EEE 117L Laboratory – Network Analysis
Lab #3: Calculation of the Internal Resistance of the Ammeter and Voltmeter

Lab Day and Time: Wednesday 1:30pm - 4:30pm

Group Number: #03

Group Members: (Last Name, First Name)

Member #1: Algador, Vigomar Kim

Member #2: Chan, Casey

Member #3: Trihn, Bon

General Instructions:

Theoretical analyses and making predictions regarding the behavior of circuits is one of the most crucial, yet underrated and often ignored, jobs among young engineers. This includes the ability to carry out hand calculations in the abstract and running circuit simulations. You may use any technique of circuit analysis in order to obtain the solutions, but you must clearly state which technique of analysis you are using. You must show all work to receive credit. No credit will be given for answers with no justification. Your work should be neat and organized. If I can't follow your work or read your writing, then you will not get full credit. You may attach extra sheets if you need more space to show all your work. Remember that the ability to clearly explain what you are doing to other engineers is one of the most important skills you need to develop.

Total Score: /100

Work Breakdown Structure: It is important that every group member do their share of the work in these labs. Remember that you will receive no credit for the lab worksheet if you did not contribute. Write in the Table provided below, which group member(s) contributed to the solution of each problem in the lab worksheet. Also remember that only on lab worksheet per group will be turned in to Canvas. If there was any group member that did not contribute, then write their name in the space provided below.

Problem Number	Group member(s) that worked on the problem.
Part IA	Algador, Vigomar Kim
Part IB	Trinh, Bon
Part IC	Chan, Chasey
Part IIA	Algador, Vigomar Kim
Part IIB	Trinh, Bon Chan, Chasey
Part IIIA	Algador, Vigomar Kim
Part IIIB	Trinh, Bon
Part IIIC	Chan, Chasey
Part IVA	Algador, Vigomar Kim
Part IVB	Trinh, Bon Chan, Chasey
Part V	Algador, Vigomar Kim Trinh, Bon Chan, Chasey

General Theory:

Every component in the circuits we will build and test in this lab is associated with an ideal model that is an approximation as to how the actual component will operate in a real circuit. This includes components such as resistors, capacitors, operational amplifiers, and even wires and your breadboard. Often times we make assumptions regarding our circuit components that will simplify our ability to analyze the circuits mathematically. For example, we often ignore the capacitive effects that the breadboards have on the circuits that we assemble on them. Depending upon the circuit in question, our models and assumptions may or may not be adequate to accurately predict the actual behavior of the circuit in question.

When it comes to measuring currents in a circuit, it is assumed that the internal resistance of the measurement device (usually an ammeter) is ideally zero. Similarly, when it comes to measuring voltages accurately, it is assumed that the internal resistance of the device used to measure said voltage (usually a voltmeter or an oscilloscope) is infinite. These are clearly ideal internal resistances that cannot be realized by actual physical devices. Depending on the quality of the device, these ideals internal resistances may be approached, but will never be reached. Depending upon the circuit being tested, these non-ideal internal resistances might need to be taken into consideration or may be safely ignored.

Both ammeters and voltmeters have internal resistances that can be experimentally determined and taken into account if need be. This lab is meant to show you the limitations of equipment you have at your disposal to make current and voltage measurements. Depending upon the circuit being tested, these limitations may or may not play a significant role in the difference between how the circuit actually behaves versus how you predict it should behave.

Part I: Ideal Ammeter (Ammeter has zero internal resistance) Total Score: /20

A. Theoretical Calculation: Score: /5

Given the circuit shown in Figure 1 below, choose R to be the resistor whose value is closest to 10 Ω. Set the voltage of the source, V_s, to be 1.0 V and assume the internal resistance of the ammeter is zero, $R_{int} = 0\ \Omega$. Calculate the value of the current i_m. Actually measure the value of R and use the measured value in the hand calculations and simulations.

