Teacher's Preparatory Guide

Lesson 2: Ohm's Law with Light Bulbs and LEDs

Purpose: The purpose of this activity is to illustrate ohmic and non-ohmic materials in a simple series circuit. This activity will introduce semiconductors as diodes so that future activities may build upon this idea to conclude with micro/nano-circuits.

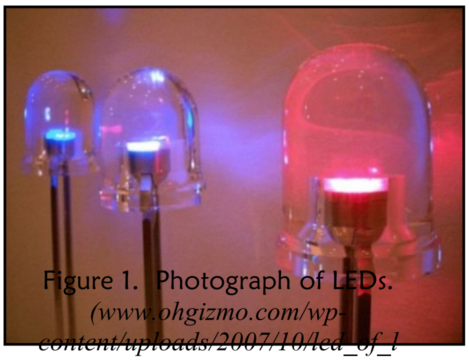

Figure 1. Photograph of LEDs. *(www.ohgizmo.com/wp-content/uploads/2007/10/led_of_led_1%20(Custom).jpg)*

Time required: 45 – 55 minutes
Level: High School Physics

Teacher Background: *Ohm's Law.* Georg Simon Ohm discovered that materials have an ohmic, or linear, region. His equation (Eqn 1) explains that as the potential difference (ΔV) increases, so does the current (I), and the relationship is linear to a point. The slope of a voltage vs. current plot yields the resistance (R). Temperature affects the resistance. If a resistor heats up, the value of its resistance increases, and the resistor is now considered non-ohmic. Non-ohmic materials have a non-linear relationship between voltage and current.

$$\Delta V = IR \qquad \text{Eqn 1}$$

Resistivity

Resistivity (ρ) is an electrical property of a material. Its relation to resistance (R) is shown in Equation 2. The equations that relate resistivity to temperature, and resistance to temperature, are shown below in Equation 3 & 4. The temperature coefficient of resistance is alpha (α) and it is a material constant. T_0, ρ_0, and R_0 represent the known temperature, resistivity, and resistance, respectively.

$$R = \rho \frac{L}{A} \qquad \text{Eqn 2}$$

$$\rho = \rho_0 \left[1 + \alpha \left(T - T_0\right)\right] \qquad \text{Eqn 3}$$

$$R = R_0 \left[1 + \alpha \left(T - T_0\right)\right] \qquad \text{Eqn 4}$$

Diodes & LEDs

Figure 1 shows typical LEDs used in electrical circuits. LEDs are found in digital clocks, remote controls; light up watches, and traffic lights. An LED creates light without the use of a filament. Incandescents use filaments to light their bulbs. Besides shining light, incandescents also emit heat. LEDs do not heat up; therefore, less energy is lost thereby making them more efficient than the typical incandescent light bulb. Below is an explanation of the technology used within LEDs.

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Figure 4. Light emission.

LEDs are made from semiconductors. Semiconductors have the ability to be insulators or conductors with some manipulation from scientists/engineers. A semiconductor with extra electrons (free electrons) is called N-type material. These free electrons want to move to an area of positive charge. Semiconductors with extra "holes" (positive charge) are called P-type materials. The holes have a tendency to move towards the negatively charged electrons. A diode consists of both types of semiconductors as shown below. Diodes will only allow current to flow in one direction. Figure 2 shows a simple circuit in which current will not flow through. The electrons contained on the N-type material are attracted to the positive terminal of the battery. The P-type material contains the holes, acting as positive charges, which are attracted to the negative terminal of the battery. If the battery were switched as shown in Figures 3 and 4, the electrons and holes would be drawn to each other in attempt to reach the other side. On the way to the opposite wall, to reach the appropriate battery terminal, the holes and electrons interact. As they collide with one another they momentarily reach a higher energy level and then release the energy as light, in the case of a light emitting diode (LED).

