Ryerson University
Department of Electrical,
Computer, & Biomedical Engineering
Faculty of Engineering & Architectural Science

ELE 202
Laboratory #2 (Virtual)

Basic Concepts, Relationships and Laws of Electric Circuits

1.0 INTRODUCTION

The relationship between *current* (**I**) and *voltage* (**V**) across the terminals of a circuit element defines the behavior of that element within the circuit. The graphical means of representing the terminal characteristics of a circuit element is done by introducing the variable **I** to represent current flowing through the element, while voltage **V** is the *Potential Difference* (**P.D.**) or voltage across the element. If the voltage applied to the element were varied and the resulting current measured, it would be possible to construct a functional relationship between voltage and current known as the ***I-V*** characteristic. Depending on the electrical properties of a circuit element, this ***I-V*** relationship can be "*linear*" or "*non-linear*".
Electrical current, **I** (= $d\mathbf{Q}/dt$) is the rate at which *free* electrons (or charge, **Q**) is made to drift through a material in a particular direction, that is, moved around a circuit. In order to cause the *free* electrons to drift in a given direction, an Electro-Motive Force (**EMF**) must be applied, and which ends up being the driving force in an electrical circuit. The electrical symbol for an EMF is **E**, the unit of measurement is in **volts (V)**, and the typical voltage-sources of EMF are cells, batteries (or power-supplies), and generators.
When current flows through a metal wire or other circuit elements, it encounters a certain amount of *resistance*, the magnitude of which depends on the electrical properties of the material. Practically all circuit elements exhibit some resistance; as a consequence, the current flowing through an element will cause energy to be dissipated in the form of heat. An ideal resistor, **R,** is a circuit element that exhibits "*linear*" resistance properties according to **Ohm's Law**, whereby the voltage across the resistor element is directly proportional to the current flow through it. The unit of electrical resistance (R) is the **ohm (Ω)**. It should be noted that the EMF (the driving force, **E**) causes current to flow in a circuit, whereas a **P.D.** (Potential-Difference) is the result of current flowing through a resistor, **R**. Hence, EMF is a "*cause*" and P.D. is an "*effect*".
These basic concepts of current, voltage and power in an electric circuit are easy to grasp however, to actually determine the values and relationships of these variables in a given circuit requires a sound understanding of some "*fundamental laws*" that govern electric circuits. These laws, known as **Ohm's Law** and **Kirchhoff's Laws** (**KVL** and **KCL**) form the foundation upon which electric circuit analysis is built. So, for this particular lab, the student is urged to review Ohm's and Kirchhoff's laws, and related techniques commonly applied in circuit design and analysis.

References:- (i) Course Textbook: "*Fundamentals of Electric Circuits*" by C. K. Alexander and M. N. O. Sadiku; and (ii) "*Principles and Applications of Electrical Engineering*" by G. Rizzoni.

2.0 OBJECTIVES

- To enhance understanding of the basic electric circuit laws: Ohm's law, Kirchhoff's voltage law (**KVL**), and Kirchhoff's current law (**KCL**)
- To experimentally verify **KVL** and **KCL** in actual circuits.
- To investigate the current-voltage (***I-V***) characteristics of a linear circuit-element (e.g. Resistor) through the use of some simple D.C. circuits.
- To explore and verify the characteristics of ***series*** and ***parallel*** combinations of linear circuit-elements.

3.0 REQUIRED LAB EQUIPMENT & PARTS

- Digital Multimeter (DMM) and Power Supply
- ELE202 Lab Kit:- various components, breadboard, wires and jumpers.

