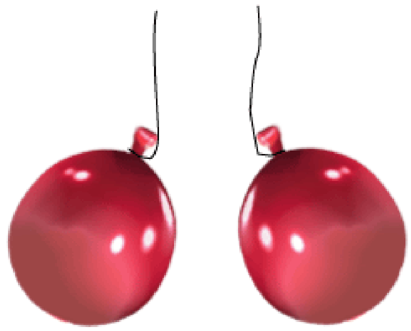
Getting Charged!

A. Suppose that you rub a balloon against your (clean) hair, and bring it near (but not touching) a metal can. What do you think will happen?

Try it. What happens?

B. Suppose that you rub two balloons on your head and bring them close to one another. What do you think will happen?



Try it. What happens?

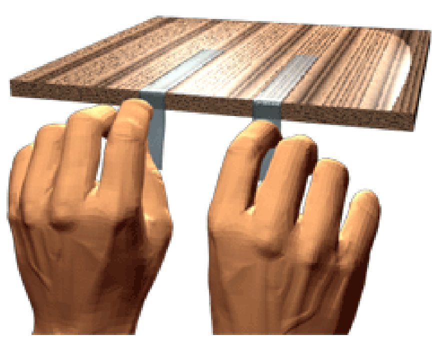
Materials:

- Two balloons, inflated, on short (15 cm) strings
- An empty soda can
- Two 10 cm (4”) long strips of scotch tape
- A rod made of PVC or rubber
- Scraps of wool, silk, polyester, or fur

C. Suppose that you rub a PVC or rubber rod with wool, fur, or silk, and touch the rod to your (clean) hair. What do you think will happen?

Try it. What happens?

D. Suppose that you stick two long strips of scotch tape on a table, pulled them off, and brought the strips close to one another. What do you think will happen?



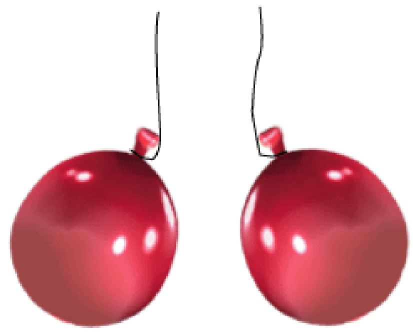
Try it. What happens?

Getting Charged - Revisited

After reading the *Reading Page: What is Static*, explain the activities in the *Getting Charged* activity in terms of positive and negative charges

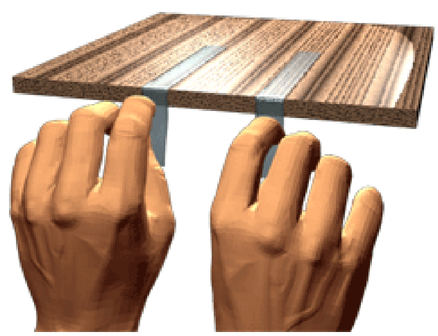
A. Suppose that you rub a balloon against your (clean) hair, and bring it near (but not touching) a metal can. What do you think will happen?

B. Rub two balloons on your head and bring them close to one another.
Explain what happens in terms of positive and negative charges.



C. Rub a PVC or rubber rod with wool, fur, or silk, and touch the rod to your (clean) hair.
Explain what happens in terms of positive and negative charges.

D. Stick two long strips of scotch tape on a table, pulled them off, and brought the strips close to one another.
Explain what happens in terms of positive and negative charges.



E. Suppose you stick two pieces of scotch tape to each other (sticky side of one to back of the other), and then rip them apart.
Predict, using your knowledge of positive and negative charges, what you think will happen:

Try it, and explain what happened.

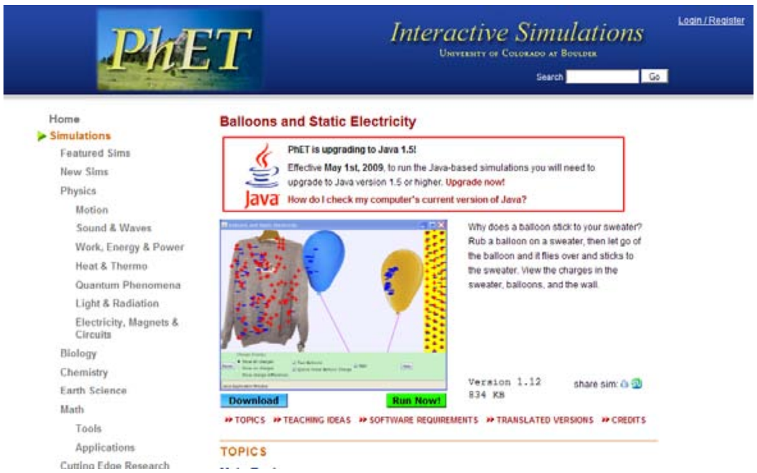
Exploring electric charges

Purpose:

How do charges interact? When do they move?

Part 1. Balloons and Static Electricity Simulation

To interactively explore some of the concepts go to the Physics Education Technology Web site (http://phet.colorado.edu/en/simulations/category/new). We will start with the Balloons and Static Electricity simulation, found under Physics -> Electricity, Magnets and Circuits.



The simulation “Balloons and Static Electricity” can be run online (chose “Run now”) or downloaded and runs on your own computer (choose “Download”).

Once your application has started, click “Reset All”. Make sure that only the “**show all charges**” and “**wall**” buttons are selected.

1. Examine the charges on the balloon and the sweater.

   a) Look at the balloon. What can you say about its charge? (Hint: count both types of charges)

   b) Click and drag the balloon and rub it against the sweater. What happens to the balloon?

   c) How did the balloon get charged, with what type of charge?

d) Where did that charge come from?

e) What happened to the sweater? How did it get charged?

2. Moving the balloons around.

a) Bring the balloon in the middle, between the sweater and the wall. What happens to the balloon when you let it go? Explain.

b) What is the overall charge of the wall?

c) What do you think will happen when the balloon is brought close to the wall? Predict first.

d) Bring the balloon in contact with the wall. What happens to the charges in the wall?

e) Let go of the balloon. What happens? Explain.

3. Two balloons

a) Click the "Reset All" button. Select "show all charges", and "Two balloons". What can you tell about the overall charge of all the objects in your simulation window?

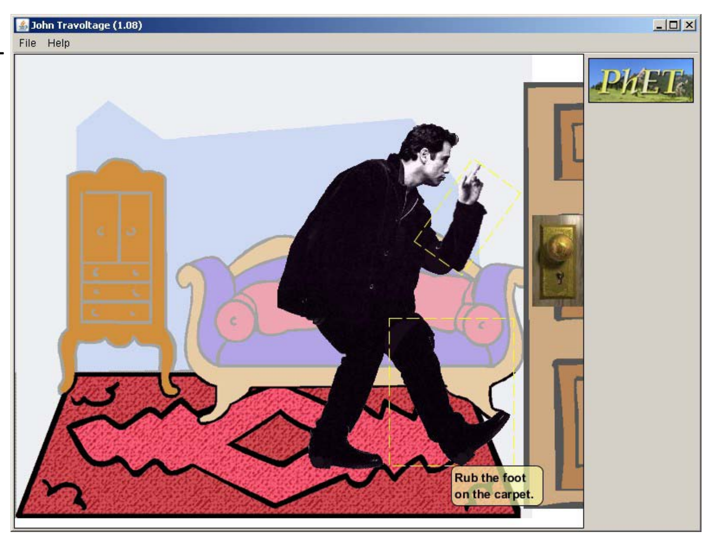
b) Select "Show charge differences". Rub each balloon against the sweater. What happens to each one of them?

c) Why are the two balloons stuck on the sweater?

d) Try to get one balloon off the sweater by using the other balloon. Can you do it? If yes, explain why this is possible.

4. John Travoltage

Go back to your web browser window and from the simulations under Physics -> Electricity, Magnets and Circuits, select "John Travoltage".



a) Predict what will happen to John if he rubs his foot against the carpet.

b) Rub John's foot on the carpet by clicking and dragging his foot few times. What happens?

c) Predict what will happen if John touches the door knob.

d) Click and drag John's hand such that it touched the doorknob. What happened?

e) What would you call what happened to John?

f) How is this different from the balloon and sweater or balloon and wall touching each other?

5. Summarize what you learned in this activity

A Bulb, A Battery and A Wire

Materials

Part I:

- One light bulb (without wires)
- One wire with ends stripped (about 10 cm long)
- One AA battery

Part II:

- A collection of bulbs
- A magnifying glass
- A Christmas bulb (with socket) to take apart
- A large holiday bulb with socket
- (Optional) A regular light bulb with the glass removed. Be careful of the sharp edges

Purpose:

What does it take to light a bulb?

Part I.

Pre-lab discussion:

BEFORE you start playing with the materials…

1. Can you light a bulb using a wire and a battery?

2. How about using two wires and a battery?

3. Draw two ways to connect one bulb, a AA battery and <u>one</u> wire so that the bulb *does* light.

4. Draw two ways to connect the bulb, the battery and <u>one</u> wire so that the bulb *does not* light.

5. Discuss your ideas within your groups, and draw your favorite circuits – one that does not light, and one that lights – on your whiteboards. (Save these whiteboard drawings, since you will use them again later).

Directions

6. Use the materials, and make the bulb light. You may find more than one method to get the bulb to light. Draw one of your working circuits below, and on the whiteboard along with your predictions.

Part II

Directions:

7. Examine the bulbs given to you using a magnifying glass. Draw pictures of each bulb, and write what was special about each bulb.

8. Discuss your drawings within your groups, and draw your most interesting bulb on your white-board.

9. Take apart a Christmas light. Draw diagrams, and
   a) Identify the contact points in the bulb.
   b) Identify the contact points of the sockets.
   c) How is the bulb assembly, including the socket and wires, put together?
   d) Connect another Christmas light to a battery and identify the part of the bulb that glows.

10. Summarize the characteristics of light bulbs.

Are these Electrical Materials? Lab

Purpose:

What materials conduct electrical current?

