Ohm's Law
Spring 2024

Introduction

This week we will measure the current through two resistors in series. We will work with a power supply whose voltage can be continuously adjusted, and fixed resistors. The goal is to measure the resistance of two resistors and see if they act like a single resistor equal to the sum of the two when connected in series.

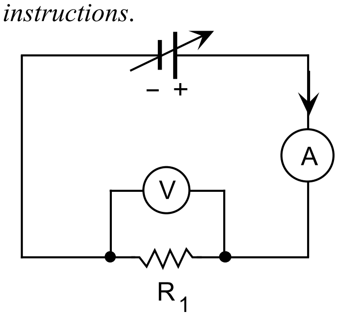
***Note**: The success of today's experiment depends upon the care and precision of your measurements!*

IMPORTANT NOTES ABOUT THE POWER SUPPLY:

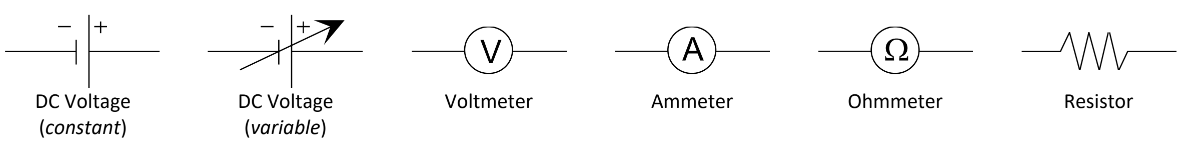
- Always connect your wires to the + and – terminals of the power supply *after* your elements are connected; never leave bare wires hanging from the power supply
- Don't use the GND connector on the power supply
- Turn the voltage knob on the power supply, but not the current knob!
- Never pull on the wire, only on the end connector

Experiment

1. Record in your journal the set designation ("A", "B", etc.) written on the block with your pair of resistors; you will need this information for the experiment next week! *If you are interested in the meaning of the color stripes on each resistor, read through the Appendix at the end of these instructions.*
2. Connect the circuit shown at right, beginning at the (+) terminal of the DC power supply and working around the circuit until you've reached the (–) terminal. The voltmeter should be connected *last*. You should draw a new circuit diagram whenever you change any of the components – a set of conventional circuit symbols that you will use this semester appears below.



Ask your instructor to check the connection of your circuit before turning on the power supply!



3. Measure and plot the current as a function of the voltage for R_1. Begin with the voltage at the maximum of 30.0 volts, then decrease by 5-volt increments down to 0 (set the multimeters so that the voltage is read to 0.1 V, and current read to 0.01 mA). Plot your data in Kaleidagraph *as it is measured*. This is important in identifying bad points or incorrect measurements. Take your readings from the digital ammeter and voltmeter, *not* the built-in meters on the power supply!

   - *Be sure that you include {0,0} in your data table. Note that your meters might read something other than zero even though the power supply is turned off!*

4. Now repeat the measurements on R_2, and finally on the set of R_1 and R_2 *in series* (call these measurements V_{set} and I_{set}). In each case you should use the **same** voltages as you did for R_1, so that in KaleidaGraph you will need to enter the voltages only once.

   Time saving tip: use one data table to record all your measurements!

   Be sure to graph the data for all three resistor measurements on a *single* Kaleidagraph plot (don't create three separate graphs!) You will add your data for R_2 to your graph of R_1 as follows: After creating the plot for R_1, enter your current data for R_2, then select your graph and again choose *Scatter* from the *Gallery* menu. Click the box next to the current data for R_2 and click "**Replot**". Repeat these steps to also add the data for R_1 and R_2 in series. *Be sure to leave the legend displayed on your graph!*

Analysis

For most single solid materials ***at constant temperature***, the relation between current and voltage is linear, making it useful to define resistance and Ohm's law: $I = \left(\frac{1}{R}\right)V$. Here R is the reciprocal slope of your graph and has units of *ohms* $\left(\Omega = \frac{\text{volts}}{\text{amperes}}\right)$. The units you'll use today are *kilohms* $\left(k\Omega = \frac{\text{volts}}{\text{milliamperes}}\right)$; leave your current measured in milliamperes (mA) – don't bother converting to amperes (A).

5. Fit a straight line (use "Linear w/Uncertainties") to each of your three current measurements; record the slopes and their uncertainties in your journal (recall that the uncertainty is twice the standard error calculated in KaleidaGraph), as well as the SSR for each fit. ***Save your graph*** *– you will need it for the upcoming "Systematic Error" experiment.*

   - *Carefully* examine your graph. If the best-fit line is not close to the center of **every** point, check that you have entered the data correctly. If it was entered correctly, then you **must** measure that point again, or you'll get erroneous results!

6. Print both the graph and data table you created in KaleidaGraph (*making it easier for your instructor to find typos*). Note that this data table does not replace the one you record in your journal!

