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

ELE 202
Laboratory #1

Introduction to Basic Lab Equipment, Tools, & DC Measurements

1.0 INTRODUCTION

Laboratory work involving electric circuits depends on various devices to supply power to a circuit, to generate controlled input signals, and for circuit measurements. The basic operation of these instruments may seem somewhat complicated at first, but the student should gain confidence as the student's experience grows from more in-lab exercises to follow. Eventually, the operation of the commonly used instruments such as Power Supply, Oscilloscope, Multimeter and Function Generator should feel natural and intuitive. Likewise, over time the student should become increasingly comfortable with the use of circuit simulation software tool and breadboard device for convenient prototyping and testing of electrical circuits.
The aim of this lab exercise is to familiarize students with the laboratory facilities and safety procedures; to introduce the use of Digital Multimeter (DMM) and Power Supply (PS) instruments for basic DC measurements; and use of the MultiSIM simulation tool and a breadboard for constructing and testing of circuits. For the in-lab exercise, a "cookbook-like" approach is used to help student effectively navigate through this first, yet important, in-lab exposure to circuit prototyping and measurements.

1.1 Digital Multimeter (DMM)

A digital multimeter is an electronic measurement instrument that combines several AC/DC measurement functions and displays its results digitally. The one used for this lab is **Keysight Model EDU34450A** as shown in **Figure 1.0a**. *Refer to the DMM user manual, related FAQs and video tutorials on the course website (D2L) for proper setup and operations.* Specifically, the DMM can be configured to measure voltage (as a ***Voltmeter***), current (as an ***Ammeter***) or resistance (as an ***Ohmmeter***):

- ***Voltmeter***: It measures the voltage difference between two nodes in a circuit. The DMM *Voltmeter* is placed *in parallel* with the circuit branch as shown in **Figure 1.0b(i)**.
- ***Ammeter***: It measures current through a circuit branch by letting the current go through the DMM. Hence, the circuit must temporarily be "broken" to allow the *Ammeter* to be connected *in series* with a circuit branch as shown in **Figure 1.0b(ii)**, and then connection "restored" after the measurement is completed. (**Note:** when inserting or removing the Ammeter from the circuit, the power to the circuit must be turned off to avoid damaging the instrument.)
- ***Ohmmeter:*** Resistance measurement is done similar to the voltage measurement by placing the DMM *Ohmmeter* directly across, or *in parallel with*, the resistor to be measured as shown in **Figure 1.0b(iii)**. (**Note:** the resistor being measured should be disconnected from the rest of the circuit during this measurement.)

Figure 1.0a: Keysight Digital Multimeter

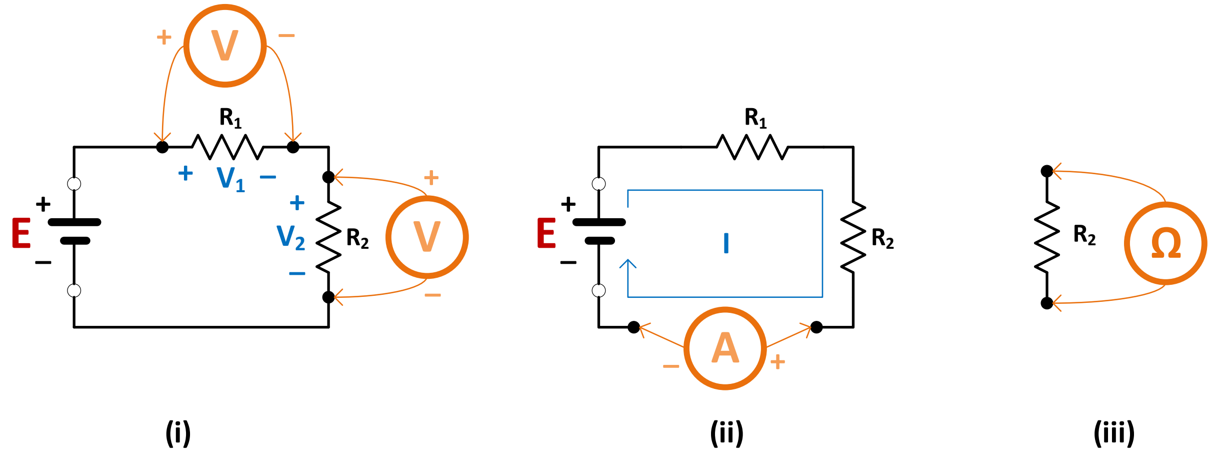


Figure 1.0b: Basic circuit connections - (i) Voltmeter, (ii) Ammeter, and (iii) Ohmmeter

1.2 DC Power Supply (PS)

Active electronic circuits require a power supply providing electrical energy as the driving electromotive force (EMF) to operate the circuit. The power supply can be a battery, a DC supply operating from the AC power line, or some other source such as a solar source, fuel cell, generator or thermoelectric element. A DC Power Supply (PS) is an instrument or device that supplies DC voltage and current to a circuit, and used for the lab experiments in this course. The one used for this lab is **Keysight Model EDU36311A** as shown in **Figure 1.0c**. *Refer to the Power Supply user manual, related FAQs and video tutorials on the course website (D2L) for proper setup and operations.* This Power Supply accommodates ***triple*** DC power supply sources, and each has a "*floating*" ground ("-" terminal), meaning it is not internally connected to each other or any other instruments. Hence, each of these three power supply sources can be used as an ***independent*** DC source, just like a battery.

Figure 1.0c: Keysight Power Supply

1.3 Breadboard

A breadboard is a convenient device for prototyping electrical and electronic circuits in a form that can be easily tested and changed. **Figure 1.0d** illustrates a typical breadboard, and its layout consists of a rectangular matrix of insertion points (or holes) which can be used to plug resistors, capacitors, inductors, Integrated Chips (ICs), wires, connectors, etc. Each group of five holes of the breadboard are connected inside the board by a metal strip to form a single five-hole node. Different components at a given node are connected by pushing in a corresponding end of each component into holes connected to the same node. The horizontal lines of nodes (shown as red and blue lines) are common nodes that are all connected., i.e., all the holes (nodes) across the red (or blue) line are connected from one end to the other, and these are typically used for power supply connections or for those nodes to which many components are connected. A jumper wire can also be used to combine two nodes into one. The three binding posts (**RED**, **BLACK** and **GREEN**) are typically used for DC or AC power supply source connections, from which jumper wires are used to connect to the respective horizontal common nodes. *Refer to the Breadboarding instructions, FAQs and video tutorials on the course website (D2L) for proper use of the breadboard to implement and test circuits*

