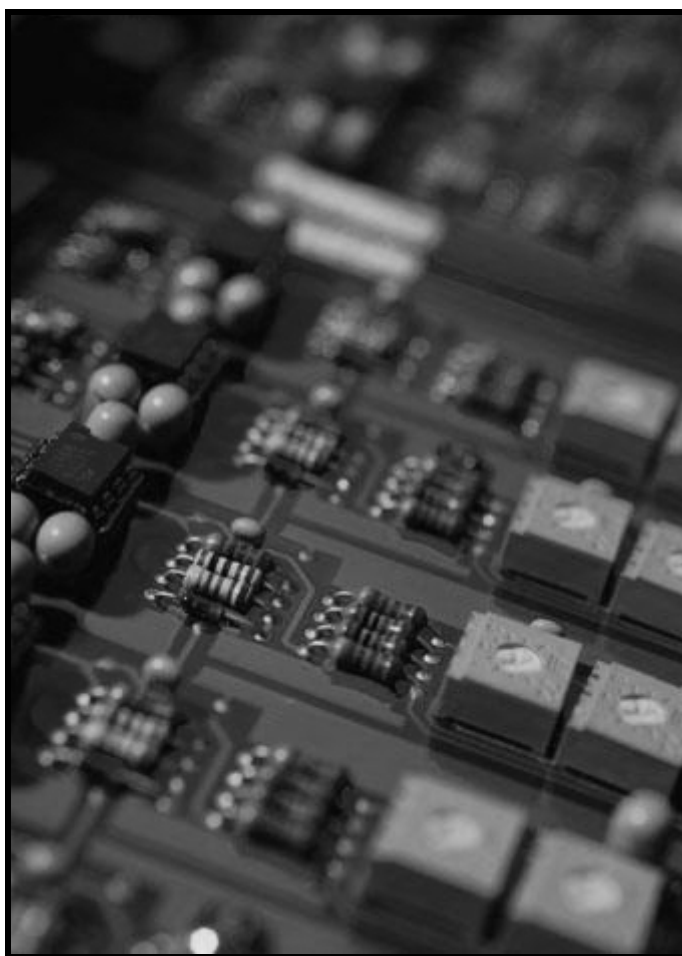


## ***Resistors in Series and Parallel***



***Produced by the Physics Staff at  
Collin County Community College***

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## **Purpose**

In this experiment, you will investigate the characteristics of circuits containing resistors connected in series and parallel.

## **Equipment**

- Ammeter
- Power Supply
- Three resistors
- Four clip leads
- Voltmeter
- Basic Electric Lab board
- Switch

## **Introduction**

Most resistive elements in simple circuits are connected in either series or parallel combinations. You can represent each element as a resistance to current flowing in the circuit. In order to compute the potential difference across or the current in each element in the circuit, you must know the equivalent resistance of the series and/or parallel combination.

If  $n$  resistors are connected in series with a voltage source, they collectively behave as an equivalent single resistor of resistance  $R_s$ , where

$$R_s = R_1 + R_2 + R_3 + \dots + R_n \quad \text{Equation 4.1}$$

The same current flows in each resistor. The potential difference across the source is equal to the sum of the potential differences across the various resistors.

If the same  $n$  resistors are connected in parallel to the voltage source, then they collectively behave as an equivalent single resistor of resistance  $R_p$ , where

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n} \quad \text{Equation 4.2}$$

The potential difference across each resistor is equal to the potential difference across the source. The current from the source is equal to the sum of the currents in the various resistors.

When two or more resistors are connected in line or “head to tail”, so that the same current passes through each as in Figure 4.1 in the Procedure section, they are said to be connected *in series*. On the other hand, if the resistors are arranged such that all “heads” are connected together and all “tails” are connected together so the current from the source splits into separate branches as shown in Figure 4.3, they are said to be connected *in parallel*. In a parallel circuit, the same potential difference exists across each resistor.

In either case, it is convenient, and often necessary, to find the single equivalent resistance that could replace the combination of resistors without altering the voltages and currents in the rest of the circuit. The resistors in the circuit could be any kind of commercial resistor, or they could be light-bulb filaments or other resistive circuit devices.

### Resistors in series

If the resistors are connected in series (as shown in Figure 4.1), the same current  $I$  passes through each resistor. Let  $V$  represent the voltage supplied by the source, and assume that the resistance in the wires can be ignored. Then  $V$  is the emf of the battery and  $V_1$ ,  $V_2$ , and  $V_3$  are the potential differences across each of the resistors  $R_1$ ,  $R_2$ , and  $R_3$ . Using Ohm's law, you can write

$$V_1 = R_1 I, \quad V_2 = R_2 I, \quad \text{and} \quad V_3 = R_3 I \quad \text{Equations 4.3}$$

Because both energy and charge are conserved, the total voltage  $V_T$  is equal to the sum of the voltages across each resistor:

$$V_T = V_1 + V_2 + V_3 = (R_1 + R_2 + R_3)I \quad \text{Equation 4.4}$$

If an equivalent single resistor  $R_s$  replaces the three resistors and draws the same current, you can write

$$V_T = R_s I \quad \text{Equation 4.5}$$

If you eliminate  $V_T$  and  $I$  between Equations 4.4 and 4.5, you get

$$R_s = R_1 + R_2 + R_3 \quad \text{Equation 4.6}$$

Therefore, when you connect several resistors in series, the single equivalent resistance is simply the sum of the individual resistances. This applies to any number of resistors, not just for three. Clearly, when you add more resistance to the circuit, the current will decrease.

### Resistors in parallel

For a parallel circuit (such as that shown in Figure 4.3), you again want to find the single resistance  $R_p$  that is equivalent to three resistors in parallel. In this circuit, the total current  $I_T$  from the battery splits into three branches. Let  $I_1$ ,  $I_2$ , and  $I_3$  be the current in each of the resistors  $R_1$ ,  $R_2$ , and  $R_3$ . Because charge is conserved, the total current  $I_T$  flowing into a junction must equal the current flowing out of it, so

$$I_T = I_1 + I_2 + I_3 \quad \text{Equation 4.7}$$

Also, the full voltage of the battery is applied to each resistor, so

$$I_1 = \frac{V}{R_1}, \quad I_2 = \frac{V}{R_2}, \quad \text{and} \quad I_3 = \frac{V}{R_3} \quad \text{Equation 4.8}$$

Furthermore, the single equivalent resistor  $R_p$  that will draw the same total current  $I_T$  as these three resistors in parallel must satisfy the relationship

$$I_T = \frac{V}{R_p} \quad \text{Equation 4.9}$$

If you insert the values of current in Equation 4.8 into Equation 4.7, and then use Equation 4.9 to replace the values of  $I_T$ , you get

$$\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \text{Equation 4.10}$$

Divide Equation 4.10 by  $V$  to get the relationship between the equivalent resistor and the three parallel resistors

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{Equation 4.11}$$

# Procedure

## A. Resistors in Series

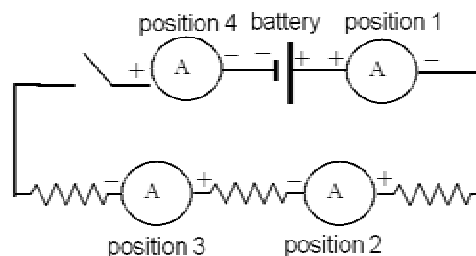
1. Choose 3 resistors –  $R_1$ ,  $R_2$ , and  $R_3$ . The colored bands reveal a code that gives the value of the resistance. Use a color code chart to determine the resistance value of each resistor and record the resistance values in Data Table 4.1. In order to ensure measurable currents, select resistances less than  $300 \Omega$ .
2. Using the spring clips on the circuit board, connect the three resistors in series as in Figure 4.1. Scrape the leads of the resistors until they shine before you insert them into the spring clips, but do not bend the leads. Leave the switch open. Using the color-code resistance values, compute the equivalent resistance  $R_s$  of the circuit. Record this value in the Table 4.1.

3. Place the power supply in series (in place of the 3-volt battery in the figure) and set it to 3.0 volts. Connect a red lead to the positive terminal and a black lead to the negative terminal so you will not have to check the polarity each time you measure current and voltage.



**Figure 4.1**

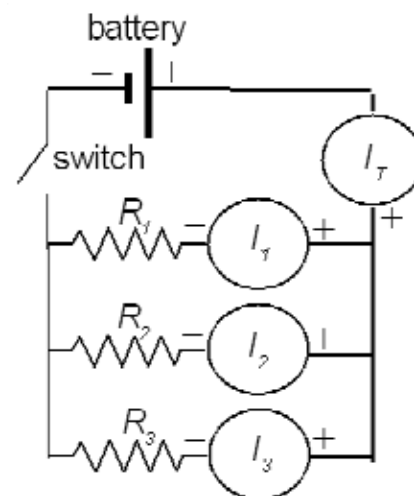
4. Connect the voltmeter across all three resistors combined. Close the switch, read the voltmeter value  $V_T$ , and record it in Table 4.1 (Note:  $V_T$  is also the power supply voltage). Open the switch after you take the reading. Use  $V_T$  and  $R_s$  to compute and record the total current  $I$  in the circuit and the voltage across each resistor ( $V_1$ ,  $V_2$ , and  $V_3$ ) in Table 4.1.
5. With the switch closed, use the voltmeter to measure the voltage across each individual resistor. Record your measured voltages in Table 4.1.
6. To measure the current in the circuit, you must allow the current to go through the ammeter. Insert the ammeter in the circuit as in Figure 4.2, **position 1** as follows: (a) Disconnect the red lead from the positive terminal of the power supply and connect it to the positive terminal of the ammeter. (b) Connect the ammeter's negative lead to  $R_1$ , where the power supply originally was connected.
7. Close the switch, read the current, then open the switch. Change the ammeter scale as needed. Record this total current  $I$  in Table 4.1.
8. Compute and record the percent differences between your measured and computed values of  $I$ ,  $V_1$ ,  $V_2$ , and  $V_3$ .



**Figure 4.2**

## **B. Resistors in Parallel**

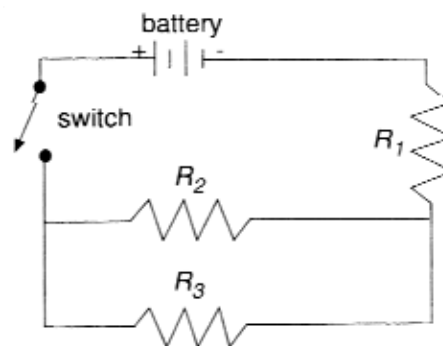
1. Connect the same three resistors in parallel as shown in Figure 4.3. You will use the meters to measure voltage and current as you did in Part A, investigating the circuit by checking the current from the battery through the circuit to see that it divides into three branches at one junction of the resistors and comes together again at the opposite junction.
2. Using the color-code resistor values and the power supply voltage  $V_T$ , compute the equivalent resistance  $R_p$  of the circuit, the total current  $I_T$ , and the current in each resistor ( $I_1$ ,  $I_2$ , and  $I_3$ ). Record these values in Table 4.2.
3. Insert the ammeter in position  $I_T$  as follows: Disconnect the red lead from the positive terminal of the power supply and connect it to the negative terminal of the ammeter. Connect the ammeter's positive lead to the first resistor junction where the power supply originally was connected.
4. Close the switch, read and record the current, then open the switch.
5. Repeat steps 3 and 4 three more times, each with the ammeter inserted in one of the positions 1, 2, and 3 indicated in the Figure 4.3.
6. Compare the values of current you computed in step 2 with your experimentally measured values by calculating and recording the percent difference in the current in each resistor.



**Figure 4.3**

## **C. Resistors in Series-Parallel**

1. Connect the same three resistors in the series-parallel configuration shown in Figure 4.4, using the smallest value resistor as  $R_1$ .
2. Using the color-code resistance values and the power supply voltage  $V_T$ , compute and record the equivalent resistance  $R_{sp}$  of the circuit, the current in each resistor, and the voltage drop across each resistor. Record these values in Table 4.3.
3. Insert the ammeter between the power supply and resistor  $R_1$  as follows: Disconnect the red lead from the positive terminal of the power supply and connect it to the negative terminal of the ammeter. Connect the ammeter's positive lead to the first resistor junction where the power supply originally was connected. Close the switch, read and record the current  $I_1$ , then open the switch.



**Figure 4.4**

4. Repeat step 3 three more times with the meter inserted in the  $R_2$  leg ( $I_2$ ), in the  $R_3$  leg ( $I_3$ ), and between the switch and the power supply ( $I_T$ ).
5. Remove the ammeter from the circuit and use the voltmeter to measure and record the voltage drop across each resistor:  $V_1$ ,  $V_2$ , and  $V_3$ .
6. Compare the theoretically computed values of current and voltage from step 2 with your experimentally measured values by calculating and recording the percent difference in current and voltage in each resistor.