

EXPERIMENT 9 KIRCHHOFF'S RULES

I. THEORY

A systematic way of solving complex DC circuits was worked out by Gustav Kirchhoff. The purpose of this experiment is to test the accuracy of the two rules formulated by Kirchhoff.

Kirchhoff's First Rule states that the algebraic sum of all currents approaching any junction is zero. Currents leaving a junction are considered negative. This is another way of saying that as much charge enters a junction as leaves it in a given interval of time. Seen in this way, Kirchhoff's First Rule is a restatement of the Law of Conservation of Charge.

In symbols, we may write Kirchhoff's First Rule as follows:

$$\sum I = 0$$

If a circuit contains N junctions, we can obtain N-1 independent equations by repeated use of Kirchhoff's First Rule.

Kirchhoff's Second Rule states that the algebraic sum of the changes in potential around any closed path is zero. In symbols, we may write

$$\sum \Delta V = 0$$

This rule is a consequence of the uniqueness of potential at a point which, in turn, is related to the fact that the work done in moving a test charge from one point to another is independent of the path chosen, provided only conservative forces are present.

Kirchhoff's Second Rule yields as many independent equations as there are elementary loops in a circuit. An elementary loop is a loop which contains no smaller loops within it.

In order to use Kirchhoff's Second Rule in this experiment, it will be necessary to calculate potential differences across two types of circuit elements: resistors and cells.

The magnitude of the potential difference across a resistor is IR . The sign of the potential difference is found using the principle that conventional current must flow from high to low potential through the resistor.

In general, the potential difference across a cell depends on the emf and internal resistance of the cell, and on the magnitude and sense of the current passing through the cell. In this experiment, however, we will simplify things by measuring the magnitude of the potential difference across each cell while it is under load. The sign of each potential difference is found by observing which terminal is marked as positive (high potential)

and which as negative (low potential) on the cell itself. This procedure is equivalent to treating each cell as having no internal resistance, and an emf equal to the voltmeter reading when the cell is under load.

If the direction of any of the branch currents is unknown, an assumed direction should be assigned to each such current, and clearly marked in a circuit diagram. Kirchoff's Rules should be written out using the assumed current directions. Any current which turns out to be negative when the equations are solved will have the opposite direction from that assumed. The magnitude will be correct.

In this experiment we will treat resistances and emf's as "known" quantities. We will solve for the "unknown" currents, and compare the calculated values with the measured values.

II. LABORATORY PROCEDURE

NOTE: Record all currents to the nearest mA.

1. Record the circuit board identifying letter.
2. Use the Resistor Color Code in the introduction of this manual to determine the nominal resistances of the four resistors. Since all are between 2 and 30 ohms, the third band is either gold or black, but not brown.
3. Use a piece of emery cloth to clean the switch contacts. Leave the switch in the open position.
4. Wire up Circuit #1, found in section IV. To connect a wire to a Fahnestock clip, depress the end of the clip so that a hole opens up, and insert the wire terminal into the hole. Note that the negative terminal of the ammeter is connected to point 1, and the positive terminal to point 2. So that current can flow in R_2 and R_3 , wires must connect points 6 and 7, and also points 11 and 12. Connect the positive terminal of the large 1.5 V cell to point 5. Connect the negative terminal of the cell either to point 13 or point 16, as these two points are equivalent. Connect the positive terminal of one small 1.5 V cell to point 10; connect the negative terminal of this cell to the positive terminal of the other small 1.5 V cell; connect the negative terminal of the second cell to point 13 or point 16. When connecting a wire to any cell, make certain that the wire touches the metal terminal, not just cardboard. If necessary, peel away some cardboard.
5. Insert the banana plug of the black probe into "COM" on the multimeter. Insert the banana plug on the red probe into "V• Ω •mA•Temp" on the multimeter. Nothing will be connected to "10A" on the meter. Turn the selector dial to point at "V". You should see a "DC" in the upper left corner above the numeric display. If you see "AC" in the upper left corner, press the select key and it should turn to "DC".