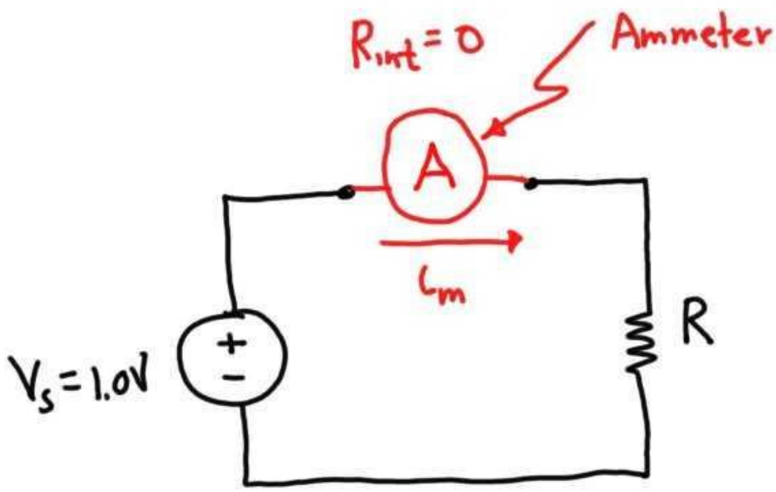


Figure 1. Ideal Ammeter Current Calculation

$$i_m = \frac{V_s}{R} = \frac{1.0\ V}{11.015\ \Omega} = 0.091\ \text{A} \cong 91\ \text{mA}$$

Answers:

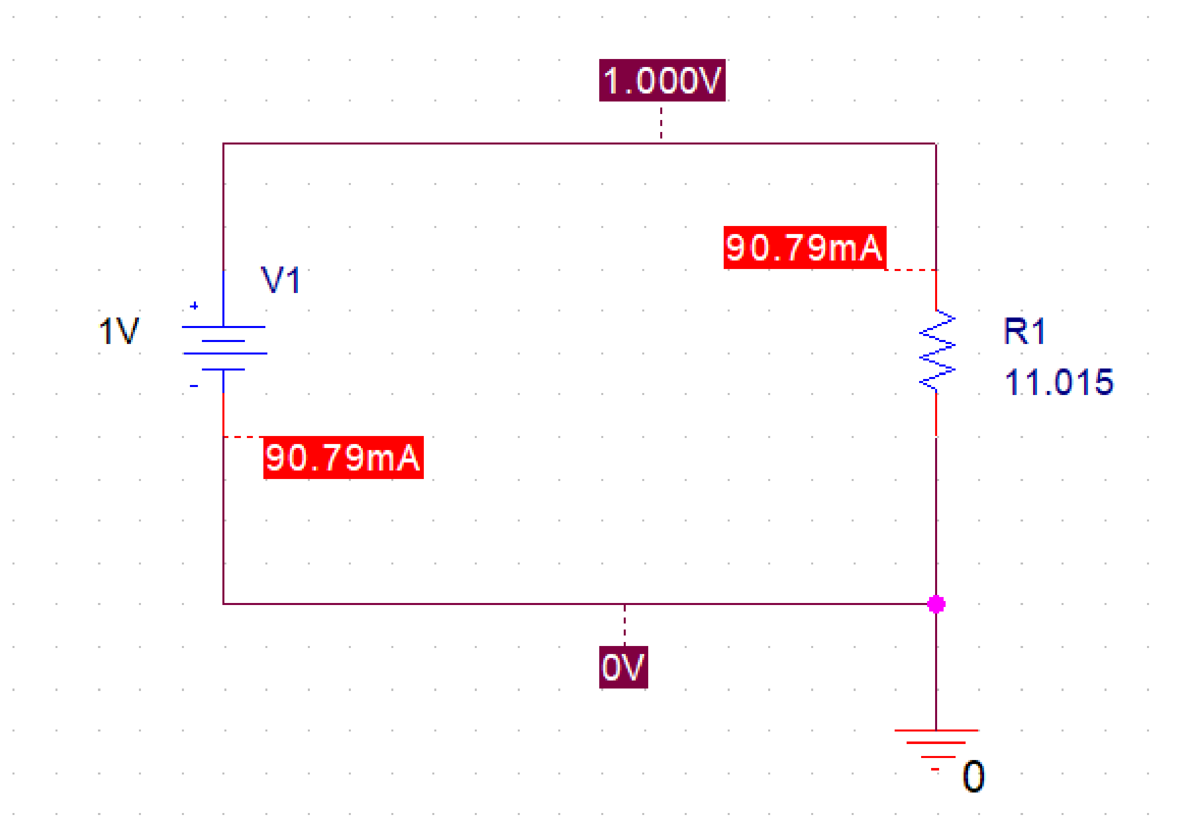
$R = 11.015\ \Omega$

$i_m = 0.091\ \text{A} \cong 91\ \text{mA}$

B. Simulation: Score: /5

Using PSpice run a bias point simulation to determine the value of i_m. Using the snipping tool, show the results of the simulation below. How does the theoretical value of i_m compare to the simulated value of i_m? Record your results in Table 1 below.

Simulation Result:



	Theoretical Value	Simulated Value	% Difference
Current, i_m	91 mA	90.79 mA	0.23%

Table 1. Simulation Result for an Ideal Ammeter

C. Data Collection and Analysis: Score: /10

Actually build the circuit shown in Figure 1 on your breadboard and use your ammeter to measure the current i_m. Now compare your measured value for i_m to the theoretical value predicted in part A above. Express the difference as a percent difference. Record your results in Table 2 below.

	Theoretical Value	Measured Value	% Difference
Current, i_m	91 mA	60.1 mA	33.94%

Table 2. Ideal Ammeter Data

Do you believe this percent difference is acceptable? Why or why not? Explain.

- The percentage difference is unacceptable. When we did the theoretical calculation, it was under the assumption that the internal resistance of the ammeter is zero, $R_{int} = 0\ \Omega$.

Part II: Real Ammeter (Calculating the internal resistance of the ammeter)   Total Score: /25

A. Theoretical Calculation: Score: /10

Given the circuit shown in Figure 2 below, use any technique of circuit analysis to verify the following equation:

$$V_s = \left(R_{int} + R\right)i_m \qquad (1)$$

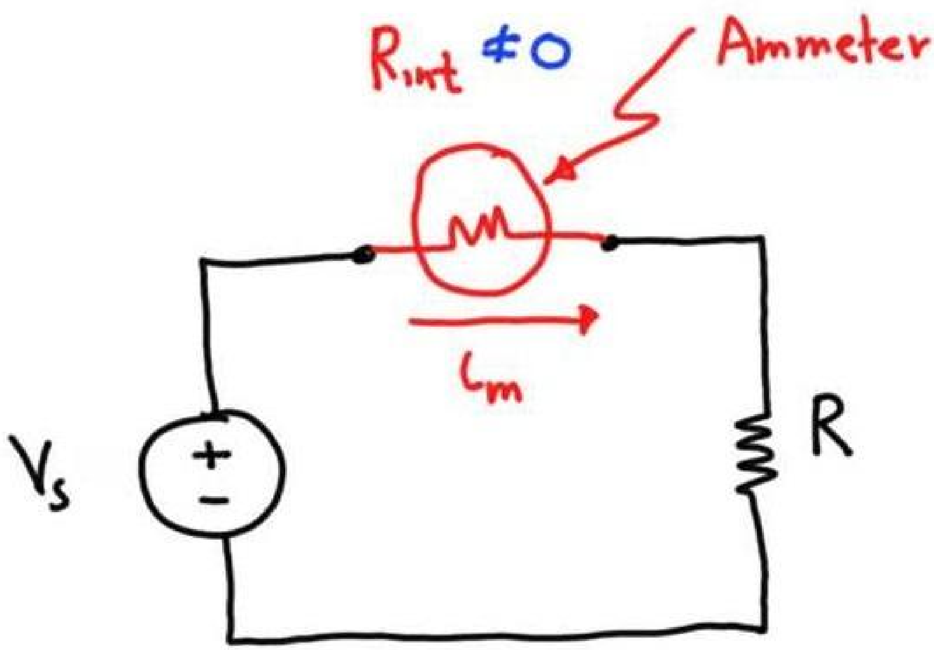


Figure 2. Ammeter with Internal Resistance

By using the KVL:

$$-V_s + i_m R_{int} + i_m R = 0$$

$$V_s = i_m R_{int} + i_m R$$

$$V_s = (R_{int} + R)i_m$$

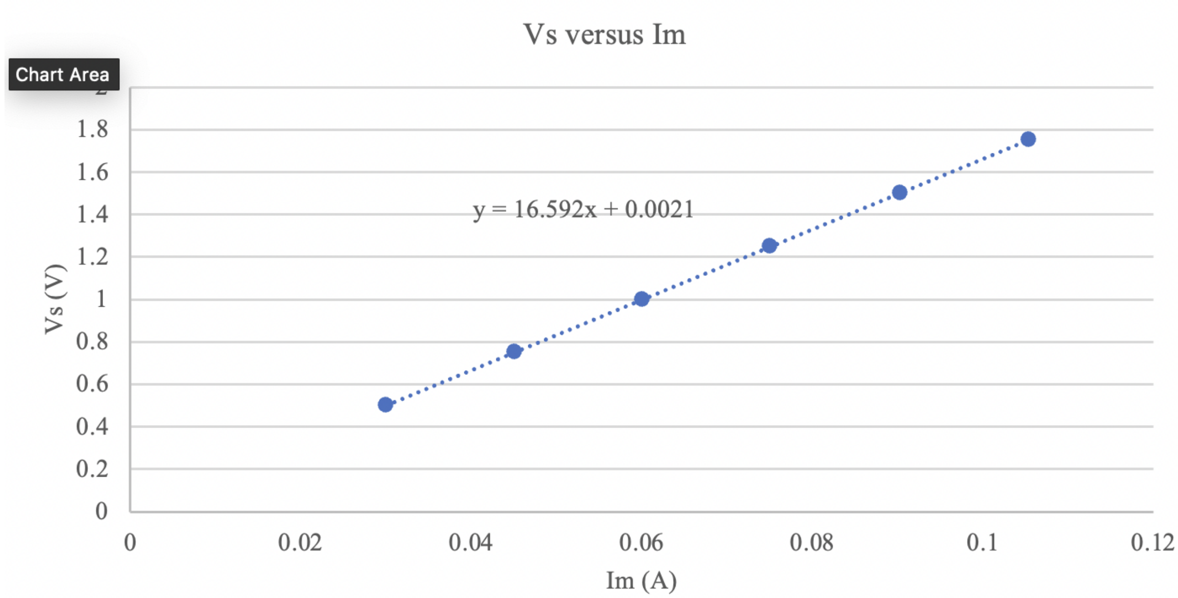
B. Data Collection and Analysis: Score: /15

Build the circuit shown in Figure 2 above. Vary the voltage provided by the source, V_s, from 0.5V up to 2.0V in increments of 0.25V and measure how the current i_m changes. Record these values in Table 3, shown below.

Source Voltage, V_s (V)	Current (mA)	Current (A)
2	173.5	0.1735
1.75	105.4	0.1054
1.5	90.3	0.0903
1.25	75.1	0.0751
1	60.1	0.0601
0.75	45.1	0.0451
0.5	30.05	0.03005

Table 3. Ammeter with Internal Resistance

Using MS Excel (or a similar program) plot V_s versus i_m and add a linear trendline along with the equation of the line to linearize the data. Use the snipping tool to include a picture of the data, plot, and trendline and include it below.



