<u>EET 2035C – Electrical Circuits</u>

Summer 2024

Experiment 1

Current, Voltage, Power, and Resistance in Series and Parallel Circuits

Performed By:

Anthony Paul Sevarino

Submitted to:

Prof. Ali Notash

Department of Electrical & Computer Engineering Technology (ECET) Division of Engineering, Computer Programming, & Technology Valencia College

Date Submitted

06/04/2024

OBJECTIVE

The purpose of this lab experiment is to build and analyze circuits for the purpose of observing the relationship between current and voltage, otherwise known as potential, in resistor circuits of various types. Also analyzed and calculated will be resistance of circuits, the law of conservation of energy, as well as the conservation of power.

LIST OF EQUIPMENT/PARTS/COMPONENTS

- 150 Ω resistor ($\mathbf{R_1}$)
- 270 Ω resistor ($\mathbf{R_2}$)
- 330 Ω resistor ($\mathbf{R_3}$)
- 470 Ω resistor ($\mathbf{R_4}$)
- 560 Ω resistor ($\mathbf{R_5}$)
- 680 Ω resistor ($\mathbf{R_6}$)
- DC Power Supply
- Multimeter (DMM)
- Breadboard Trainer
- Triple Power Supply

THEORETICAL BACKGROUND

Fundamental Instruments and Values

There are many measurements to be taken in this lab, including the resistance of resistors, potential difference, and current through components of a circuit. To measure the voltage across an individual component, a **voltmeter** must be attached to the respective component in parallel. The circuit, however, still functions normally, as the voltmeter has a large resistance value and only allows enough current to make a measurement, as the rest continues through the circuit. Voltage can also be measured regardless of whether there is a current flowing or not [1].

Alternatively, measuring the current through a component in a circuit requires the use of an **ammeter**, attached in series to the respective component. In contrast to a **voltmeter**, an **ammeter** requires current to be flowing through it in order to measure the current. It is important to take precautions to not place an ammeter in parallel to any components in a circuit, as it would receive the entire current of said circuit and blow the fuse of the **ammeter**.

In order to measure resistance of a resistor, an **ohmmeter** is used in either parallel or in series, and does not require a current flowing through a component as it creates its own current, and measures using it.

For the purposes of this lab, a **Digital Multimeter**, or a **DMM**, will be used as it can act as all three aforementioned instruments. Alongside the **DMM**, the **Breadboard Trainer** will house the breadboard each of the circuits will be built on, and the power supply will be provided by a **Triple Power Supply**.

The theoretical **Resistance** of a resistor can be found by using the Color Code procedure, through analyzing the following table (read from left to right)

Band Color	**Digit**	**Multiplier**	**Tolerance**
Black	0	10^0	
Brown	1	10^1	±1%
Red	2	10^2	±2%
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
No Band			±20%
Silver			±10%
Gold			±5%

Formulas and Laws

There are a few formulas and theories that will assist in calculating various things throughout the lab. **Ohm's Law** is one such law, and states that the voltage through a component is equal to the current through the component multiplied by the resistance of the component

[1].

$$V = IR$$

Also, **Kirchhoff's Voltage Law** states that the sum of each voltage drop through a circuit is zero, while the current is equivalent [1].

$$\sum_{k=1}^{n} V_k = 0$$

$$n = number\ of\ components\ in\ loop$$

Kirchhof's Current Law states that the current into a node is equal to the current out of it [1].

$$\sum_{k=1}^{n} I_k = 0$$

$$n = number\ of\ branches\ connected\ to\ a\ node$$

There are a few different methods to finding the **power absorbed** or **delivered** by an element of a circuit. Either the voltage and the current can be multiplied together (1), the current squared can be multiplied by the resistance of the element (2), or the voltage squared divided by the resistance of the element (3).

$$(1)\ P = VI$$

$$(2)\ P = I^2R$$

$$(3)\ P = \frac{V^2}{R}$$

In a **series** circuit, if only the voltage source V_S and all resistor values are known, the voltage of any component can be calculated using the **Voltage Divider** formula, which divides the voltage source by the value of every resistor in the circuit **except** the resistance of the component being measured [1].

$$V_x = V_s(\frac{R_x}{\sum_{k=1}^{n} R_k})$$

$$n = number\ of\ resistors$$

$$x = component\ being\ measured$$

In a **parallel** circuit, if only the total current I_T and all resistor values are known, the current through any component can be calculated using the **Current Divider** formula, which divides the total current by the value of every resistor in the circuit **except** the resistance of the component being measured [1].

