Name ______________________ Section ____________ Date ____________

Laboratory 28

Measurement of Electrical Resistance and Ohm's Law

PRELABORATORY ASSIGNMENT

Read carefully the entire description of the laboratory and answer the following questions based on the material contained in the reading assignment. Turn in the completed prelaboratory assignment at the beginning of the laboratory period prior to the performance of the laboratory.

1. If a circuit element carries a current of 3.71 A, and the voltage drop across the element is 8.69 V, what is the resistance of the circuit element? Show your work.

   R = ________________ Ω

2. A resistor is known to obey Ohm's law. When there is a current of 1.72 A in the resistor it has a voltage drop across its terminals of 7.35 V. If a voltage of 12.0 V is applied across the resistor, what is the current in the resistor? Show your work.

   I = ________________ A

3. The resistivity of copper is 1.72×10^{-8} Ω−m. A copper wire is 15.0 m long, and the wire diameter is 0.0500 cm. What is the resistance of the wire? Show your work.

   R = ________________ Ω

4. A wire of length 10.0 m has a resistance of 2.75 Ω. What is the resistance of a piece of that same wire whose length is 25.0 m? Show your work.

   R = ________________ Ω

5. A wire of cross-sectional area 5.00×10^{-6} m^2 has a resistance of 1.75 Ω. What is the resistance of a wire of the same material and length as the first wire, but whose cross-sectional area is 8.75×10^{-6} m^2? Show your work.

R = ________________ Ω

6. A wire of length 10.0 m and cross-sectional area 6.00×10^{-6} m^2 has a resistance of 3.75 Ω. What is the resistance of a wire of the same material as the first wire, but whose length is 30.0 m, and whose area is 9.00×10^{-6} m^2? Show your work.

R = ________________ Ω

7. Three resistors of resistance 20.0 Ω, 30.0 Ω, and 40.0 Ω are connected in series. What is their equivalent resistance? Show your work.

R = ________________ Ω

8. Three resistors of resistance 15.0 Ω, 25.0 Ω, and 35.0 Ω are connected in parallel. What is their equivalent resistance? Show your work.

R = ________________ Ω

Laboratory 28

Measurement of Electrical Resistance and Ohm's Law

OBJECTIVES

In this experiment, measurements of the voltage across a wire coil and the current in the wire coil will be used to accomplish the following objectives:

1. Definition of the concept of electrical resistance of matter using coils of wire as an example
2. Demonstration of the dependence of the resistance on the length, cross-sectional area, and resistivity of the wire
3. Demonstration of the equivalent resistance of resistors in series and in parallel arrangements

EQUIPMENT LIST

1. Resistance coils (standard set available from Sargent-Welch or Central Scientific consisting of 10-m and 20-m length of copper and German silver wire)
2. Ammeter (range, 0–2 A; direct current)
3. Voltmeter (range, 0–30 V; direct current, preferably digital readout)
4. Direct-current power supply (0–20 V at 2 A will provide the necessary 2 A for all but the German silver coil)

THEORY

If a potential difference V is applied across some element in an electrical circuit, the current I in the element is determined by a quantity known as the resistance R. The relationship between these three quantities serves as a definition of the quantity resistance. This relationship, and thus the definition of R is

$$R = \frac{V}{I} \tag{1}$$

An object that is a pure resistor has its total electrical characteristics determined by equation 1. Other circuit elements may have other important electrical characteristics in addition to resistance such as capacitance or inductance. The resistance of any circuit element, whether it has other significant electrical properties or not, is given by the ratio of voltage to current as described in equation 1. For any given circuit element, the value of this ratio may change as the voltage and current changes. Nevertheless, the ratio of V to I defines the resistance of the circuit element at that particular voltage and current. The units of resistance are thus volt/ampere, which is given the name ohm. The symbol for ohm is Ω.

Certain circuit elements obey a relationship that is known as Ohm's law. For these elements, the quantity R (equal to V/I) is a constant for different values of V and thus different values of I. Therefore, in order to show that a circuit element obeys Ohm's law, it is necessary to vary the voltage V (the current I will then also vary) and observe that the ratio V/I is in fact constant. In this experiment such measurements will be performed on five different coils of wire to show that they do obey Ohm's law and to determine the resistance of the coils.

The resistance of any object to electrical current is a function of the material from which it is constructed, as well as the length, cross-sectional area, and temperature of the object. At constant temperature the resistance R is given by

$$R = \rho\frac{L}{A} \tag{2}$$

where R is the resistance (Ω), L is the length (m), A is the cross sectional area (m^2), and ρ is a constant dependent on the material called the resistivity (Ω-m). Actually ρ is a function of temperature, and if the coils of wire that are used in this experiment heat up as a result of the current in them, this may be a source of error.

