



Title:	Notebook Circuits With Metering
Original:	22 February 2007
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Authors:	Jim Overhiser, Monica Plisch, and Julie Nucci
Appropriate Level:	Regents Physics
Abstract:	Students are introduced to concepts of electrical energy and electrical current using a paper model. They construct simple circuits using inexpensive household items and explore their behavior. Next they extensively meter series and parallel circuits, calculate equivalent resistances, and extract laws for series and parallel circuits from their data. A series of questions leads students to consider energy transformations that occur in the electrical circuits they constructed.
Time Required:	Two to three 40-minute periods
NY Standards Met:	<p>4.1j Power is the time-rate at which work is done or energy is expended.</p> <p>4.1n A circuit is a closed path in which a current can exist.</p> <p>4.1p Electrical power and energy can be determined for electric circuits.</p> <p>4.1o Circuit components may be connected in series or in parallel. Schematic diagrams are used to represent circuits and circuit elements.</p>
Special Notes:	Created by the CNS Institute for Physics Teachers via the Nanoscale Science and Engineering Initiative under NSF Award # EEC-0117770, 0646547 and the NYS Office of Science, Technology & Academic Research under NYSTAR Contract # C020071

Xraise Outreach for CLASSE

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Behavioral Objectives:

Upon completion of this lab a student should be able to:

- To introduce concepts of electrical energy and electrical current
- To learn about the transformation of electrical energy in a circuit
- To learn that a complete circuit is required for current to flow
- To construct simple series and parallel circuits
- To gain familiarity with circuit diagrams

Class Time Required: Two to three 40-minute periods

Teacher Preparation Time: 5-10 minutes to set out supplies

Materials Needed:

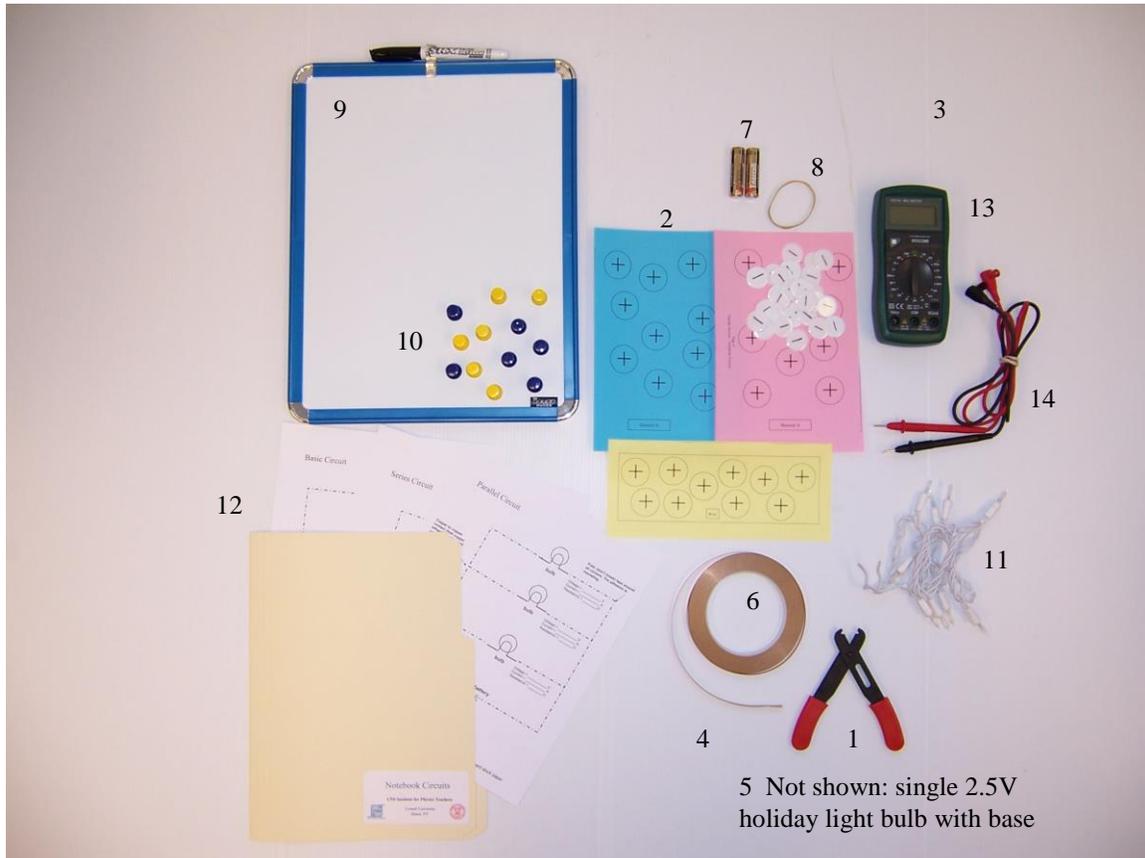
- *Material cards* (2) – photocopied from original in Teacher Section
- Electron circles (30 minimum) – 1” plastic disks marked with a negative sign (-)
- *Electrical Current Student Sheet* – photocopied from original in Teacher Section
- Hand magnifier
- 2.5V holiday light bulbs with bases
- Wire stripper
- Manila folder
- Copper foil tape
- AA batteries (2)
- Elastic band
- Magnetic board
- Neodymium push pin magnets
- Multimeter
- Probes for multimeter

Teacher Notes:

Meter settings:

- *Voltmeter:* black in COM, red in VΩmA, meter setting 20 DCV
- *Ammeter:* black in COM, red in VΩmA, meter set at 200 mA (**exception: use the high current configuration to measure the total current in parallel – 10ADC port and 10A dial setting**)
- *If you get a reading of 0, make sure you have the digital multimeter set appropriately. If your circuit still doesn't work, then look for the problematic contacts that are causing the open circuit.*