$$I_x = I_T\left(\frac{R_x}{\sum_{k=1}^{n} R_k}\right)$$

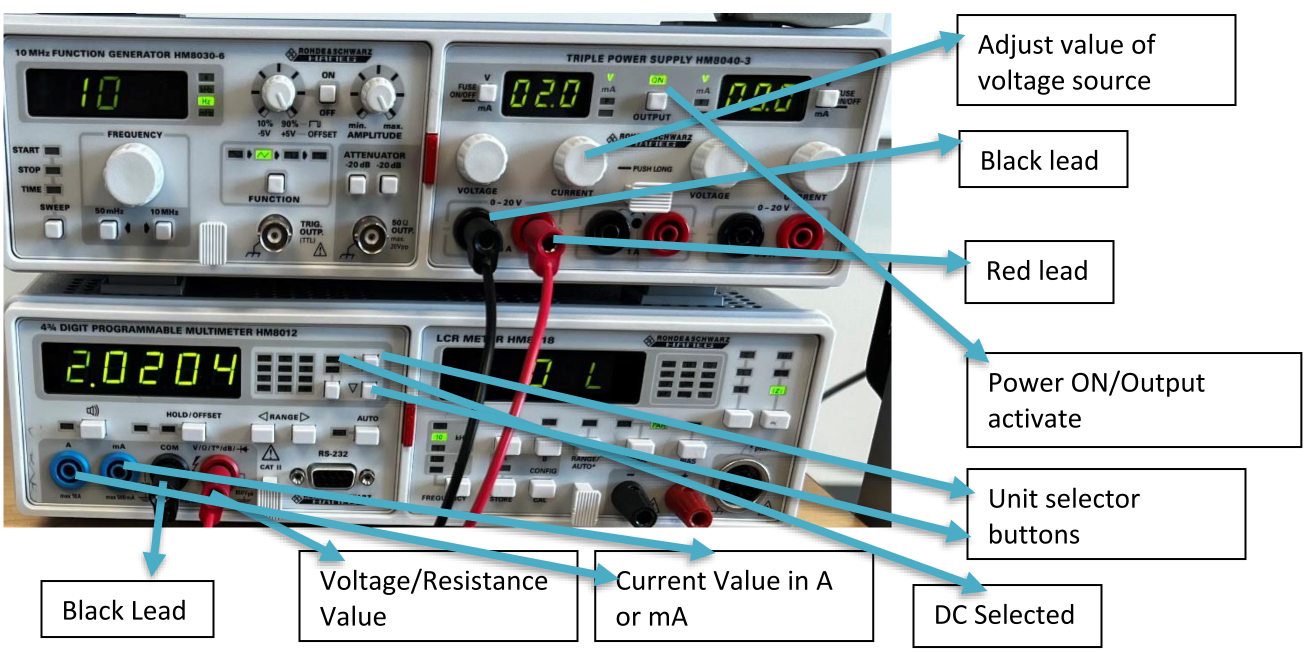
$$n = number\ of\ resistors$$

$$x = component\ being\ measured$$

The DMM

The labelled DMM diagram is adopted from the following reference:

Ali Notash, “Current, Voltage and Resistance in Series and Parallel Circuits”, in *EET 3081C – Circuit Analysis 1*, Florida: Valencia College, 2018.



PROCEDURE / RESULTS / OBSERVATIONS

If you are adopting procedure as-it-is from the lab handout, just give proper reference in IEEE citation format. For example:

Procedure is adopted from the following reference:

Prof. Ali Notash, "Current, Voltage, Power, and Resistance in Series and Parallel Circuits," in *Electrical Circuits Laboratory Manual*, 1st Ed. Florida: Valencia College, 2017, pp. 8-15.

Part 1 – Determining the Resistance of a Resistor & Proof of Ohm's Law

Use the color code procedure to determine nominal values for R_1 through R_6. Record results in **Table 1**.

Measure the actual value for each resistor using the DMM, and record in **Table 1**. The resistors will plug into the DMM in the COM/Ω terminals and the DMM should be set to ohms.

Table 1

Resistor, R	R_1	R_2	R_3	R_4	R_5	R_6	R_T
Nominal Value (Ω)	150Ω	270Ω	330Ω	470Ω	560Ω	680Ω	2460Ω
Measured Value (Ω)	148.27Ω	269.37Ω	329.10Ω	467.56Ω	561.00Ω	677.50Ω	2453.16Ω

The following is an example of how the resistance of each resistor can be measured using the **DMM**:

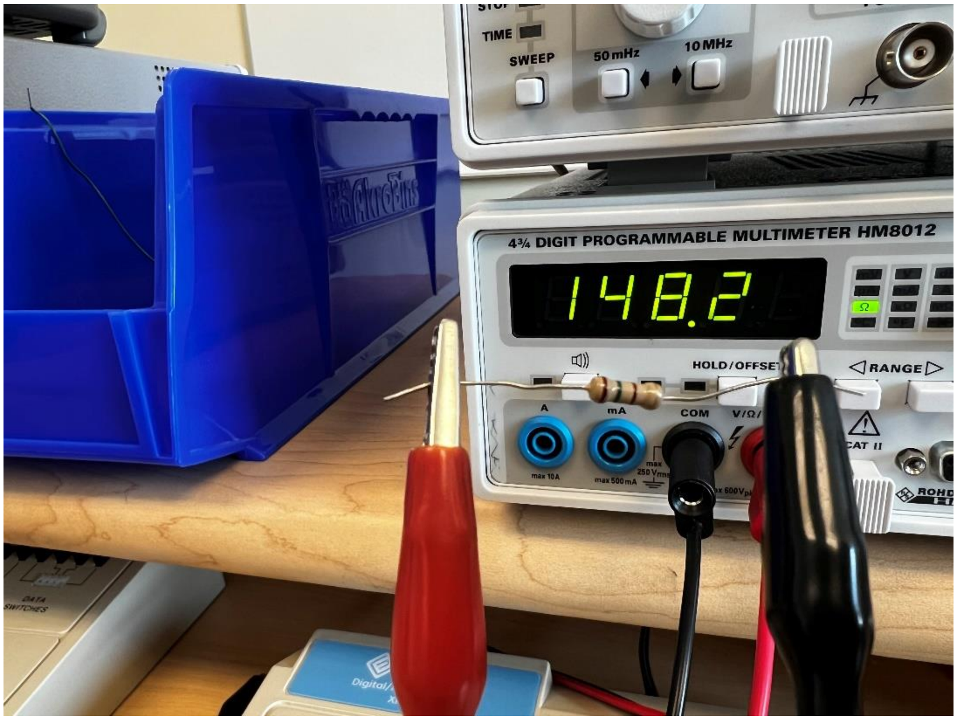


Figure 1

For each resistor, build the circuit found in **Fig. 2** on the breadboard.