7. Calculate R_1, R_2, and R_{set} from the reciprocals of the slopes for each line. *Don't round off until your final result; resistances should be calculated to 0.01 kΩ!*

8. The calculation of resistance is meaningless without considering the uncertainty of the measurements. The resistance was calculated from the reciprocal of the slope, but the uncertainty in the slope is ***not*** the same as the uncertainty in the reciprocal. Therefore, we will use a different procedure to calculate uncertainty, as outlined below (follow along with the example so that your calculations are correct):

   First, we will calculate the *% uncertainty* of the slope. The % uncertainty *is the same* for the slope and its reciprocal, so it will be used to calculate the % uncertainty of the resistance, R:

$$\%\text{ uncertainty of slope} = \frac{\text{uncertainty of slope}}{\text{slope}} \times 100$$

   For example, with the following values of the slope and its uncertainty (recall that the uncertainty in the slope is *twice* the standard error), we have:

$$\text{slope} = 0.339\,\tfrac{mA}{V}; \quad \text{uncertainty} = 0.001\,\tfrac{mA}{V}$$

$$\%\text{ uncertainty of slope} = \frac{0.001}{0.339} \times 100 = 0.3\%$$

Since the resistance is the inverse of the slope, we now have:

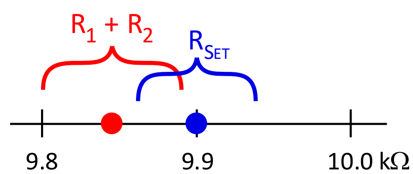
$$R = \frac{1}{\text{slope}} \pm \left(\%\ \text{uncertainty}\right) = \frac{1}{0.339} \pm 0.3\% = 2.95k\Omega \pm 0.3\%$$

Now use this % uncertainty to calculate the uncertainty of the resistance:

$$\text{uncertainty} = 2.95k\Omega \times 0.3\% = 2.95 \times 0.003 = 0.009k\Omega$$

Therefore, the resistance and its uncertainty R = 2.95±0.009 kΩ.

9. In class you found that two resistors connected in series can be replaced by a single equivalent resistor whose value is the sum of the two resistors. Today we are checking this: does R_{set} (the measured resistance of the series) equal $R_1 + R_2$ (the sum of the individual measured resistances)? You must include the uncertainties to answer this question (the uncertainty of $R_1 + R_2$ is the sum of the individual uncertainties.) Display your results on a number line as shown below, using your calculated uncertainty to show the spread in values.



Discussion

- Begin by restating your experimental results: the values for the resistances and their uncertainties, as well as the SSR of each fit.
- Did you find a substantial overlap ($\geq 0.1\ k\Omega$) between the uncertainties of R_{set} and $R_1 + R_2$? If not, then $R_{set} \neq R_1 + R_2$ within the range of uncertainty. Discuss reasons why you think the data are inconsistent with the theory.
- Which value is greater: R_{set} or $R_1 + R_2$? Look at the results from the other groups – do they agree with yours? Why do you think all groups get similar results?
    - The answer to these last two questions is not obvious, but consider this: *What assumption is made about the resistors?* (Hint: Did you read these instructions carefully?)
- **Finally, the person that plotted today's data should share the graph file with their lab partner(s)**. You will need this graph for the "Systematic Error" experiment later this semester, and it's helpful for each partner to have a copy of the graph.

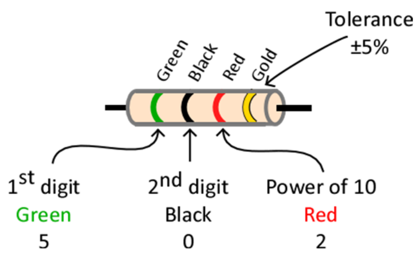
WHEN YOU ARE FINISHED, PLEASE:

- TURN THE POWER SUPPLY VOLTAGE KNOB DOWN TO ZERO
- DISCONNECT ALL WIRES FROM THE CIRCUIT
- LEAVE THE CURRENT KNOB WITH THE WHITE MARK VERTICAL
- TURN THE POWER SUPPLY AND MULTIMETERS OFF

Appendix: Resistor Color Codes

You will notice that each resistor on your block has stripes of different colors. Those colors represent the *nominal resistance* of the resistor, that is, the manufacturers rating of the resistance. One of the stripes also represents the *tolerance*, the percentage that the manufacturer says actual resistance will deviate from the nominal resistance.

Resistors can have from three to six stripes indicating the resistance and tolerance. These instructions tell you how to read the color code with four stripes (three for resistance, one for tolerance) using the table below:



0 – Black	5 – Green
1 – Brown	6 – Blue
2 – Red	7 – Violet
3 – Orange	8 – Gray
4 – Yellow	9 – White

Tolerance	
None:	±20%
Silver:	±10%
Gold:	±5%

- The first two colored bands give the first two significant figures.
- The third band gives the multiplier, 10^x.
- The fourth band gives the tolerance to which the resistor has been manufactured.

So, in the example shown above, the first band is green (5), the second is black (0), the third is red (2, so the multiplier is 10^2), and the fourth is gold (±5%). Therefore, the resistance is $50\times10^2\ \Omega$, or 5 kΩ, with a tolerance of ±5%.

Note that the tolerance is a value provided from the resistor's manufacturer; in the above example it means that the actual resistance of this resistor is within 5% of 5 kΩ.