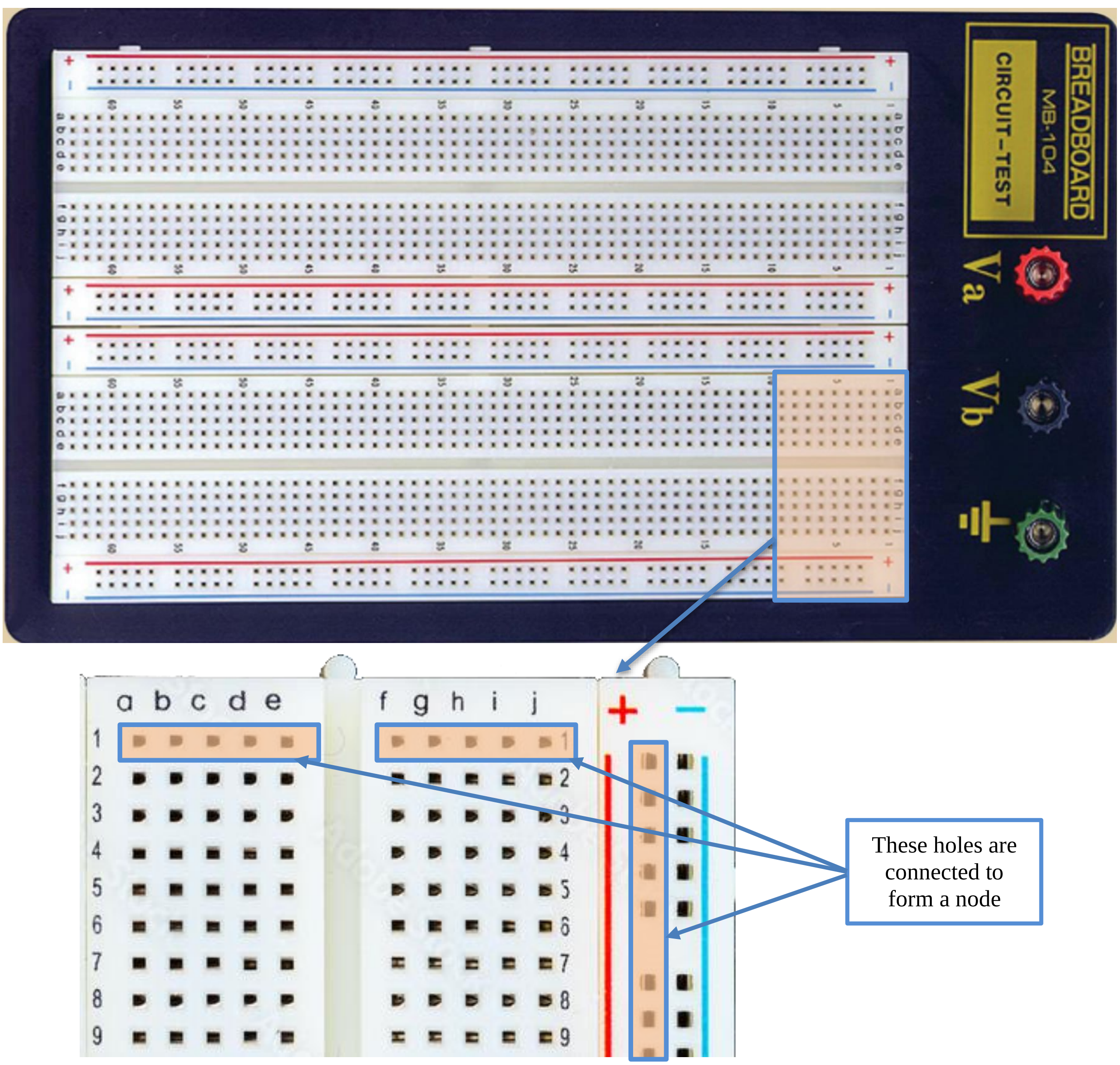
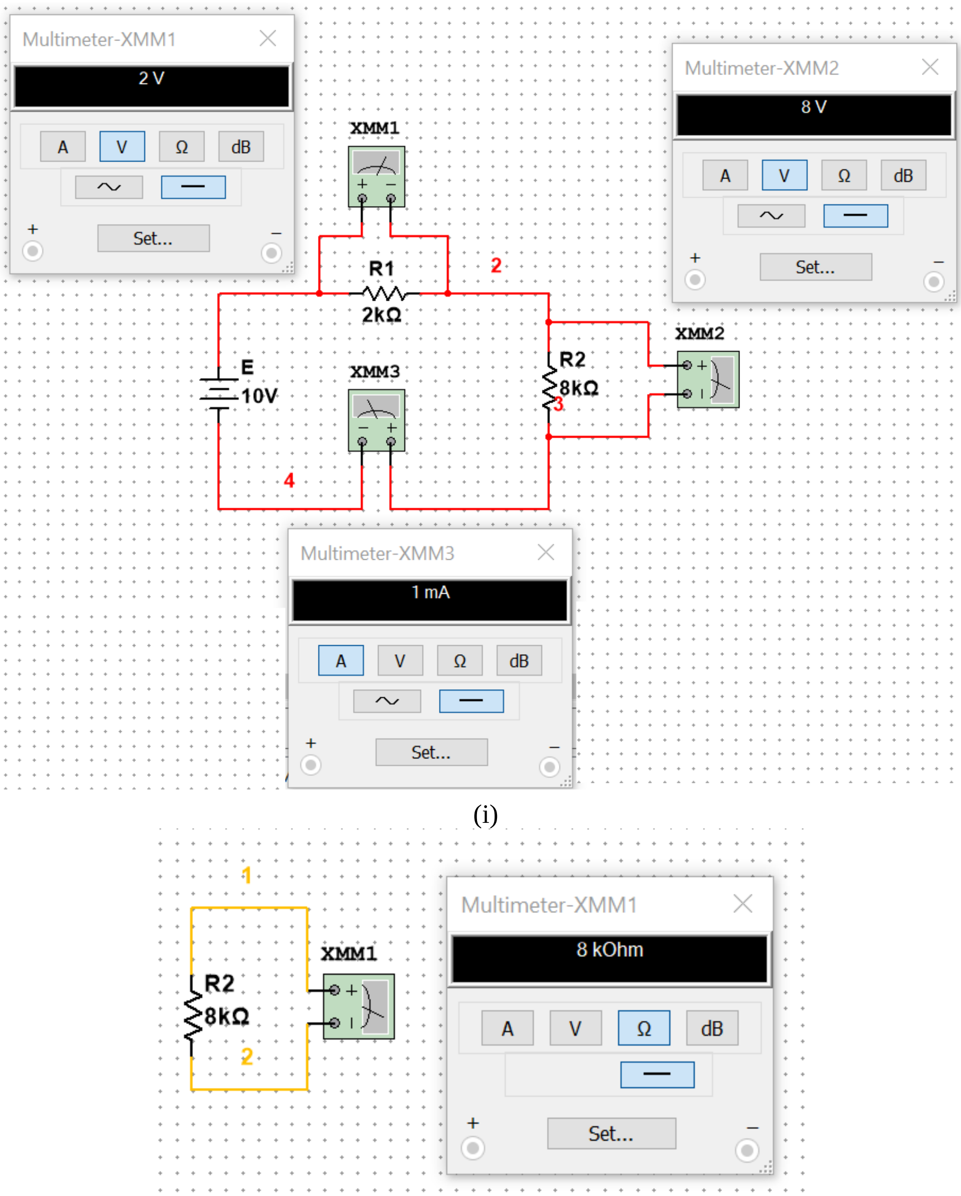


Figure 1.0d: Breadboard

1.4 MultiSIM

MultiSIM is an electronic schematic capture and simulation program used to analyze circuit behavior. All AC/DC voltages, AC/DC currents, resistance, frequency, phase-shift, time-domain waveform, etc. can be determined using this software. An example circuit simulation measurement is shown below in **Figure 1.0e** that corresponds to the example circuit in **Figure 1.0b**. In this simulation, all components are visually laid out in a way that is the same as the circuit diagram. Each DMM configuration is connected the same way that a physical DMM would be connected on the breadboard. Results are obtained by running the simulation and then double clicking on each piece of equipment to read the desired output values. *Refer to the MultiSIM software download procedures, related FAQs and video tutorials on the course website (D2L) to get acquainted with proper use of this simulation tool, and become proficient at it.*



(i)

(ii)

Figure 1.0e: Examples of using MultiSIM

1.5 Standard Resistor Color-Code

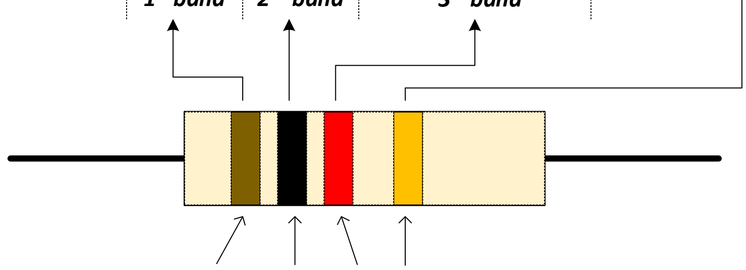
The resistance of a resistor determines how much current it will carry when a given voltage is applied across it. A resistor is a passive electrical component to create specific resistance in the flow of electric current, commonly found in almost all electrical networks and circuits. The unit of measure is Ohms (**Ω**), which is the resistance of a conductor such that a constant current of *one* Ampere in it will produce a voltage of *one* Volt between its ends. Hence, the current (**I**) *through* a resistor (**R**) is proportional to the voltage (**V**) *across* the resistor, and this is represented by Ohm's Law: **I** = **V**/**R**. This expression can be used as **V = I.R** to calculate the voltage across the resistor, or as **R = V/I** to find the resistance value.