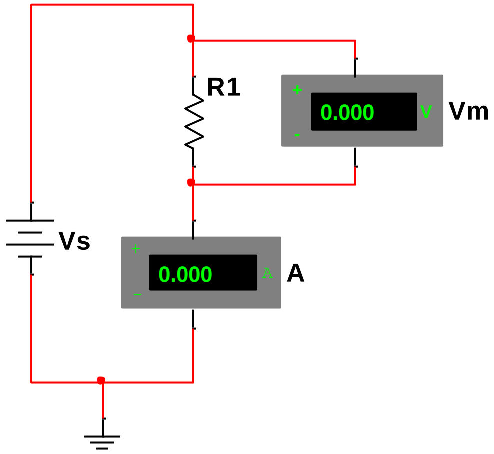


Figure 2

Utilizing theory, calculate the potential difference across each resistor for the following voltage source values: 2v, 4v, 6v, 8v, and 10v.

2v	**4v**	**6v**	**8v**	**10v**
$V_{150} = 2v\left(\frac{150}{150}\right) = 2v$	$V_{150} = 4v\left(\frac{150}{150}\right) = 4v$	$V_{150} = 6v\left(\frac{150}{150}\right) = 6v$	$V_{150} = 8v\left(\frac{150}{150}\right) = 8v$	$V_{150} = 10v\left(\frac{150}{150}\right) = 10v$
$V_{270} = 2v\left(\frac{270}{270}\right) = 2v$	$V_{270} = 4v\left(\frac{270}{270}\right) = 4v$	$V_{270} = 6v\left(\frac{270}{270}\right) = 6v$	$V_{270} = 8v\left(\frac{270}{270}\right) = 8v$	$V_{270} = 10v\left(\frac{270}{270}\right) = 10v$
$V_{330} = 2v\left(\frac{330}{330}\right) = 2v$	$V_{330} = 4v\left(\frac{330}{330}\right) = 4v$	$V_{330} = 6v\left(\frac{330}{330}\right) = 6v$	$V_{330} = 8v\left(\frac{330}{330}\right) = 8v$	$V_{330} = 10v\left(\frac{330}{330}\right) = 10v$
$V_{470} = 2v\left(\frac{470}{470}\right) = 2v$	$V_{470} = 4v\left(\frac{470}{470}\right) = 4v$	$V_{470} = 6v\left(\frac{470}{470}\right) = 6v$	$V_{470} = 8v\left(\frac{470}{470}\right) = 8v$	$V_{470} = 10v\left(\frac{470}{470}\right) = 10v$
$V_{560} = 2v\left(\frac{560}{560}\right) = 2v$	$V_{560} = 4v\left(\frac{560}{560}\right) = 4v$	$V_{560} = 6v\left(\frac{560}{560}\right) = 6v$	$V_{560} = 8v\left(\frac{560}{560}\right) = 8v$	$V_{560} = 10v\left(\frac{560}{560}\right) = 10v$
$V_{680} = 2v\left(\frac{680}{680}\right) = 2v$	$V_{680} = 4v\left(\frac{680}{680}\right) = 4v$	$V_{680} = 6v\left(\frac{680}{680}\right) = 6v$	$V_{680} = 8v\left(\frac{680}{680}\right) = 8v$	$V_{680} = 10v\left(\frac{680}{680}\right) = 10v$

Now do the same, but for the current through each circuit.

2v	**4v**	**6v**	**8v**	**10v**
$I_{150} = \frac{2v}{150\Omega} = 13.33mA$	$I_{150} = \frac{4v}{150\Omega} = 26.67mA$	$I_{150} = \frac{6v}{150\Omega} = 40mA$	$I_{150} = \frac{8v}{150\Omega} = 53.33mA$	$I_{150} = \frac{10v}{150\Omega} = 66.67mA$
$I_{270} = \frac{2v}{270\Omega} = 7.41mA$	$I_{270} = \frac{4v}{270\Omega} = 14.82mA$	$I_{270} = \frac{6v}{270\Omega} = 22.22mA$	$I_{270} = \frac{8v}{270\Omega} = 29.63mA$	$I_{270} = \frac{10v}{270\Omega} = 37.03mA$
$I_{330} = \frac{2v}{330\Omega} = 6.06mA$	$I_{330} = \frac{4v}{330\Omega} = 12.12mA$	$I_{330} = \frac{6v}{330\Omega} = 18.18mA$	$I_{330} = \frac{8v}{330\Omega} = 24.24mA$	$I_{330} = \frac{10v}{330\Omega} = 30.30mA$
$I_{470} = \frac{2v}{470\Omega} = 4.26mA$	$I_{470} = \frac{4v}{470\Omega} = 8.51mA$	$I_{470} = \frac{6v}{470\Omega} = 12.77mA$	$I_{470} = \frac{8v}{470\Omega} = 17.02mA$	$I_{470} = \frac{10v}{470\Omega} = 21.28mA$
$I_{560} = \frac{2v}{560\Omega} = 3.57mA$	$I_{560} = \frac{4v}{560\Omega} = 7.14mA$	$I_{560} = \frac{6v}{560\Omega} = 10.71mA$	$I_{560} = \frac{8v}{560\Omega} = 14.29mA$	$I_{560} = \frac{10v}{560\Omega} = 17.86mA$
$I_{680} = \frac{2v}{680\Omega} = 2.94mA$	$I_{680} = \frac{4v}{680\Omega} = 5.82mA$	$I_{680} = \frac{6v}{680\Omega} = 8.82mA$	$I_{680} = \frac{8v}{680\Omega} = 11.77mA$	$I_{680} = \frac{10v}{680\Omega} = 14.71mA$

In **Table 2**, observe and measure each resistor circuit with each given potential difference in Multisim, then in **Table 3** and on the bench using the **DMM**.