V_s (V)	im (A)
2	0.1735
1.75	0.1054
1.5	0.0903
1.25	0.0751
1	0.0601
0.75	0.0451
0.5	0.03005

Based on equation (1) and the value of the slope of the trendline, calculate the value of the internal resistance of the ammeter, R_{int}. Is this internal resistance relatively low? Pay particular attention to the units and order of magnitude. How does the internal resistance of the ammeter compare to the value of the resistor R in the circuit?

We observed that the equation: $V_s = \left(R_{int} + R\right)i_m$ is similar format to $y = mx + b$ shown in the plot. We used it as equivalent to the relationship $m = R_{int} + R$.

$$m = R_{int} + R$$

$$16.592 = R_{int} + 11.015$$

$$R_{int} = 5.577$$

- The internal resistance of the ammeter is 5.557, which is relatively low. The resistor in the circuit is 11.015. The internal resistance is about half of the resistor in the circuit.

Part III: Ideal Voltmeter (Voltmeter has infinite internal resistance) Total Score: /20

A. Theoretical Calculation: Score: /5

Given the circuit shown in Figure 3 below, choose R_1 and R_2 to be the resistors whose values are closest to $10.0\ M\Omega$. Set the voltage of the source, V_s, to be 5.0V and assume the internal resistance of the voltmeter is infinite, $R_{int} \rightarrow \infty\ \Omega$. Calculate the value of the voltage V_m. Actually measure the values of R_1 and R_2 and use the measured values in the hand calculations and simulations.

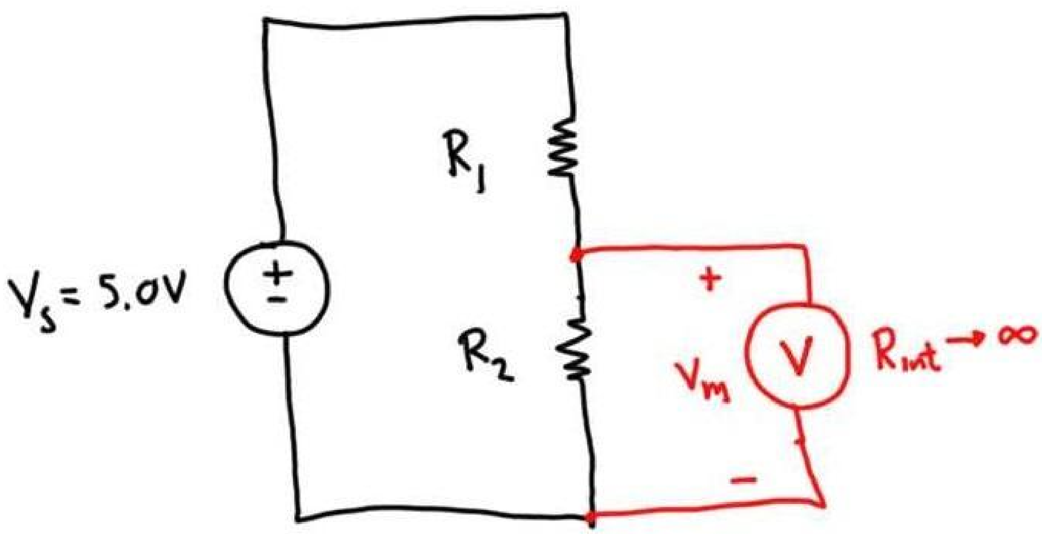


Figure 3. Ideal Voltmeter Voltage Calculation

Using Voltage Divider:

$$V_m = \frac{V_s R_2}{R_1 + R_2} = \frac{(5.0\ V)(10.30\ M\Omega)}{10.17\ M\Omega + 10.30\ M\Omega} = 2.516\ \text{V}$$

Answers:

$R_1 = 10.17\ M\Omega$

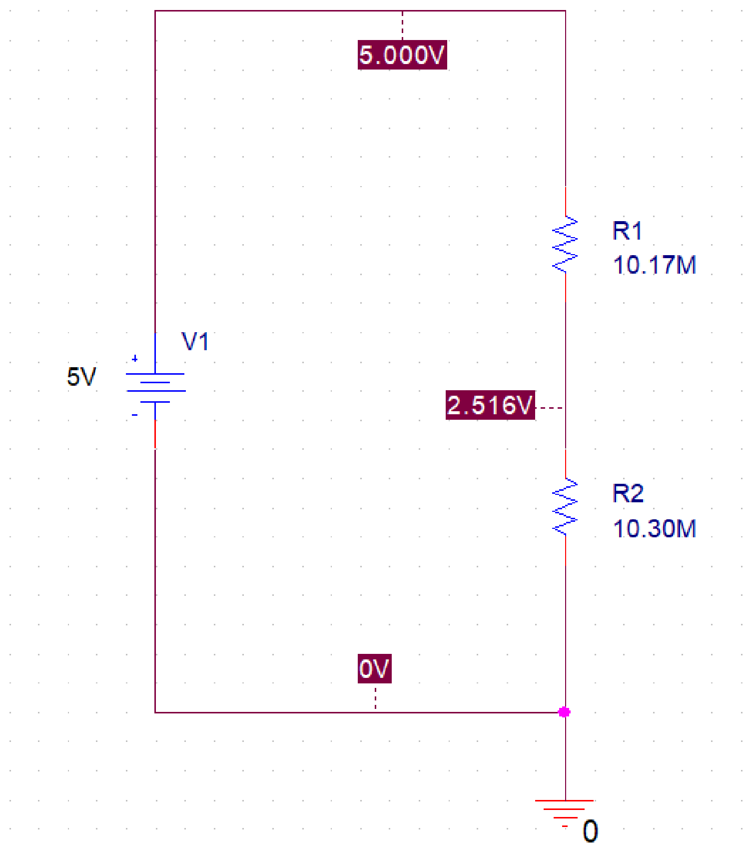
$R_2 = 10.30\ M\Omega$

$V_m = 2.516$ V

B. Simulation: Score: /5

Using PSpice run a bias point simulation to determine the value of V_m. Using the snipping tool, show the results of the simulation below. How does the theoretical value of V_m compare to the simulated value of V_m? Record your results in Table 4 below.

Simulation Result:



	Theoretical Value	Simulated Value	% Difference
Voltage, V_m	2.516 V	2.516 V	0 %

Table 4. Simulation Result for an Ideal Voltmeter

C. Data Collection and Analysis: Score: /10

Actually build the circuit shown in Figure 3 on your breadboard and use your voltmeter to measure the voltage V_m. Now compare your measured value for V_m to the theoretical value predicted in part A above. Express the difference as a percent difference. Record your results in Table 5 below.

	Theoretical Value	Measured Value	% Difference
Voltage, V_m	2.516 V	1.66 V	34.02 %

Table 5. Ideal Voltmeter Data

Do you believe this percent difference is acceptable? Why or why not? Explain.

- The percentage difference is unacceptable. From what we did in theoretical calculations, we assumed that the internal resistance of the voltmeter is infinite, $R_{int} \to \infty\ \Omega$. However, measuring the actual current gives a different value, the internal resistance is not zero.

Part IV: Real Voltmeter (Calculating the internal resistance of the voltmeter) Total Score: /25

A. Theoretical Calculation: Score: /10

Given the circuit shown in Figure 2 below, use any technique of circuit analysis to verify the following equation:

$$V_s = \left(1 + \frac{R_1}{R_2} + \frac{R_1}{R_{int}}\right)V_m \qquad (2)$$

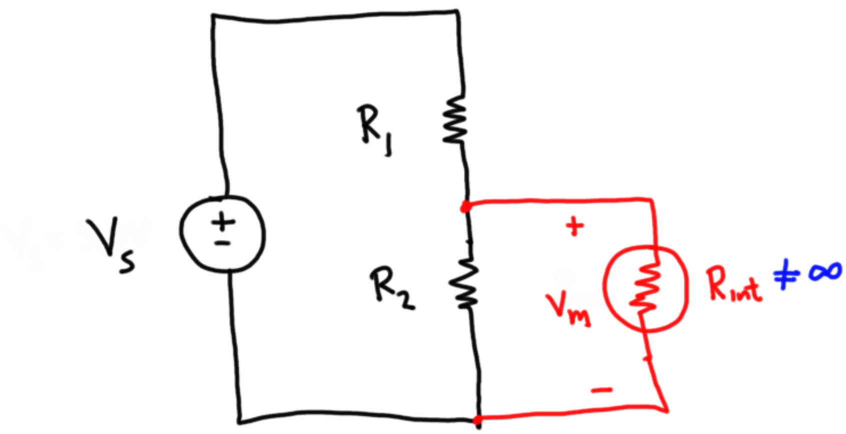


Figure 4. Voltmeter with Internal Resistance

Using Voltage Divider:

$$V_m = \frac{V_s\,(R_2 \,//\, R_{int})}{R_1 + (R_2 \,//\, R_{int})} \qquad R_2 \,//\, R_{int} = \frac{R_2 R_{int}}{R_2 + R_{int}}$$

$$V_s = \frac{[R_1 + (R_2 \,//\, R_{int})]V_m}{(R_2 \,//\, R_{int})} = \frac{[R_1 + \frac{R_2 R_{int}}{R_2 + R_{int}}]V_m}{\frac{R_2 R_{int}}{R_2 + R_{int}}}$$

$$= \frac{\left(\frac{R_1(R_2 + R_{int}) + R_2 R_{int}}{R_2 + R_{int}}\right)(R_2 + R_{int})V_m}{R_2 R_{int}}$$

$$= \left(\frac{R_1 R_2 + R_1 R_{int} + R_2 R_{int}}{R_2 R_{int}}\right)V_m = \left(\frac{R_1}{R_{int}} + \frac{R_1}{R_2} + 1\right)V_m$$

$$V_s = \left(1 + \frac{R_1}{R_2} + \frac{R_1}{R_{int}}\right)V_m$$

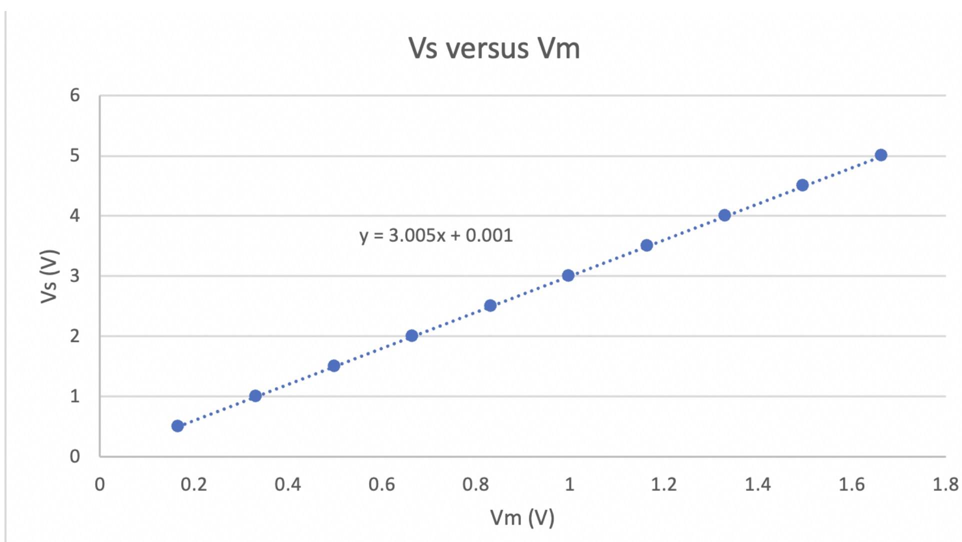
B. Data Collection and Analysis: Score: /15

Build the circuit shown in Figure 4 above. Vary the voltage provided by the source, V_s, from 0.5V up to 5.0V in increments of 0.5V and measure how the voltage V_m changes. Record these values in Table 6, shown below.