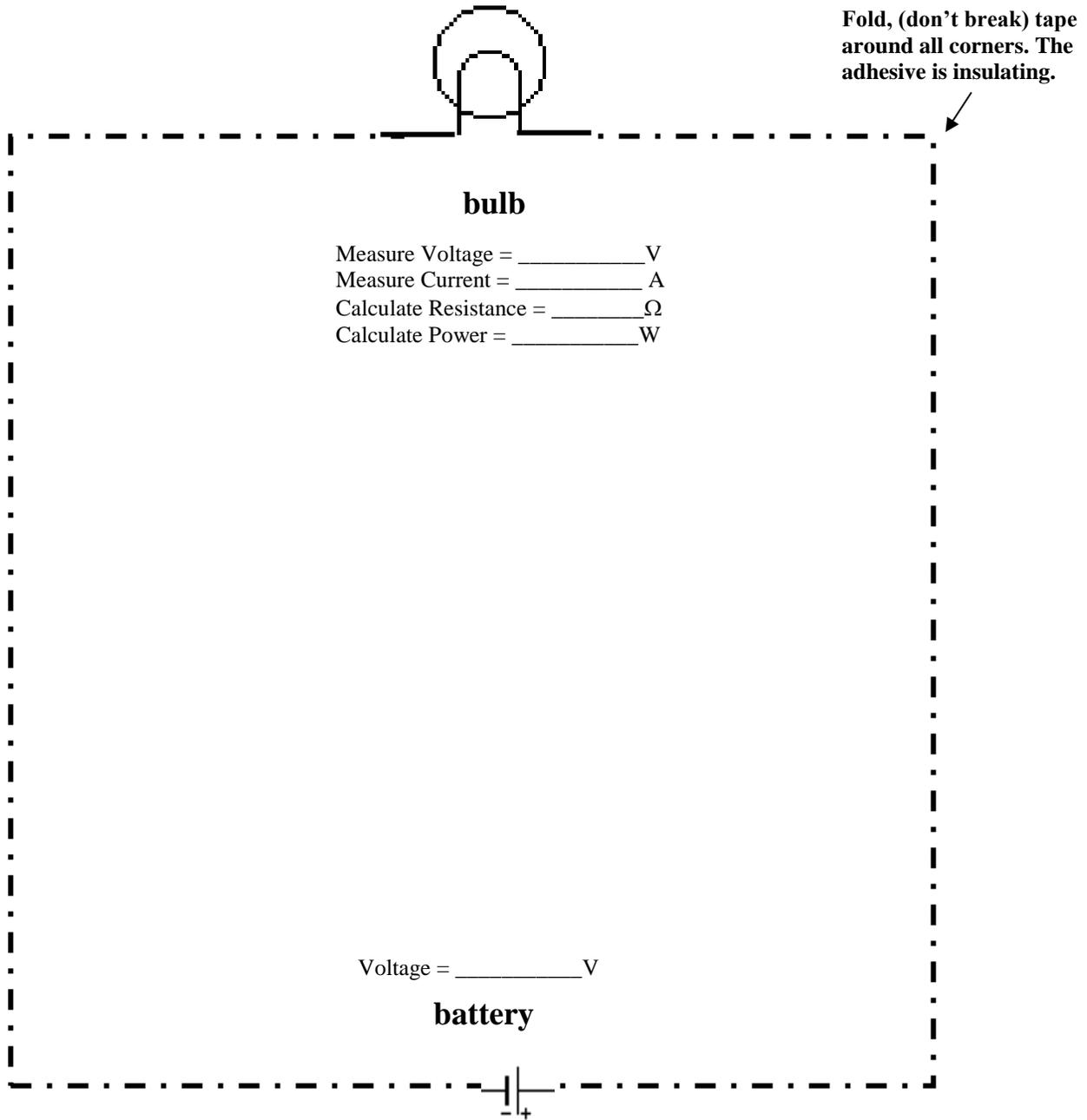
Equipment



Item Number	Quantity	Item
One set per individual for Activities 1, 2, and 3		
1	1	Wire stripper
2	1 set	Material cards
3	30	Plastic disks with negative signs
4	1	Hand magnifier
5	1	2.5V holiday light bulb with base (not shown)
One set per 2 - 3 students for Activities 4, 5, 6, and 7		
1	1	Wire stripper
6	1	Copper foil with self-stick backing
7	2	AA batteries
8	1	Elastic band
9	1	Magnetic board
10	12	Neodymium push pin magnets
11	1	10 linked 2.5V holiday light bulbs with bases
12	1 set	Manila folder with circuits on card stock
13	1	Multimeter
14	1 set	Probes for multimeter

The following three circuit pages should be printed onto card stock. The Material Cards and Wires should be printed on differing colors of paper.

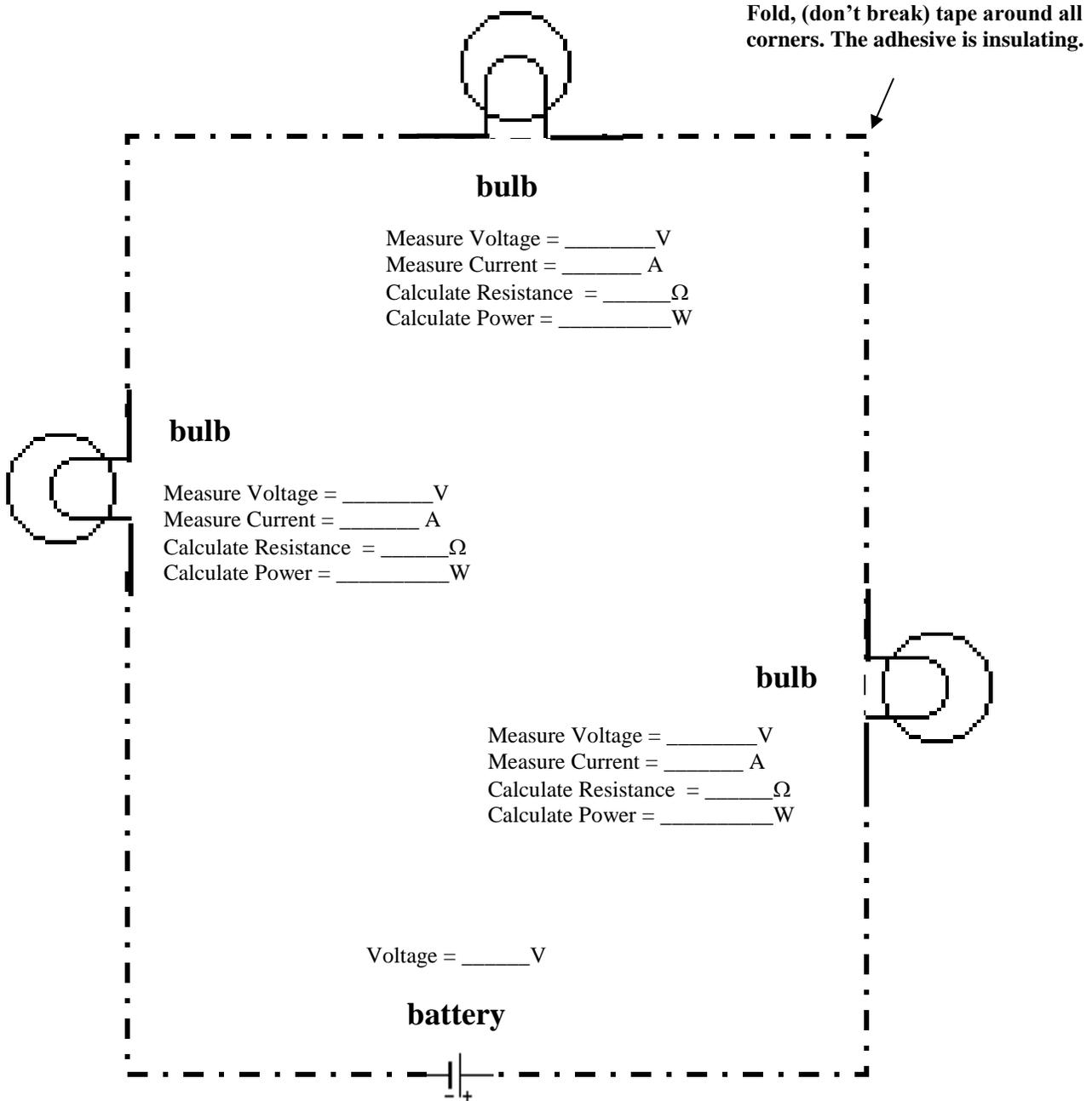
Basic Circuit



Place copper tape on the dashed line only!