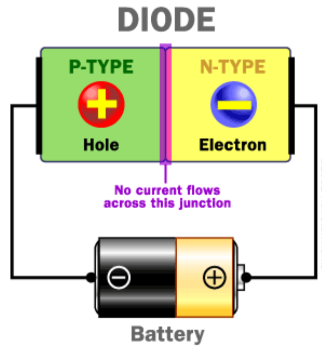

Figure 2. No current flow. *(electronics.howstuffworks.com/led1.htm)*

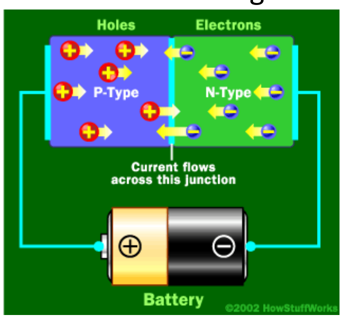

Figure 3. Diode operation. *(electronics.howstuffworks.com/led1.htm)*

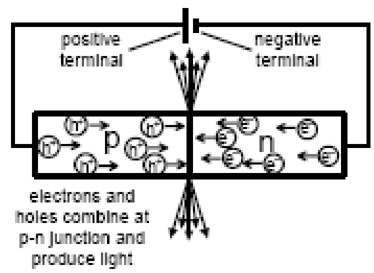

Figure 4. Light leaving the LED. *(mrsec.wisc.edu/Edetc/reprints/JCE_2001_p1664A.pdf)*

As previously mentioned, current only flows in one direction in an LED. Semiconductors have varying resistance which depends on the voltage and current flow. An ohmmeter will not work in finding the resistance. LEDs are not Ohmic materials, meaning the relationship between current and voltage is not linear. To find the resistance measure the current at different voltages. Figure 5 shows the housing and structure of the LED. The terminal pins separately attach to the P-N diode. When the light is emitted it will hit the sides of the plastic case. Depending on the angle it might go right through or reflect off and cross the plastic covering at the top.

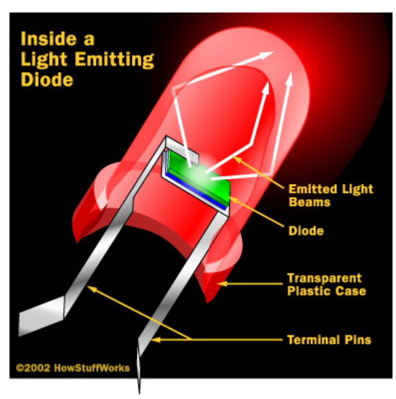

Figure 5. LED structure. *(static.howstuffworks.com/gif/led-diagram.jpg)*

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Materials (Per each lab setup):

- Power Supply
- Resistors (any values)
- Holiday Light Bulb
- Holiday LED or Circuit Board LED
- Breadboard
- Jumper wires
- Digital multimeter or Vernier current probe
- LabPro and LoggerPro (if using the Vernier current probe)
- Computer with Excel

Advance Preparation:
Purchase resistors, light bulbs, and LEDs from Radio Shack. Holiday light bulbs and LEDs can be purchased at Home Depot, Walmart or other box stores during the holidays. If holiday lights are chosen, the lights will need to be cut. A wire cutter can cut and strip the ends to create leads. Twist the exposed copper so that it is easier to place in the breadboard.

Safety Information:
Make sure the students turn off the power supply when they are switching out circuit components. It might be helpful to install a switch in the circuit.

Directions for the Activity:

1. Students should have done the previous activity, *The Effect of Temperature on the Electrical Resistive Properties of a Thermistor),* so that they are aware of Ohm's law. They should also understand that not every material obeys Ohm's law with a linear region.
2. Discuss LEDs and how materials can be non-ohmic.
3. Remind students to turn off the power when switching circuit components.

Procedure is from Student Activity Guide below.

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Student Worksheet (with answers in red)

Ohm's Law with Light Bulbs and LEDs

Objective: The objective is to observe the behavior of ohmic and non-ohmic materials in a circuit.