Table 2

Resistor (Ω)		**2V**	**4V**	**6V**	**8V**	**10V**
R_1	V (v)	2V	4V	6V	8V	10V
	I (A)	13.00mA	27.00mA	40.00mA	53.00mA	67.00mA
R_2	V (v)	2V	4V	6V	8V	10V
	I (A)	7.41mA	15.00mA	22.00mA	30.00mA	37.00mA
R_3	V (v)	2V	4V	6V	8V	10V
	I (A)	6.06mA	12.00mA	18.00mA	24.00mA	30.00mA
R_4	V (v)	2V	4V	6V	8V	10V
	I (A)	4.25mA	8.51mA	13.00mA	17.00mA	21.00mA
R_5	V (v)	2V	4V	6V	8V	10V
	I (A)	3.57mA	7.14mA	11.00mA	14.00mA	18.00mA
R_6	V (v)	2V	4V	6V	8V	10V
	I (A)	2.94mA	5.88mA	8.82mA	12.00mA	15.00mA

Table 3

Resistor (Ω)		**2V**	**4V**	**6V**	**8V**	**10V**
R_1	V (v)	2.02V	3.9869V	6.008V	7.973V	9.914V
	I (A)	14.00mA	27.00mA	40.00mA	53.00mA	67.00mA
R_2	V (v)	2.057V	4.0317V	6.027V	7.990V	9.975V
	I (A)	8.00mA	15mA	23mA	29mA	37mA
R_3	V (v)	2.0581V	3.9832V	6.07V	8.008V	10.034V
	I (A)	6mA	12mA	18mA	24mA	30mA
R_4	V (v)	2.0088V	4.0584V	6.024V	8.004V	9.977V
	I (A)	5mA	9mA	13mA	18mA	21mA
R_5	V (v)	2.0488V	4.0699V	6.067V	8.01V	9.987V
	I (A)	3.13mA	7.12mA	10.57mA	14.11mA	17.66mA
R_6	V (v)	2.059V	4.086V	6.008V	8.023V	10.046V
	I (A)	2.62mA	5.88mA	8.72mA	11.64mA	14.56mA

Fig. 3 depicts an example of a built circuit being measured for voltage

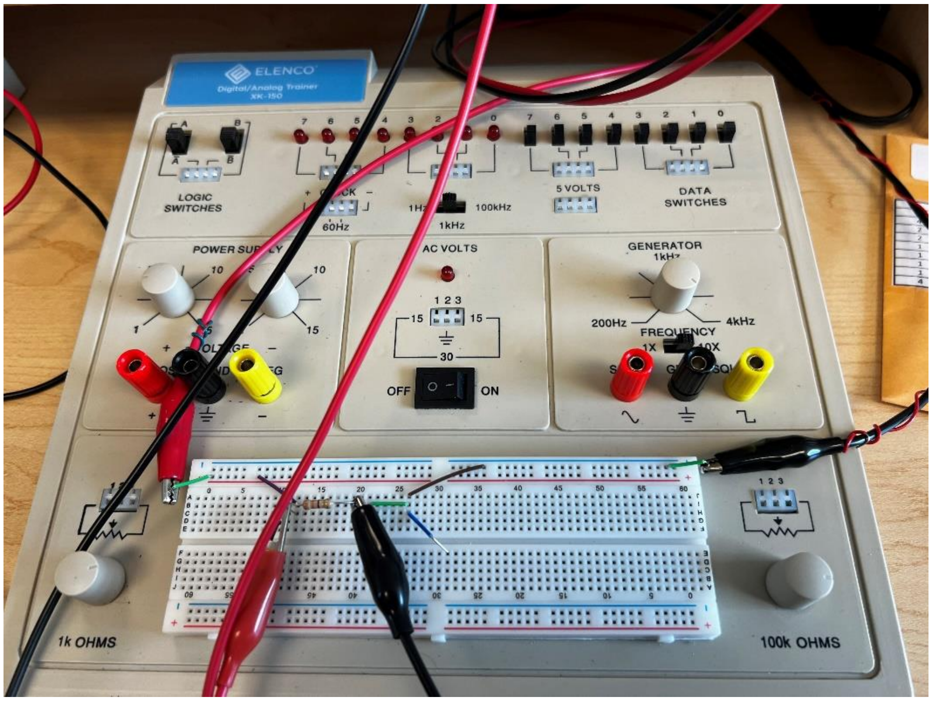
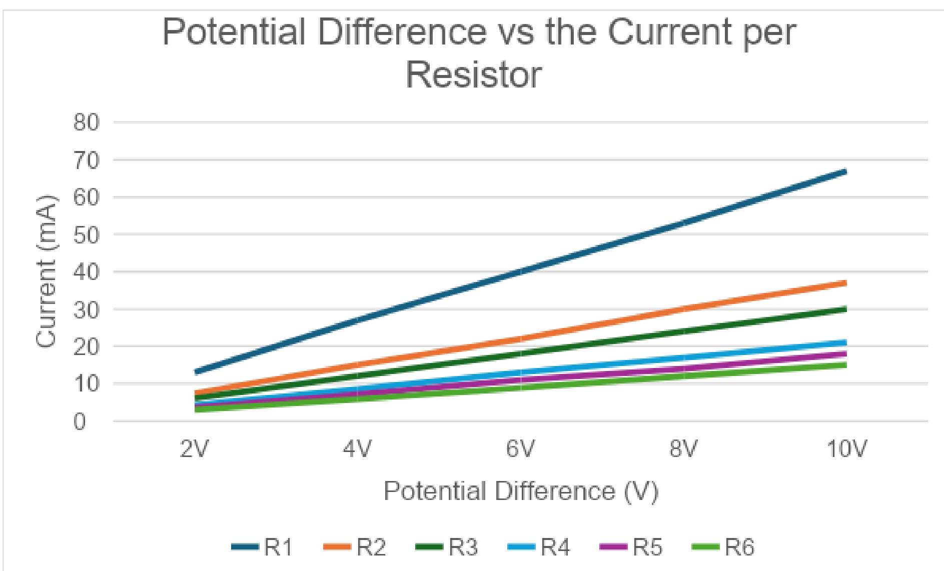


