Ohm's Law

1. Introduction

An electrical circuit is any continuous path or array of paths along which current may flow. A circuit usually contains a battery or other sources of EMF and may contain anything from a single wire to a complicated collection of wires, resistor, and other circuit elements. For example, in a flashlight the path from one terminal of a flashlight battery through the lamp and back to the other terminal of the battery is a simple circuit. In this lab we study Ohm's law in the context of a few simple electrical circuits.

1.1 Current-Voltage (I-V) Characteristics of Circuit Elements: Ohm's Law

Part A: Carbon Resistor. If both positive and negative electric potential differences V (voltage) are applied across a carbon resistor (maintained at a constant temperature) and the current I that flows is measured, we find that I is proportional to V and the resistance R is a constant. When I versus V is plotted, as shown in Figure 1, a straight line graph is obtained. The resistance is the same for all data points and is therefore independent on the direction (positive and negative) and magnitude of the current used. Materials which obey this linear relationship are referred to as ohmic conductors. This straight line is symmetric with respect to the origin: R(V, I) = R(-V, -I). Note that if the current's magnitude is increased too much, the circuit element may start to heat up and lose its linear ohmic I-V characteristics.

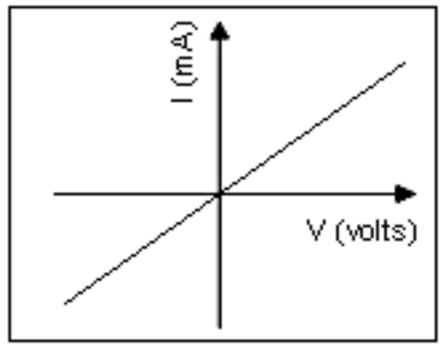


Figure 1: I-V of ohmic resistor

Ohm's law is given as V = IR. We define the resistance as R = V/I ohms. For an ohmic conductor, at a given temperature, R is a constant independent of I and V and is equal to the inverse of the linear slope of the I versus V graph for that conductor (Figure 1):

$$R = \frac{1}{\text{Slope of I–V graph}} \qquad \text{That is, } R = \frac{1}{\frac{\Delta I}{\Delta V}} = \frac{\Delta V}{\Delta I}$$

Part B: Light Bulb. Tungsten is a metallic conductor, yet the I-V characteristics of a light bulb with a tungsten filament exhibit a nonlinear (Figure 2) behavior because the temperature of the filament varies from around 20ºC to around 2000ºC. The temperature increases as the power (P = VI in units of Watts) increases. The temperature of a hot filament can be accurately determined from its electrical resistance. The resistance of the tungsten filament is not constant, but is dependent on the magnitudes of I and V, the power. The light bulb has point symmetry which displays 180 degree rotational symmetry with respect to the origin. That is, the current-voltage curve is origin symmetric, as the magnitude of the current flowing for a given

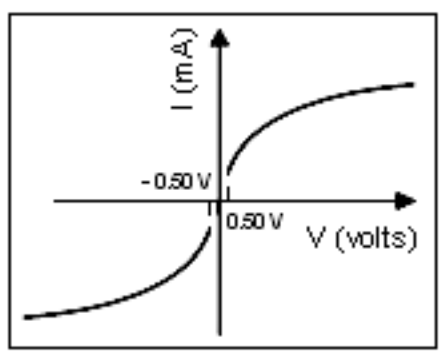


Figure 2: I-V of light bulb

applied voltage value is the same regardless of voltage polarity (positive or negative sign). The currents for 5 volts and -5 volts are approximately the same, however, the current changes direction (sign) when the voltage polarity changes. In Figure 2, resistance and power are approximately the same at each symmetric point, R(V, I) = R(-V, -I), but changes at each symmetric point as both are dependent on I and V, the power. In terms of power, at each symmetric point, P(V, I) = P(-V, -I). The magnitude of the power changes the temperature. The resistance in Figure 2 depends on the magnitude of the current and not its direction. Note that for tungsten, higher power means a higher temperature and a higher resistance. For the device in Figure 1, power is not significantly changing the temperature for the range of values of I and V used. Resistance for tungsten is:

$$R = \frac{V}{I}$$

Again, it should be noted that at each symmetric point in Figure 2, R(V, I) and R(-V, -I), both the temperature and the resistance are approximately the same. In addition, I is proportional to V at these points. The light bulb is therefore ohmic at symmetric points but is not ohmic for the range of data used when the power (I and V) is changed during the experiment.

