonstration 2: What will happen to the image if you block the top half of the *lens* with a card? Answer in words and show what happens on the diagram on the right by making any changes needed in the rays you drew in Demonstration 1.



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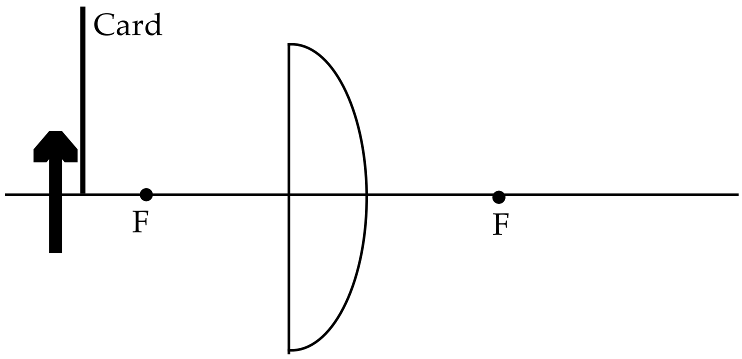
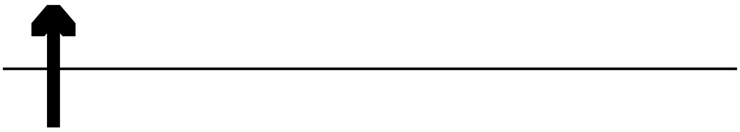


Demonstration 4: What will happen to the image if you remove the lens? Answer in words and show what happens on the diagram on the right by making any changes needed in the rays you drew above for Demonstration 1.



Demonstration 5: What will happen to the image if the object is moved further away from the lens? Will the position of the image change? If so, how?

Will the size of the image change? If so, how?

Will the image be real or virtual?

Demonstration 6: What will happen to the image if the object is moved closer to the lens (but is still further away than the focal point)? Will the position of the image change? If so, how?

Will the size of the image change? If so, how?

Will the image be real or virtual?

Demonstration 7: What will happen to the image if the object is moved closer to the lens so that it is closer to the lens than the focal point? Will the position of the image change? If so, how?

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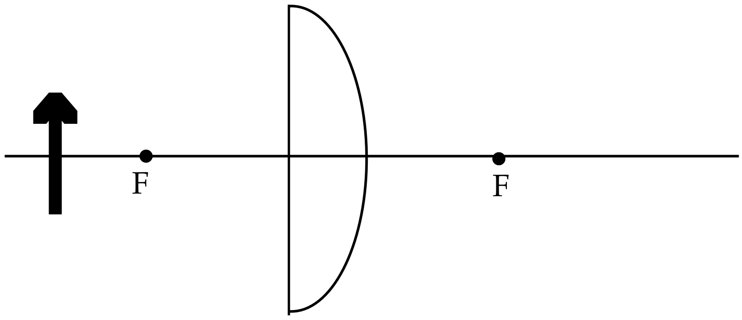

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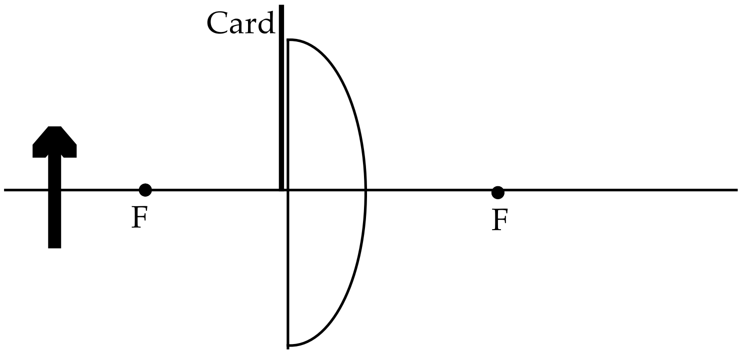

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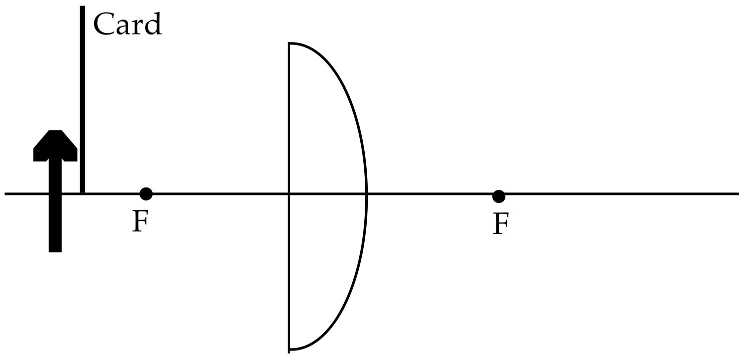

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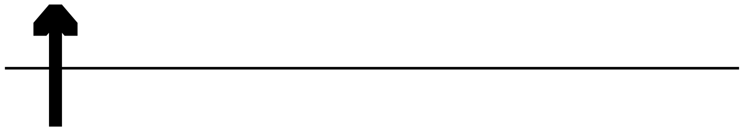

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Section VI

RealTime Physics: Active Learning Labs

Name________________________________ Date____________________

PRE-LAB PREPARATION SHEET FOR LAB 1—BATTERIES, BULBS, AND CURRENT

(Due at the beginning of lab)

Directions:
Read over Lab 1 and then answer the following questions about the procedures.

1. Explain why in Activity 1-1 the angle irons will be charged in several different ways.

2. Sketch below one arrangement of the battery, bulb, and wire (other than the one in Figure 1-3), which you will try in Activity 1-2.

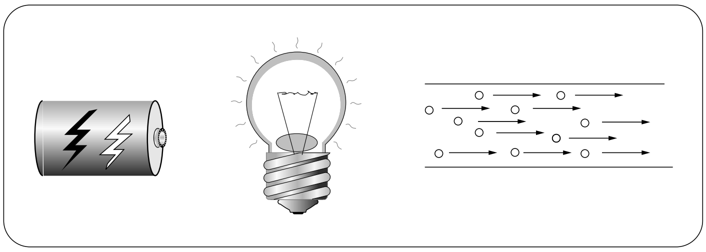
3. At this time, which model for current in Figure 1-6 do you favor? Why?

4. Describe briefly how you will test the models for current. What device will you use to measure current?

5. What is the symbol for a battery? A light bulb?

Name________________________________ Date______________ Partners________________________________

Lab 1: Batteries, Bulbs, and Current*



You cannot teach a man anything; you can only help him to find it within himself.

—Galileo

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 the measurement of current and voltage using microcomputer-based probes.
- To understand currents at all points in simple circuits.

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. What you learn will be one of the most practical parts of the whole physics course, since electric circuits form the backbone of twentieth-century technology. Without an understanding of electric circuits we wouldn't have lights, air conditioners, automobiles, telephones, TV sets, dishwashers, computers, or photocopying machines.

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.

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

If this conductor happens to be 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 and the potential difference (voltage), respectively, and display these quantities on a computer screen.

INVESTIGATION 1: MODELS DESCRIBING CURRENT

What is electric current? The forces between objects that are rubbed in particular ways can be attributed to a property of matter known as *charge* (static electricity). Most textbooks assert that the electric currents through the wires connected to a battery are charges in motion. How do we know this? Perhaps current is something else—another phenomenon.

This is a question that received a great deal of attention from Michael Faraday, a famous early-nineteenth-century scientist. Faraday studied the effects of electricity from animals such as electric eels and tabulated his results in a table like the one shown in Figure 1-1. He concluded that "electricity, whatever may be its source, is identical in its nature."[1]

	Physiological effect	Magnetic deflection	Magnets made	Spark	Heating power	True chemical action	Attraction and repulsion	Discharge by hot air
1. Voltaic electricity	X	X	X	X	X	X	X	X
2. Common electricity	X	X	X	X	X	X	X	X
3. Magneto-electricity	X	X	X	X	X	X	X	
4. Thermo-electricity	X	X	+	+	+	+		
5. Animal electricity	X	X	X	+	+	X		

Figure 1-1: Reproduction of Faraday's table. The X's denote results obtained by Faraday and the +'s denote positive results found by other investigators later.

The purpose of the first activity is to compare carriers of the current produced by a battery to the static charges deposited by rubbing materials together. You will observe a demonstration using the following materials:

- 2 metal angle irons (approx. 15 cm long)
- foil-covered Styrofoam ball on a string (2.5 cm diameter)
- 300-V battery pack or power supply

[1]Faraday, M. "Identity of Electrocutes Derived from Different Sources," in *Experimental Researches in Electricity, Vol. I*, Taylor and Francis, London. (Reprinted by Dover Publications, New York, 1965, p. 76).

- rubber rod and cat fur
- glass rod and polyester cloth or silk
- electroscope
- alligator clip leads
- Wimshurst or Van de Graaff generator (optional)

Activity 1-1: Comparing Stuff from a Battery to the Rubbing Stuff

1. The angle irons, ball, and electroscope will be set up as shown in Figure 1-2.

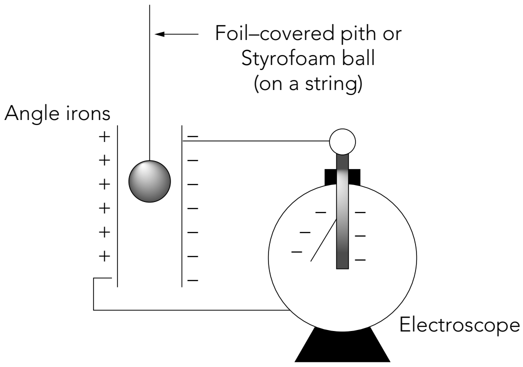


Figure 1-2: Apparatus for detecting charge.

2. The metal angle irons will be charged in two or more of the following ways:

a. *Electrostatic Charging by Rubbing.* Stroke one plate with a rubber rod that has been rubbed with the cat fur. Repeat this several times. Stroke the other plate with the glass rod that has been rubbed with the polyester cloth or silk.

b. *Charging with a Battery.* Connect a wire from the negative terminal of the battery pack to one of the angle irons. At the same time connect a wire from the positive terminal of the battery pack to the other plate.

c. *Charging with a Wimshurst or Van de Graaff Generator.* Connect a wire from one of the two terminals of the generator to one angle iron, and a wire from the other terminal to the other angle iron.

3. Observe whether the different charging methods have different effects on the electroscope and on the ball when it is dangled between the two metal angle irons.

4. The metal angle irons will then be separated so the gap between them is just barely bigger than the diameter of the foil covered ball, and the ball will be carefully placed between them.

Question 1-1: What happened to the electroscope when the angle irons were charged with the familiar rubbing method—method (a)? Why?

Question 1-2: What happened when the ball was placed between the angle irons? In terms of the attraction and repulsion of different types of charges, explain why this unusual phenomenon happened.

Question 1-3: Describe what happened when the battery was used to "charge" the angle irons. What differences (if any) did you observe in the response of the electroscope and the ball to the charges on the angle irons?

Question 1-4: If the Wimshurst or Van de Graaff generator was also used, describe what happened. What differences (if any) did you observe in the response of the electroscope and the ball to the charges on the angle irons?

Question 1-5: Do the charges generated by rubbing and from the output of the battery cause different effects? If so, describe them. Do the charges generated in these two ways appear to be different?

The rate of flow of electric charge is more commonly called *electric current*. If charge Δq flows through the cross section of a conductor in time Δt, then the average current can be expressed mathematically by the relationship

$$\langle i \rangle = \frac{\Delta q}{\Delta t}$$

Instantaneous current is defined as the charge per unit time passing through a particular part of a circuit at an instant in time. It is usually defined using a limit:

$$i = \text{limit } \frac{\Delta q}{\Delta t}$$

as $\Delta t \rightarrow 0$

The unit of current is called the ampere (A). One ampere represents the flow of one coulomb of charge through a conductor in a time interval of one second. Another common unit is the milliampere (mA) (1 ampere = 1000 milliamperes). Usually people just refer to current as "amps" or "milliamps."

In the next activity, you can begin to explore electric current by lighting a bulb with a battery. You will need the following:

- flashlight bulb (#14)
- flashlight battery (1.5-V D cell)
- wire (6 inches or more in length)

Activity 1-2: Arrangements That Cause a Bulb to Light

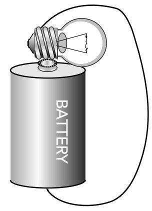


Figure 1-3: A wiring configuration that might cause a bulb to light in the presence of a battery.

Use the materials listed above to find some arrangements in which the bulb lights and some in which it does not light. For instance, try the arrangement shown in Figure 1-3.

Question 1-6: Sketch below two different arrangements in which the bulb lights.

Question 1-7: Sketch below two arrangements in which the bulb *doesn't* light.

Question 1-8: Describe as fully as possible what conditions are needed if the bulb is to light, and why the bulb fails to light in the arrangements drawn in answer to Question 1-7.

Next you will explore which types of materials connected between the battery and the bulb allow the bulb to light and which do not. Since it seems that something flows from the battery to the bulb, we refer to materials that allow this flow as *conductors* and those that don't as *nonconductors*.
You will need

- common objects (paper clips, pencils, coins, rubber bands, fingers, paper, keys, etc.)

Activity 1-3: Other Materials Between the Battery and Bulb

Set up the single wire, battery, and bulb so that the bulb lights, e.g., one of the arrangements drawn in your answer to Question 1-6. Then, with the help of your partner, stick a variety of the common objects available between the battery and the bulb.

Question 1-9: List some materials that allow the bulb to light.

Question 1-10: List some materials that prevent the bulb from lighting.

Question 1-11: What types of materials seem to be conductors? What types seem to be nonconductors?

Are you having trouble holding your circuits together? Let's make it easier by using a battery holder and a bulb socket. While we're at it let's also add a switch in the circuit. In addition to the materials you've already used, you will need:

- battery holder (for a D cell)
- several wires (6 inches or more in length)
- flashlight bulb socket
- contact switch

Activity 1-4: Using a Battery Holder, Bulb Socket, and Switch

1. Examine the bulb socket carefully. Observe what happens when you unscrew the bulb.

2. Examine the bulb closely. Use a magnifying glass, if available. Figure 1-4 shows the parts of the bulb that are hidden from view.

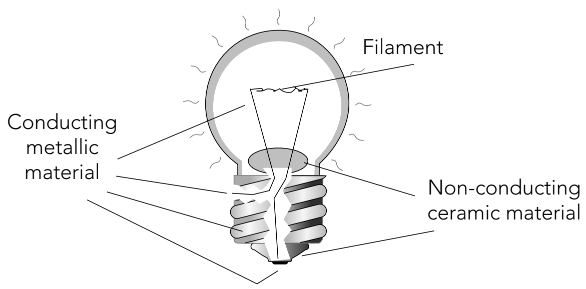


Figure 1-4: Wiring inside a light bulb.

