



NOTEBOOK CIRCUITS (with Metering)

Introduction

These experiments will introduce you to the concepts of charge, electrical energy and electric current, using paper models. You will physically see what a simple circuit looks like and how it works, and how more complex circuits are different. You will also be able to measure voltage and current with a multimeter, to learn about energy transformations occur in the examples of the different kinds of circuits you construct.

After building and learning about these circuits, you should be able to:

- Use the correct symbols to draw circuit diagrams
- Assemble simple, series and parallel circuits
- Describe the concepts of electrical energy and electric current
- Describe the transformation of energy in a circuit

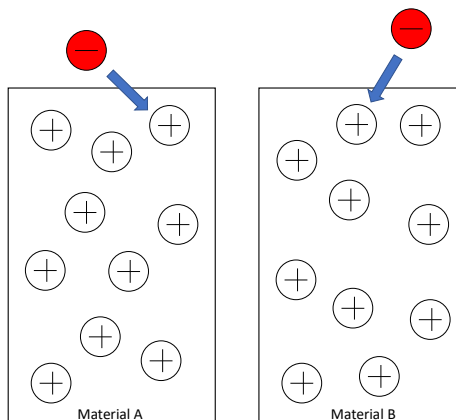
Activity 1: Electric Charges

What you will need:

- Material cards A and B – each card a different “material” (like copper or aluminum)
- 20 red plastic “electron” disks, each representing a negative (-1) charge.

Electric charges - directions:

1. Cover each + “atom” on both of the material cards with a $-$ (electron) disk.
2. Remove one of the electron disks from material A and place it on Material B.
3. Repeat step 2.
4. *Answer the related questions.*



Electric charges - questions

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, explain which of the arrangements of charges on materials A and B would take the most energy to create, starting from neutral materials.

- Batteries are labeled with a + at one end, and a – symbol at the other end. Explain what you think this means.
- A chemical reaction occurs inside of a battery, that causes electrons to move from the positive + terminal to the negative – terminal. What would you call the type of energy used to make electrical energy inside of a battery?

Activity 2: Electrical Current

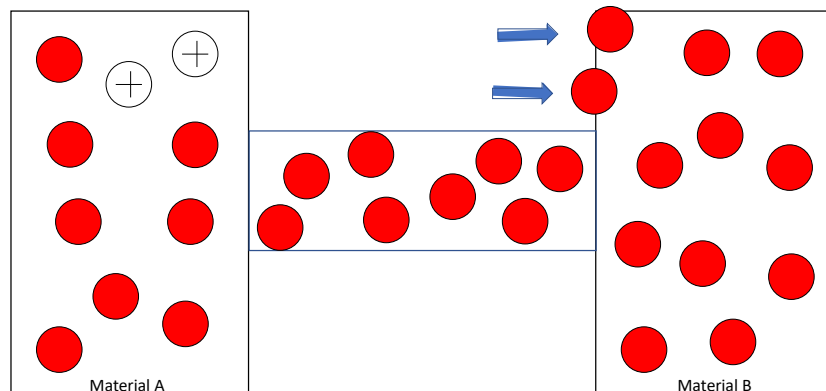
What you will need:

- Material cards A and B
- Wire card (a conducting material)
- 30 red plastic “electron” disks

Electrical current - directions:

1. Cover each positive “atom” on the wire card with an electron.
2. Place material A so that it touches one end of the wire, and material B so that it comes in contact with the other end of the wire.
3. Cover all of the atoms in materials A and B with electrons.
4. Remove two electrons from material A and place them on Material B.

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).



5. Next, slide an electron from the end of the wire touching Material A, to cover a nearby positive center on Material A.
6. Then, move electrons one at a time by sliding them to cover nearby positive center until there are no more excess charges and every positive center has an electron.
7. *Answer the questions below.*

Electrical current - questions

1. If electrical current is created by moving electrons, how do you think you could increase an electrical current?
2. When you moved two electrons from Material A to Material B, what effect did this have on the electrical nature of the wire?
3. When the + and – terminals of a battery are connected by a conducting pathway, describe what do you think causes a current flow.
4. If the conducting pathway between the + and – terminals of a battery breaks, does a current still flow? Explain why.
5. Which way do think electrons move through a wire connected to a battery, from + to – , or from – to +?

