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## Experiment 3: Simple DC Circuits and Resistors

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Section 221-006

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## Statement of Objectives

The purpose of this experiment was to investigate Ohm's Law and how resistors behave in various combinations.

## Theory

### *Part A: Ohm's Law*

In a direct current (DC) circuit, Ohm's Law describes the relationship between the current  $I$  passing through a resistor, the potential difference  $V$  across the resistor, and the resistance  $R$  as being:

$$V = IR \qquad \text{Equation (1)}$$

Where  $V$  = voltage  
 $I$  = current  
 $R$  = resistance

Carbon resistors are marked with color bands to indicate resistance used. Each color has a value associated with it to indicate the resistance in Ohms. By measuring the potential difference across a resistor with varying current one could verify Ohm's Law.

### *Part B: Resistors in Combination*

Resistors behave in different ways when connected in various combinations. Kirchhoff's Laws give important information regarding how current and voltage act in these combinations.

Kirchhoff's First Law:

The current entering a junction is equal to the current leaving a junction.

Kirchhoff's Second Law:

The sum of all the voltage drops around a closed circuit is zero.

When N resistors are connected in series there are no branching junctions. The current through all the resistors are identical:

$$I = I_1 = I_2 = I_3 = \dots = I_N \quad \text{Equation (2)}$$

From Kirchhoff's second law we get:

$$\begin{aligned} V - V_1 - V_2 - V_3 - \dots - V_N &= 0 \\ \text{Or } V &= V_1 + V_2 + V_3 + \dots + V_N \end{aligned} \quad \text{Equation (3)}$$

Since  $V=IR$  (Ohm's Law, from Equation 1), Equation 3 becomes:

$$IR = I_1R_1 + I_2R_2 + I_3R_3 + \dots + I_NR_N \quad \text{Equation (4)}$$

But since the currents are identical to each other Equation 4 becomes:

$$R = R_1 + R_2 + R_3 + \dots + R_N \quad \text{Equation (5)}$$

When we consider resistors in parallel however we must modify the equations to take branching into account. As shown in figure 2, the current entering the resistors branch in to N separate paths. Using Kirchhoff's First Law we can write:

$$I = I_1 + I_2 + I_3 + \dots + I_N \quad \text{Equation (6)}$$

Since the all the resistors are connected to the same point, the potential difference is the same for all resistors. Therefore:

$$V = V_1 + V_2 + V_3 + \dots + V_N \quad \text{Equation (7)}$$

From  $V=IR$  (Ohm's Law, Equation 1) we can derive from equation 7 that:

$$\frac{V}{R} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \dots + \frac{V_N}{R_N} \quad \text{or} \quad \text{Equation (8)}$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_N} .$$

## Equipment List

- Ammeter
- Voltmeter
- Power Supply
- Resistor Board (series)
- Resistor Board (parallel)

## Procedure

### *Part A: Ohm's Law*

The DC circuit in figure 1 was constructed. The voltage on the power supply was adjusted until the voltmeter across the resistor read 1 V. The voltage at the source was documented along with the current in the circuit that was found using an ammeter. This procedure was repeated for voltmeter readings of 2, 3, 4, and 5 V. The circuit was changed to mimic that in figure 2 and the entire procedure above was repeated.

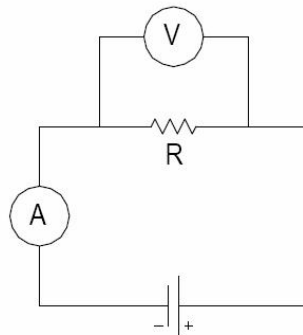


Figure 1: DC Circuit – R is the resistor, A is the ammeter, and V is the voltmeter

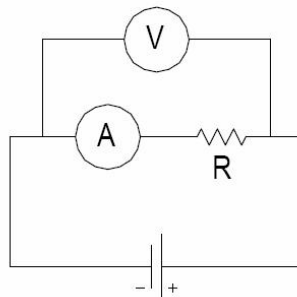


Figure 2: Variation of DC Circuit in Figure 1

### Part B1: Resistors in Series

The circuit in figure 3 was constructed. The power supply was set to 10 V and recorded. We then measured the current in the circuit. The potential difference across all three resistors was measured and recorded. The total potential difference across all three resistors was also measured and recorded. The color codes on the resistors were used to find the theoretical value for each resistor.