Question 1-12: Why is the filament of the bulb connected in this way?

Question 1-13: Explain how the bulb socket works. Why doesn't the bulb light when it is unscrewed?

Prediction 1-1: If you wire up the configuration shown in Figure 1-5, will the bulb light with the switch open (i.e., so no contact between the wires is made)? Closed (i.e., so that contact is made)? Neither time? Explain your predictions.

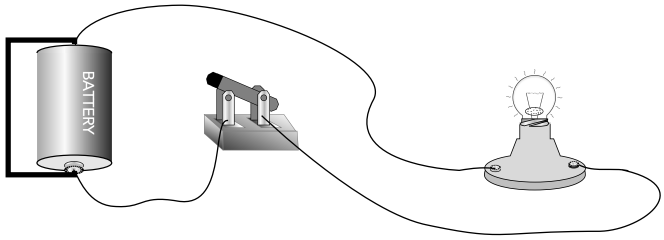


Figure 1-5: A circuit with a battery, switch, and bulb holder.

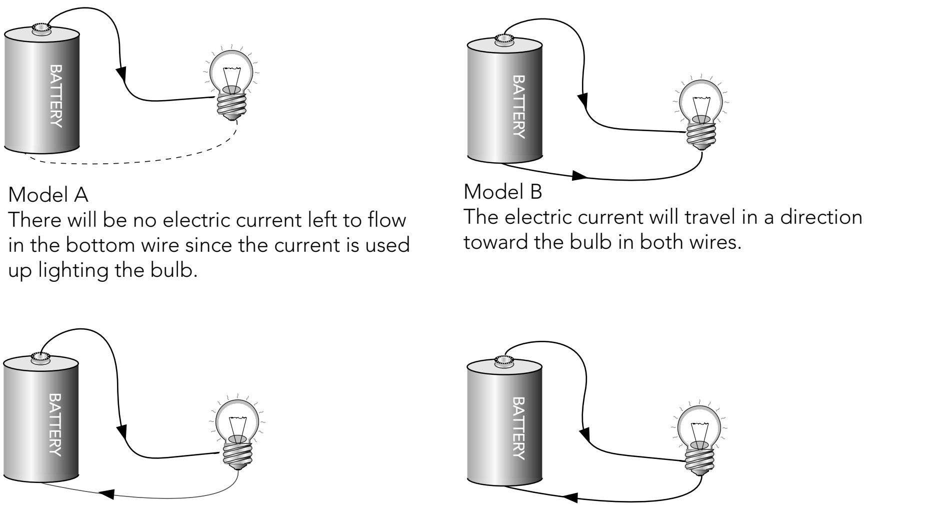
3. Wire the circuit shown in Figure 1-5 and test it.

4. Leave the switch closed so that the bulb remains on for 10–20 seconds. Feel the bulb.

Question 1-14: What did you feel? Besides giving off light, what happens to the bulb when there is a current through it?

Question 1-15: What do you conclude about the path needed by the current to make the filament heat up and the bulb glow? Explain based on all the observations you have made so far.

You are now ready to explore models for current in a circuit. The circuit to be considered is the one shown in Figure 1-5 with the switch closed. Figure 1-6 shows several models for the current in this circuit that are often proposed.



Model A
There will be no electric current left to flow in the bottom wire since the current is used up lighting the bulb.

Model B
The electric current will travel in a direction toward the bulb in both wires.

Model C
The direction of the current will be in the direction shown, but there will be less current in the return wire since some of the current is used up lighting the bulb.

Model D
The direction of the current will be as shown, and the magnitude will be the same in both wires.

Figure 1-6: Four alternative models for current.

Prediction 1-2: Which model do you think best describes the current through the bulb? After you make your own prediction, talk things over with your partner. Explain your reasoning.

After you have discussed the various ideas with your partner, and chosen your favorite model, you can test your prediction. In Activity 1-5 you will use one or more current probes in your circuit to measure current. In addition to the battery, bulb, and wires you used above, you will need:

- computer-based laboratory system
- two current probes
- *RealTime Physics Electric Circuits* experiment configuration files

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.

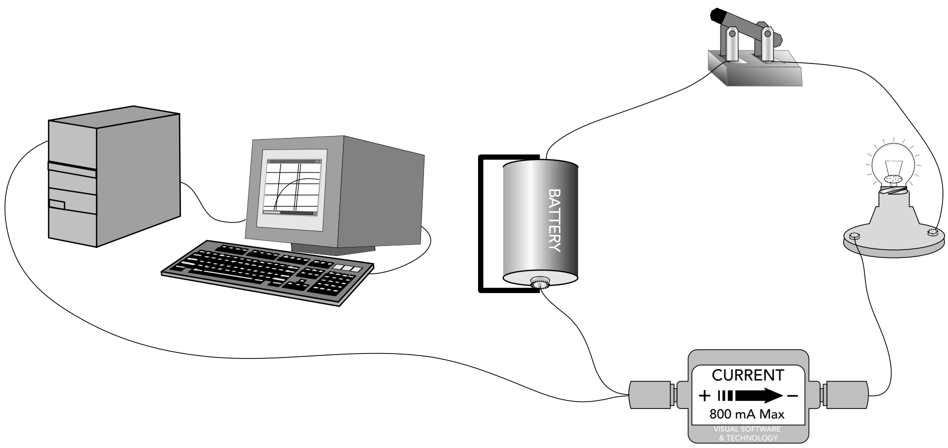


Figure 1-7: A circuit with a battery, bulb, switch, and current probe connected to the computer interface.

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 it in place.* For example, to measure the current in the bottom wire of the circuit in Figure 1-5, the current probe should be connected as shown in Figure 1-7.

Note that the current probe measures both the *magnitude* and *direction* of the current. A current that flows 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 1-7 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 1-7 (flowing into the − terminal and out of the + terminal of the probe).

Figure 1-8a shows a simplified diagram representing a current probe connected as shown in Figure 1-7.

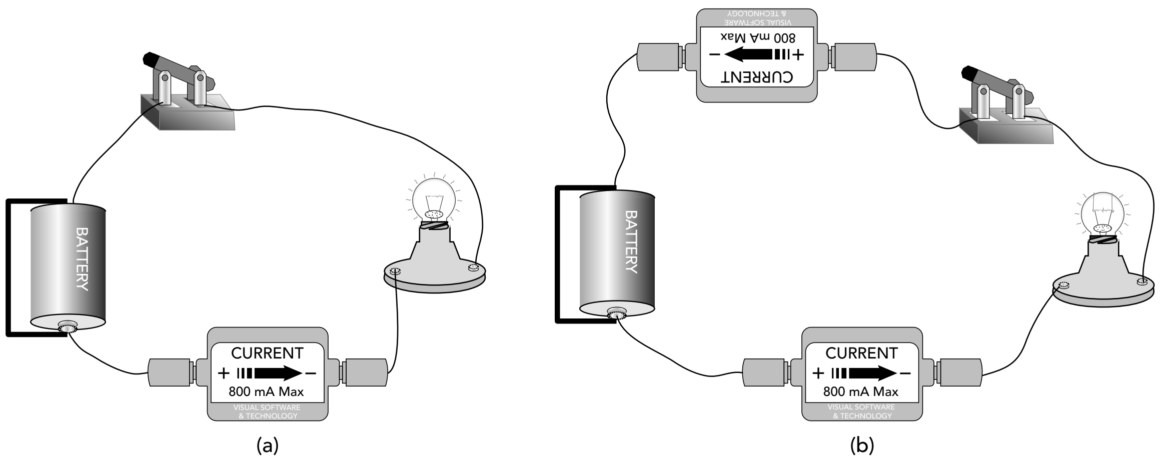


Figure 1-8 (a) Current probe connected to measure the current out of the + terminal of the battery and into the bulb. (b) Two current probes, one connected as in (a) and the other connected to measure the current out of the switch and into the − terminal of the battery.

Look at Figure 1-8b and convince yourself that if the currents measured by current probes 1 and 2 are both positive, this shows that the current is in a counterclockwise direction around all parts of the circuit.

You will use one or more bulbs and one or more current probes for the next activity. Design measurements that will allow you to choose the model (or models) that best describe the actual current through the circuit. (For example, to see if the current has a different magnitude or direction at different points in a circuit [model B or model C in Figure 1-6] you should connect two current probes in various locations around the circuit as in Figure 1-8b, to measure the current.)

Prediction 1-3: Use Table 1-1 to describe how the readings of current probe 1 and current probe 2 in the circuit in Figure 1-8b would compare with each other for each of the current models described in Figure 1-6.

Table 1-1

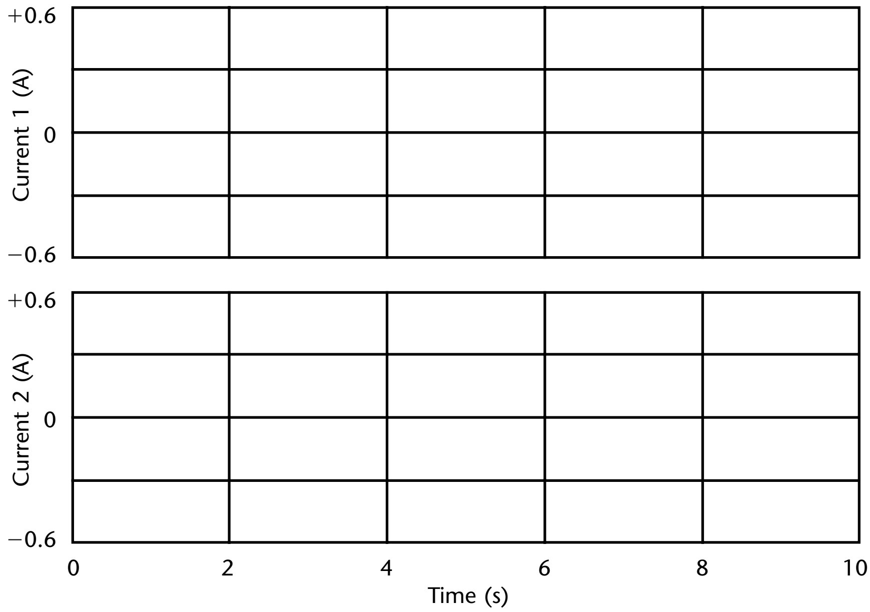
	Probe	Positive, negative, or zero?	CP1 > CP2, CP1 < CP2, or CP1 = CP2?
Model A	CP1		
	CP2		
Model B	CP1		
	CP2		
Model C	CP1		
	CP2		
Model D	CP1		
	CP2		

Activity 1-5: Developing a Model for Current in a Circuit

1. Be sure that current probes 1 and 2 are plugged into the interface.
2. Open the experiment file called **Current Model (L01A1-5).** The two sets of axes that follow should appear on the screen. The top axes display the current through probe 1 and the bottom the current through probe 2.

   The amount of current through each probe is also displayed digitally on the screen.
3. Be sure to **calibrate** the probes, or **load the calibration. Zero** the probes with them disconnected from the circuit.
4. To begin, set up the circuit in Figure 1-8b. **Begin graphing,** and try closing the switch for a couple of seconds and then opening it for a couple of seconds. Repeat this several times during the time when you are graphing. Sketch your graphs on the axes, or **print** your graphs and affix them over the axes.

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).



Question 1-16: How could you determine if an observed difference in the currents read by probe 1 and probe 2 is real or if it is the result of small calibration differences in the probes?

Question 1-17: Did you observe a *significant* difference in the currents at these two locations in the circuit, or was the current the same?

5. Try any other tests you need to decide on a current model among the choices in Figure 1-6, or any others you come up with. Sketch drawings of the circuits you used, showing where the probes were connected. **Print** all graphs, label them and affix them below.

Question 1-18: Based on your observations, which model seems to correctly describe the behavior of the current in your circuit. Explain carefully based on your observations.

INVESTIGATION 2: CURRENT AND POTENTIAL DIFFERENCE

Since you now know what it takes to get a light bulb to light, you can design and build some simple electrical devices before you learn more about what goes on in electric circuits. You can use extra switches, wires, bulbs, etc. as needed. You will have available

- 3 #14 bulbs and sockets
- 1.5-V D battery (must be very fresh alkaline) with holder
- 6 alligator clip leads
- single-pole–single-throw (SPST) switch
- single-pole–double-throw (SPDT) switch
- double-pole–double-throw (DPDT) switch

Activity 2-1: Inventing and Constructing Electric Circuits

Invent and construct one of the electric circuits described below. Sketch the circuit in the space below.

1. *Christmas Tree Lights:* Suppose you want to light up your Christmas tree with three bulbs. What happens if one of the bulbs fails? (Don't break the bulb! You can simulate failure by loosening a bulb in its socket.) Figure out a way to connect all three bulbs so that the other two will still be lit if any one of the bulbs burns out.
2. *Lighting a Tunnel:* The bulbs and switches must be arranged so that a person walking through a tunnel can turn on a lamp for the first part of the tunnel and then turn on a second lamp for the second half of the tunnel in such a way that the first one is turned off.
3. *Entry and Exit Light Switches:* A room has two doors. Light switches at both doors are wired so that either switch turns the lights in the room on and off.

Circuit diagram for circuit #____

Question 2-1: Describe how your circuit works, and why you connected it in the way you did.

Extension 2-2: Inventing other Electric Circuits

Invent and construct one or both of the other electric circuits described in Activity 2-1, or invent your own circuit that performs a certain task. Sketch each circuit diagram and describe how the circuit works in the space below.

Now that you have been wiring circuits and drawing diagrams of them you may be getting tired of drawing pictures of the batteries, bulbs, and switches. There are a series of symbols that have been created to represent circuits. A few of the electric circuit symbols are shown in Figure 1-9.

