Kuwait University Physics Department
Physics 107

Parallel and Series Resistors, Kirchoff's Law

Introduction

In this experiment the relations among voltages, currents and resistances for both series and parallel resistors networks are going to be studied. Furthermore, Kirchoff's law including its two rules: a) the junction rule and b) the loop rule is going to be verified by applying it to a complex network that consists of multi-loops.

Objectives

- To be familirized in handling electrical measuring devices.
- To gain skills in safety requirements in handling electrical components.
- To understand the relations among voltage, current and resistance for an ohmic material.
- To acquire an understanding of the conceptual meanings of the loop and junction theorems.
- To be able to apply Kirchoff's rules to a multi-loop circuit.

Equipment to be Used:

- Analog trainer.
- Wires.
- Resistors: 470 Ω , 1 kΩ , 390 Ω , 560 Ω .

- Multimeter.

Theory

Resistors in Series:

When two or more resistors are connected in series to each other to an electromotive force (emf) ε , the current passing through all resistors is the same, which equals the current delivered by the source:

$$I = I_1 = I_2 = ... = I_n, \tag{1}$$

Where I is the total current delivered by the emf force ε, and I_1, I_2,... are the currents through individual resistors.
The potential difference, ε, that is applied across the combination equals the sum of the resulting potential differences across all the resistances. (**Energy Conservation Principle**):

$$\varepsilon = V_1 + V_2 + ... + V_n, \tag{2}$$

The equivalent resistance R_{eq} of the combination of individual resistors is given as:

$$R_{eq} = R_1 + R_2 + ... + R_n, \tag{3}$$

Note that the equivalent resistance is greater than the greatest resistor in the series circuit.

Resistors in Parallel:

When two or more resistors are connected in parallel to each other and to an emf, the voltage drop across all the elements is the same and equals the applied voltage (ideally):

$$\varepsilon = V_1 = V_2 = ... = V_n, \tag{4}$$

The total current I delivered by the emf branches through the individual resistors such that it equals the sum of the individual currents (**Charge Conservation Principle**):

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

The equivalent resistance is given as:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}. \tag{6}$$

Note that the equivalent resistance of a parallel circuit is always less than the smallest resistance in the circuit.

Kirchoff's laws:

Simple circuits can be analyzed using Ohm's law and the rules for series and parallel combination of resistors. Very often it is not possible to reduce a complex circuit to a single loop. Therefore, to analyze complex circuits, we may use Kirchoff's law. We can simplify complicated circuits using of Kirchoff rules mentioned above. But before introducing the rules we need to define the technical meanings of a **junction**, and a **loop**.

> **Junction**: (or Branch point (B.P)): The term refers to any point where three or more circuit elements meet.
>
> **Loop**: The term refers to any closed path of a circuit such that the point you start with is also the point you end up with.

To illustrate these concepts consider the electric circuit shown in Figure 1. There are two branch points: **B** & **E**, and three loops: **ABEFA**, **BCDEB** and **ACDFA**.

Junction rule: It states that: "*Algebraic sum of all the currents entering and leaving any branch point in a circuit is equal to zero*". The represents a reformulation of charge conservation principle. Mathematically, we may write the principle for any junction point as follows:

$$\sum_i I_i \tag{7}$$

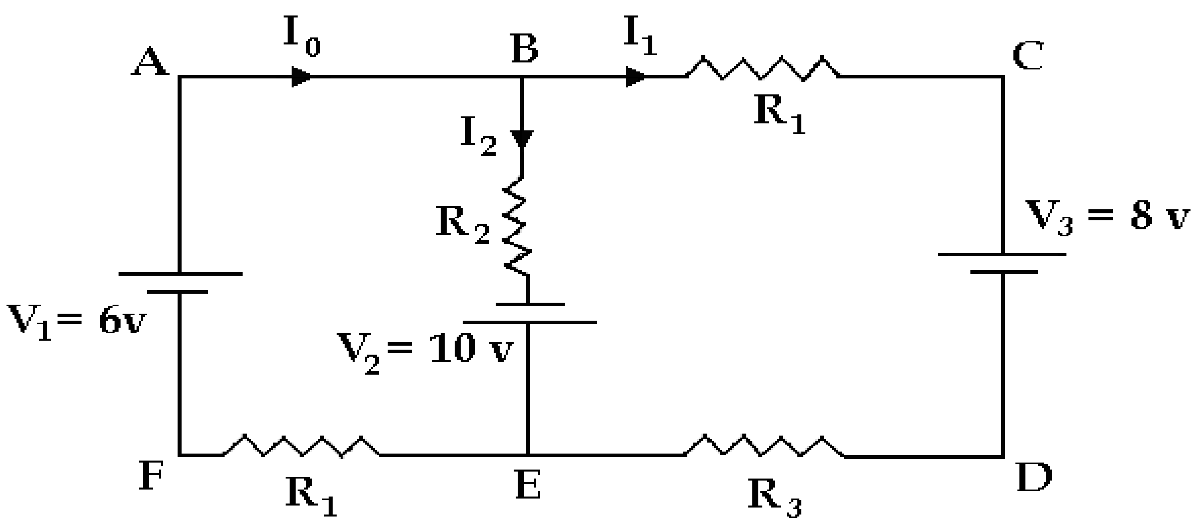

Figure 1.

Loop rule: It states that: "*Algebraic sum of all the potential differences around any loop in a circuit is equal to zero*". The loop theorem is a restatement of energy conservation principle. Mathematically the rule is presented as follows

$$\sum_i V_i \tag{8}$$

To apply the junction rule follow the steps outlined below:

i. Choose a branch point (B.P).

ii. Set the direction of the current flow for this B.P (you may assume currents flowing **toward** the junction point to be + and those flowing **away** to be −, or visa versa).

iii. Apply the junction rule, Equation 7.

As an aid in applying the loop rule, the following points should be noted:

* If a resistor is traversed in the direction of the current, the change in potential across the resistor is assumed negative, $(-IR)$.
* If a source of emf (battery) is traversed in the direction of the emf (from $-ve$ to $+ve$), the change in potential is assumed positive, $(+\varepsilon)$.

Procedure

Part One: Resistors in Series

1) **Measure** R_1 and R_2, **record** the values in the top of Table 1. ($R_1 = 560\ \Omega$, $R_2 = 390\ \Omega$).
2) **Connect** the two resistors in series then **measure** their equivalent resistance R_{eq} and **record** the data in the Table 1.
3) **Set** the power supply to 8 V, and then **connect** it across the two resistors as shown in Figure 2.
4) **Measure** the current passing through each resistor as I_1 and I_2. Also measure the total current in the circuit I_{eq}. **Record** the data in Table 1.
5) **Measure** the voltage drop across each resistor as V_1 and V_2. **Record** the data in Table 1.
6) **Calculate** R_{eq}, I_{eq}, I_1, I_2, V_1, and V_2. **Record** the values in Table 2.

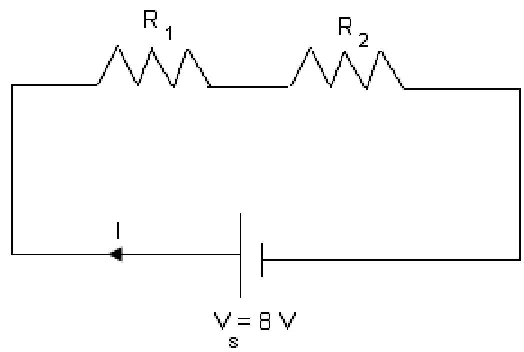

Figure 2. Two resestors are connected end-to-end (series)

Table 1. (Measured values) R_1=............................ R_2=............................

R_{eq} (Ω)	I_{eq} (mA)	I_1 (mA)	I_2 (mA)	V_1 (v)	V_2 (v)

Table 2. (Calculated values) R_1=............................ R_2=............................

R_{eq} (Ω)	I_{eq} (mA)	I_1 (mA)	I_2 (mA)	V_1 (v)	V_2 (v)

7) Compare the measured values with the calculated ones.

....

8) Verify the relations for the voltage, current, and resistance given for the series connection.

....

Part Two: Resistors in Parallel

1) Use the same resistors used in part one.

2) **Connect** the two resistors in parallel then **measure** their equivalent resistance R_{eq}, and **record** the data in the Table 3.

3) **Set** the power supply to 5 V, and then **connect** it across the two resistors as shown in Figure 3.