Circuit elements in an electrical circuit can be connected in series or parallel. Consider the case of three resistors, R_1, R_2, and R_3, connected in series as shown in Figure 28.1. For resistors in series, the current is the same for all the resistors, but the voltage drop across each resistor depends on the value of the resistors. For resistors in series the equivalent resistance R_e of the three resistors is given by the equation

$$R_e = R_1 + R_2 + R_3 \tag{3}$$

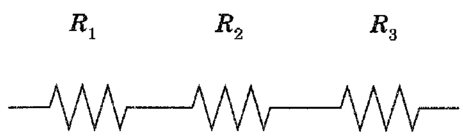

Figure 28.1 Resistors in series.

Consider the case of three resistors in parallel as shown in Figure 28.2. For resistors in parallel the current is different in each resistor, but the voltage across each resistor is the same. In this case the equivalent resistance R_e of the three resistors in terms of the individual resistors is given by

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \tag{4}$$

One of the objectives of this experiment will be to confirm the behavior of resistors in series and parallel which has been described above.

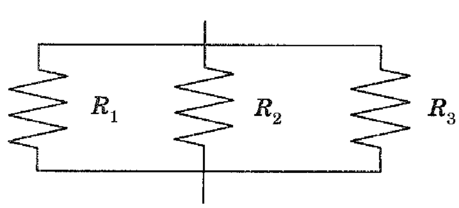

Figure 28.2 Resistors in parallel.

EXPERIMENTAL PROCEDURE

1. Connect the ammeter A, the voltmeter V, and the power supply PS to the first resistor as shown in Figure 28.3. Note that the basic circuit is the power supply in series with a resistor. In order to measure the current in the resistor, the ammeter is placed in series with it. In order to measure the voltage drop across the resistor, the voltmeter is placed in parallel with it.

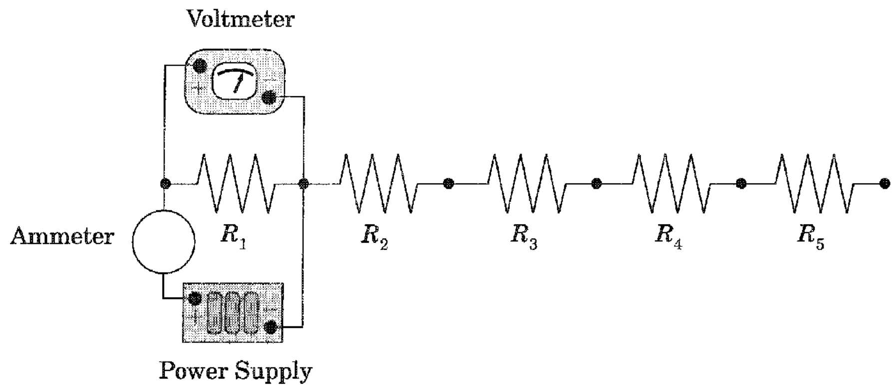

Figure 28.3 Measurement of current and voltage for resistor R_1

2. Vary the current through resistor R_1 in steps of 0.250 A up to 1.000 A. For each specified value of the current, measure the voltage across the resistor and record the values in Data Table 1. The resistors will heat up and may be damaged by allowing the current to pass through them for long periods. For this reason, measurements should be made quickly at each value of the current, and the power supply should be turned up only while measurements are actually being taken. *DO NOT LEAVE THE VOLTAGE TURNED UP WHILE DECIDING WHAT TO DO NEXT!*

3. Repeat step 2 for each of the five resistors. Be sure that for each resistor the ammeter is in series with that resistor and the power supply and the voltmeter is in parallel with the resistor. If the ammeter and voltmeter being used have multiple scales, be sure that the scales agree at the crossover point. Record all values in Data Table 1.

4. Connect the first four resistors in series and measure the equivalent resistance of the combination. To accomplish this, use two values of current, 0.500 A and 1.000 A, and measure the value of the voltage drop for these two values of current. Record these values of voltage in Data Table 2, and from these values of voltage and current, a value for the resistance will be later calculated.

5. Measure the voltage drop across the combination of the second, third, and fourth resistors in series for the current values of 0.500 A and 1.000 A and record in Data Table 2.