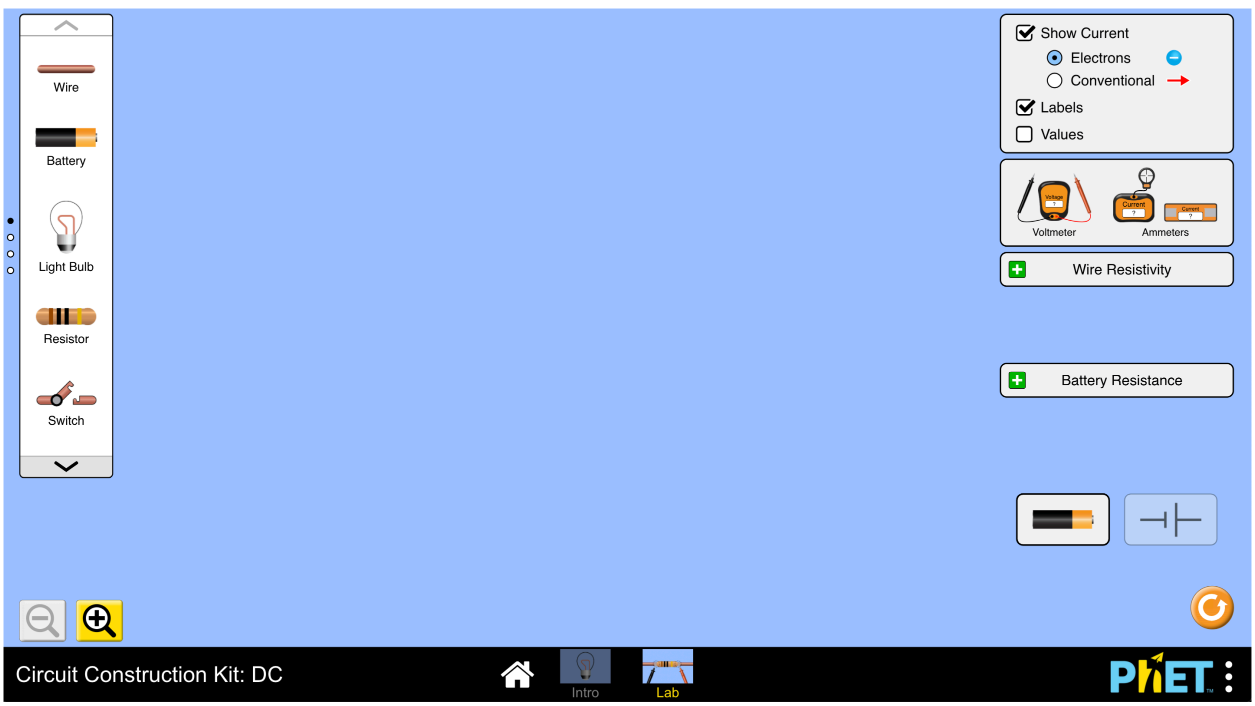
2. Experimental Apparatus and Procedure

- PhET Interactive Simulations: *Circuit Construction Kit: DC*

2.2 Procedure. Measurements are entered into the data section of the Lab Report.

Getting started

Go to phet.colorado.edu. On the home screen, go to the tab marked "Simulations" and select "Physics." You should then see a list of simulations. Choose the one titled "Circuit Construction Kit: DC" and download the simulation. Take some time to familiarize yourself with the simulation's features before beginning the experiment. We will be using the "Ideal" screen as labeled at the bottom of the simulation.