6. Close the switch. Read and record the current I_1 through R_1 . While the switch is closed, use the voltmeter and probes to read and record the terminal voltages of the cell (V_1) and the battery (V_2). If either terminal voltage differs markedly from the nominal values of 1.5 and 3.0 V, have the instructor check your circuit. Open the switch.
7. With the switch open, move the ammeter from the top branch to the middle branch. The wire which previously connected points 6 and 7 should now connect points 1 and 2. Close the switch and read the current I_2 through R_2 . It is not necessary to measure the terminal voltages of the cell and battery again. Open the switch.
8. Move the ammeter from the middle branch to the bottom branch (R_3). The polarity of the ammeter must be reversed, compared to the top and middle branches, as conventional current must flow from left to right through R_3 . The wire which previously connected points 11 and 12 must now connect points 6 and 7. Close the switch and record the current I_3 . No voltage measurements are necessary.
9. Repeat steps 4-8 for Circuit #2, in which R_4 replaces R_3 . All three currents will, in general, be different from those in Circuit #1. The terminal voltages of the cell and battery should be measured again.
10. Remove the cell, battery, and connecting wires from the circuit. Close the switch.
11. Use the box form of Wheatstone Bridge to measure the actual values of the four resistors as follows: Check to see that the BA and GA buttons are not stuck in the depressed position. If they are, rotate them to release them. Connect clips 2 and 5 to the binding posts labeled X. If the switch of the circuit board is closed, R_1 is now connected to the bridge. Connect a 1.5 V cell to the binding posts labeled BA, observing polarity. Connect the galvanometer to the binding posts labeled GA, again observing polarity. If the galvanometer has a CLAMP button, slide it to release the meter movement.
12. Round the nominal value of resistor R_1 to one significant figure. Set the thousands dial of the Wheatstone Bridge to the first digit of the rounded value. Set the other three dials to zero. Set the multiplier dial so that the product of its setting and the total resistance of the four resistance dials equals the nominal resistance of the resistor. Hold the BA button down and gently tap the GA button. Observe the direction of the galvanometer deflection. A positive deflection means that the resistance dials are set too high; a negative deflection means that they are set too low. Change the setting and test again. Continue this process until no deflection is observed when both buttons are held down for several seconds. Record the measured resistance.
13. Repeat this process for the three remaining resistors. (Due to age or abuse some resistors may differ substantially from their nominal values.) If the galvanometer has a CLAMP button, secure it when finished.

III. CALCULATIONS

For Circuit #1

Make a diagram of the circuit.

- Label the resistors with the symbols R_1 , R_2 , and R_3 .
- Label the terminal voltages V_1 and V_2 of the sources.
- Mark each junction by a letter.
- Use an arrow to indicate the direction of the current in each branch.
- Label the currents I_1 , I_2 , and I_3 .
- Mark the appropriate polarity of the cell, the battery, and each resistor.

Write out Kirchhoff's Rules for enough junctions and loops to enable you to solve the resulting equations simultaneously for the "unknown" currents. For each junction equation, give the letter labeling the junction. For each loop equation, clearly indicate the loop being used.

Solve your equations symbolically for the theoretical currents.

Calculate the theoretical currents using the numerical values of the resistors as measured by the Wheatstone Bridge and the measured values of the terminal voltages.

Make a table containing the quantities Current Label (I_1 , I_2 , ...), Theoretical Current, Measured Current, and Percent Difference. Give currents in mA.

For Circuit #2

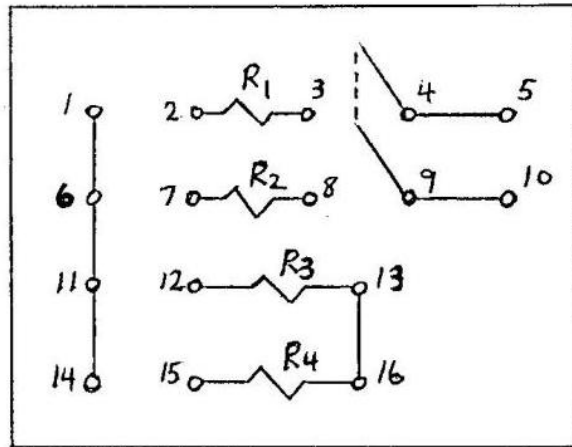
Replace I_3 and R_3 with I_4 and R_4 in your symbolic solutions for the theoretical currents.

Calculate the theoretical currents using the numerical values of the resistors as measured by the Wheatstone Bridge and the measured values of the terminal voltages.

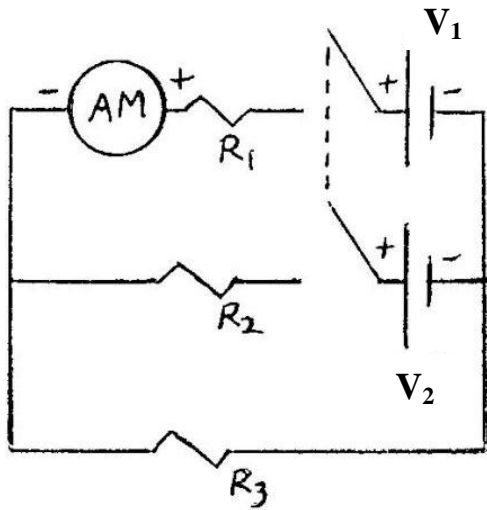
Make a table containing the quantities Current Label (I_1 , I_2 , ...), Theoretical Current, Measured Current, and Percent Difference. Give currents in mA.

IV. DIAGRAMS

Circuit Board



Circuit #1



Circuit #2