6. Connect R_1 and R_2 in parallel as shown in Figure 28.4 and measure the resistance of this parallel combination. Measure the voltage drop across the combination for current values of 0.500 A and 1.000 A and record in Data Table 2 for later calculation.

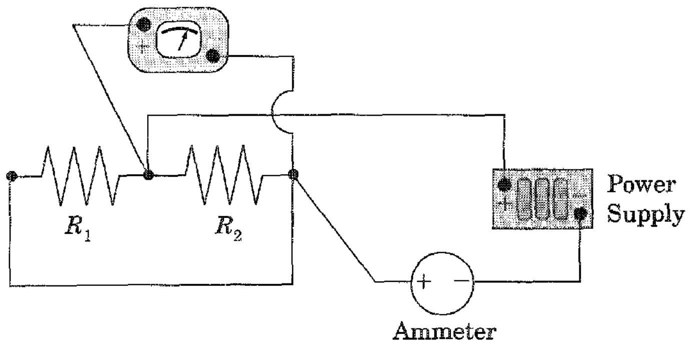

Figure 28.4 Resistors R_1 and R_2 in parallel.

7. Connect R_1 and R_3 in parallel as shown in Figure 28.5 and again measure the voltage drop for current values of 0.500 A and 1.000 A and record in Data Table 2.
8. Connect R_2 and R_3 in parallel and perform the same measurements as described in steps 6 and 7. Record the results in Data Table 2.

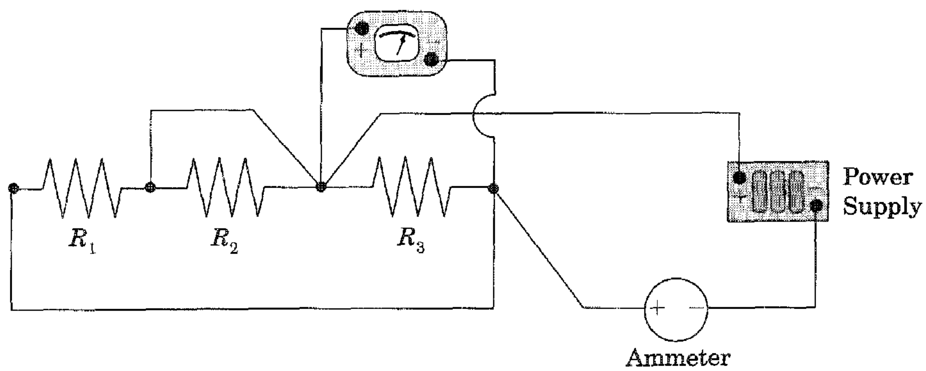

Figure 28.5 Resistors R_1 and R_3 in parallel.

CALCULATIONS

1. The first four coils are made of copper with a value of resistivity of $\rho = 1.72 \times 10^{-8}$ Ω-m. The fifth coil is made of an alloy known as German silver, which has a resistivity of $\rho = 28.0 \times 10^{-8}$ Ω-m. The first, second, and fifth coils are 10.0 m long, and the third and fourth coils are 20.0 m long. The diameters of the first, third, and fifth coils are 0.0006439 m, and the diameters of the second and fourth coils are 0.0003211 m. Using these values in equation 2, calculate the value of the resistance for each of the five coils and record the results in Calculations Table 1 as the theoretical values for the resistance R_{theo}.
2. If equation 1, which defines R is solved for V, the result is $V = IR$. This equation states that there is a linear relationship between the voltage and the current, and that the slope of the straight line in a graph of V versus I will be the resistance R. Perform a linear least squares fit to the data in Data Table 1 for the voltage as a function of the current for each of the five resistors. Make V the ordinate and I the abscissa in the fit. Determine the slope of the fit for the data on each resistor

and record it in Calculations Table 1 as the experimental value for the resistance R_{exp}. Also calculate and record the value of the correlation coefficient r for each of the least squares fits.

3. Calculate the percentage error in the values of R_{exp} compared to the values of R_{theo} for the five resistors and record the results in Calculations Table 1.

4. For the data of Data Table 2, calculate the values of the equivalent resistance for the various series and parallel combinations listed in the table. Record in Calculations Table 2 these experimental values of the equivalent resistance for each of the two trials as the value of the measured voltage divided by the appropriate current ($V/0.500$ and $V/1.000$). Calculate and record the mean of the two trials as $\overline{(R_e)_{exp}}$ in both Calculations Table 2 and Calculations Table 3.

