Experiment 5: Simple Resistor Circuits

Introduction

In this lab, 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. 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 Part 1 of the experiment, we will verify this law by measuring the potential difference (i.e. voltage drop) across resistors in series and parallel. The typical resistor used here is a carbon resistor that is usually marked with colored bands to indicate its resistance in Ohms, as seen in Figure 1 (see Lab 2 for more detail). In Part 2, 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.
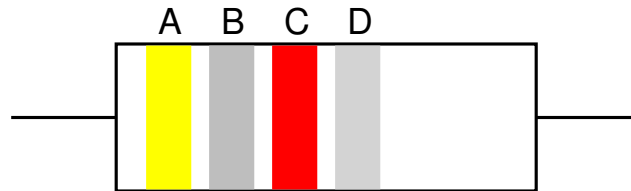

Figure 1: Resistor color codes: Black=0, Brown=1, Red=2, Orange=3, Yellow=4, Green=5, Blue=6, Violet=7, Gray=8, White=9.

We first consider N resistors in *series* as shown in Figure 2. Since there are no branching junctions in the circuit, the current entering through all the resistors is identical, i.e. $I = I_1 = I_2 = I_3 = ... = I_N$. We also know from Kirchhoff's Second Law that $V - V_1 - V_2 - V_3 - ... - V_N = 0$ or

$$V = V_1 + V_2 + V_3 + ... + V_N \tag{2}$$

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 from Ohm's Law V=IR, Equation 2 becomes

$$IR = I_1R_1 + I_2R_2 + I_3R_3 + ... + I_NR_N. \tag{3}$$

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

$$R = R_1 + R_2 + R_3 + ... + R_N. \tag{4}$$

We next consider N resistors in parallel as shown in Figure 3. Since the current entering the resistors branches out into N separate paths, using Kirchhoff's First Law we can write

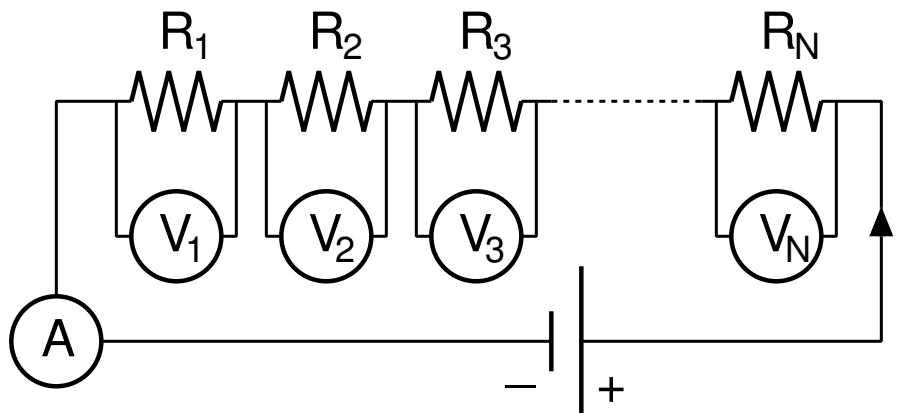$$I = I_1 + I_2 + I_3 + ...I_N \tag{5}$$

Figure 2: Resistors in series.

For a parallel arrangement, all the resistors have the same potential difference (since they are essentially connected to the "same" two points). Thus $V_1 = V_2 = V_3 = ... = V_N$. Since I=V/R (from Ohm's Law), we can write Equation 3 as

$$\frac{V}{R} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + ... + \frac{V_n}{R_N} \tag{6}$$

or equivalently as

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_N} \tag{7}$$

Equation 7 gives the effective resistance for resistors in parallel. Using equations 4 and 7, we can find all the properties of any circuit containing resistors in series or parallel or any combination of the two. In this lab, we will be studying circuits containing resistors in series and in parallel.
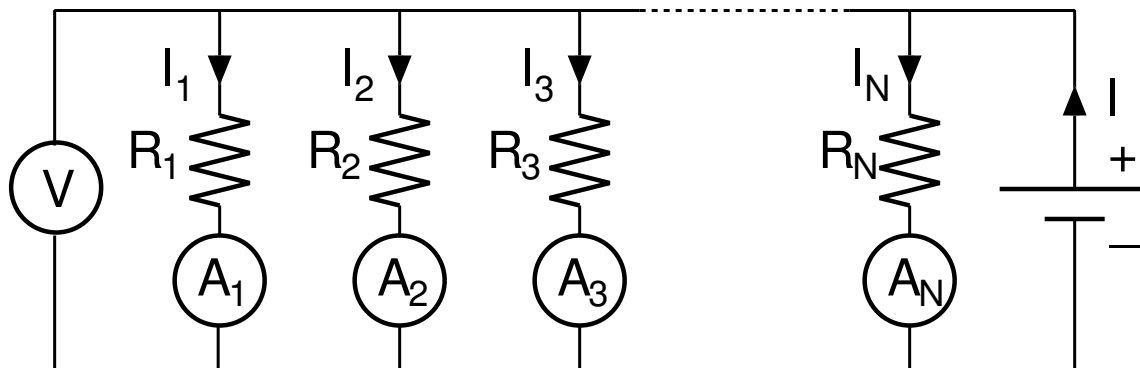

