

**OBJECTIVE**

The purpose of this lab will be to experimentally demonstrate Kirchhoff's Rules for electrical circuits.

**EQUIPMENT**

PhET interactive simulation tool (Circuit Construction Kit: DC - Virtual Lab):

<https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc-virtual-lab>

For an introduction on using the PhET Circuit Construction simulation, see: 00-PhET Simulation Tool instructions for Electric Circuits Labs.

**THEORY**

Electronic circuits that cannot be reduced to simple series of parallel circuits can be analyzed by different methods. As an example, consider the circuit of figure 1. The currents and voltage drops across the resistances cannot be found by a simple application of Ohm's Law. In this circuit, points A and D are called Junctions, since more than two wires connect there. A closed loop is any path that starts at some point in the circuit, passes through the elements of the circuit, and arrives back at the same point, without passing through any element more than once. There are three such closed loops in the circuit of Figure 1. These are Loop 1: A-B-C-D-A, Loop 2: A-D-E-F-G-A, and Loop 3: B-C-D-E-F-G-A-B. The junctions and loops are used in two Kirchhoff's rules to analyze the circuit.

**KCR- Kirchhoff's Current Rule:** The sum of the currents entering a junction = sum of currents leaving a junction. Or equivalently: the net current entering a junction is zero.

**KVR-Kirchhoff's Voltage Rule:** The algebraic sum of the voltage changes around any closed loop is zero.

We would usually know the values of the battery voltages and resistances. As a first step, we label and assign directions (arbitrarily) to the currents in each section of the circuit (i.e. between each junction). We then write the junction equation (assuming a current entering the junction is positive, and leaving the junction is negative) at node D as:

$$i_1 + i_3 - i_2 = 0 \quad (1)$$

We now traverse the closed loops in any direction (clockwise or counter-clockwise, the resulting equations are equivalent) and add up all the changes in the voltages and set them to zero, i.e.

$$\sum \Delta V = 0 \quad (2)$$

The voltage change across a resistor is found by Ohm's Law as

$$\Delta V = I R \quad (3)$$

The sign of  $\Delta V$  is positive if we are crossing the resistance in a direction that is against the direction of the current in that resistor, and it is negative if we go across the resistor in the same direction as the current. The  $\Delta V$  across the battery is positive if we cross it from its negative to its positive side. With these, the equations for the three loops become:

Loop 1 (starting at the point A and going clockwise):

$$V_1 - i_1 R_1 - i_1 R_2 + i_3 R_3 = 0.0 \quad (4)$$

Loop 2 (starting at A and going clockwise):

$$-i_3 \cdot R_3 - i_2 \cdot R_4 + V_2 - i_2 \cdot R_5 = 0.0 \quad (5)$$

Loop 3 (starting at A, and going clockwise):

$$+V_1 - i_1 \cdot R_1 - i_1 \cdot R_2 - i_2 \cdot R_4 + V_2 - i_2 \cdot R_5 = 0.0 \quad (6)$$

Note that equation (6) is simply the sum of equations (4) and (5), and is therefore not an independent equation. The same would apply to the junction rule applied at node A. So the useful (or independent) number of Junction equations that we can use are one less than the number of junctions, and the Loop equations are one less than the number of loops.

We then simultaneously solve equation (1) and any two out of equations (4), (5) and (6) to obtain the values of the currents  $i_1$ ,  $i_2$  and  $i_3$ . In case any of the currents comes out to be negative, it simply means that we had chosen then wrong direction for that current.

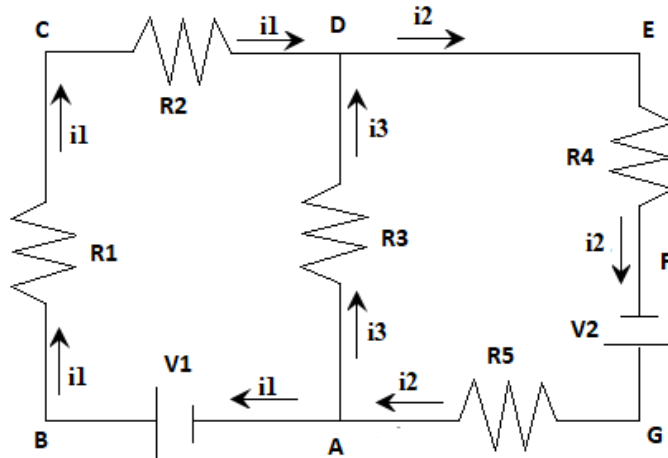


Figure 1

## PROCEDURE

- 1 Select five resistors and measure and note their resistances. Label them as  $R_1$ ,  $R_2$ , ...,  $R_5$ . Select resistors that are in the range of  $10.0 \Omega$  to  $100.0 \Omega$ .
- 2 Connect the resistors on the PhET simulation to make the circuit as shown in Figure 1. Attach the two batteries to appropriate points on the circuit. Set their voltages between  $6.0$  to  $10.0$  volts each. (The two voltages may or may not be the same). Note the positions of the resistors  $R_1$ ,  $R_2$ , ...,  $R_5$ . Measure the voltages across the batteries and note these as  $V_1$  and  $V_2$  in the Data Sheet.
- 3 Using the values of the resistances and battery voltages, calculate the currents  $i_1$ ,  $i_2$  and  $i_3$  by using the two Kirchhoff's Rules. Use the same notation and directions of the currents as used in Figure 1. Use the calculated currents to calculate the potential difference across each resistor by using Ohm's Law.
- 4 Once the calculations are done, you have an idea of what values to expect. First measure the voltages across each of the resistors and note it.
- 5 Now measure the currents  $i_1$ ,  $i_2$  and  $i_3$ . For this you would need to break the circuit and insert the ammeter in series with the wires to complete the loop.
- 6 Calculate the percent errors in the calculated and measured values of the currents and voltages. Check to see if the Kirchhoff's Junction rule and Loop Rules are verified.

**DATASHEET: KIRCHHOFF'S RULES**

$V_1 =$
$V_2 =$

RESISTANCE
$R_1 =$
$R_2 =$
$R_3 =$
$R_4 =$
$R_5 =$

CURRENT		
CALCULATED	MEASURED	% ERROR

VOLTAGE		
CALCULATED	MEASURED	% ERROR