Manufacturers specify a resistor's *nominal* resistance value and its *tolerance* using color-codes on the resistor. The *tolerance* means that the **actual value** of the resistor is guaranteed to be within this amount of its *nominal* value. For example, a resistor with its nominal value labelled as 1kΩ ± 5% means that the manufacturer guarantees the actual resistance will be between 950Ω and 1050Ω. The standard resistor Color-Codes Chart[1] is illustrated in **Figure 1.0f**.

COLOR		VALUE of RESISTANCE		
		1st band	*2nd band*	*3rd band*
Black			0	$10^0 = 1$
Brown		1	1	$10^1 = 10$
Red		2	2	$10^2 = 100$
Orange		3	3	$10^3 = 1{,}000$
Yellow		4	4	$10^4 = 10{,}000$
Green		5	5	$10^5 = 100{,}000$
Blue		6	6	$10^6 = 1{,}000{,}000$
Violet		7	7	$10^7 = 10{,}000{,}000$
Grey		8	8	$10^8 = 100{,}000{,}000$
White		9	9	$10^9 = 1{,}000{,}000{,}000$

COLOR		TOLERANCE
Red		2 %
Gold		5 %
Silver		10 %
None		20 %

4th band



Example: => | Brown | Black | Red | Gold |
1 0 10^2 5 % => 10 x 10^2Ω = 1 kΩ (with ± 5 % tolerance)

Figure 1.0f: Standard Resistor Color-Code Chart

[1] There are some easy to remember mnemonics that can help you remember the order of the resistor color chart, e.g., **B**lack **B**eautiful **R**oses **O**ccupy **Y**our **G**arden, **B**lue **V**iolets **G**row **W**ild. Check out this Wikipedia link: https://en.wikipedia.org/wiki/List_of_electronic_color_code_mnemonics

1.6 Lab Safety, Rules and Operating Procedures

Electrical voltages and currents can be dangerous if they occur at values that interfere with physiological functions. All of the laboratory exercises for this particular course are designed to use AC and DC voltages much less than 20 volts, values that should not cause perceptible shock through the skin. Nevertheless, since the lab instruments are powered by "household" line voltage (110 volts-rms), one must be extremely careful to avoid shock or potentially lethal situations. Hence, safety becomes an important component of good lab practice. Accordingly, it is mandatory for each student to review and follow the Power Point Presentation on "Laboratory Safety" provided by the Electrical, Computer, and Biomedical Engineering (ECBE) department at this link: http://www.ee.ryerson.ca/guides/labsafety and on the D2L course website. The Lab Instructor will also spend the first few minutes of this first lab session to go over laboratory safety procedures.

The key lab safety rules and operating procedures that MUST be followed are:

- Students are allowed in the Laboratory only when the Lab Instructor is present.
- Be aware of the physical location of the **RED** POWER CUTOFF button in the Lab Room to shut off power in an emergency; and the **BLUE** EMERGENCY PULL STATIONS in the case of any emergency, be it medical, accident, smoke, fire or electrocution.
- Open drinks and food are not allowed near the lab benches.
- Remove all loose conductive jewelry and trinkets, including rings, which may come in contact with exposed circuits.
- Report any broken equipment or defective parts to the Lab Instructor immediately. Do not open, remove the cover, or attempt to repair any equipment.
- When the experiment is finished, all equipment must be turned OFF. Return any cables or components to the designated locations in the lab room.
- Do not move equipment between lab stations. No equipment should be taken out of the lab room by the student under any circumstances.

ANYONE VIOLATING ANY LAB SAFETY RULES OR REGULATIONS MAY BE DENIED FURTHER ACCESS TO THESE LAB FACILITIES.

1.7 Lab Reporting Guidelines (****IMPORTANT ****)

The following guidelines should help each student produce more consistent lab records with clear distinctions between the student's expectations, the actual data, and the analysis of the data. To this end, each lab exercise for this course is structured to include *self-contained* Pre-Lab Work, In-Lab Work and Post-Lab Work, explained below:

Pre-Lab Work: *The Pre-Lab Work (**Section 4.0** of each Lab Exercise) is designed to motivate and define the student's experiments, and thus prepare the student for the in-Lab work. Pre-Lab work should be treated like a small yet important homework assignment, to be handwritten in the workspaces provided in **Section 4.0** and completed prior to the student's scheduled In-Lab work. The Pre-Lab assignments will generally analyze and predict the performance of an electric circuit and follow it with simulation of the circuit, to result in predictions for the measurement data student will record during the In-Lab work. Hence, for each Lab Exercise, the Pre-Lab Work in **Section 4.0** MUST be completed and submitted (online via D2L) **prior** to the start of the student's scheduled In-Lab work, otherwise a zero mark will be assigned for the entire lab exercise. Refer to **Section 7.0** of each Lab Exercise for more information.*

In-Lab Work: *Each student will use a single lab-station for the In-Lab work. The In-Lab work involves breadboard implementation, testing and measurements of the circuits using lab equipment, the procedures for which are outlined in **Section 5.0** of each Lab Exercise. The experimental data or results are recorded in the workspaces provided in **Section 5.0**.*

Post-Lab Work: *The Post-Lab Work (**Section 6.0** of each Lab exercise) entails interpretation of the student's In-Lab work results in terms of the analyses and predictions of the student's Pre-Lab Work. It presents the student with opportunity to discuss not only the circuit operation but also whether the results answer the questions from the Pre-Lab Work. The Post-Lab Work is done in the workspaces provided in **Section 6.0**. As long as the Pre-Lab Work was submitted in a timely manner, the student's completed In-Lab Work (**Section 5.0**) and Post-lab Work (**Section 6.0**) can be submitted on-line (via D2L) by the deadline stated in **Section 7.0** of each Lab Exercise, and on D2L.*

2.0 OBJECTIVES

- To introduce use of MultiSIM circuit simulation tool for capturing and analyzing circuits,
- To familiarize with the operation of basic electrical equipment such as a DC Power Supply (PS) and Digital Multimeter (DMM).
- To construct and test basic electrical circuits using a Breadboard device,
- To properly use a Digital Multimeter (DMM) to measure DC voltage, current and resistance.
- To learn the Standard Resistor Color-Code scheme necessary to read resistor values and tolerances.

