PHYSICS 221

EXPERIMENT 3 : Simple DC Circuits And Resistors

INTRODUCTION :

In this experiment, we will investigate Ohm's Law, and study how resistors behave in various combinations. Along the way, you will establish that certain measurements are affected by the way in which circuit elements are connected to each other.

NOTE: Although the circuit diagrams are usually shown in the laboratory instruction, you *must* always show a sketch of your properly-labeled circuit diagram in your laboratory report!

PART A : OHM'S LAW

In a direct current (DC) circuit, the relationship between the current I passing through a resistor, the potential difference V across the resistor, and the resistance R of the resistor is described by Ohm's Law:

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

In this part of the experiment, we will verify this law by measuring the potential difference across a resistor with varying current. The typical resistor used here is a carbon resistor that is usually marked with colored bands to indicate its resistance in Ohms (see Figure 1).
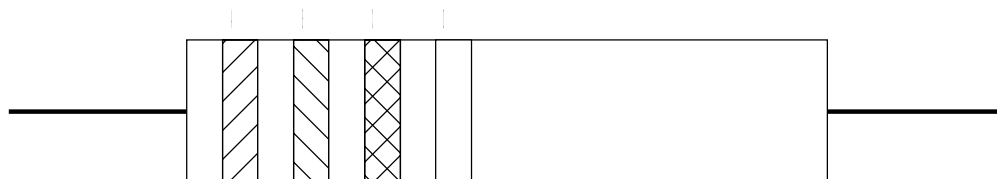

Figure 1: A Carbon Resistor With Four Colored Bands.

Each color has a value associated with it. A table of the color code is given below. To be able to read the color code, first orient the resistor as shown in the figure so that it "reads" from left to right. The first band on the left is called the "A" band, while the last band is called the "D" band. The D band is usually either gold or silver. The value of the resistance (in Ohms) is $AB \times 10^C \pm D$. The D band represents the tolerance of the resistor, i.e. how close its resistance is to what the actual value is. A gold band denotes a tolerance within $\pm5\%$, a silver band denotes within $\pm10\%$, while no band denotes within $\pm20\%$.

Let us try to read the resistance of the above resistor. For example, if the bands are yellow-gray-red-silver, then it has a value of $48 \times 10^2 \pm 10\%$ Ohms, or $4800 \pm 480\ \Omega$.

Black = 0	Blue = 6
Brown = 1	Violet = 7
Red = 2	Gray = 8
Orange = 3	White = 9
Yellow = 4	Silver = 10%
Green = 5	Gold = 5%

Table 1: Resistor Color Codes.

PROCEDURE :

Before beginning, it is important to mention some safety and measuring rules. First of all, do not hook up any power to your circuit until you have finished assembling it <u>and</u> the laboratory instructor has checked it out. When measuring the current or voltage of a system that you are not familiar with, always set your Ammeter or Voltmeter to maximum scale and work your way down so that you do not overload the meter. Also, always make sure your polarities are correct, and always turn the power off when changing the configuration of the circuits.

1. Construct the circuit shown in Figure 2. Make sure that the polarity of the meters is correct (if any meter gives a negative reading, you have to reverse the connection). Note that the resistor R, the Ammeter A, and the power supply are all in series with each other, while the Voltmeter V is parallel to R. [Hint: It is usually less confusing if you *first* construct all the components that are in series and *then* add the components that are placed in parallel. For this case, construct the series circuit of the power supply, Ammeter, and resistor. Then connect the Voltmeter across the two ends of the resistor.]

2. Vary the voltage on the power supply until the Voltmeter V across the resistor reads 1.0 V. Record the current in the circuit using the Ammeter.
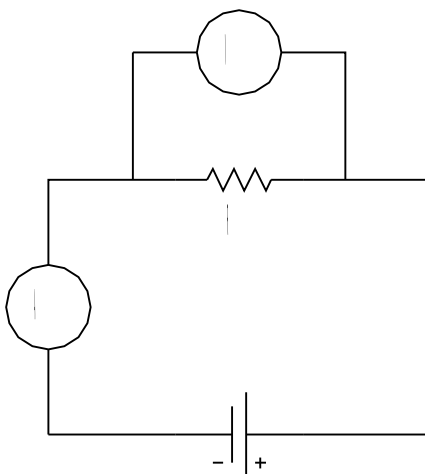
Figure 2: DC Circuit to Verify Ohm's Law. *R* is the resistor, *A* is
the Ammeter, and *V* is the Voltmeter.

