Lab Experiment 5

Series circuits, Kirchhoff's Voltage Law (KVL), and Voltage Divider Rule

Part 1 - Ohm's Law

George Ohm formulated the relationship among Voltage (V or E), Resistance (R) and Current (I). Knowing two of the values, the third value may be computed using the following:

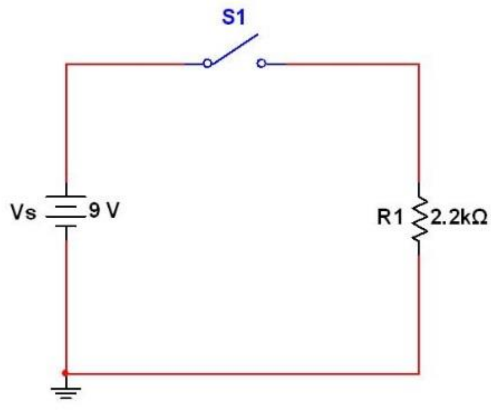
$$I = \frac{V}{R} \qquad V = I\,R \qquad R = \frac{V}{I}$$

I is the electronic current measured in Amperes (A), V is the voltage measured in volts (V) and R is the resistance measure in ohms (Ω)

Formula 5.1 – Ohm's Law

Circuit 5.1 shows a 2.2 kΩ resistor connected across a 9-volt battery. Using Formula 5.1 the current can be calculated to be 4.09 mA.

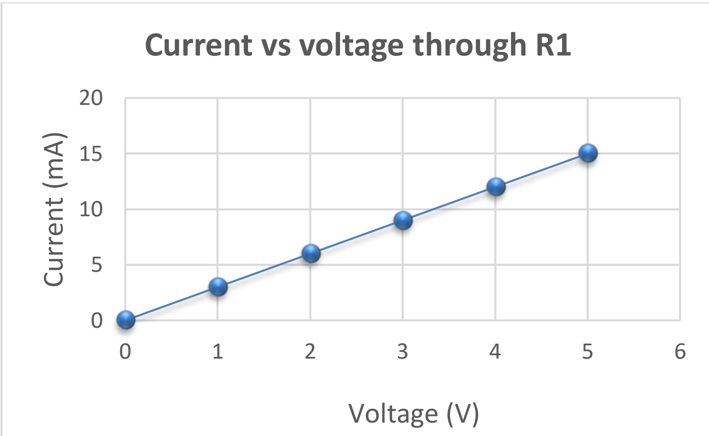
$$I = \frac{V}{R} = \frac{9}{2.2k\Omega} = 4.09mA$$



Circuit 5.1. 2.2 kΩ resistor across 9V DC Supply

Plotting Ohm's law behavior

The relationship between the current and voltage through a resistor is a linear response. This means that the slope of the line is the value of the resistance.



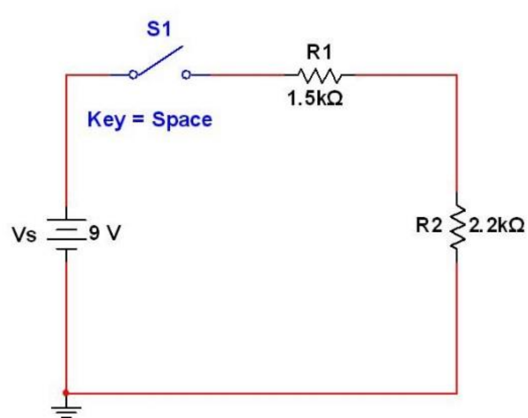
Part 2 - Series Circuits

Circuit elements are said to be in SERIES when they are connected TERMINAL-TO-TERMINAL, like a chain.

Elements connected in series configuration:

- Have the same current, because after the current goes through one component it has to go through the other. It has no other place to go.
- The total applied voltage gets divided between the series components in such way that the sum of all the voltages across the series components is equal to the total applied voltage. This is also known as **Kirchhoff's Voltage Law** (or KVL).
- The equivalent or total resistance is the sum of all individual resistance.

Circuit 5.2 shows a circuit with two resistors connected in series. The 1.5 kΩ resistor is in series with the 2.2 kΩ resistor, because they are connected in chain fashion. Notice that they have one connection in common and nothing else is connected to that point (or node).