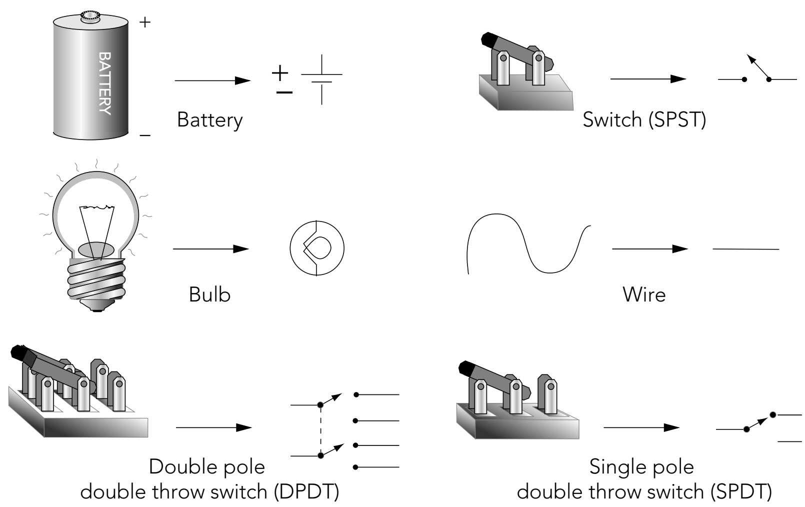


Figure 1-9: Some common circuit symbols.

Using these symbols, the circuit from Figure 1-5 with a switch, bulb, wires, and battery can be sketched as on the right in Figure 1-10.

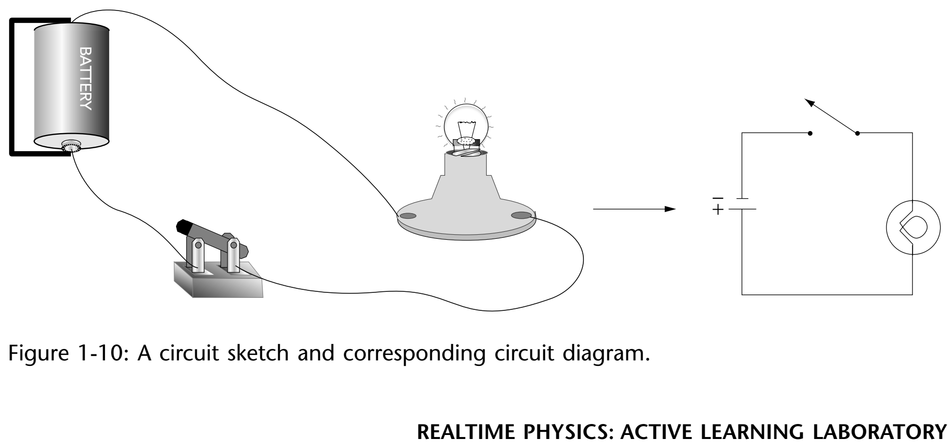


Figure 1-10: A circuit sketch and corresponding circuit diagram.

Activity 2-3: Drawing Circuit Diagrams

Sketch a nice neat "textbook" style circuit diagram for each of the circuits you designed in Activity 2-1 and Extension 2-2.

Question 2-2: On the battery symbol, which line represents the positive terminal—the long one or the short one? [**Note:** You should try to remember this convention for the battery polarity because some circuit elements, such as *diodes*, behave differently if the battery is turned around so it has opposite polarity.]

There are actually two important quantities to consider in describing the operation of electric circuits. One is *current*, and the other is *potential difference*, often referred to as *voltage*. In Activity 1-5 you measured the current at two different positions in a circuit. Now, as an introduction to our studies of more complex circuits, let's actually measure *both current and voltage* in a familiar circuit.

In addition to the equipment you have been using so far, you will need:

- computer-based laboratory system
- two voltage probes
- two current probes
- *RealTime Physics Electric Circuits* experiment configuration files

Figure 1-11 shows the symbols we will use to indicate a current probe or a voltage probe.

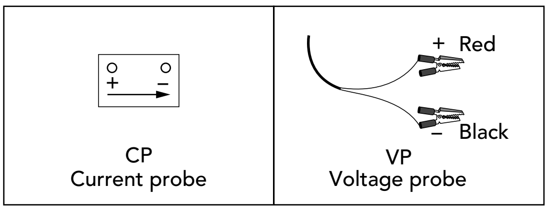


Figure 1-11: Symbols for current probe and voltage probe.

Figure 1-12a shows our simple circuit from Figure 1-5 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 1-12b. Note that the word *across* is very descriptive of how the voltage probes are connected.

Activity 2-4: Measuring Potential Difference (Voltage) and Current

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

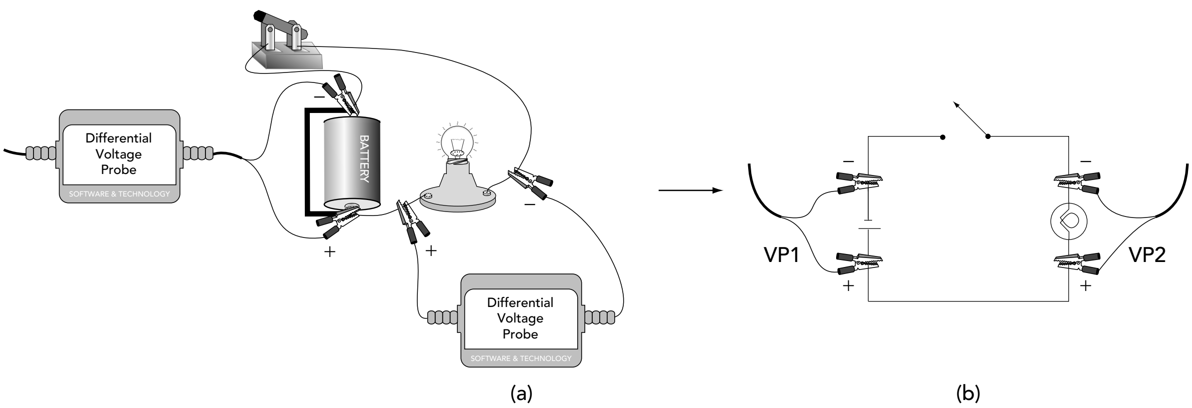
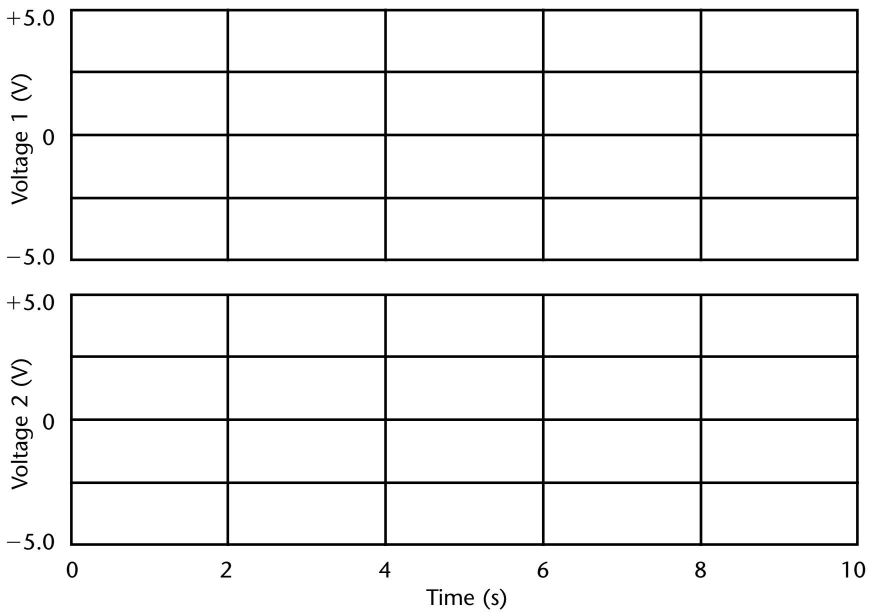


Figure 1-12: Two voltage probes connected to measure the voltages across the battery and the bulb.

2. Open the experiment file called **Two Voltages (L01A2-4a)** to display the axes for two voltage probes that follow.
3. **Zero** the voltage probes with them disconnected from the circuit.
4. Connect the circuit shown in Figure 1-12, but *do not connect the probes yet*.
5. First connect both the + and the − clips of one voltage probe together. Observe the reading. Next connect both clips to the *same point* in the circuit. Close the switch.
6. Finally connect the + clip to the + end of the battery and the − clip to the side of the bulb indicated with a + in Figure 1-12. Close the switch.

Question 2-3: What do you conclude about the voltage when the voltage probe leads are connected to the same point or to the two ends of the same wire?



Prediction 2-1: In the circuit in Figure 1-12, how would you expect the voltage across the battery to compare to the voltage across the bulb with the switch open and closed? Explain.

7. Now test your prediction. Connect the voltage probes to measure the voltage *across* the battery and the voltage *across* the bulb simultaneously.
8. **Begin graphing,** and close and open the switch several times. **Print** your graphs and affix them over the axes above, or sketch them on the axes.

Question 2-4: What do you conclude about the voltage across the battery and the voltage across the bulb when the switch is open and when it is closed? Are the graphs the same? Why or why not? What is going on as the switch is closed and opened?

9. Now 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 1-13).
10. Open the experiment file called **Current and Voltage (L01A2-4b)** to display the current and voltage axes that follow.

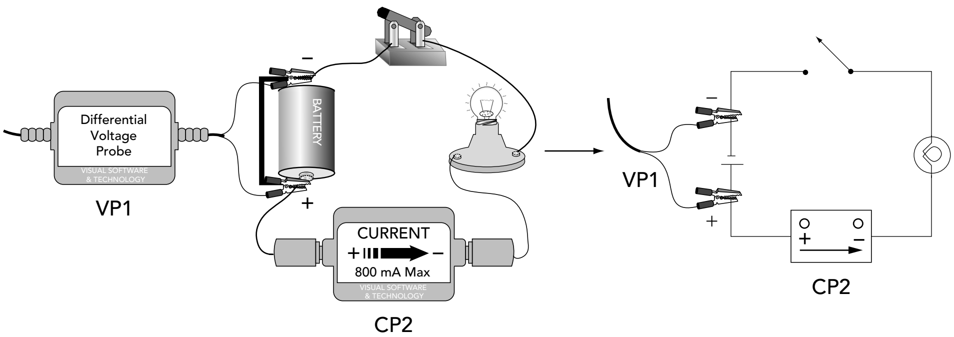
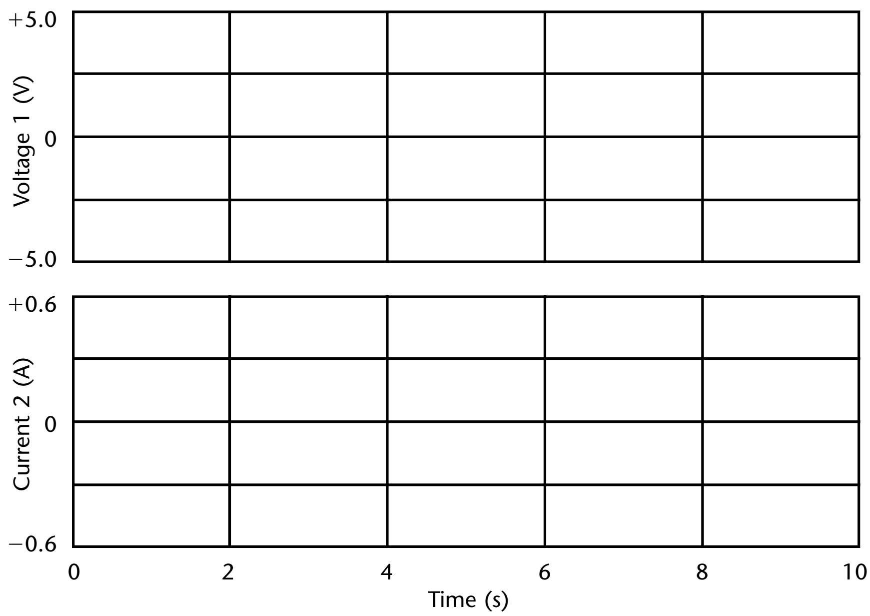


Figure 1-13: Probes connected to measure the voltage across the battery and the current through it.

11. **Begin graphing,** and close and open the switch several times, as before. Sketch your graphs, or **print** them and affix over the axes.



Question 2-5: 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?

12. Find the voltage across and the current through the battery when the switch is closed and the bulb is lit. (You can use the digital display on the computer screen.)

Average voltage: ___ Average current: ___

Prediction 2-2: Now suppose you connect a second bulb in the circuit, as shown in Figure 1-14. How do you think the voltage across the battery will compare to that with only one bulb? Will it change significantly? Explain.

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

Average voltage: ___ Average current: ___

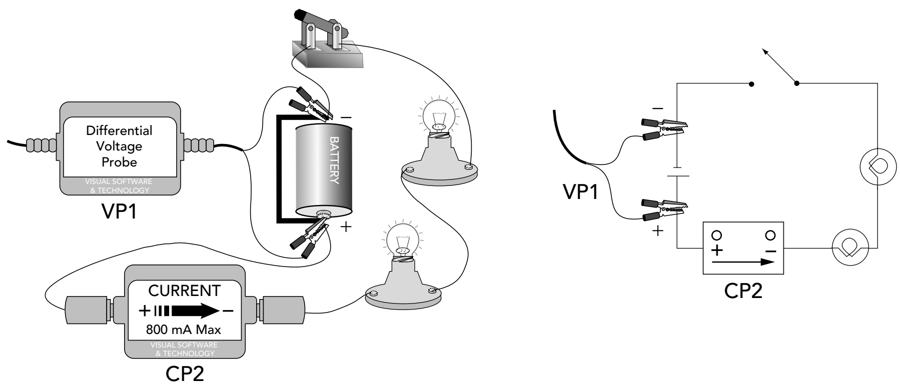


Figure 1-14: Two bulbs connected with voltage and current probes.

Question 2-6: Did the current through the battery change significantly when you added the second bulb to the circuit (by more than several percent)?

Question 2-7: Did the voltage across the battery change significantly when you added the second bulb to the circuit (by more than several percent)?

Question 2-8: 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: AN ANALOGY TO CURRENT AND RESISTANCE

You found in Activity 1-5 that current is not used up in passing through a bulb, but this may seem counterintuitive to you. Also, how can we explain that there is less current in the circuit with two bulbs instead of one? Lots of physics teachers have invented analogies to help explain these electric circuit concepts. One approach is to construct a model of a gravitational system that is in some ways analogous to the electrical system you are studying (Figure 1-5).

It is believed that the electrons flowing through a conductor have frequent collisions that slow them down and change their directions. Between collisions each electron accelerates and finally staggers through the material with an average drift velocity, $\langle \vec{v}_{\text{drift}} \rangle$.