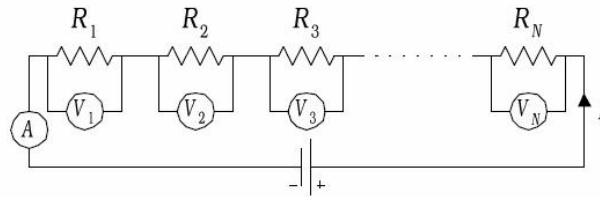


Figure 3: N Resistors in Series

### Part B2: Resistors in Parallel

The circuit in figure 4 was constructed. The power supply was set to 10 V and recorded. The ammeter was used to measure  $I_1$ ,  $I_2$ , and  $I_3$ . The ammeter was then connected in series with the battery and the combination resistors and the total current  $I$  was measured.

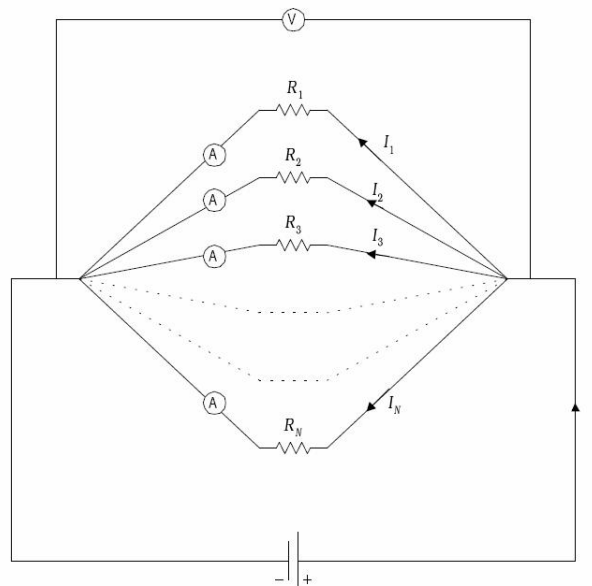


Figure 4: Resistors in Parallel

*Part C: More Resistors in Combination*

The circuit in figure 5 was set up.  $R_1$ ,  $R_2$ , and  $R_3$  were known resistors. Using the ammeter and voltmeter we found the values for  $I_1$ ,  $I_2$ ,  $I_3$ ,  $V$ ,  $V_1$ ,  $V_2$ , and  $V_3$ .

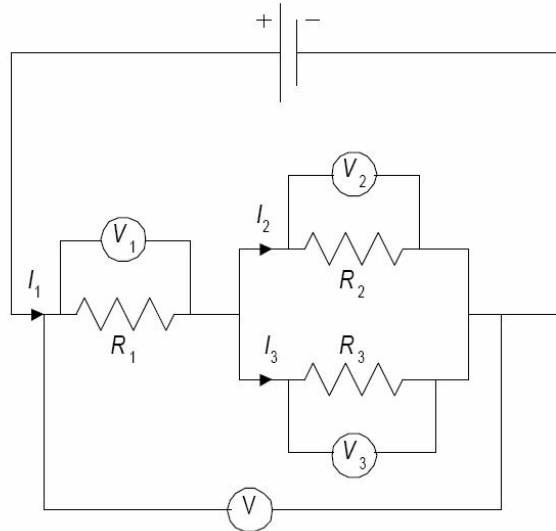


Figure 5: Resistors in Series and Parallel

**Data**

*Part A: Ohm's Law*

Voltmeter in Parallel to Resistor

Voltage @ Source (V)	Voltage @ Resistor (V)	Current @ Resistor (A)
1.0	1	.00270
2.1	2	.00540
3.1	3	.00805
4.2	4	.01200
5.0	5	.01400

Table 1-A

Resistor Used in Part A

Theoretical Value ( $\Omega$ )	Actual Value ( $\Omega$ )
$330 \pm 5\%$	363

Table 1-B

## Voltmeter in Parallel to Resistor and Ammeter

Voltage @ Source (V)	Voltage @ Resistor (V)	Current @ Resistor (A)
0.9	1	.0026
1.9	2	.0051
2.9	3	.0076
3.9	4	.0110
4.9	5	.0140

**Table 1-C**

### *Part B1: Resistors in Series*

The total current passing through the system was .0005A and the total voltage passing through the system was 10V.

