EXPERIMENT 2
Electrical Measurements: Breadboarding, NI ELVIS, Multimeter, Lab Reporting

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The objectives of this experiment are to:

- Become familiar with the equipment that will be used in the lab for the rest of the semester such as the NI ELVIS board and multimeter
- Learn how to measure and record resistances, voltages, and currents
- Learn how to write a good lab report

I. Introduction

This lab experiment is designed to introduce you to the primary lab equipment to be used throughout the semester, how to make basic electronic measurements, and highlight various features of a technical lab report. The key to a good lab report is the proper use of figures, tables, lists, calculations, and having just the right amount of explanation, not too little or too much. Record and explain your experiment processes and results in a way that an Electrical Engineer without access to the lab manual could understand what you did.

This lab manual will vary somewhat from future ones: future lab manuals will not be as clear on what and, especially, how to include things in your lab report. Take note on how and when this lab manual instructs you to record data, figures, calculations, etc. You will need to apply these principles yourself on future labs.

Throughout this semester (and, most likely, your entire career), you will use a multimeter to measure various electrical quantities. It is called a "multimeter" because it is a combination of *multiple* meters: an ohmmeter, voltmeter, ammeter, etc. This lab uses the digital multimeter (DMM) shown in Figure 1. It has the following components:

1) Display
2) POWER Button
3) Function/Range Dial
4) Socket for measuring Capacitance
5) Protective Holster
6) HOLD Button
7) Input Jack for Thermocouple
8) Socket for Measuring Transistor Beta
9) Input Jacks (or "Input Terminals")

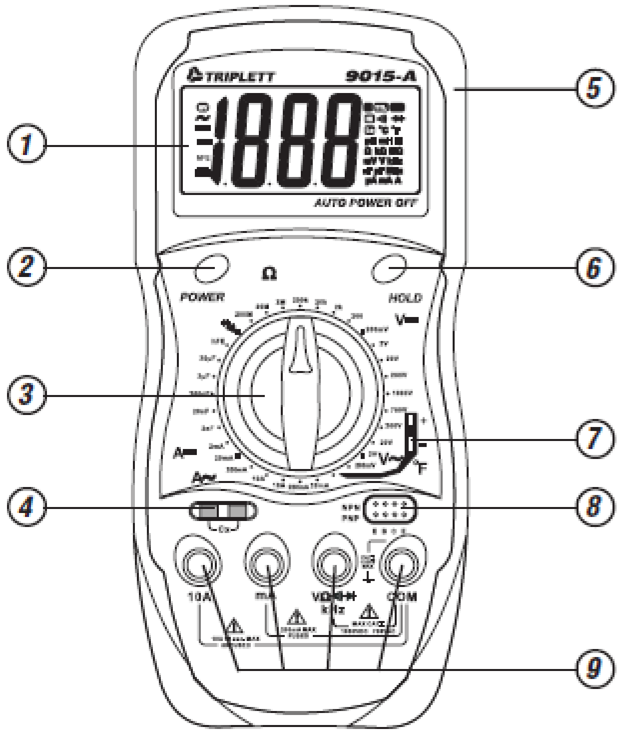

Figure 1: DMM Features

The input terminals are where you connect your probes for making measurements. The far right terminal is the “neutral” or “common” or “reference” terminal. You will always have one of your probes, as a convention, the black probe, connected to this input terminal. The input terminal 2nd to the right is used if you are measuring voltage and resistance. NEVER ATTEMPT TO MEASURE CURRENT WITH A PROBE CONNECTED TO THE “VΩ” INPUT TERMINAL. The input terminal 2nd to the left is used if you are measuring relatively small currents. It is fused to protect the meter from being damaged in case you disregard the following rule: NEVER ATTEMPT TO MEASURE VOLTAGE OR RESISTANCE WITH A PROBE CONNECTED TO THE “mA” INPUT TERMINAL. If you do, you will probably not see or hear anything, but you will have blown a fuse. Points will be deducted from you lab report for every fuse you blow. The far left terminal is for measuring larger currents. It is unfused and, therefore, you will never use this terminal this semester.