4.0 PRE-LAB: ASSIGNMENT

(a) *I-V* Characteristics of Ohmic Resistor using a simple D.C. Circuit

(i) Assume varying values of the DC source-voltage, **E** applied as shown in **Figure 2.0a**. For each source-voltage value, use Ohm's Law to determine the corresponding value of the current, $\mathbf{I_R}$ when the resistance, **R** is 2.2 kΩ and when it is 3.3 kΩ. Record your theoretical results in **Table 2.0. Use the space below to show your work.**

$V = IR$

$\therefore \frac{V}{R}$

Pre-Lab workspace

$I_R = \frac{V}{R}$

$= \frac{3V}{2.2\,k\Omega}$

$I_R = 1.3636\,mA$

$I_R = \frac{6V}{2.2k\Omega}$

$I_R = 2.72727\,mA$

$I_R = \frac{9V}{2.2k\Omega}$

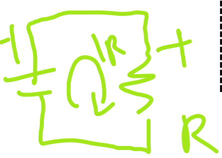
$= 4.0909\,mA$

$I_R = \frac{12V}{2.2k\Omega}$

$= 5.4545\,mA$

$I_R = \frac{15V}{2.2\,k\Omega}$

$= 681818\,mA$



[3 marks]

(ii) Change the resistor to **R** = 3.3kΩ, and repeat **step (i)**.

Pre-Lab workspace

$I_R = \frac{6V}{3.3k\Omega}$

$= 1.81818\,mA$

$I_R = \frac{9V}{3.3k\Omega}$

$= 2.72727\,mA$

$I_R = \frac{12V}{3.3k\Omega}$

$= 3.63636\,mA$

$I_R = \frac{3V}{3.3\,k\Omega}$

$= 0.90909\,mA$

$I_R = \frac{15V}{3.3k\Omega}$

$= 4.5454545\,mA$

[3 marks]

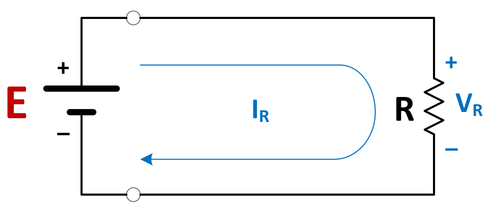


Figure 2.0a: Simple DC Circuit

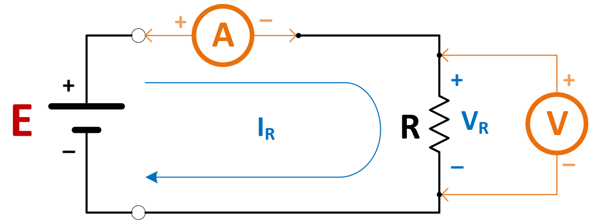


Figure 2.0b: Simple DC Circuit showing Voltmeter & Ammeter connections

	V_R =>	**3V**	**6V**	**9V**	**12V**	**15V**
R		Theory result	Theory result	Theory result	Theory result	Theory Result
2.2 kΩ	**I_R =>** (mA)	1.3636	2.72727	4.0909	5.4545	6.81818
3.3 kΩ	**I_R =>** (mA)	0.90909	1.81818	2.72727	3.63636	4.54545

Table 2.0: Theoretical results of the Simple DC Circuit in Figure 2.0 **[5 marks]**

(b) Series Resistors Circuit - KVL

(i) For the circuit of **Figure 2.1a**, assume the source-voltage, **E = 15V**, **R_1** = 3.3 kΩ, **R_2** = 2.2 kΩ and **R_3** = 1.0 kΩ. Determine the expected current, **I** and the voltages across resistors **R_1** (=**V_{ab}**), **R_2** (= **V_{bc}**) and **R_3** (=**V_{cd}**) for the respective values of resistors shown. Record your theoretical results in **Table 2.1**. Determine the sum ΣV = (**V_{ab}** + **V_{bc}** + **V_{cd}**) to verify the KVL law.

Pre-Lab workspace

I is consistent across Ω..

$V_a = \frac{R_a}{R_a+R_b+R_c} V$

$= \frac{3.3k\Omega}{6.5k\Omega} (15V)$

$V_{ab} = 7.6 V$

I =

$V_b = \frac{R_b}{R_a+R_b+R_c} V$

$= \frac{2.2k\Omega}{6.5k\Omega} (15V)$

$V_{bc} = 5.0769$

$V_c = \frac{R_c}{R_a+R_b+R_c} V$

$= \frac{1.0k\Omega}{6.5k\Omega} (15V)$

$V_{cd} = 2.3076 V$

[6 marks]