### Resistors

Resistor	Theoretical Resistance ( $\Omega$ )	Experimental Resistance ( $\Omega$ )	Voltage Difference (V)
R <sub>1</sub>	5600 $\pm$ 10%	6030	3.13
R <sub>2</sub>	12000 $\pm$ 5%	11950	6.18
R <sub>3</sub>	1200 $\pm$ 10%	1194	0.61

**Table 2**

### *Part B2: Resistors in Parallel*

The total current passing through the system was .0110A.

### Resistors

Resistor	Theoretical Resistance ( $\Omega$ )	Experimental Resistance ( $\Omega$ )	Current @ Resistor (A)
R <sub>1</sub>	5600 $\pm$ 10%	6030	.0016
R <sub>2</sub>	12000 $\pm$ 5%	11950	.0008
R <sub>3</sub>	1200 $\pm$ 10%	1194	.0081

**Table 3**

*Part C: More Resistors in Combination*

**Resistors**

<b>Resistor</b>	<b>Theoretical Resistance (<math>\Omega</math>)</b>	<b>Experimental Resistance (<math>\Omega</math>)</b>
R <sub>1</sub>	1200 $\pm$ 10%	1194
R <sub>2</sub>	12000 $\pm$ 5%	11950
R <sub>3</sub>	5600 $\pm$ 10%	6030

**Table 4-A**

**Voltage**

<b>Location</b>	<b>Voltage Reading (V)</b>
V <sub>Source</sub>	10
V <sub>1</sub>	2.3
V <sub>2</sub>	7.7
V <sub>3</sub>	7.7
V <sub>Total</sub>	10.01

**Table 4-B**

**Current**

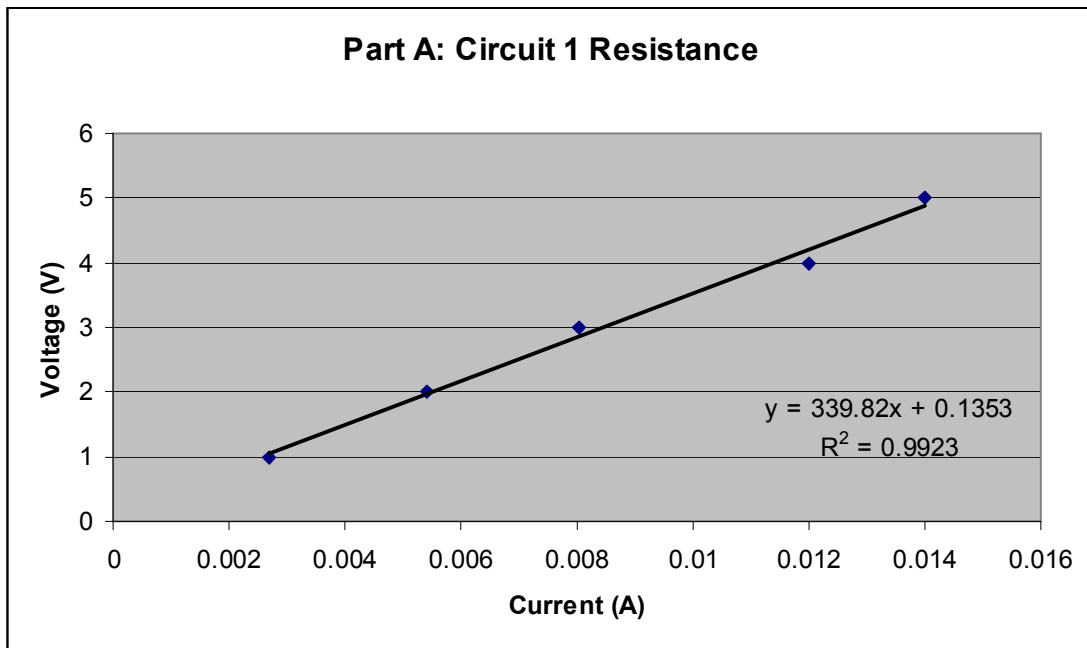
<b>Location</b>	<b>Current Reading (A)</b>
I <sub>1</sub>	.0019
I <sub>2</sub>	.0006
I <sub>3</sub>	.0012