Figure 3: Resistors in parallel.

Part 1

Procedure 1A - Resistors in Series:

In this part you are given four different resistors. Measure their values using an Ohmmeter and compare them with the color-codes. Construct the circuit as in Figure 2 using the breadboard, jumper wires, and ONLY use resistors numbers 1, 2, and 3. Note: Although the circuit diagrams are usually shown in the laboratory instruction, you must always show a sketch of your properly-labeled circuit diagram (with actual resistor values) in your laboratory report. You only have one Voltmeter, so hook it up initially across R_1

(your first resistor). Setting the power supply to 10 V, measure the current in the circuit, and the potential difference across R_1. Record this as V_1. Move the Voltmeter to measure the potential difference across R_2 and R_3. Now find the total potential difference across all three resistors. Record this as V and verify that $V = V_1 + V_2 + V_3$. Discuss the following questions in the analysis section of your lab report:

1. Find the experimental value of the resistance of each resistor using Equation 1 (i.e. $R_1 = V_1/I$, etc.).

2. Find the experimental value of the total effective resistance R in series using the value of I, total V, and Equation 3.

3. Compare resistance values for R_1, R_2, and R_3 obtained from the ohmmeter with those found using Ohm's Law.

4. (Why didn't we use resistor number 4?!?) Using the measured values of resistance, estimate the value of I with all 4 resistors in series (v=10V), and compare the result to the resolution of the Ammeter on it's most sensitive scale.

Procedure 1B - Resistors in Parallel:

Construct a parallel circuit as shown in Figure 3 using **ALL** four resistors (if you are not sure how to connect the resistors, ask your laboratory instructor for advice). You only have one Ammeter so hook it up initially to measure I_1, the current through your first resistor. Set the power supply to 10 V and measure V and I_1. Continue moving the Ammeter to measure I_2, I_3, and I_4. Now connect the Ammeter in series with the power supply and the combination of resistors. Measure the total current I. Verify that $I = I_1 + I_2 + I_3 + I_4$. Discuss the follwoing questions in the analysis section of your lab report:

1. Find the experimental value of the resistance of *each* resistor using Equation 1.

2. Find the experimental value of the total effective resistance R using the value of total I, total V, and Equation 1.

3. Compare the experimental value of R with the one calculated using Equation 7.

Part 2 - Resistors in Parallel and Series Combination

We will now look at resistors in both series and parallel. Set up the circuit shown in Figure 4 using the breadboard and 3 resistors, where R_1, R_2, and R_3 are known resistances (use the ohmmeter). Using an Ammeter and a Voltmeter, find $I_1, I_2, I_3, V, V_1, V_2$, and V_3 and show that they obey Kirchhoff's Laws.

For your lab write-up, use the given resistance values and Kirchhoff's Laws to find the theoretical values of I_1, I_2, and I_3. Show your work explicitly.
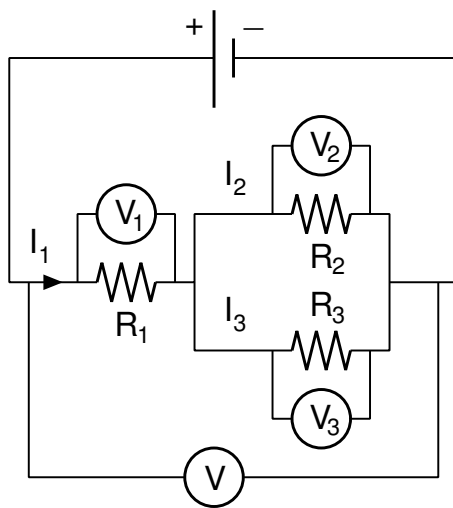
Figure 4: Resistors in series-parallel combination.