3.0 REQUIRED LAB EQUIPMENT & PARTS

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

4.0 PRE-LAB: ASSIGNMENT

(a) Use the Standard Resistor Colour-Code Chart in **Figure 1.0f** to: **(i)** determine the numerical value, tolerance and acceptable resistance range for each colour-coded resistor listed in **Table 1.0a**, and **(ii)** identify the corresponding 4-band colour codes of each resistor value listed in **Table 1.0b**. (Note: 1 kΩ = $1 \times 10^3 \Omega$ = 1000 Ω)

Lab workspace

Resistor	Color of Bands				Color Code Value	Tolerance (%)	Range of Acceptable Values	
	1st band	2nd band	3rd band	4th band			Minimum	Maximum
1	Brown	Red	Black	Red	12	2 %	11.76	12.24
2	Green	Violet	Yellow	Gold	57x10^4	5 %	54.2 x10^4	59.9x10^4
3	Blue	Red	Red	Gold	62 x10^2	5 %.	58.9x10^2	65.1 x10^2
4	Yellow	Violet	Orange	Silver	47x10^3	10 %.	42.3x10^3	51.7x10^3

Table 1.0a

Resistor Value	Colour of Bands			
	1st band	2nd band	3rd band	4th band
100 Ω ± 2%	brown	black	brown	red
680 Ω ± 5%	blue	grey	brown	gold
3.3 kΩ ± 5%	orange	orange	red	gold
47 kΩ ± 2%	yellow	violet	orange	red

Table 1.0b

(b) The simple DC circuit in **Figure 2.0** is powered by a **15 volts** DC battery input-source (V_I) which will cause currents to flow through the resistors, R_1, R_2 and R_3 as illustrated. When current flows through a resistor, it creates a voltage across the resistor as governed by the **Ohm's Law** expression, $V = I.R$. The **Kirchhoff's Current Law** (KCL) states that the sum of all currents entering (or leaving) a node is zero. Therefore, $I_1 + (-I_2) + (-I_3) = 0$, resulting in $I_1 = I_2 + I_3$.
Even though the basic circuit laws may not be fully covered in class as yet, you may use the above circuit law expressions to determine the missing values in **Table 2.0**. Show your analysis on the below workspace provided. **Note:** 1 **mA** = $1\text{x}10^{-3}$**A** = 0.001**A**; and 1 **kΩ** = $1\text{x}10^{3}$**Ω** = 1000**Ω**

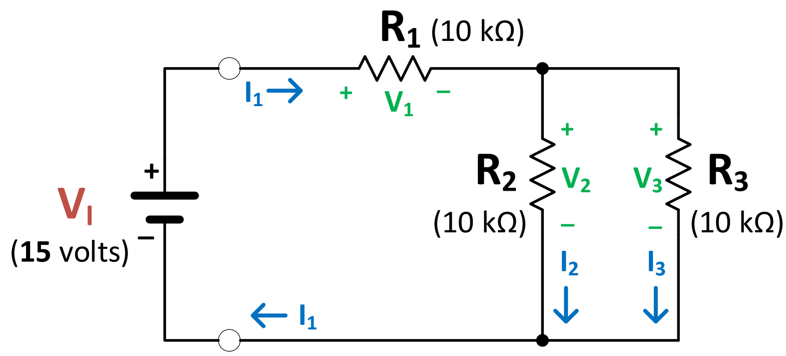


Figure 2.0: Simple D.C. circuit for voltage and current measurements

Pre- Lab workspace

V_1	V_2	V_3	I_1	I_2	I_3
10V	5V	**5** volts	1 mA	**0.5** mA	0.5 mA

Table 2.0

What relationship exists between voltages V_2 and V_3? and between currents, I_2 and I_3? Why?

R_2 & R_3 are equal & parellel resistors, so voltages and currents are the same.

Was the voltage relationship $V_I = V_1 + (V_2 \text{ or } V_3)$ established? If so, why would it be the case?

yes. The voltage source (V_I) supplies all V_1 so internal voltages in series need to add up to V_I.

If the resistor, R_1 is replaced with a wire (i.e. make $R_1 = 0\ \Omega$), intuitively what might the resultant value of the voltage, V_3 be? Explain.

V_3 would be $15/2$, since half of the voltage going through the branch (15V) would pass through R_3 while the other half goes to R_2

(c) The circuit in **Figure 2.1** is a simple voltage-divider configuration that uses two resistors in series to create an output voltage, V_O which is a fraction of the input voltage, V_I. The basic circuit laws dictate that the circuit current, **I** and the resultant voltage division output, V_O of this basic circuit configuration can be expressed as:

$$I = \frac{V_I}{R_X + R_Y} = \frac{V_O}{R_Y} \qquad\qquad V_O = \left[\frac{R_Y}{R_Y + R_X}\right] \cdot V_I$$

If the input voltage, V_I = **15** volts, and resistors R_X = **10** kΩ and R_Y = **5.0** kΩ, find the values of the output voltage, V_O and the circuit current, **I** by <u>using the above expressions</u>. Record the results in **Table 2.1**.

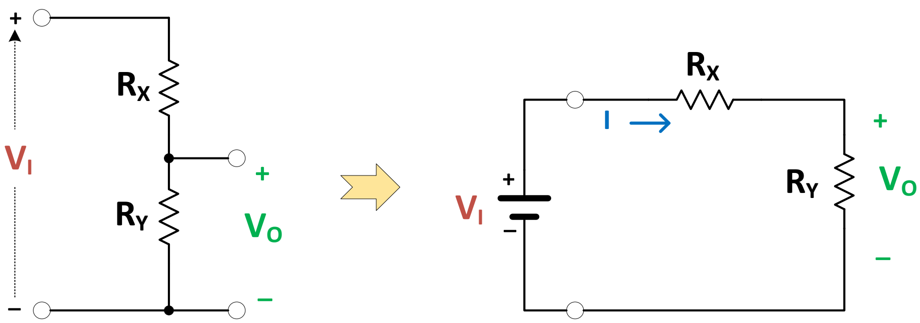


Figure 2.1: Simple voltage-divider circuit

Pre- Lab workspace

V_O	I
5 V	1 mA

Table 2.1

For the resistor values selected for circuits in **Figure 2.0** and **Figure 2.1**, and <u>comparing</u> your results in **Table 2.0** with those in **Table 2.1**, answer the following questions:

(i) Why would the value of $I = I_1$ and $V_O = V_3$ (or V_2)? Explain.

$V_I = V_{I_1}$ & $R_I = R_{I_1}$ ∴ $i_I = i_{I_1}$

V_O & V_3/V_2 were both measured around equivalent resistor(s) connected in series to a 15V source & 10 kΩ resistor.

(ii) Would it be reasonable to conclude that resistor, R_Y value chosen must be equivalent to the value of parallel resistors, R_2 and R_3 combined? Why?

I believe it would be more reasonable to assume

$R_y = \frac{1}{\frac{1}{R_2} + \frac{1}{R_3}}$ since they're in parallel

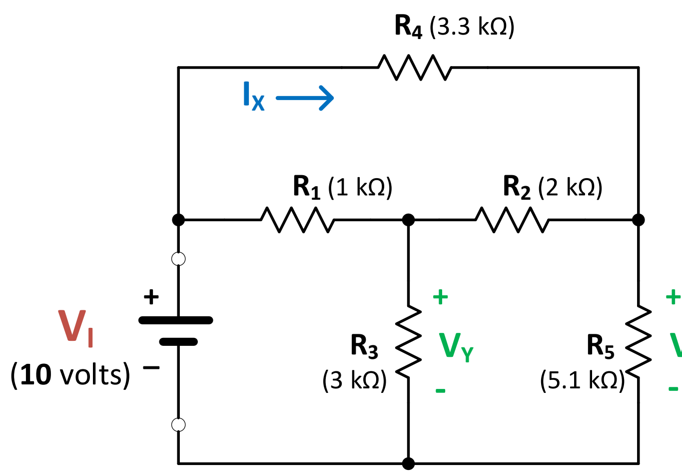
(d) Practice Exercise for MultiSIM simulation: At this point, the student should have already downloaded and installed the licenced version of MultiSIM software, and become familiar with the basic use of this simulation tool to construct and test simple electrical circuits. As was noted earlier, student should "*Refer to the MultiSIM software download procedures, related FAQs and video tutorials on the course website (D2L) to get acquainted with proper use of this simulation tool, and become proficient at it*."