Series Circuit



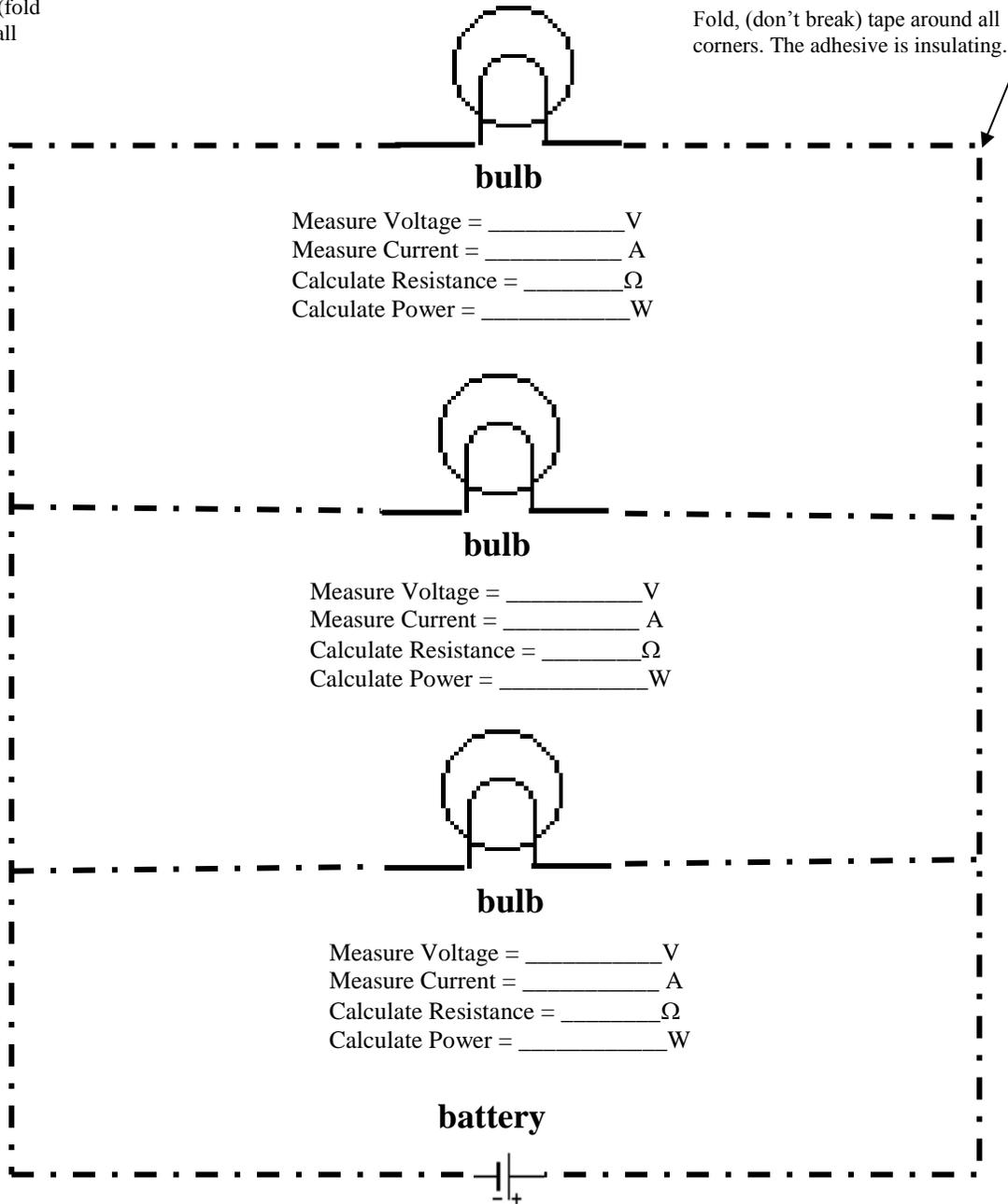
Place copper tape on the dashed line only!



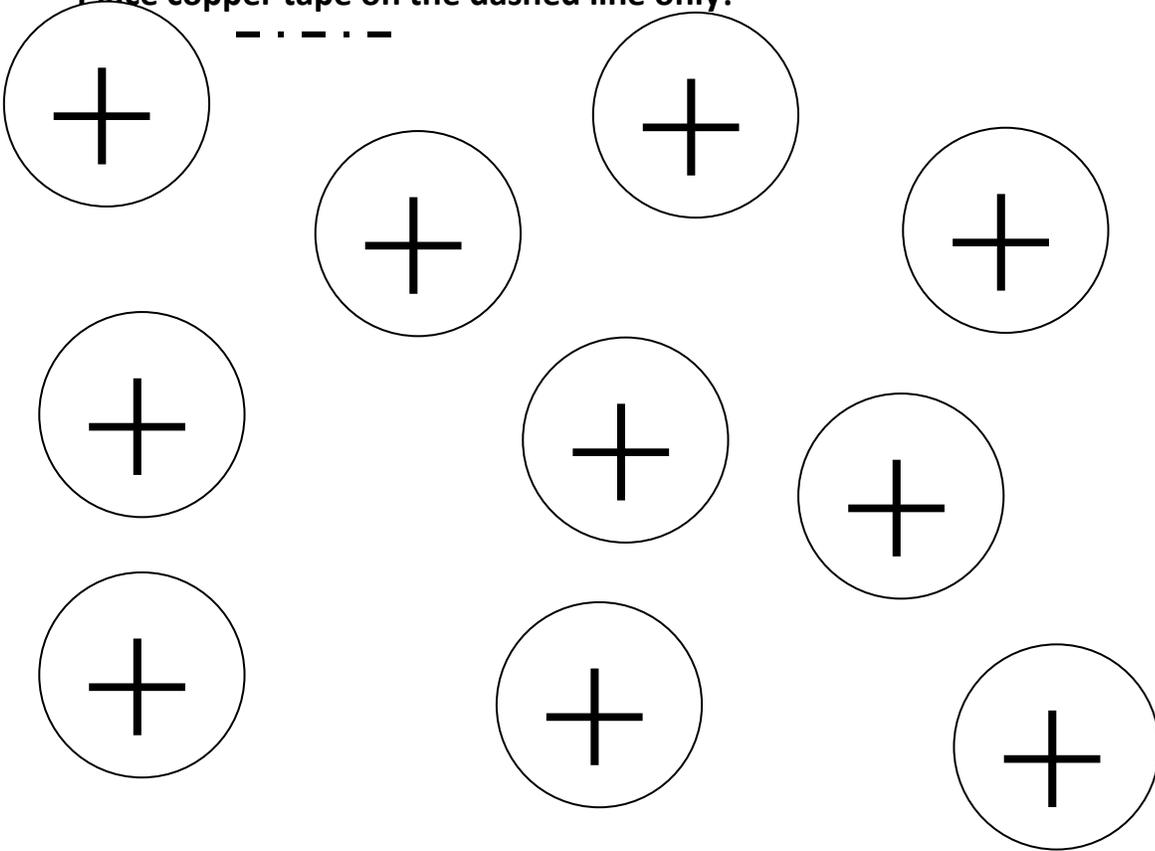
Parallel Circuit

Copper to copper contact (fold copper adhesive under at all connection points)