V = IR

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

$= \frac{15V}{6.5k\Omega}$ =

(ii) **<u>Design Problem:</u>** Referring to the circuit of **Figure 2.1a**, a designer wishes to create three *equal* potential differences (i.e. $V_{ab} = V_{bc} = V_{cd}$) of **5V** each from a source-voltage, **E = 15V.** The **maximum** source-current, **I** available from the **E** battery-source is **5mA**, and so the designer must ensure the current value stays within this requirement, and **not exceed**. Using KVL concept, analyse and determine a set of values for **I**, R_1, R_2 and R_3 the designer can use to meet the above design specifications. Record the results of your design analysis in **Table 2.2**.

$V = IR$

$\frac{V}{R}$

Pre-Lab workspace

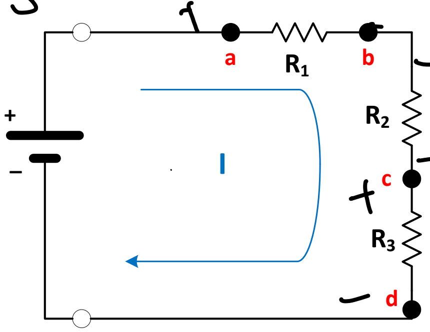
$V_1 = 5V$	$V_2 = 5V$	$V_3 = 5V$
$I = 5mA$	$I = 5mA$	$I = 5mA$
$R_1 = \frac{5V}{5mA}$	$R_2 = \frac{5V}{5mA}$	$R_3 = \frac{5V}{5mA}$
$R_1 = 1k\Omega$	$= 1k\Omega$	$= 1k\Omega$

[6 marks]

$E = 15V$

$3.3K\Omega$

$I = 5mA$



$2.2K\Omega$

$1K\Omega$

Figure 2.1a: KVL Series Circuit

$I = ?$

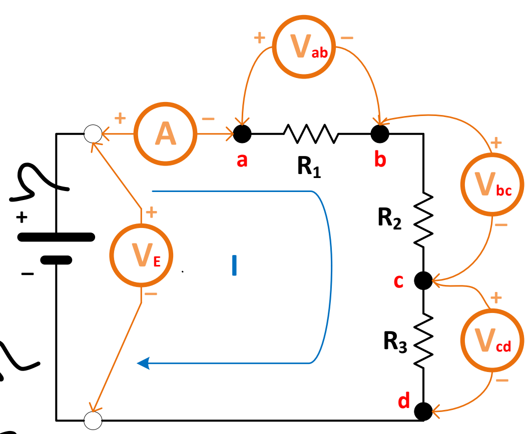


Figure 2.1b: KVL Series Circuit showing Voltmeter & Ammeter connections

$5mA = I_A + I_B + I_C$

V_E	I (mA)	V_{ab} (Volts)	V_{bc} (Volts)	V_{cd} (Volts)	ΣV = (V_{ab} + V_{bc} + V_{cd})
	Theory result	Theory result	Theory result	Theory result	Theory result
15V	17.7mA	7.6V	5.1V	2.3V	15V

Table 2.1: Theoretical results of the Series Circuit in Figure 2.1a **[2.5 marks]**

Design values => **R_1** = 1kΩ **R_2** = 1kΩ **R_3** = 1kΩ				
V_E	I (mA)	V_{ab} (Volts)	V_{bc} (Volts)	V_{cd} (Volts)
	Theory result	Theory result	Theory result	Theory result
15V	5mA	5V	5V	5V

Table 2.2: Theoretical results of the ***re-designed*** Series Circuit in Figure 2.1a **[2.5 marks]**

(c) Parallel Resistors Circuit - KCL

(i) For the circuit of **Figure 2.2a**, assume the source-voltage, **E = 15V**, R_1 = 3.3 kΩ, R_2 = 2.2 kΩ and R_3 = 1.0 kΩ. Determine the expected currents **I**, I_1, I_2 and I_3 as shown in **Figure 2.2a**. Record your theoretical results in **Table 2.3**. Determine the sum $\Sigma I = (I_1 + I_2 + I_3)$ to verify the KCL law.