3.   Repeat Procedure 2 for voltage reading of 2.0, 3.0, 4.0, and 5.0 volts.

4.   Record your raw data in a table.

5.   Repeat the entire experiment, but this time with a slight variation to the circuit as
      shown in Figure 3.

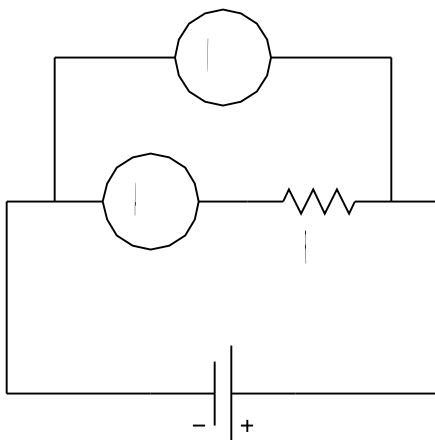6.   You should have a total of two sets raw data tables by the end of this part.

Figure 3: A Variation of the DC Circuit of Figure 2.

ANALYSIS :

1.   Plot V versus I using your data. You may plot both data sets on the same graph if they are clearly labeled.

2.   Using Equation 1, prove that the slope of the best-fit line of your data is equal to the resistance R (this must be shown in the theory section of your report).

3.   Using the best-fit line, find the resistance of the resistor for each data set.

4.   Using the color codes, what is the resistance of the resistor? Verify this by using an Ohmmeter (multimeter) and finding directly the resistance of the resistor.

5.   If the two experimental values of R that you have obtained are different from each other, which one is closest to the value found in Procedure 4? Why are the experimental values different from each other? Which circuit should give a more accurate reading of the actual resistance?

Additional note: Voltmeters should always be connected in parallel with the circuit element for which you want to measure the voltage. This is because Voltmeters have very high resistances. Current travels in the path of least resistance, so in the *ideal* case, no current from the circuit should flow into the Voltmeter. On the other hand, Ammeters should always be connected in series to determine the current at a certain location. Ammeters have very low resistances, so as the current flows through the meter, ideally there is zero voltage drop across the Ammeter. As long as the resistances of meters are being discussed, it seems appropriate to add the fact that a power supply can simply be thought of as a battery connected in series with a resistor. This fact is helpful when studying circuit diagrams.

PART B : RESISTORS IN COMBINATION

Now that we have studied Ohm's Law, we will proceed to investigate how resistors behave in various combinations. To help us, we introduce two additional circuit laws:

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.

We first consider N resistors in series as shown in Figure 4. Since there are no branching junctions in the circuit, the current entering through all the resistors are all identical, i.e. $I = I_1 = I_2 = I_3 = \ldots = I_N$. We also know from Kirchhoff's Second Law that

$$V - V_1 - V_2 - V_3 - \ldots - V_N = 0 \qquad \text{or}$$
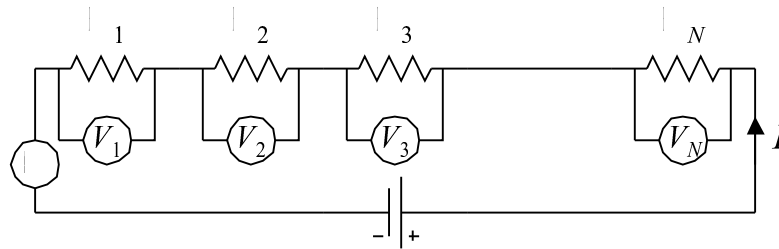$$V = V_1 + V_2 + V_3 + \ldots + V_N \tag{2}$$

Figure 4: N Resistors in Series.

since, along the direction of current flow, potential difference for the power supply is a voltage *step-up* $+V$ while potential difference from a resistor is a voltage *step-down* $-V$. Since $V = I$ from Ohm's Law, Equation 2 becomes

$$I = I_1 \text{}_1 + I_2 \text{}_2 + I_3 \text{}_3 + \ldots + I_N \text{}_N. \tag{3}$$

