Theory

When it comes to electricity, materials can be placed into one of three categories: insulators, conductors, and semiconductors. A perfect insulator would be a device that completely resisted the flow of electricity through it. A perfect conductor would be a device that allowed electricity to flow through it with no impedance. Semiconductors are the middle ground between the two, acting like insulators under certain conditions and conductors under others.

Ohm's Law

The earliest studies of electricity showed that most conductors have a similar profile in how they transmit electricity. As discovered by Georg Ohm in 1827, the current flowing through a conductor is proportional to the voltage applied to it. This relationship, known as Ohm's Law, can be stated mathematically as

$$V = IR$$
(Equ. 1)

where V is the applied voltage, I is the current, and R is the proportionality constant known as the resistance. Materials that follow this equation are now known as ohmic devices and include most metals found in nature. The resistance for these types of materials was found to have a very simple form, it is inversely proportional to the cross-sectional area of the material A and linearly dependent on the length of the material L.

$$R = \rho \frac{L}{A}$$
(Equ. 2)

where ρ is the resistivity of the conducting material. The resistivity depends only upon what the substance is composed and its temperature (for most materials, the hotter it is, the higher its resistivity). The equation shows that the longer a wire is, the more resistance it has. It also shows that the thicker the wire, the less resistance it has.

A devices is said to obey Ohm's law if its current voltage characteristic is described by equation 1. The purpose of this lab is to investigate whether the two provided devices obey Ohms law. To be able to do that, we need to take voltage and current measurements.

Use of Meters

We usually use an Ammeter to measure current and a Voltmeter to measure voltage. When drawing a schematic of a circuit, we usually label the Ammeter as "A" and the voltmeter with "V". An example schematic is shown in Figure 1. Along with the ammeter and the voltmeter, the schematic includes 4 other devices; a power supply designated by E, and three resistors designated by R.

Fig. 1: Use of an ammeter and a voltmeter

When measuring current with an ammeter, the ammeter should be placed in series with the device we want to measure the current through. For example, as shown in the Figure, if we want to measure the current through R_1, we place the ammeter in series with R_1. The same current should flow through both R_1 and the ammeter.
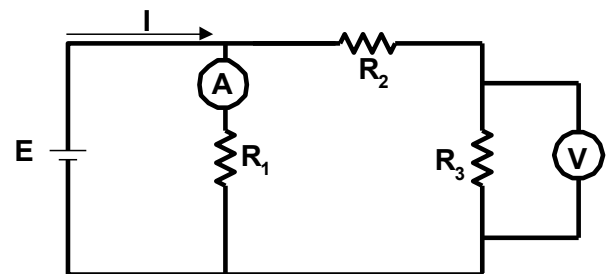
On the other hand, if we want to measure voltage, we have to connect the voltmeter in parallel with the device you want to measure the voltage across. For example, as shown in the Figure, if we want to measure the voltage across R_3, we place the voltmeter in parallel with R_3. Both R_3 and the voltmeter are subject to the same voltage.

Use of the Vernier Interface for powering the circuit

Starting this lab, we will use a computer interface to power the circuit. The interface is made by Vernier. Directions on its use are available at http://physics.kennesaw.edu/L00_vernier-power.pdf. The settings file you will use is called **power** and is available in the "VERNIER" folder on the computer desktop. It can also be downloaded from here http://science.kennesaw.edu/physics/vernier.zip.
The hardware needed for powering the circuit is available in the box title "LabPro."

Note that for this lab, we are using the interface for powering the circuit only and not for graphing or taking measurements.

Please make sure not to mix the content of the "LabPro" box with the content of the lab box.

Part One: Setup/Meters

The diagram provided below shows a schematic of our experimental set up. A variable voltage power source, a device (unknown or lamp) designated by R and a voltmeter and an Ammeter.
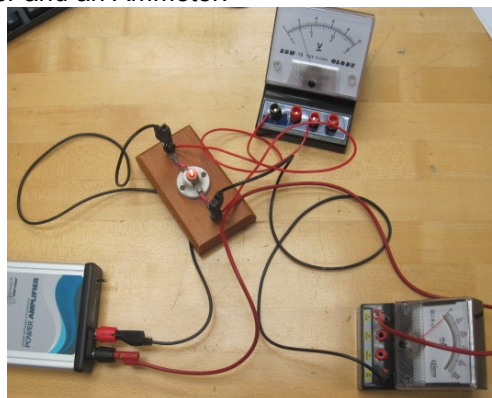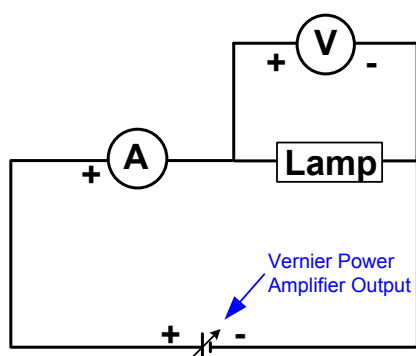
1. Wire the circuit as shown in the diagram while paying attention to the proper polarity (+ and -).

2. Use the Vernier LabPro interface as the variable power supply.

   ▪ **DO NOT TURN ON THE POWER SUPPLY UNTIL YOU GET THE TEACHER TO VERIFY YOUR CIRCUIT! That is step 4.**
   ▪ PLEASE Note the Following
      o The positive output is red.
      o You will need to connect the voltage probe to input 1 even when you don't intend to use the voltmeter feature of the software.
      o **The interface does not deliver negative voltages even when the software indicates otherwise**.

3. Use the analog meters for voltmeter and ammeter (identify them and connect them as shown.)

Note that you need to connect the end at the lower voltage to the black end of the meter and the higher voltage to the red knob corresponding to the highest reading (that is the knob the furthest from the black knob.) Once you power the circuit, if the needle reading is too small, you gradually move your connection to the red knob that gives the most accurate result.