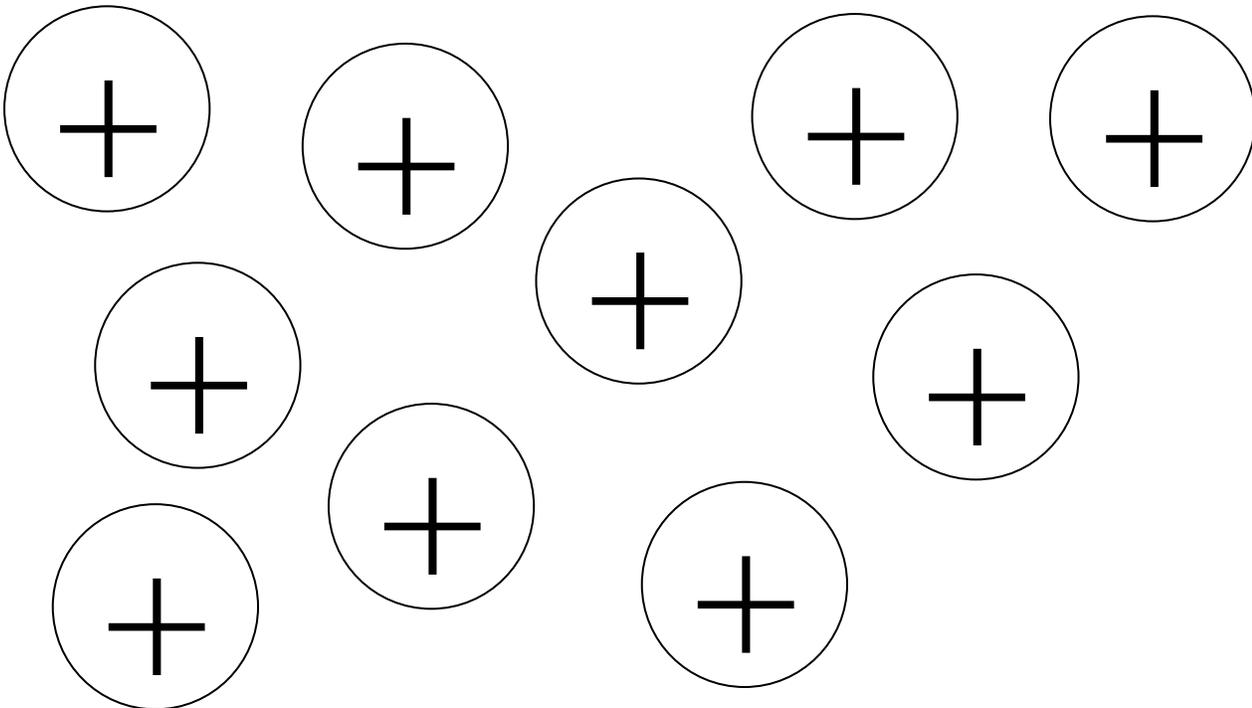
Fold, (don't break) tape around all corners. The adhesive is insulating.



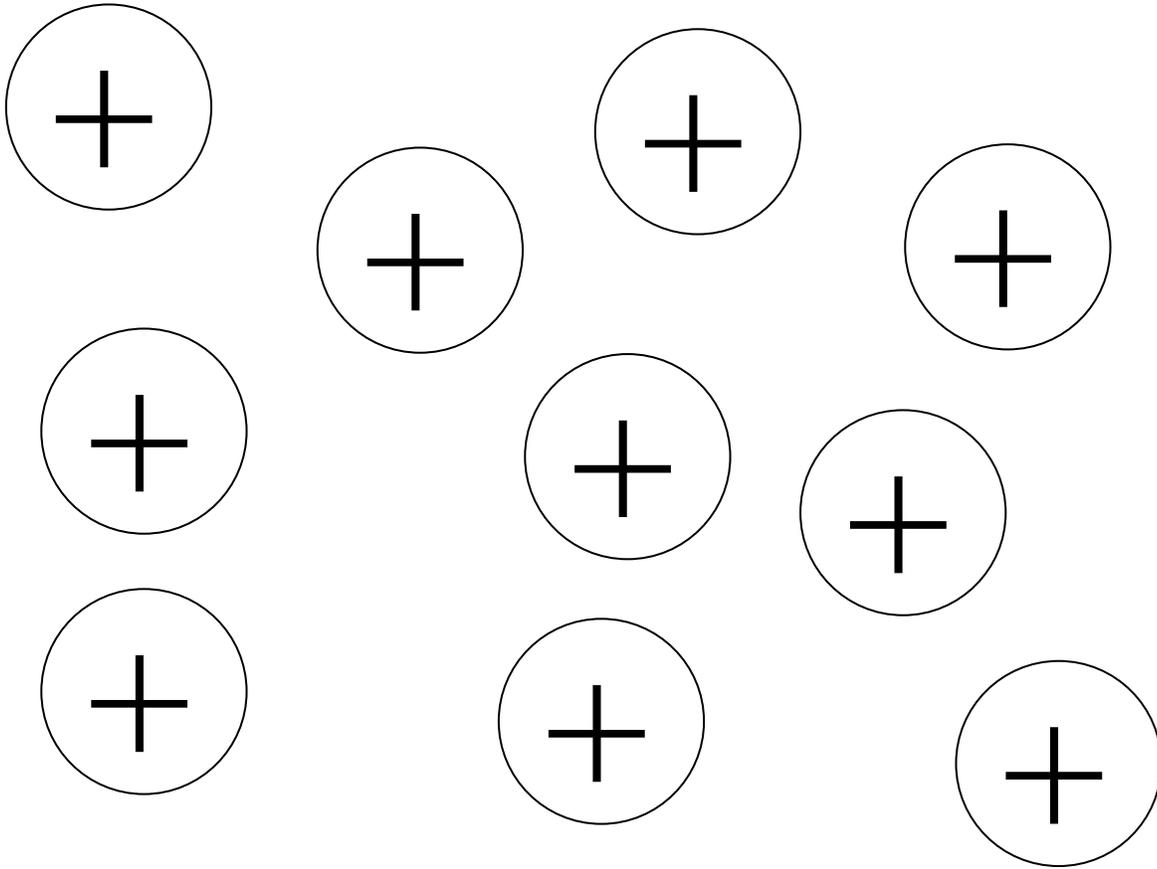
Place copper tape on the dashed line only!