Figure 3

Take the recorded data and plot the potential difference against the current for each resistor.



Part 2 – Series Circuit

Use R_1 and R_2 to construct the series circuit shown in **Fig. 4**

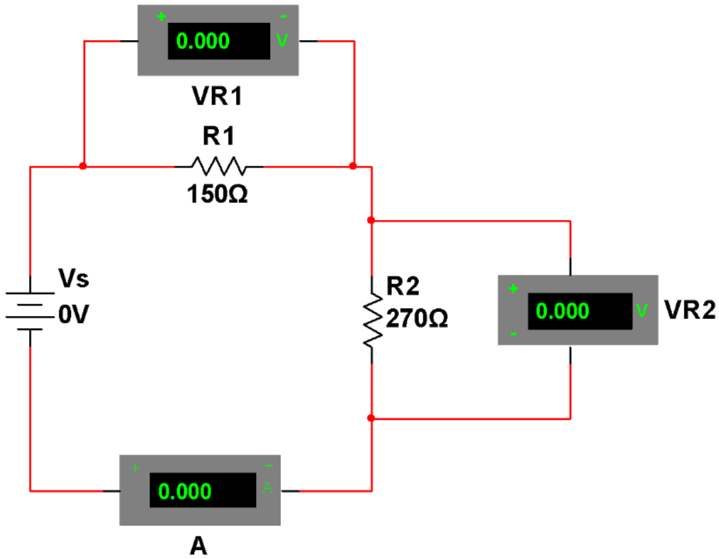


Figure 4

Set V_S to 2V and calculate the current through each resistor before R_1, between R_1 and R_2, and after R_2.

V_1 = 2150150+270 = 0.714V V_2 = 2270150+270 = 1.29V   I = 0.7142857143150 = 4.762mA

It can here be observed that in a series circuit, the current through each element will be the same. Therefore at each of the three aforementioned positions, the current will be 4.762mA.

Set V_S to 4, 6, 8, and 10V respectively and calculate the same measurements.

V_1 = 4150150+270 = 1.43V V_2 = 4270150+270 = 2.57V   I = 1.4285714286150 = 9.52mA
V_1 = 6150150+270 = 2.14V V_2 = 6270150+270 = 3.86V   I = 2.14150 = 14.29mA
V_1 = 8150150+270 = 2.86V V_2 = 8270150+270 = 5.14V   I = 2.86150 = 19.05mA
V_1 = 10150150+270 = 3.57V V_2 = 10270150+270 = 6.43V   I = 3.57150 = 23.81mA

Measure simulation data alongside bench data, and organize in **Table 3**.

Table 3

Input Voltage Vs (V)		Currents (A)			V_{R1} (V)	V_{R2} (V)
		Before R_1 (mA)	Between R_1 and R_2 (mA)	After R_2 (mA)		
2	Theory	4.76	4.76	4.76	0.714	1.29
	Simulation	4.76	4.76	4.76	0.714	1.29
	Measured	3.975	3.974	3.976	710m	1.292
4	Theory	9.52	9.52	9.52	1.43	2.57
	Simulation	9.524	9.524	9.524	1.429	2.571
	Measured	9.507	9.504	9.50	1.4399	2.6209
6	Theory	14.29	14.29	14.29	2.14	3.86
	Simulation	14.00	14.00	14.00	2.143	3.857
	Measured	14.13	14.13	14.12	2.135	3.888
8	Theory	19.05	19.05	19.05	2.86	5.14
	Simulation	19.00	19.00	19.00	2.857	5.143
	Measured	18.68	18.69	18.70	2.838	5.167
10	Theory	23.81	23.81	23.81	3.57	6.43
	Simulation	24.00	24.00	24.00	3.571	6.429
	Measured	23.27	23.28	23.38	3.544	6.453

Below is an example of how the current can be measured at a point in the given circuit.