**Table 4-C**

## Analysis

### *Part A: Ohm's Law*

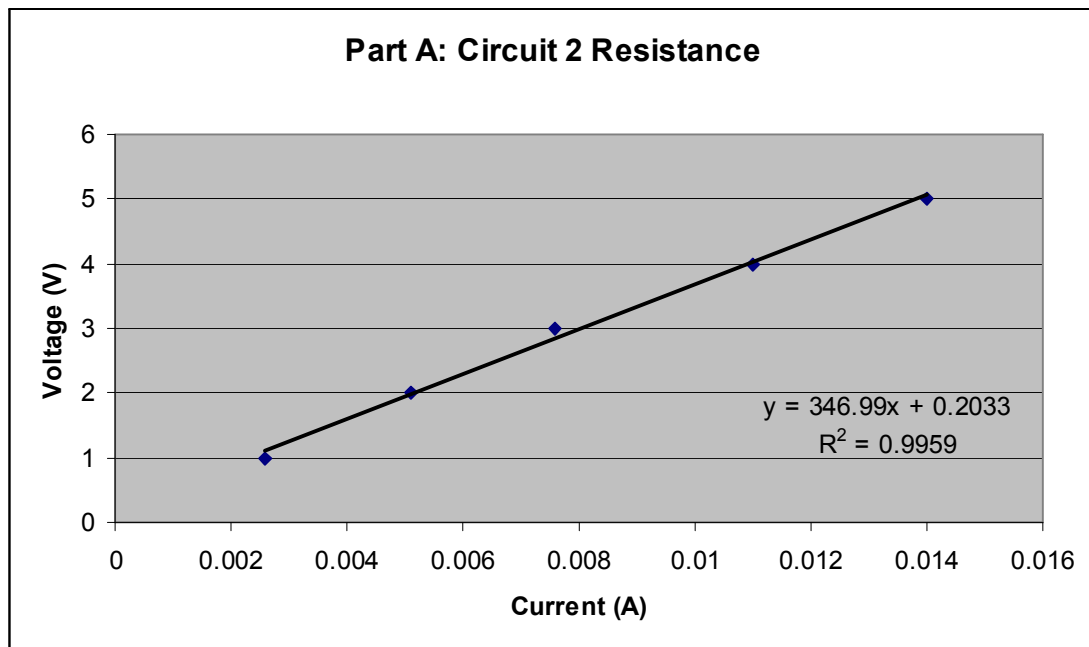
Using Table 1-A, a graph of Voltage vs. Current was made:



**Graph 1**

As stated in Equation 1 of the theory section,  $V = IR$ . With simple alterations to the equation, it is shown that the resistance is equal to the voltage divided by the current  $R = \frac{V}{I}$ . Thus, the slope of the graph gives us the resistance of the resistor. The slope of the graph above is 340 which tells us that the resistance is equal to 340  $\Omega$ . This value falls within the theoretical approximation of  $330 \pm 16.5 \Omega$ . The actual value computed using the ammeter was 363  $\Omega$ . We can use this to calculate the percent error, which in this case is 6.3%.