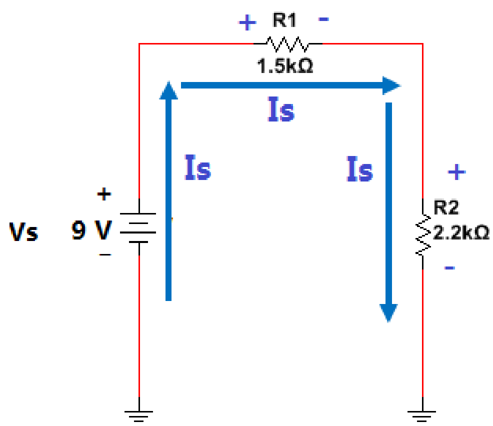


Circuit 5.2 – Series resistivity circuit

When the 9V battery "looks" out, it doesn't know what is connected to it. It only "knows" the total resistance. In this case, the battery "sees" 3.7 kΩ. Since all batteries know Ohm's Law, it puts out 2.43mA. The calculations are shown here.

$$I_S = \frac{V_S}{R_T} = \frac{9V}{3.7k\Omega} = 2.43 \quad mA$$

This current comes out of the positive side of the battery, goes through the connecting wire, goes through the 1.5kΩ resistor (R1), comes out of the 1.5kΩ resistor, goes through the 2.2kΩ (R2) resistor, comes out of the 2.2kΩ resistor and finally goes back to the negative side of the battery through the connecting wire. So you see that the current is the same in the whole loop or closed circuit, $I_S = I_{R1} = I_{R2}$. The current direction is clockwise. Check Circuit 5.3.



Circuit 5.3 – Current flow in a series circuit

Ohm's Law may be applied to each resistor to find the voltage dropped across each resistor. Note that the voltage polarity across a resistor is positive at the terminal where the current enters the resistor and negative at the terminal where the current leaves the resistor. Figure 5.1 shows this relationship. Make a mental picture of Figure 5.1 and **never forget it**.

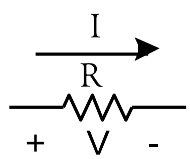


Figure 5.1 Voltage Polarity Across a Resistor

Since the current direction is clockwise, it comes down through the two resistors. According to Figure 5.1, the voltage polarity across each resistor caused by the downward current is positive on top and negative on the bottom of each resistor. Ohm's Law allows us to calculate the magnitude of each resistor voltage.

$$V_{R1} = I_{R1}R_1 = (2.43mA)(1.5k\Omega) = 3.65V$$

$$V_{R2} = I_{R2}R_2 = (2.43mA)(2.2k\Omega) = 5.35V$$

Kirchhoff's Voltage Law can be confirmed, because the 9V rise provided by the battery is equal to the sum of the 3.65V drop across the 1.5kΩ resistor and the 5.35V drop across the 2.2kΩ resistor.

Part 3 - The Voltage Divider Rule (VDR)

The Voltage Divider Rule is another way to obtain the voltage drop across series resistors. It says that the voltage dropped across one of two resistors in series is the product of the applied voltage and the ratio of the particular resistor divided by the sum of the two resistors. This is shown symbolically as follows.

$$V_{Rx} = V_T \left(\frac{R_x}{R_{T(series\ resistors)}} \right)$$

Formula 5.2 – Voltage Divider Rule Formula

Using voltage divider rule, Formula 5.2, we can calculate the voltage across R1 and R2:

$$V_{R1} = V_T \left(\frac{R_1}{R_{T(series\ resistors)}} \right) = 9\ V \left(\frac{1.5\ k\Omega}{1.5\ k\Omega + 2.2\ k\Omega} \right) = 9\ V(0.405) = 3.65\ V$$

$$V_{R2} = V_T \left(\frac{R_2}{R_{T(series\ resistors)}} \right) = 9\ V \left(\frac{2.2\ k\Omega}{1.5\ k\Omega + 2.2\ k\Omega} \right) = 9\ V(0.595) = 5.36\ V$$

Notice that these were the same values that we obtained using Ohm's Law. The main advantage of using the VDR is that once the multiplying factors are obtained for the two resistors, they will never change. In other words, the 1.5kΩ resistor will always drop 0.405 or 40.5% of the applied voltage while the 2.2kΩ resistor will always drop 0.595 or 59.5% of the applied voltage. If the power supply voltage is increased to 18V. The voltage drop in 1.5 kΩ is also 40.5% of the applied voltage, and 2.2 kΩ is also 59.5% of the applied voltage.