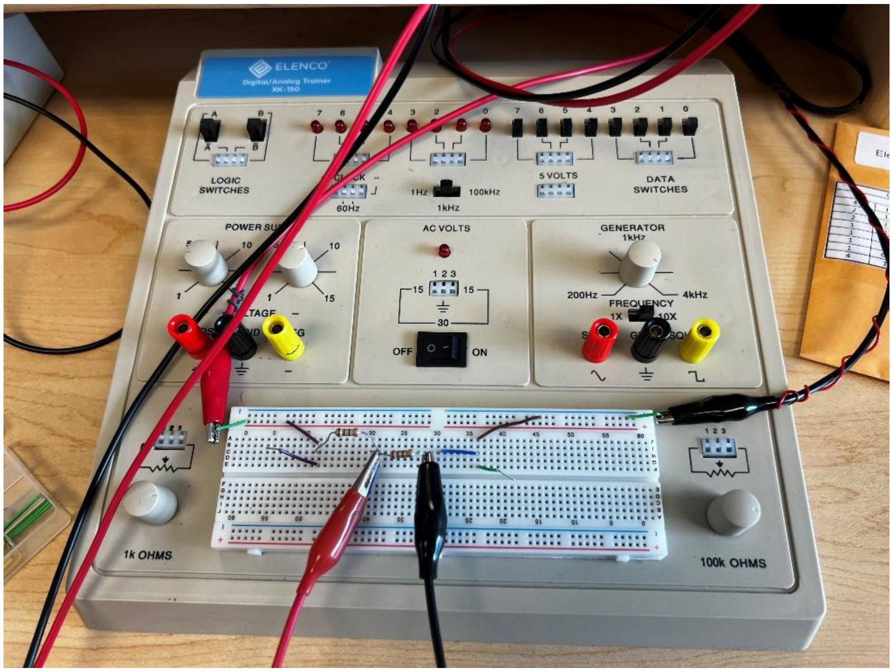
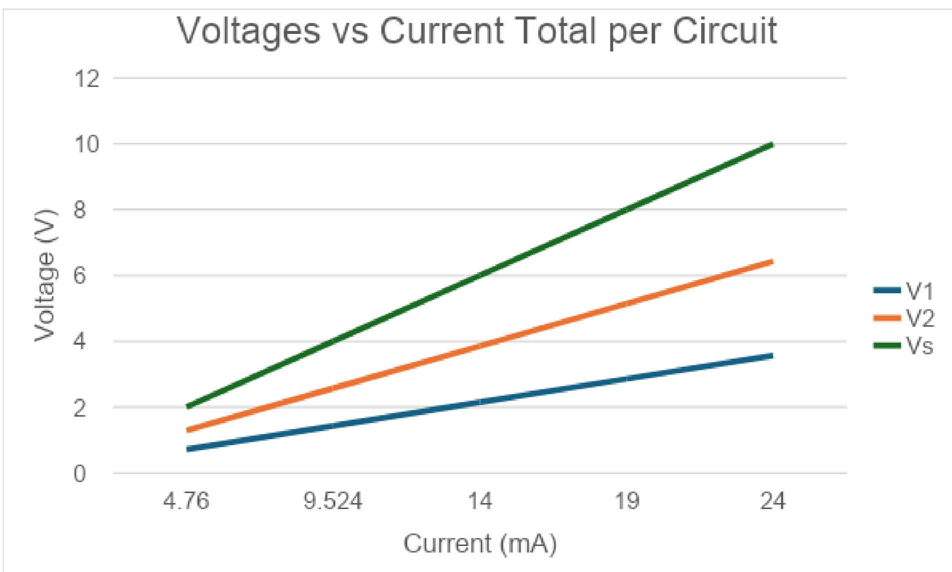


Figure 6

Using measured values, plot V_S, VR_1, and VR_2 against i_T.



Part 3 – Parallel Circuits

Using R_1 and R_4, construct the circuit shown in **Fig. 5**.

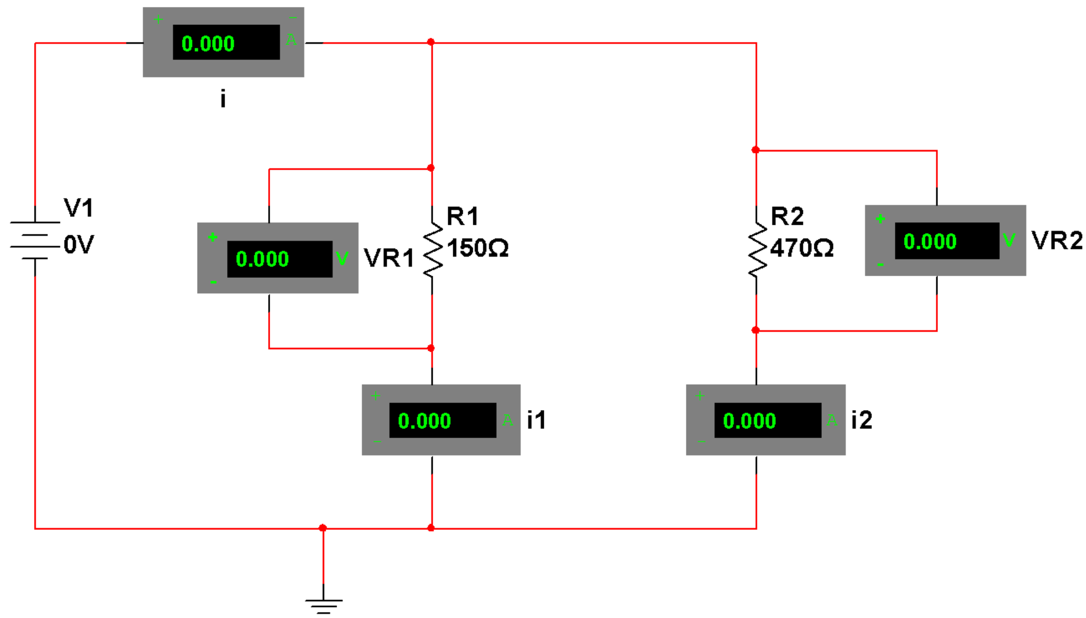


Figure 5

Set V_S equal to 2V, and calculate the current through each resistor at i, i_1, and i_2.

$$VR_1 = 2v, \quad VR_2 = 2v, \quad i_1 = \frac{2}{150} = 13.33mA, \quad i_2 = \frac{2}{470} = 4.26mA, \quad i = i_1 + i_2 = 17.60mA$$

Now find the same values from **Multisim** and the bench work, and record all data in **Table 4.**

Table 4

Input Voltage Vs (V)		Currents (A)		
		i	i_1	i_2
R1	Theory	0.0176A	0.0133A	4.256mA
	Simulation	0.018A	0.013A	4.256mA
	Measured	16.37mA	12.57mA	4.17mA
R4	Theory	0.0176A	0.0133A	4.256mA
	Simulation	0.018A	0.013A	4.256mA
	Measured	16.37mA	12.57mA	4.17mA

From the data, it is evident the potential difference across each resistor in a parallel circuit is equivalent.

