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Partners: ____

PHYS-2212 LAB

Ohm's Law and Measurement of Resistance

Objectives

Part I: Comparing the relationship between electric current and potential difference (voltage) across an *ohmic* resistor with the voltage-current relationship for the filament of an incandescent light bulb (a *non-ohmic resistor*)

Part II: Evaluating two methods of measuring resistance using the voltmeter-ammeter method

Introduction

When a potential difference ΔV is applied across a resistor or some other circuit element in an electric circuit, experiment shows that the electric current I through that element is defined as:

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

Eqn. 1

where R is the electrical resistance of the conductor. This relationship is known as Ohm's law, and the ratio V/I may be used to calculate the resistance of a circuit element for known values of the current and potential difference (voltage) across the conductor. The resistance of a conductor depends only on the geometric dimensions (such as length, cross-sectional area), the nature of the material from which it is constructed, and its temperature. Circuit elements, such as resistors, that obey Ohm's law, within the range of voltage and current values for which the ratio V/I is constant, can be described as "*ohmic*". Thus, for an ohmic circuit element, the current is directly proportional to the voltage across its ends and inversely proportional to its resistance. Therefore, the graph of the voltage against the current is linear, and the slope of the graph is the value of the resistance. For "*non-ohmic*" circuit elements, the relationship between the voltage and current is not linear. The filament of an incandescent light bulb is a typical example of a non-ohmic resistor. As the filament heats up and cools down, its resistance changes significantly.

In Part I of these experimental activities, students will explore how the response of an ohmic resistor to an applied potential difference compares to the response of small light bulb. For this activity, a small potential difference is applied across a resistor from a signal generator of the *ScienceWorkshop* (computer-based interface) while a series current sensor and a parallel voltage sensor measure the current through the resistor and voltage across the resistor, respectively.

Part II focuses on how the resistance values of the ammeter and voltmeter used in an electric circuit affect the measurements of current and voltmeter across a circuit resistor. The use of ammeters and voltmeters in a circuit intrinsically alters the circuit such that the measured values of the current and voltage may differ from the actual values. Therefore, it is not so straightforward to determine the resistance of a resistor by measuring the voltage and current values and finding the ratio *V/I*.

When the voltmeter is connected in *parallel* across only the resistor, the ammeter that is in series with this parallel combination measures the total current (*I*) that passes through the voltmeter as well as the resistor. [Figure 5] Therefore, though the voltmeter gives the desired voltage across the resistor, the ammeter reading does not give the exact value of the current through the resistor (*R*). If the resistance of the voltmeter in the 20-V range is R_v, the current through the voltmeter is given by Ohm's law as $I_v = V/R_v$ and the current through the resistor *R* becomes $(I - I_v)$. Therefore, the resistance *R* is given by

$$R = \frac{V}{I - I_v} = \frac{V}{I - V/R_v}$$

Eqn. 2

With the voltmeter connected to include the resistor and the ammeter, as in Figure 6, the ammeter reads the desired current through the resistor. However, the voltmeter reads the voltage across both the resistor and the ammeter in *series*. If the resistance of the ammeter is R_a, then

$$V = I(R + R_a)$$

Eqn. 3

Apparatus

Low voltage (0 – 12 V dc) variable power supply, two digital multimeters (DMM), a resistor, light bulb (3 V), connecting wires, PASCO *ScienceWorkshop750* module that is interfaced with a computer running *DataStudio* software, current sensor, voltage sensor, and PASCO AC/DC Electronics Laboratory unit.

Figure 1: *ScienceWorkshop*

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Experimental Procedure

Part I: Voltage and Current relationship for Ohmic and Non-ohmic resistors

1. The *ScienceWorkshop* should be already connected to the lab computer. Connect the cylindrical din plug of the voltage sensor to the analog input socket *A*. Connect the cylindrical din plug of the current sensor to the analog input socket *B* of the *ScienceWorkshop*, as shown in Figure 1 above.
2. Place the resistor in the pair of component springs nearest to the input jacks at the lower left corner of the AC/DC lab board, as shown in Figure 2.
3. The current sensor will now be connected in series with the signal generator and the resistor. Using a connecting wire, connect the "OUTPUT" (positive) terminal of the signal generator, on the lower right corner of the *ScienceWorkshop*, to the positive (red) jack of the current sensor. Connect the other jack (black) of the current sensor, using another wire, to one end of the resistor, at one jack on the AC/DC circuit lab board. Connect the other end of the resistor, at the other jack on the AC/DC lab board, to the ground (±) terminal (0 *V*) of the signal generator of the *ScienceWorkshop*.
4. Connect the red and black leads of the voltage sensor in parallel across the ends of the resistor on the AC/DC lab board, with the positive (red) lead connected to the jack previously connected to the current sensor, and the negative (black) lead connected to the jack that is already connected to the ground terminal of the signal generator.