Materials:

- Puzzle board piece with bulb and battery
- Three alligator clip wires
- Assorted materials: metal wire, paper clip, plastic coated paper clip, eraser, pencil, pencil lead, ruler, coins, poker chips, small squares of metal and plastic mesh, small squares of paper towel soaked with liquids.
- A brightness meter – probe or home-made (see notes)

Pre-lab discussion:

1. Will all materials allow current to flow easily in a circuit? Discuss this question and make predictions from your everyday experience.

2. Examine the puzzle board piece. Design a circuit that will allow you to answer your question, and write your design below. Things to think about:

   a) How will you know whether a material does or does not conduct electricity?

   b) How can you design your circuit so that you can answer the question above?

   c) What observations can you make, and what conclusions will your observations provide?

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3. After the class discussion, modify your design, if necessary, and conduct an experiment to determine materials that conduct electricity.

a) The Experimental Question:

b) IV:

c) DV:

d) Constants:

e) Hypothesis:

f) Materials List:

g) Procedure:

A diagram of your circuit design:

h) Data Table: *SAMPLE: The effect of the material that completes the circuit on the brightness of the bulb. (Test at least ten materials)*

Material that completes the circuit	Prediction	Try it: Result

i) Group your data into categories (make a table, if you wish)

4. Discussion questions about your data:

   a) What types of materials are in the category that allows the bulb to light? What types do *not* allow the bulb to light?
   What might be possible names for the categories above?

   b) Give examples of other materials in the categories above.

5. Discussion questions about what is happening in the circuit:

   a) When you use a material that allows the bulb to light, what do you think is happening in the circuit?

b) Do you think anything is moving or flowing in the circuit? If so, how do you know or not know?

c) If something is moving, can you tell what it is?

d) If something is moving, can you tell which way it is moving / flowing? Explain your reasoning.

6. Summarize your findings from this lab on the *Student Summary Page: Current Information*. You will return to this table and add to the list as you go through this unit.

7. Connections: Describe the relationship between what you learned in this lab and what you learned about light bulbs and closed circuits in the previous activities.

Student Summary Page: Current Information

Use this or a similar table in your notebook to summarize your observations on electric current. Allow 2-3 pages of blank space in your notebook so you can add to the list.

What I learned about electrical current	Observation or evidence for my statement

The Buzzer and the Motor Lab

Materials:
- Puzzle board pieces that contain the buzzer, the motor with propeller attached, and the batteries
- Three alligator clip wires

Purpose:

What do buzzers and motors tell us about electricity?

Part I: The Buzzer
Pre-lab discussion:

1. Connect the light bulb to the battery and observe it.
What do you think will happen if you switch the wires connected to the battery?

Try it. Note any similarities/differences.

2. Before trying it, predict what you think will happen when you connect the buzzer to the batteries.

Directions:

3. Design a circuit to make the buzzer work. Draw the circuit in great detail – with the colors of the buzzer wires specified, and all contact points labeled.

Draw your circuit:

4. Next, build the circuit, and describe what happened.

5. Reverse the wires to the battery, and describe what happens.

6. Discussion questions:

    a) What is the job of the battery?

    b) Why does the buzzer buzz?

    c) Why do you think switching the wires on the buzzer make it buzz or not buzz?

d) What do you think the + and – marks on the battery mean?

e) What do you think happens inside an electrical circuit?

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Part II: The Motor:

7. Design a circuit to connect the motor to the batteries. Draw two circuits below – one circuit with the + and – of the battery connected one way, and the second one with the + and - terminals switched.

Circuit 1	**Circuit 2**
Diagram:	Diagram:
Prediction:	Prediction:
Because:	Because:
Connect the circuits and make observations. Explain why you think the circuits behaved as they did.	
Observations and Reasoning:	Observations and Reasoning:

8. Discussion questions (parts I and II):

a) What conclusions can you draw about current in an electrical circuit?

b) Why do you think the motor does something a bit different when you exchange the + and the -? How does that behavior connect with the flow of (whatever) in an electrical circuit?

c) From your observations of the buzzer and the motor circuits, what do you think happens in an electrical circuit that makes devices work?

9. Summarize your conclusions and add them to the *"Current Information" Student Summary Page*.

10. Connections: Describe the relationship between what you learned in this lab and what you learned about light bulbs, closed circuits and conductors and insulators in the previous activities.

Bulbs and Switches Lab

Materials:

Part I:

- Puzzle Board piece with bulb and battery
- Puzzle Board piece with switch
- Three alligator clip wires

Part II

- A variety of switches, including SPDT knife switch, push button normally closed and normally open, wall switch

Part III

- Car door circuit
- Buzzer Circuit box
- Staircase switch box

Purpose:

How do you include a switch in a circuit?

Pre-lab discussion:

1. What do you think a switch does in a circuit? Explain also what makes the switch function as it does.

2. Identify the contact points of a switch (draw a diagram).

Directions:

Part I.

3. Draw the two circuits below. Use arrows to show the direction in which current flows in the circuit.

(a) a circuit with a battery and a bulb	(b) a circuit with a battery, a bulb and a switch.
	 ©Exploring Physic
Build the circuit. How would you turn the bulb on and off in this circuit? How is it different from circuit (b)?	Build the circuit. How would you turn the bulb on and off in this circuit? How is it different from circuit (a)?

Part II.

4. Examine the switches in the collection. Look at least three different kinds of switches, draw diagrams, and figure out how they work (use the bulb and battery with the switch, if you prefer).

	Switch 1	Switch 2	Switch 3
Draw a picture of each switch			
(a) How many contact points does the switch have?			
(b) How does this switch work?			
(c) What uses might it have?			
(d) What are other parts of the switch (other than the contacts)?			

Part III.

5. Examine these three circuits:

Draw a circuit diagram	Describe how you think the circuit and switch(es) operate
a) Car door circuit:	
b) Buzzer Circuit:	
c) Staircase Switch Circuit:	

6. Summarize what you learned about switches from this activity.

7. Connections: Describe the relationship between what you learned in this lab and what you learned about closed circuits and conductors and insulators in the previous activities.

Electrical Elements Application Lab

Materials:

- Puzzle board piece with LEDs and photoresistor
- Puzzle board piece with battery
- Puzzle board piece with buzzer
- 4 Alligator clip wires

Purpose:

How do LEDs and photoresistors work?

Pre-lab discussion:

1. Examine the puzzle board piece that consists of several small devices. The yellow, red and white ones are called LEDs (light-emitting diodes). The little brown/grey one is called a photoresistor.

Directions:

2. First try out circuits with each of those devices *individually*, and figure out the conditions under which they work. Describe your observations:

   a) the red-colored LED:

   b) the yellow-colored LED:

   c) the white-colored LED:

   d) the photoresistor:

3. Next, add the buzzer to the individual circuits to change the working conditions of the devices, and describe what each of the devices do.

   a) the red-colored LED:

   b) the yellow-colored LED:

   c) the white-colored LED:

Draw a picture of the circuit:

d) the photoresistor:

4. Discussion questions:

a) Can you connect the + of the battery to *either* side of the LED and make it work?

b) Where have you seen LEDs before?

c) Where do you think one can use the two-color LED?

d) What do you think the name “photo-resistor” implies?

e) Can you think of an application where a photoresistor might be used?

f) Research LEDs and discuss whether LEDs should be used instead of light bulbs. Discuss where they are used.

5. Summarize what you learned about LEDs, and about photoresistors:

6. Connections: Describe the relationship between what you learned in this lab and what you learned about the flow of electrons in a circuit, conductors and insulators in the previous activities.

The Everyday-stuff Battery Lab

Purpose:

What does it take to make a battery?

Materials:

- A digital multimeter
- Two wires with alligator clips
- 4-6 batteries of different values for Part I
- Two pairs of copper and zinc rods (~1/8" dia x 2 to 4" long)
- One rod each of various metals - aluminum, brass, steel, etc
- The buzzer piece of the puzzle board
- A sheet of graph paper
- A variety of vegetables for part II
- Liquid battery test-tube holder with holes cut in the lid for part III
- A variety of liquids (e.g., soda, salt water, vinegar, fruit juice, sugar water)
- An analog 25 μA ammeter (or the digital multimeter) for part IV

Using the Multimeter

1. You are going to make batteries and measure a characteristic of the battery, which is its voltage. Here's how you measure the voltage difference across a battery using a multimeter:

- Turn the selector knob on the multimeter to "DC voltage" or "DC V." This makes the meter function as a voltmeter.
- Select the range of measurement. For example, if the voltage of the battery is 6V, the multimeter should be in a 0-20V range. If it is in the 0 - 2V range, it will overload.
- Plug one of the multimeter leads into the socket marked "common" or COM and the other into "DC V" or V.
- Connect the multimeter leads to the + and the – of the battery, and read the voltage.
- If the + of the battery is connected to the "DC V" socket, and the – of the battery to the "common," the reading will be positive. If the terminals are reversed, you will get a negative reading.
- For more detailed information read *Reference Page: Using a Multimeter.*

Directions:

This lab consists of four parts: I. Testing Regular Batteries: II. The Veggie Battery Lab; III. The Liquid Battery Lab; and IV. The Human Battery.

Part I. Testing Regular Batteries

2. Examine the collection of batteries, and measure their voltages. Are the voltages close to what was printed on the outside? If it was different, what do you think made it different? Make a table below.

Part II: The Veggie Battery Lab

3. Insert two rods into a vegetable or fruit (roll lemons first to pop their interior chambers). Measure the voltage produced with <u>one</u> fruit or vegetables, and for the following combinations of rods:

One **copper** rod and one rod of the following metal:	Voltage produced (V)	One **zinc** rod and one rod of the following metal:	Voltage produced (V)

4. What do you observe in the data above? (Note: the rods used for a battery are called electrodes).

Did two electrodes of the same kind work?

5. Use the combination of electrodes that gives you the highest voltage, and test it on all the fruit and vegetables given to you.

a) Draw a diagram of the circuit, clearly identifying the metals that were the + and the – terminals of the battery. Mark the direction of electron flow in this circuit.

b) Make a table below.

