# Resistance Networks

## Introduction

When constructing electrical circuits for home use or in building equipment, we often have to use large numbers of devices like lamps, resistors, and capacitors. When using these devices, we commonly have to combine them in special ways. The purpose of this lab is to explore how we combine resistors and how do those combinations affect currents and voltages in simple circuits.

## Resistors Combinations

Resistors are usually combined in one of two ways, parallel or series. Both are depicted in Figures 1 and 2. In the simplest of cases, when connected in parallel, both ends of the resistors are connected to each other, when in series only one end is connected. For more complicated cases, we can use the following rule:

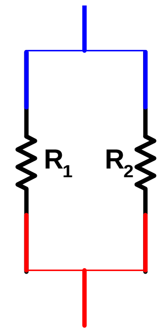


Fig. 1: Parallel

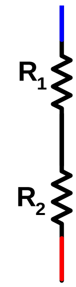


Fig. 2: Series

**Series and Parallel Rule**

- Resistors (or any other device) $R_1$ and $R_2$ are in series **if and only if** **every loop that contains $R_1$ also contains $R_2$**
- Resistors (or any other device) $R_1$ and $R_2$ are in parallel **if and only if** you can **find a loop that has ONLY $R_1$ and $R_2$**

**Series and Parallel Example**
Consider the circuit in Figure 3 for example. The only resistors that are in series are $R_1$ and $R_6$. Every loop that you can trace around the circuit includes both of them. As an example loop, you can think of a loop starting at $E_1$ and going clockwise through $R_1$, $E_3$, $R_4$, $R_5$, $R_6$ and ending back at $E_1$. A second loop can start at $E_1$ and going clockwise through $R_1$, $R_2$, $E_2$, $R_6$ and ending back at $E_1$. It is worth noting that $R_5$ is in series with the combination of $R_3$ and $R_4$ but not in series with either one of them.
The only resistors that are in parallel are $R_3$ and $R_4$.

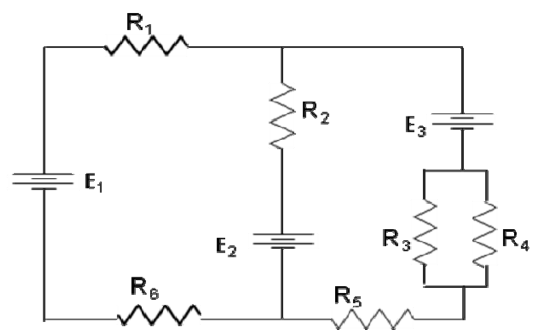


Fig. 3: Example of a complicated circuit

### Use of Meters Reminder

We usually use an Ammeter to measure current and a Voltmeter to measure voltage. When drawing a schematic of a circuit, we usually label the Ammeter as “A” and the voltmeter with “V”. An example schematic is shown in Figure 4. Along with the ammeter and the voltmeter, the schematic includes 4 other devices: a power supply designated by E, and three resistors designated by R.

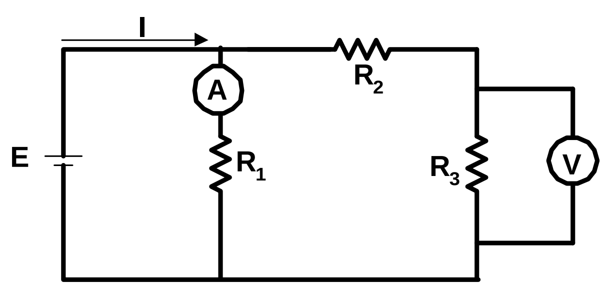


Fig. 4: Use of an ammeter and a voltmeter

When measuring current with an ammeter, the ammeter should be placed in series with the device we want to measure the current through. For example, as shown in the Figure, if we want to measure the current through $R_1$, we place the ammeter in series with $R_1$. The same current should flow through both $R_1$ and the ammeter.

On the other hand, if we want to measure voltage, we have to connect the voltmeter in parallel with the device you want to measure the voltage across. For example, as shown in the Figure, if we want to measure the voltage across $R_3$, we place the voltmeter in parallel with $R_3$. Both $R_3$ and the voltmeter are subject to the same voltage.

## Use of a Voltmeter to Measure Currents

As we have learned from previous labs, resistors obey ohms law. This means that we have a simple relationship between the voltage across a resistor and the current flowing through it: V= R I
In cases where it is more convenient to use a voltmeter than an ammeter, this relationship can be used to find the current.

