Electrical Circuits: Ohm and Kirchhoff Laws

1 Purpose

An electrical circuit with series and parallel resistors and non-ohmic devices will be constructed. Voltages and currents will be measured at different points around the circuit to verify Ohm's law, the Kirchhoff voltage and current laws.

2 Theory

All devices in an electrical circuit will follow Ohm's Law, $i = \frac{\Delta V}{R}$, where i is the electrical current in [A], ΔV is the electric potential difference or voltage across the device in [V], and R is the electrical resistance of the device in [Ω].

An ohmic device is a device that exibits a linear relationship between voltage and current. Such as

$$V \propto i, \qquad \text{or} \qquad V = iR \tag{1}$$

where the electrical resitance R is constant over a large range of current. An non-ohmic device does not have a constant resistance over a large range of current. Examples of non-ohmic devices are incandescent lightbulbs and light emitting diodes (LEDs).

Kirchhoff's voltage law essentially states that sum of the voltage drops across across all devices (ohmic or non-ohmic) in a loop (possible charge path) is zero.

$$\sum_i \Delta V_i = 0 \text{ , around a loop, or} \tag{2}$$

$$\sum_{i, i \neq bat} |\Delta V_i| = |\Delta V_{bat}| \tag{3}$$

Kirchhoff's current law states that at a node or branch point the sum of the currents entering must equal the sum of currents leaving the node. This is basically another statement for the conservation of charge.

$$i_{1,e} + i_{2,e} = i_{3,l} + i_{4,l} \tag{4}$$

It can be show using Kirchhoff's laws that for series resistors,

$$R_{eq} = R_1 + R_2 + R_3 + ... \tag{5}$$

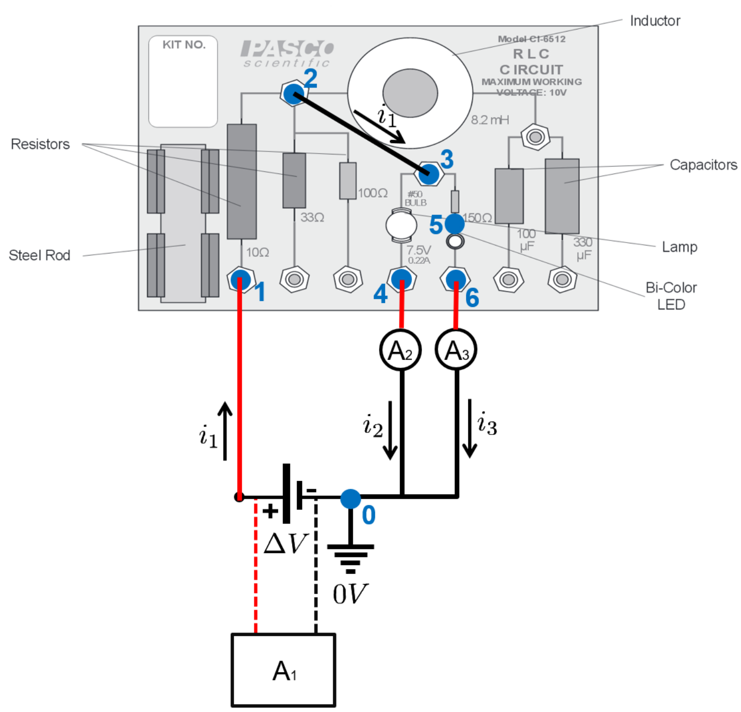
and for resistors in parallel,

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... \tag{6}$$

3 Procedure

3.1 Ohmic and non-ohmic devices

1. Construct an electrical circuit with one (internal) current sensor A_1 and two ammeters A_2 and A_3 as follows:



2. Connect the negative (black) probe voltage sensor of Channel A of the 750 interface to point 0. For the power supply voltage of 0.5V, 1.0V, 1.5V, 2V, 3V, 4V, 5V, 6V, 7V, 8V, 8.5V, 9V, 9.5V, and taking care to NOT EXCEED 200 mA on the A_2 ammeter, use the positive probe (red) of the voltage sensor to measure the voltage at points 1 and 2, 3 and 4, 5 and 6. Record the currents i_1, i_2, and i_3.