Part 4 - Non-Resistive series circuits

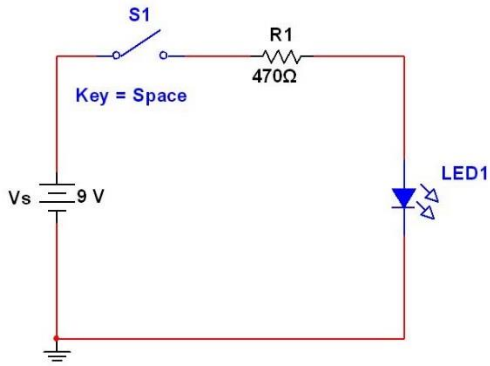
In practical circuits, resistors in series are seen very seldom. Usually, a resistor is in series with another circuit component. Circuit 5.4 shows a resistor in series with a standard size light emitting diode, LED. It is a well-known fact that a standard size light emitting diode needs 2 V and 20 mA to operate. Since the applied voltage is 9V, according to KVL the voltage across the resistor must be 7V (9 V – 2 V = 7 V). Since the two elements are in series and the LED needs 20 mA, the current must come through the resistor. Knowing the voltage drop in the resistor, Ohm's law can be applied to find the resistance. In this case, a resistor of 350 Ω must be used to produce a current of 20 mA with a voltage drop of 7 V.

$$R = \frac{7V}{20mA} = 350\Omega$$

Since 350 Ω produces exactly 20 mA, for safety purpose a larger resistance is needed to limit the current to a safe value that is less than 20 mA. In this case, a 470 Ω resistor is used because it produces a current flow of 15 mA.

$$I = \frac{7V}{470\Omega} = 0.015A = 15mA$$

The brightness of an LED is proportional to the LED current. 20mA is the rated current for good brightness for a standard LED. Currents higher than 20mA should be avoided. In our case, 15mA is enough to light the LED with sufficient brightness without exceeding the 20mA rating.



Circuit 5.4 A Resistor in Series with a Light Emitting Diode

LED is a semiconductor light source widely used in the field of electronics. Its function is to emit light when is active or when current flows through the diode from the anode to the cathode. Check Figure 5.2.

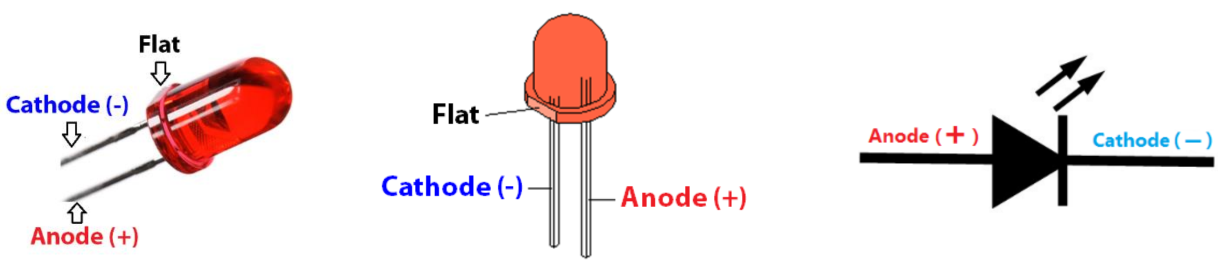


Figure 5.2. LED terminals

Lab Experiment Procedure

Notation: All measurements and calculations must be written in engineering notation rounded off the hundredth.

Part 1: Ohm's Law

- Obtain 2.2 kΩ resistor from the component kit.
- Measure the resistance and record the measurement in Table 5.1.
- Build Circuit 5.1 into a protoboard.
- Measure the voltage across the resistor.
- Measure the current through the resistor.
- Record the measurements in Table 5.1.
- Power OFF the circuit.