## Theory and Model

In a series circuit (see Figure 5), since there is no branching in the circuit, the current going through each resistor is the same. By using Ohm's law (V = IR) we can find the voltage across each of the resistors. The source voltage is then given by:

$$V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3 = I\,(R_1 + R_2 + R_3)$$

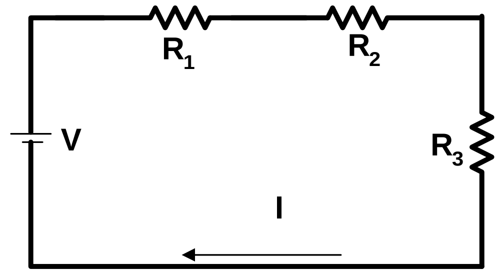

Fig. 5: Resistors in series

This means that we can draw the same current from the source if we replace the resistors by an "equivalent" resistor given by:

$$R_{equivalent} = (R_1 + R_2 + R_3)$$

In a parallel circuit, the current through the resistors is related to the current through the source by:

$$I = I_1 + I_2 + I_3$$

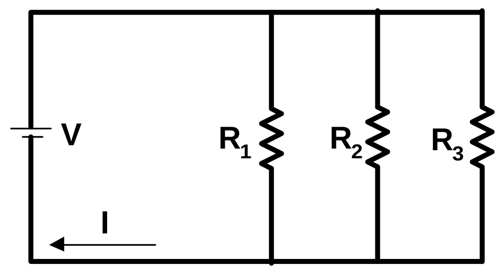

Fig. 6: Resistors in parallel

But they are subject to the same voltage:

$$V = I_1R_1 = I_2R_2 = I_3R_3$$

The equivalent resistance is in this case given by:

$$1/\,R_{equivalent} = 1/R_1 + 1/R_2 + 1/R_3$$

We will now verify the two relations for series and parallel resistors.

## Procedure

Please make sure that you do not add or remove items to the lab box. Broken items will be replaced by your teachers. Additionally, please do not remove the cables that are connected to the power supply.

For this experiment, we are going to verify the equations for resistors in series and in parallel. We will need a power supply, six resistors, wires for connecting the parts and a multimeter to use for measuring voltages.

1. You are provided with 6 resistors but only 3 different value resistance. Use the multimeter to measure each of the resistances. If you need information on how to measure resistance, follow the tutorial at http://physci.kennesaw.edu/physlets/dig/ You can also figure out the resistance by using the resistance color codes. This utility can help guide you with that: http://physci.kennesaw.edu/physlets/dig/resistors.htm

Resistors Values:

| | | | | | |
|---|---|---|---|---|---|
| $R_1$= _______ $\Omega$ | $R_2$= _______ $\Omega$ | $R_3$= _______ $\Omega$ | $R_4$= _______ $\Omega$ | $R_5$= _______ $\Omega$ | $R_6$= _______ $\Omega$ |

2. In the sake of clarity, we will refer to the smallest value resistance as $R_S$, the middle value as $R_M$ and the large value as $R_L$.

| | | |
|---|---|---|
| $R_S$ = _______ $\Omega$ | $R_M$ = _______ $\Omega$ | $R_L$ = _______ $\Omega$ |

**Resistors in Series**

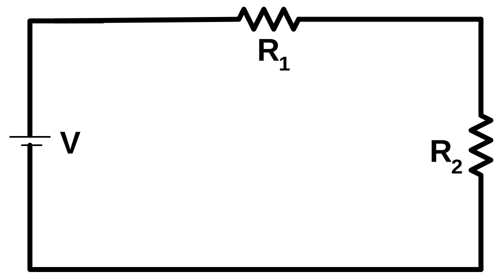

Fig. 7: Resistors in series

1. Wire the circuit as shown in Figure 7. Use two identical resistors ($R_S$).
2. With the power supply still off, turn both current knobs fully **clockwise** and both voltage knobs fully **counterclockwise**.
3. **GET THE TEACHER TO VERIFY YOUR CIRCUIT before you turn on the Power Supply!**
4. Gradually adjust the voltage knobs of the power supply until you get a 3.0 volt output. That is the voltage we will use throughout the lab..
5. Use the multimeter to measure the voltage across each of the resistors ($V_1$ and $V_2$), the voltage across the power supply, and use ohm's law to calculate the current through each of the resistors ($I_1$ and $I_2$).

Remember that since for measuring current, if we use an ammeter, we need to first break the circuit then add the ammeter in series in the branch where we want to measure current, and since we are using only resistors and we know that resistors obey Ohm's law, we can forego measuring current directly and use the voltmeter readings to deduce the current values.

| $V_1$ | $V_2$ | $I_1$ | $I_2$ | V |
|---|---|---|---|---|
| | | | | |

6. What do you conclude?
   - How does $I_1$ compare to $I_2$?
   - How do you think $I_1$ and $I_2$ compare to I, the current through the power supply? How does that value compare to the current readout of the supply?
   - How does $V_1$ compare to $V_2$?
   - How do $V_1$ and $V_2$ compare to V? Is there a relationship between all three?
7. Disconnect the supply, remove both resistors and replace them by one resistor $R_M$.
8. Reconnect the supply and measure V, $V_M$ (voltage across $R_M$) and $I_M$. Be smart, don't repeat measurements that are obviously the same.
9. What do you conclude?
   - How does $R_M$ relate to $R_1$ and $R_2$?
   - How do $I_1$ in the first circuit compare to $I_M$ in the second?
   - How does V in the first circuit compare to V in the second circuit?
   - Explain your observations?

10. Wire the circuit as shown in Figure 5. Use three different resistors.
11. Use the multimeter to measure the voltage across each of the resistors ($V_1$, $V_2$ and $V_3$), the voltage across the power supply (V) and calculate the current through each of the resistors ($I_1$, $I_2$ and $I_3$).

| $V_1$ | $V_2$ | $V_3$ | $I_1$ | $I_2$ | $I_3$ | V |
|---|---|---|---|---|---|---|
| | | | | | | |

12. What do you conclude?
    - How do $I_1$, $I_2$ and $I_3$ compare?
    - How do $I_1$, $I_2$ and $I_3$ relate to I the current through the power supply?
    - How do $V_1$, $V_2$ and $V_3$ relate to V?
    - What would be the equivalent resistance for all three resistances?

13. Disconnect $R_3$ by just un-connecting one of its ends while keeping it in the circuit (Fig. 8). Repeat the following measurements:

| $V_1$ | $V_2$ | $V_3$ | $I_1$ | $I_2$ | $I_3$ | V |
|---|---|---|---|---|---|---|
| | | | | | | |

14. What do you conclude?
    - What is the effect of disconnecting one end of $R_3$ or any other resistor on the rest of the circuit?

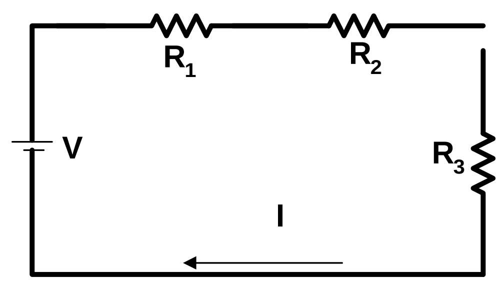

Fig. 8: Disconnecting $R_3$

**Resistors in Parallel**

1. Wire the circuit as shown in Figure 9. Use two identical resistors ($R_M$) for $R_1$ and $R_2$.
2. **GET THE TEACHER TO VERIFY YOUR CIRCUIT!**
3. Use the multimeter to measure the voltage across each of the resistors ($V_1$ and $V_2$), and the voltage across the power supply.
4. Calculate the current through each of the resistors ($I_1$ and $I_2$).
5. Use the power supply current readout to read the current through the power supply..
6. Connect the supply and get your current reading.

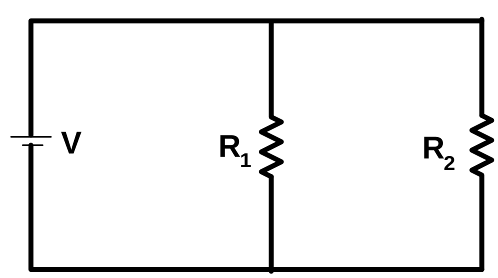

Fig. 9: Resistors in Parallel

| $V_1$ | $V_2$ | $I_1$ | $I_2$ | V | I |
|---|---|---|---|---|---|
| | | | | | |

7. What do you conclude?
    - How does $I_1$ compare to $I_2$?
    - How do $I_1$ and $I_2$ relate to I?
    - How does $V_1$ compare to $V_2$?
    - How do $V_1$ and $V_2$ relate to V?

8. Disconnect supply, remove both resistors and replace them by one resistor $R_S$.
9. Turn on the supply, measure V and deduce I.
10. What do you conclude?
    - How does I in the first circuit compare to I in the second circuit?
    - How does V in the first circuit compare to V in the second circuit?
    - Explain your observations? How does $R_S$ compare to $R_1$ and $R_2$?

11. Wire the circuit as shown in Figure 6. Use three different resistors.
12. Use the multimeter to measure the voltage across each of the resistors ($V_1$, $V_2$ and $V_3$), and the voltage across the power supply.
13. Calculate the current through each of the resistors ($I_1$, $I_2$ and $I_3$).
14. Measure the current through the power supply (I)

| $V_1$ | $V_2$ | $V_3$ | $I_1$ | $I_2$ | $I_3$ | V | I |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

15. What do you conclude?
    - How do $I_1$, $I_2$ and $I_3$ compare?
    - How do $I_1$, $I_2$ and $I_3$ relate to I?
    - How do $V_1$, $V_2$ and $V_3$ compare?
    - How do $V_1$, $V_2$ and $V_3$ relate to V?
    - What would be the equivalent resistance for all three resistances?

16. Disconnect $R_2$ by just un-connecting one of its ends while keeping it in the circuit (Fig. 10). Repeat the following measurements:

| $V_1$ | $V_2$ | $V_3$ | $I_1$ | $I_2$ | $I_3$ | V | I |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

17. What do you conclude?
    - How do $I_1$, $I_2$ and $I_3$ compare to the values you have measured before disconnecting $R_2$?

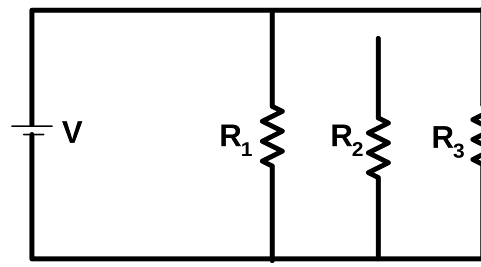


Fig. 10: Disconnecting $R_2$

    - What is the effect of disconnecting $R_2$ on the rest of the circuit?
    - Would the effect on the circuit have been different if we disconnected $R_3$ or $R_1$ instead?
    - Explain your observations?

**Combination Circuit**

18. Wire the circuit as shown in Figure 11. Use $R_S$ for $R_1$ and $R_2$, $R_M$ for $R_3$ and $R_5$ and $R_L$ for $R_4$.

19. Before making any measurement, what are the resistors, if any, that are in series in this circuit?

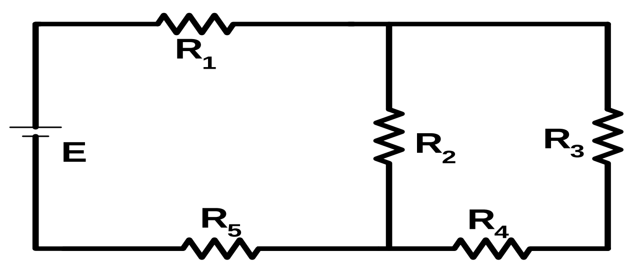


Fig. 11: A combination circuit

20. Again before making any measurement, what are the resistors, if any, that are in parallel in this circuit?

21. How many different current values you expect to find in this circuit?

22. Measure the voltage across each of the resistors ($V_1$, ..), the voltage across the power supply (V), and calculate the current through each of the resistors ($I_1$, …), and deduce the current through the power supply (I).

| $V_1$ | $V_2$ | $V_3$ | $V_4$ | $V_5$ | V | I |
|---|---|---|---|---|---|---|
| | | | | | | |
| $I_1$ | $I_2$ | $I_3$ | $I_4$ | $I_5$ | | |
| | | | | | | |

23. Based on the data, what are the resistors, if any, that are in series in this circuit?
    - Consider the voltage and the current through each of the resistors that you think are in series.
    - Also apply the rule as stated in the introduction: **if and only if** **every loop that contains $R_1$ also contains $R_2$**

24. Based on the data, what are the resistors, if any, that are in parallel in this circuit?
    - Consider the voltage and the current through each of the resistors that you think are in parallel.
    - Also apply the rule as stated in the introduction: **if and only if** you can **find a loop that has ONLY $R_1$ and $R_2$**

25. What do you conclude?
    - How do the various currents that you have measured relate?
    - How do the various voltages that you have measured relate?
    - What would be the equivalent resistance for all five resistances?

26. Shut off power supply and return all equipment where it was found.

Please make sure that you do not add or remove items to the lab box. Broken items will be replaced by your teachers. Additionally, please do not remove the cables that are connected to the power supply.

27. A good resource for learning about circuit and trying different configurations virtually (with the use of a simulation) is available at the following site: http://phet.colorado.edu/sims/cck/cck-ac.jnlp