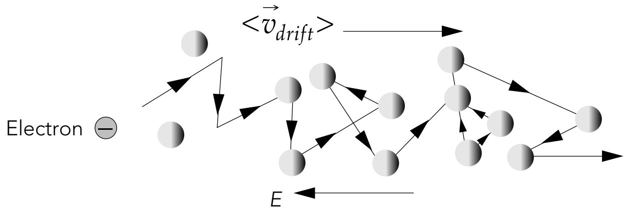


Figure 1-15: A simplified depiction of an electron in a uniform electric field staggering through a conductor as a result of collisions. Despite the constant force to the right caused by the electric field, these collisions cause the electron to move through the conductor with a constant average velocity, $\langle \vec{v}_{\text{drift}} \rangle$, the "drift velocity" (instead of accelerating).

As you saw in Investigation 2, we can talk about the *resistance* to flow of electrons that materials offer. A wire has a low resistance. A light bulb has a much higher resistance. Special electric elements that resist current are called *resistors*. You will examine the behavior of these in electric circuits in future labs.

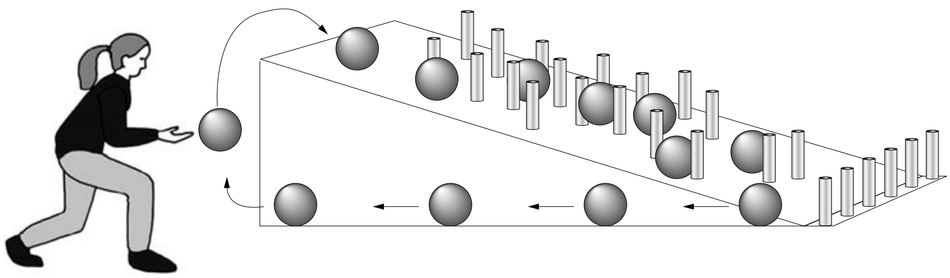


Figure 1-16: An analog to electric current and resistance.

It is possible to use a two-dimensional mechanical analog to model this picture of current through conductors. You should note that the real flow of electrons is a three-dimensional affair. The diagram for the two-dimensional analog is reproduced in Figure 1-16.

Extension 3-1: Drawing an Analogy

Look at the current and resistance analog in Figure 1-16, and then answer the following questions.

Question E3-1: What part of the picture represents the action of the battery? What represents the electric charge and current? What part represents the collisions of electrons? Explain.

Question E3-2: What ultimately happens to the "energy" given to the bowling balls by the "battery"? What plays the role of the bulb? How is this energy loss exhibited in the circuit you wired that consists of a battery, two wires, and a bulb?

Question E3-3: How does this model help explain the fact that electric current doesn't decrease as it passes through the bulb?

Question E3-4: How does this model help explain the fact that electrons move with a constant average speed v_{drift}, rather than having a constant acceleration caused by the constant electric field?

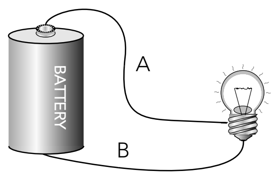
Question E3-5: In this model what would happen to the "ball" current if the drift velocity doubled? What can you do to the ramp to increase the drift velocity?

Name________________________ Date____________ Partners________________________

Homework For Lab 1
Batteries, Bulbs, and Current

1. Is there any difference between the static charges generated by rubbing a glass rod with silk or a rubber rod with cat fur and the charges that flow (from a battery) through wires in an electric circuit? Give evidence for your answer.

2. For the circuit on the right, indicate whether the statements below are TRUE or FALSE. If a statement is TRUE, briefly describe the evidence from this lab which supports this statement. If a statement is FALSE, give a correct statement, and briefly describe the evidence from this lab which supports this new statement.



a. The current is from the battery, through wire A, through the bulb, and then back to the battery through wire B.

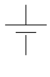
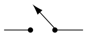
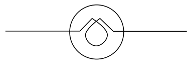
b. Since current is used up by the bulb, the current in wire B is smaller than the current in wire A.

c. The current is toward the bulb in both wires A and B.

d. If wire B is disconnected, but wire A is left connected, the bulb will still light, but if wire A is disconnected and wire B is left connected, the bulb will not light.

e. A current probe will read the same magnitude if connected to measure the current in wire A or wire B.

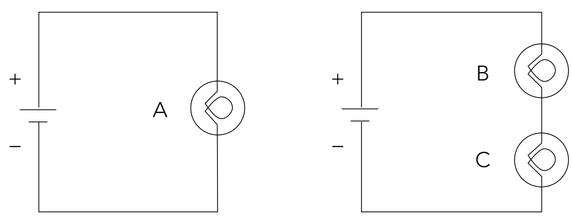
3. What circuit element is represented by each of the following symbols?

a.  **b.**  **c.** **d.** 

4. Draw below a circuit diagram using the symbols in Question 3 for at least one circuit you worked on in Activity 2-1.

5. Draw below a circuit diagram for the circuit in Question 2 with one current probe hooked up to measure the current in wire A and a voltage probe hooked up to measure the voltage across the light bulb. Also include a switch in the circuit to turn the bulb on and off. Use correct symbols for all circuit elements.

6. Consider the two circuits below. All bulbs and all batteries are identical. Compare the voltage across the battery in the left circuit to that in the right circuit. *Describe the evidence in this lab for your answer.*



Name____ Date______________________

Pre-Lab Preparation Sheet for Lab 2—Current in Simple DC Circuits

(Due at beginning of lab)

Directions:
Read over Lab 2 and then answer the following questions about the procedures.

1. What do you predict for the rankings of the brightness of bulbs A, B, and C in Figure 2-1?

2. How do you predict that changing the direction of the current by reversing the connections to the battery in Figure 2-1 would change the rankings in (1)?

3. How will you compare the currents in the circuits in Figure 2-1 experimentally? What equipment will you use?

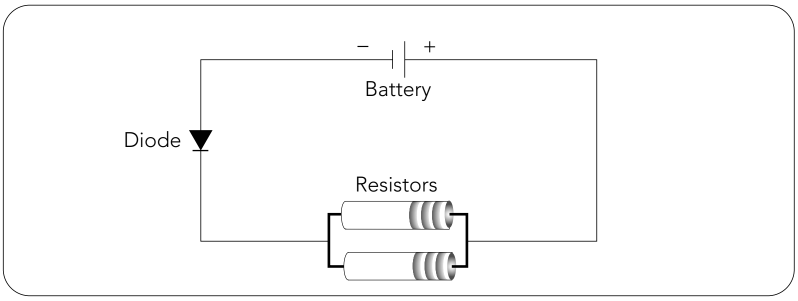
4. Define *series* and *parallel* connections. Sketch two light bulbs connected in series and to a battery, and two light bulbs connected in parallel and to a battery.

5. How do you predict the brightness of bulb D will change when the switch is closed in Figure 2-6?

6. How do you predict the current through the battery will change when the switch is closed in Figure 2-6?

Name________________________________ Date______________ Partners__________________________________

LAB 2: CURRENT IN SIMPLE DC CIRCUITS*



If it's green and it wiggles, it's biology.
If it stinks, it's chemistry.
If it doesn't work, it's physics.
If it's incomprehensible, it's mathematics.
If it doesn't make sense, it's either economics or psychology.

—From A. Bloch's
Murphy's Law Book 3

OBJECTIVES

- To understand current in a circuit where a battery lights a bulb.
- To understand the meaning of series connections in an electric circuit.
- To understand the relationship between the current in all parts of a series circuit.
- To understand the meaning of parallel connections in an electric circuit.
- To understand the relationship between the currents in all parts of a parallel circuit.
- To begin to understand the concept of resistance.

OVERVIEW

In the Lab 1 you saw that when there is an electric current through a light bulb, the bulb lights. You also saw that to cause current through a bulb, you must connect the bulb in a complete circuit with a battery. There will be a current only when there is a complete path from the positive terminal of the battery, through the connecting wire to the bulb, through the bulb, through the connecting wire to the negative terminal of the battery, and through the battery.

By measuring the current at different points in a simple circuit consisting of a bulb, a battery, and connecting wires, you discovered a model for current, namely

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

that the electric current was the same in all parts of the circuit. By measuring the current and voltage in this circuit and adding a second bulb, you also discovered that a battery maintains essentially the same voltage whether it is connected to one light bulb or two.

You also observed that the current was smaller when a second bulb was added to the circuit. This led us to introduce the concept of *resistance* of a circuit element such as a bulb. The total resistance of a circuit determines the current when the circuit is connected to a battery.

In this lab 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. In Lab 3, you will further examine the role of the battery in causing a current in a circuit, and compare the potential differences (voltages) across different parts of your circuits.

INVESTIGATION 1: 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. To make the required observations you will need the following items:

- computer-based laboratory system
- two current probes
- *RealTime Physics Electric Circuits* experiment configuration files
- 1.5-V D battery (must be very fresh, alkaline) with holder
- 6 wires with alligator clip leads
- 4 #14 bulbs in sockets
- contact switch

Prediction 1-1: Consider the two circuits shown in Figure 2-1.

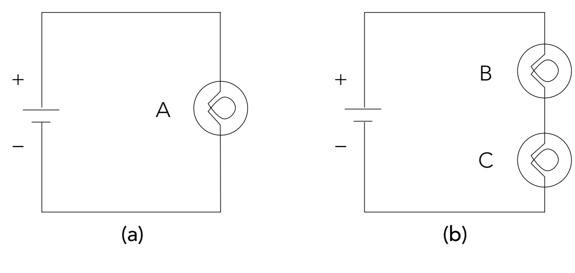


Figure 2-1: Two different circuits: (a) a battery with a single bulb, and (b) a battery with two identical bulbs identical to the one in (a).

Predict the relative brightness of the three bulbs shown in Figure 2-1 from brightest to dimmest, assuming that the batteries and bulbs have identical characteristics. (Remember that you saw in the last laboratory that the battery maintains essentially the same *voltage* across its terminals whether there is one light bulb or two.)

If two or more bulbs are equal in brightness, indicate this in your response. Explain the reasons for your rankings.

> **Hint:** Helpful symbols are $>$, "is greater than"; $<$, "is less than"; $=$, "is equal to." For example, B $>$ C $>$ A.

Activity 1-1: The Relative Brightness of Bulbs

1. Now connect the circuits, observe the relative brightness of the bulbs, and rank the bulbs in order of the brightness you actually observed.

> **Comment:** These activities assume *identical* bulbs. Differences in brightness may arise if the bulbs are not exactly identical. In this and later activities, 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 nonglowing bulb actually has a current through it, unscrew the bulb and see if anything else in the circuit changes.

Ranking of the bulbs:

Question 1-1: Did your observations agree with your predictions? If not, explain what assumptions you were making that now seem false.

Prediction 1-2: What do you predict will happen to the brightness of bulbs A, B, and C in Figure 2-1 if the battery is connected to the bulbs with its terminals reversed? Explain the reason(s) for your prediction.

2. Test your prediction. Reverse the terminals of the battery in each of your circuits.

Question 1-2: What do you observe? Does this agree with your prediction? Did you make any false assumptions? Explain.

Question 1-3: Can you tell anything about the direction of the current through the circuit by just looking at the brightness of the bulbs without knowing how the battery is hooked up? Explain.

How does each bulb affect the current in a circuit? Does current get used up after passing through a bulb? How does the current in the two-bulb circuit compare to that in the single-bulb circuit? First make predictions and then observe experimentally.

Prediction 1-3: What would you predict about the relative amount of current going through each bulb in Figures 2-1a and b? Write down your predicted rankings of the currents through bulbs A, B, and C, and explain your reasoning.

Activity 1-2: Current in a Simple Circuit with Bulbs

You can test your prediction by using current probes. Recall from Lab 1 that to measure the current through a bulb, a current probe must be connected so that the current through the current probe is the same as the current through the bulb. Convince yourself that the current probes shown in Figure 2-2 measure the currents described in the figure caption.

> **Comment:** In carrying out your measurements, it is important to realize that the measurements made by the current probes are only as good as their calibrations. Small differences in calibration can result in small differences in readings.

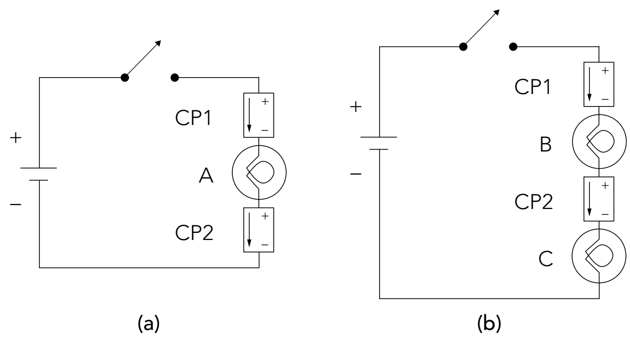
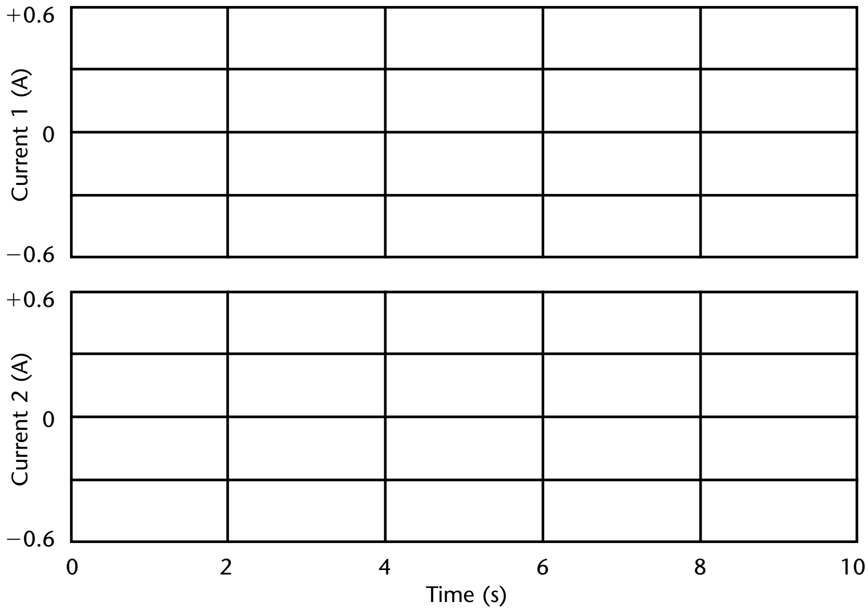


Figure 2-2: Current probes connected to measure the current through bulbs. In circuit (a), CP1 measures the current into bulb A, and CP2 measures the current out of bulb A. In circuit (b), CP1 measures the current into bulb B while CP2 measures the current out of bulb B and the current into bulb C.