Resistor Value	Measured Resistance (Unit)	Measured Voltage (Unit)	Measured Current (Unit)
2.2 kΩ			

Table 5.1- Ohm's law

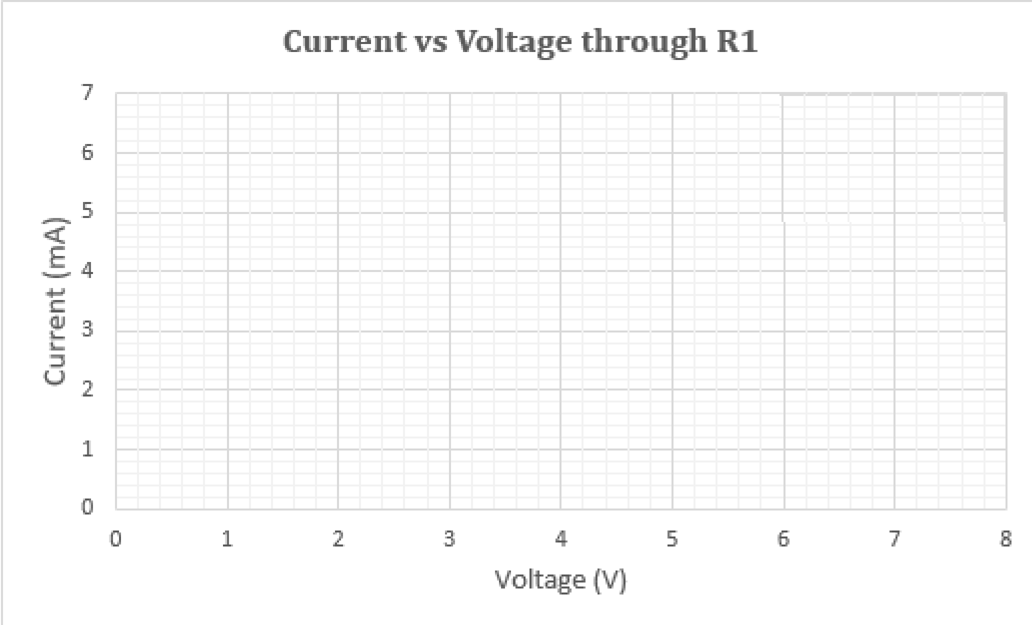
Plotting Ohm's law behavior

- Obtain a second resistor 1.5kΩ (color code: BROWN, GREEN, RED, GOLD).
- From the circuit, replace the 2.2 kΩ resistor with a 1.5 kΩ resistor in its place.
- Turn on the power supply and the set the voltage to 0 V.
- Connect the power supply to the circuit.
- Measure the voltage and current across the resistor, and record the values in Table 5.2.
- Set the voltage in the power supply to the values in Table 5.2, measure the voltage and current, and record the values in Table 5.2.
- Repeat the previous step until you complete Table 5.2.
- Disassemble the circuit.

Power supply voltage (V)	**Measured Voltage (V)**	**Measured Current (mA)**
0		
1.0		
2.0		
3.0		
3.5		
4.0		
4.5		
5.0		
5.5		
6.0		
6.5		
7.0		

Table 5.2 – Measured voltage and current

- Using the value from Table 5.2, sketch the Ohm's law behavior graph below.



- Using the measured values from Table 5.2 or the graph above, pick two sets of voltage and current through R1, record these two sets in Table 5.3, and calculate the resistance value of the line using the slope formula:

$$Slope = \frac{\Delta V}{\Delta I} = \frac{V_2 - V_1}{I_2 - I_1}$$

- Record the calculate slope resistance in Table 5.3.
- Calculate the percent of difference between the resistor value and the calculated slope resistance value.

$$\% \; of \; Difference = \left(\frac{Resistance_{Actual} - Resistance_{Measured}}{Resistance_{Actual}} \right) \times 100 \;\%$$

Formula 5.3 – Percentage of difference between the measured and calculated value

Resistance Value	Slope Resistance	% of difference
1.5 kΩ		

Table 5.3 – Measured resistance

Part 2: Series Circuit

- Obtain a 1.8 kΩ and 3.6 kΩ resistors and measure each resistor individually. Record the measured resistance in Table 5.4.
- Build a series circuit in a protoboard using the resistors (1.8 k and 3.6 k) obtained in the previous steps.
- Measure the current flow through R_1 and R_2 resistor and record the measurement in Table 5.4.
- Measure the voltage across each resistor, V_{R1} and V_{R2}. Record measurements in Table 5.4

- Disassemble the circuit.

