Chapter 20

DC Circuits II

20.1 Purpose

The purpose of this lab is to introduce the student to Kirchhoff's rules and the Wheatstone bridge.

20.2 Important Equipment

Power source, various resistors, variable resistor, digital multi-meter and ammeter (galvanometer).

20.3 Introduction

Kirchhoff's Rules

There are two important rules which greatly simplify the analysis of electric circuits. A current rule and a voltage rule. These rules are referred to as Kirchhoff's rules. The current rule is as follows:

The current entering a node always equals the current leaving a node.

By a node, we mean a point in the circuit where a single conductor branches off into two or more conductors. This situation is illustrated below in Figure 20.1, for one conductor branching into three and then back into one.

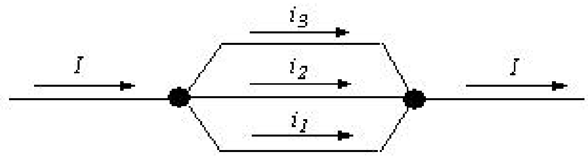

Figure 20.1: Diagram of current entering a node, dividing into three branches then reuniting at another node.

The second of Kirchhoff's rules has to do with voltage in a circuit. It is as follows:

The sum of the voltages around any closed loop in a circuit equals zero.

To understand this we must assign a polarity to each voltage in a circuit. Power sources are said to give a voltage "rise" while resistors have a voltage "drop". We make the distinction between these two voltage types by using polarity markings, that is, a positive and minus sign. For instance, if we move around a circuit in the direction of current flow then a voltage rise will be given by a minus sign followed by a plus sign. Alternatively, a voltage drop is given as a plus sign followed by a minus sign. We see this situation depicted for a circuit in Figure 20.2.

Now, when applying the voltage rule, a voltage rise is taken as a positive voltage and a voltage drop is assigned a negative value. By Kirchhoff's voltage rule, these voltages must sum to zero. So, from Figure 20.2, the closed counter clockwise loop gives the following:

$$V - V_1 - V_2 - V_3 = 0 \ . \tag{20.1}$$

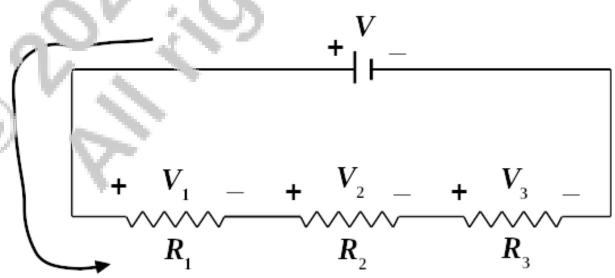

Figure 20.2: Schematic diagram of a series circuit with polarity markings which indicate voltage rises or drops.

The above is true even if the circuit contains more than one loop. Consider the circuit shown below in Figure 20.3. Here Kirchhoff's voltage rule is valid for both loops. If we move around the bottom loop in the direction shown we get the following:

$$-V_1 - V_2 + V_3 = 0 \ . \tag{20.2}$$

Using Ohm's law, we can write Eq. (20.2) as,

$$-i_1 R_1 - i_1 R_2 + i_2 R_3 = 0 \ . \tag{20.3}$$

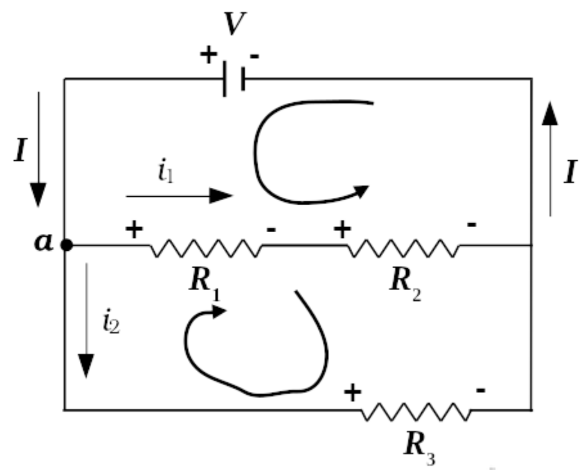

Figure 20.3: Schematic diagram showing a circuit with two *loops*. A suggested direction for summing the voltage drops around each loop is indicated by the circular arrows inside.