On MultiSIM, construct and simulate the practice circuit in **Figure 3.0** using the values shown. Measure the voltages, V_Y (across R_3) and V_Z (across R_5) and current, I_X (through R_4) as shown.

To know your practice simulation of the circuit is done correctly, the measured results should show:

$$V_Y = \mathbf{7.275}\text{ V},\quad V_Z = \mathbf{6.674}\text{ V}\quad\text{and}\quad I_X = \mathbf{1.008}\text{ mA}$$

- Copy and paste a screenshot showing your MultiSIM readings on the circuit. Include the MultiSIM circuit file (**.ms14**) in your Pre-Lab submission.
- All screenshots should show your name printed on the center-top of the MultiSIM screen and the timestamp at the bottom-lower corner.



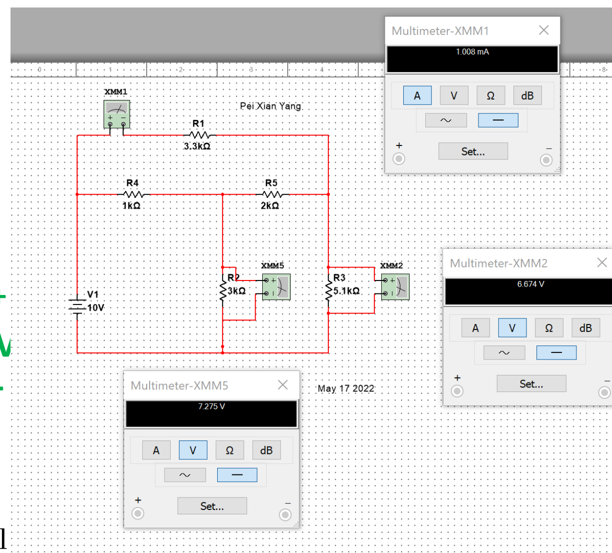


Figure 3.0: Practice circuit for MultiSIM tool

(e) Use MultiSIM to:

(i) Construct and simulate the circuit of **Figure 2.0**, with V_I = **15** V and $R_1 = R_2 = R_3 =$ **10** kΩ. Measure the voltages V_1, V_2 and V_3; and currents I_1, I_2 and I_3. Record the results in below **Table 2.2**.

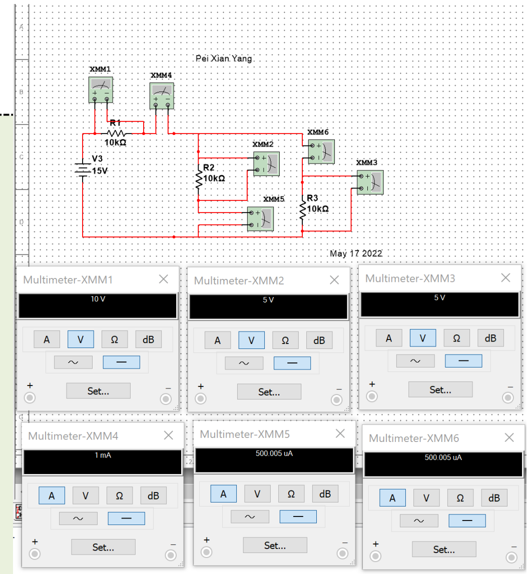
(ii) Construct and simulate the circuit of **Figure 2.1**, with V_I = **15** V, R_X = **10** kΩ and R_Y = **5** kΩ. Measure the voltage, V_O and current, **I**. Record the results in below **Table 2.3**.

- Copy and paste a screenshot showing your MultiSIM readings on each circuit. Include the MultiSIM circuit file (**.ms14**) of each circuit in your Pre-Lab submission.
- All screenshots should show your name printed on the center-top of the MultiSIM screen and the timestamp at the bottom-lower corner.

Pre-Lab workspace

V_1	V_2	V_3	I_1	I_2	I_3
10V	5V	5V	1mA	0.5mA	0.5mA

Table 2.2



V_O	I
5V	1 mA

Table 2.3

Compare your above simulation results with the respective theoretical ones from **Table 2.0** and **Table 2.1**, and comment.

Values are the same

Do these simulation results support your answers to the questions posed earlier in the Pre-Lab sections **4(b)** and **4(c)**? Explain.

yes. The values are identical.

5.0 IN-LAB Experiments: IMPEMENTATION & MEASUREMENTS

(a) Resistance Measurement.

1. Select three **10** kΩ resistors from your Lab Kit and mark (or label) each one as $\mathbf{R_1}$, $\mathbf{R_2}$ and $\mathbf{R_3}$ respectively, so that each resistor can be correctly identified when later used in a circuit.

2. Turn ON the DMM multimeter and set it as an ***Ohmmeter*** by pressing the "**Ω**2W" function key on the instrument. Then, as illustrated in **Figure 5.0a**, directly measure the actual resistance value of each **10** kΩ resistor. Record yours results in **Table 3.0** in the appropriate column. Fill in the remaining columns later for Post-Lab work.

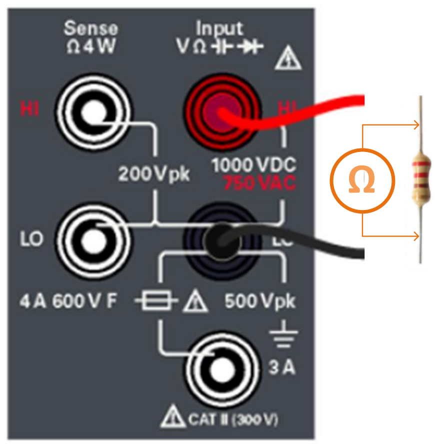


Figure 5.0a: DMM "Ohmmeter" Connection

	THEORETICAL			ACTUAL	ACTUAL DEVIATION
	Color Code (C.C.) value	Minimum value	Maximum value	Measured value	$\text{Dev.}\% = \frac{(\text{C.C. value} - \text{ACTUAL value}).100}{(\text{C.C. value})}$
$\mathbf{R_1}$	10 kΩ	9.5 kΩ	10.5 kΩ	9.83 kΩ	1.7%
$\mathbf{R_2}$	10 kΩ	9.5 kΩ	10.5 kΩ	9.84 kΩ	1.6%
$\mathbf{R_3}$	10 kΩ	9.5 kΩ	10.5 kΩ	9.85 kΩ	1.5%

Table 3.0: Actual vs Theoretical values of resistance

Prepared by Dr. M.S. Kassam, Dr. S. Hussain & K. Tang. © Ryerson University, ECBE Department, 2021

(b) Breadboard Implementation, and Voltage-Current Measurements:

Implementation of the Simple DC Circuit in Figure 2.0

1. Turn OFF the Power Supply (PS) and the DMM multimeter.

2. Follow proper breadboarding procedures to neatly construct the DC circuit in **Figure 2.0** on your breadboard using the three **10** kΩ resistors that were previously marked and identified as R_1, R_2 and R_3. For convenience, connect a red wire from the **RED** binding terminal to one of a "red lined" horizontal node on the breadboard, and a green wire from the **GREEN** binding terminal to the "blue lined" common node. This way, the "**+**" side of the input DC voltage, V_I from the Power Supply can be securely connected to the **RED** terminal with a **banana** cable, and the "**-**" side of the input DC voltage from the Power Supply securely connected to the **GREEN** binding terminal using a second **banana** cable. ***Banana** cables are made available in the lab room.*

Below **Figure 5.0b** shows a possible breadboard setup of the DC circuit in **Figure 2.0** to serve as a reference guide.