Pre-Lab workspace

$i_1 = \frac{R_{eq}}{R_n} i$

$= \frac{0.56896 k\Omega}{3.3 k\Omega}(26.36 mA)$

$= 4.544 mA$

$i_2 = \frac{0.56896 k\Omega}{2.2 k\Omega}(26.36)$

$i_2 = 6.81717 mA$

$i_3 = \frac{0.56896 k\Omega}{1 k\Omega}(26.36)$

$= 14.997 mA$

[6 marks]

$V_1 = V_2 = V_3$

15V

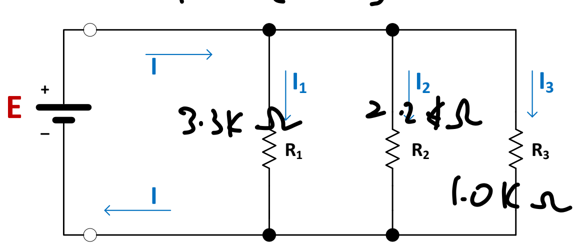


Figure 2.2a: KCL Parallel Circuit

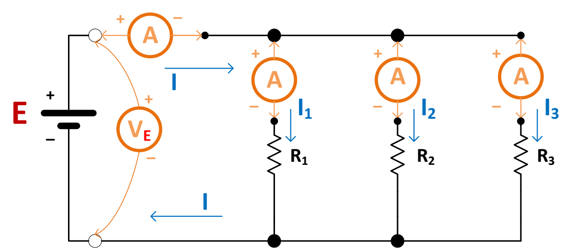


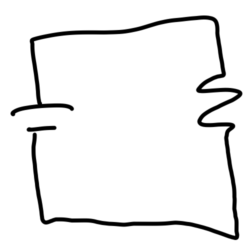
Figure 2.2b: KCL Parallel Circuit with Ammeter & Voltmeter connections

V_E	I (mA)	I_1 (mA)	I_2 (mA)	I_3 (mA)	$\Sigma I = (I_1 + I_2 + I_3)$
	Theory result	Theory result	Theory result	Theory result	Theory result
15V	26.36 mA	4.54	6.82 mA	15.0 mA	26.36 mA

Table 2.3: Theoretical results of the Parallel Circuit in Figure 2.2a **[6 marks]**

$\frac{1}{R_{eq}} = \frac{1}{3.3} + \frac{1}{2.2} + \frac{1}{1}$

$R_{eq} = 0.56896 k\Omega$



$R_{eq} = 0.56896 k\Omega$

$V = IR$

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

$I = 15 / R_{eq}$

$= 26.36$

5.0 IN-LAB Experiment (*Virtual*): IMPEMENTATION & MEASUREMENTS

Please use **Multisim** to simulate & complete the following (*virtual version*)

(a) *I-V* Characteristics of Ohmic Resistor using a simple D.C. Circuit

1. From your lab kit, select 2.2 kΩ and 3.3 kΩ resistors (color-coded values). Use the DMM to measure their actual values. List the measured values in **Table 2.4**.

2. Build and connect the circuit of **Figure 2.0a** with **R** = 2.2 kΩ on the breadboard.
   Note 1: *When using the DMM as a Voltmeter, connect the DMM* ***in parallel*** *with the resistor as shown in the Figure 2.0b.* **Note 2:** *When using the DMM as an Ammeter, you must connect it* ***in series*** *with the resistor you need to measure the current passing through it as shown in the Figure 2.0b.*

3. Use the **red** and **black** "banana" cables (*available in the Lab room*) to connect the "+" and "-" terminals of the power supply to the **RED** and **GREEN** binding terminals on your breadboard, respectively. Turn ON the power supply.

4. Vary the power-supply source voltage, **E** such that the voltage across the resistor has the voltage, V_R values as listed in **Table 2.4** [*refer to the* ***Pre-Lab 4(a)***]. Use the Voltmeter to monitor the V_R voltage. Measure and record the corresponding current (I_R) values in **Table 2.4a**.

5. Turn OFF the power supply. Replace the 2.2kΩ resistor in circuit of **Figure 2.0a** with 3.3kΩ resistor. Repeat the above **Step 4,** and list your results in **Table 2.4b**.