The center dial is used to select whether one wants to measure resistance, DC voltage, AC voltage, DC current, AC current, etc. The dial also lets you choose which significant digits to display. Each number represents the largest possible value to be displayed. If you are measuring a quantity that exceeds the max number, a “1.” will display on the screen, indicating an overflow. In this instance, you ought to turn the dial to a higher number. As a principle, try to set the dial to the number that is immediately higher than the quantity you are measuring (e.g., if you are measuring a resistance that is 3.2 kΩ, you should end up with the dial set to 20k under the resistance section).

II. Lab Exercises

A. Resistance

Resistance Defined

Resistance is the relationship between voltage and current in a conductor. It impedes current flow; i.e., resistance is the reason why, when a voltage is applied to a conductor, there is not infinite current. The relationship is given by one of the forms of Ohm's Law: R=V/I, where R is the resistance, V is the voltage, and I is the current. Resistance is a phenomenon we observe in the real world. We then make things that replicate this phenomenon and call them resistors.

Resistor's Color Code

Manufactured resistors have stripes of color printed on them to identify the intended resistance value of the component by sight. There are usually four colored stripes. The first and second colored stripes indicate the numerical value of the intended resistance, the third stripe is a multiplier, and the fourth stripe is the tolerance. Table 1 shows the values assigned to the colors used in the code. For example, a resistor with the colors brown, black, green, and silver (metallic color always comes last) would have a resistance value within $\pm$10% of 1 MΩ.

$$(10 * 10^5 \text{ with a tolerance of } \pm 10\%)$$

Table 1: Resistor Color Code Values

Color	First Stripe	Second Stripe	Third Stripe	Fourth Stripe
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Grey	8	8	10^8	
White	9	9	10^9	
Gold				$\pm$5%
Silver				$\pm$10%

There should be three resistors at your lab station that you will use throughout this lab. Designate them as follows:

R_1 = orange, orange, brown, gold
R_2 = brown, green, red, gold
R_3 = brown, black, red, gold

Referring to Table 1, determine the theoretical resistance of the three resistors you have been provided and record them in the appropriate column of Table 2. The remaining columns will be filled in as you complete more steps of the experiment.

Table 2: Theoretical Resistance Values

Resistor	Theoretical Resistance	Minimum Resistance	Maximum Resistance	Actual Resistance	Percent Difference
R_1					
R_2					
R_3					

Given that no manufactured resistor is perfect, sometimes we need to know the range of values a given resistor could possibly have. Using the color of the fourth stripe on each resistor, determine the theoretical minimum and maximum resistance values that R_1, R_2, and R_3 could have. Record these values in the appropriate columns of Table 2.

Measuring Resistance

Digital multimeters measure resistance by supplying a constant current and then measuring the voltage drop across the terminals. Ohm's law is then used to calculate the resistance that must exist between the multimeter terminals given the supplied current and measured voltage. This method relies on the fact that the multimeter is supplying ALL of the current through the resistor, so never measure resistance in a circuit with the power on. MAKE SURE YOUR PROBES ARE CONNECTED TO THE CORRECT MULTIMETER INPUT TERMINALS BEFORE MEASURING RESISTANCE.

Hold one of the multimeter's measurement probes in each hand and measure the resistance. The resulting resistance measurement is the resistance of your skin from one hand to the other, across your chest (R_{skin}). The path that the current will take is through your skin, as the resistance provided by the rest of your body (ionized water) is negligible. The actual resistance value that you find will vary greatly depending on how you grip the probes and how sweaty you are. As a result, this measurement will "jump around", so approximate it the best you can.

The multimeter is an open circuit when measuring resistance. This means that the internal resistance when measuring resistance is infinite. Calculate the equivalent resistance of the parallel combination of the theoretical value for R_1, the internal resistance of the multimeter ($\infty\ \Omega$), and the resistance across your chest (R_{skin}). From your result, do you think it is okay to hold some resistors while measuring their individual resistances? Why or why not? Include your calculations and your answer to this question in your lab report.

Using a multimeter, measure the actual resistance values of R_1, R_2, and R_3. Record these measured values in the appropriate column of Table 2.