Now, conduct the same process for V_S = 4, 6, 8, and 10V. Record relevant data in **Table 5**.

$VR_1 = 4v \quad VR2 = 4v \quad i_1 = 4/150 = 0.0267A \quad i_2 = 4/470 = 8.51mA \quad I = i_1 + i_2 = 0.035A$

$VR_1 = 6v \quad VR2 = 6v \quad i_1 = 6/150 = 0.04A \quad i_2 = 6/470 = 12.77mA \quad I = i_1 + i_2 = 0.0527A$

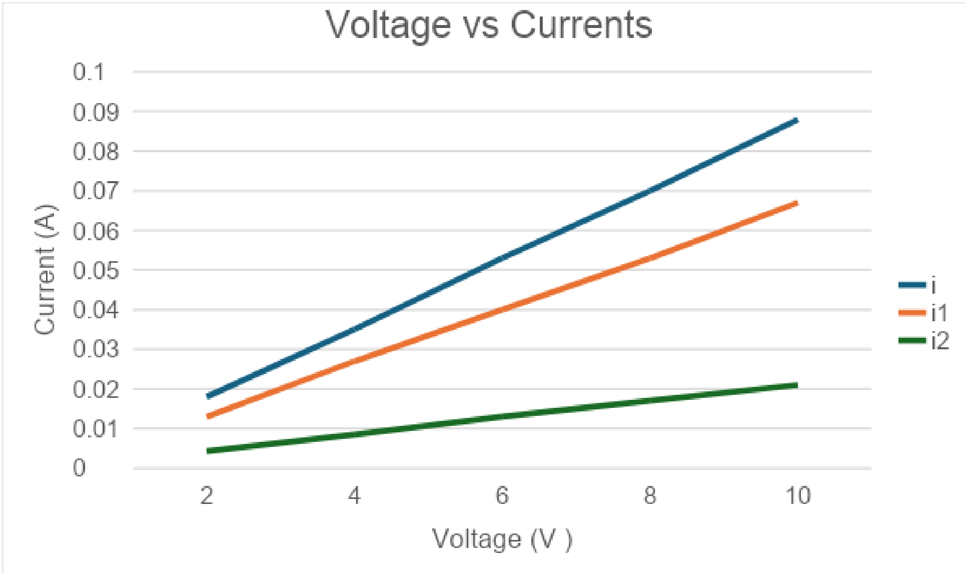
$VR_1 = 8v \quad VR_2 = 8v \quad i_1 = 8/150 = 0.0533A \quad i_2 = 8/470 = 0.017A \quad I = i_1 + i_2 = 0.0703A$

$VR_1 = 10v \quad VR_2 = 10v \quad i_1 =10/150 = 0.067A \quad i_2 = 10/470 = 0.0212mA \quad I = i_1 + i_2 = 0.088A$

Table 5

Input Voltage Vs (V)		Currents (A) A	B	C	V_{R1} (V)	V_{R2} (V)
2	Theory	0.0176A	0.0133A	4.256mA	2	2
	Simulation	0.018A	0.013A	4.256mA	2	2
	Measured	16.37mA	12.57mA	4.17mA	1.99	1.99
4	Theory	0.035A	0.0267A	8.51mA	4	4
	Simulation	0.035A	0.027A	8.511mA	4	4
	Measured	32.5mA	25.21mA	8.35mA	3.962	3.970
6	Theory	0.0527A	0.04A	12.77mA	6	6
	Simulation	0.053A	0.04A	0.013A	6	6
	Measured	48.03mA	37.15mA	12.36mA	6.003	6.01
8	Theory	0.0703A	0.0533A	0.017A	8	8
	Simulation	0.07A	0.053A	0.017A	8	8
	Measured	69.16mA	52.68mA	16.93mA	7.96	7.97
10	Theory	0.088A	0.067A	0.0212A	10	10
	Simulation	0.088A	0.067A	0.021A	10	10
	Measured	86.12mA	65.46mA	20.99mA	9.95	9.91

Plot the data of V_S, VR_1, and VR_4 against i_T.



From the data, is it apparent that both the voltage and the current increase with each other.

Part 4 – Error Calculations and Conservation of Power Calculations

The following are the power measurements for each component in the lab:

Part 1

2v

$$P=20.013=0.026w$$

$$P=20.007408=0.0148w$$

$$P=20.006061=0.012122w$$

$$P=20.004256=0.008512w$$

$$P=20.003572=0.007144w$$

$$P=20.002941=0.005882w$$

4v

$$P=40.027=0.108w$$

$$P=40.015=0.06w$$

$$P=40.012=0.048w$$

$$P=40.008511=0.034w$$

$$P=40.007143=0.028572w$$

$$P=40.005883=0.023532w$$

6v

$$P=60.04=0.24w$$

$$P=60.022=0.132w$$

$$P=60.018=0.026w$$

$$P=60.013=0.078w$$

$$P=60.011=0.066w$$

$$P=60.008824=0.052944w$$

8v

$$P=80.053=0.424w$$

$$P=80.03=0.24w$$

$$P=80.024=0.192w$$

$$P=80.017=0.136w$$

$$P=80.014=0.112w$$

$$P=80.012=0.096w$$

10v

$$P=100.067=0.67w$$

$$P=100.037=0.37w$$

$$P=100.03=0.3w$$

$$P=100.021=0.21w$$

$$P=100.018=0.18w$$

$$P=100.015=0.15w$$

Part 2

2v

R1

$$P=0.714(0.004762)=0.00532787w$$

R2

$$P=1.286(0.004762)=0.006123932w$$

4v

R1

$$P=1.429(0.009523)=0.013608367w$$

R2

$$P=2.5710.004762=0.012243102w$$

6v

R1

$$P=2.1430.014=0.030002w$$

R2

$$P=3.8570.014=0.053998w$$

8v

R1

$$P=2.8570.019=0.054283w$$

R2

$$P=5.1430.019=0.097717w$$

10v

R1

$$P=3.5710.024=0.085704w$$

R2

$$P=6.429(0.024)=0.154296w$$

Part 3

2v

R1

$$P=20.013=0.026w$$

R2

$$P=20.004256=0.008512w$$

4v

R1

$$P=40.027=0.108w$$

R2

$$P=40.008511=0.034044w$$

6v

R1

$$P=60.04=0.00532787w$$

R2

P=60.013=0.00532787w

8v

R1

P=80.053=0.424w

R2

P=80.017=0.136w

10v

R1

P=100.067=0.67w

R2

P=100.021=0.21w

Next, calculate the percent error for the measured **voltages** and **currents** obtained in all parts of the lab, using the following formula.

$$\%\,Error = \frac{Experimental - Theoretical}{Theoretical} * 100\%$$

Part 1 Voltage:

Table 6 (%)

R1	1	0.3275	0.133333	0.3375	0.86
R2	2.85	0.7925	0.45	0.125	0.25
R3	2.905	0.42	1.166667	0.1	0.34
R4	0.44	1.46	0.4	0.05	0.23
R5	2.44	1.7475	1.116667	0.125	0.13
R6	2.95	2.15	0.133333	0.2875	0.46

Part 1 Current:

Table 7 (%)

R1	4.785714	1.222222	0	0.622642	0.492537
R2	7.375	1.2	3.391304	2.172414	0.081081
R3	1	1	1	1	1
R4	14.8	5.444444	1.769231	5.444444	1.333333
R5	14.05751	0.280899	1.324503	1.275691	1.132503
R6	12.21374	1.020408	1.146789	1.116838	1.03022

Part 2 Voltage:

Table 8 (%)

	VR1	VR2
2v	0.560224	0.155039
4v	0.692308	1.980545
6v	0.233645	0.725389
8v	0.769231	0.525292
10v	0.728291	0.357698

Part 2 Current:

Table 9 (%)

2v	16.4916	16.51261	16.47059	0.560224	0.155039
4v	0.136555	0.168067	0.210084	0.692308	1.980545
6v	1.119664	1.119664	1.189643	0.233645	0.725389
8v	1.942257	1.889764	1.83727	0.769231	0.525292
10v	2.267955	2.225955	1.805964	0.728291	0.357698

Part 3 Voltage:

Table 10 (%)

	VR1	VR2
2v	0.5	0.5
4v	0.95	0.75
6v	0.05	0.166667
8v	0.5	0.375
10v	0.5	0.9

Part 3 Current:

Table 11 (%)

	A	B	C
2v	6.988636	5.701425	2.020677
4v	7.142857	5.580524	1.880141
6v	8.86148	7.125	0
8v	1.621622	1.163227	0
10v	2.136364	2.298507	0

From the power calculations, the **Law of Conservation of Power** is evident, as the power nearly sums to zero for each circuit with marginal % error.

There is also % error between the theoretical calculations and measured values throughout the lab, which is likely due to differing tolerances from resistors practically, as well as potential human measuring error.

DISCUSSION

There are a couple of key details to ensure understanding of following this lab, such as KCL, KVL, and Ohm's law. Additionally, ensuring proper practices when conducting bench work, such as connecting voltmeters in parallel and ammeters in series, help to ensure accurate measurements and safe testing conditions. The theoretical results obtained in the lab largely matched the practical and simulation measurements, and the percent error calculations allow for understanding that in the real world, there are various factors that contribute to differing values (i.e. resistance tolerance values).

CONCLUSION

Part 1 of this report, in essence, confirms Ohm's law, wherein the voltage of an element of a circuit is equal to that of its current multiplied by its resistance. Therefore, a larger voltage value will in turn yield a larger current value, and a smaller resistance value. Plotting data found in part 1 shows that as the resistance decreases, both the current and the potential difference increases.

In part 2 of the lab, series circuits were analyzed and measured. Here, it can be concluded that the sum of the potential differences of each component of a series circuit should yield 0, confirming KVL. The graph plotted using data from this section of the lab shows that the absolute value of the potential difference across the voltage source cannot be less than the absolute value of any individual component in the series circuit.

From part 3, KCL was proven through the collection of data from various parallel circuits. It can thus be derived that the potential difference between components in parallel circuits are equivalent, while the sum of the current through branches connected to a node is equivalent to that of the current flowing into the node. Graphing the data from part 3 yields evidence that, similar to part 2 with voltage, the absolute value of the current of any individual branch out of a node cannot be larger than the absolute value of the current leading into said node.

REFERENCES

[1] W. H. Hayt, J. E. Kemmerly, J. D. Phillips, and S. M. Durbin, *Engineering Circuit Analysis*, 9th ed. New York, NY: McGraw Hill, LLC, 2019.