It is interesting to use this same circuit to study Kirchhoff's current rule. This rule states that the following must be true for current entering and leaving node a:

$$I = i_1 + i_2 \, . \qquad (20.4)$$

From these results, it is easy to see that Kirchhoff's rules are a significant aid in the analysis of electric circuits.

The Wheatstone Bridge

The Wheatstone bridge is a circuit that can be used to measure the resistance value of an unknown resistor. The schematic for this circuit is shown below in Figure 20.4. Here, the unknown resistor is R_X. The value for resistor R_3 is varied until the ammeter (galvanometer) reads zero. At this point, the unknown resistance, R_X, can be computed using the following formula:

$$R_X = \frac{R_1 R_2}{R_3} \, . \qquad (20.5)$$

(Note, from Eq. (20.5), that the range of the variable resistance, R_3, determines a finite range of values for R_x which can be measured, given set values for R_1 and R_2.)

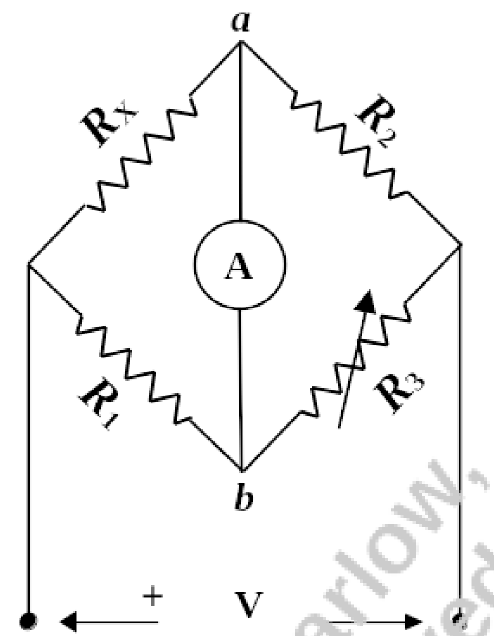

Figure 20.4: Schematic diagram of the Wheatstone bridge circuit used for measuring an unknown resistance. The encircled A represents a galvanometer or current meter.

20.4 Lab Activity

Using the circuit experimenter's board or breadboard, battery and available resistors, assemble the circuit shown in Figure 20.3. Measure the voltage of the battery and across resistors R_1, R_2, and R_3. Using those values, with the use of Eq. (20.2), attempt to verify Kirchhoff's voltage rule. Mention your conclusions in your report.

Now, at one of the nodes in the circuit from Figure 20.3 measure the three currents that go into or out of the node. Then, with the use of Eq. (20.4) attempt to verify Kirchhoff's current rule.

Now, assemble the Wheatstone bridge depicted in Figure 20.4.

For best range and sensitivity of measurement, the value for R_2 should be similar to the values of the unknowns R_X. Also, R_1 should have a resistance value within the range of the variable resistor R_3.

You will be given several resistors of unknown resistance value. Insert one of your unknown resistors R_X into the circuit. With the power source on, vary the variable resistor until the galvanometer reads zero. Once zero current is obtained, measure the resistance of the variable resistor. Using Eq. (20.5), compute the value of the unknown resistor. Repeat this for the other unknowns. Measure the resistance values for these unknowns using the digital multi-meter.

Compare these values with those you obtained with the Wheatstone bridge by computing a percent difference. Mention these results in your report.

Questions

1. What fundamental law of nature is Kirchhoff's current rule based upon?

2. What fundamental law of nature is Kirchhoff's voltage rule based upon?

Problems

1. Using one of Kirchhoff's rules and Ohm's law, derive Eq. (20.5). Hint: When the galvanometer reads zero current, the potential is the same at points a and b in Figure 20.4.

2. Suppose in Figure 20.3, $V = 10.0$ V, $R_1 = 12.0\ \Omega$, $R_2 = 30.0\ \Omega$ and $R_3 = 5.00\ \Omega$. Use Kirchhoff's rules to set up three independent equations and solve for the unknown resistor voltage drops V_1, V_2 and V_3.