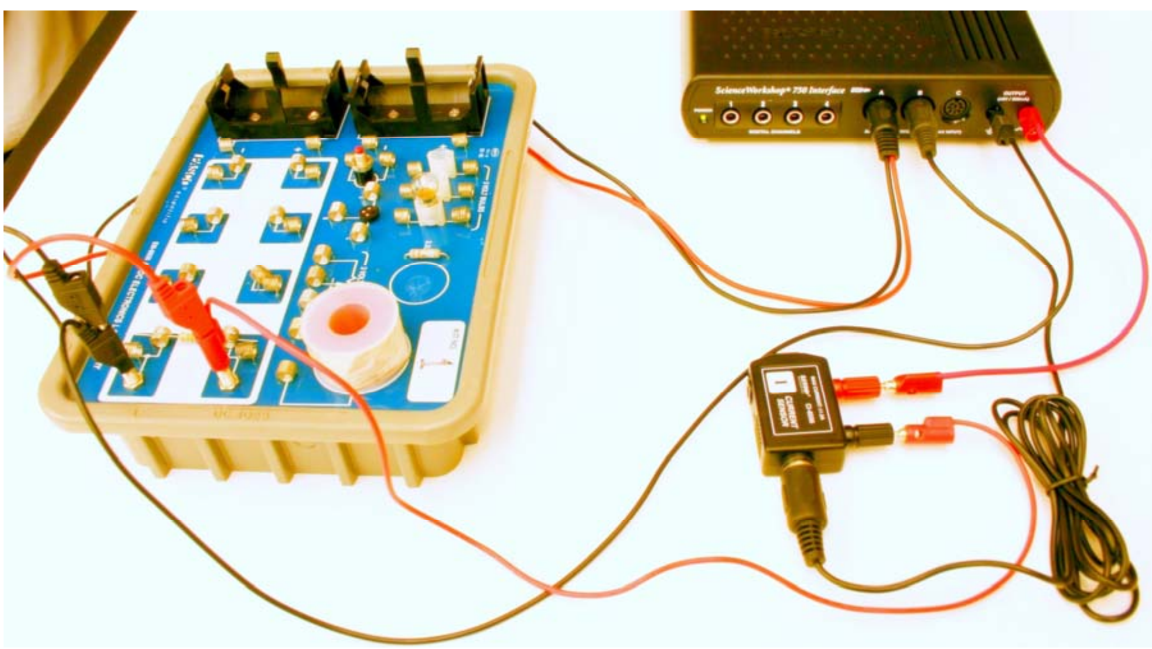


Figure 2: Ohm's Law setup

5. Open the *DataStudio* activity document titled – "*Resistance.ds*" – and located in the Physics Labs folder.
6. If not already open, click on the "Experiment SETUP" button visible on the file. On the image of the *ScienceWorkshop*, click at the "OUTPUT" port of that image to open the dialog box for setting the parameters of the signal generator. Verify that the signal generator is already preset to provide a triangle wave at 1.0 *Hz*, with voltage amplitude between + 2.0 *volts* and – 2.0 *volts*.
7. Click the "Start" button in *DataStudio* to begin the automatic acquisition of data for a period of 1.0 s for a full cycle of potential difference.
8. Observe a display of the plot of the voltage and current data similar to Figure 3. The line of best fit through the data points will be displayed with its parameters. If these parameters (e.g. slope, *y*-intercept, etc.) are not displayed, click the "Fit" button and select "Linear fit".
9. Click the "Smart Tool" and move the box to trace the "*Voltage–Current*" coordinates of any point on the graph. Record the ratio of voltage versus current (should be the same as the slope) as the resistance of the resistor. Print and submit one copy of the graph display.