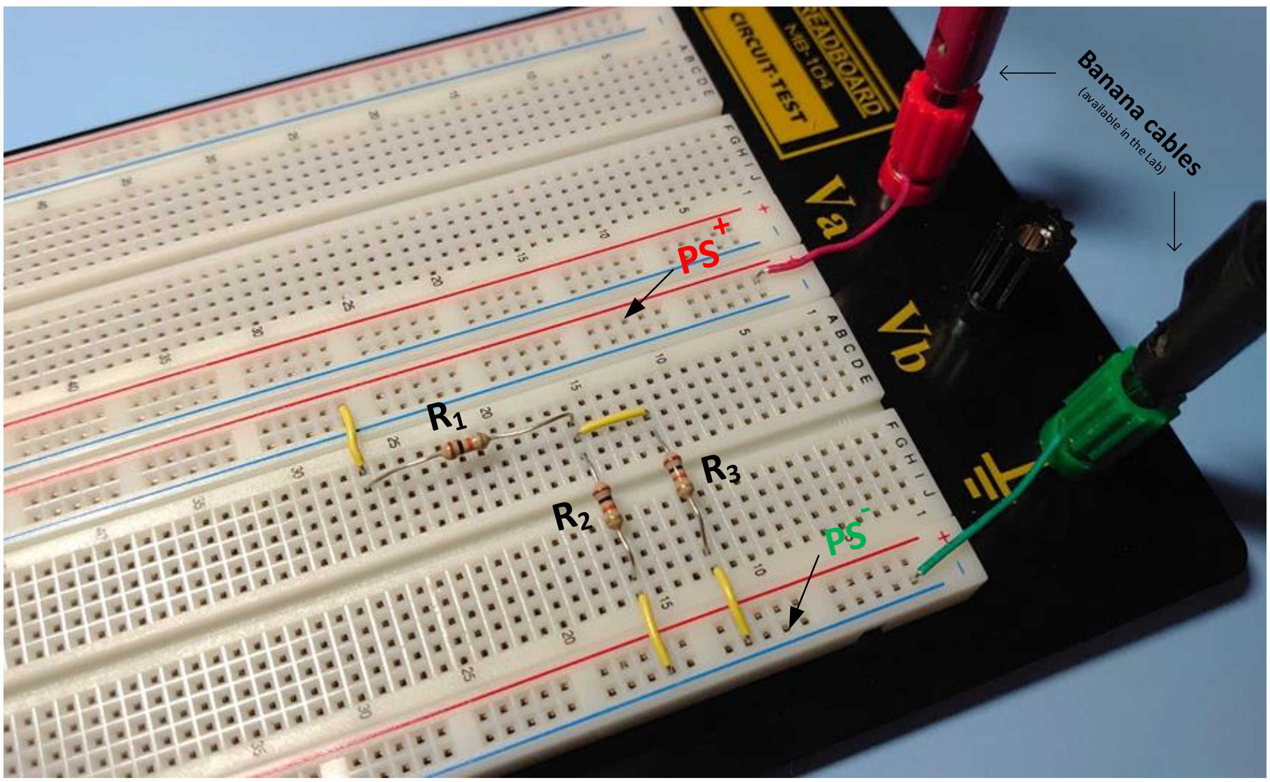
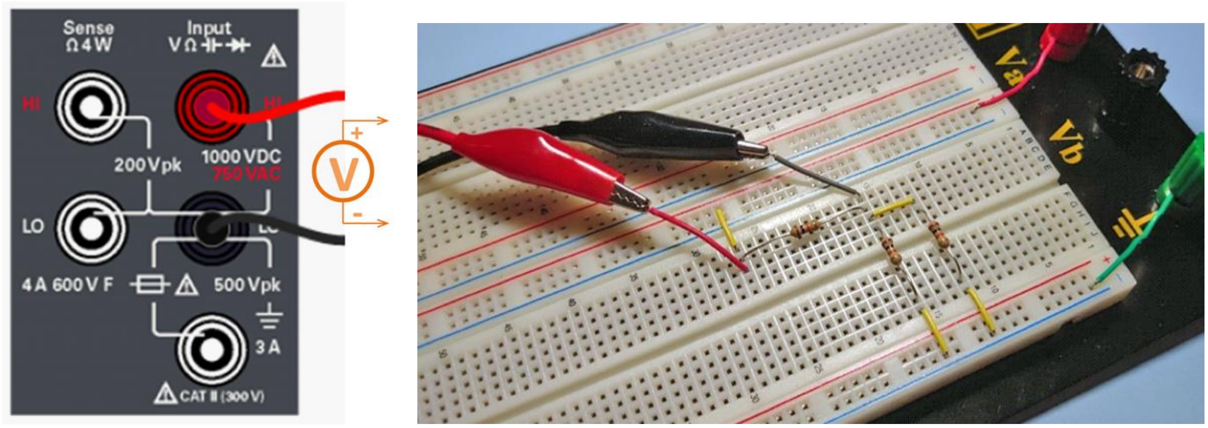


Figure 5.0b: Example of breadboard setup for the circuit in Figure 2.0.

3. Voltage Measurements: Turn ON the DMM multimeter and set it as a ***Voltmeter*** by pressing the "**DCV**" function key on the instrument. Connect the cable probes to the DMM as shown in **Figure 5.0c-(i)**.

- Turn ON the Power Supply (PS) and set its voltage value to **15 volts** (to serve as your V_I input source). Use the probes to measure V_1 (across R_1), V_2 (across R_2) and V_3 (across R_3) *one at a time*. Example of the voltage measurement of V_1 across resistor, R_1 is illustrated in **Figure 5.0c-(ii)**. Record your measured values in **Table 4.0**.

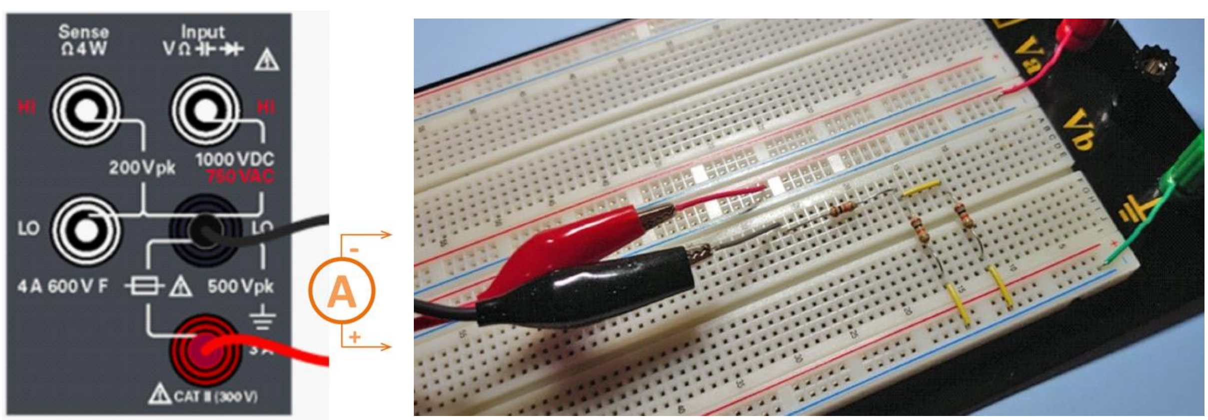
- Turn OFF the Power Supply (PS) and DMM.