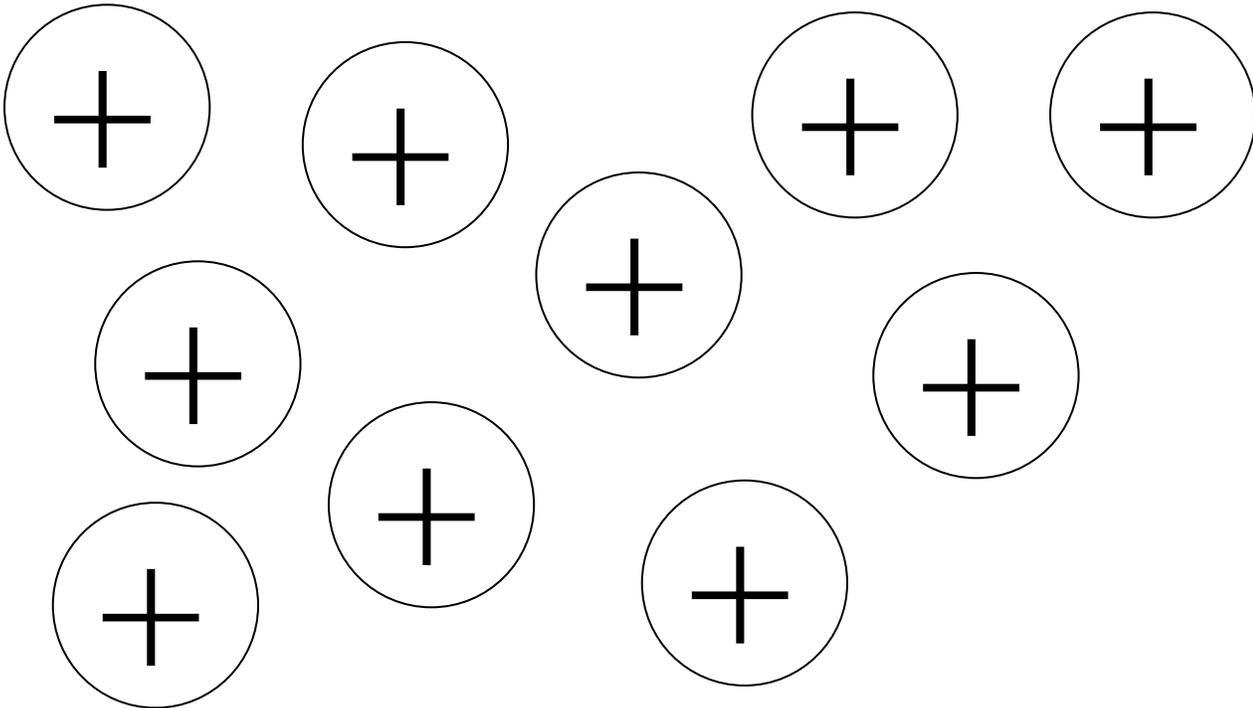
Material A



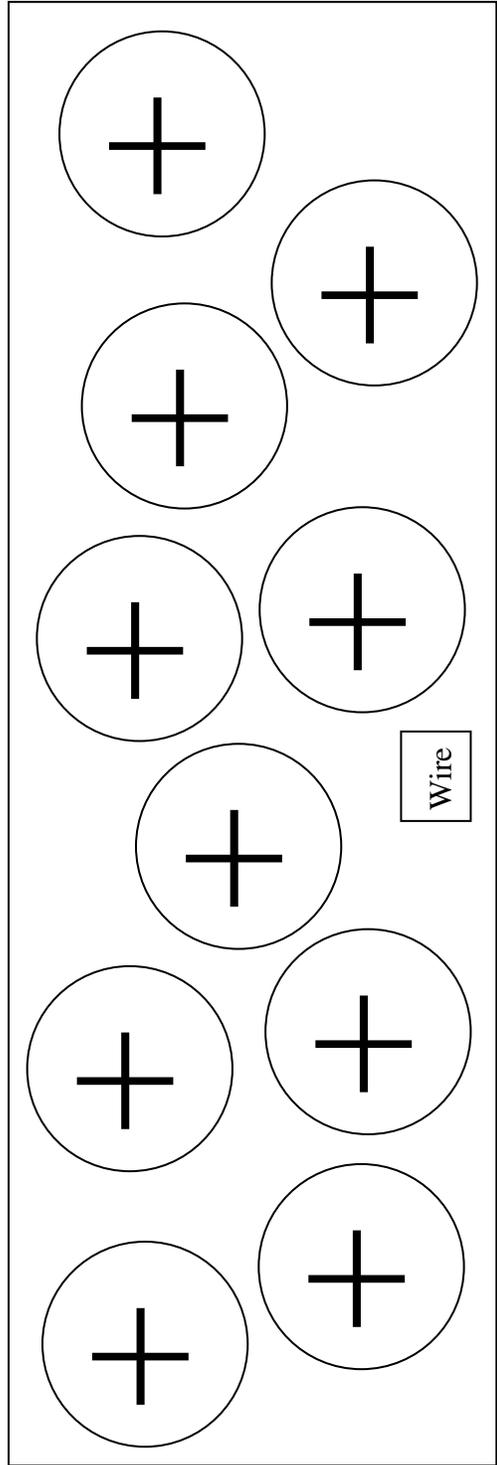
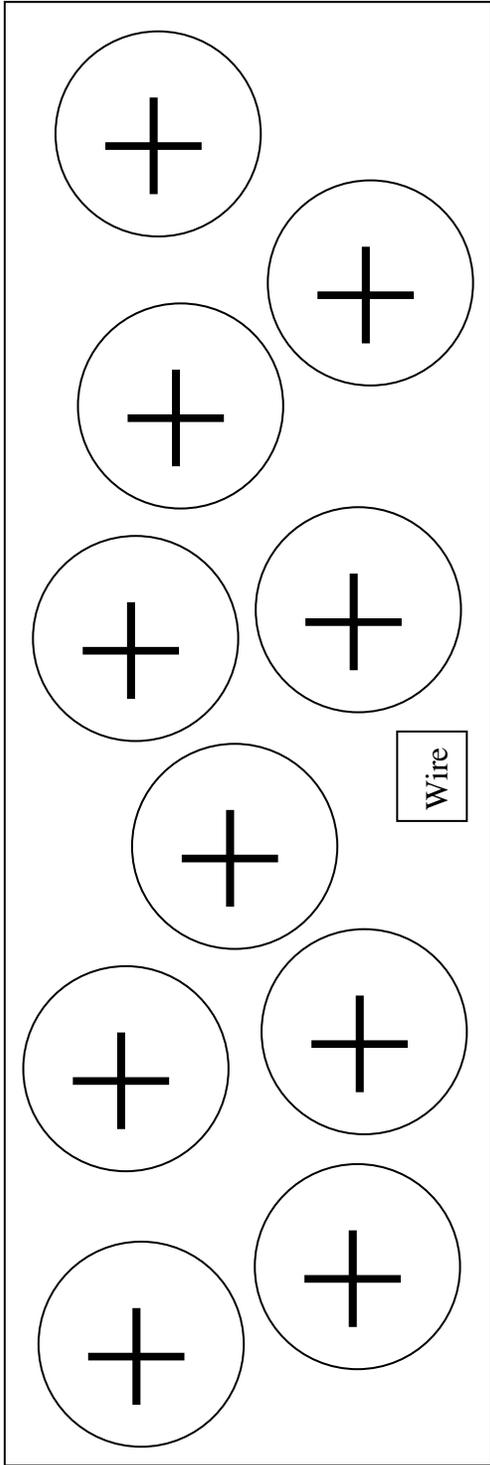
Material A



Material B



Material B



NOTEBOOK CIRCUITS WITH METERING

Individual Activities

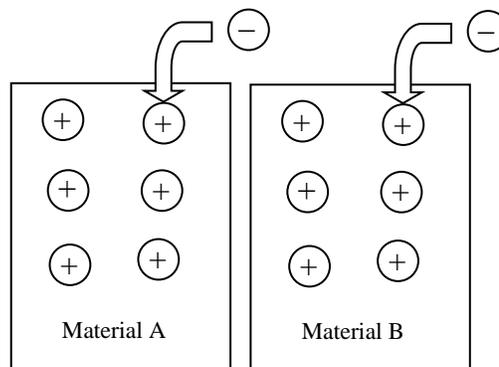
Activity 1: Electron checkers

Materials:

- Material cards A and B – photocopied from Teacher Section
- Electron circles (20) – plastic disks marked with a negative sign (“-”).

