Interpreting Your *Ohm's Law* Results: Finding the Systematic Error
Spring 2024

Introduction

When the results from the *Ohm's Law* experiment earlier this semester were assembled, it was clear that there was a *systematic error* in the experiment. In every case, $R_1 + R_2 < R_{set}$. The purpose of today's experiments is to figure out *why* the sum of resistances measured separately was less than the measured combined resistance. *Be sure to use the same resistor set as you used for the Ohm's Law experiment!*

EXPERIMENT 1 – EXAMINING THE RESIDUALS FROM YOUR OHM'S LAW DATA

Figure 1: Extracting data from KaleidaGraph plot.

- *Note: Before proceeding, you must correct any calculation or plotting errors you might have previously made!*

1. Open your *Ohm's Law* KaleidaGraph plot and click on the "grid" icon in the upper right corner of the graph window to extract your data from the plot (**Figure 1**). If you chose not to follow the instructions from that experiment, create a plot of I vs. V, and make linear curve fits for R_1, R_2, and R_{set}.
2. Follow the instructions in "Graphing & Curve Analysis Using KaleidaGraph" to easily calculate the *residuals* from your graph. Recall that the residuals are the difference between the *predicted* y-value of a data point (as indicated by the best-fit line) and the *measured* y-value. Each residual indicates the amount by which the best-fit line misses each data point.
3. Rename each residual column (e.g., "Residuals R1", "Residuals R2", etc.) in the data window. *You should include the residual units as well!*
4. Graph the residuals vs. voltage for all three sets of data on *one* KaleidaGraph plot. Fit a 2^{nd} order polynomial curve to each residual set (The equations are not important today, so they don't need to be shown on the plot. The legend *must* be shown on the plot.)
5. Examine the curve fits you just applied. Which set of residuals show the greatest deviation from the expected current? Which has the smallest deviation? What does this tell you?
6. Print the residuals plot you just created.

EXPERIMENT 2 – DIRECT MEASUREMENT OF RESISTANCE AT ROOM TEMPERATURE

Figure 2: Circuit symbol for an ohmmeter.

1. Set up your multimeter as an ohmmeter to measure resistance (refer to the document "Using a Digital Multimeter"). *Without connecting the resistors to a power supply*, use the ohmmeter to measure R_1, R_2, and R_{set}. Set the ohmmeter to measure resistance as precisely as possible. Draw your ohmmeter (**Figure 2**) connected to the resistors and record your results.
2. How do the direct measurements of resistance with the ohmmeter compare to the values you calculated in *Ohm's Law* from your I vs. V graph – are they higher or lower?
3. Calculate $R_1 + R_2$ from the individual ohmmeter measurements, and compare to the *direct* ohmmeter measurement of R_{set}; how do they compare with each other? What conclusion can you draw? Be sure to restate your numerical results of resistance from the previous experiment!

EXPERIMENT 3 – OVERLOADING THE RESISTOR

1. The resistors used in this experiment will produce ¼ Watt of power when used at the rated current and voltage suggested by the manufacturer. Use your measured resistance for R_1 (from Experiment 2) to calculate the rated *current* for R_1; that is, find the amount of current that will produce ¼ Watt of power dissipation (recall that $P = I^2R$, where R is in ohms).
2. We'll call the amount of voltage needed to produce the rated current just calculated V_{max}. Calculate V_{max} for resistor R_1.
3. Look at the range of voltages used in the *Ohm's Law* experiment. What does your calculated value of V_{max} tell you might have happened to your resistor during the previous experiment?
4. Connect a circuit with a voltmeter, ammeter, and the single resistor. *You will be using a different power supply today, so your instructor will assist you.* Draw a circuit diagram in your journal, using the symbol in **Figure 3** for a *dual*, variable DC voltage supply. Measure the current (set the voltmeter to read with 0.1 *V* precision and the ammeter set to read to 0.01 *mA*) through the resistor as a function of the voltage, up to V_{max}. Then increase the voltage higher than V_{max} until you reach a maximum of 50 volts; record at least 6 data points above V_{max}. *Note that the resistor will get very hot above V_{max}!*

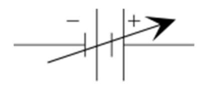

Figure 3: Circuit symbol for a dual, variable DC voltage supply

5. We wish to see what happens in the resistor as the voltage goes over V_{max}. You will create a plot of *I* vs. *V* in KaleidaGraph, but enter the data as shown in **Table 1**. I_{low} represents the current measured up to and including V_{max}; I_{high} is the current measured above V_{max}. Each dash (–) represents your measured voltage and current data (*your table will obviously have more data than shown*).
6. Set the minimum *x*- and *y*-axis values of your graph to 0 (*Plot → Axis Options*)
7. Apply a simple linear fit to I_{low}, the points *below* V_{max} (you don't need to display the equation). Do the data points above V_{max} lie on this best-fit line? Print the graph, label the V_{max} point and explain what your graph shows (*what happens to the slope above V_{max}?*)

	V (*volts*)	I_{low} (*mA*)	I_{high} (*mA*)
	0	0	
	5.0	–	
	10.0	–	
	–	–	
V_{max} →	–	–	
	–		–
	50.0		–

Table 1: Current through R_1 measured up to and above V_{max}.

8. Create a second graph of the resistance vs. the voltage for all the data you just collected (use the "Formula Entry" window to calculate the resistance – see page 4, steps 14-16 of your KaleidaGraph instructions). Mask the point at {0,0} by selecting the coordinates in the data table, then choosing **Mask** from the **Functions** menu, and then updating the plot. Print this graph as well, again labeling V_{max}. What do you notice happening to the resistance as the voltage increases?
9. **Draw and label** a horizontal line across your resistance vs. voltage graph that represents the resistance measured using the ohmmeter (Experiment 2, step 1). *If the measured resistance is off your chart, estimate its position.*

EXPERIMENT 4 – THE EFFECTS OF A CHANGE IN TEMPERATURE

10. Your instructor will perform a demonstration using conductors (metals), semi-conductors (e.g., the carbon resistors you previously used) and liquid nitrogen (LN_2: T = 77 K = -196 °C = -321 °F). Record the results and briefly describe the demonstration. *Note that the wire does not connect through a carbon resistor (**Figure 4a**), rather, the current flows through the resistor material (**Figure 4b**).*

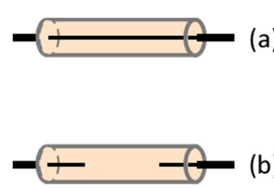

Figure 4: The wire does not extend through the resistor (a) but allows the current to flow through the resistor material (b)

Discussion

- Using what you have learned today, and your *I vs. V* graph from the *Ohm's Law* experiment, explain the cause of the systematic error that occurred during the *Ohm's Law* experiment; specifically, why was $R_1 + R_2 < R_{set}$? *Be sure to cite specific examples from* ***each experiment*** *performed today to support your explanation*.

WHEN FINISHED, PLEASE TURN OFF THE POWER SUPPLY AND MULTIMETERS, AND DISCONNECT ALL WIRES!