The formula for percent difference between an expected value and a measured value is:

$$\%diff = \left(\frac{expected - measured}{expected}\right) \times 100\%$$

Using this formula, determine the percent difference between the theoretical and measured resistance values of R_1, R_2, and R_3. Record your results in the final column of Table 2. Remember, your tables are simply summaries of your results. Any calculations or other explanations should also be included.

Breadboarding with Resistors

A breadboard is a plastic block with an array of holes which are electrically connected to one another on the underside of the block. Breadboards are useful for building electronic circuits quickly and easily for testing purposes. In this experiment, we will use a breadboard and the three resistors you have already measured to create a resistive circuit with an equivalent resistance.

In order to build circuits on your breadboard, you need to know how the holes on the breadboard are connected. As is shown in Figure 2, the long, vertical rows on the edges of the breadboard are connected internally, and the shorter, horizontal rows are connected internally. In the center of each breadboard, there is a trench which separates the horizontal rows.

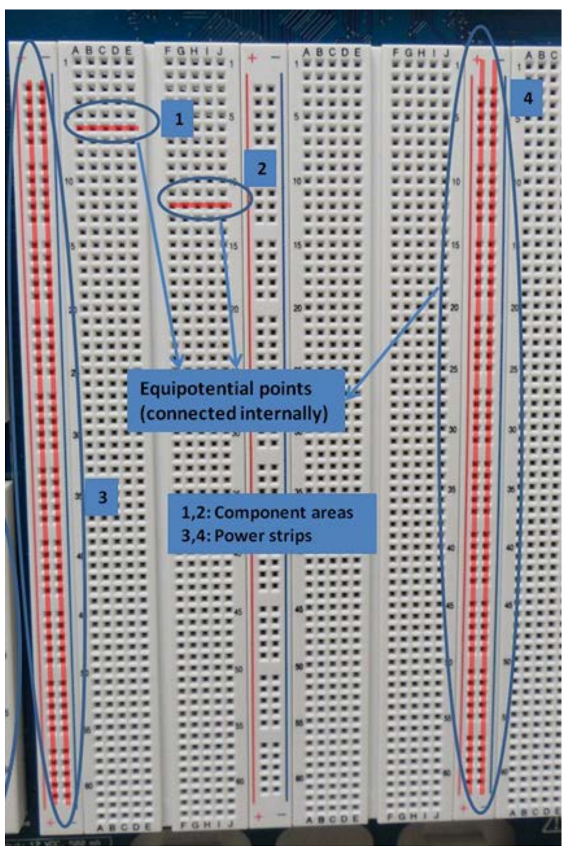

Figure 2: Breadboard Internal Connections

Connect R_2 and R_3 in parallel on your breadboard as shown in Figure 3. Hint: when breadboarding a simple circuit, try to arrange components so they resemble the schematic. Measure the resistance of the parallel combination (R_{eq}) and record your result in the appropriate cell of Table 3.

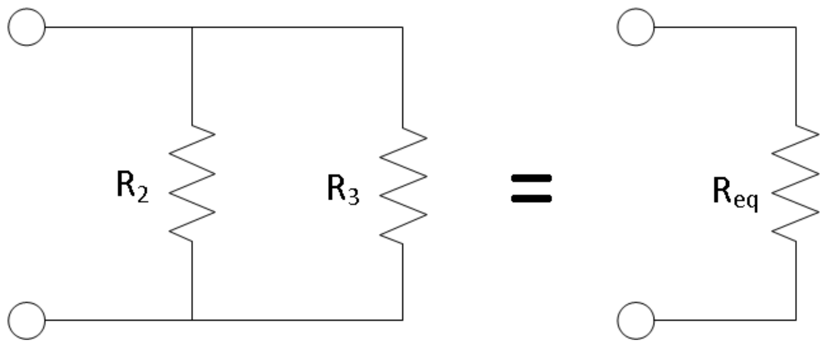

Figure 3: R2 and R3 in Parallel

Table 3: Combination Equivalent Resistance

Resistor	Measured Resistance	Calculated Resistance
R_{eq}		
R_{tot}		

Using the measured values you recorded in Table 2, calculate the theoretical equivalent resistance for the parallel combination of R_2 and R_3 (R_{eq}). Record your result in the appropriate cell of Table 3.