Directions:

1. Cover each “+” circle with a “-” circle on “Material A” and “Material B.”
2. Remove one of the “-” circles from Material A and place it on Material B.
3. Repeat step 2.
4. *Answer the related questions on the Student Data Sheet.*



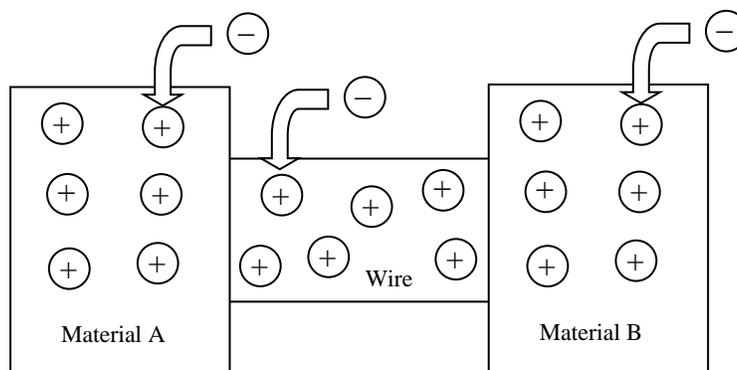
Activity 2: Electrical current

Materials:

- Material cards A and B – photocopied from Teacher Section
- Wire card – photocopied from Teacher Section
- Electron circles (30) – plastic disks marked with a negative sign (“-”).

Directions:

1. On a “Wire” card cover each positive ion (“+” circle) with an electron (“-” circle).
2. Place Material A so it touches one end of the Wire and Material B so it touches the other end. Make sure each positive ion is covered with an electron.
3. Remove two electrons from Material A and place them on Material B.
4. The electrons in the wire will be attracted to the excess positive charges in Material A (and repelled by the excess negative charges in Material B). Slide an electron from the end of the wire touching Material A to cover a nearby positive ion on Material A.
5. Move electrons one at a time by sliding them to cover nearby positive ions until there are no more excess charges and every positive ion has an electron.

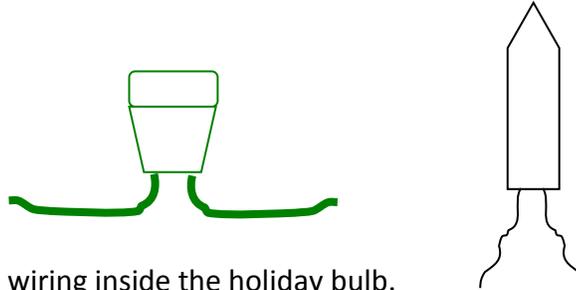


6. Answer the related questions on the Student Data Sheet.

Activity 3: What's inside a bulb?

Materials:

- Hand magnifier
- 2.5 V holiday light bulb w/base



Directions:

1. Use the hand magnifier to view the wiring inside the holiday bulb.
2. Use the hand magnifier to view the wiring inside the holiday bulb base.
3. Answer related questions on the student data sheet.

To be done in groups of 2 -3

Activity 4: Basic circuit

Making the battery

Materials:

- Copper foil tape
- AA batteries (2)
- Rubber band
- Neodymium push pin magnets (2)

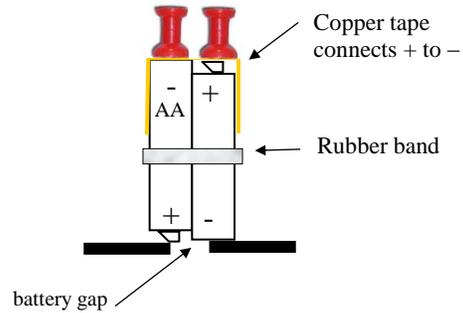


Figure A: 3 V Battery pack

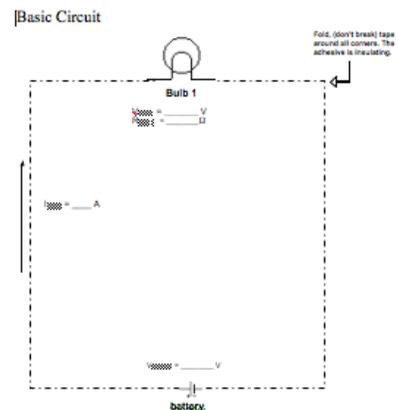
Directions:

1. Join the two AA batteries together with a rubber band. Orient the batteries as shown in Figure A.
2. To make a copper tape switch for your battery:
 - Cut a 10 cm piece of Cu tape.
 - Remove the paper backing.
 - Fold 4 cm of the tape over onto itself so that you have only 2 cm left with the sticky back.
 - Attach the sticky end to the side of the battery as shown in Figure A.
 - Make sure the switch is long enough to cover both battery terminals.
 - Use two neodymium magnets to keep your battery switch closed as shown in Figure A.

Making the basic circuit:

Materials

- Copper foil tape
- Basic circuit template on card stock
- 2.5V holiday light bulb (1)
- Magnetic white board



Place copper tape on the dashed line only!

- Neodymium push pin magnets (2)

1. Cover the dashed lines of your circuit template with copper tape.
 - **You must fold the tape around the corners to form your circuit. The sticky backing of the tape is an insulator. If you cut the copper tape and tape one piece on top of another you will have an open circuit.**
2. Place your circuit template on your white board.
3. Use two neodymium push pin magnets to attach the light bulb to the circuit.
4. Position the two sides of the battery pack on each end of the battery gap (Figure A).
5. *Answer the related questions on the student data sheet.*

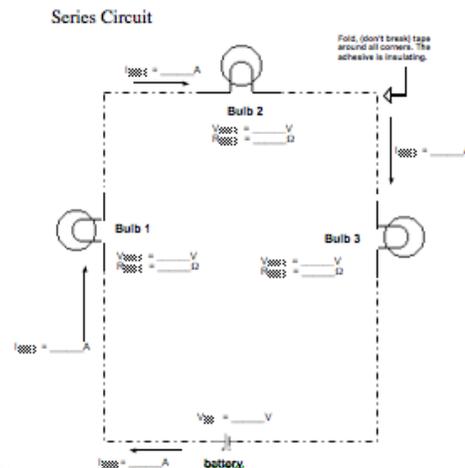
Activity 5: Series Circuits

Materials:

- Copper foil tape
- Series circuit template on card stock
- 2.5 V holiday light bulbs (3)
- 3.0 V battery pack (Figure A)
- Magnetic whiteboard
- Neodymium push pin magnets (6)

Directions:

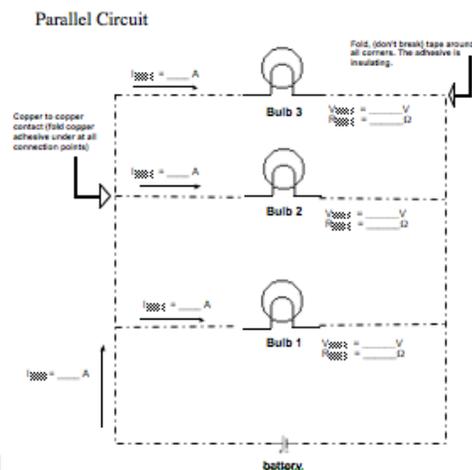
1. Construct the series circuit on the series circuit template.
2. Connect **only one** of the two bare wires on each of three holiday bulbs with the neodymium magnets.
3. Position the 3 V battery pack across the battery gap.
4. Now connect the other wires one at a time and observe the behavior of the holiday bulbs.
5. *Answer the related questions on the student data sheet.*