6. Turn OFF the power supply.

- Copy and paste a screenshot showing your MultiSIM readings on each circuit. Include the MultiSIM circuit file (**.ms14**) of each circuit in your Post-Lab submission. **[4 marks]**

Simulation value of **R** = 2.2kΩ					
V_R (Volts)	**3V**	**6V**	**9V**	**12V**	**15V**
I_R (mA) **as measured** (*using Multisim*)	1.364	2.727	4.091	5.455	6.818
I_R (mA) **as calculated** in Pre-Lab (*Theory*)	1.364	2.727	4.091	5.454	6.818
Deviation (%) = 100.(measured - calculated)/(calculated)	0%	0%	0%	0.02%	0%

Table 2.4a: Experimental (*using Multisim*) results of the Simple DC Circuit in Figure 2.0 with **R** = 2.2 kΩ **[4 marks]**

Simulation value of **R** = 3.3kΩ					
V_R (Volts)	**3V**	**6V**	**9V**	**12V**	**15V**
I_R (mA) **as measured** (*using Multisim*)	0.909	1.818	2.727	3636	4.545
I_R (mA) **as calculated** in Pre-Lab (*Theory*)	0.909	1.818	2.727	3636	4.54
Deviation (%) = 100.(measured - calculated)/(calculated)	0%	0%	0%	0%	0.02%

Table 2.4b: Experimental results (*using Multisim*) of the Simple DC Circuit in Figure 2.0 with **R** = 3.3 kΩ **[4 marks]**

(b) Series Resistors Circuit - KVL

1. Using $\mathbf{R_1}$ =3.3 kΩ, $\mathbf{R_2}$ = 2.2 kΩ and $\mathbf{R_3}$ = 1.0 kΩ**,** construct on your breadboard the series circuit shown in **Figure 2.1**.

2. Turn ON the power supply. Adjust to set the source voltage, **E** to **15 V**. Measure the current **I** and the voltages $\mathbf{V_{ab}}$, $\mathbf{V_{bc}}$, and $\mathbf{V_{cd}}$. Record the values in **Table 2.5**. **Note:** *Make sure the DMM is set to the right function before using it as Voltmeter or Ammeter, and accordingly connected to the circuit.*

3. Turn OFF the power supply.

4. **Design Problem Circuit**: Implement on your breadboard the re-designed circuit of **Figure 2.1** of Pre-Lab section [**4(b)(iii)**] using the standard-resistance value(s) that you had determined for $\mathbf{R_1}$, $\mathbf{R_2}$ and $\mathbf{R_3}$ to meet the requirements.

   4.0.1 Turn ON the power supply. Set the source voltage, **E** to **15 V**.

   4.0.2 Measure the current, **I** and the voltages across resistors $\mathbf{R_1}$ (=$\mathbf{V_{ab}}$), $\mathbf{R_2}$ (= $\mathbf{V_{bc}}$) and $\mathbf{R_3}$ (=$\mathbf{V_{cd}}$), and record the results in **Table 2.6**.

   4.0.3 Turn OFF the power supply.

Copy and paste a screenshot showing your MultiSIM readings on each circuit. Include the MultiSIM circuit file (**.ms14**) of each circuit in your Post-Lab submission. **[5 marks]**

V_E	I (mA)	V_{ab} (Volts)	V_{bc} (Volts)	V_{cd} (Volts)	ΣV = (V_{ab} + V_{bc} + V_{cd})
15V	2.308 mA	7.615V	5.077V	2.308V	15V ✓

Table 2.5: Experimental (*using Multisim*) results of the Series Circuit of Figure 2.1 **[5 marks]**

Design values used => **R_1** = 1KΩ?		**R_2** = 1KΩ?		**R_3** = 1KΩ?
V_E	**I** (mA)	**V_{ab}** (Volts)	**V_{bc}** (Volts)	**V_{cd}** (Volts)
15V	5 mA	5V	5V	5V

Table 2.6: Experimental (*using Multisim*) results of the ***re-designed*** Series Circuit in Figure 2.1
[5 marks]

(c) Parallel Resistors Circuit - KCL

1. Using **R_1** = 3.3 kΩ**,** **R_2** = 2.2 kΩ and **R_3**=1.0 kΩ**,** construct the parallel circuit shown in **Figure 2.2**.