A diagram of your circuit design:

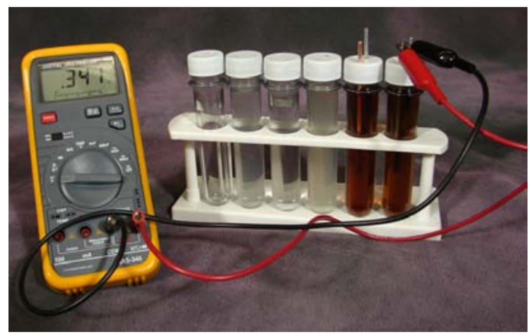
c) What do you observe in the data above?

6. Discussion questions:

   a) Test if your best vegetable battery will do anything. Connect it to a buzzer, and describe what happens. Draw a circuit diagram, clearly identifying the colors of the buzzer wires and the metal rods of the battery.

   b) What do you need to do to make the buzzer louder, still using fruit batteries? You might have to get help from a neighboring group!

Part III. The Liquid Battery lab



7. Instead of vegetables or fruit, how might you use a vial to make a battery? Design an experiment to measure the effectiveness of several liquids (electrolytes) in batteries.

   a) The Experimental Question:

   b) IV:

   c) DV :

   d) Constants:

   e) Hypothesis:

   f) Materials List:

   g) Procedure:

A diagram of your circuit design:

h) Data Table:

i) Graph: Create a graph for this investigation. What type of graph should you make (line or bar)?

Title of graph:

8. Conclusions: Summarize what you learned from this activity.

Part IV. The Human Battery

9. Can a human being be a battery? After all, we do have electrolytes inside of us. What might we need to function as batteries?

a) Measure the voltage you produce (hold on to two electrodes!).

b) What helped produce a larger voltage?

10. The best combination of electrodes you used produced about 1 to 1.5 V. Commercial batteries are not a lot better when it comes to voltage produced (AA, AAA, C and D cells all produce 1.5 V). How do you think a 6 V battery is made? Or a 9 V or 12 V?

11. Summarize what you learned about batteries from all four parts of this lab.

Current in Series Circuits Lab

Materials:

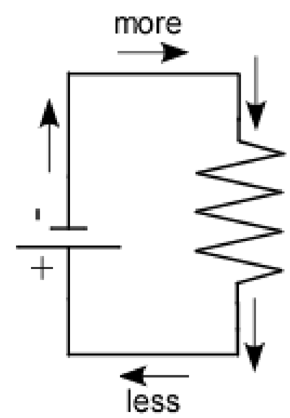
- A sheet of plastic canvas
- Three Christmas light bulbs with wires
- A digital multimeter
- A 6V lantern battery
- Three alligator clip wires
- A wire stripper

Purpose:

Is current different in different circuits?

Pre-lab discussion:

1. A student draws the flow of current in a one-bulb circuit as shown, where "less" and "more" refers to the amount of current at that point in the circuit. The arrows represent the direction of the current. Is this diagram correct? Explain your reasoning.



2. In the space provided below, using the symbols for different circuit elements, draw the following circuits and show the direction of the current.

A circuit made of one battery, one light bulb, and wires.	A circuit made of one battery, 2 light bulbs connected one after the other, and wires.

3. Predict three factors that may be different for the two circuits above.

4. Which factors you predicted above are measurable?

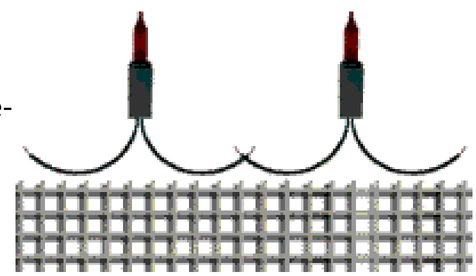
Part I.
Directions:

5. Build the circuit containing one single light bulb. If necessary, strip about 1 cm of insulation from the end of each wire (on the light bulbs) using the wire stripper. Weave each wire of the bulb in and back out of the plastic canvas, so that the bulb and the ends of the wires are on the same side of the canvas. Connect the battery using alligator clips.

6. Describe the brightness of the bulb in the 1-bulb circuit.

7. What do you think will happen to the brightness of the light bulb if you add a second light bulb to your circuit as shown in the figure? Predict first (do not build the circuit yet!)

8. Now build a two-bulb series circuit (keep the one-bulb circuit - you will need it later). Compare the brightness of the bulbs in the two-bulb series circuit to the brightness of the one-bulb circuit.

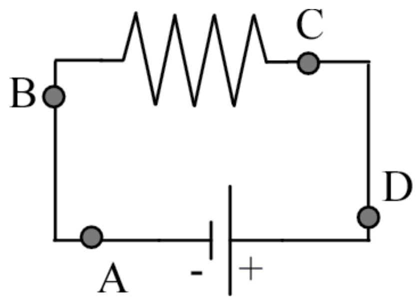
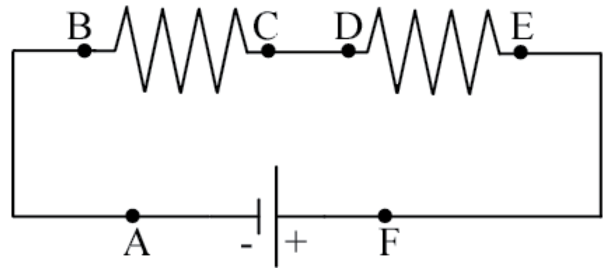


Note: When circuit elements are strung one after the other in a single path, they are in series.

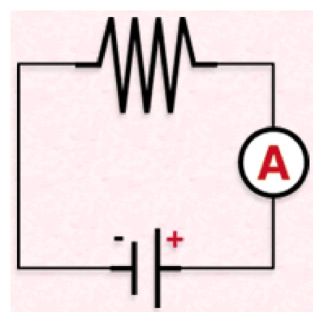
9. Describe a major concept you learned so far about series circuits.

Part II.

10. Predict: In the diagrams below, compare the amount of current at point A to the current at B, C and D (if marked) *within* each circuit.

One-bulb circuit	Two-bulb series circuit
	
Prediction:	Prediction:

11. To measure current: current is a measure of how many electrons flow at any point in the circuit every second. Since the number of electrons is huge (a few billion trillions/second), a different unit called amperes (or amps) is used to measure current. Current is measured using a multimeter. Here's how:



a) Turn the selector knob on the multimeter to "current" or "A." This makes the meter function as an ammeter.

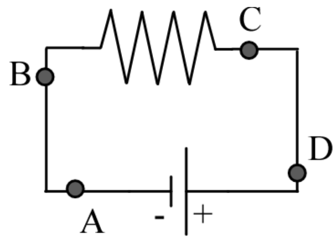
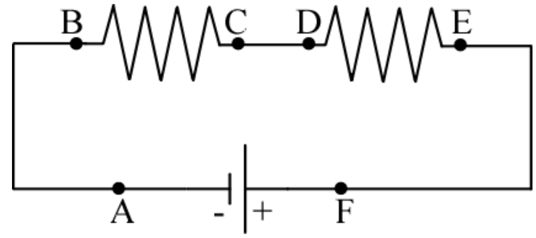
b) Select the range of measurement (if the meter is not autoranging).

c) Plug one of the leads coming out of the multimeter into the socket marked "common" and the other into "DC A."

d) Connect the circuit, with the multimeter in the same path as the battery and the bulb, and read the current.

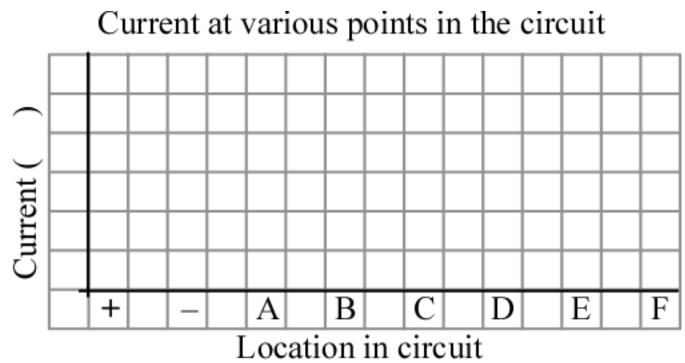
e) When you measure current the meter needs to have the same number of electrons flowing through it as the circuit it is testing -- so it is connected in series within the circuit.

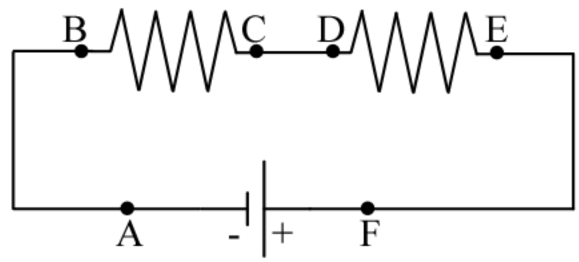
12. Use the ammeter to measure the current in the one-bulb and two-bulb series circuits at the points indicated. Then answer the questions relating to the measurements:

Measure the current in one-bulb circuit: 	Measure the current in two-bulb series circuit: 
• At A:	• At A:
• At C:	• At C:
	• At E:
a) What can you conclude about current in the one-bulb circuit at points A and C?	b) What can you conclude about current in the two-bulb series circuit at A, C and E?
c) Do you think the value will change if you pick any other point (such as B in the one-bulb circuit)?	d) Do you think the value will change if you pick any other point (such as B in the two-bulb circuit)?
e) How does this measurement compare with your prediction for the one-bulb circuit?	f) How does this measurement compare with your prediction for the two-bulb circuit?
g) How does this measurement compare with your answer to question 1?	h) How does the amount of current in the one-bulb circuit compare with that in the two-bulb series circuit?

i) How does the current relate to the brightness of the bulbs?

13. Plot a graph of the current at various points in the two-bulb series circuit (see diagram). Make a similar diagram and graph for the one-bulb circuit. What do these graphs represent?





14. Discussion Questions:

a) What do you think will happen if you add more bulbs to the circuit?

b) Build a new circuit with three or more bulbs. Describe it.

c) How many bulbs must you add to the series string before the bulbs do not light up any more?

d) Does this mean that there is NO current flowing when the bulbs don't light up any more? Explain

e) Qualitatively, how would the current graph look for a three- and four-bulb circuit (as compared to the two-bulb circuit)? Explain.

f) In a three-bulb series circuit, what do you think would happen if you remove one bulb from its socket?

g) In these circuits, how is the brightness related to the current flowing through the bulb?