1. Open the experiment **Two Currents (L02A1-2)** to display the two sets of current axes that follow.
2. **Calibrate** the current probes, or load the calibration. **Zero** the probes with them disconnected from the circuit.
3. Connect circuit (a) in Figure 2-2.

4. **Begin graphing,** close the switch for a second or so, open it for a second or so, and then close it again. Sketch your graphs on the axes, or **print** your graphs and affix them over the axes.
5. Use the **analysis feature** of the software to measure the currents into and out of bulb A when the switch is closed:

   Current into bulb A:______ Current out of bulb A:______



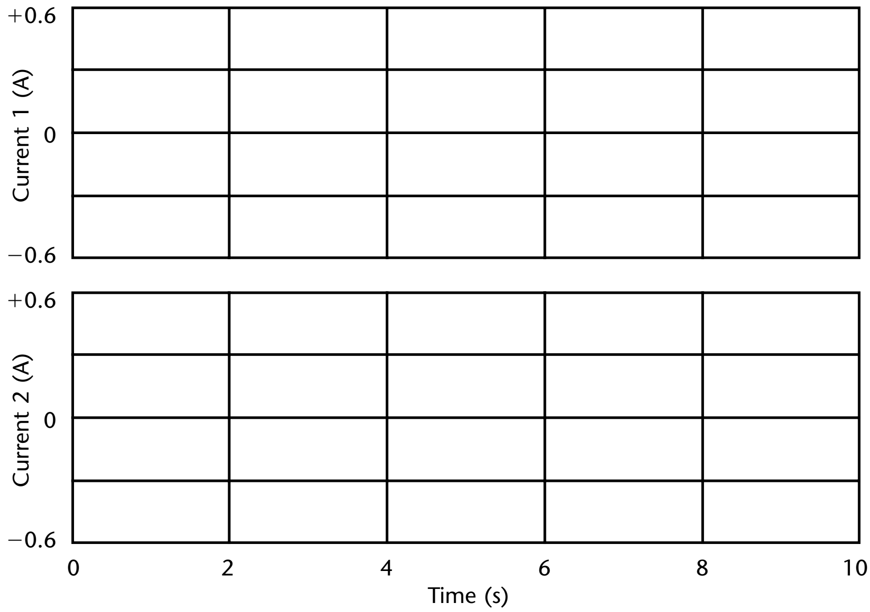
Question 1-4: Are the currents into and out of bulb A equal or is one significantly larger (do they differ by more than a few percent)? What can you say about the directions of the currents? Is this what you expected? Explain.

6. Connect circuit (b) in Figure 2-2. **Begin graphing** current as above, and record the measured values of the currents.

   Current through bulb B:_____Current through bulb C:_____
7. Sketch the graphs on the axes that follow, or **print** and affix over the axes.

Question 1-5: Consider your observation of the circuit with bulbs B and C in it. Is current "used up" in the first bulb or is it the same in both bulbs? Explain based on your observations.

Question 1-6: 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 1-7: Based on your observations, how is the brightness of a bulb related to the current through it?

Question 1-8: How does the amount of current produced by the battery in the single bulb circuit (Figure 2-1a) compare to that produced by the battery with two bulbs connected as in Figure 2-1b? Does the addition of this second bulb in this manner affect the current through the original bulb? Explain.

Question 1-9: Suppose you think of the bulb as providing a *resistance* to the current in a circuit, rather than something that uses up current. How do you expect the total resistance in a circuit is affected by the addition of more bulbs in the manner shown in Figure 2-1b?

Question 1-10: Formulate a rule 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 resistance of a bulb to current changes as the current through the bulb changes. You will explore this in more detail in Lab 3.

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

First a prediction.

Prediction 1-4: Consider the circuit diagrams in Figure 2-3 in which the light bulbs in Figure 2-1 have been replaced by identical resistors.

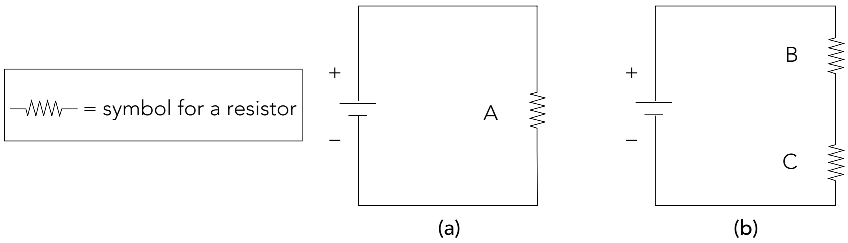


Figure 2-3: Two different circuits: (a) a battery with a single resistor, and (b) a battery with two resistors identical to the one in (a).

What would you predict about the relative amount of current going through each resistor in Figures 2-3a and b? Write down your predicted rankings of the currents through resistors A, B, and C, and explain your reasoning. (Remember that a resistor has a constant resistance to current regardless of the current through it.)

In addition to the equipment listed above, you will need the following to test your predictions:

- two 10-Ω resistors

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

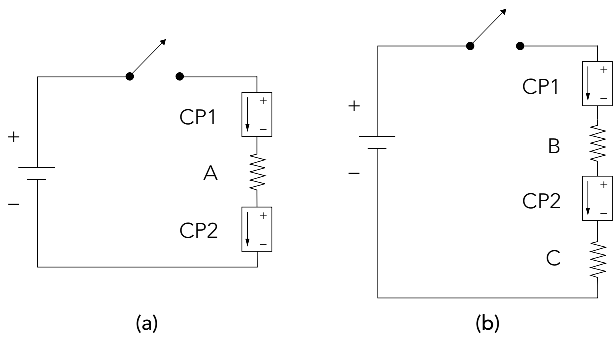


Figure 2-4: Current probes connected to measure the current through resistors. In circuit (a), CP1 measures the current into resistor A, and CP2 measures the current out of resistor A. In circuit (b), CP1 measures the current into resistor B, while CP2 measures the current out of resistor B and into resistor C.

1. Continue to use the experiment file **Two Currents (L02A1-2).**
2. **Calibrate** the current probes, or load the calibration if this has not already been done. **Zero** the probes with them disconnected from the circuit.
3. Connect circuit (a) in Figure 2-4.
4. Use the current probes and the **analysis feature** in the software to measure the current through resistor A in circuit 2-4a and the currents through resistors B and C in circuit 2-4b.

   Current through resistor A:______

   Current through resistor B:______ Current through resistor C:______

Question 1-11: 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 1-12: How does the amount of current produced by the battery in the single resistor circuit (Figure 2-3a) compare to that produced by the battery with two resistors connected as in Figure 2-3b? Does the addition of this second resistor in this manner affect the current through the original resistor? Explain.

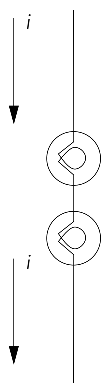
Question 1-13: How did your observations with resistors differ from your observations with bulbs in Activity 1-2.

Question 1-14: Reformulate 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 2-3b.

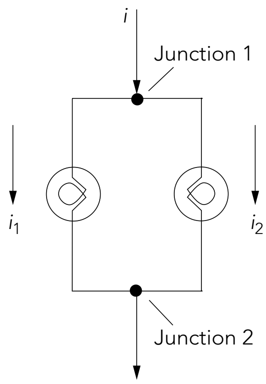
Question 1-15: Is your rule in Question 1-14 also correct for bulbs connected as in Figures 2-1a and b? Explain.

INVESTIGATION 2: 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 below.



Series connection:
Two resistors are in series if they are connected so that the same current that passes through one bulb passes through the other.



Parallel connection:
Two resistors are in parallel if their terminals are connected so that at each junction one terminal of one bulb is directly connected to one terminal of the other.

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 2-5).

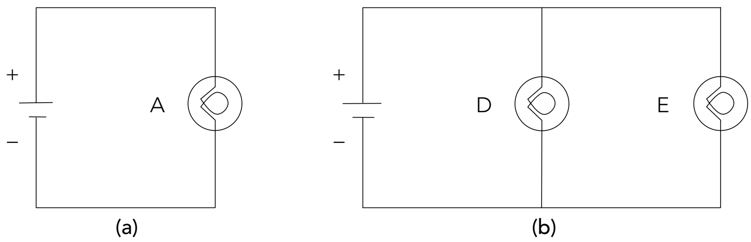


Figure 2-5: Two different circuits: (a) a single-bulb circuit and (b) a circuit with two bulbs identical to the one in (a) connected *in parallel* to each other and *in parallel* to the battery.

Note that if bulbs A, D, and E are identical, then the circuit in Figure 2-6 is equivalent to circuit 2-5a when the switch is open (as shown) and equivalent to circuit 2-5b when the switch is closed.

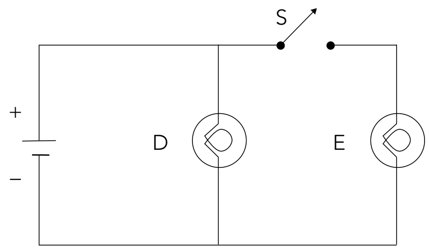


Figure 2-6: When the switch is open, only bulb D is connected to the battery. When the switch is closed, bulbs D and E are connected *in parallel* to each other and *in parallel* to the battery.

Question 2-1: Explain how you know that the caption of Figure 2-6 correctly describes the circuit.

Prediction 2-1: Predict how the brightness of bulbs D and E in the parallel circuit of Figure 2-5b will compare to bulb A in the single bulb circuit of Figure 2-5a. How will D and E compare with each other? Rank the brightness of all three bulbs. Explain the reasons for your predictions.

To test this and other predictions, you will need:

- computer-based laboratory system
- two current probes
- *RealTime Physics Electric Circuits* experiment configuration files

- 1.5-V D battery (must be very fresh, alkaline) with holder
- 8 wires with alligator clip leads
- 3 #14 bulbs in sockets
- contact switch

Activity 2-1: Brightness of Bulbs in a Parallel Circuit

Set up the circuit in Figure 2-6, and describe your observed rankings for the brightness of bulb D with the switch open, and D and E with the switch closed.

Question 2-2: Did the observed rankings agree with your prediction? If not, can you explain what assumptions you were making that now seem false?

Prediction 2-2: Based on your observations of brightness, what do you predict about the relative amount of current through each bulb in a parallel connection, i.e., bulbs D and E in Figure 2-5b?

Prediction 2-3: Based on your observations of brightness, how do you think that closing the switch in Figure 2-6 affects the current through bulb D?

Activity 2-2: Current in Parallel Branches

You can test Predictions 2-2 and 2-3 by connecting current probes to measure the currents through bulbs D and E.

1. Open the experiment file called **Two Currents (L02A1-2),** if it is not already opened.
2. **Calibrate** the current probes, or load the calibration, if this hasn't already been done. **Zero** the probes with them disconnected from the circuit.
3. Connect the circuit shown in Figure 2-7.

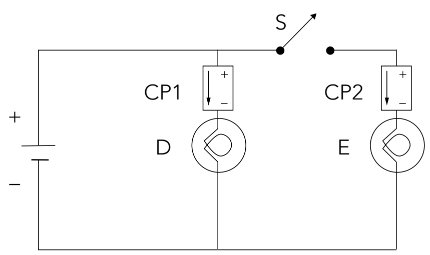
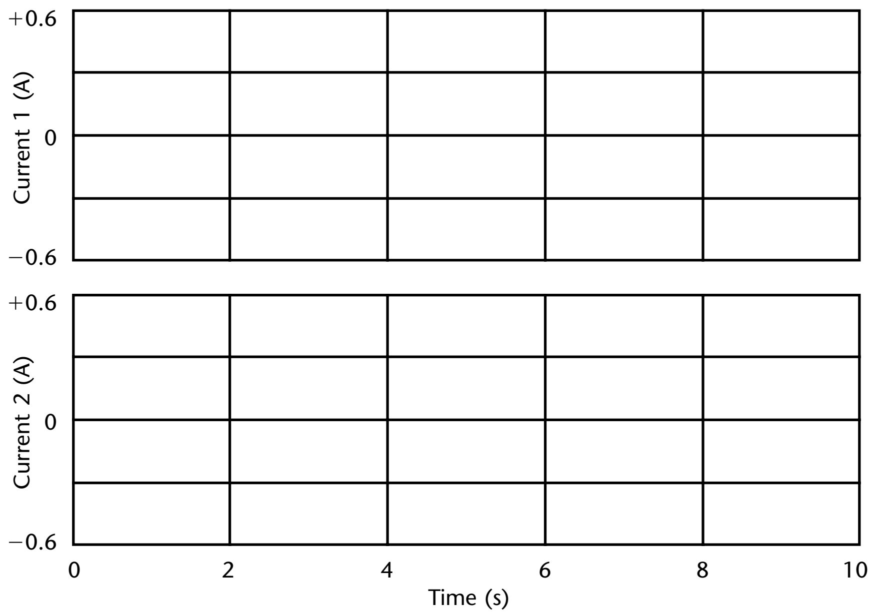


Figure 2-7: Current probes connected to measure the current through bulb D and the current through bulb E.

4. **Begin graphing** the currents through both probes then close the switch for a second or so, open it for a second or so, and then close it again.
5. Sketch the graphs on the axes below, or **print** them and affix them over the axes.
6. Use the **analysis feature** of the software to measure both currents.

   Switch open: Current through bulb D:_____ Current through bulb E:_____

   Switch closed: Current through bulb D:_____ Current through bulb E:_____



Question 2-3: Based on your graphs and measurements, were the currents through bulbs D and E what you predicted based on their brightness? If not, can you now explain why your prediction was incorrect?

Question 2-4: Did closing the switch 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 in Lab 1 that the voltage maintained by a battery doesn't change appreciably no matter what is connected to it. 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? (Is the current through the battery the same whether the switch in Figure 2-6 is open or closed?) This is what you will investigate next.

Prediction 2-4: Based on your observations of the brightness of bulbs D and E in Activity 2-2, what do you predict about the amount of current through the battery in the parallel bulb circuit (Figure 2-5b) compared to that through the single bulb circuit (Figure 2-5a)? Explain.

Activity 2-3: Current Through the Battery

1. Test your prediction with the circuit shown in Figure 2-8. Use the same experiment file, **Two Currents (L02A1-2),** as in the previous activities.