	Measure Resistance (Include unit)	Measure Voltage (Include unit)	Measure Current (Include unit)
R_1 (1.8 kΩ)			
R_2 (3.6 kΩ)			

Table 5.4 Voltages & Currents in a Series Circuit

Part 3: Voltage Divider Rule

- Use the voltage divider formula, Formula 5.2, and calculate the voltage across R_1 and R_2. Record calculations in Table 5.5.

Show calculations here

- Using Table 5.4, record the measured voltage in R1 and R2, V_{R1} and V_{R2}, in Table 5.5
- Find the percentage of difference between the calculated and measured of voltage V_{R1} and V_{R2} using Formula 5.3.
- Record calculation in Table 5.5

	Calculated Voltage	**Measured Voltage from Table 5.4**	**% of difference**
$\mathbf{V_{R1}}$			
$\mathbf{V_{R2}}$			

Table 5.5 Confirmation of the Voltage Divider Rule

Part 4 - Non-Resistivity Series Circuit

- Obtain a 470 Ω resistor and a red LED.
- Build Circuit 5.4. Make sure that the cathode of your red LED is connected to the negative of the voltage source (Observe Figure 5.2 to find the cathode of the LED).
- Power ON the circuit.
- Measure the voltage across R_1 and the red LED. Record your measurement in Table 5.6
- Measure the current through R_1 and the red LED. Record your measurement in Table 5.6

- Disassemble the circuit.

Measure voltage across R_1, V_{R1}	Measure voltage across LED, V_{LED}	Measure current through R_1, I_{R1}	Measure current through LED, I_{LED}	$V_{LED}+V_R$
Does the sum of the LED voltage and the resistor voltage equal or almost equal the applied voltage? In other words, does KVL hold? Justify your answer.				

Table 5.6 Voltage & Current Measurements for the LED & KVL Confirmation

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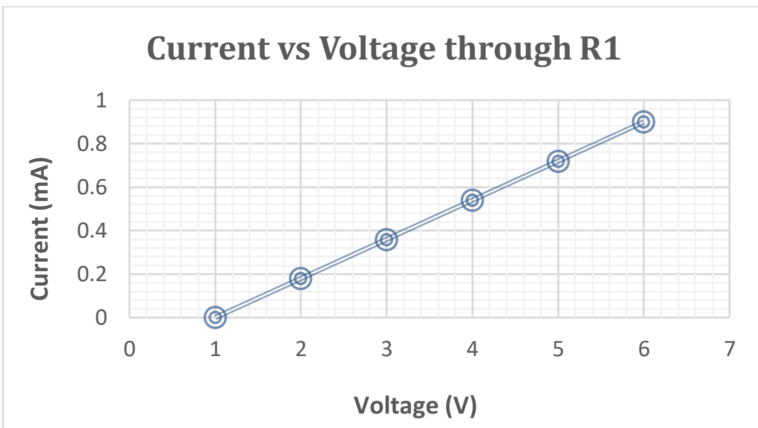
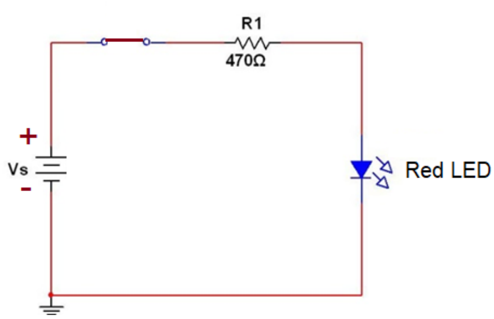
Questions

Question 1 and 2. A student measured and sketch the current and voltage through a resistor, R1:



1. The student recorded a resistor value of 2.7 kΩ. Is this the correct resistor value? Explain and justify your answer.
2. Which do you think was the student's error, if any, during the experiment? Justify your answer.

Question 3 and 4. A student built a series circuit with a 470 Ω connected in series with a red LED as below:



3. The red LED will light up completely if a 20 mA flows through it. The student measured the voltage across R1 as 2 V. Would the student be able to observe the red LED lights up? Justify your answer.
4. If the student wants to generate a 20mA current through the red LED, what would be the total voltage, Vs, that would have to apply to the circuit? Justify your answer.

Student's Name:______________________________Lab instructor's signature ____________________________

-- LAB EXPERIMENT ENDS HERE ---