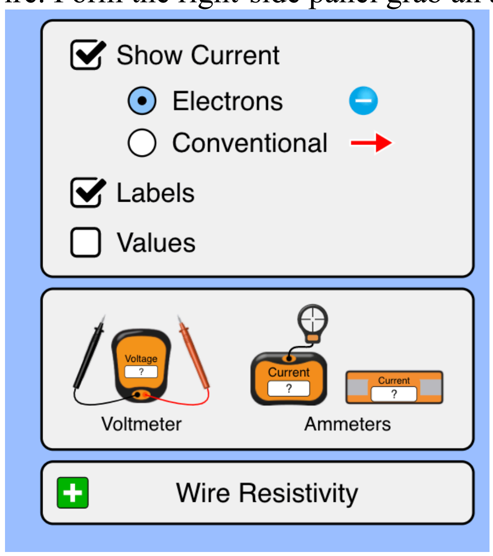


Determination of the I-V characteristics of various electrical elements

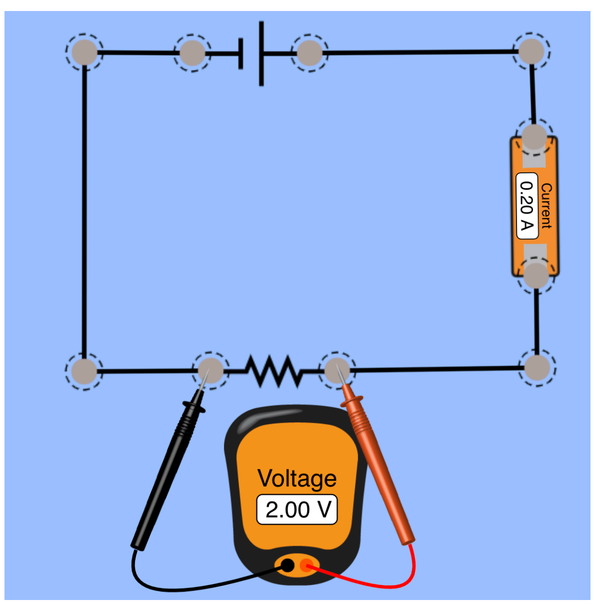
In the following studies, you will assemble the circuit shown to measure the current through the circuit element as a function of the applied voltage across the element. Make sure you associate a plus + (positive high potential) or minus - (negative low potential) sign to each voltage and current measurement. <u>The correct range on the voltmeter will determine the amount of digits after the decimal point</u>.

2.2.1 Carbon Resistor at Room Temperature <u>Part A 1.</u>

1. From the left-hand panel of the simulation, click and drag into the "work bench" a battery, a resistor and some pieces of wire. Form the right-side panel grab an ammeter, and voltmeter.



2. Connect the pieces that you have laid out to match Figure shown below.



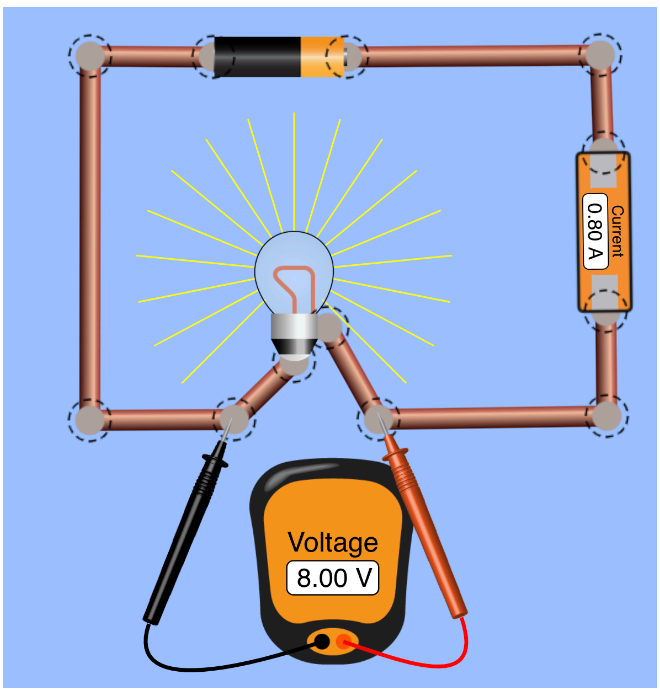
3. Set the resistance of the resistor to 120Ω.