4. **GET THE TEACHER TO VERIFY YOUR CIRCUIT!** Turn on the power supply.

5. Gradually (the interface allows for 0.1 volt steps) change the voltage and observe the effect on the light bulb and both meters. You can change the voltage by pressing the up and down triangles on the Amplitude control box.
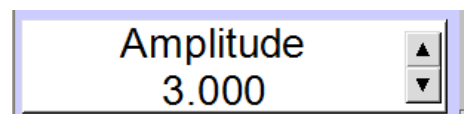
6. Once the bulb is lit, with the voltage set at 3.0 V (that is 3 V at the interface and 6 V at the circuit), read the voltage and the current then disconnect the voltmeter by unplugging one of its ends. How did that affect the reading of the ammeter and the light on the bulb?

7. Without changing the setting on the Vernier interface, reconnect the voltmeter but connect it now across both the ammeter and lamp (not just lamp as before – positive end connected to positive end of ammeter.). Read the voltage and the current. How are they different from the values you read with the previous position of the voltmeter? Explain the result.
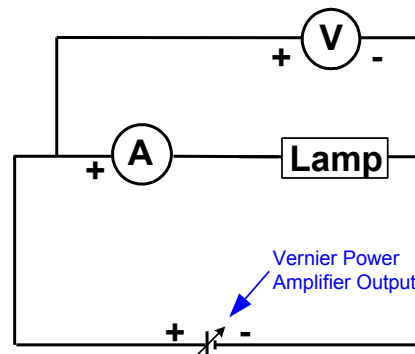
8. With the bulb still lit, and the Vernier voltage setting set at 3.0 V, read the voltage and the current then disconnect one end of the ammeter. How did that affect the reading of the voltmeter and the light on the bulb? If you think that the position of the voltmeter has a role in what you have observed, test it out.

Part Two: Ohm's Law – Light Bulb

1. Use the circuit you have built in the last step to collect data and determine whether the lamp obeys Ohm's law. Take readings for both positive and negative voltages (**Note that the Vernier interface does not provide negative voltages**: **you get negative voltages by swapping the leads of the interface**. **Alternatively, you get negative voltages by flipping the device you are testing**). V_L is the voltage across the lamp and I_L is the current through the lamp.

Supply Setting (volts)	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.0
V_L(volts)									
I_L(amps)									
Swap the leads of the light bulb. **This way, you will effectively subject the device to negative voltages and negative currents.**									
Supply Setting (volts)	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.0
V_L(volts)									
I_L(amps)									

2. Use a spreadsheet to plot your results. What do you conclude; does the light bulb obey Ohm's law? Explain your answer and if it does, determine the resistance of the light bulb.

Part Three: Ohm's Law – Resistor

1. Use the circuit you have built in the last step but replace the light bulb by the resistor. Take readings for both positive and negative voltages.

Supply Setting (volts)	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.0
V_R(volts)									
I_R(amps)									
Swap the leads of the resistor.									
Supply Setting (volts)	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.0
V_R(volts)									
I_R(amps)									

2. Use a spreadsheet to plot your results. What do you conclude; does the resistor obey Ohm's law? Explain your answer and if it does, determine its resistance.

Part Four: Ohm's Law – Propagation of Uncertainties

We will now make a first attempt at QUANTIFYING the uncertainties (errors) in our measurements.

For every basic measurement we make, there is an associated uncertainty. For a measurement coming from a ruler the uncertainty is roughly equal to the smallest notch on the ruler; i.e. if the smallest notch on the ruler is one mm = 0.1 cm, then a measurement of 40 cm should REALLY look like:

Distance = 40.0 cm ± 0.1 cm   or Distance = 0.400 m ± 0.001 m

Similarly, for voltage and current measurements the uncertainty is roughly equal to the smallest digit we can read out. You should have recorded these uncertainties in the earlier part of the experiment. You should be able to write voltage and current measurements in the form:

Voltage = 1.5 V ± 0.1 V and Current = 0.12 A ± 0.01 A

When combining these to form a resistance we obtain:

Resistance = Voltage / Current = (1.5 V ± 0.1 V)/(0.12 A ± 0.01 A)

In order to deal with the uncertainties in the equation and find the uncertainty in the overall velocity we use the formula:

$$(\text{Resistance Uncertainty/Resistance})^2 = (\text{Voltage Uncertainty/Voltage})^2 + (\text{Current Uncertainty/Current})^2$$

Think of this as a special Pythagoras-type ($a^2 + b^2 = c^2$) rule for combining the uncertainties of two measurements into one combined uncertainty. In the example above

$$(\text{Resistance Uncertainty/Resistance})^2 = (0.1 \text{ V} / 1.5 \text{ V})^2 + (0.01 \text{ A}/ 0.12 \text{ A})^2$$
$$= 0.0044 + 0.0069 \approx 0.011$$

Thus (Resistance Uncertainty/Resistance) = $\sqrt{(0.011)}$ = 0.107

And if Resistance = Voltage / Current = 1.5 V /0.12 A = 12.5 Ω

Then Resistance Uncertainty = 0.107 × (Resistance) = 0.107 × 12.5 Ω = 1.4 Ω

And we can express the final resistance with its uncertainty as R = 12.5 Ω ± 1.4 Ω (or even 13 Ω ± 1 Ω)

Now try it yourself with the light bulb and resistor measurements you did earlier. You can use the back of this sheet if you need additional space for your calculations. Use the numbers from the largest voltage and current measurements in each case. What uncertainties do you get for each resistance? How do these compare with the uncertainty given by measuring the resistance directly from the multimeter?