Activity 6: Parallel Circuits

Materials:

- Copper foil tape
- Parallel circuit template on card stock
- 2.5V holiday light bulbs (3)
- 3V battery pack (Figure A)
- Magnetic whiteboard
- Neodymium push pin magnets (10)



Directions:

1. Construct the parallel circuit on the parallel circuit template.
2. Place neodymium magnets where the copper connecting bulbs 2 and 3 intersects the basic circuit.
3. Attach **only one** of the two bare wires on each of three holiday bulbs with the neodymium magnets.
4. With the battery in position, connect the other wires one at a time and observe the behavior of the holiday bulbs.
5. Answer the related questions on the student data sheet.

Activity 7: Metering Notebook Circuits

Materials:

- Notebook circuits on card stock already constructed
- 3V battery pack (Figure A)
- Digital multimeter
- Magnetic whiteboard
- Neodymium push pin magnets (10)

Procedure:

Important information you need to meter your notebook circuits is listed below:

Measuring the current at the light bulbs and the total circuit current

- To measure current, connect the meter in series, as shown on the next page in Figure 1a.
- To measure the **current that goes through a light bulb**, probe the circuit as shown in Figure 1b. Use the $V\Omega mA$ setting. Disconnect one wire from the notebook circuit and connect it to one probe. Connect the other probe to the copper tape. *If you don't have good electrical contact, you will not get good data. If you notice that the bulb you are measuring is dimmer than the other bulbs, then redo the contacts to maximize its brightness.*
- To measure the **total current at the battery**, probe the circuit as shown in Figure 1c. *Make sure to push the battery down onto the probe to ensure good contact. You must use the 10A setting on the multimeter to measure the total circuit current for the parallel circuit. If you use the $V\Omega mA$ setting you will blow the fuse in the multimeter.*

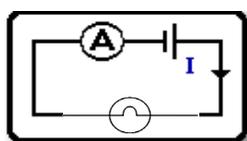


Figure 1a

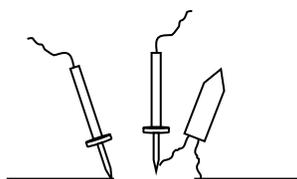


Figure 1b
Page 12

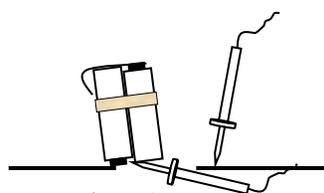


Figure 1c

Measuring the voltage across the light bulbs and the battery

- To measure voltage, connect the meter in parallel, as shown in the circuit diagram in Figure 2a. Connect one probe to each side of the lighted bulb or battery as shown in Figures 2b and 2c.

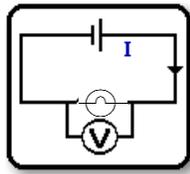


Figure 2a

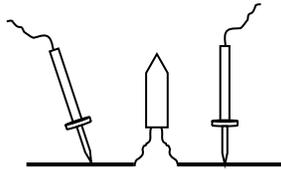


Figure 2b

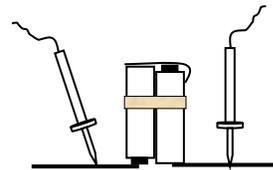


Figure 2c

Gathering data from your basic, series, and parallel circuits

- Units: Voltage: in Volts, V
Resistance: in Ohms, Ω
Current: your meter will read mA in the low current setting and Amps in the high current setting
- *First measure the battery voltage and then the voltage across the light bulbs.*
- For each circuit, measure the voltages and currents at locations shown on the diagrams and *record the values on the circuit templates.*
- Calculate the resistances listed above using Ohm's Law and add the data to the schematics.
- Calculate the power consumed by each light bulb and add the data to the schematics.

Equivalent Resistance

The **equivalent resistance**, $R_{\text{equivalent}}$ or R_{eq} , for a circuit is the single resistance which, if substituted for an arrangement of multiple resistors (or light bulbs), will leave the current unchanged. The equations for the equivalent resistance of a series and parallel circuit are:

$$\text{Series circuit equivalent resistance: } R_{eq} = R_1 + R_2 + R_3$$

Parallel circuit equivalent resistance: $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Power

The power consumed by the circuit can be calculated in various ways. Here are two common equations for the circuit power, P:

Equation 1: $P = VI$

Equation 2: $P = I^2R$

$P \text{ (Watts)} = V \text{ (volts)} * I \text{ (amps)}$

NOTEBOOK CIRCUITS WITH METERING STUDENT DATA SHEETS

Name _____

Activity 1: Electron Checkers

1. Complete the following chart.

Electrons moved from A to B	Charges on Material A		Charges on Material B		Net charge on Material A	Net charge on Material B
	+	-	+	-		
None moved	10+	10-	10+	10-		
One electron						
Two electrons						

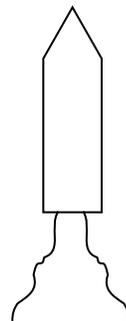
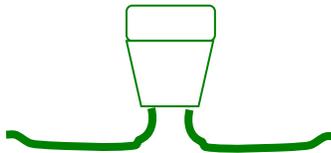
2. If you move a third electron from Material A to Material B, will that electron be repelled or attracted to Material B? What about Material A?
3. Considering your answer to the previous question, do you think it takes energy to move electrons from Material A to Material B? Explain.
4. Referring to the chart in question 1, which configuration of charges takes the most energy to create, starting from neutral materials?
5. Is there a type of energy that exists based on the locations of charges relative to each other? What is this type of energy called?
6. When a battery is labeled with a "+" and a "-" symbol, what do you think that means?
7. A chemical reaction occurs inside of a battery to move electrons from the positive "+" terminal to the negative "-" terminal. Therefore, what type of energy is used to make electrical energy inside of a battery?

Activity 2: Electrical current

1. A conducting material contains both positive ions and electrons—which of these particles can move?
2. Electrical current is created by moving electrons. How could you increase an electrical current?
3. When you moved two electrons from Material A to Material B, what effect did this have on the Wire?
4. When the “+” and “-” terminals of a battery are connected to each other by a conducting pathway, why does a current flow?
5. If the conducting pathway between the “+” and “-” terminals of a battery breaks, does a current still flow? Explain why.
6. Which way do electrons move through a wire connected to a battery, from “+” to “-” or from “-” to “+?”
7. (challenge) If you observed carefully, as you moved the electrons one by one along the Wire, the position of the bare positive ion also moved. Did the positive charge move from “+” to “-” or from “-” to “+?”

Activity 3: What’s inside a bulb?

1. On the illustration to the right, draw in the parts of the twinkle light that you observed using the magnifier.
2. Using your magnifier, look inside the bulb base. On the illustration of this base below, draw and label what you see in the socket.