Source Voltage, V_s (V)	V_m (V)
5.0	1.663
4.5	1.497
4.0	1.331
3.5	1.165
3.0	0.998
2.5	0.832
2.0	0.665
1.5	0.499
1.0	0.332
0.5	0.166

Table 6. Voltmeter with Internal Resistance Data

Using MS Excel (or a similar program) plot V_s versus V_m and add a linear trendline along with the equation of the line to linearize the data. Use the snipping tool to include a picture of the data, plot, and trendline and include it below.



Based on equation (2) and the value of the slope of the trendline, calculate the value of the internal resistance of the voltmeter, R_{int}. Is this internal resistance high? Pay particular attention to the units and order of magnitude. How does the internal resistance of the voltmeter compare to the value of the resistors R_1 and R_2 in the circuit? Consult the manual for your particular DMM and look up the "input impedance".

Based on our observation, we used the relationship of equation (2) to the y = mx + b. As a result, we form a new equation $m = 1 + \frac{R_1}{R_2} + \frac{R_1}{R_{int}}$. With this new equation, we place the slope from the plot, m = 3.005, and the resistance, R_1 and R_2, to get the internal resistance R_{int} shown below.

$$3.005 = 1 + \frac{10.17\ M}{10.30\ M} + \frac{10.17\ M}{R_{int}}$$

$$R_{int} = 9.994\ M \cong 10\ M\Omega$$

- The internal resistance is high. Comparing the internal resistance to R_1 and R_2, the values are close. The value of R_1 is $10.17\ M\Omega$ and R_2 is 10.30 $M\Omega$.

Part V: Conclusion Total Score: /10

Explain as a group in a few paragraphs what you learned from this lab and these experiments. Some of the topics that you should cover are, for example: What did you find easy to do? What challenges did you encounter? Was it difficult to assemble the circuits? Did your experimental results match with your predictions with both the hand calculations and simulations? If there were differences, were they acceptable? Did you find it difficult to work in a group? Write the conclusion as if you were writing an English essay. This is an important portion of the lab, so make sure to do a good and thorough job.

The first circuit we were working with was a circuit with an ammeter. Since we did not have a 10 Ω resistor, we used a resistor whose value was the closest, which was an 11 Ω resistor. We simulated the circuit on PSpice and the simulated values and the theoretical values were within an acceptable range. There was a 0.23% difference between the two values. We had to build the circuit on the breadboard and measure current with an ammeter. Assembling the circuit was not difficult. When measuring the current, we knew we were not getting the correct measurements, but we did not know why. We learned that instead of connecting all the test probes to the resistors, we had to connect two of the test probes together. The measured value of the current was vastly different from the theoretical value. There was a 33.94% difference. This percent difference is not acceptable. This occurred because we are assuming the internal resistance of the ammeter is zero. We varied the voltage from 0.5V to 2.0V in increments of 0.25V and graphed the changes in i_m. At voltage 2, the value for i_m was vastly different from the other data points, so we removed it from the graph because it is an outlier.

The second circuit we were working with was a circuit with a voltmeter. We simulated the circuit on PSpice. The theoretical value we calculated by hand, matched with the simulated value. Then we had to build the circuit on the breadboard and measure the voltage with a voltmeter and compare it with the theoretical value. This circuit was also easy to build, since we learned how to build parallel circuits from lab 2. There was a 34.02% difference between the two values which is not acceptable. This occurred because we are assuming that the internal resistance of the voltmeter is infinite. We then varied the voltage from 0.5V to 5.0V in increments of 0.5V and graphed the changes in V_m. All in all, we found it easy to work in a group because we were able to communicate clearly and help each other complete each part of the lab.