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However, we know that all the currents are identical to each other. Therefore, for resistors in series, the effective resistance R is

$$R = R_1 + R_2 + R_3 + \ldots + R_N. \qquad (4)$$

We next consider N resistors in parallel as shown in Figure 5. Since the current entering the resistors branches out into N separate paths, using Kirchhoff's First Law we can write

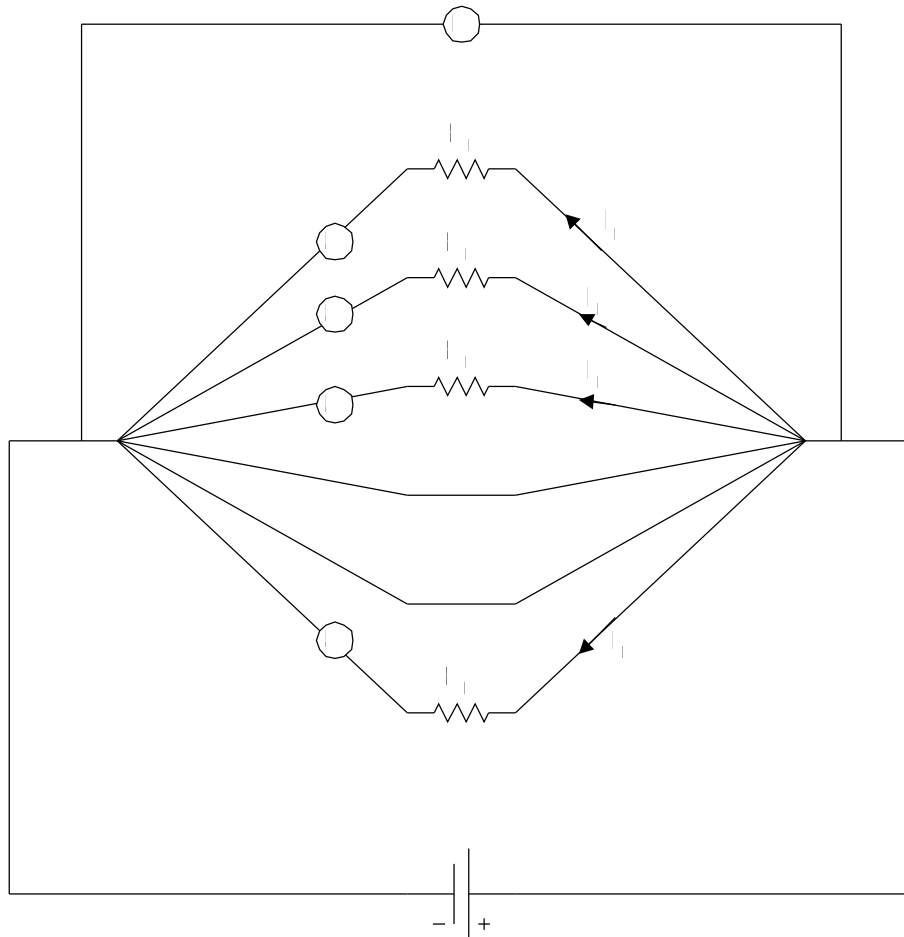$$I = I_1 + I_2 + I_3 + \ldots + I_N. \qquad (5)$$

Figure 5: Resistors in Parallel.

For a parallel arrangement, all the resistors have the same potential difference (since they are essentially connected to the "same" two points). Thus $V = V_1 = V_2 = V_3 = \ldots = V_N$. Since I = V/R (from Ohm's Law), we can write Equation 5 as

$$\frac{V}{R} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \square + \frac{V_N}{R_N} \qquad \text{or}$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \square + \frac{1}{R_N}. \tag{6}$$

Equation 6 gives the effective resistance for resistors in parallel. With these two derived resistor relationships, we can find all the properties of any circuit containing resistors in series or parallel or any combination of the two. In this portion of the lab, we will be studying circuits containing resistors in series and in parallel.

PART B1 : RESISTORS IN SERIES

PROCEDURE :

1. Construct the circuit as in Figure 4 using the three resistors given to you. You only have one Voltmeter, so hook it up initially across R_1.