4. By changing the voltage on the power supply, you will measure and record the current through the resistor as a function of the voltage V across it. Increasing V from 1 to 7 volts in steps of 1 volt.

5. Reverse the direction of the applied voltage across the circuit element by reversing the leads on the power supply. Again measure and record the current through the resistor for applied voltages across the resistor in 1 volt increments between -1 and -7 volts (arbitrarily designated as the negative polarity of applied voltage).

2.2.2 Six-volt Electric Light Bulb Part B.

Disconnect the resistor from the circuit and connect a electric light bulb in its place. Measure the current-voltage characteristics between .5 to 5 volts (plus and minus polarity) in **0.5 volt steps** following the procedure above (steps 5, 6, and 7). Continue to read this section first before starting your measurements to see how the above steps will be modified. As you increase the voltage, the tungsten will increase in temperature. As the temperature does increase, first do .5 volts, then -.5 volts. Next will be -1 volts followed by 1 volts. Use this staggered method of increasing the volt for your light bulb measurements.



2.2.3 Pencil and Hand:

Now replace the light bulb with Pencil and then with hand. Repeat above procedure and obtain the resistance of these two materials.

Data for 2.2.1 Carbon Resistor <u>Part A.</u>

Table 1: Measurements of voltage and current from +1V to +7V and -1V to -7V in steps of 1 volt both at room temperature and at LN_2 temperature (if measured).

(Both R's at the top of the table are direct measurements (dm) using a multimeter)

	$R_{dm} =$ $k\Omega$

$\sim V$	V	I	N	R_{ROOM}	V	I	N	R_{LN_2}
(V)	(V)	(mA)		$(k\Omega)$	(V)	(mA)		$(k\Omega)$
1			$slope$				$slope$	
-1			$(1/k\Omega)$	$S_{R_{ROOM}}$			$(1/k\Omega)$	$S_{R_{LN_2}}$
-2				$(k\Omega)$				$(k\Omega)$
2			$intercept$				$intercept$	
3			(mA)				(mA)	
-3								
-4			R^2				R^2	
4								
5			S_I				S_I	
-5			(mA)				(mA)	
-6								
6			S_{slope}				S_{slope}	
7			$(1/k\Omega)$				$(1/k\Omega)$	
-7								
			$S_{intercept}$				$S_{intercept}$	
			(mA)				(mA)	

Data for 2.2.2 SIX VOLT LIGHT BULB <u>Part B.</u>

Measurements of voltage and current from +.5V to +5V and from -.5V to -5V in steps of ±0.5V.

$\sim V$	V	I	$R = V/I$	$P = IV$
(V)	(V)	(mA)	$(k\Omega)$	(mW)
0.5				
-0.5				
-1				
1				
1.5				
-1.5				
-2				
2				
2.5				
-2.5				
-3				
3				
3.5				
-3.5				
-4				
4				
4.5				
-4.5				
-5				
5				

3. Calculations, Analysis and Graphs

Your lab report should include 3 plots of the current, *I* (vertical axis) as a function of the voltage, V (horizontal axis) for the current-voltage data obtained for each circuit element. The linear data for the 1 kΩ resistor at room and liquid nitrogen temperatures (Parts 3.2.1 and 3.2.2) may be plotted together on the same graph.

1. Use your data for *I* vs. *V* and perform 2D Stats in *Excel* to calculate the electrical resistances of the carbon 1kΩ resistor.

$$R = \frac{1}{slope}$$
$$S_R = R\frac{S_{slope}}{slope}$$

   Graph both lines on the same graph in *Excel* (see the *Help Sheet* if you are not sure how).