15. Summarize your conclusions from these activities. Some conclusions should involve the brightness of the bulbs and the current in the circuits.
Enter your conclusions on the *Student Summary Page: Comparing Two Circuits*.

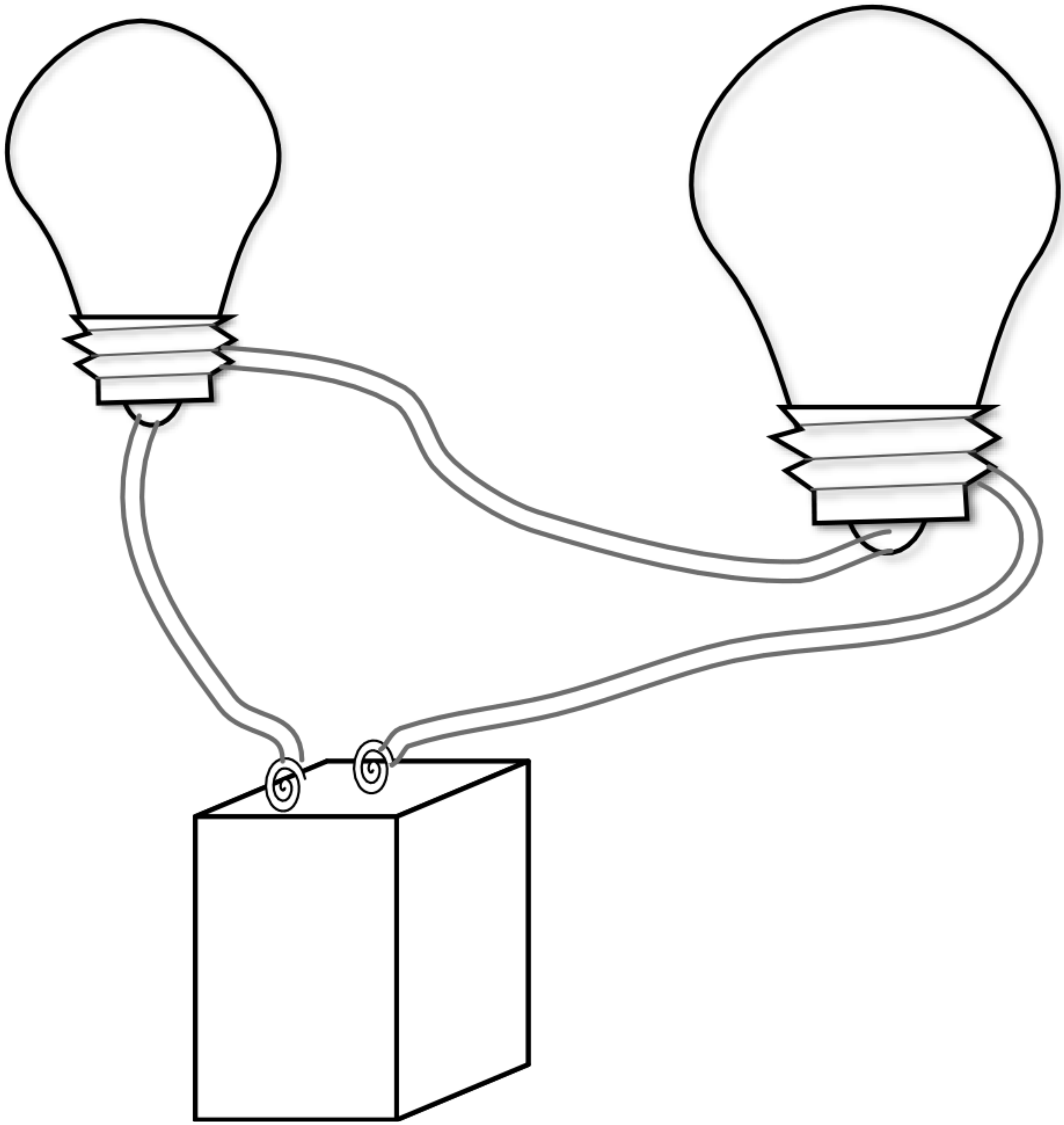
Student Summary Page: Comparing Two Circuits

1. Compare a one-bulb to a two-bulb series circuit (in your notebook, if you wish).

Factor being compared	**One-bulb Circuit**	**Two-bulb Series Circuit**
Example: Picture of circuit		

(Make more rows, if needed)

2. In the picture below draw in and label all details of the devices in the circuit, and describe what happens in various parts of the circuit. You could use balloons as in a cartoon, if you wish.



Resistance in Series Circuit Lab

Purpose:

What is the total resistance in a series circuit?

Materials:

- One small bulb and one large (110 V) bulb
- Plastic canvas with one-bulb circuit and two-bulb series circuit
- Three alligator clip wires
- A multimeter
- A variety of carbon resistors

Pre-lab discussion:

1. What is the difference (electrically) between bulbs and the wires that connect bulbs together? After all, bulbs have a thin wire inside them that glows.

2. Why do the alligator clip wires not glow in a circuit?

Part I. Using the Multimeter to measure resistance:

3. Here is how resistance is measured: ***without*** a battery!

   a) Turn the selector knob on the multimeter to "resistance" or "Ω."

   b) Plug one lead of the multimeter into "common." Plug the other lead into "Ω." This makes the multimeter function as an ohmmeter.

   c) Select the range of measurement (if the meter is not autoranging).

   d) Check all the multimeter connections: connect the multimeter leads to each other: since there is no resistance, the meter should read 0 Ω.

   e) Connect the multimeter leads to the wires coming out of the light bulb using the alligator clip wires. Read the display.

   f) Resistance is measured in units of ohms, abbreviated "Ω."

4. Measure the resistance of a variety of devices, including bulbs, wire and carbon resistors. Present your data in a table.

Part II. Resistors in Series

Pre-lab discussion:

Compared to one bulb, what do you think the resistance will be for a circuit that has:

two bulbs in series : same larger smaller ?

three bulbs in series : same larger smaller ?

Directions:

5. Measure of the resistance of carbon resistors from Part I individually and then strung together in series. Do the same for one, two and three bulbs individually and then strung together in series. Enter the values of resistance you measure in the table below.
(X indicates no measurements for that cell of the table).

Build series circuits with:	R_1	R_2	R_3	R_1 and R_2 in series	R_1, R_2 and R_3 in series
a) 2 carbon resistors			X		X
b) 3 carbon resistors					
c) 2 bulbs			X		X
d) 3 bulbs					

6. Discussion questions:

a) If you add more bulbs to a series string, what do you think will happen to the resistance of the string?

b) Based on your data above, what do you think is the mathematical relationship between the total resistance in a series circuit and the resistance the individual resistors?

c) If you connected different kinds of bulbs in series, (for example, a Christmas bulb, a flashlight bulb and a table lamp bulb), would the rule that you inferred still hold? If not, how must the rule be modified? Explain.

d) What do you think causes resistance in a bulb?

e) If the same battery were connected to a one-bulb circuit and a two-bulb series circuit, what effect do you think resistance has on the current of a bulb? Explain your reasoning.

7. Summarize what you learned from this activity about the resistance of bulbs in series.
Add your observations to *Student Summary Page: Comparing Two Circuits*

8. Connections: Describe the relationship between what you learned in this lab and what you learned about current and bulb brightness in the one-bulb and two-bulb series circuit in the previous activities.

What Causes Resistance? Lab

Purpose:

Investigate factors that affect the resistance of an electrical device.

Materials:

- Pencil Lead Resistance Board
- Wire Resistance Board
- Four alligator clip wires
- A small Christmas bulb
- A large (110 V) bulb
- A digital multimeter

Pre-lab discussion

1. Examine the large bulb and the small bulb. Predict which one might have the larger resistance. Explain you reasoning.

2. Measure the resistance of the small and the large bulbs, and record the values below:

   a) Do your measurements align with your prediction?

   b) Conjecture why the bulbs might have the resistance that they do.

3. Brainstorm factors that can affect the resistance of an object, for example a light bulb.

4. Discuss whether each of those factors has a direct or inverse relationship with resistance; for example, "as __________ increases, _______ resistance increases/decreases."

Part I. Pencil Lead Resistance Board

Directions:

5. Examine the pencil lead resistance board. The lead is brittle, and will break if handled roughly. Brainstorm the electrical factors you can study for one given piece of pencil lead.

Note: Pencil leads are characterized by their hardness, which is defined by numbers and letters. The list, from hardest to softest is 6H, 5H, ...2H, H, HB, B, 2B, 3B...6B

6. Use the above ideas to design an experiment. Define the factor you will use as an independent variable, the factor you will measure as a dependent variable, and the factors that remain constant.

First conduct the experiment on one piece of lead and then repeat for the other pieces of lead. Use the same format as previous experiments:

a) The Experimental Question:

b) IV:

c) DV:

d) Constants:

e) Hypothesis (for one piece of lead):

f) Second hypothesis: If you conduct the same experiment on the other pieces of lead, what do you think would be different in this situation?

g) Materials List:

h) Procedure:

i) Data Table:

j) Graph:

Title of graph:

7. Discussion questions:

   a) How does resistance vary with length? Express this relationship in words and as a mathematical relationship.

   b) What differences did you notice between the slopes for the different pencil leads? What do you think caused these differences?

   c) Suppose a 12 cm long piece of 2H pencil lead has a resistance of 24 Ω. What is the resistance of the lead/cm? If you broke off a 3-cm long piece of the lead, how much resistance would the piece have?

   d) Does this experiment tell you how the resistance would change if you took a fatter piece of lead that was also 12 cm long? Explain your reasoning.