2. Turn ON the power supply. Adjust the source voltage to **15V**.

3. Measure the currents **I**, **I_1, I_2 and I_3** as depicted in **Figure 2.2b**, and record your experimental results in **Table 2.7**. **Note:** *Make sure the DMM is set to the Ammeter function, and accordingly connected.*

4. Turn OFF the power supply.

- Copy and paste a screenshot showing your MultiSIM readings on each circuit. Include the MultiSIM circuit file (**.ms14**) of each circuit in your Post-Lab submission. **[5 marks]**

V_E	**I** (mA)	**I_1** (mA)	**I_2** (mA)	**I_3** (mA)	ΣI = (**I_1** + **I_2** + **I_3**)
15V	26.364	4.545	6.818	15	26.363

Table 2.7: Experimental (*using Multisim*) results of the Parallel Circuit in Figure 2.2 **[5 marks]**

6.0 POST-LAB: OBSERVATIONS AND ANALYSIS OF RESULTS

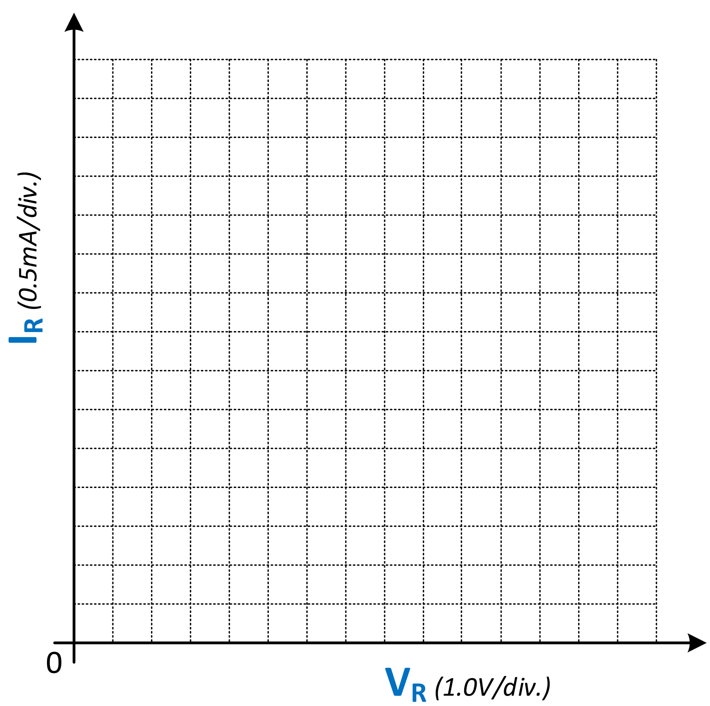
1. Compare your theoretical values from **Table 2.0** and lab experimental values (*using MultiSIM simulation tool*) of **Table 2.4a** and **Table 2.4b**. Explain your observations. **[2 marks]**

Workspace

2. Use the below Graph to plot the ***I-V*** characteristics **for each resistor** using the measured values listed in **Table 2.4a and Table 2.4b**, respectively. Then:-

(a) For the measured values plotted, estimate the slope of each ***I-V*** graph and determine the resistance from the slope. Compare these values with your actual used resistance values of 2.2 kΩ and 3.3 kΩ. Explain any discrepancies. **[1.5 marks]**

(b) Is the ***I-V*** characteristics of each resistor consistent with the Ohm's law? Explain. **[1 marks]**



Workspace

Graph - **[2 marks]**

3. For the KVL experiment, how well did your experimental results of **Table 2.5** conform to the Kirchhoff's Voltage Law? Explain. **[1.5 marks]**
Compare the experimental results (*using Multisim*) of **Table 2.5** with your theoretical Pre-Lab values shown in **Table 2.1**, and explain reason(s) for any relative discrepancies/deviations observed. **[1.5 marks]**