(i) DMM Voltmeter Configuration **(ii)** Example of how to take voltage across resistor R_1, with the DMM

Figure 5.0c: DMM Voltmeter Connections

4. Current Measurements: Connect the cable probes to the DMM as shown in **Figure 5.0d-(i)**. Turn ON the DMM multimeter and set it as an ***Ammeter*** by pressing the "**DCI**" function key on the instrument.
   - To measure current, I_1 (through $\mathbf{R_1}$), break the circuit to insert the ***Ammeter*** in series with $\mathbf{R_1}$. Example of the ***Ammeter*** connected in series with $\mathbf{R_1}$ is shown in **Figure 5.0d-(ii)**. **Note**: Be very careful when using the ***Ammeter*** feature of the multimeter. If the ***Ammeter*** is not placed in series with the resistor and the probe leads are placed across the resistor instead, then you can burn out the multimeter's fuse and/or damage the instrument.
   - Turn ON the Power Supply (PS) and set its voltage value back to **15 volts** for the $\mathbf{V_I}$ input source. Record your ***Ammeter*** measured value of the current in **Table 4.0**.
   - Turn OFF the Power Supply (PS)**.** Then, disconnect the ***Ammeter*** and restore the original wire connection in place.
   - Follow the above procedures to measure current, I_2 (through $\mathbf{R_2}$). Repeat the same to measure current, I_3 (through $\mathbf{R_3}$). Record the ***Ammeter*** measured values of the respective currents in **Table 4.0**.
   - Turn OFF the Power Supply (PS) and the DMM.



(i) DMM Ammeter Configuration **(ii)** Example of how to measure current through resistor R_1, with the DMM

Figure 5.0d: DMM Ammeter Connections

V_1	V_2	V_3	I_1	I_2	I_3
9.99V	5.0 V	5.0 V	1.02 mA	0.51 mA	0.51 mA

Table 4.0: Measured values for the circuit in Figure 2.0

Implementation of the Voltage-Divider circuit in Figure 2.1

1. Turn OFF the Power Supply (PS) and the DMM multimeter.

2. Modify your existing breadboard circuit in **Figure 2.0** to construct the voltage-divider circuit in **Figure 2.1**, as follows:

- Leave resistor, $\mathbf{R_1}$ (**10** kΩ) from the previous circuit in place to serve as the required value for resistor $\mathbf{R_X}$ (**10** kΩ) of the voltage-divider circuit in **Figure 2.1**.
- Remove resistor, $\mathbf{R_3}$ from the previous circuit.
- Select **5.1** kΩ from your Kit for the resistor value for $\mathbf{R_Y}$. (Note: *For the Pre-Lab analysis, a **5.0** kΩ value was used for the resistor, $\mathbf{R_Y}$. However, in practice the closet standard value resistor available to use is **5.1** kΩ.*)
- Replace resistor, $\mathbf{R_2}$ (10 kΩ) in the previous circuit with the **5.1** kΩ resistor to serve as the required resistor, $\mathbf{R_Y}$ of the voltage-divider circuit in **Figure 2.1**.

3. Turn ON the Power Supply (PS) and set its voltage value to **15 volts** for your $\mathbf{V_I}$ input source.

4. Turn ON the DMM multimeter and set it as a ***Voltmeter*** by pressing the **DCV** function key on the instrument, and connect the cable probes as was shown in **Figure 5.0c-(i)**. Measure the voltage, $\mathbf{V_O}$ across resistor, $\mathbf{R_Y}$. Record the measured value in **Table 4.1**.

5. Turn OFF the Power Supply (PS).

6. Set the DMM multimeter as an ***Ammeter*** by pressing the **DCI** function key on the instrument, and connect the cable probes as was shown in **Figure 5.0d-(i)**.

7. Insert the ***Ammeter*** in series with resistor, $\mathbf{R_X}$ [as was illustrated in **Figure 5.0d-(ii)**] to measure the current, **I** through it.

8. Turn ON the Power Supply (PS) and set its voltage value to **15V** for your $\mathbf{V_I}$ input source.

9. Record the measured value of the current, **I** in **Table 4.1**.

10. Turn OFF the Power Supply (PS) and the DMM multimeter.

V_O	I
5.09V	1.01 mA

Table 4.1: Measured values for the circuit in Figure 2.1

(c) Potentiometer – as a variable Resistor

A potentiometer is a manually adjustable *variable resistor* with 3 terminals, and can be used for varying resistance in a circuit. An example of a physical potentiometer and its basic symbol of operation is shown in **Figure 6.0a**. The two outer terminals "**1**" and "**3**" of the potentiometer are internally connected to both ends of a fixed value resistive element that defines the potentiometer's resistance rating (**R_p**), and the middle terminal "**2**" internally connects to a sliding contact that moves over the fixed resistive element like a *wiper*. The *wiper* action is controlled by a central knob, which when turned in CW or CCW direction, resistance between the *wiper* (terminal "**2**") and one outer terminal goes up while resistance between the *wiper* and the other terminal goes down. In essence, the potentiometer resistance, **R_P** can be seen as two resistors in series, **$R_{1\text{-}2}$** and **$R_{2\text{-}3}$** where the sum always equals **R_P** = **$R_{1\text{-}2}$** + **$R_{2\text{-}3}$** for any wiper position. The potentiometer configures as a ***variable resistor*** when used as **$R_{1\text{-}2}$** between terminals "**1**" and "**2**" or as **$R_{2\text{-}3}$** between terminals "**2**" and "**3**".

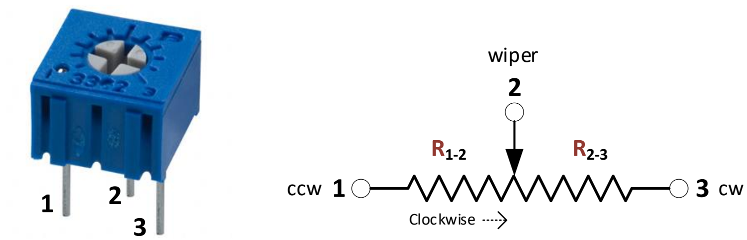


Figure 6.0a: Potentiometer

The purpose of this experiment is to explore the workings of a potentiometer explained above.

1. Select a **5** kΩ potentiometer from your Lab Kit. Place and wire the potentiometer on the breadboard as illustrated in **Figure 6.0d** for easier DMM multimeter access to the potentiometer terminals.

2. Turn ON the DMM multimeter and press the Ω2W function key to set it as an ***Ohmmeter***. Refer to **Figure 5.0a** for proper cable connections to the multimeter.

3. Turn the potentiometer knob (wiper) using a screw driver (or another suitable tool) to **Fully CCW** position.

   (i) Connect the ***Ohmmeter*** between terminals "**1**" and "**2**" of the potentiometer for direct measurement of resistance, **$R_{1\text{-}2}$**. Record your result in **Table 5.0**.

   (ii) Connect the ***Ohmmeter*** between terminals "**2**" and "**3**" of the potentiometer for direct measurement of resistance, **$R_{2\text{-}3}$**. Record your result in **Table 5.0**.

   (iii) Connect the ***Ohmmeter*** between terminals "**1**" and "**3**" of the potentiometer for direct measurement of resistance, **$R_{1\text{-}3}$**. Record your result in **Table 5.0**.

4. Turn the potentiometer knob (wiper) clockwise to the **Half-Way** (i.e. "12 O'Clock" position) and repeat above steps **3(i)**, **3(ii)** and **3(iii)**.

5. Turn the potentiometer knob (wiper) to the **Fully CW** position, and repeat above steps **3(i)**, **3(ii)** and **3(iii)**.