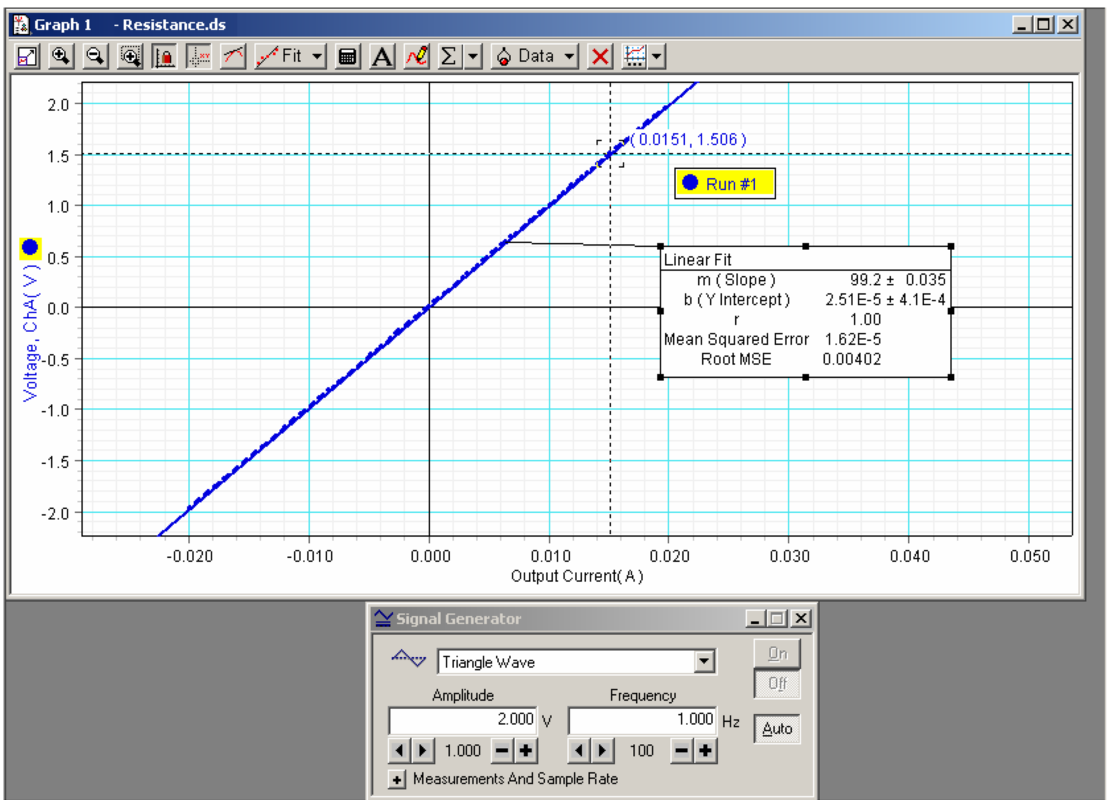
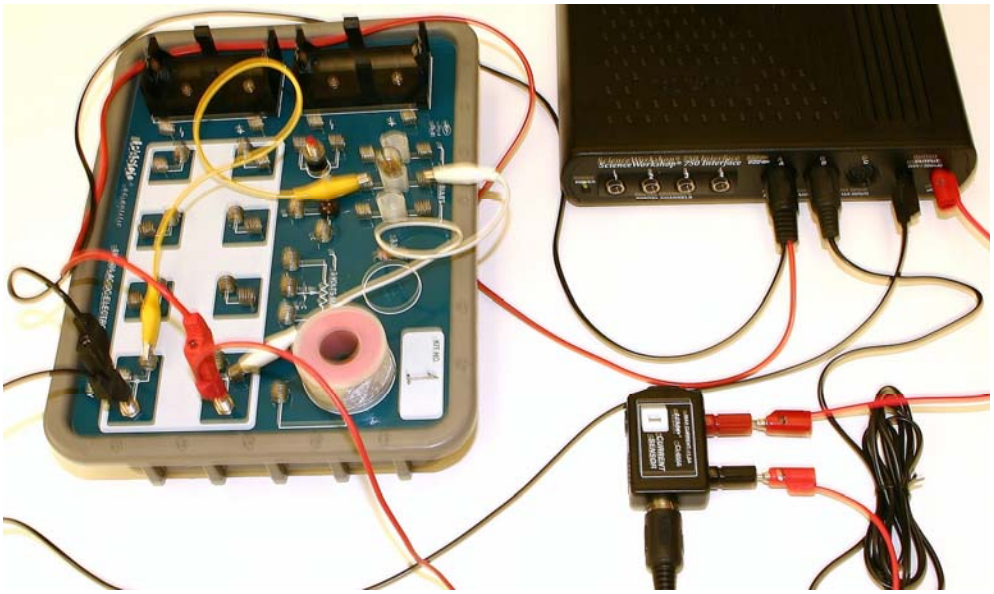