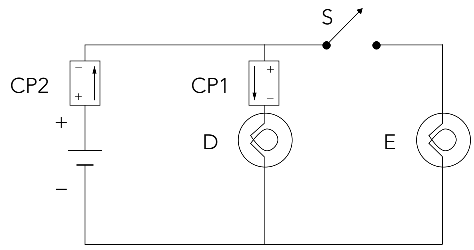


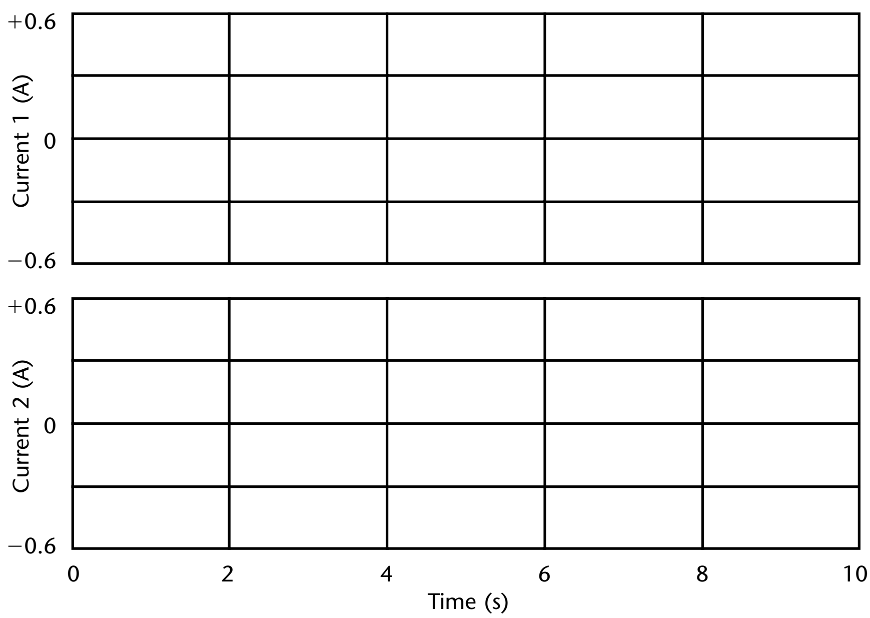
Figure 2-8: Current probes connected to measure the current through the battery and the current through bulb D.

2. **Begin graphing** while closing and opening the switch as before. Sketch your graphs on the axes that follow, or **print** and affix over the axes. Label on your graphs when the switch is open and when it is closed.
3. Measure the currents through the battery and through bulb D.

   Switch open: Current through battery:_____ Current through bulb D:_____

   Switch closed: Current through battery:_____ Current through bulb D:_____

Question 2-5: Describe how the connection of current probes in Figure 2-8 differs from that in Figure 2-7. How do you know that probe 2 is measuring the current through the battery?



Question 2-6: Use your observations to formulate a rule to predict how the current through a battery will change as the number of bulbs connected *in parallel* increases. Can you explain why?

Question 2-7: Comparing your rule in Question 2-6 to the rule you stated in Questions 1-10 and 1-14 relating the current through the battery to the total *resistance* of the circuit, does the addition of more bulbs in parallel increase, decrease, or not change the total *resistance* of the circuit? Explain.

Question 2-8: Can you explain your answer to Question 2-7 in terms of the number of paths for current available in the circuit? Explain.

Question 2-9: Considering your experiences with series and parallel circuits in Investigations 1 and 2, does the current through the battery depend only on the number of bulbs or resistors in the circuit, or does the arrangement of the circuit elements matter?

Question 2-10: Since current and resistance are related, does the resistance depend just on the number of bulbs or resistors, or does it depend on the arrangement of the circuit elements as well? Explain.

INVESTIGATION 3: 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 2-9a. What will happen if you add a third bulb, C, in parallel with bulb B as shown in Figure 2-9b? You should be able to predict the relative brightness of A, B, and C based on previous observations. The tough question is: how does the brightness of A change when C is connected in parallel to B?

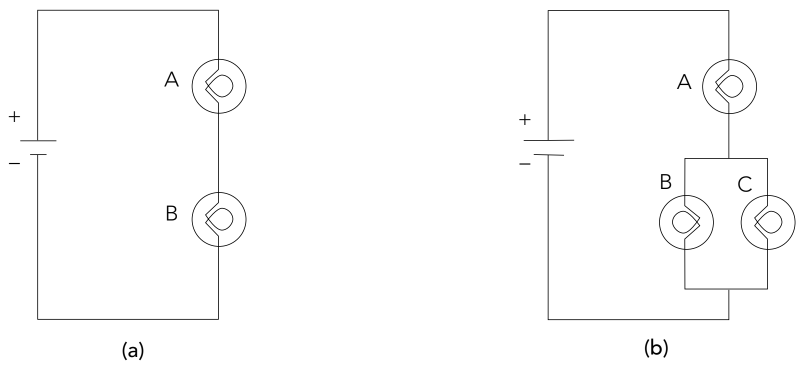


Figure 2-9: Two circuits with identical batteries and bulbs A, B, and C.

Question 3-1: In Figure 2-9b 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 at the beginning of Investigation 2.)

Question 3-2: In Figure 2-9b are bulbs B and C connected in series or in parallel with each other, or neither? Explain.

Question 3-3: Is the resistance of the combination of bulbs B and C larger than, smaller than, or the same as bulb B alone? Explain.

Question 3-4: Is the resistance of the combination A, B, and C in Figure 2-9b larger than, smaller than, or the same as the combination of A and B in Figure 2-9a? Explain.

Prediction 3-1: Predict how the current through bulb A will change, if at all, when circuit 2-9a is changed to 2-9b (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 3-2: Predict how the current through bulb B will change, if at all, when circuit 2-9a is changed to 2-9b (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.

Prediction 3-3: Also predict the relative rankings of brightness for all the bulbs, A, B, and C, after bulb C is in the circuit. Explain the reasons for your predictions.

Activity 3-1: A More Complex Circuit

1. Set up the circuit shown in Figure 2-10a. Convince yourself that this circuit is identical to Figure 2-9a when the switch, S, is open, and to Figure 2-9b when the switch is closed.
2. Observe the brightness of bulbs A and B when the switch is open, and then the brightness of the three bulbs when the switch is closed. Compare the brightness of bulb A with the switch open and closed, and rank the brightness of bulbs A, B, and C with the switch closed.

Question 3-5: If you did not observe what you predicted about the brightness, what changes do you need to make in your reasoning? Explain.

3. Connect the two current probes as shown in Figure 2-10b. Open the experiment file called **Two Currents (L02A1-2),** if it is not already opened.

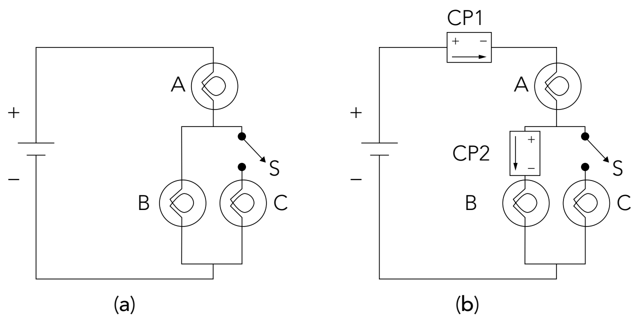


Figure 2-10: (a) Circuit equivalent to Figure 2-9a when the switch, S, is open and to Figure 2-9b when the switch is closed. (b) Same circuit with current probes connected to measure the current through bulb A (CP1) and the current through bulb B (CP2).

4. **Begin graphing** and observe what happens to the current through bulb A (through the battery) and the current through bulb B when the switch is opened and closed.

Question 3-6: What happens to the current through the battery and through bulbs A and B when bulb C is added in parallel with bulb B? What do you conclude happens to the total resistance in the circuit? Explain.

If you have additional time, do some or all of the following Extensions to examine some more complex circuits.

Extension 3-2: An Even More Complex Circuit

Let's look at a somewhat more complicated circuit to see how series and parallel parts of a complex circuit affect one another. The circuit is shown in Figure 2-11.

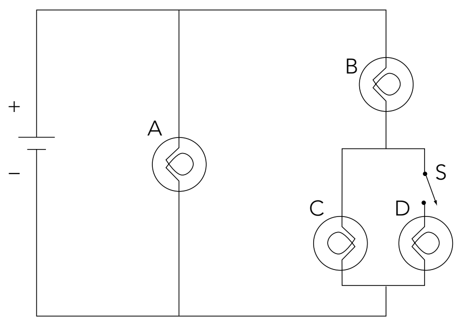


Figure 2-11: A complex circuit with series and parallel connections.

Question E3-7: When switch S is open, which bulbs are connected in parallel with each other? (If you need to, review the definitions of series and parallel at the beginning of Investigation 2 before answering.)

Is A parallel to B?

Is A parallel to C?

Is C parallel to D?

Is A parallel to the combination of B and C?

Question E3-8: When switch S is open, which bulbs are connected in series with each other?

Is A in series with B?

Is A in series with C?

Is B in series with C?

Question E3-9: When switch S is closed, which bulb(s) are connected in parallel with A?

Question E3-10: When switch S is closed, which bulb(s) are connected in series with B?

Prediction E3-4: Predict the effect on the current through bulb A for each of the following separate alterations in the circuit:

a. unscrewing bulb B

b. closing switch S

Prediction E3-5: Predict the effect on the current through bulb B of each of the following separate alterations in the circuit:

a. unscrewing bulb A

b. adding another bulb in series with bulb A

Connect the circuit in Figure 2-11, and observe the effect of each of the alterations in Predictions E3-4 and E3-5 on the brightness of each bulb. Describe your observations.

Question E3-11: Compare your results with your predictions. How do you account for any differences between your predictions and observations?

Question E3-12: In this circuit, two parallel branches are connected *directly across* a battery. For this type of connection, what do you conclude about the effect of changes in one parallel branch on the current in the other?

Extension 3-3: Series and Parallel Networks

Now let's practice with some more complicated series and parallel circuits. Suppose you had three boxes, labeled A, B, and C, each having two terminals. The arrangement of resistors in the boxes is shown in Figure 2-12.

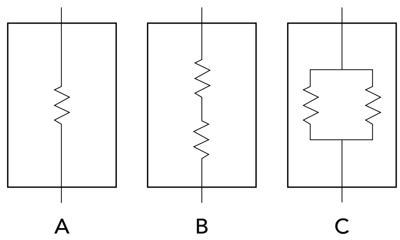


Figure 2-12: Parallel and series circuits.

Consider the five circuits shown in Figure 2-13 in completing the next activity.

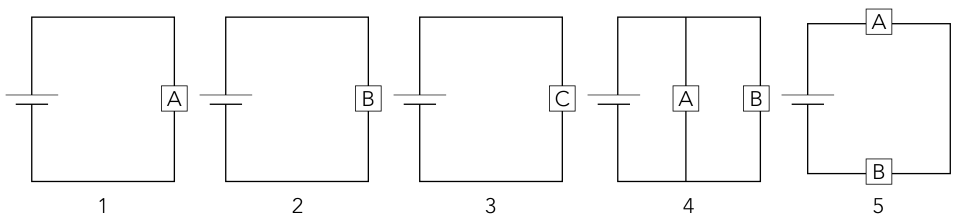


Figure 2-13: Circuits featuring parallel and series connections.

Question E3-13: For each of the circuits in Figure 2-13, sketch a standard circuit diagram showing all the resistors in the circuit. In each diagram number the resistors and describe which resistors or combination of resistors are in series and parallel with each other.

Question E3-14: Rank the five circuits in Figure 2-13 by their total resistance. Which has the most resistance? The least resistance? Explain your reasoning.

Question E3-15: Rank each of the circuits in Figure 2-13 according to the total current through the battery. Explain your reasoning.

You can now test your understanding of current and resistance on another puzzling circuit.

Extension 3-4: The Puzzle Problem

Question E3-16: Use reasoning based on your model of electric current to predict the relative brightness of each of the bulbs shown in Figure 2-14. Explain the reasons for your rankings.

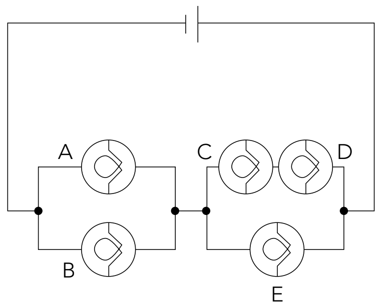
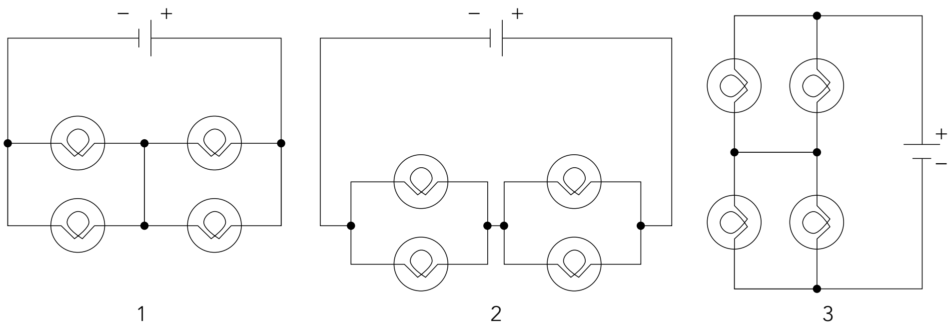


Figure 2-14: A complicated battery and bulb circuit.

Name________________________ Date____________ Partners________________________

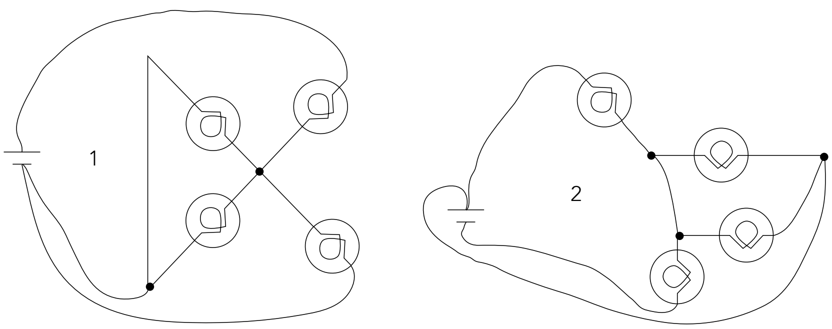
Homework for Lab 2
Current in Simple Direct Current Circuits

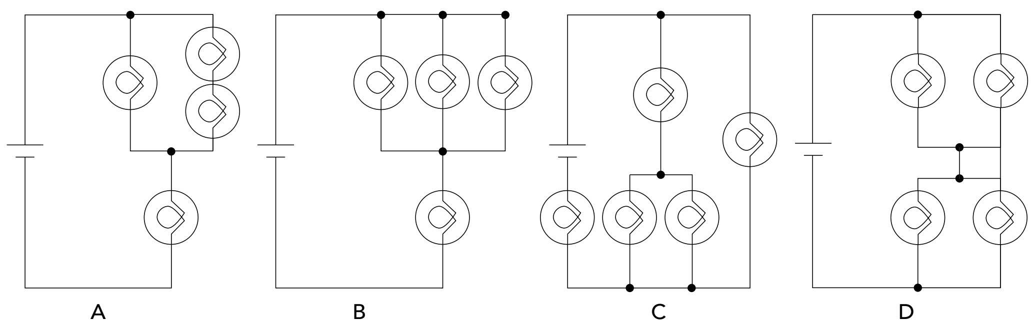
1. Which of the three circuits shown below, if any, are the same electrically? Which are different? Explain your answers.