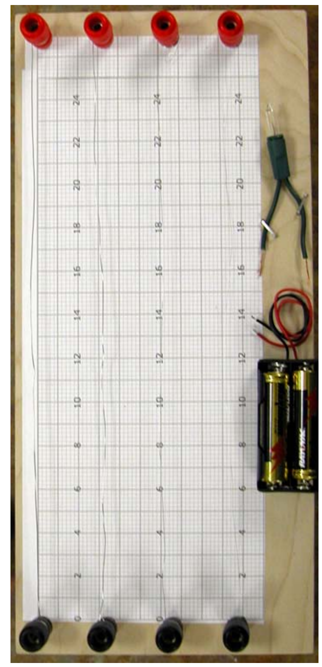
   e) From this experiment, what can you tell about the resistance of a piece of 3H lead that was 12 cm long? Explain your reasoning.

Part II. Wire Resistance Board

Directions:

8. Examine the wire resistance board. It consists of four wires made of the same material, nichrome, but with different diameters. The gauges of the wires are 26, 28, 32 and 36. Obtain the diameters from *Reading Page: The resistance of a wire.* The wire is fragile, and will break if handled roughly.

9. Design and conduct an experiment that involves the effect of the diameter of the wire on the resistance. Your design should include:



a) The Experimental Question:

b) IV:

c) DV:

d) Constants:

e) Hypothesis:

f) Materials List:

g) Procedure:

h) Data Table:

i) Graph:

Title of graph:

10. Discussion Questions:

a) How does resistance vary with diameter?

b) What differences did you notice between the thin and the thick wires? What do you think caused the differences? After all, both are nichrome wire, right?

11. Summarize what you learned from both parts of this experiment.

12. Connections: Describe the relationship between what you learned in this lab and what you know about the filament of a bulb and the wires in a circuit from previous activities.

Voltage in Series Circuit Lab

Materials:
- A sheet of plastic canvas
- One Christmas light bulb with wires
- A voltmeter or multimeter
- A 6 V lantern battery
- Two wires with alligator clips
- A wire stripper

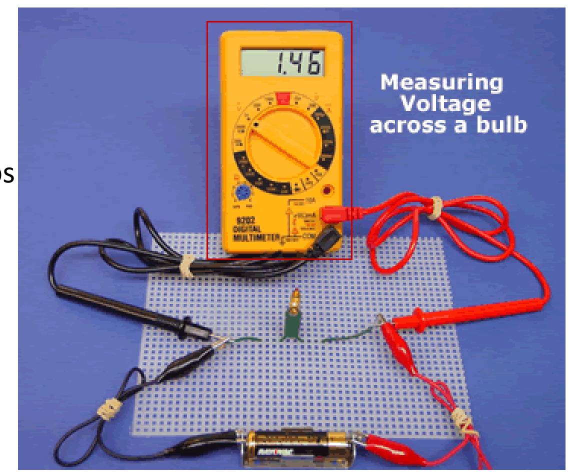
Purpose:

What is voltage difference, and how is it different between different points in a circuit?

Pre-lab discussion:

1. Here is how voltage difference across a resistor is measured:

- Connect the circuit.
- Turn the selector knob on the multimeter to “dc voltage” or “DC V.” This makes the meter function as a voltmeter.
- Select the range of measurement (if the meter is not autoranging).
- Plug one of the multimeter leads into the plug marked “common” and the other into “DC V.”
- Connect one probe of the multimeter to one side of the bulb, and the other probe to the other side of the bulb. (This is called a parallel connection - different from that used to measure current)
- The voltage is measured in V (volts).

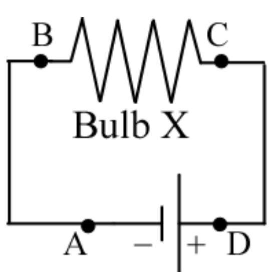


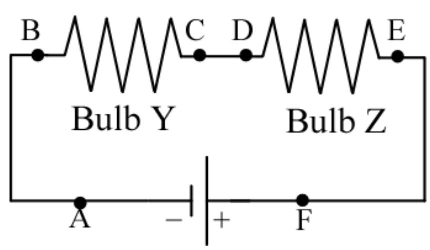
2. You will be comparing voltages across *individual* bulbs in a one-bulb circuit and a two-bulb series circuit.

   a) Predict the voltage across the bulb in a one-bulb circuit as compared to the battery voltage.

   b) Predict the voltage across one bulb in a two-bulb circuit as compared to the battery voltage.

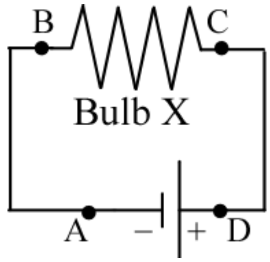
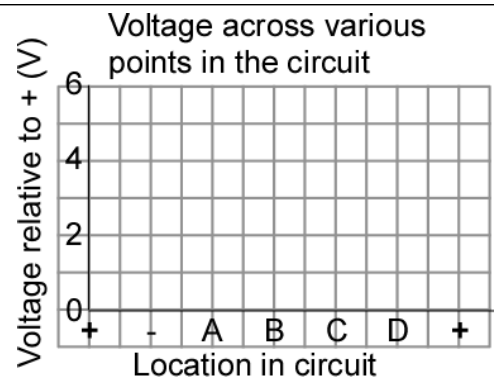
   c) For the two circuits on the right:
   Draw the path of the current in both circuits.
   Then sketch how you would connect voltmeter(s) so you can measure the voltage across *each* bulb (X, Y, and Z) in the circuits *separately*.

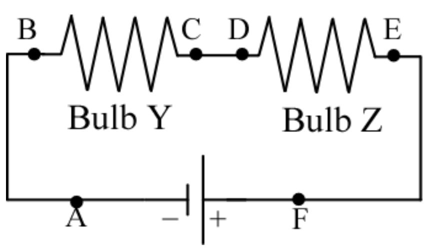
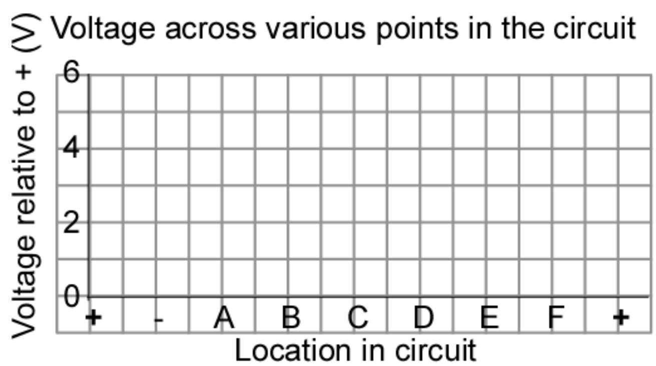




Directions:

3. Use the PHET website to construct the one-bulb and two-bulb series circuits to make measurements and fill information in the table below (set the battery voltage to 6 V):

One-bulb circuit: 	
Connect the circuit, and measure the voltage between:	
+ and + of battery	
+ and - of battery	
Between + of battery and A	
Between + of battery and B	
Between + of battery and C	
Between + of battery and D	
Read *Reading Page: What is Voltage?* and then draw a graphical representation of the voltage in the one-bulb circuit. Use the graph above.	

Two-bulb series circuit: 	
Connect the circuit, and measure the voltage between:	
+ and + of battery	
+ and - of battery:	
Between + of battery and A	
Between + of battery and B	
Between + of battery and C	
Between + of battery and D	
Between + of battery and E	
Between + of battery and F	
Draw a graphical representation of the voltage in the two-bulb circuit. Use the graph above.	

4. Discussion of voltage in the one-bulb circuit: (You may need to read *Reading Page: What is Voltage?*)

a) What happens to the reading on the meter as you move around the circuit? Explain why you think this happens.

b) What do you think the voltage reading in the meter represents?

5. Discussion of voltage in the two-bulb circuit:

a) What happens to the reading on the meter as you move around the circuit? Explain why you think this happens.

b) What do you think the voltage reading in the meter represents?

6. Compare the one-bulb circuit to the two-bulb circuit.

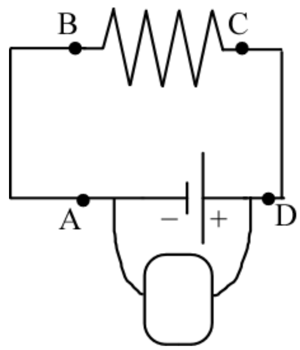
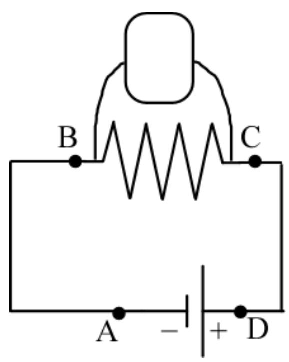
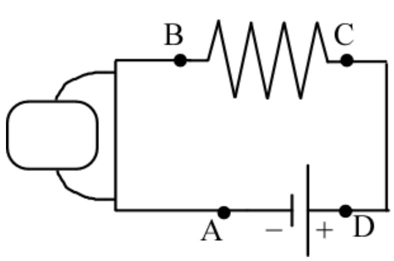
a) What do you notice about the brightness of the bulbs in the two circuits?

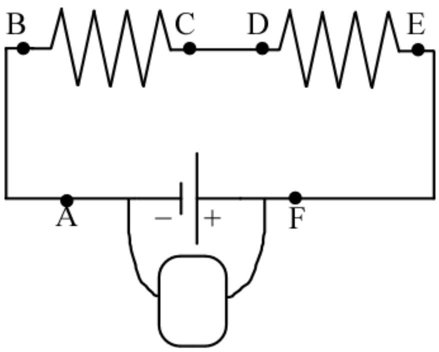
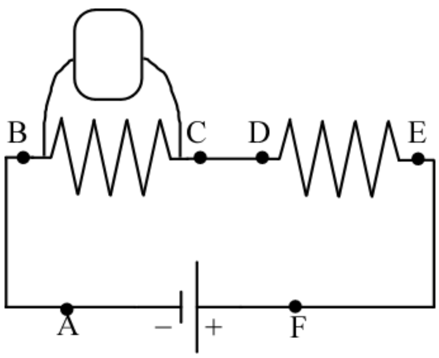
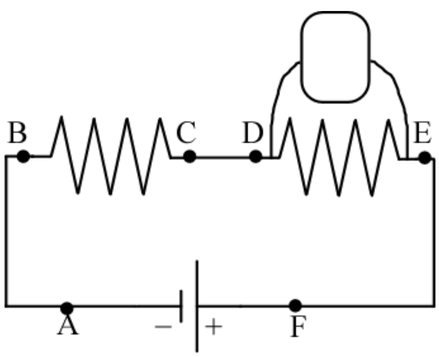
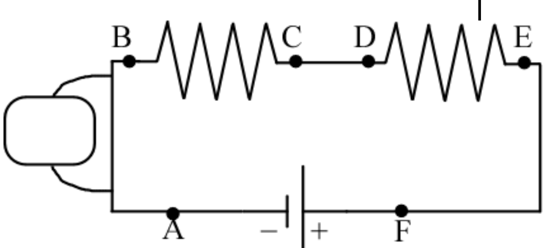
b) What do you notice about the voltage drop across the bulb(s) in the two circuits?

c) What do you think is the connection between the bulb brightness and the voltage across it?

d) What do you think would happen if we had three identical bulbs in the series circuit? Compare brightness and voltage drop to the one-bulb and the two-bulb circuits.