Figure 3: *DataStudio* display of Voltage vs. Current for an *ohmic* resistor

10. Remove the resistor from the component springs on the AC/DC lab board. Measure and record the value of the resistance.

11. To investigate the behavior of the voltage and current for the small incandescent light bulb (3 *V*), connect the bulb to the input jacks on the lab board using two connecting wire leads.



12. Delete the "Linear Fit" dialog box. Click "Start" and observe the data display similar to Figure 4. Print and submit one copy of the graph display. Use the "Scale-to-fit" button to adjust the display, if necessary.
13. Use the built-in analysis tools, such as the "Smart Tool" to determine the voltage-to-current ratio at each point on the trace and record your observations.

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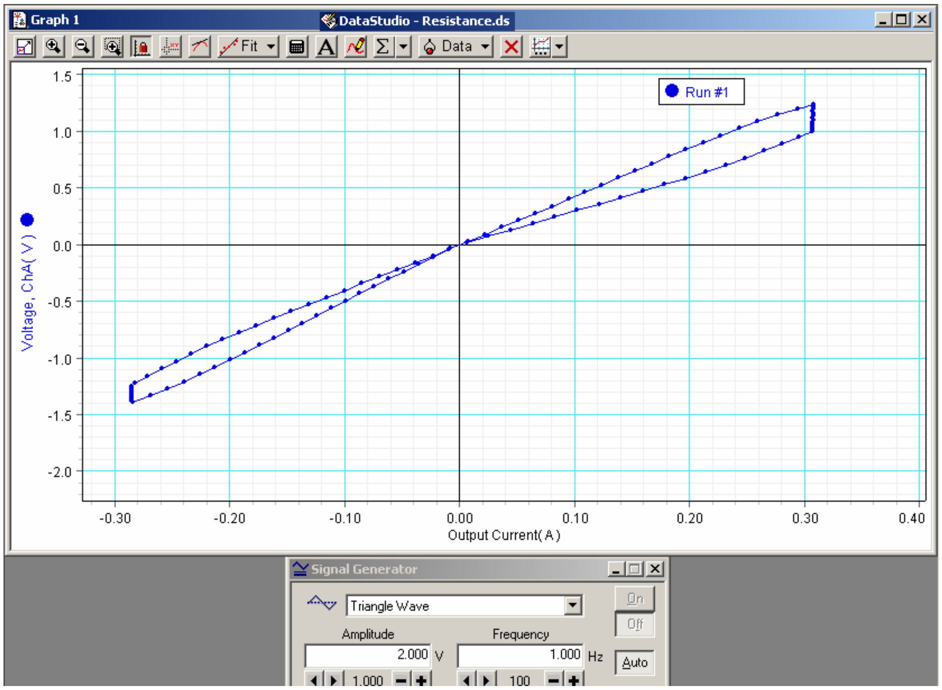

Figure 4: *DataStudio* display of Voltage vs. Current for a non-*ohmic* bulb filament

14. Disconnect the circuit connecting wires from the light bulb. Measure and record the (room) resistance of the bulb filament using a DMM. Note the current room temperature in the lab.

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Part II: Methods of Measuring Resistance

15. Measure and record the actual resistance of the given nominal 100-ohm resistor using a digital multimeter (DMM).
16. Connect the power supply in series with one DMM (as an ammeter) and the 100-ohm resistor. Connect the second DMM as a voltmeter (in parallel) directly across the 100-ohm resistor, with the positive terminal of the voltmeter connected to the end of the resistor closest to the positive (+) side of the power supply, as shown in Figure 5.