3. When the bulb is plugged into the socket, is there a conducting pathway for current to get from one wire of the socket to the other?

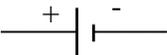
4. If you touch the two wires of the bulb to the “+” to “-” terminals of a battery, the bulb will light up. If the bulb “goes out” but the wires are still connected to the battery, what do you think happened to make it go out?

Activity 4: Basic circuit

1. Using the following symbols, draw a circuit diagram of the basic circuit you constructed in the space below.

Wire 

Bulb 

Battery 

2. On your diagram question 1, draw arrows showing the path the electrons take in the circuit.
3. Energy can be neither created nor destroyed; it can only be transformed from one form to another. Describe all of the energy transformations that occur when you light a bulb with a battery.
4. You hook up a battery to a bulb and it does not light up. In the space below, list at least three different things that may have caused this failure.

Activity 5: Series Circuits

1. Using the appropriate symbols, draw a diagram of the series circuit you constructed in the space below.

2. Use arrows to show the path of the electrons on the diagram you drew.

3. Complete the following chart based on your experience with your series circuit.

# of bulbs connected	Result
1	
2	
3	

4. Why do you think you got these results?

Activity 6: Parallel Circuits

1. Using the appropriate symbols, draw a diagram of the parallel circuit you constructed in the space below.

2. Use arrows to show the path of the electrons on the diagram you drew.
3. Complete the following chart based on your experience with your parallel circuit.

# of bulbs connected	Result
1	
2	
3	

4. When the three bulbs were in series all three had to be connected in order for them to light, but this was not the case for the bulbs in parallel. Why?
5. If you were given three 2.5-V lamps (resistors), a battery and wire, illustrate below four (4) different ways to connect them.

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Activity 7: Metering Notebook Circuits

1. Why is it important to measure the battery voltage at the start of each circuit analysis?

2. The three bulbs in series were dim, but the three bulbs in parallel were bright. Using the results of your measurements, explain why this is the case.

3. The “voltage” of a battery is a measure of how much electrical energy is given to each electron. What do you think would happen if you hooked up a 9V battery to a bulb instead of the 3V battery pack that you used in the lab?

4. Extract the laws of series and parallel circuits from the data on your series and parallel circuit templates.
 - a. Write a general current equation for the series circuit in terms of the total current and the current through each lamp. Describe in words what this equation means.

 - b. Write a current equation for the parallel circuit in terms of the total current and the current through each lamp. Describe in words what this equation means.

 - c. Write a voltage equation for a series circuit in terms of the battery voltage and the voltage across each lamp. Describe in words what this equation means.

- d. Write a voltage equation for a parallel circuit in terms of the battery voltage and the voltage across each lamp. Describe in words what this equation means.
5. Equivalent Resistance questions:
- a. Calculate the equivalent resistance of your series and parallel circuits from your calculated resistances and enter the value on your circuit schematic. Show your work.

 - b. Now use the total current value and the equivalent resistance for the series circuit to calculate the circuit voltage. Do this for the parallel circuit as well. Do you get a number higher or lower than the battery voltage? Suggest explanations for the deviation in the expected value.

 - c. If you have a circuit with too large a resistance, what can you do to lower it?
6. What are sources of error in these measurements?
7. Power questions:
- a. Use Ohm's law to derive the equation 2 from equation 1 on page 6. Show your work.

 - b. Calculate the total power consumed by the light bulbs for each circuit. Show your work. Express your answers in Watts.

- c. What observation that you made can support the difference in power consumption calculated for the series and parallel circuits?
- d. Which circuit will drain the battery the fastest and why?

Notebook Circuits Challenge:

Create the notebook circuits that have the specification listed below using the same materials used in this activity.

- A circuit with two bulbs having a 3.0 volts drop across each and two bulbs with a 1.5 voltage drop across each.
- Draw the circuit diagram in the space below
- Construct the circuit
- Use the multimeter to test your results

Notebook Circuits with Metering (Supplement)

Making a compound circuit cards set-up:

Materials:

- Manila folder
- Manila folder cut into 5 cm x 17 cm cards (several)
- Copper foil tape
- 3 VDC battery pack
- Cellophane tape
- 2.5 V holiday light bulbs (several)
- Multimeter
- Magnetic white board
- Neodymium push pin magnets

Directions:

- Construct the *base circuit* shown in Figure 4.
- Construct several 5-cm x 17-cm circuit cards as shown in Figure 5. (*Make certain that the sticky surface on the copper tape that is hanging off the card is folded back on itself. This will make sure a good contact is made between the base circuit and the circuit card.*)
- Use the cards to construct several compound circuits on the base circuit page. See example in Figure 6. (*Note: If the Base circuit is made on the inside of the manila folder, you can use the same folder to store the cards and have a set.*)
- Place the neodymium magnets at the intersection of the base circuit and overhanging Cu tape from the circuit cards to ensure good electrical contact.

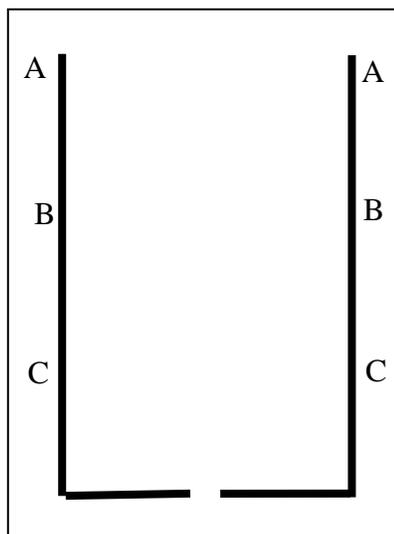


Figure 4: Base circuit

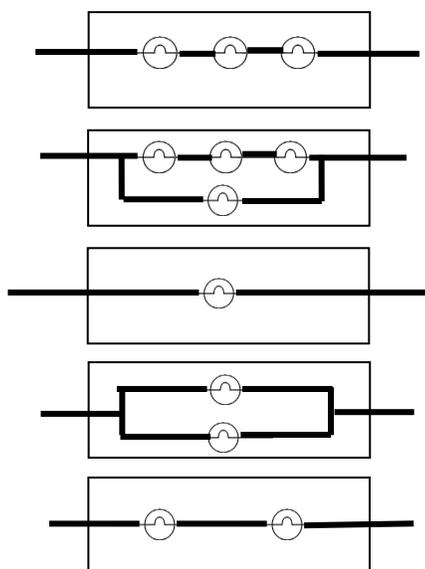


Figure 5: Sample circuit cards

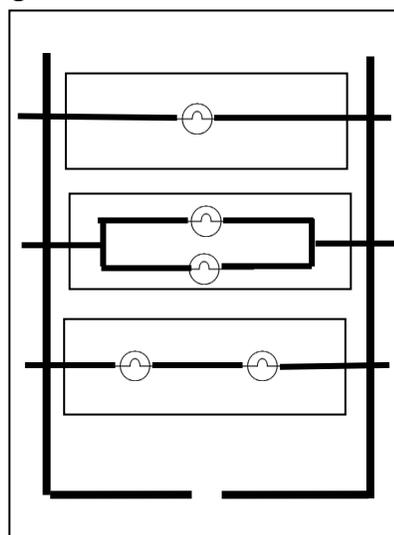


Figure 6: Compound circuit set-up