2. Consider the two messy circuit diagrams 1 and 2 below.

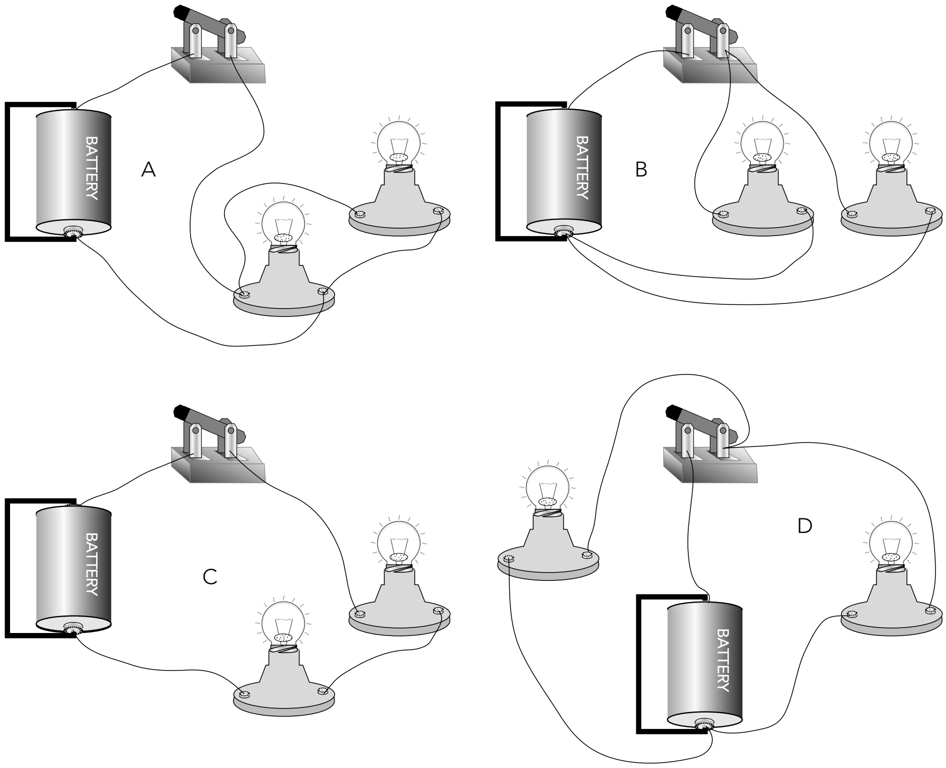
a. Identify which of the nice neat circuit diagrams below (A, B, C, or D) corresponds to circuit 1. Explain the reasons for your answer.





b. Which circuit diagram (A, B, C, or D) corresponds to circuit 2? Explain the reasons for your answer.

3. Three of the circuits drawn below are electrically equivalent and one is not.



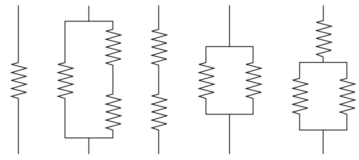
a. Which circuit is not like the others? Explain how it is different.

b. Which circuits represent parallel arrangements for the bulbs? Which represent series arrangements?

c. In the boxes below, draw neat circuit diagrams for each of the arrangements.

A	B
C	D

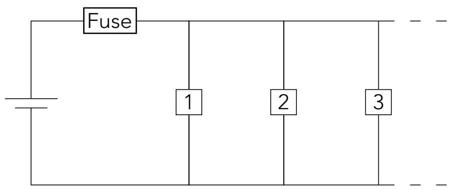
4. Use the model for electric current to rank the resistor networks shown below in order by resistance from largest to smallest. Explain your reasoning.



5. If a battery were connected to each of the circuits in Question 4, in which network would the current through the battery be the largest? The smallest? Explain your reasoning.

6. The diagram below shows a typical household circuit. The appliances (lights, television, toaster, etc.) are represented by boxes labeled 1, 2, 3, and so on. The fuse, or circuit breaker, shown in the diagram is a switch intended to shut off the circuit automatically if the wires become too hot because the current in the circuit is too large.

Note: Although houses in the United States use alternating current (AC), which differs in some ways from the direct current (DC) we have been studying, you can use the model you developed for this problem. (AC circuits will be studied in Labs 7 and 8.)



   a. What happens to the current through the fuse when more appliances are added to the circuit? Describe evidence from this lab for your answer.

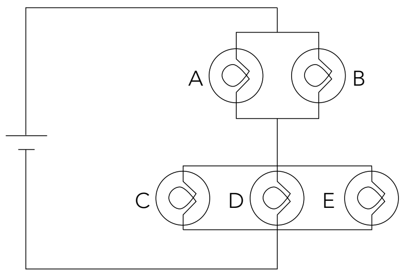
   b. Does the current through element 1 change when elements 2 and 3 are added to the circuit? Describe evidence from this lab for your answer.

   c. Is this model consistent with your observations of everyday household electricity? For example, what happens to the brightness of a light bulb in a room when a second one is turned on?

d. What may happen to the fuse if too many appliances are added to the circuit? Why?

e. What kind of circuit connection for elements 1, 2, and 3 is shown in the diagram?

7. Consider the circuit shown on the right.

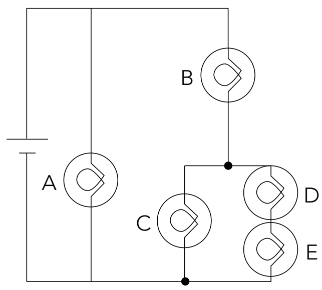


a. Are the bulbs C, D, and E connected in series, parallel or neither? Explain.

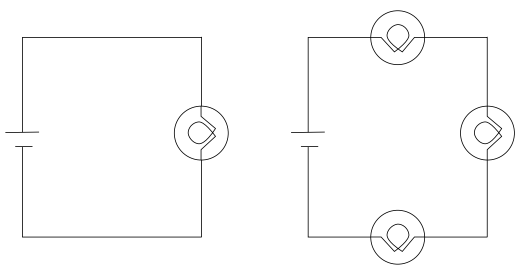
b. Rank the bulbs in order of brightness. Use the symbols =, <, and >. Explain your ranking.

c. How will the brightness of bulbs A and B change if bulb C is unscrewed? Will the result be different if bulb D or E is unscrewed instead? Explain.

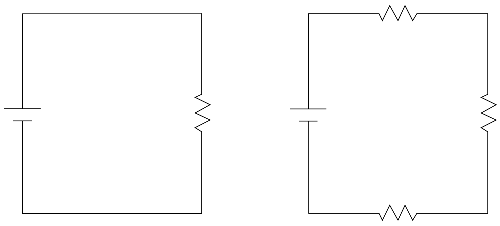
8. Consider the circuit shown on the right. Rank the brightness of the bulbs in the circuit. Use the symbols =, <, and >. Explain your ranking.



9. In the two circuits below, the batteries and all bulbs are identical. Compare the current in the circuit on the left to the current in the circuit on the right. Be as quantitative as possible.



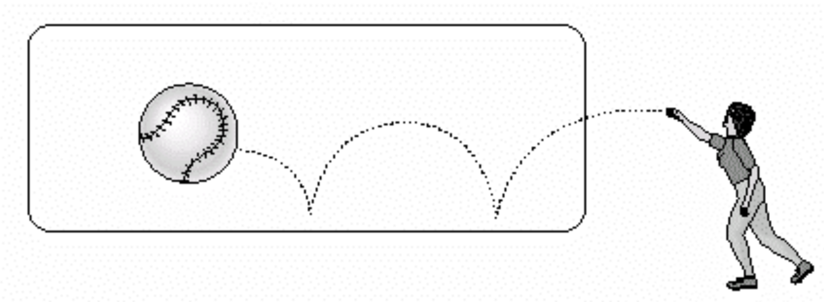
10. In the two circuits below, the batteries and all resistors are identical. Compare the current in the circuit on the left to the current in the circuit on the right. Be as quantitative as possible.



Is your answer the same as in Question 9? Explain any differences.

Name______________________ Date__________ Partners______________________

LAB 10: TWO-DIMENSIONAL MOTION (PROJECTILE MOTION)



The essential fact is that all the pictures which
science now draws of nature . . . are mathematical pictures.
—Sir James Jeans

OBJECTIVES

- To explore the type of motion that results when an object falls close to the Earth's surface.
- To review how vector quantities like velocities and accelerations in two dimensions can be represented as components that can be treated independently.
- To understand the experimental and theoretical basis for describing projectile motion as the superposition of two independent motions: (1) that of a body falling in the vertical direction under the influence of a constant force, and (2) that of a body moving in the horizontal direction with no applied forces.

OVERVIEW

So far we have been dealing separately with motion along a horizontal straight line and motion along a vertical straight line. The focus of this lab is the description of motion that occurs when an object is allowed to move in both the vertical and horizontal directions at the same time, close to the surface of the Earth. Examples are the motion of a baseball or tennis ball after it is hit. This type of motion is commonly called *projectile motion.* To understand this motion, it is helpful to review the vertical and the horizontal types of motion separately and then see how they might be combined.

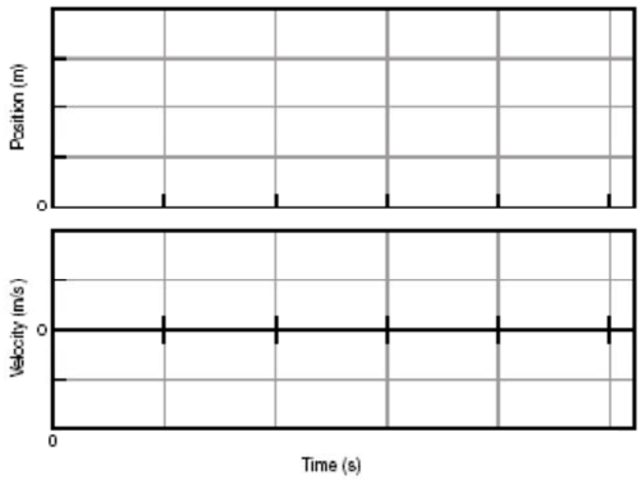
This lab begins with a review of the classic *kinematic equations* that describe the relationships between instantaneous position, velocity, and acceleration for an object that moves along a straight line (called one-dimensional motion), which you have probably seen in lecture or in your textbook. You have already examined a number of examples of such motion. In some the object moved with a constant velocity (zero acceleration). In others—such as the motion of a cart pushed along by the constant force of a fan unit as in Lab 2 or the falling motion of a ball pulled by the constant gravitational force in Lab 6—the object moved with a constant acceleration (steadily increasing velocity).

In this lab you will consider the motion of a ball thrown through the air. The gravitational force of attraction by the Earth on the ball is downward along the vertical direction, while, normally, the ball is moving along a curved trajectory, with components of velocity along both the vertical and horizontal directions.

INVESTIGATION 1: REVIEW OF ONE-DIMENSIONAL MOTION

You'll begin by reviewing the one-dimensional motions of a ball.

Prediction 1-1: Suppose that you roll a basketball along a horizontal table and measure its position and velocity as functions of time over a short enough distance so that the ball's velocity remains fairly constant. Sketch on the axes below the ball's position and velocity as functions of time.

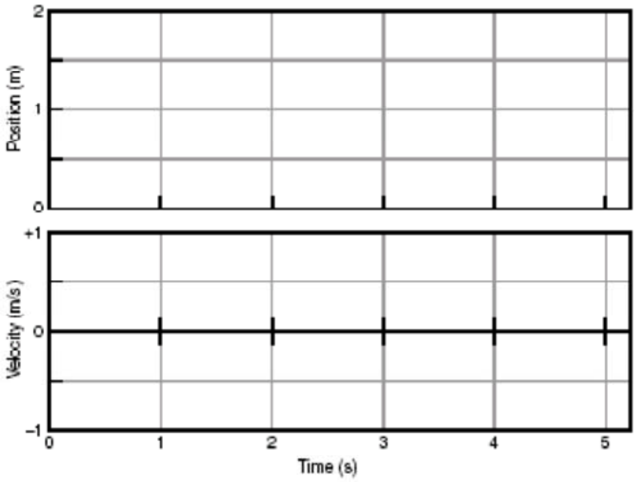


To test your predictions, you will need

- basketball
- smooth, horizontal surface (e.g., tabletop)
- motion detector
- computer, interface and software
- *RealTime Physics* experiment configuration files

Activity 1-1: The Motion of a Ball Rolling Horizontally

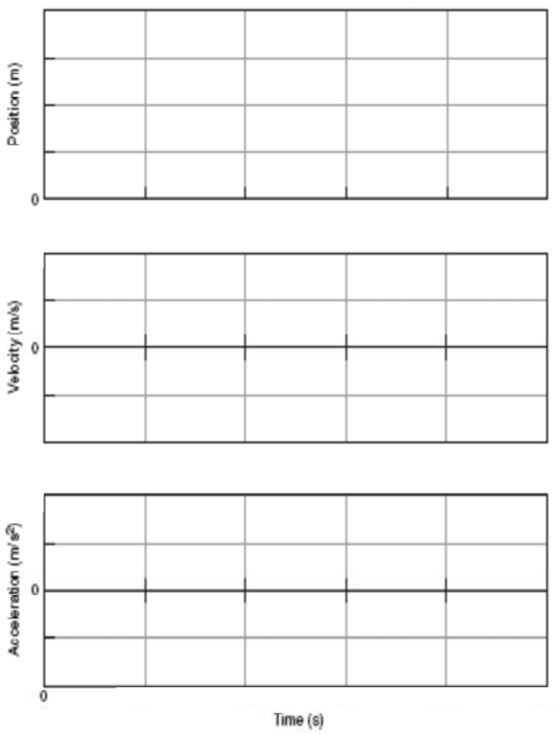
1. Set up the motion detector at one end of the table. Connect it to the interface.
2. Open the experiment configuration file **L10A1-1 (Horizontal Motion).**
3. Collect graphs for the motion of the ball along the smooth surface after a push.
4. Sketch your graphs on the axes that follow, or print them and affix them to these sheets. (Be sure that the graphs are labeled clearly.)