Activity 3: What's Inside a Bulb?

What you will need:

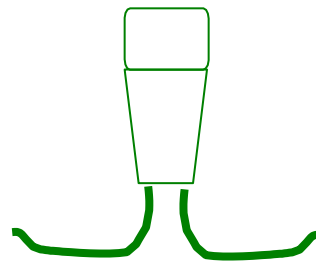
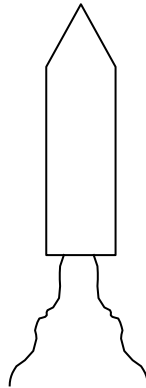
- Hand magnifier
- Holiday light bulb (and socket)

What's inside a bulb - directions:

1. Use the hand-held magnifier to look in detail at what is inside the bulb.
2. Use the magnifier to see the wiring inside the socket that holds the bulb.
3. *Answer the following questions.*

What's inside a bulb? - questions

1. Draw in the parts of the light bulb that would complete a circuit.
2. Draw and label what you see in the socket.



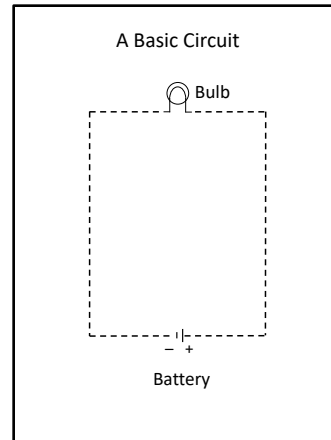
3. When the bulb is plugged into the socket, explain how electric current gets from one (green) wire of the socket to the other (green) wire?

4. If you touch the two wires of the bulb to the + and – 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 Circuits

What you will need

- AA battery pack
- Magnetic push pins (2)
- Basic circuit drawing
- Magnetic white board



Basic circuits - directions:

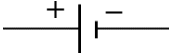
1. Place your circuit template on the magnetic white board.
2. Use two magnetic push pins to attach the light bulb to the circuit.
3. Position the two sides of the battery pack on each end of the battery gap (Figure A).
4. *Answer the related questions.*

Basic circuits - questions

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

Wire 

Bulb 

Battery 

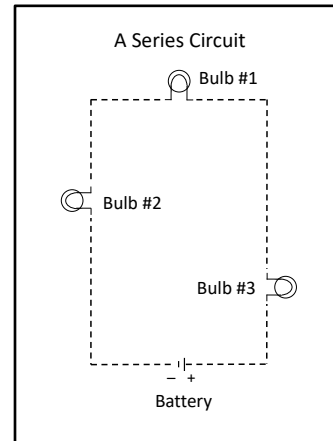
2. On your diagram in question 1, draw arrows showing the path the electrons take in the circuit.
3. Energy can be neither created nor destroyed; but, it can be transformed from one form to another. List all of the energy transformations that you think occur when you light a bulb with a battery.

4. You hook up a battery to a bulb and it does not light up. List at least three different things that may have caused this failure.
 - a.
 - b.
 - c.

Activity 5: Series Circuit

What you will need:

- Series copper foil circuit card stock
- 3 holiday light bulbs
- AA 3V battery pack
- Magnetic whiteboard
- 6 Magnetic push pins



Series circuits - directions:

1. Place your series circuit template on the magnetic white board.
2. Connect **only one** of the two bare wires on each of three holiday bulbs with the push pin magnets.
3. Position the AA 3V 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.*

Series circuits - questions

1. Using the symbols you used before, draw a diagram of the series circuit you constructed in the space to the right.

2. Draw arrows along each part of your diagram above to show the direction of the electrons in the circuit.

- Describe what happens as you connect each of the individual bulbs in your series circuit.