7. Use the circuits you have built to make predictions and measurements below (meters shown):

Circuit	Predict the voltage read by the meter	Measure the voltage	Explain
One-bulb circuit:			
A. Voltage across the battery 			
B. Voltage across resistor 			
C. Voltage across wire: 			

Circuit	Predict the voltage read by the meter	Measure the voltage	Explain
Two-bulb series circuit:			
D. Voltage across battery 			
E. Voltage across Resistor 1 			
F. Voltage across Resistor 2 			
G. Voltage across a wire 			

8. Examine your observations:

   a) What is the voltage between two points separated by only a wire (e.g., A and B on the one bulb circuit) as compared to the voltage across the bulb in the same circuit? Provide numbers, and then describe it qualitatively. Explain.

   b) In both circuits, between which two points in a circuit is the voltage the largest? Provide numbers, and then describe it qualitatively.

   c) What relationship do you find between the brightness and the bulb voltage in the two circuits?

   d) In both circuits, how are the battery voltage and the bulb voltage related to each other?

   e) Why do you think the voltages across <u>one</u> bulb are not the same in the two circuits?

9. Relate voltage to previous measurements in series circuits:

   a) From your previous experiments, describe the currents flowing through bulbs X, Y, and Z.

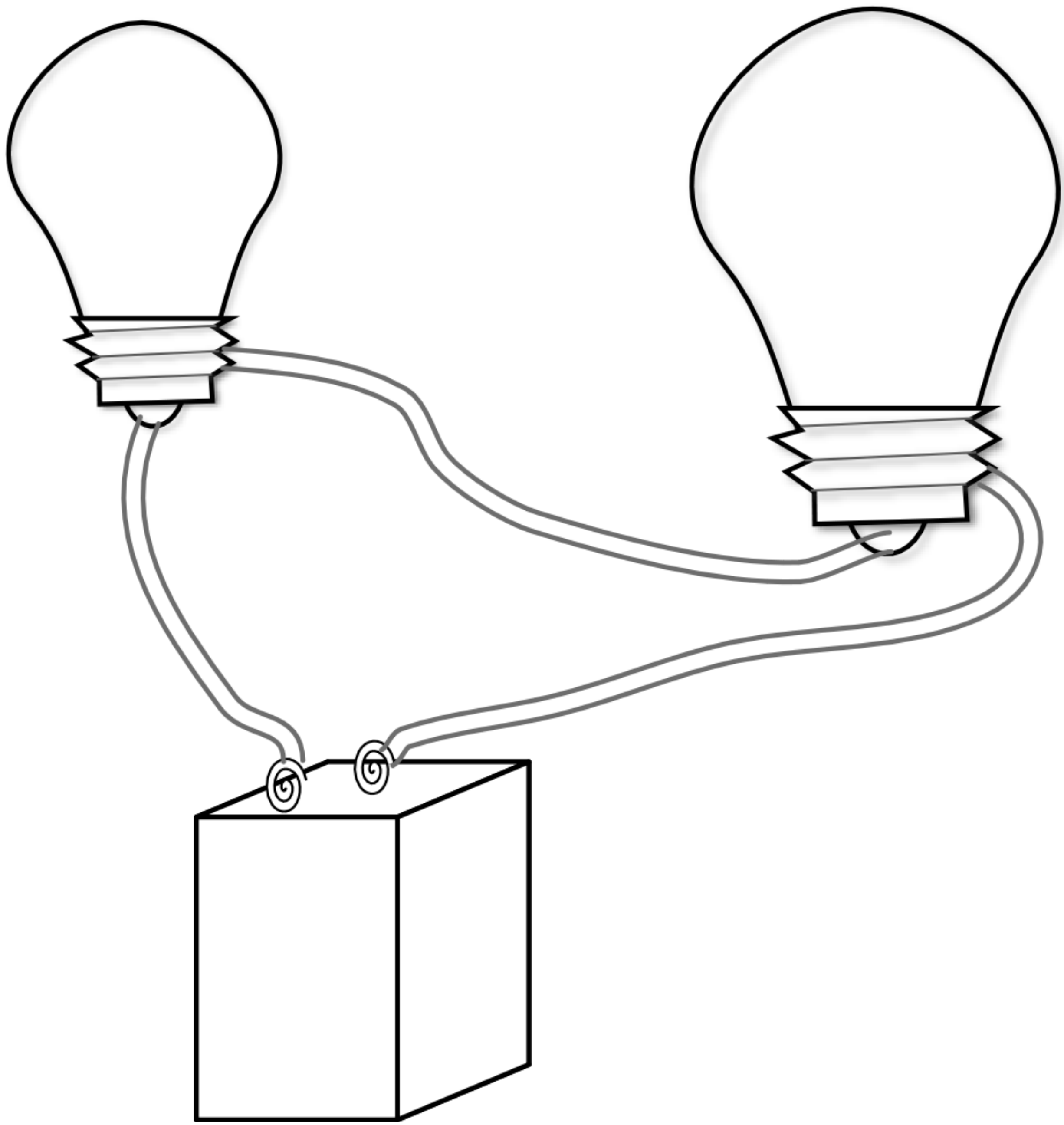
   b) From your previous experiments, describe the resistances of the circuits relative to each other.

   c) Among your group brainstorm the connection between current, resistance and voltage in a circuit. You could use statements such as “when I increase the battery voltage in a circuit, but the resistance is the same, then ....” Or you could describe the connections in a table.

10. Summarize what you learned in this activity; then update your “Student Summary Page: Comparing Two Circuits.”

11. Connections: Describe the relationship between what you learned in this lab and what you learned about current and bulb brightness in the one-bulb and two-bulb series circuit in the previous activities.

12. In the picture below, draw and label all parts of the devices in the circuit, focusing on ideas that relate to resistance and to voltage. You may use cartoon-like balloons, if you wish.



Figuring out a Law Lab

Materials:

- 1 AA battery in a holder
- 2 AA batteries in a holder
- 6 V battery
- Carbon resistors of four or five different values (preferably 1 W resistors between 200 and 5000 ohms)
- Two multimeters

Purpose:

What is a relationship among voltage, current and resistance?

Pre-lab discussion:

1. Draw three circuits: Circuit 1 has a resistor R_1 and a 3 V battery; Circuit 2 has the same resistor R_1 and a 6 V battery; Circuit 3 the same resistor R_1 and a 9 V battery.

Circuit 1	Circuit 2	Circuit 3

2. Make a table (sample shown) to predict your comparison of the circuits. You might use phrases such as small, medium, large for your comparisons.

   a) Compare the total resistance in Circuits 1, 2, and 3.

   b) Compare the voltage applied across the resistance in Circuits 1, 2 and 3.

   c) Compare the currents through the resistor in Circuits 1, 2, and 3.

Sample Prediction Table:

	Circuit 1	Circuit 2	Circuit 3
Resistance			
Voltage			
Current			

   d) From your table, what mathematical proportionalities can you predict between current and voltage when the resistance is a constant?

Directions:

3. Design an experiment to obtain the relationship between current, voltage and resistance. Draw a diagram of circuit, including multimeters.
Start with one specific resistor, and if time permits, investigate the other resistors one at a time.
Note: combine given batteries to obtain battery voltages of (nominally) 1.5, 3.0. 4.5, 6.0, 7.5, 9.0 and 10.5 V)

Diagram:

a) The Experimental Question:

b) IV:

c) DV:

d) Constants:

e) Hypothesis:

f) Materials List:

g) Procedure:

h) Data Tables:

Resistance of R_1 (Ω)	Voltage across R_1 (in V)	Current through R_1 (in mA)

Repeat the experiment for each of the other three resistors, and fill out the tables below:

Resistance of R_2 (Ω)	Voltage across R_2 (in V)	Current through R_2 (in mA)

Resistance of R_3 (Ω)	Voltage across R_3 (in V)	Current through R_3 (in mA)

Resistance of R_4 (Ω)	Voltage across R_4 (in V)	Current through R_4 (in mA)

i) Plot a graph with <u>voltage on the vertical axis,</u> and <u>current on the horizontal axis</u> (even if voltage is the IV). Should it be a line or bar graph? (Use larger graph paper if you wish)

Title of graph:

4. Discussion Questions: Analysis of the Voltage vs. Current (V vs. I) graph:

   a) From these graphs, what conclusion can you draw about the relation between current and voltage?

   b) From the graphs, deduce a mathematical relationship between voltage and current (or, what kind of proportionality do you observe?).

   c) Calculate the slopes of the graphs (slope= rise/run). What units does this slope have?

   d) Examine the slopes obtained for different resistors (by other groups, if necessary). Compare the calculated slopes with the resistance of the resistor used to gather the data. Do the slopes show any correlation to the resistor used?

   e) From all these data and graphs, deduce a mathematical relationship between voltage, current and resistance.

5. Connections: Describe the relationship between what you learned in this lab and how it relates to current, voltage and resistance in the one-bulb and two-bulb series circuits in previous activities.