4) **Measure** the current passing through each resistor as I_1 and I_2. Also, **measure** the total current in the circuit I_{eq}. **Record** the data in Table 3.

5) **Measure** the voltage drop across each resistor as V_1 and V_2. **Record** the data in Table 3.

6) **Calculate** R_{eq}, I_{eq}, I_1, I_2, V_1, and V_2. **Record** the values in Table 4.

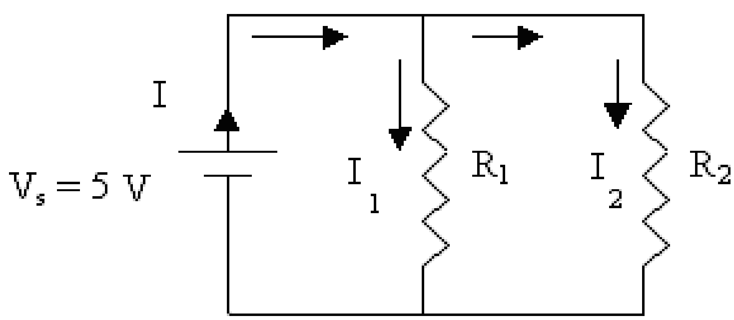

Figure 3. Two resistors connected on parallel to the voltage source.

Table 3. (Measured values) R_1=............................ R_2=............................

R_{eq} (Ω)	I_{eq} (mA)	I_1 (mA)	I_2 (mA)	V_1 (v)	V_2 (v)

Table 4. (Calculated values) R_1=............................ R_2=............................

R_{eq} (Ω)	I_{eq} (mA)	I_1 (mA)	I_2 (mA)	V_1 (v)	V_2 (v)

7) Compare the measured values with the calculated ones.

   ....

8) Verify the relations for the voltage, current, and resistance given for the parallel connection.

   ....

   ....

   ....

Part Three: Combination of series and parallel resistors

1) **Measure** R_1, R_2, and R_3 and **record** the values in the top of Table 5. ($R_1 = 560\Omega$, $R_2 = 1$ kΩ, $R_3 = 470$ Ω), then **connect** the circuit as shown in Figure 4.

2) **Measure** the equivalent resistance R_{eq} with the power supply disconnected. **Record** the data in Table 5.

3) **Apply** 8V to the circuit as shown in Figure 4. Then **measure** the current passing through each resistor as I_1, I_2, I_3. **Measure** I_{eq} too. **Record** the data in Table 5.

4) **Measure** the voltages V_1, V_2, and V_3. **Record** the data in Table 5.

5) **Calculate** I_{eq}, I_1, I_2, I_3, V_1, V_2, V_3, and R_{eq}. **Record** the values in Table 6.

6) **Compare** the measured values with the calculated ones.

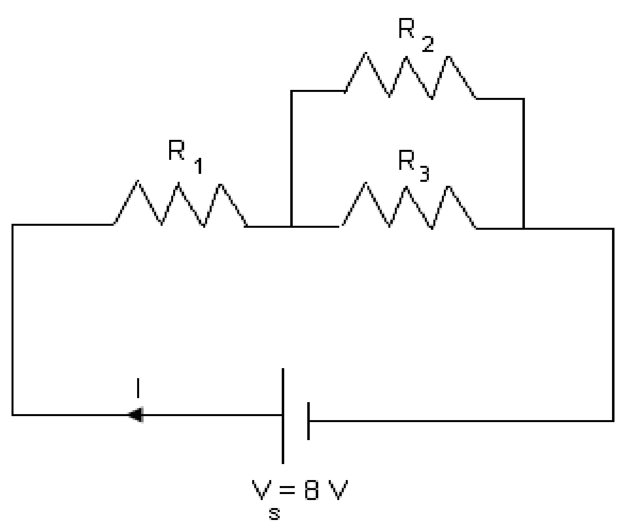

Figure 4. Two resistors in parallel connected in series to another resistor.

Table 5. (Measured values) R_1=................ R_2=................ R_3=..................

R_{eq} (Ω)	I_{eq} (mA)	I_1 (mA)	I_2 (mA)	I_3 (mA)	V_1 (v)	V_2 (v)	V_3 (v)

Table 6. (Calculated values) R_1=........................... R_2=...........................