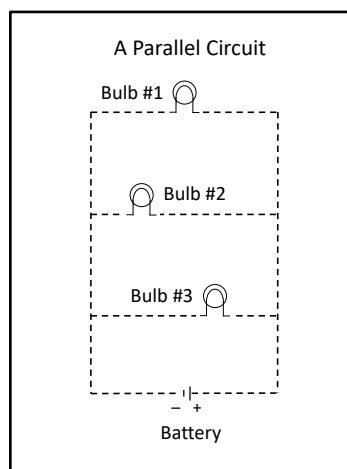
# of bulbs connected	Describe what you observed.
1	
2	
3	

- Write a sentence to summarize your conclusion.
- What do you think accounts for the difference in the brightness of the bulbs between the series circuit to the one bulb in the basic circuit?

Activity 6: Parallel Circuits

What you will need:

- Parallel circuit template on card stock
- 3 holiday light bulbs
- AA 3V battery pack
- Magnetic whiteboard
- 10 magnetic push pins



Parallel circuits - directions:

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

Parallel circuits - questions

1. Using the appropriate symbols, draw a diagram of the parallel circuit you constructed in the space to the right.
2. Use arrows to show the path of the electrons in each part of the circuit you drew.
3. Compare the appearance of the bulbs based on your experience with your parallel circuit.

# of bulbs connected	Describe what you observe with the bulbs connected.
1	
2	
3	

4. When the three bulbs were placed in series, all three had to be connected in order for any one of them to light, but this was not the case for the bulbs in parallel. Why is this?
5. You have three bulbs, a battery and some wire. In the spare to the right, draw one way you could connect them, that would include both a series and a parallel circuit.

Activity 7: Measuring Circuit Current and Voltage

Using a multimeter

A multimeter is a device that can be used to collect data from electrical circuits. We will be using the multimeter to measure voltage and current on the direct current (DC) setting. When measuring voltage, we refer to the multimeter as a voltmeter; when measuring current, an ammeter.

Units: Voltage is measured in Volts (V); current is measured in amps (A), or milliamps (mA).

What you will need:

- Your three card stock circuits
- AA 3V battery pack
- Digital multimeter
- Magnetic whiteboard
- 10 Push pin magnets

Part 1 – How to Measure Current:

1. Insert black probe in COM, red in VΩmA, meter set at 200 mA.
2. To measure current, the meter will be connected in series (Figure 1a).
3. To measure the **current going through a light bulb**, connect the probes as shown in Figure 1b.

If you don't have good electrical contact, (the bulb is dimmer than the other bulbs) then re-connect the contacts to maximize its brightness.

Wait to record any values until the reading stabilized to a constant number. This may take half a minute in some cases.

4. To measure the **total current at the battery**, connect the leads as shown in Figure 1c.

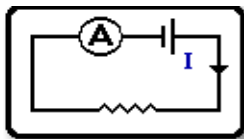


Figure 1a

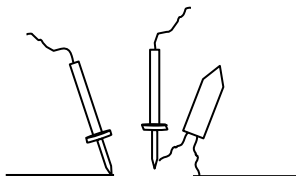


Figure 1b

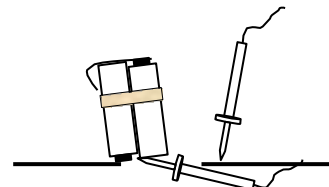


Figure 1c

Part 2 – How to Measuring Voltage:

1. Insert the black probe in COM, the red probe in VΩmA and set meter to 20 DCV.
2. To measure current, the meter will be connected in parallel (Figure 2a).
3. To measure the voltage across your battery pack, place the probes on the copper tape on either side of the battery pack (Figure 2c).
4. To measure voltage across a bulb, connect the probes to the copper tape on either side of the lighted bulb (Figure 2b).

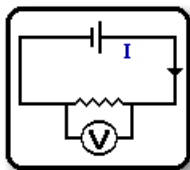


Figure 2a

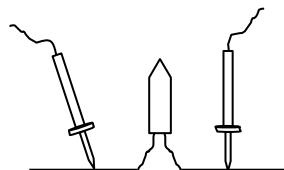


Figure 2b

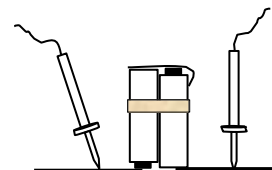


Figure 2c

Part 3 - Gathering Data from your Basic, Series, and Parallel Circuits

1. The Basic Circuit

Measured **current** going through the lighted bulb (Figure 1b) _____ mA

Measured **voltage** across the lighted bulb (Figure 2b) _____ V

Measured **voltage** across the battery (Figure 2c) _____ V

2. The Series Circuit

	Bulb 1	Bulb 2	Bulb 3
Measured current going through the lighted bulb	_____ mA	_____ mA	_____ mA
Measured voltage across the lighted bulb	_____ V	_____ V	_____ V
Measured voltage across the battery	_____ V		