5. Equations 3 and 4 give the theoretical expressions for equivalent resistance for series and parallel combinations of resistance. Calculate a theoretical value for the equivalent resistance for each series and parallel combination measured in Data Table 2. However, for the values of the individual resistances R_1, R_2, and R_3 in equations 3 and 4, use the experimental values determined from the least squares fit to the data on the individual resistors. These values are the appropriate ones to use because often these resistor coils have been abused over the years by being overheated, and their present resistance may no longer be the same as that calculated by equation 2. Record this theoretical value for the equivalent resistance in each case as $(R_e)_{theo}$ in Calculations Table 3.

6. Calculate the percentage difference between the values of $\overline{(R_e)_{exp}}$ and $(R_e)_{theo}$ for each of the series and parallel combinations measured and record the results in Calculations Table 3.

GRAPHS

Construct graphs of the data in Data Table 1 with V as the ordinate and I as the abscissa. Use only one piece of graph paper for all five resistors, making five small graphs on that one sheet. Choose different scales for each graph if needed, but make the five graphs as large as possible while still fitting on one page. Also, show on each small graph the straight line for the least squares fit.

Name ______________________ Section ____________ Date ____________

Laboratory 28

Measurement of Electrical Resistance and Ohm's Law

LABORATORY REPORT

Data Table 1

I (A)	V_{R1} (V)	V_{R2} (V)	V_{R3} (V)	V_{R4} (V)	V_{R5} (V)
0.250					
0.500					
0.750					
1.000					

Data Table 2

Combination	I (A)	V (V)
$R_1 R_2 R_3 R_4$ Series	0.500	
	1.000	
$R_2 R_3 R_4$ Series	0.500	
	1.000	
$R_1 R_2$ Parallel	0.500	
	1.000	
$R_1 R_3$ Parallel	0.500	
	1.000	
$R_2 R_3$ Parallel	0.500	
	1.000	

SAMPLE CALCULATIONS

Calculations Table 1

	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	R_4 (Ω)	R_5 (Ω)
R_{theo}					
R_{exp}					
r					
% error R_{exp}					

Calculations Table 2

Combination	$(R_e)_{exp}{}^1$ (Ω)	$(R_e)_{exp}{}^2$ (Ω)	$\overline{(R_e)_{exp}}$ (Ω)
$R_1 R_2 R_3 R_4$ Series			
$R_2 R_3 R_4$ Series			
$R_1 R_2$ Parallel			
$R_1 R_3$ Parallel			
$R_2 R_3$ Parallel			

Calculations Table 3

Combination	$(R_e)_{theo}$ (Ω)	$\overline{(R_e)_{exp}}$ (Ω)	% diff
$R_1 R_2 R_3 R_4$ Series			
$R_2 R_3 R_4$ Series			
$R_1 R_2$ Parallel			
$R_1 R_3$ Parallel			
$R_2 R_3$ Parallel			

QUESTIONS

1. Do the individual resistors you have measured obey Ohm's law? In answering this question, consider the least squares fits and the graphs you have made for each resistor. Remember linear behavior of V versus I is the proof of ohmic behavior.

2. Evaluate the agreement between the theoretical values for the individual resistances and the experimental values. As noted in the Calculations section, there may be significant disagreement between these values if the coils have been overheated in the past. Do any of your experimental values suggest that any of your coils may have been abused in the past?

3. If a coil became heated during your measurements, its resistance would tend to increase with temperature. State if any of the graphs give evidence of heating during your measurements, which would show up at higher current as an increase in the voltage above that expected from extrapolating the data at lower current.

4. Evaluate the agreement between the experimental and theoretical values of the series combinations of resistors. Do the results support equation 3 as the model for series combination of resistors? The agreement is not expected to be perfect, but you should determine if the agreement is reasonable within the expected experimental uncertainty.

5. Evaluate the agreement between the experimental and theoretical values of the parallel combinations of resistors. Do the results support equation 4 as the model for the parallel combination of resistors within the expected experimental uncertainty?

6. According to the data given in step 1 of the Calculations section, the first and second coils have the same length and the third and fourth coils have the same length. They differ only in cross-sectional area. According to theory, what should be the ratio of the resistance of the second coil to the first and the fourth coil to the third? Calculate these ratios for your experimental results and compare the agreement with the expected ratio.

7. According to the data given in step 1 of the Calculations section, the first and third coils have the same cross-sectional area and the second and fourth coils have the same cross-sectional area. They differ only in length. According to theory, what should be the ratio of the resistance of the third coil to the first and the fourth coil to the second? Calculate these ratios for your experimental results and compare the agreement with the expected ratio.

8. Evaluate the extent to which you have accomplished the objectives of this laboratory.