Workspace

4. For the KVL experiment, using your measured voltages and currents of **Table 2.5**, calculate the power absorbed (dissipated) by **each** series resistor, and the total power delivered by the input-source. **[3.5 marks]**
How does the sum of power absorbed by the resistances in this series circuit compare to the amount delivered by the source? Explain. **[1 marks]**

workspace

$\mathbf{P}_{R1}$ =

$\mathbf{P}_{R2}$ =

$\mathbf{P}_{R3}$ =

$\mathbf{P}_{VE}$ =

5. For the KVL "**Design Problem**" experiment, do your results in **Table 2.6** confirm the design requirements of $\mathbf{V_{ab}} = \mathbf{V_{bc}} = \mathbf{V_{cd}} = \mathbf{5V}$; and the current $\mathbf{I \leq 5mA}$? How do these experimental results (*using Multisim*) compare to your theoretical Pre-Lab values of **Table 2.2**. Explain reason(s) for any discrepancies/deviations. **[1.5 marks]**

Workspace

6. For the KCL experiment, how well did your experimental results of **Table 2.7** conform to the Kirchhoff's Current Law? Explain. **[1.5 marks]**
Compare the experimental results (*using Multisim*) of **Table 2.7** with your theoretical Pre-Lab values shown in **Table 2.3**, and explain reason(s) for any relative discrepancies/deviations observed. **[1.5 marks]**

Workspace

7. For the KCL experiment, using your measured voltages and currents of **Table 2.5**, calculate the power absorbed (dissipated) by **each** series resistor, and the total power delivered by the input-source. **[3.5 marks]**

Workspace

$\mathbf{P}_{R1}$ =

$\mathbf{P}_{R2}$ =

$\mathbf{P}_{R3}$ =

$\mathbf{P}_{VE}$ (source) =

How does the sum of power absorbed by the resistances in this series circuit compare to the amount delivered by the source? Explain. **[1 marks]**

7.0 LAB REPORT REQUIREMENTS & GUIDELINES

Lab reporting is to be completed and submitted separately as **Part I** and **Part II**, noted below:

Part I (**Pre-Lab Work**) => represents **40%** of the pre-assigned Lab weight.

Pre-Lab Work (assignment) of **Section 4.0** that includes handwritten calculations and analysis is to be completed and submitted **prior to the start** of your scheduled lab. *The grading is commensurate with: - completeness and accuracy of your handwritten calculations and analysis*

Note the following requirements for the document submission for Part I:

- A completed and signed "COVER PAGE – **Part I**" has to be included with your submission, a copy of which is available on D2L. The report will not be graded if the signed cover page is not included.
- Collate and create a .pdf or .docx file of the above, and upload it via D2L **any time prior to the start of your scheduled lab**. Upload instructions are provided on D2L.

Zero marks will be assigned for the entire lab if this Part I is not submitted prior to your scheduled lab

No e-mail submission.

Part II (**In-Lab (*virtual*) Work** and **Post-Lab Work**) => represents **60%** of the pre-assigned Lab weight.

In-Lab Work - Virtual (**Section 5.0**) and **Post-Lab Work** (**Section 6.0**) that include in-lab (*virtual*) results, handwritten analysis and observations are to be completed and submitted **within 24 hours** of the completion of your lab. *The grading is commensurate with: - completeness, correctness and collection of all experimental results (data and waveforms); merits of observation of the correlations between the experimental and pre-lab assignment results; and reasonableness of the answers to questions posed*.

Note the following requirements for the document submission for Part II:

- A completed and signed "COVER PAGE – **Part II**" has to be included with your submission, a copy of which is available on D2L. The report will not be graded if the signed cover page is not included.
- MultiSIM simulation circuits/plots **ms14** files
- Scan your completed pages of **Section 5.0** and **Section 6.0** (via a scanner or phone images), together with any required In-Lab Oscilloscope screen-shot images.
- Collate and create a .pdf or .docx file of the above, are to be completed and submitted on the D2L **within 24 hours of the completion of your lab**.

No e-mail submission.