3. The Parallel Circuit

	Bulb 1	Bulb 2	Bulb 3
Measured current going through the lighted bulb	_____ mA	_____ mA	_____ mA
Measured voltage across the lighted bulb	_____ V	_____ V	_____ V
Measured voltage across the battery	_____ V		

Part 4 – Calculating Resistance and Power

You now have what you need to calculate the equivalent resistance, and the power consumed, for the bulbs in each of the circuits, using the formulas below. These equations will be useful for some of the questions that follow, in Activity 7a, below.

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:

$$\text{Series circuit, } R_{eq} = R_1 + R_2 + R_3$$

$$\text{Parallel circuit, } \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Power

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

$$\text{Equation 1: } P = VI$$

$$\text{Equation 2: } P = I^2R$$

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

Activity 7a: Circuit Current and Voltage – Making Sense

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

2. The three bulbs in series were very dim, but the three bulbs in parallel were much brighter. Using the results of your measurements, explain why this might be 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 AA 3 V battery pack that you used?

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 do you think you might do to lower it?

d. List some possible sources of error in these measurements.

6. Power questions:

a. Use Ohm's law to derive 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.

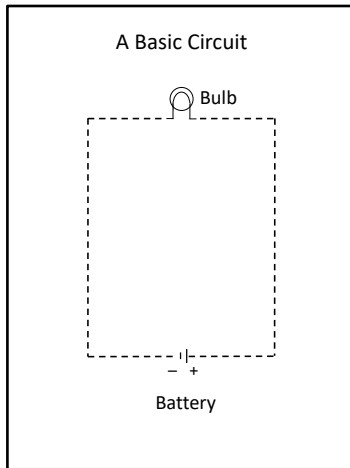
- c. What observation that you made can support the difference in power consumption calculated for the series and parallel circuits?

- d. Which circuit will drain the battery the fastest and why?

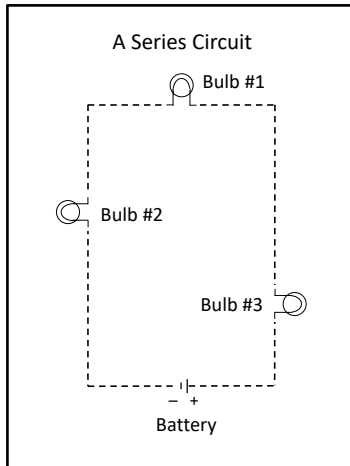
Note of Acknowledgement:

The author of this revision gratefully acknowledges Cornell University CNS Institute for Physics Teachers for the original work in the development of this procedure.

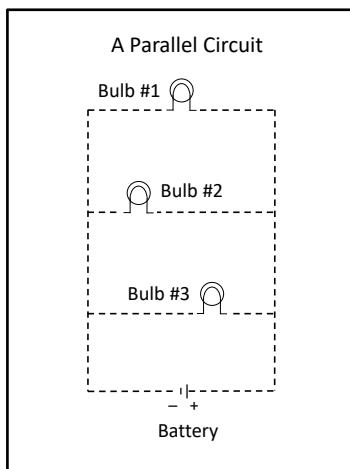
Circuit Metering Data



	Measured Current	Measured Voltage
Bulb	_____ mA	_____ V
Battery	_____ mA	_____ V



	Measured Current	Measured Voltage
Bulb 1	_____ mA	_____ V
Bulb 2	_____ mA	_____ V
Bulb 3	_____ mA	_____ V
Battery	_____ mA	_____ V



	Measured Current	Measured Voltage
Bulb 1	_____ mA	_____ V
Bulb 2	_____ mA	_____ V
Bulb 3	_____ mA	_____ V
Battery	_____ mA	_____ V