2. Plot your *I* vs. *V* data for the light bulb in *Excel*. For each (V, I) pair, calculate the resistance and power:

$$R = \frac{V}{I}$$
$$P = IV$$

3. Plot your *I* vs. *V* data for the diode in *Excel*.

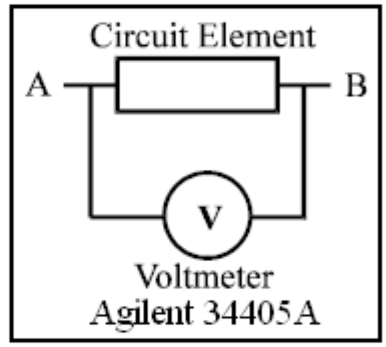
4. Questions

1. Questions related to light bulb:
   a. Does the resistance of the electric light bulb depend on the direction of current flow through it? Explain.
   b. Does the resistance of the electric light bulb increase, decrease or remain constant as the power, $I*V$, is increased? Consult your data table.
   c. Does the temperature of the light bulb filament increase, decrease or remain constant as the power, $I*V$, to the bulb is increased? (Hint: Associate a higher electrical power with an increase in temperature.)
2. Does the carbon resistor allow to current to flow through? How can you tell? Why the current is passing or not passing through this component?
3. Does current passes through the hand? How can you tell? Why the current is passing or not passing through this component?

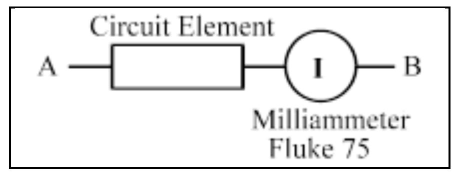
5. Discussion

Remember to include a discussion section in your lab report. Refer to the Appendix on writing lab reports in the Course Syllabus for guidelines and suggestions. In this experiment, for quantitative discussion of precision and accuracy you can focus on the (room temperature) carbon resistor data obtained from the slope of your graph and compare with its expected value.

APPENDIX I: Instrumentation

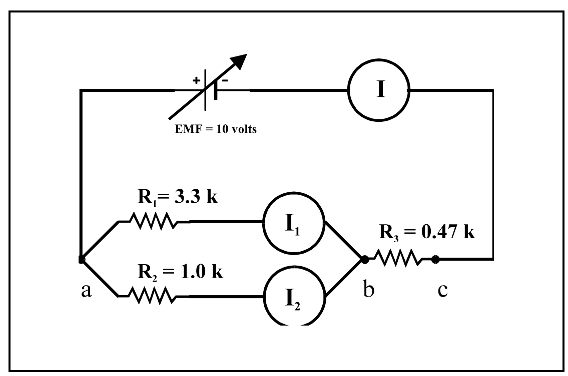


1. The **DC Voltmeter** measures the voltage difference between two points to which its terminals are connected. The voltmeter is always connected **in parallel** to the part of the circuit across which the potential difference is to be measured (Figure A1). In this experiment the Agilent 34405A multi-meter is used to measure voltage differences and the resistance of the carbon resistor.



2. The **DC Milliammeter** measures the electric current between any two points to which its terminals are connected. To measure the current in any part of the circuit, the circuit must be broken at that point and the ammeter must be inserted in the gap with loose ends connected to its terminals, i.e., the meter is connected **in series** with that part of the circuit where the current is to be measured (Figure A2). The Fluke 75 battery powered multi-meter is used to measure the current in milliamperes in this experiment.

3. Connecting wire leads. Assumed to be made of a good conducting material, e.g., a metal such as copper, and of a large enough cross-section to have negligible resistance and voltage drop across them.



4. The **DC Power supply** is a device used to supply a constant source of EMF between its output terminals. The electric current flows internally in the power supply from the minus to the plus terminal. In the external circuit it flows from the plus to the minus terminal (Figure A3). The voltmeter on the actual power supply is not accurate and should not be used to determine the output voltage. The Agilent 34405A multi-meter is used to measure voltages.