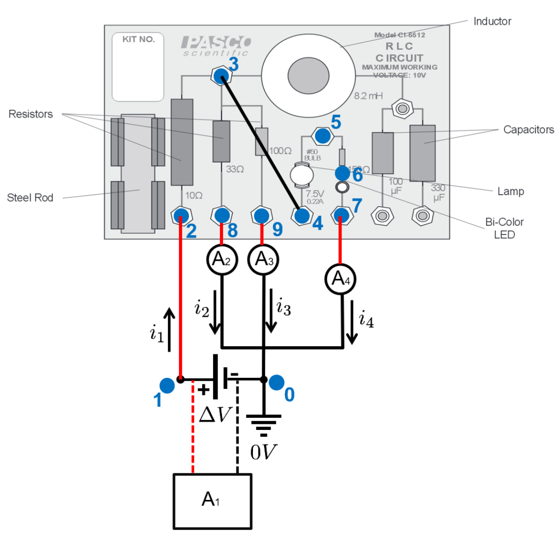
3. Organize your data in a table such as,

Table 1

V_1 (V)	V_2 (V)	V_3 (V)	V_4 (V)	V_5 (V)	V_6 (V)	i_1 (mA)	i_2 (mA)	i_3 (mA)

3.2 Ohm's Law and Kirchhoff's voltage and current law

4. Construct an electrical circuit with one (internal) current sensor A_1 and three ammeters A_2, A_3, and A_4 as follows:



5. Connect the negative probe of the voltage sensor of Channel A of the 750 interface to point 0.

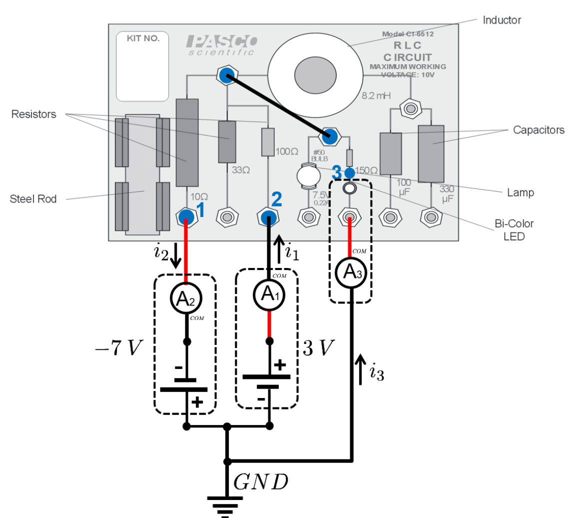
Taking care to NOT EXCEED 200 mA on the A_2 or A_3 ammeter increase the power supply voltage to the maximum of 9 or 9.5V, and with the positive probe measure the voltage at points 0 through 9, and record the currents i_1, i_2, i_3, and i_4.

6. Organize your data in a table such as,

Table 2									
V_1 (V)	V_2 (V)	V_3 (V)	V_4 (V)	V_5 (V)	V_6 (V)	V_7 (V)	V_8 (V)	V_9 (V)	V_0 (V)
i_1 (mA)	i_2 (mA)	i_3 (mA)	i_4 (mA)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
				xxxx	xxxx	xxxx	xxxx	xxxx	xxxx

3.3 Kirchhoff Circuit Analysis

7. Construct the electrical circuit using the electrical trainer to generate the positive and negative voltage, three ammeters A_1, A_2 and A_3 as follows:



8. Connect the negative probe of the voltage sensor of Channel A of the 750 interface to ground of the trainer. In order to account for the ammeters internal resistance, with its own voltage drop, we will consider that each ammeter is part of the positive and negative power supply and also part of the LED. Adjust, and set, the power supply voltage of the electrical trainer to $+3.00 \pm 0.5$ V and -7.00 ± 0.5 V at points 2 and 1 using the positive probe of the voltage