Question 1-1: Describe your graphs. Did they agree with your predictions?

Question 1-2: Would you describe this motion as constant velocity motion or constantly accelerated motion. Explain.

Prediction 1-2: Now suppose you tossed the ball up into the air and caught it on its way down. Sketch on the axes below your predictions for the position, velocity and acceleration of the ball from the moment it left your hands until just before you caught it.

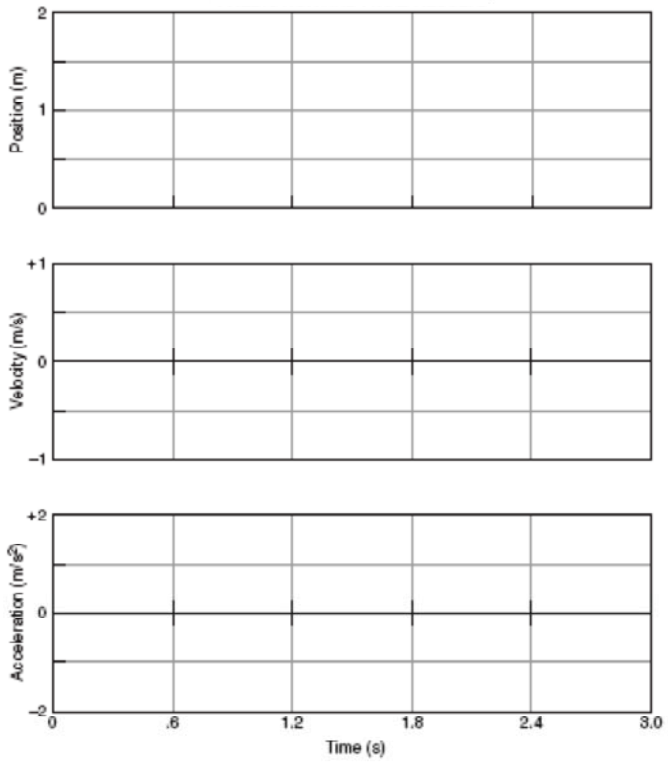


To test your predictions, you will need

- basketball
- motion detector
- computer, interface and software
- *RealTime Physics* experiment configuration files

Activity 1-2: The Motion of a Ball Tossed Vertically

1. Set up the motion detector on the floor pointed upwards.
2. Open the experiment configuration file **L10A1-2 (Vertical Motion).**
3. Collect graphs for the motion of the ball tossed upwards and caught on the way down. (Be sure that your hands are not between the ball and the motion detector from the moment the ball is released until just before you catch it.)
4. Sketch your graphs on the axes that follow, or print them and affix them to these sheets. (Be sure that the graphs are labeled clearly.)



Question 1-3: Describe your graphs. Did they agree with your predictions?

Question 1-4: Would you describe this motion as constant velocity motion or constantly accelerated motion. Explain.

The motions of the basketball examined in Activities 1-1 and 1-2 can be represented as functions of time by a series of mathematical equations called the kinematic equations. In the following activities, you will identify these equations.

Activity 1-3: Kinematic Equations for Motion with Constant Velocity (Zero Acceleration)

Below, you will find some equations that might represent the position, velocity, and acceleration of an object as functions of time:

Set #1	Set #2
$(1) x = x_o + v_o t$	$(4) x = x_o + v_o t + \frac{1}{2} a t^2$
$(2) v = v_o$	$(5) v = v_o + at$
$(3) a = 0$	$(6) a = constant$

The symbols have the following meanings:

x = position t = time

v = instantaneous velocity

a = acceleration along the x axis. (It could vary in time, but we have chosen to consider only those cases for which the acceleration is constant.)

x_0 = initial position at $t = 0$. (Tells you where the object was at the moment you started counting time.)

v_0 = initial velocity component (Tells you how fast the object was moving at the moment you started counting time.)

Question 1-5: Use your results from Activity 1-1 to determine which set of kinematic equations could be used to represent the motion of the basketball along the table. Explain your choice based on the graphs you measured.

Question 1-6: Use your graphs from Activity 1-1, and the kinematic equations you chose in Question 1-5 to determine the values of x_o and v_o. Explain how you found these values, and what they represent.

Activity 1-4: Kinematic Equations for Motion with Constant Acceleration

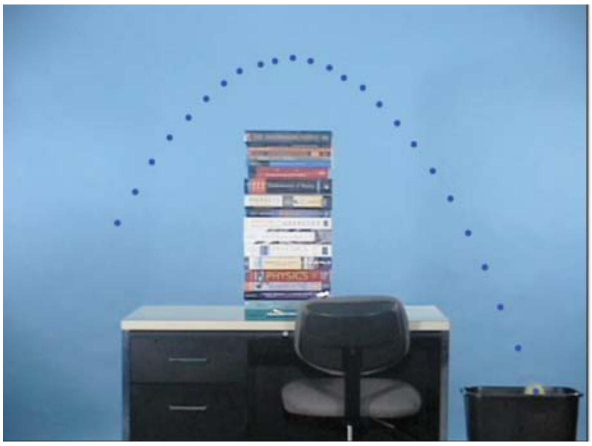
Question 1-7: Use your results from Activity 1-2 to determine which set of kinematic equations could be used to represent the motion of the tossed basketball. Explain your choice based on the graphs you measured.

Question 1-8: Use your graphs from Activity 1-2, and the kinematic equations you chose in Question 1-7 to determine the values of x_o and v_o. Explain how you found these values, and what they represent.

Question 1-9: Use your graphs from Activities 1-1 and 1-2 to determine the values of a for (a) the motion of the ball along the horizontal surface and (b) the motion of the ball tossed vertically upward. Explain how you determined these values.

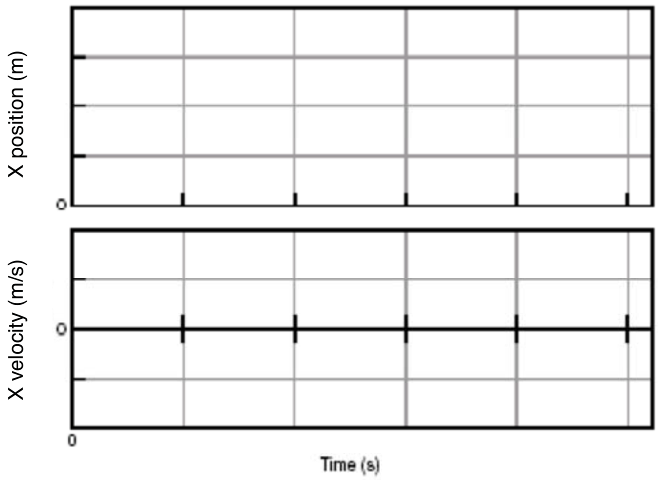
INVESTIGATION 2: EXAMINATION OF TWO-DIMENSIONAL MOTION

In this investigation you will examine the motion of a tennis ball that is tossed into the air. The toss of the ball, and its trajectory are shown in the figures below.

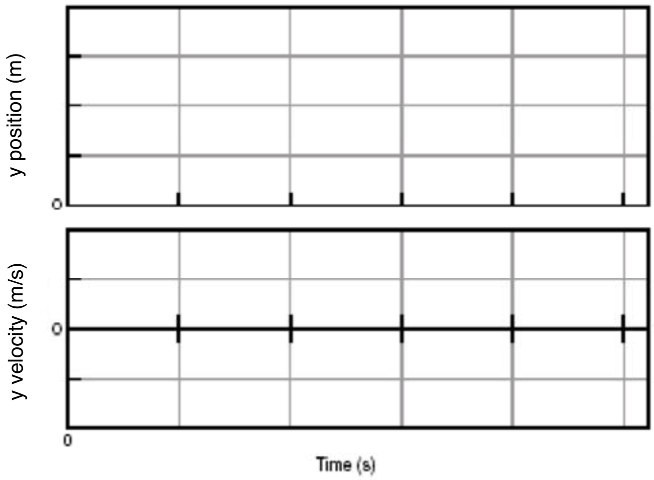


Since the motion of the ball is in two dimensions, it is not easy to make measurements using a motion detector. Instead, you will use the method of video analysis to examine the motion, and to determine the mathematical representations of the horizontal and vertical components of the motion. First some predictions.

Prediction 2-1: On the axes below, predict how the *x* coordinate of the ball and the *x* component of the velocity will vary with time.



Prediction 2-2: On the axes below, predict how the *y* coordinate of the ball and the *y* component of the velocity will vary with time.



To test your predictions, you will need

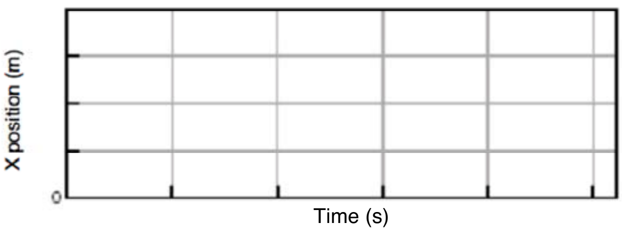
- video analysis software
- *RealTime Physics* experiment configuration files

Activity 2-1: Horizontal Motion of a Projectile

1. Open the experiment configuration file **L10A2-1 (Projectile Motion).** This will open the software with a movie called **Ball Toss**.
2. Play the movie and observe the motion of the ball.

Question 2-1: Describe the shape of the trajectory of the ball.

3. Search the **Help** menu for **Video Analysis** to find the "Video Analysis How To." This will give you directions on how to record the position of the ball, frame by frame.
4. Follow the directions to set the scale of the measurements, using the height given for the pile of books in frame 0.
5. Record the positions of the ball for all frames.
6. Sketch below the graph you determined for *x* vs. time for the ball, or print the graph and attach it to these sheets.



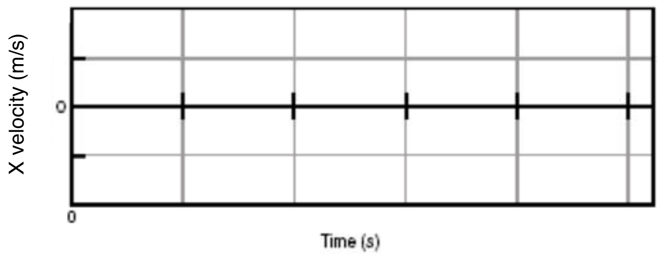
Question 2-2: Does the graph for x vs. time agree with your Prediction 2-1. Explain.

Question 2-3: Does the graph for x vs. time represent motion at a constant velocity or constant acceleration? How do you know? Refer back to your observations in Investigation 1, if necessary.

7. Choose the kinematic equation that describes x vs. time for this motion, and model it to find the values of the parameters in that equation, e.g., v_o and x_o. (That is, use the modeling feature in the software to find the equation that best represents the data, and find the parameters from this model.)

Question 2-4: What is the kinematic equation? Give the values of all parameters.

8. Display the graph of v_x vs. time. Sketch the graph on the axes below, or print the graph and attach it to these sheets.



Question 2-5: Does the graph for v_x vs. time agree with your Prediction 2-1. Explain.

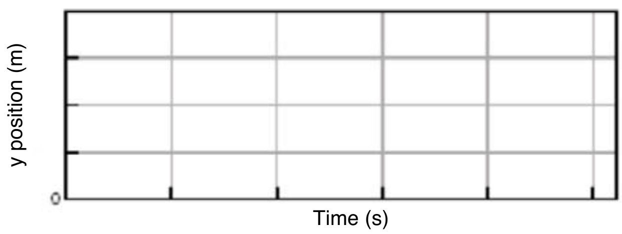
Question 2-6: Does the graph for v_x vs. time represent motion at a constant velocity or constant acceleration? How do you know? Refer back to your observations in Investigation 1, if necessary.

9. Choose the kinematic equation that describes v_x vs. time for this motion, and model it to find the values of the parameters in that equation, e.g., v_o and x_o. (Again, use the modeling feature in the software to find the equation that best represents the data, and find the parameters from this model.)

Question 2-7: What is the kinematic equation? Give the values of all parameters.

Activity 2-2: Vertical Motion of a Projectile

1. Display the graph of *y* vs. time. Sketch the graph on the axes below, or print the graph and attach it to these sheets.



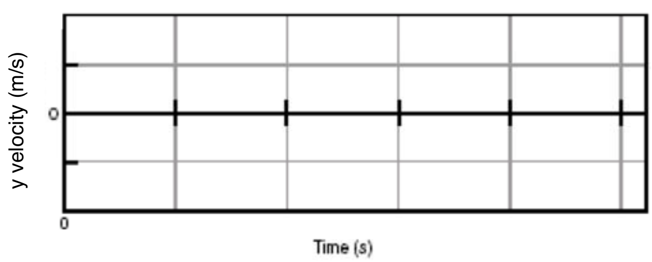
Question 2-8: Does the graph for *y* vs. time agree with your Prediction 2-2. Explain.

Question 2-9: Does the graph for *y* vs. time represent motion at a constant velocity or constant acceleration? How do you know? Refer back to your observations in Investigation 1, if necessary.

2. Choose the kinematic equation that describes for *y* vs. time for this motion, and model it to find the values of the parameters in that equation, e.g., v_o and x_o. (Again, use the modeling feature in the software to find the equation that best represents the data, and find the parameters from this model.)

Question 2-10: What is the kinematic equation? Give the values of all parameters.

3. Display the graph of v_y vs. time. Sketch the graph on the axes below, or print the graph and attach it to these sheets.



Question 2-11: Does the graph for v_y vs. time agree with your Prediction 2-2? Explain.

Question 2-12: Does the graph for v_y vs. time represent motion at a constant velocity or constant acceleration? How do you know? Refer back to your observations in Investigation 1, if necessary.

4. Choose the kinematic equation that describes v_y vs. time for this motion, and model it to find the values of the parameters in that equation, e.g., v_o and x_o. (Again, use the modeling feature in the software to find the equation that best represents the data, and find the parameters from this model.)

Question 2-13: What is the kinematic equation? Give the values of all parameters.

5. Find the value of the y component of the acceleration of the tennis ball.

Question 2-14: Is this value for the vertical component of acceleration what you expected? Explain.

Question 2-15: Use your observations in the two investigations of this lab to justify the statement that projectile motion is a combination of horizontal motion at a constant velocity (zero acceleration) and vertical motion with a constant (gravitational) acceleration.