Notice that you usually cannot directly measure the resistance of a particular resistor once it is connected to a circuit. You will always measure an equivalent resistance including it and other resistances; e.g., you cannot directly measure R_3 without removing it from the circuit.

Add R_1 in series with the other two resistors as in shown in Figure 4. Measure the new total resistance (R_{tot}) and record your result in the appropriate cell of Table 3. Again, using the measured resistance values recorded in Table 2, calculate the theoretical R_{tot} and record your result in the last cell of Table 3.

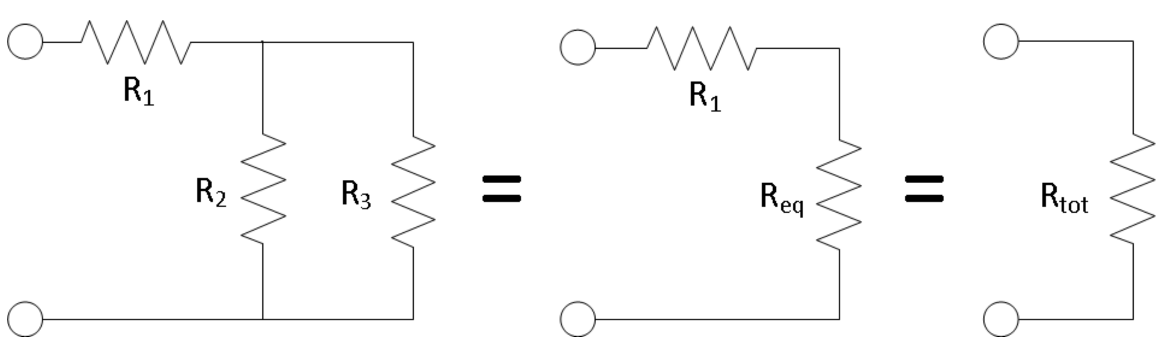

Figure 4: R1 in Series with R2 and R3

For Your Report

Include the results that you recorded in Tables 2 and 3. Be sure to label the tables properly and describe the information shown in the tables using a paragraph. Ensure all calculations are clearly recorded.

Using those results, answer the following questions:
Did the measured resistance values for R_1, R_2, and R_3 fall within the theoretical maximum and minimum values for those resistors?
From your results, do the formulas for parallel and series resistance appear to be accurate?
Further, do not forget to answer the question regarding Rskin from page 4.

B. Voltage

Definition

Voltage is defined as the difference in electric potential between two points. This means that there is never just a voltage at a point in a circuit. There is always a reference to which that point is compared. Often all nodes are referenced to the same node; in that case, we conveniently call that node, "ground".

Measuring Voltage

When a multimeter measures voltage, the leads are placed in parallel with the component you are trying to measure. In order for no current to suddenly flow through the multimeter instead of the component in question, the multimeter acts as an open circuit. Therefore, when measuring voltage, the internal resistance of a multimeter is theoretically infinite. Realistically, the internal resistance is merely very, very large. MAKE SURE YOUR PROBES ARE CONNECTED TO THE CORRECT MULTIMETER INPUT TERMINALS BEFORE MEASURING VOLTAGE.

Turn on your ELVIS board. Using a multimeter, connect the voltage probe to the 15 V power supply pin on the ELVIS board. Connect the neutral probe on the multimeter to the ground pin on the ELVIS board. You are set up to measure the voltage output of the 15 V power supply. Remember that you can only have voltage as a difference between two points. That is why the neutral probe is connected to ground. See Figure 5 for an example of how to make this voltage measurement. Record your measured result in Table 4.