R_{eq} (Ω)	I_{eq} (mA)	I_1 (mA)	I_2 (mA)	I_3 (mA)	V_1 (v)	V_2 (v)	V_3 (v)

Part Four: Kirchoff's law

1) Using the given four resistors (R_1 = 560 Ω, R_2 =1 kΩ, R_3 = 470 Ω, R_4 = 390 Ω), **connect** the circuit as shown in Figure 5.

2) **Measure** the equivalent resistance R_{eq} with the power supply disconnected. **Record** the data in Table 7.

3) **Measure** the current through each resistor as I_1, I_2, I_3, I_4, and **measure** the equivalent current I_{eq} too. **Record** the data in Table 7.

.

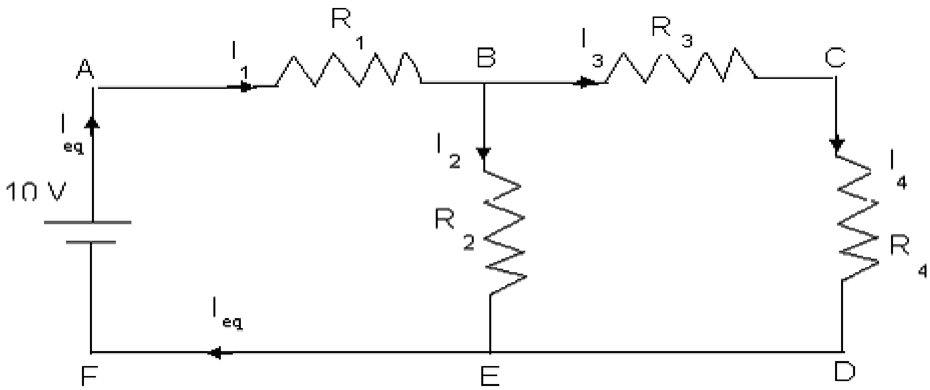

Figure 5.

Table 7.

R_{eq} (Ω)	I_{eq} (mA)	I_1 (mA)	I_2 (mA)	I_3 (mA)	I_3 (mA)

4) Verify the junction rule for the branch points B & E.

- For B.P (B):

$I_1 =$ .... $(I_2 + I_3) =$ ....

Therefore, ...

- For B.P (E):

....

....

Therefore, ...

Is the junction rule verified? ....

5) Verify the loop rule for the loops ABEFA and BCDEB.

- For the loop ABEFA: Calculate

$I_1R_1 =$ ...., $I_2R_2 =$ ....

$+\varepsilon - I_1R_1 - I_2R_2 =$ ....

- For the loop BCDEB: Calculate

$I_2R_2 =$ ...., $I_3R_3 =$ ...., $I_4R_4 =$ ....

$+I_2R_2 - I_3R_3 - I_4R_4 =$ ....

Is the loop rule verified? ....

Part Five: Shorting out a resistor

1) Refer to Figure 5. **Short out** R_2. (Shorting out a resistor means connecting a wire across the two ends of the resistor, so that the total current passes through the wire and non passes through the resistor because of its zero resistance (ideally). See Figure 6.

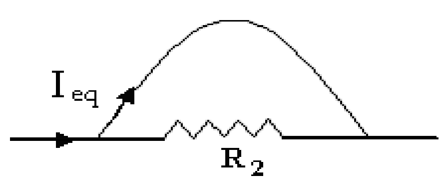

Figure 6.

2) **Measure** R_{eq} with the power supply disconnected.

$R_{eq} =$ ....

What is the value of R_{eq} after shorting out R_2? Explain.

....

3) **Connect** the power supply then, **measure** the current I_{eq}.

$I_{eq} =$ ....

What is the value of I_{eq} after shorting out R_2? Explain.

....

....

Part Six: Opening a resistor

1) Refer to Figure 5. **Open** the resistor R_2. (Opening a resistor means disconnecting one end of the resistor from the circuit, so that no current passes through it).

2) Measure R_{eq} with the power supply disconnected.

$R_{eq} =$ ....

What is the value of R_{eq} after opening R_2? Explain.

....

....

3) **Connect** the power supply then, **measure** the current I_{eq}.

$I_{eq} =$ ....

What is the value of I_{eq} after opening R_2? Explain.

....

....

Conclusion: