DC CIRCUIT EXPERIMENT

Short description
In this experiment we will determine how voltages are distributed in resistor circuits according to Ohm's law and explore series and parallel combinations of resistors. We will also study the behavior of the current and voltages in an $RC$ circuit.

Equipment

DC power supply, three 470 $\Omega$ resistors, one 1000 $\Omega$ resistor, one unknown resistor. Multimeter, one large capacitor (about 2500$\mu$F), Resistance box. 5 banana cables

PART 1: Resistors

Resistors are passive electronic devices which have fixed values. The resistance follows Ohm's Law:

$$V = IR.$$  

The SI unit of resistance is the ohm, $1 \Omega = 1 \text{ V/A}$. The schematic symbol for a resistor is below:

There are two ways to connect two passive (no polarity) components in an electronic circuit—series or parallel connection. In a series connection the components are connected at a single point, end to end as shown below:

For a series connection, the equivalent resistance

**SERIES:**  

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

In the parallel connection, the components are connected together at both ends as shown below:

For a parallel connection, the equivalent resistance

**PARALLEL:**  

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$
1) Set the DC voltage on the power supply to 10 V. Measure the accurate voltage with the multimeter.

\[ V_{\text{acc}} = \boxed{\text{_____________ V}} \]

Connect two 470 Ω resistors in **series**. Measure \( V_1 \) (across \( R_1 \) which is the one in the box) with the meter and record it below.

\[ V_1 \text{ (measured)} = \boxed{\text{_____________ V}} \]

Compute the expected value of \( V_1 \) by using \( V_{\text{acc}} \), the values of \( R_1 \) and \( R_2 \). (You have to calculate the total resistance and the current first).

\[ V_1 \text{ (expected)} = \boxed{\text{_____________ V}} \]

\[ \% \text{ Error} = \left| \frac{\text{measured} - \text{expected}}{\text{measured}} \right| \times 100 \% = \boxed{\text{_____________}} \]

2) Connect a third 470 Ω resistor in **parallel** with the first resistor. Compute the equivalent resistance \( R_{\text{box}} \) of the two resistors in the box on the figure to the right.

\[ R_{\text{box}} = \boxed{\text{_________ Ω}} \]

Measure and compute the voltage across \( R_{\text{box}} \)

\[ V_{\text{box}} \text{ (measured)} = \boxed{\text{_________ V}}, \]

\[ V_{\text{box}} \text{ (expected)} = \boxed{\text{_________ V}}, \]

\[ \% \text{ Error} = \left| \frac{\text{measured} - \text{expected}}{\text{measured}} \right| \times 100 \% = \boxed{\text{_____________}} \]

3) Now replace the third resistor of question 3), with a 1000Ω resistor. Compute the equivalent resistance \( R_{\text{box}} \) of the two resistors in the box on the figure to the right.

\[ R_{\text{box}} = \boxed{\text{_________ Ω}} \]

Measure and compute the voltage across \( R_{\text{box}} \)

\[ V_{\text{box}} \text{ (measured)} = \boxed{\text{_________ V}}, \]

\[ V_{\text{box}} \text{ (expected)} = \boxed{\text{_________ V}}, \]

\[ \% \text{ Error} = \left| \frac{\text{measured} - \text{expected}}{\text{measured}} \right| \times 100 \% = \boxed{\text{_____________}} \]
4) Now connect two 470 Ω and the 1000 Ω resistors in **series** (with the 1000 Ω in the middle). Compute the equivalent resistance \( R_{\text{Box}} \) of the two resistors in the box

\[ R_{\text{Box}} = \quad \Omega. \]

Measure and compute the voltage across \( R_{\text{Box}} \)

\[ V_{\text{Box}} \text{ (measured)} = \quad \text{V}, \]

\[ V_{\text{Box}} \text{ (expected)} = \quad \text{V}, \]

\% Error = \frac{|\text{measured} - \text{expected}|}{|\text{measured}|} \times 100 \% = \quad \%

**PART 2: RC combination**

**Charging the capacitor**

When a capacitor is **charged** through a resistor by a constant voltage source, the voltages across the capacitor and resistor change exponentially with time. That is,

\[ V_C = V \left(1 - e^{-\frac{t}{RC}}\right) \]

\[ V_R = V e^{-\frac{t}{RC}} \]

\( V \) is the applied voltage. The rate at which the capacitor charges or discharges can be characterized by the time constant \( \tau = RC \)

5) Set the resistance of the resistance box to 5000 Ω. Check its actual value with the multimeter. If you read a bad value (~ M Ω) change the resistance. Try in the range 4000 to 7000 Ω.

\[ R = \quad \Omega \]

For the lab you will use the above resistor and a capacitor with a capacitance of the order 2500 μF. What is the time constant for this RC combination?

\[ \tau = \quad \text{s} \]

6) Before starting check the DC voltage of the power supply – it should be set at 5V. Measure the voltage using the multimeter. Record the applied voltage.

\[ V = \quad \text{V} \]

7) First we need to make sure the capacitor is discharged. What does it means that a capacitor is discharged?
8) To discharge it, simply connect both ends of the capacitor using one cable as shown in the picture below (and wait about 5 seconds):

Why does connecting both ends of a capacitor discharge it?

9) Turn off the power supply and build the circuit. Take a close look at the circuit diagram below. It is important that you connect the negative output of the DC power supply to the end of the capacitor that has a minus sign "-" on it and the positive output of the DC power supply to the resistor and then the resistor to the end of the capacitor that has a plus sign "+" on it. If you do not connect the components accordingly to the right polarity, the capacitor might blow up and be dangerous (if you’re not sure, ask the instructor to check). Set the multimeter to measure DC voltages across the capacitor $V_C$ by connecting it as shown in the diagram below:

10) Take the measurement. Search online for a web-based stopwatch, or use an app on your phone to measure time intervals. Make sure the stopwatch has the lap function and know how to use it to record different times as an event takes place. You will measure several time intervals as $V_C$ increases from 0 to the voltage provided by the power supply. Set the power supply ready: disconnect the two cables from the power supply, turn on the power supply and adjust it to 5V, turn off the power supply, re-connect the cables. Now it’s all ready. Turn on the power supply and the capacitor will start to charge. Read several values of $V_C$ on the multimeter and measure the times that $V_C$ takes to reach these values. Use the lap function to measure these time intervals. Collect your data in the table below. The voltage will increase faster at the beginning of the charging process, so try to take most of the time measurements between 0V and 2V. Repeat the charging to improve your data.

<table>
<thead>
<tr>
<th>$V_C$</th>
<th>0V</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>5V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11) PLOT 1: Using Excel, plot VC as a function of time. Looking at the plot determine RC by estimate the time at which the voltage has increased to 63% of the power supply value. Assume that you do not know the capacitance, calculate it from the measured resistance R and the time constant you just determined.

\[ C = \text{___________} \mu F \]

\[ \% \text{ Error} = \frac{|\text{measured} - \text{expected}|}{|\text{expected}|} \times 100 \% = \text{__________} \]

12) PLOT 2: Now plot this same data in semi log format. Plot the natural log of \((1 - VC / V)\) on the vertical axis and t on the horizontal axis. Draw a single “best fit” straight line through your data and determine RC from this line. What capacitance does this correspond to?

\[ C = \text{___________} \mu F \]

\[ \% \text{ Error} = \frac{|\text{measured} - \text{expected}|}{|\text{expected}|} \times 100 \% = \text{__________} \]

13) Set the resistance of the box to about half of the value you just used. Repeat the measurement described in step 10. How is the time to charge the capacitor different in this case?

**Discharging the capacitor**

When a capacitor is **discharged** through a resistor, the voltages are given by

\[ V_C = V_0 e^{-\frac{t}{RC}} \]

\[ V_R = -V_0 e^{-\frac{t}{RC}} \]

where \(V_0\) is the initial voltage across the capacitor.

14) In order to discharge the capacitor in the RC circuit unplug the two cables from the power supply, add the resistance box, set at 5000 \(\Omega\) and get ready to connect the cables to each other. Make sure also you have the stop watch ready. Connect the cable and using the lap function, measure several time intervals for the capacitor voltage VC to drop to about 0V. Again, try to take most of the measurements at the beginning of the discharging process. Repeat the discharging if needed. Collect you data in the table below:

| \(V_C\) | 5V | | | | | | | | 0V |
| Time | | | | | | | | | |
15) PLOT 3: Using Excel, plot VC as a function of time. Determine RC by finding the time at which the voltage has dropped to 36.8% of the original value. Assume that you do not know the resistance and use the given value of C to calculate the resistance R.

\[ R = \text{_____________} \, \Omega \]

% Error = \[ \frac{|\text{measured} - \text{expected}|}{|\text{expected}|} \times 100\% = \text{__________} \]

16) PLOT 4: Now plot this same data in semi log format. Plot the natural log of VC on the vertical axis and t on the horizontal axis. Draw a single “best fit” straight line through your data and determine RC from this line. Again use the given value of C to calculate R.

\[ R = \text{_____________} \, \Omega \]

% Error = \[ \frac{|\text{measured} - \text{expected}|}{|\text{expected}|} \times 100\% = \text{__________} \]

17) Set the resistance of the box to about half of the value you just used. Repeat the measurement described in step 8. How the time to discharge the capacitor is different in this case?