Experiment 3

Ohm Law and Applying of Kirchhoff Rules

Purpose: Determination of the unknown \( R_1, R_2, R_{SERIES}, R_{PARALLEL} \) resistances with ohm's law and applying Kirchoff Rules to multi-loop circuits

Equipments: Resistor box, DC power supply, multimeter, milimetric graphic paper.

1. Introduction

Current, Resistor and Ohm Law: An electric current is a flow of electric charges. The SI unit of electric current is the ampere (A), which is equal to a flow of one coulomb of charge per second.

\[
I = \frac{q}{t}
\]

The direction of the current is opposite the direction of flow of electrons. The cell, battery etc. generators are source of electrical energy in electrical circuits and they allow for the movement of charge carriers creating the potential difference between terminals which they are connected. A battery is called either a source of electromotive force or, more commonly, a source of emf. The emf \( \varepsilon \) of a battery is the maximum possible voltage that the battery can provide between its terminals and it is given by

\[
\varepsilon = \frac{w}{q}
\]

where \( w \) is the work done by generator, \( q \) is the load.
Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference across the two points. Introducing the constant of proportionality, the resistance one arrives at the usual mathematical equation that describes this relationship:

\[ I = \frac{V}{R} \]

where \( I \) is the current through the conductor in units of amperes, \( V \) is the potential difference measured across the conductor in units of volts, and \( R \) is the resistance of the conductor in units of ohms. More specifically, Ohm's law states that the \( R \) in this relation is constant, independent of the current.

**Resistors in Series and Parallel:**

The circuit, which is shown in figure 1a, connected in series. For series combination of two resistors, the current is the same in both resistors because the amount of charge that passes through \( R_1 \) must also pass through \( R_2 \) in the same time interval. The potential difference applied across the series combination of resistors will divide between the resistors. In figure 1a, because the voltage drop from a to b equals \( IR_1 \) and the voltage drop from b to c equals \( IR_2 \), the voltage drop from a to c is

\[ \Delta V = IR_1 + IR_2 = I(R_1 + R_2) \]

The potential difference across the battery is also applied to the equivalent resistance \( R_{eq} \).

\[ \Delta V = IR_{eq} \]

Where we have indicated that the equivalent resistance has the same effect on the circuit because it results in the same current in the battery as the combination of resistors. Combining these equations, we see that we can replace the two resistors in series with a single equivalent resistance whose value is the sum of the individual resistances:

\[ \Delta V = IR_{eq} = I(R_1 + R_2) \]

\[ R_{eq} = R_1 + R_2 \]

The equivalent resistance of three or more resistors connected in series is
\[ R_{eq} = R_1 + R_2 + R_3 + \ldots \]

This relationship indicates that the equivalent resistance of series connection of resistors is the numerical sum of the individual resistance and is always greater than any individual resistance.

**Figure 1.** (a) A series connection for two-resistor circuit, (b) A parallel connection for two-resistor circuit.

The circuit, which is shown in figure 1b, connected in parallel. Because the electric charge is conserved the current \( I_1 \) that enters to a point must be equal the total current leaving that point:

\[ I = I_1 + I_2 \]

Where \( I_1 \) is the current in \( R_1 \) and \( I_2 \) is the current in \( R_2 \). When resistors are connected in parallel, the potential differences across the resistors is the same.

Because the potential differences across the resistors are the same, the expression \( \Delta V = IR \) gives

\[ I = I_1 + I_2 = \frac{\Delta V}{R_1} + \frac{\Delta V}{R_2} = \Delta V \left( \frac{1}{R_1} + \frac{1}{R_2} \right) = \frac{\Delta V}{R_{eq}} \]

From this result, we see that the equivalent resistance of two resistors in parallel is given by,

\[ \frac{1}{R_{eq}} = \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \]

An extension of this analysis to three or more resistors in parallel gives,

\[ \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \]
We can see from this expression that the inverse of the equivalent resistance of two or more resistors connected in parallel is equal to the sum of the inverses of the individual resistances. Furthermore, the equivalent resistance is always less than the smallest resistance in the group.