6. Turn OFF the DMM multimeter.

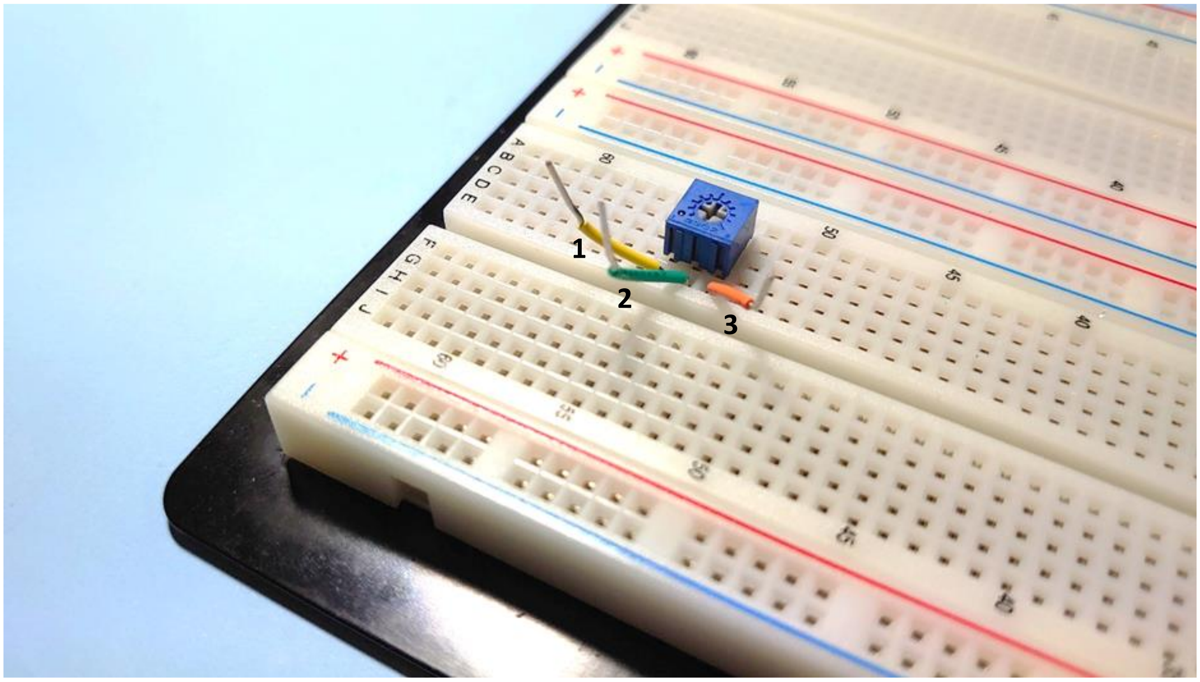


Figure 6.0b: Potentiometer placement on the breadboard

Wiper position	Measured values			Total resistance
	R_{1-2} *variable resistance*	R_{2-3} *variable resistance*	R_{1-3} *fixed resistance*	$R_P = R_{1-3} = R_{1-2} + R_{2-3}$
Fully CCW	0.24 Ω	5.06 KΩ	5.06 KΩ	10.12 KΩ
Half Way	2.55 KΩ	2.5 KΩ	5.03 KΩ	10.08 KΩ
Fully CW	5.06 KΩ	0.24 Ω	5.06 KΩ	10.12 KΩ

Table 5.0: Measured values of the Potentiometer

6.0 POST-LAB: OBSERVATIONS AND ANALYSIS OF RESULTS

(a) Resistance Measurements

Workspace

From your observation of the results in **Table 3.0**:

- Was the actual value of each of the three **10** k**Ω** resistors within the expected maximum-minimum resistance range? Stated differently, was the "**Dev.%**" of each resistor within its specified ± 5% tolerance? If not, what might be the reason(s) for the discrepancy?

Yes, the measured values were within the tolerated range.

- Even though the same **10** kΩ color-code valued resistors were selected, the actual measured resistances of these three **10** kΩ resistors are not expected to be same. Is that what you have observed? If so, why should that be the case?

I observed that the 3 resistors had different measured values. This could be the result of unique flaws in the material from manufacturing/usage, that decrease the resistor's measured value.

(b) Voltage-Current Measurements

Workspace

With reference to the "Simple DC Circuit" in **Figure 2.0**:

Explain how your measurement results in **Table 4.0** compare to the corresponding theoretical values in **Table 2.0** and MultiSIM simulation values in **Table 2.2**? Explain possible causes of any discrepancies.

The values are nearly identical. The slight difference is likely due flaws in the physical components.

Did the experimental results in **Table 4.0** confirm the Kirchhoff's Current Law expression: $I_1 = I_2 + I_3$ provided earlier? Explain?

Yes. The equation holds true when the measured values are used.

From your measurement results in **Table 4.0**, calculate the resistance value of R_1 (= V_1/I_1), R_2 (=V_2/I_2) and R_3 (= V_3/I_3) => R_1 = 9.79 kΩ, R_2 = 9.8 kΩ, and R_3 = 9.8 kΩ

Are these values expected to be the same as the corresponding *directly* measured resistance values in **Table 3.0**.? Why?

$R_1 = \frac{V_1}{I_1} = \frac{9.99\text{V}}{1.02\text{mA}} = 9.79\text{ k}\Omega$

$R_2 = \frac{V_2}{I_2} = \frac{5\text{V}}{0.51\text{mA}} = 9.8\text{ k}\Omega$

$R_3 = \frac{V_3}{I_3} = \frac{5\text{V}}{0.51\text{mA}} = 9.8\text{ k}\Omega$

These values should equal the measured values, since the measured volt & current was used.

Workspace

With reference to the "Simple Voltage Divider" circuit in **Figure 2.1**:

Explain how your measurement results in **Table 4.1** compare to the corresponding theoretical values in **Table 2.1** and MultiSIM simulation values in **Table 2.3**? Explain possible causes of any discrepancies.

The values are extremely close. Discrepancies could be a result of issues in the physical circuit.

Use your Pre-Lab 4(c) analysis to recalculate a more reasonable theoretical prediction of the expected V_0 and **I** values, taking into consideration the use of a standard value of **5.1** kΩ resistor (instead of the **5.0** kΩ) for R_Y. How do these recalculated values compare to the measured ones in **Table 4.1**? Explain.

$$V_0 = \left[\frac{R_Y}{R_Y+R_X}\right]V_1 \qquad i = \frac{V_1}{R_X+R_Y}$$

$$= \left[\frac{5k\Omega}{5.1k\Omega + 10k\Omega}\right]15V \qquad = \frac{15V}{10k\Omega+5.1k\Omega}$$

$$V_0 = 5.066V \qquad i = 0.9933\ mA$$

These values are nearly the same.

(c) Potentiometer – as a Variable Resistor

Workspace

From your observation of the measurement results in **Table 5.0**, was the operation of a potentiometer verified? Explain.

Yes. Resistance on every connection changed as the knob was turned.

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, MultiSIM results, 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, analysis and MultiSIM simulation circuits/plots.*

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.
- Your completed handwritten pages of **Section 4.0** should be scanned (via a scanner or phone images), together with the required MultiSIM images. **Note:** *MultiSIM results must be generated using the Department's licensed version of MultiSIM, and the captured screenshots should show your name (at the center-top) and the timestamp (at the bottom-right corner of your screen).*
- Collate and create a .pdf or .docx file of the above, and upload it via D2L within 24 hours after the lab session is done. (only for Prelab # 1) For example, if you have lab on May 16, Monday 8 AM to 12 PM, then the prelab # 1 will be due by May 17,Tuesday12:00 pm. No e-mail or lab submissions.

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

In-Lab Work (**Section 5.0**) and **Post-Lab Work** (**Section 6.0**) that include in-lab results, handwritten analysis and observations are to be completed and submitted individually. The lab report should be completed and submitted **within 24 hours after the lab session** is done. For example, if you have a lab on May 3, Tuesday 12 - 2 pm, then the in-lab and post-lab submission will be due by May 4, Wednesday 2:00 pm. No e-mail or late submissions.

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.
- 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, and upload it via D2L (https://my.ryerson.ca/). Late submissions will not be graded.