Table 4: Measured Voltages

Voltage	**Value**
Unloaded Source	
Vs	
V_1	
Veq	
Va	
Vb	

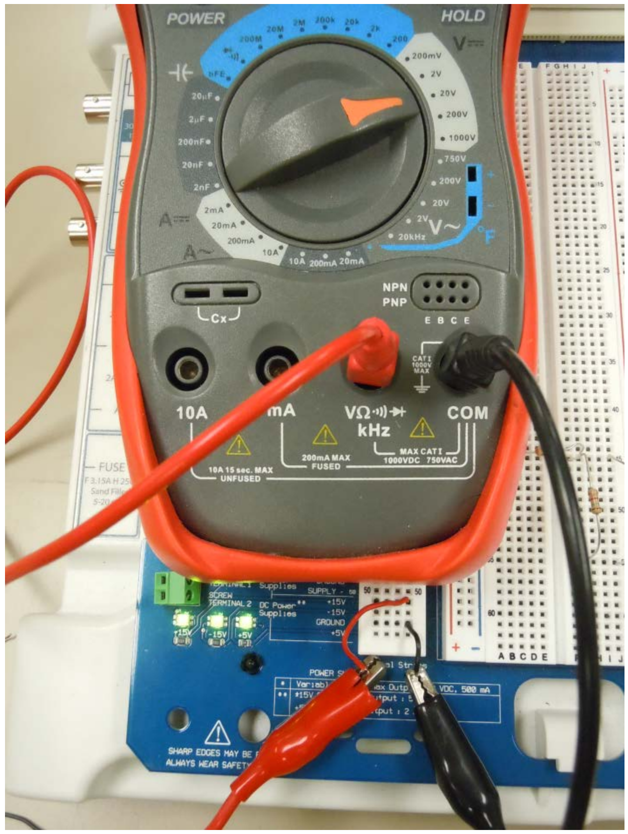

Figure 5: Measuring Vs

Connect the 15 V power supply pin and the ground pin to the breadboard left-most power strip (or "power rails") as identified in Figure 2. BE SURE THAT YOU DO NOT CONNECT THE POWER SUPPLY DIRECTLY TO THE GROUND PIN as this will cause a short circuit across the power supply (remember, I = V/R; you do not want an R that is close to zero). Use your multimeter to verify that the correct voltage appears on the power rails.

Now connect the power rails to the resistor network you constructed for part A and measure the voltage between the two power rails again and record your measured value in Table 4 in the cell labeled "Vs." Did the voltage change? It probably did not change much, but there will be some measurable change. Remember that a voltage source which supplies the same voltage no matter what is connected to it is called an ideal voltage source. Ideal sources do not exist. However, we can make things that are close.

A simple model of a non-ideal source is a series combination of an ideal source and a resistor. This model is shown in Figure 6. When you measure the non-ideal source with nothing connected, there is no current, and therefore, no voltage drop across internal resistance. Once this source is supplying current, there will be a voltage drop across its internal resistance, so the output voltage will change. This is called the "loading effect." The ELVIS board has built-in controllers to limit this voltage change. It is much closer to an ideal source than, say, a dc battery.

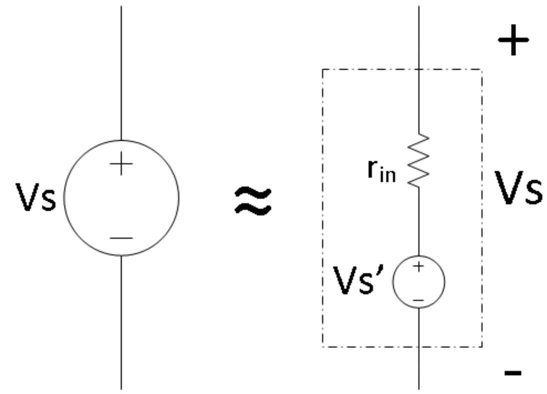

Figure 6: Non-Ideal Voltage Source Model

Measure V_1 and Veq as defined in Figure 7. Record your measurements in the appropriate cells of Table 4. Using the values for Vs, V_1, and Veq that you have recorded, verify KVL.