Materials:

- Power Supply
- Resistors
- Christmas Tree Light Bulb
- Christmas Tree LED or Circuit Board LED
- Breadboard
- Jumper wires
- Digital multimeter or Vernier current probe
- LabPro and LoggerPro (if using the Vernier current probe)
- Computer with Excel

Procedure:

Part A: Reading Resistors

1. Use a multimeter on the ohmmeter (⍰⍰ setting to measure the value of resistance for each of the resistors. Look at Figure 1 for help.
2. Find the value of each resistor using Figure 2 (below). The last color band is the tolerance.
3. Enter all the values in Table 1.

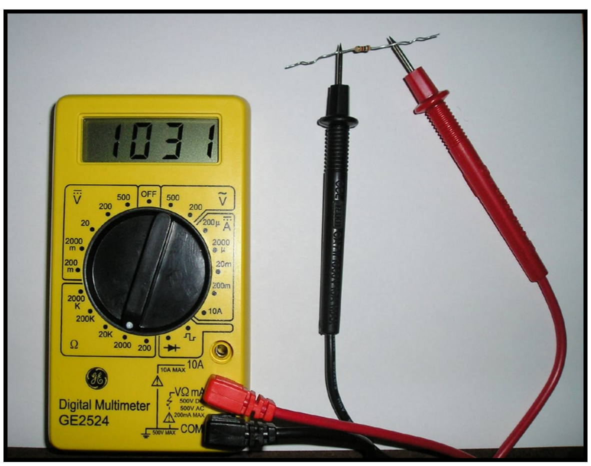

Figure 1. Measuring Resistance.

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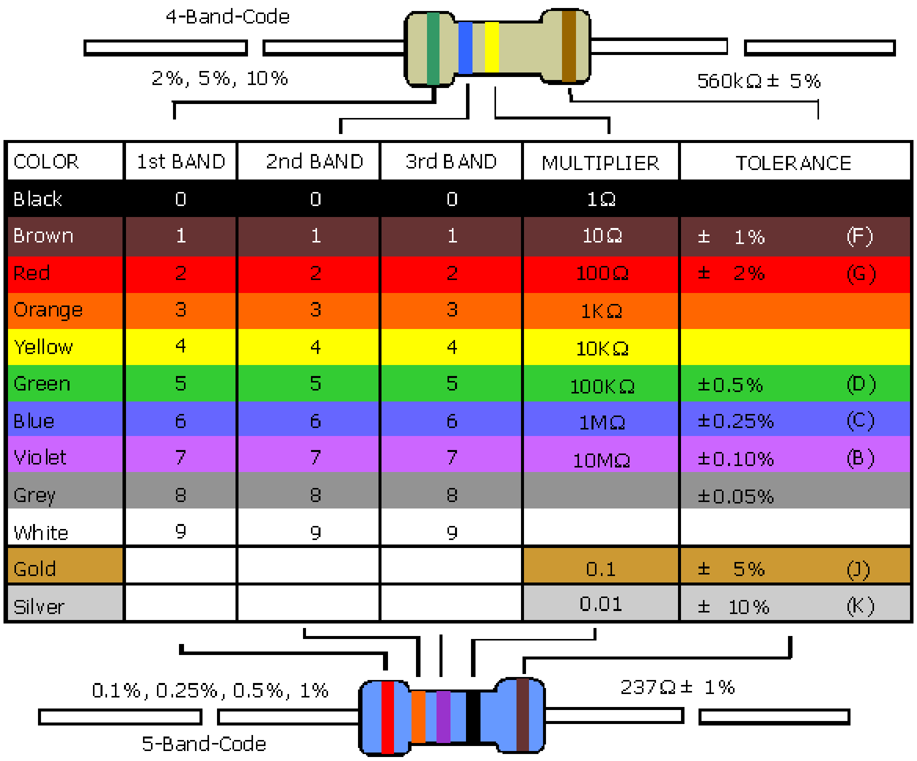

COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)

Figure 2. Resistor color code chart.
(www.elexp.com/tips/clr_code.gif)

Table 1. Data for the resistors.