2. Set the power supply to 10 V.

3. Measure the current in the circuit, and the potential difference across R_1. Records this as V_1.

4. Move the Voltmeter to measure the potential difference across R_2 and record this as V_2, and similarly for R_3.

5. Now find the total potential difference across all three resistors. Records this as V.

6.   Reduce the voltage supply back to zero, then switch it off. Find the resistance of each of the resistors by reading the color codes and by using an Ohmmeter as in Part A.

ANALYSIS :

1.   Verify that $V = V_1 + V_2 + V_3$.
2.   Find the experimental value of the resistance of each resistor using Equation 1 (i.e. $R_1 = V_1/I$, etc.).
3.   Find the experimental value of the effective resistance R in series using the value of I, total V, and Equation 1.
4.   Compare the sum of the individual resistance from Analysis 2 with the value obtained from Analysis 3. Verify Equation 4 for this case.

PART B2 : RESISTORS IN PARALLEL

1.   Construct the circuit as in Figure 5 using the three resistors given to you. You only have one Ammeter so hook it up initially to measure I_1.
2.   Set the power supply to 10 V.
3.   Measure V and I_1. Continue moving the Ammeter to measure I_2 and I_3.
4.   Now connect the Ammeter in series with the battery and the combination resistors and measure the total current I (if you are not sure where to connect the resistor, ask your laboratory instructor).

ANALYSIS :

1.   Verify that $I = I_1 + I_2 + I_3$.
2.   Find the experimental values of the resistance of each resistor using Equation 1.
3.   Find the experimental value of the effective resistance R using the values of V, total I, and Equation 1.

4.   Compare the experimental value of R with the one calculated using Equation 6.

PART C : MORE RESISTORS IN COMBINATION

PROCEDURE :

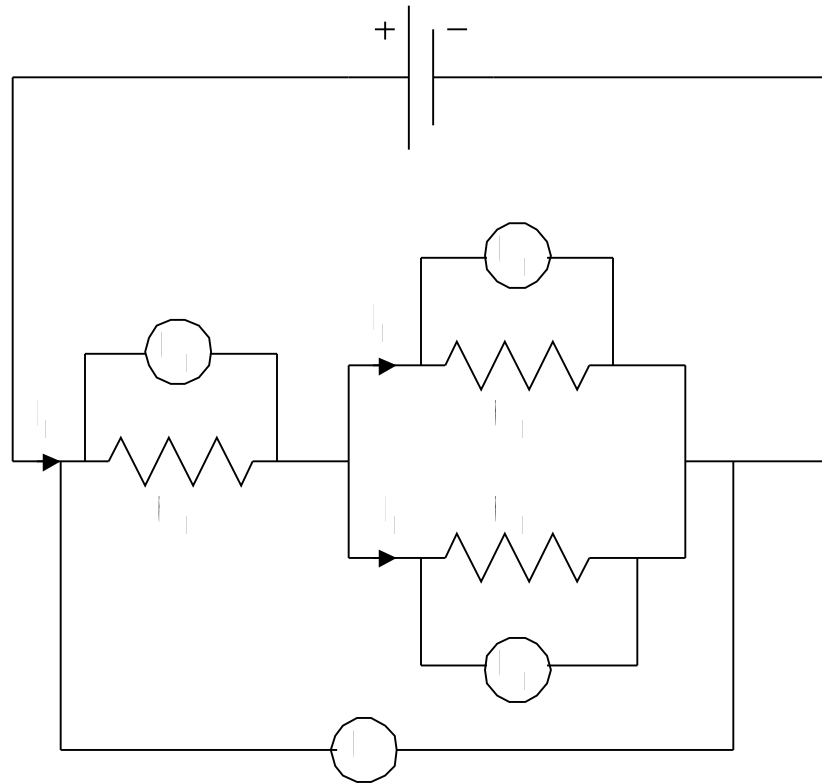1.   Set up the circuit show in Figure 6. R_1, R_2, and R_3 are known resistance (use an Ohmmeter).

Figure 6: Resistors In Series And Parallel.

2.   Using an Ammeter and a Voltmeter, find I_1, I_2, I_3, V, V_1, V_2, and V_3.

ANALYSIS :

1.   Using the given resistance values and Kirchhoff's Laws, find the theoretical values for I_1, I_2, I_3, V, V_1, V_2, and V_3. Show your work *explicitly*.

2.   Compare these values with the experimental values.