**Kirchhoff’s Rules:**

Simple circuits can be analyzed using the expression $\Delta V = IR$ and the rules for series and parallel combinations of resistors. Very often, however, it is not possible to reduce a circuit to a single loop. The procedure for analyzing more complex circuits is greatly simplified if we use two principles called Kirchhoff’s rules:

**i. Junction rule.** The sum of the currents entering any junction in a circuit must equal the sum of the currents leaving that junction:

$$\sum I_{\text{in}} = \sum I_{\text{out}}$$

**ii. Loop rule.** The sum of the potential differences across all elements around any closed circuit loop must be zero:

$$\sum_{\text{closed loop}} \Delta V = 0$$

When applying Kirchhoff’s second rule in practice, we imagine traveling around the loop and consider changes in electric potential, rather than the changes in potential energy. You should note that the following sign conventions when using the second rule:

- Because charges move from the high-potential end of a resistor toward the low potential end, if a resistor is traversed in the direction of the current, the potential difference $\Delta V$ across the resistor is “$-IR$” (Fig. 3a). If a resistor is traversed in the direction opposite the current, the potential difference $\Delta V$ across the resistor is “$+IR$” (Fig. 3b).

- If a source of emf is traversed in the direction of emf (from - to +), the potential difference $\Delta V$ is $+\varepsilon$ (Fig. 3c). If a source of emf is traversed in the direction opposite the emf (from + to -), the potential difference $\Delta V$ is $-\varepsilon$ (Fig. 3d).

![Figure 3. Potential differences in circuit elements.](image)
**Measurement instruments:** The current intensity passing from circuit is measured with ampermeter; potential difference is measured with a voltmeter. Both quantities can be measured with a multimeter. Ampermeter is connected in series with the circuit elements. Ideally, an ampermeter should have zero resistance so that the current being measured is not altered. Voltmeter is connected in parallel and it should have infinite resistance so that no current exists in it.

2. **Experiment**

**Ohm Law**

1. Chose two resistors from resistance box and set the circuit as shown figure 4. Adjust power supply to values which is in Table 1. Read the current passing from resistor and write down to Table 1.

![Figure 4.](image)

**Table 1**

<table>
<thead>
<tr>
<th>V(V)</th>
<th>$I_1$(mA)</th>
<th>$R_1$=……………</th>
<th>$I_2$(mA)</th>
<th>$R_2$=……………</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$R_{1\text{calculation} \ (k\Omega)}$</td>
<td></td>
<td>$R_{2\text{calculation} \ (k\Omega)}$</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>$R_1$ average=</th>
<th>$R_2$ average=</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R_1$ graph=</td>
<td>$R_2$ graph=</td>
</tr>
</tbody>
</table>

2. Draw $V=f(I)$ graph for each conductor, find resistance values, compare the average of the resistors values which are calculated and write the results down to Table 1.

3. Connect the resistors in series, as repeating the measurements which is in step 1, write the results down Table 2.

4. Connect the resistors in parallel, as repeating the measurements which is in step 1, write the results down Table 2.
5. Draw $V=f(I)$ graphs for series and parallel connected resistors. Find the equivalent resistance values, compare the average of the resistors values which is calculated and write the results down to Table 2.

Table 2

<table>
<thead>
<tr>
<th>V(V)</th>
<th>I(mA)</th>
<th>Connected in series</th>
<th>Connected in parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$R_{\text{calculation}}$ ($k\Omega$)</td>
<td>$I$(mA) $R_{\text{calculation}}$ ($k\Omega$)</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$R_{\text{average}} =$

$R_{\text{eq}} =$

$R_{\text{graph}} =$

$R_{\text{average}} =$

$R_{\text{eq}} =$

$R_{\text{graph}} =$
1. Set the circuit as shown Figure 5. Measuring the current intensity and voltage differences from each resistance write them down Table 3.

![Circuit Diagram]

<table>
<thead>
<tr>
<th></th>
<th>$V_1$ (V)</th>
<th>$V_2$ (V)</th>
<th>$I_{AB}$ (mA)</th>
<th>$V_{AB}$ (V)</th>
<th>$I_{BC}$ (mA)</th>
<th>$V_{BC}$ (V)</th>
<th>$I_{BD}$ (mA)</th>
<th>$V_{BD}$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculated values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative error</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Using Kirchhoff’s Rules, calculate the current passing from each resistor and potential difference between the terminals of resistor. Write results down Table 3.

3. Calculate the relative errors and write them down Table 3.