Resistor Colors	Measured Resistance (Ω)	Calculated Resistance (Ω)

Part B: Resistor in a Circuit

1. Using the breadboard, build a simple circuit consisting of a 1 kΩ resistor connected to a power supply. In your circuit, include a digital multimeter to measure the voltage across and the current through the 1 kΩ resistor.
2. Adjust the power supply until the voltage across the resistor is about 1.0 V. Record both the voltage across and the current

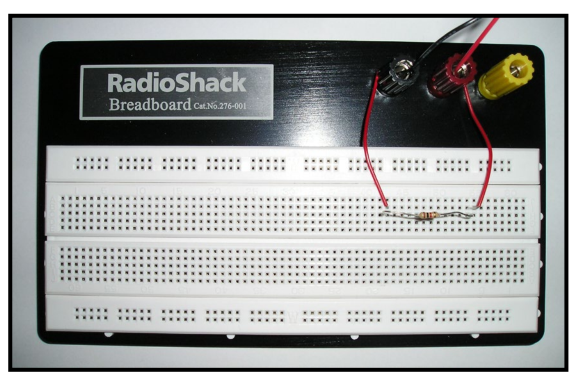

Figure 3. Resistor circuit setup.

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through the resistor.

3. Increase the voltage across the resistor to about 2.0 V and record the voltage and current. Continue to increase the voltage in 1.0 V increments until you reach 10.0 V. Record all your data on Table 2.
4. When the voltage across the resistor is 10 V, watch the current through the resistor for about 30 s. Does the current through the resistor change during the 30 s? What does this tell you about the temperature of the resistor?
5. Turn the power supply off.
6. Switch the leads from the resistor. Check on the current for two or three different values of the voltage and compare with your previous results. Does the polarity of the voltage across the resistor make any difference in the current through the resistor?
7. Use Excel to fit the data to a straight line or curve. From the slope of your line, calculate the resistance.

Table 2. Data for the resistor circuit.

Voltage (V)	**Current (A)**
1.0	
2.0	
3.0	
4.0	
5.0	
6.0	
7.0	
8.0	
9.0	
10	

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Part C: Light Bulb in a Circuit

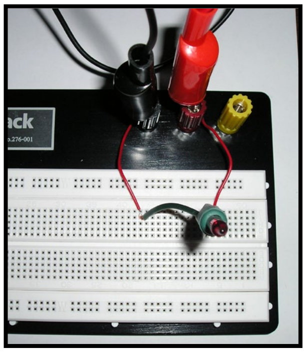

Figure 4. Light Bulb Circuit Setup

1. Build a simple circuit consisting of a light bulb connected to a power supply. In your circuit, include a digital multimeter to measure the voltage across and the current through the light bulb.
2. Adjust the power supply until the voltage across the light bulb is about 0.5 V. Record both the voltage across and the current through the light bulb.
3. Increase the voltage across the light bulb to about 1.0 and record the voltage and current. Continue to increase the voltage in 0.5 V increments until you reach 3.0 V. Record all of your data in Table 3.
4. Use Excel to make a plot of I (current) vs. V (voltage). Is the light bulb ohmic or non-ohmic? How do you know? Does the light bulb filament have a constant resistance? Why or why not? *If it is ohmic there will be a diagonal line. If it in non ohmic the graph will not be linear.*

Table 3. Data for the light circuit.

Voltage (V)	**Current (A)**
0.5	
1.0	
1.5	
2.0	
2.5	
3.0	
3.5	
4.0	
4.5	
5.0	

Part D: Light Emitting Diode (LED) in a Circuit

1. Using the breadboard, build a simple circuit consisting of a 1 kΩ resistor and an LED connected in series with a power supply. In your circuit use a digital multimeter to measure the voltage across and the current through the LED.
2. Adjust the power supply until the voltage across the LED is about 1.75 V. Is there any current flowing through the LED?