Parallel Circuit Lab

Materials:
- Plastic canvas from previous activity
- Two Christmas light bulbs with wires
- A 6 V lantern battery
- Two wires with alligator clips
- A voltmeter or multimeter
- A wire stripper

Purpose:

How does a parallel circuit work?

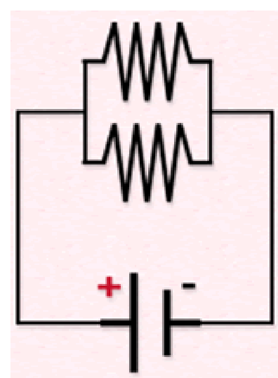
Pre-lab discussion:

1. Examine the diagram of the circuit with two bulbs, called a parallel circuit.

   a) Predict what factors might be different from the *two-bulb series* circuit.

   b) In what way will these factors be different?

   c) What factors do you think you can measure?



Two bulbs connected across a battery in a Parallel Circuit.

Directions:

2. Build this circuit on the plastic canvas, alongside the one-bulb and two-bulb series circuit.

3. Describe the brightness of the bulbs in the two-bulb parallel circuit as compared to those in the single-bulb circuit and the two-bulb series circuits.

4. Measure the voltage difference across each bulb, and the battery voltage while the circuit is connected:

Voltage across...	**In one-bulb circuit**	**In the two-bulb series circuit**	**In the two-bulb parallel circuit**
Bulb 1			
Bulb 2	X		
Battery (with circuit connected)			

Discussion Questions:

a) What relationship do you find between the brightness and the bulb voltage in the one bulb, two-bulb series, and two-bulb parallel circuits?

b) How are the battery voltage and the bulb voltage related to each other in the one bulb, two-bulb series, and two-bulb parallel circuits?

c) Using a colored pencil, trace the path of the current in the two-bulb parallel circuit, starting from the negative (minus) of the battery (use the diagram on the previous page). Draw arrows to show the direction of the current. What does the current do when it reaches the "split" in the wires?

d) What do you think will happen if you remove one bulb from the parallel circuit?

e) Try it. What happened?

f) What are some examples of series circuits? How do you know they are series circuits?

g) What are some examples of parallel circuits? How do you know they are parallel circuits?

5. Use the Student Summary Page: Comparing Series and Parallel Circuits and summarize what you know about these circuits.

6. Connections: Describe the relationship between what you learned in this lab and what you learned about the one-bulb and series circuits in the previous activities.

Student Summary Page: Comparing Series and Parallel Circuits

Sample summary table (if you write this in your notebook, allow 10 rows and at least two pages)

Factor being compared	Series Circuit	Parallel Circuit

Simulations:
http://phet.colorado.edu/simulations/sims.php?sim=Circuit_Construction_Kit_DC_Only

Practice 1.10: Designing Series and Parallel Circuits

In the following problems, all bulbs are similar, and the same battery is used. Test your circuits after you design them!

1. Design a circuit to have four bulbs, all very dim. Draw a circuit diagram. Explain why it has the features required.	2. Design a circuit to have four bulbs, all very bright. Draw a circuit diagram. Explain why it has the features required.
3. Design a circuit to have four bulbs, all medium bright. Draw a circuit diagram. Explain why it has the features required.	4. Design a circuit to have four bulbs, three of them dim and one of them very bright. Draw a circuit diagram. Explain why it has the features required.
5. Design a circuit to have four bulbs, two of them medium bright and two of them very bright. Draw a circuit diagram. Explain why it has the features required.	6. Make up your own design:

Current in a Parallel Circuit Lab

Purpose:

What is the path of current in a parallel circuit?

Materials:

- The two-bulb parallel circuit on plastic canvas from previous activity
- Four wires with alligator clips
- Two multimeters (check that they can handle currents of 1 A)
- A 6 V lantern battery

Pre-lab discussion:

1. Design a two-bulb parallel circuit (on paper) so that you can measure the current through each branch of the circuit separately. Draw a diagram.

2. Connect the circuit, except for one of the connections on the battery. The teacher will check the connected circuit before you proceed. (Note:. Be sure to check your diagram as you connect the circuit. It can be a bit tricky).

Directions:

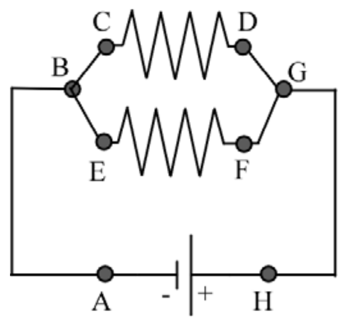
Part I.

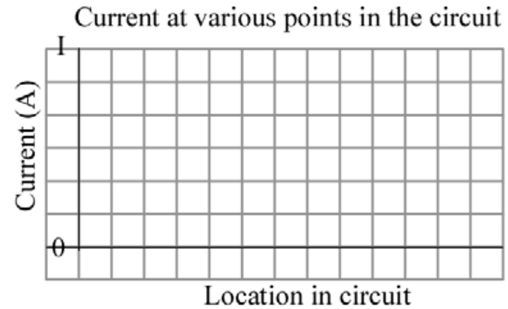
3. Connect the battery and measure the current through each of the bulbs, and note the values.

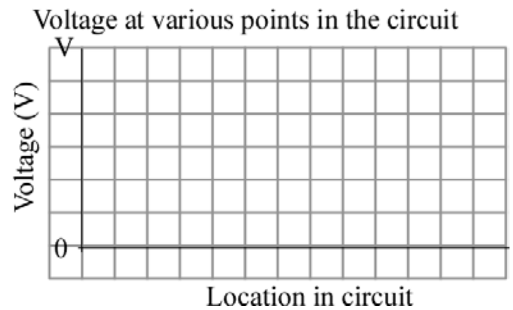
4. How much current do you think the battery has to supply? Write your predicted value.

5. Redesign the circuit so you can measure the current supplied by the battery. Draw a diagram. Connect the circuit, and measure the battery current.

6. Represent current and voltage as a function of the position in a circuit graphically (see *Reading Page*: Parallel Circuits).







7. Discussion Questions:

   a) How is the current supplied by the battery related to the current in the branches of the circuit?

   b) What would happen to the current supplied by the battery if you added one more bulb in parallel to the first two?

   c) Try it. How much current did the battery supply?

   d) What would happen to the battery current if you added more bulbs in parallel?

   e) How does this relate to what happens when someone plugs several appliances into a single household outlet?

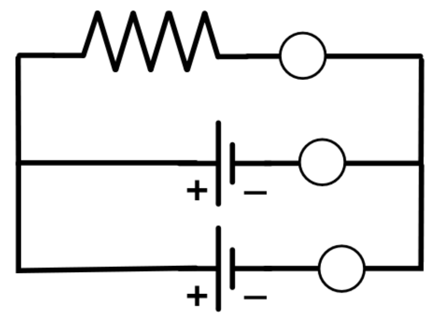
f) How are homes wired – in series or parallel? How do you know?

8. Summarize what you learned about currents in parallel circuits.
Return to the *Student Summary Page* - Comparing Series and Parallel Circuits and add your observations from this activity to the list.

9. Connections: Describe the relationship between what you learned in this lab and what you learned about the movement of charge in previous activities.

Part II.

Pre-lab discussion:



10. Suppose that you place two 6V batteries in parallel, and then connect a 4 Ω bulb to it.

a) What do you think is the voltage across the bulb?

b) How much current so you think will go through the bulb?

c) How much current do you think each battery will provide?

Directions:

11. Connect the circuit shown (your bulb's resistance and batteries' voltages may be different from the previous step). Make sure that both batteries have the same voltage rating.
After the circuit is connected, measure the voltage across each battery, the voltage across the bulb, the current through the bulb, and the current in each branch of the battery.

12. Revisit your answers to the questions in the pre-lab discussion of part II, and explain what happens in this circuit.

Resistance of a Parallel Circuit Lab

Materials:

- Pre-lab discussion Two-bulb circuit on plastic canvas from previous activity
- Four carbon resistors
- Two alligator clip wires
- A multimeter

Purpose:

What is the resistance of a parallel circuit?

Pre-lab discussion:

1. Review how resistance is measured – particularly, that the battery should NOT be connected to the circuit when measuring resistance!

2. How do you think the resistance of this circuit will compare to that of the one-bulb circuit? Explain your reasoning.

Directions:

1. Measure the resistance of each bulb individually first, and note the values in the table below. Then connect the *same* bulbs in parallel and measure the resistance of the two-bulb "tree." Enter your values in a table:

Bulb A	Bulb B	Bulb A and B in parallel

1. Discussion Questions:

a) How does the resistance of the two-bulb parallel circuit compare with the resistance of the one-bulb circuit?

b) How does this resistance compare with the resistance of the two-bulb series circuit?

c) If you added more bulbs to the parallel circuit, how do you think the resistance of the circuit would change?

d) What do you think makes the resistance of the parallel circuit different from that of the series circuit?

2. Return to *Student Summary Page* - Comparing Series and Parallel Circuits and add your observations to the list.

Name That Circuit - Application Lab

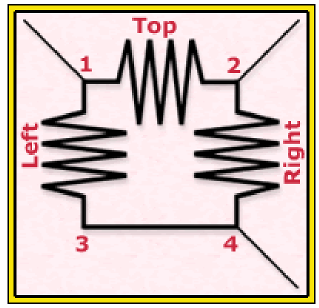
Purpose:

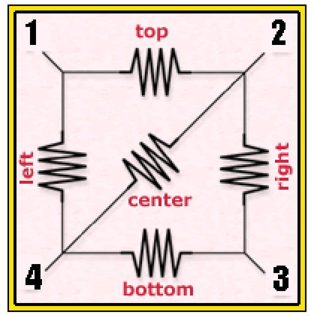
How do mixed series/parallel circuits behave?

Pre-lab discussion:

1. Connect the circuits shown in the pictures. Circuits 1-3 use a 3-bulb circuit connected to the battery in different ways. Circuits 4-6 use a 5-bulb circuit (also called the Wheatstone Bridge). Identify the points where the wires connect, with numbers (1 through 4, see picture), and to identify the bulbs with names (top, bottom, left, right and center).

