**Objective:**
In this experiment you will set up three circuits: one with resistors in series, one with resistors in parallel, and one with some of each. You will be building circuits similar to the ones you will be working with in homework and exam problems. *This experiment should show you the difference between resistors in series and parallel. If you understand what we are doing in this experiment, you will be all set to do well on the midterm questions about circuits!*

**Equipment:**
Resistors ($R_1 = 2.2 \, k\Omega$, $R_2 = 6.8 \, k\Omega$, and $R_3 = 4.7 \, k\Omega$), multimeter, and DC power supply.

**Theory:**
In the first part of this experiment we will study the properties of resistors, which are connected “in series”. Figure 1 shows two resistors connected in series (a) and the equivalent circuit with the two resistors replaced by an equivalent single resistor (b), as we discussed in the lecture. Remember from lecture that, when resistors are connected in series, each one “sees” the same current. Recall the water analogy: If you have two pipes that have different diameters but are connected in series and you send water through them, each receives the same amount of water, there are no branches into which the water can split. In lecture, we showed that the equivalent resistance for resistors in series is

$$R_{eq} = R_1 + R_2.$$  

Of course, this equation can be extend to any number of resistors in series, so that for $N$ resistors the equivalent resistance is given by

$$R_{eq} = \Sigma R_i \quad (\text{for } i=1,2,3,\ldots,N)$$

or

$$R_{eq} = R_1 + R_2 + R_3 + \ldots + R_N.$$
You (hopefully!) remember from lecture this isn't the only way to hook up resistors in a circuit. In the second part of this lab we'll hook them together as in Figure 2.

![Figure 2: Two resistors in parallel](image)

We say these resistors are connected in parallel. In series they were connected one after the other, but in parallel, as the name suggests, they are 'side by side' in the circuit. When resistors are in parallel, the current flowing from the battery will come to a junction where it has a “choice” as to which branch to take. Therefore, they “see” different amounts of current, just the way water branching into two different pipes will flow more through the larger pipe (lower resistance) than through the narrower pipe (greater resistance). Resistors in parallel “see” different currents, but they each experience the same potential difference (voltage). In lecture, we used this property of resistors in parallel to derive an equation for calculating the equivalent resistance. In this case, the equation is a bit more complicated than for resistors in series. Instead of the resistances adding directly, we calculate

\[
\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}
\]

It’s important to remember that after you do this calculation, you will have gotten \(1/R_{eq}\). You have to flip that over in order to get \(R_{eq}\)! Here’s an example: If we have \(R_1 = 270\Omega\) and \(R_2 = 330\Omega\) we would find \(R_{eq}\) as follows:

\[
\frac{1}{R_{eq}} = \frac{1}{270\Omega} + \frac{1}{330\Omega} = .0037037\Omega^{-1} + .003030\Omega^{-1}
\]

\[
= .006734\Omega^{-1}
\]

So, \(R_{eq} \approx 148\Omega\)

We can generalize this equation to any number of resistors, just the way we did for resistors in series. As in the case for series we can generalize this law to any number of resistors:

\[
\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_N} = \sum_{i=1}^{N} \frac{1}{R_i}
\]
The Experiment

Part 1

1. Take three resistors. Measure the resistance of each resistor individually using the ohmmeter (i.e., the multimeter). Record the values in Data Table 1.
2. Determine the resistance of each resistor, using the Resistor Color Code Chart on page 17. Record the values in Data Table 1.
3. Now, connect the resistors in series, as shown in Figure 3a, and connect them to the power supply that is set at 12 V. Record the voltage across each resistor, using the multimeter. Record the measured values in Data Table 1.

Data Table 1

<table>
<thead>
<tr>
<th>R_1 (measured)</th>
<th>R_1 (from color code)</th>
<th>V_1 (measured)</th>
<th>I_1 (calculated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_2 (measured)</td>
<td>R_2 (from color code)</td>
<td>V_2 (measured)</td>
<td>I_2 (calculated)</td>
</tr>
<tr>
<td>R_3 (measured)</td>
<td>R_3 (from color code)</td>
<td>V_3 (measured)</td>
<td>I_3 (calculated)</td>
</tr>
</tbody>
</table>

Figure 3: The voltages across series resistors.
**Questions: Part 1**

1. Are the voltages $V_1$, $V_2$ and $V_3$ equal to each other? Why or why not?

2. Calculate the total voltage $V = V_1 + V_2 + V_3$. Explain why it has the value it does.

3. Use Ohm’s law to calculate the current through each resistor. (e.g., $V_1 = I_1 * R_1$, so $I_1 = V_1 / R_1$). For this calculation, use the measured value of the resistances. Record these calculated values in the table above. Is the result what you expected? Why?

![Figure 4: Two resistors attached in parallel](image)

**Part 2**

In this part of the experiment, you will experimentally test the addition law for resistors in parallel.

1. Take two resistors. Measure the resistance of each resistor individually using the ohmmeter (i.e., the multimeter). Record the values in Data Table 2.

2. Calculate the resistance of each resistor, using the Resistor Color Code Chart on page 17. Record the values in Data Table 2.

3. Now, connect the resistors in parallel, as shown in Figure 4, and connect them to the power supply that is set at 12 V. Record the voltage across each resistor, using the multimeter. Record the measured values in Data Table 2.

4. Calculate the equivalent resistance ($R_{eq}$) of the circuit, based on your measured values of $R_1$ and $R_2$. Enter the value at the top of Data Table 2.

5. Measure the equivalent resistance of the circuit using the ohmmeter. This is the resistance between points P and Q in Figure 4a. Record the value at the top of Data Table 2.

6. Use Ohm’s law, with your measured value of $R_{eq}$, to calculate the total current in the circuit. Enter the value at the top of Data Table 2.
<table>
<thead>
<tr>
<th>R₁ (measured)</th>
<th>R₁ (from color code)</th>
<th>V₁ (measured)</th>
<th>I₁ (calculated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R₂ (measured)</td>
<td>R₂ (from color code)</td>
<td>V₂ (measured)</td>
<td>I₂ (calculated)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R_{eq} (calculated)</th>
<th>R_{eq} (measured)</th>
<th>I_{total}</th>
</tr>
</thead>
</table>

Questions: Part 2

4. Are the measured values of R₁ and R₂ equal to the values calculated using the color code chart? How much do they differ (calculate percent error)? Is this within the specified tolerance?

5. Is your measured value of R_{eq} similar to your calculated value? Explain.

6. Are V₁ and V₂ equal to each other? Explain.

7. Are I₁ and I₂ equal to each other? Explain.

8. Compare I_{total} to the I₁ and I₂. What do you notice?

Part 3

Now for the grand conclusion. We are going to use our techniques on a circuit that has resistors in both series and parallel connections. Below we have a circuit with three resistors. The two which are connected in parallel, R₁ and R₃, are in series with R₁.

1. Write down the resistor values from their color codes in Table 3.
2. Measure their individual resistances using your multimeter and record these values in Table 3.
3. Calculate the equivalent resistance, R_{eq}, for the three resistors hooked up as in Figure 5, first using your measured resistances (record as Measured R_{eq} in Table 3), and then using the values from the color code chart (record as Color Code R_{eq} in Table 3).
4. Now connect them to the power supply that is set at 12V.
5. Measure the voltage across R₁ and then across R₂ and R₃.
Data Table 3

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>V₀ (measured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R₁ (measured)</td>
<td>R₁ (from color code)</td>
<td>V₁ (measured)</td>
</tr>
<tr>
<td>R₂ (measured)</td>
<td>R₂ (from color code)</td>
<td>V₂ (measured)</td>
</tr>
<tr>
<td>R₃ (measured)</td>
<td>R₃ (from color code)</td>
<td>V₃ (measured)</td>
</tr>
<tr>
<td>Rₑq (measured)</td>
<td>Rₑq (from color code)</td>
<td>V₁+V₂</td>
</tr>
</tbody>
</table>

Questions: Part 3

9. Are the voltages V₁, V₂ and V₃ equal to each other? Why or why not?

10. Calculate the total voltage V = V₁ + V₂. Explain why it has the value it does. How does this sum compare with V₀? Is it the same as V₁ + V₃? Why or why not?

11. Use Ohm’s law to calculate the current through each resistor. (e.g., V₁=I₁*R₁, so I₁=V₁/R₁). For this calculation, use the measured value of the resistances. Record these calculated values in the table above. Is the result what you expected? Why?