3. Reverse the polarity of the voltage across the LED by switching the leads of the LED. Does the polarity of the voltage across the LED make any difference in the current through the LED? Yes, no current.
4. Adjust the polarity of the voltage across the LED so current flows through the LED.
5. Adjust the voltage across the LED to 0.5 V and record the current through the LED. Increase the voltage to 1.0 V and then 1.5 V and record the current through the LED.
6. Record the current through the voltage across the LED for values between 1.5 V and 2.0 V. Record all of your data into Table 4. What is the turn-on voltage of the LED?
7. Use Excel to plot current vs. voltage for the LED. Is the LED ohmic or non-ohmic? How do you know? *If it is ohmic there will be a diagonal line. If it in non ohmic the graph will not be linear.*

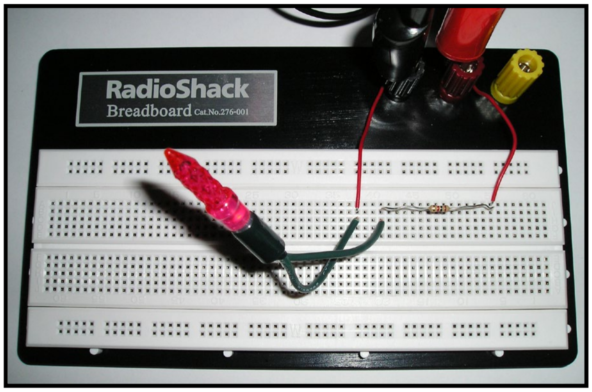

Figure 5. Resistor-LED combination circuit setup.

Table 4. Data for the LED.

Voltage (V)	**Current (A)**
0.5	
1.0	
1.5	
1.6	
1.7	
1.8	
1.9	
2.0	

Analysis and Conclusion:

1. Create Excel ® plots of I (current) vs. V (voltage) for each part (B-D).
2. Calculate the slopes or plot regression fits for each part (B-D).
3. Which parts are ohmic and which are non-ohmic?
4. What is the point of placing a resistor in series with the LED? *It reduces the current to the LED.*
5. Create Excel ® plots of I vs. V or each part (B-D).

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6. Calculate the slopes or plot regression fits for each part (B-D).
7. Which parts are ohmic and which are non-ohmic?
   The resistor is ohmic at low voltages (potential differences), but becomes non-ohmic at high voltages. The high voltages create heat removing a resistor from its ohmic region. The light bulb is non-ohmic because the filament burns at high temperatures. LEDs are non-ohmic because they are semiconductors. The heat provided by the copper attachment wires heat up the LED leads.
8. What is the point of placing a resistor in series with the LED?

The point is to reduce the flow of the current. Too much current will cause the LED to go out.

Assessment: The analysis and conclusion section may be the assessment.

Resources: To learn more about nanotechnology and LEDs, here are some web sites with educational resources:
Nanotechnology 101 https://www.nano.gov/nanotech-101
LEDs Exploring Light: https://education.mrsec.wisc.edu/leds-exploring-light-activity/
Periodic Properties and LEDs: https://education.mrsec.wisc.edu/periodic-properties-and-leds-voltmeter/ (voltmeter) and/or
https://education.mrsec.wisc.edu/periodic-properties-and-leds-national-instruments-elvis/
(National Instruments Elvis)
How Light Emitting Diodes Work: http://electronics.howstuffworks.com/led1.htm
LEDs 101: https://www.youtube.com/watch?v=Yo6JI_bzUzo

National Science Education Standards
Physical Science Standards

- Structures and properties of matter
- Interactions of energy and matter
- Structure of atoms

Next Generation Science Standards:
PS1.A: Structure and Properties of Matter

HS-PS1-1: Each atom has a charged substructure consisting of a nucleus, which is made HS-PS1-3: The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

HS-PS3: Energy

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).

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