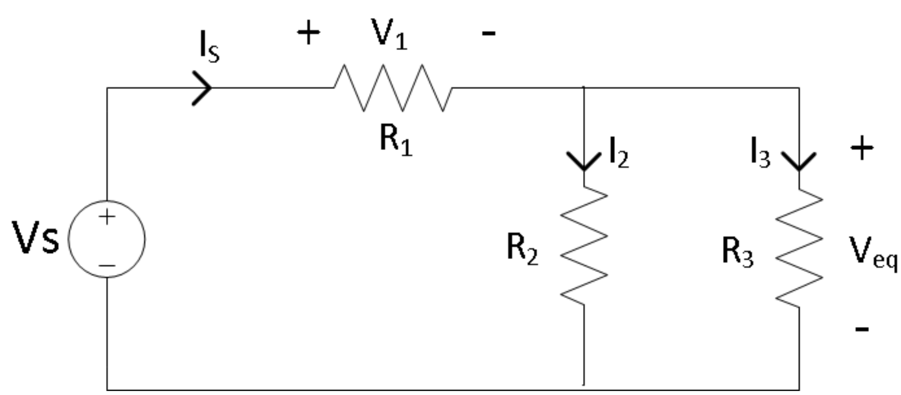

Figure 7: Voltage Measurement Schematic #1

Measure Va and Vb as defined in Figure 8. Record your measurements in the appropriate cells of Table 4. Using the values for Vs, Va, and Vb that you have recorded, verify KVL.

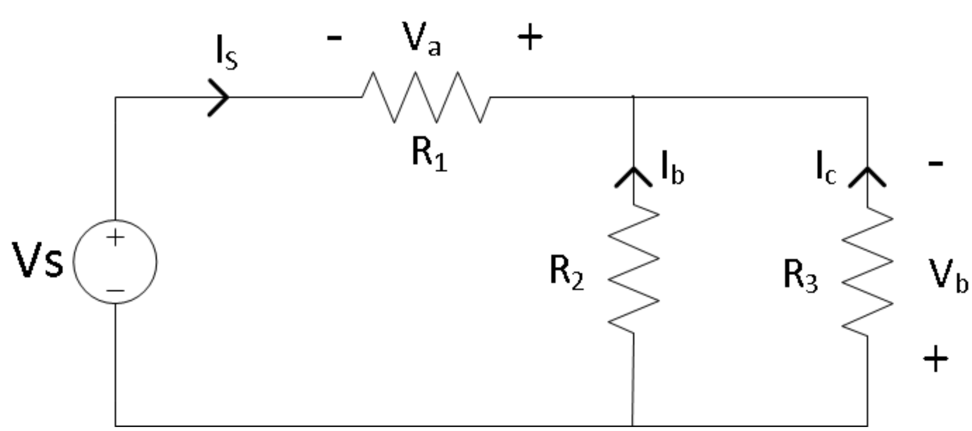

Figure 8: Voltage Measurement Schematic #2

Note that you should have found that Va ≈ -V_1 and Vb ≈ -Veq. Which set of measurements and calculations are correct? Explain.

For Your Report

Include the results that you recorded in Table 4. You also need to copy and refer to Figures 7 and 8 in your report to explain the meaning of the voltages in Table 4. Be sure to label the figures and tables properly and describe the information shown using one or more brief paragraphs. Ensure all calculations associated with both verifications of KVL are clearly recorded.

C. Current

Definition

Electric current is defined as the flow of electric charge through a conductor. In a resistive element, current is generated by the application of voltage across the element.

Measuring Current

When a multimeter measures current, the leads are placed in series with the component you are trying to measure so that all of the current which passes through the component in question will also pass through the multimeter. In order for the current to remain the same with or without the multimeter in the circuit, the multimeter acts as a short circuit. Therefore, when measuring current, the internal resistance of a multimeter is theoretically zero. Realistically, the internal resistance is merely very, very small. This means that, if connected improperly, there is no resistance to impede the flow of current. Large currents will quickly damage both the multimeter and the circuit you are testing. ALWAYS MAKE SURE YOUR PROBES ARE CONNECTED TO THE CORRECT MULTIMETER INPUT TERMINALS BEFORE MEASURING CURRENT.