Similarly, using Table 1-C, a graph of Voltage vs. Current was made:



Graph 2

Again, as stated in Equation 1 of the theory section,  $V = IR$ . With simple alterations to the equation, it is shown that the resistance is equal to the voltage divided by the current  $R = \frac{V}{I}$ . Thus, the slope of the graph gives us the resistance of the resistor. The slope of the graph above is 347 which tells us that the resistance is equal to 347  $\Omega$ . This value falls on the edge of the theoretical approximation of  $330 \pm 16.5 \Omega$ . The actual value computed using the ammeter was 363  $\Omega$ . We can use this to calculate the percent error, which in this case is 4.4%.

### *Part B1: Resistors in Series*

By using Equation 3, we can find  $V$  by adding  $V_{R1}$ ,  $V_{R2}$ , and  $V_{R3}$ . So,  $V$  is equal to  $3.13 + 6.18 + 0.61$  which is equal to 9.92V and although not exactly equal to the voltage from the source (10V), due to experimental error and varying tolerance of the resistors, we can verify Equation 3 to be correct.

### Calculated Resistance

Location	Voltage (V)	Current (A)	Calculated Resistance ( $\Omega$ )
R <sub>1</sub>	3.13	.0005	6260
R <sub>2</sub>	6.18	.0005	12360
R <sub>3</sub>	0.61	.0005	1220

**Table 5**

Using Equation 1 along with  $I$  and  $V_{\text{Total}}$  we can compute  $R$ . The calculated value of  $R$  is 20020  $\Omega$ .

In Equation 5, the total resistance should be the sum of the individual resistances.  $R_1 + R_2 + R_3 = 6260 + 12360 + 1220 = 19840$ . This falls within 0.8% of the total resistance computed and thus, we can conclude Equation 5 is accurate.

#### *Part B2: Resistors in Parallel*

By using Equation 6, we can find  $I$  by adding  $I_{R1}$ ,  $I_{R2}$ , and  $I_{R3}$ . So,  $I$  is equal to  $.0016 + .0008 + .0081$  which is equal to  $.0105\text{A}$  and although not exactly equal to the total current ( $.011\text{A}$ ), due to experimental error and varying tolerance of the resistors, we can verify Equation 6 to be correct.

### Calculated Resistance

Location	Voltage (V)	Current (A)	Calculated Resistance ( $\Omega$ )
R <sub>1</sub>	10	.0016	6250
R <sub>2</sub>	10	.0008	12500
R <sub>3</sub>	10	.0081	1235

**Table 5**

Using Equation 1 along with  $I$  and  $V_{\text{Total}}$  we can compute  $R$ . The calculated value of  $R$  is 909  $\Omega$ .

In Equation 8, the inverse of the total resistance should be the sum of the inversed individual resistances. In this case we have a 3.6% margin of error from which we can conclude Equation 8 is accurate.

### *Part C: More Resistors in Combination*

$$V = \mathcal{E} = 10\text{V (battery)}$$

$$R_1 = 1220 \Omega$$

$$R_2 = 12360 \Omega$$

$$R_3 = 6260 \Omega$$

$$R_{23} = \frac{12360 * 6260}{12360 + 6260} \approx 4155.4 \Omega$$

$$R_{123} = 4155.4 + 1220 = 5375.4 \Omega$$

$$I_1 = \mathcal{E} / R_{123} = \frac{10}{5375.4} = .00186\text{A}$$

$$V_1 = I_1 * R_1 = .00186\text{A} * 1220 \Omega = 2.2696\text{V}$$

$$V_2 = V_3 = V - V_1 = 10\text{V} - 2.2696\text{V} = 7.7304\text{V}$$

$$I_2 = V_2 / R_2 = \frac{7.7304}{12360} = .000625\text{A}$$

$$I_3 = V_3 / R_3 = \frac{7.7304}{6260} = .001235\text{A}$$

Amazingly, every value calculated matches to significant digits with the values recorded in the lab session.

### **Discussion of Results**

All results gained in this experiment were well within acceptable experimental error. The varying tolerance of resistors and problems with voltmeters and ammeters were minimal.

### **Conclusion**

With all parts of the experiment having been performed successfully and with low experimental error, Ohm's Law and the behavior of resistors in different combinations was successfully investigated.