2. The table below shows different ways in which the circuits have been connected to a battery. Make predictions about bulb brightness first, and explain your reasoning. (Think about the voltage difference across each bulb, or the path of the current.)



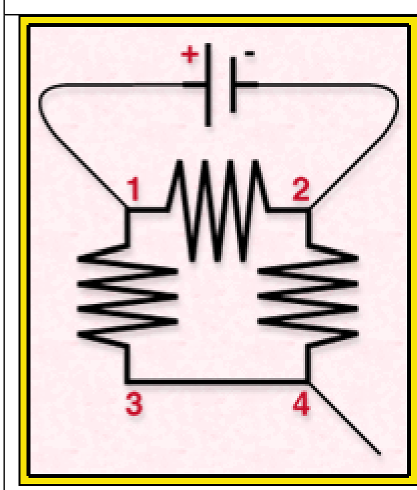


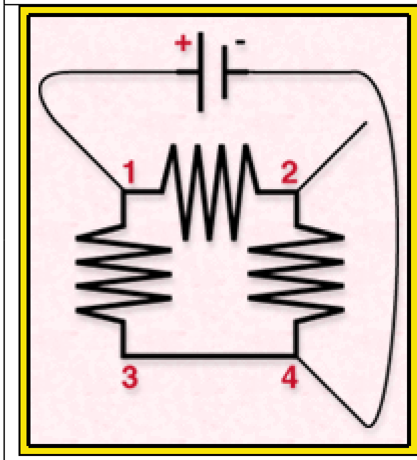
Materials:

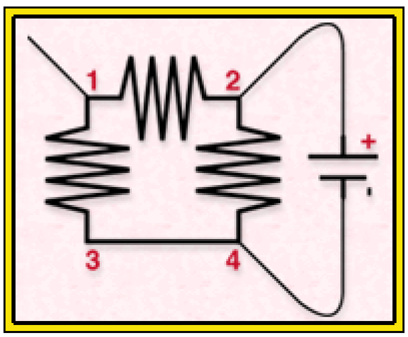
- Five Christmas light bulbs with wires: strip insulation off the ends
- A plastic canvas from previous activity
- A 6 V lantern battery
- Two wires with alligator clips
- A voltmeter or multimeter
- small stickers

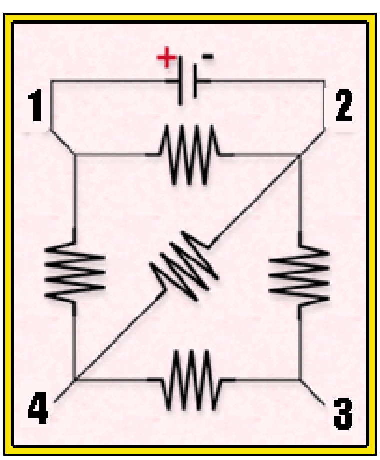
Directions:

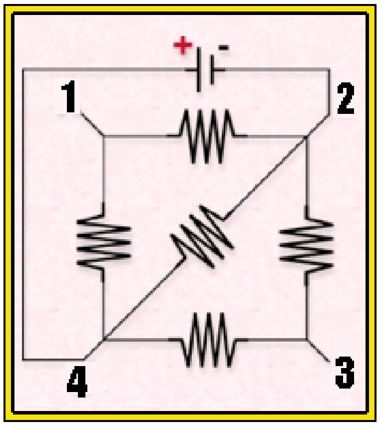
3. After you have made *all* your predictions, connect the circuits, make your observations, and explain them. All resistors in the lab have the same resistance.

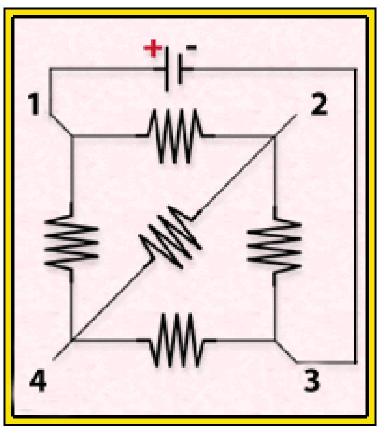
Circuit 1	Predict bulb brightness	Observations
		
	Reason:	Reason:

Circuit 2	Predict bulb brightness	Observations
		
	Reason:	Reason:

Circuit 3	Predict bulb brightness	Observations
		
	Reason:	Reason:

Circuit 4	Predict bulb brightness	Observations
		
	Reason:	Reason:

Circuit 5	Predict bulb brightness	Observations
		
	Reason:	Reason:

Circuit 6	Predict bulb brightness	Observations
		
	Reason:	Reason:

4. Write three things you learned from this activity.

Electrical Power Lab

Materials:
- Plastic canvas with one-bulb circuit and two-bulb series circuits
- Two multimeters
- 6 V lantern battery
- Six alligator clip leads
- A short extension cord
- An outlet strip
- A “Kill-A-Watt”
- A variety of 110V electrical appliances – e.g., a radio, power drill, fan, hair dryer – preferably appliances where the level/ speed can be changed.
- Two or three light bulbs of different wattage

Purpose:

How is electrical power related to current, voltage and resistance?

Pre-lab discussion:

1. Examine labels on four electrical appliances at home and list the wattage of each appliance. Caution - some labels may be in hard-to-reach places. Alternatively, you can check the manuals of appliances to figure out the wattage.

2. Examine the light bulbs. What do you think the “watts” printed on a light bulb means?

3. Here are a few ideas to help figure out what “watts” might depend on:

a) A can opener uses 100 watts. A popcorn popper uses 600 watts. Both are plugged into a 110 V household line. What electrical factor do you think causes the wattage to be different? Explain your reasoning.

b) Some appliances run off batteries. A computer laptop draws 4 amps off a 16 V battery. A microwave draws 4 amps off a 110 V line. Do you think your wattages are different? Explain your reasoning.

c) Using ideas generated from (a) and (b), what factors do you think affect “wattage” or “electrical power”?

d) Based on the above answers, how do you think electrical power might be defined?

Directions:

4. If you compare the wattage of one bulb in a two-bulb series circuit and in a one-bulb circuit, how do you think they might compare? (Both circuits are connected to a battery of the same voltage, and all bulbs have the same resistance). Explain your reasoning.

5. Using the Phet simulation, design a circuit using one bulb, a battery, and two multimeters so that you can measure the voltage difference across the bulb *and* the current through it. Measure the current and the voltage and calculate the power in the one-bulb circuit. Enter the values in "one-bulb" column of the table below.

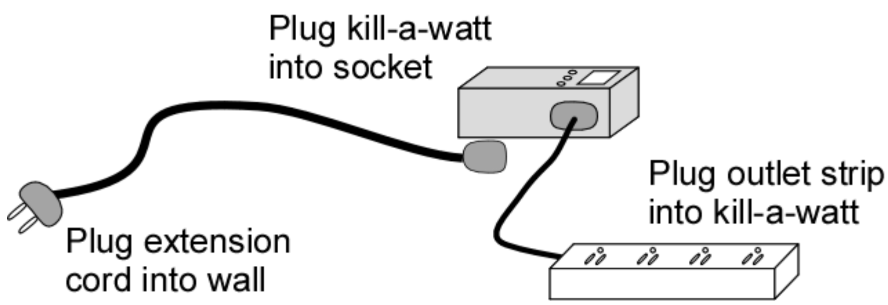
Make similar measurements and calculate the power expended by *one of the bulbs* in the two-bulb series circuit. Enter the values in the "two-bulb series" column.

Circuits:	**One-bulb**	**Two-bulb series**
Voltage across one bulb		
Current through one bulb		
Power used by one bulb (P=IV)		
Brightness of bulb		

6. What can you conclude from your measurements about power in the two circuits?

7. How does the brightness of the bulbs relate to the power consumed?

8. A device called a kill-a-watt allows you to measure the current, voltage and power consumed by devices attached to it. Set up the kill-a-watt device as shown in the diagram below. Attach appliances to the power strip individually, or together. Tabulate the volts, amps and watts (V x A) for each of the appliances in several settings (low, high, etc) Make a table similar to the sample table below.



Appliance	Voltage	Current	Power (V•A) (from kill-a-watt)	Calculated Power

9. What do you think happens to the electrical energy when it goes through the device?

a) Does it remain as electrical energy?

b) Does ALL the electrical energy get used to make the device do whatever it is supposed to do? Is there any "wastage?" If so, in what way is it "wasted"?

c) Use the internet or books/papers to conduct research on the light energy produced by an incandescent bulb, a compact fluorescent bulb and an LED bulb. If you choose bulbs that produce about the same amount of light (measured in units of lumens) how do their electrical energies compare? Provide numbers to prove your point.

d) Brainstorm your results with your group and figure out a practical application of your information - one you could implement in your school or home. What arguments could you use to convince your teachers or parents that your application is worthwhile?

10. Summarize your observations. Discuss what power is, and how it is related to energy (details on Reading Page).

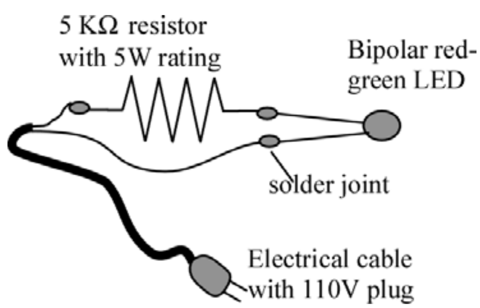
11. Connections: What is the relationship between what you learned in this lab and the brightness of the bulbs you observed in the one-bulb, two-bulb series and two-bulb parallel circuits?

Electrical Widgets Application Lab

Materials:
- Station 1. Energy Ball
- Station 2: Swinging LED circuit
- Station 3: Water battery
- Station 4: Human Battery

Purpose:
After learning about current, voltage and Ohm's Law, figure out how these widgets work.

Directions:
Visit each station, describe what happens and what you think is the design of that station, based on the knowledge you have from this unit. Make observations and explanations, and compare them to your earlier notebook entries.

Station (Draw a diagram if needed)	How the widget works
1. Energy Ball:	
2. Swinging LED 	
3. Water Battery	
4. Human Battery:	