General Physics II Lab (PHYS-2021)
Experiment ELEC-3:
OHM'S LAW and RESISTOR CIRCUITS

Objective:

The purpose of todays experiment is to verify Ohm's Law and to determine the equivalent resistance of series/parallel circuits.

Theory:

In metals and some other materials (in particular, commercially manufactured resistors), one finds experimentally that the voltage drop, V, across the material is directly proportional to the current, I, through the material (provided the temperature remains relatively constant):

$$V \propto I,$$

which is referred to as Ohm's Law. It is convenient to define a proportionality constant called the resistance (unit: Ohm [Ω] = V/A) such that

$$V = IR. \tag{1}$$

A resistor generally means a device that obeys Ohm's Law (many devices do not) and has a resistance R. Two (or more) resistors can be connected in series (as in Figure 1), or in parallel (as in Figure 2). Resistors could also be connected in a series/parallel circuit like Figure 3.

An equivalent resistor is a single resistor that could replace a more complex circuit and produce the same total current when the same total voltage is applied. For a series circuit, the resistances are additive:

$$R_{eq} = R_1 + R_2 \tag{2}$$

where R_{eq} is the equivalent resistance. For a parallel circuit, the resistances add as reciprocals

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \tag{3}$$

A more complex circuit like Figure 3 can be handled by noting that R2 and R3 are in parallel and can be reduced to an equivalent resistance using Equation 3. That equivalent resistance is then in series with R4 and can be treated using Equation 2 to find the equivalent resistance of the entire series/parallel circuit.

Equivalent Circuits Diagrams:

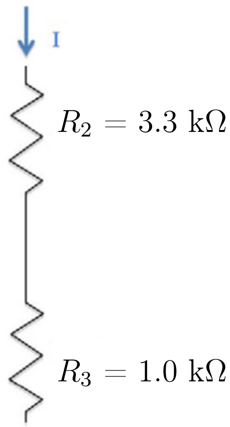


Figure 1: Series

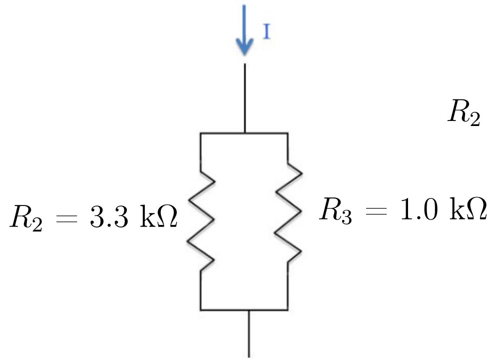


Figure 2: Parallel

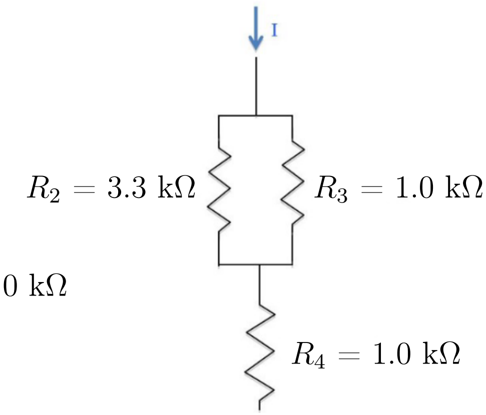


Figure 3: Series/Parallel

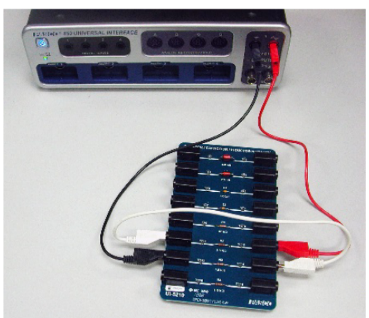


Figure 5: Series

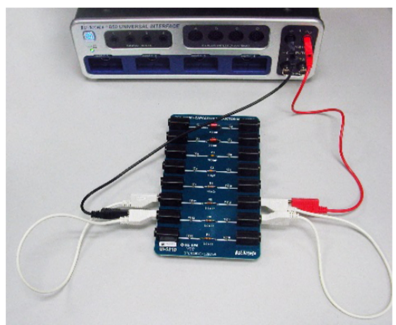


Figure 6: Parallel

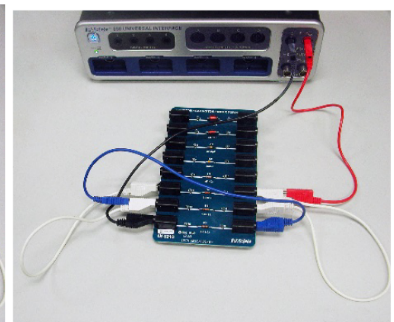


Figure 7: Series/Parallel

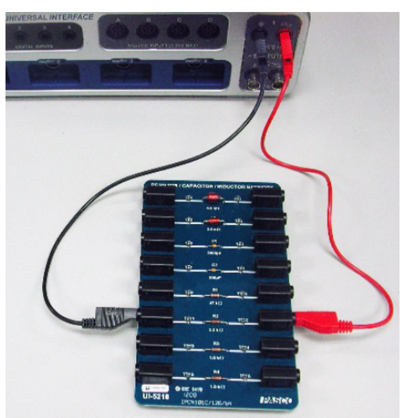


Figure 4: Initial Circuit Setup

Setup:

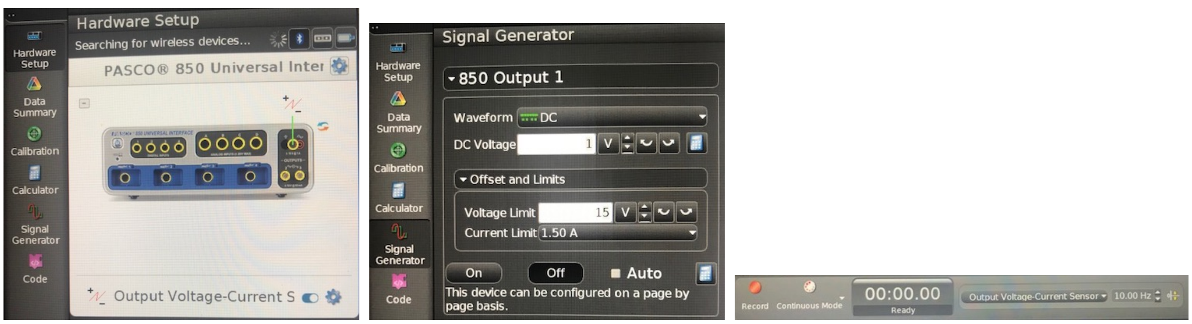
1. Setup the circuit using the 3.3 kΩ resistor as shown in Figure 4 on the previous page.

2. Verify your *PASCO 850 Universal Interface* is ***ON***.

3. Click on Hardware Setup and for Output 1, select the Output Voltage Current Sensor as shown in Figure 8(a).

4. Click open the Signal Generator at the left of the screen. Set Output 1 for a DC Waveform with a DC Voltage of 1V. Select ***ON*** as shown in Figure 8(b).

5. On the bottom of the screen, next to *Output Voltage-Current Sensor*, set the Common Sample Rate to 10 Hz as shown in Figure 8(c).



(a) Output Voltage Sensor (b) Signal Generator Setup (c) Common Sample Rate

Figure 8: Setup

6. Open the Calculator and create the following calculations:
`Iavg = avg([Output Current])*1000    (Units of mA)`

7. Create two digits displays and select the Output Voltage and the Average Current (i.e., *Iavg*). **Change the Average Current units from *A* to *mA*. Go to: Properties ( ) → Names and Symbols → Units → mA.**

6. Create a table with four columns: Create user-entered data sets called "*Voltage*" with units of V, "*Zero Current*" with units of mA, and "*Measured Current*" with units of mA.

7. Then, go to the calculator and define True Current as:
`True Current = [Measured Current]-[Zero Current]    (Units of mA)`

8. Following this, go to the 4th column of your table and select "True Current" from your options. The order is important. Your table should look like Table 1 on your data sheet.

9. The 850 Universal Interface can read currents with a resolution of about 0.01 mA. However, this is a small current and the instantaneous value fluctuates quite a bit. Fortunately, by taking an average over several seconds, we get a value with a precision of 0.01-0.02 mA. However, the noise can produce a systematic error up to about 5 mA with a variation across the range of almost 1 mA, so we must calibrate the system to get accurate values (± 0.1 mA due to variation in zero noise).

10. Calibration Run: Unplug the red lead from the 850 Universal Interface. The current should now be zero for all voltage, but is not. Click RECORD. Wait a few seconds until the Average current reading stop drifting. Record the Average Current value in the Zero Current column of Table I. If the Actual Voltage is different from the Voltage shown in the first column of the table, change the table to match the actual voltage. Click STOP.