To measure current in a circuit, you must place the multimeter in series with the element through which you want to measure the current. Because of this, you will actually have to disconnect or "break" your circuit somewhere. A useful rule of thumb is to disconnect one lead of whatever component through which the current in question is flowing. You then reconnect the component through the multimeter probes, allowing the current to flow into the “mA” input terminal, as designated by the current definition on the schematic. Remember, ALWAYS TURN OFF THE POWER TO YOUR CIRCUIT BEFORE MAKING ANY WIRING CHANGES.

Using your multimeter, measure Is, I_2, and I_3 as defined in Figure 7. Figure 9 shows an example of how to measure Is. Record these values in the appropriate cells of Table 5. Using Is, I_2, and I_3, verify KCL. Then measure Ib and Ic as defined in Figure 8. Record these values in the remaining cells of Table 4. Using Is, Ib, and Ic, verify KCL.

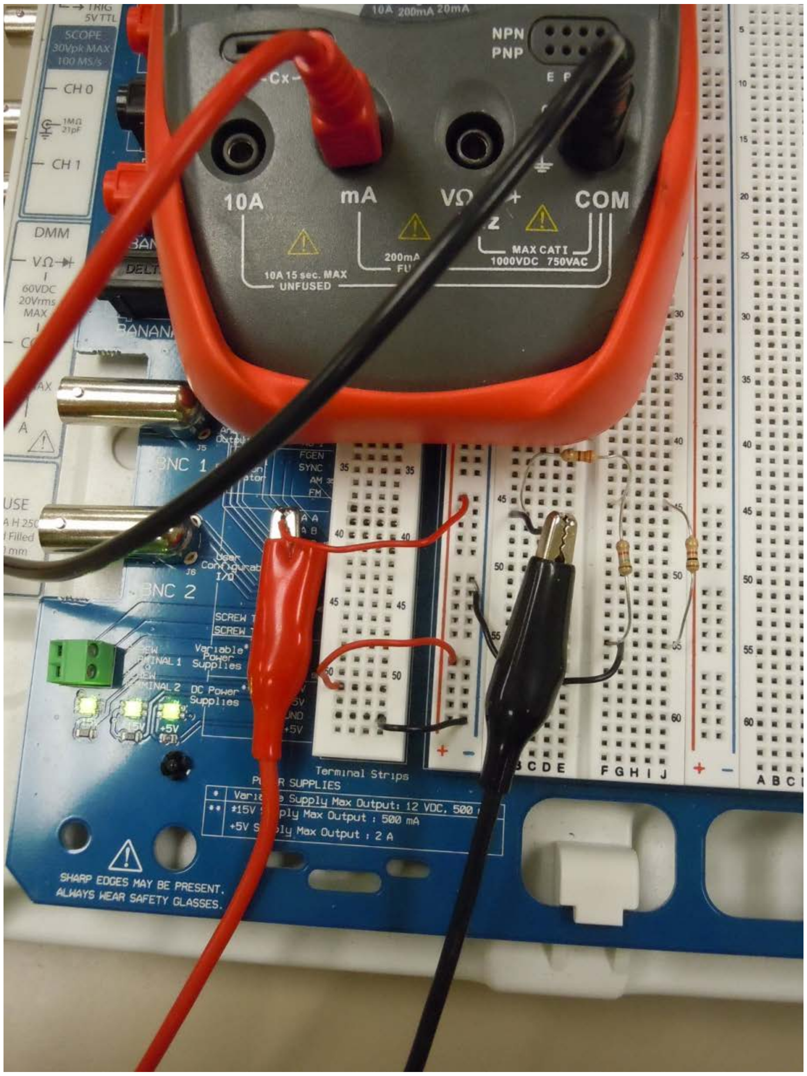

Figure 9: An Example of Measuring Is

Table 5: Measured Currents

Is	I_2	I_3	Ib	Ic

Note that you should have found that Ib = $-I_2$ and Ic = $-I_3$. Which set of measurements and calculations is correct? Explain.

For Your Report

Include the results that you recorded in Table 5. Remember to include and reference Figures 7 and 8 in your report to help explain the meaning of the currents in Table 5. Be sure to label the table properly, describe the information shown using a brief paragraph, and include all calculations associated with both verifications of KCL.