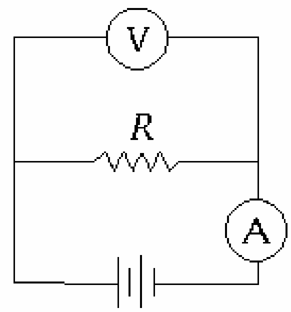

Figure 5: Voltmeter-Ammeter measurement – Circuit 1

17. Set the ammeter initially on the 10-A current range and adjust to the *milliamp* range if necessary. Set the voltmeter on the 20 V range. Switch on the power supply and increase the voltage output of the power supply from 0 to 5 V, in increments of 1.0 V. Record the readings of the voltmeter and the ammeter for each adjustment in Table 1.

18. Switch off the power supply immediately after taking the readings and reset the voltage adjust of the power supply to zero.

19. Next, connect the voltmeter in parallel across the series combination of the resistor *and* the ammeter, as shown in Figure 6.

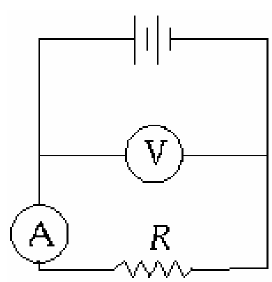

Figure 6: Voltmeter-Ammeter measurement – Circuit 2

20. Repeat the procedure step #3 above. Record the readings of the voltmeter and ammeter for 1.0-V increments of the output voltage of the power supply from 0 to 5 V in Table 2.

21. Switch off the power supply immediately after taking the readings and reset the voltage adjust of the power supply to zero.

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Analysis of Data ____

Part I: Voltage and Current relationship for Ohmic and Non-ohmic resistors

1. Present the voltage and current data acquired from the display in Procedure step#9 for the resistor.

2. Determine the standard deviation of a *significant* number of the resistance values within the range from 0 to 2 V

3. Compare the voltage/current ratio with the resistance value measured with a DMM in Procedure step#10.

4. Present the voltage and current data acquired from the display in Procedure step#12 for the incandescent light bulb.

5. Based on your experimental data, by what factor does the resistance of the bulb filament change as it heats up and cools down in the range from -2 V to 2 V?

6. Discuss the nature of the voltage/current characteristic curve and compare the voltage/current ratios with the "room temperature" resistance of the bulb filament measured with a DMM in Procedure step#14.

7. Briefly explain why the slope of the *V/I* graph in Figure 4 is not symmetric for the light bulb filament. Recall that the voltage amplitude from the signal generator varied between -2 V and +2 V.

Part II: Methods for Measuring Resistance

8. Record of the voltmeter and ammeter readings obtained in Procedure step#17.

Table 1: Voltage and Current values for the resistance – Circuit 1

Voltage across resistor, (*V*)	**Current through resistor, (*I*)**
0.00	0.00

9. Plot a graph of the data in the table above with the *Voltage* (ΔV) as ordinates (vertical axis) and the *Current* (I) as abscissa. Draw a regression line (or the line of best fit) through your points. Calculate the slope of this graph of ΔV vs. I. Submit your graph paper.

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10. Evaluate the percent difference between the resistance derived from the graph and the value determined in Procedure step#15.

11. Based on the slope of the graph from Table 1 data, apply Eqn. 2 and the measured resistance value from Procedure step#15 to estimate the resistance, R_v, of the DMM as a voltmeter in the 20-V range.

12. Record of the voltmeter and ammeter readings obtained in Procedure step#20 for Circuit 2.

Table 2: Voltage and Current values for the resistance – Circuit 2

Voltage across resistor, (*V*)	**Current through resistor, (*I*)**
0.00	0.00

13. Plot a graph of the data in the table above with the *Voltage* (ΔV) as ordinates (vertical axis) and the *Current* (I) as abscissa. Draw a regression line (or the line of best fit) through your points. Calculate the slope of this graph of ΔV vs. I. Submit your graph paper.

14. Evaluate the percent difference between the resistance derived from the graph and the value determined directly with a DMM in Procedure step#15.

15. Based on the slope of the graph from Table 2 data, apply Eqn. 3 and the measured resistance value from Procedure step#15 to estimate the resistance, R_a, of the DMM as an ammeter.

16. How can these errors associated with the connections of the voltmeter and ammeter in Circuit 1 and Circuit 2 be minimized? What factors should be considered critical in the design of the voltmeter and ammeter in order to minimize these errors?