11. Change the Signal Generator to 3V and repeat Step 10. Repeat again for voltages of 6 V, 9 V, 12 V, & 15 V.

12. Set the Signal Generator back to 1 V.

13. Experiment Run: plug the red lead back into the 850 Output 1 jack. Repeat Steps 10 & 11 except record the values for Average current in the Measured Current column. The True Current is the difference between the Measured Current and the Zero Current.

14. Turn off the Signal Generator.

GENERAL COMMENTS:

1. Using “`Iavg`“ for the Average Current provides a relatively constant value.

2. Subtracting off the Zero Current is important. It cannot be neglected. Due to the systematic error in the current, it can actually sometimes read negative. If you subtract off the Zero Current, you will get a True Current that is positive, and that scales properly with Voltage.

3. When making the plot, to put in the horizontal error bars, you will select the gear and then click on Active Data appearance, and then scroll down to the Show Horizontal Error Bars Entry reproduced in the writeup (don't forget to check the Show Horizontal Error Bars box).

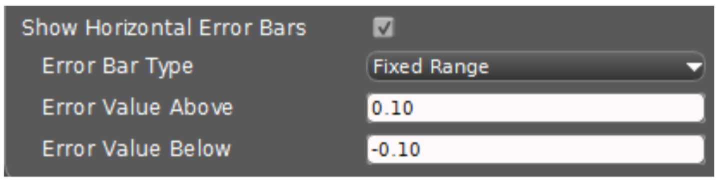
4. You have the option of either copying the data presented on the computer screen by hand, or sending the data table to the Departmental Printer in Brown Hall 262. If you plan to send any output to this printer, you will have to first log in to the wireless on the laptop. Your instructor will show you how to do that.

Procedure: Ohm's Law

1. Create a graph of Voltage (user-entered data) vs. True Current.

2. Click on the black triangle by the Curve Fit Icon ( ) on the graph toolbar and select Linear.

3. Open the properties ( ) on the graph and under "Active Data Appearance", select to show horizontal error bars for a fixed range of ±0.1 mA. This is the uncertainty in the True Current which was achieved by calibrating the system. The uncertainty in the Voltage is much too small to show.



4. The uncertainties in the slope and intercept arise from the spread of the data points but do not include the uncertainty in the True Current. This means that the quoted uncertainties are too small. You can get a good approximation to the actual uncertainties in slope and intercept (without elaborate math) by holding a transparent ruler up to the screen (or printing off the graph) and seeing how much you can vary the slope and intercept with a straight line that still fits the data (including error bars) reasonably well.

Procedure: Resistance Measurements of Isolated & combined Resistors

1. Resistor Measurement Check: The resistors on the UI-5210 circuit board are accurate to within ±5%. This can be improved substantially by measuring the resistor directly using a multimeter. These will generally measure resistance ±1%.

   (a) Disconnect all the wires from the circuit board.

   (b) Use a multimeter (if available) to measure the resistance of resistors R1, R2, R3, & R4 on the circuit board. Record these values in Table 2 of your Data Sheet.

2. Theory Resistance: Using Equivalent Circuits and the values for the resistors from Table 2, calculate the equivalent resistance for each of the three circuits shown on the previous page. Enter the values in the Theory Resistance column of Table 3.

Equivalent Circuits

1. Click open the Signal Generator. Set Output 1 for a DC waveform with a DC Voltage of 15 V. Click **ON**. Close the Signal Generator panel.

2. Calibrate Check: The zero current was measured at the beginning of class. Record the zero current you measured for 15.00 V in the I_{zero} column of Table 4.

3. Verify that Output 1 Voltage reading is set to 15.00 V.

4. Set up the circuit shown in Figures 1 & 5.

5. Click `RECORD` and record until the Average Current stops changing. Record the value of the Average Current in the I_{avg} column of Table 4. Calculate I_{true} using the equation below.
   $I_{true} = I_{avg} - I_{zero}$.

6. Using the I_{true} values and Equation 1 from Theory section, calculate the experimental resistance of the circuit and record this value in the $R_{experimental}$ column of Table 4.

7. Set up the circuit shown in Figures 2 & 6. Repeat steps 5 & 6.

8. Set up the circuit shown in Figures 3 & 7. Repeat steps 5 & 6