Using your measured values for V_1, Vb, Veq, R_1, R_2, and R_3, verify Ohm's Law for every current recorded in Table 5. (Note that there are two ways to verify Is.)

D. Verify Voltage and Current Division

Voltage Division

Voltage division is a mathematical shortcut for determining the voltage across a single resistor that is in series with other resistors when the voltage across the total series combination is known. Given the circuit in Figure 10,

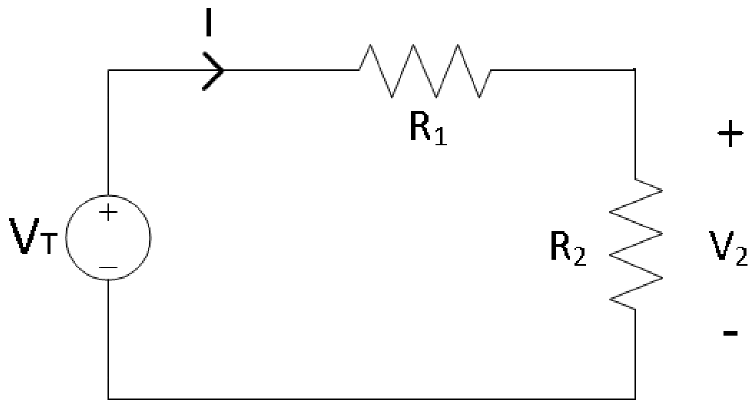

Figure 10: Example Circuit for Voltage Division

one can write:

$$I = \frac{V_T}{R_1 + R_2}$$

Since the current flowing through any part of the series combination is the same at all parts of the series combination, the current in the above equation must be the current flowing through the resistance in question. In order to find the voltage across this resistor, the current must be multiplied by the resistance in question. If we are interested in the voltage across R_2:

$$V_2 = IR_2 = \frac{V_T R_2}{R_1 + R_2}$$

Notice that this can be extended to any number of resistors in series.

Using the measured values for Vs, R_1, and R_{eq} that you have previously recorded, calculate V_1 and Veq as defined in Figure 7 with the voltage division equation. Do these results resemble your previously measured values for V_1 and Veq?

Current Division

Current division is a mathematical shortcut for determining the current through a single resistor that is in parallel with another resistor when the voltage across the parallel combination is known. For the circuit in Figure 11,

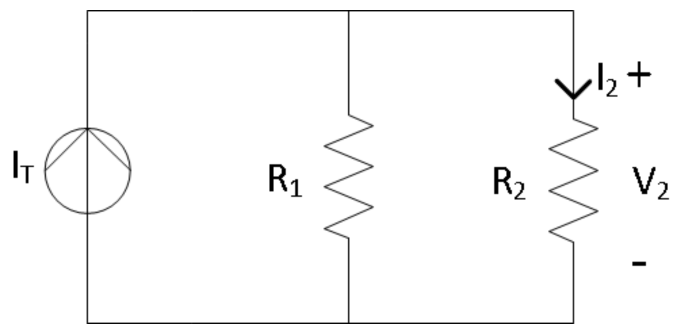

Figure 11: Example Circuit for Current Division

one can calculate the voltage across the parallel resistors, V_2, by combing R_1 and R_2 in parallel and multiplying by I_T:

$$V_2 = I_T\left(\frac{R_1R_2}{R_1+R_2}\right)$$

Since the voltage across the parallel combination is also the voltage across each individual resistance in the parallel combination, the desired current can be found by dividing the voltage across the parallel resistors by the resistor in question:

$$I_2 = \frac{V_2}{R_2} = \frac{I_T\left(\frac{R_1R_2}{R_1+R_2}\right)}{R_2} = I_T\left(\frac{R_1}{R_1+R_2}\right)$$

Notice that this <u>cannot</u> be extended to any number of resistors in parallel because of how resistors combine in parallel.

Using the measured values for Is, R_2, and R_3 that you have previously recorded, calculate I_2 and I_3 as defined in Figure 7 with the current division equation. Do these results resemble your previously measured values for I_2 and I_3?

For Your Report

Include all calculations performed in this section. Be sure to explain what values you are using along the way. Include and refer to figures as necessary.