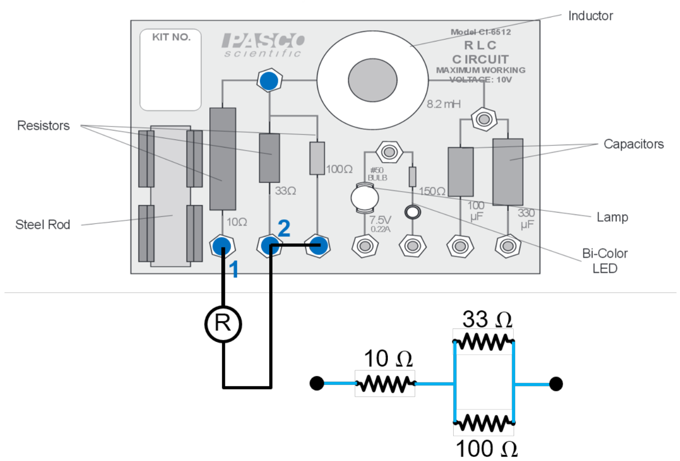
sensor and record the voltage. With the positive probe of the voltage sensor also measure the voltage at point 3 to obtain the ΔV_{LED}, and record the currents i_1, i_2, and i_3, and observe the LED color as this gives the current direction.

9. Organize your data in a table such as,

Table 3						
V+ (V)	V- (V)	ΔV_{LED} (V)	i_1 (mA)	i_2 (mA)	i_3 (mA)	color

3.4 Series and Parallel Resistance

10. Construct the electrical circuit as follows:



11. Connect the LCR meter (in R mode) between points 1 and 2 and measure the equivalent resistance of the 10 Ω resistor in series with the parallel 33 Ω and 100 Ω resistors.

4 Interpretation of Results

1. Calculate and present in tabular form the magnitudes of the voltages across the 10 Ω resistor ($|\Delta V_{12}| = V_1 - V_2$) , the light bulb ($|\Delta V_{34}| = V_3 - V_4$) , and the LED ($|\Delta V_{56}| = V_5 - V_6$) for the current i through each circuit element using the data of Table 1. Plot a graph of ΔV versus i for each of the circuit elements. Which elements are ohmic? Which elements are non-ohmic?

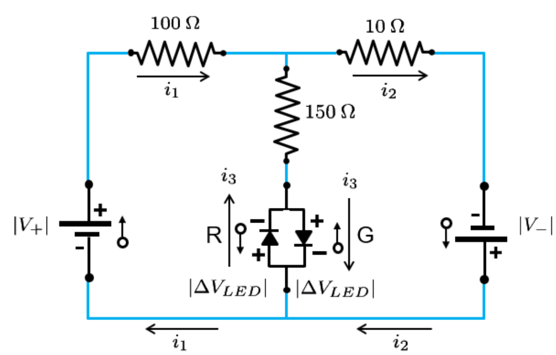
2. Do a linear regression of the above 10 Ω resistor graph. What does the slope represent? Compare, using a percentage difference, the slope to its accepted value as shown on the circuit board.

3. Use the current data from Table 2 to calculate the voltage drops (using Ohm's Law $V = iR$) across the 10 Ω, the 33 Ω, the 100 Ω resistor, and the 150 Ω resistor. Compare (using % difference) these calculated values to the experimental voltage drops using the voltage data of Table 2.

4. Verify Kirchhoff's current law at the node 0, $i_1 = i_2 + i_3 + i_4$ using the currents of Table 2. Find the percentage difference between each side of the equation.

5. Verify that the algebraic sum of the voltage differences across each elements (including cables and ammeters) in a closed loop using values of Table 2 gives the power supply voltage, $\Delta V_{12} + \Delta V_{23} + \Delta V_{34} + \Delta V_{45} + \Delta V_{56} + \Delta V_{67} + \Delta V_{70}$ gives the power supply voltage ΔV_{10}. Calculate the percentage difference between your sum of the voltage drops across the elements of your circuit to the power supply voltage.

6. Do a Kirchhoff circuit analysis of your circuit and determine the theoretical values for the currents i_1, i_2, and i_3. Use your experimental positive and negative voltages from Table 3 and use the magnitude of experimental voltage drop for the $|\Delta V|$ of the LED but use the EMF convention in your circuit analysis. Observe the polarity of the LED and the direction of current i_3 as given by the LED color. R is red and G is green. Compare your calculated currents to the observed currents. Use the following circuit as a guide.



7. Calculate the equivalent resistance of the resistors between points 1 and 2 of procedure 10. Use the circuit board values for each resistance. Compare using the percentage difference with your measured value from procedure 11.