THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

SCHOOL OF ENGINEERING AND APPLIED SCIENCE
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
ECE 2110: CIRCUIT THEORY LABORATORY

Experiment #3:
Ohm's Law, Series, Parallel, and Series-Parallel Circuits

EQUIPMENT

Lab Equipment	*Equipment Description*
(1) DC Power Supply	Keysight E36311A Triple Output DC Power Supply
(1) Digital Multimeter (DMM)	Agilent 34460A (DMM)
(1) Breadboard	Prototype Breadboard
(2) Test Leads	Banana to Alligator Lead Set

Table 1 – Equipment List

COMPONENTS

Type	*Value*	*Symbol Name*	*Multisim Part*	*Description*
Resistor	750Ω	R_1	Basic/Resistor	---
Resistor	1.5kΩ	R_2	Basic/Resistor	---
Resistor	3kΩ	R_3	Basic/Resistor	---

Table 2 – Component List

OBJECTIVES

- To understand DC series, parallel, and series-parallel combination circuit
- To connect electronic devices on a breadboard
- To calculate DC voltage across resistors in a DC series circuit
- To measure DC voltage across resistors in a DC series circuit using a DMM
- To calculate DC current through resistors in a DC parallel circuit
- To measure DC current through resistors in a DC parallel circuit using a DMM
- To calculate DC current through resistors in a DC series-parallel combination circuit
- To measure DC current through resistors in a DC series-parallel combination circuit using a DMM
- To calculate the total power dissipated by each resistor in a DC series, parallel, and seriesparallel combination circuit

INTRODUCTION

Ohm's Law

This lab will focus on **Ohm's Law**, one of the most fundamental laws governing electrical circuits. It states that voltage is equal to current multiplied by resistance. For a given current, an increase in resistance will result in a greater voltage. Alternately, for a given voltage, an increase in resistance will produce a decrease in current. As this is a first order linear equation, plotting current versus voltage for a fixed resistance will yield a straight line. The slope of this line is the conductance, and conductance is the reciprocal of resistance.

$$V = IR$$

Equation 1 – Ohm's Law

Resistors in Series

An important concept to understand in any electrical circuit is the difference between **series** and **parallel**. A **series** path is defined by a single loop in which all components are arranged one after the other. The **current is the same** at all points in the loop and may be found by dividing the total voltage by the total resistance. The voltage drops across any resistor may then be found by multiplying that current by the individual resistor value. The equivalent resistance of resistors in series is simply the sum of the resistances (see **Equation 2**).

$$R_{eq} = R_1 + R_2 + \cdots + R_n$$

Equation 2 – Series Equivalent Resistance

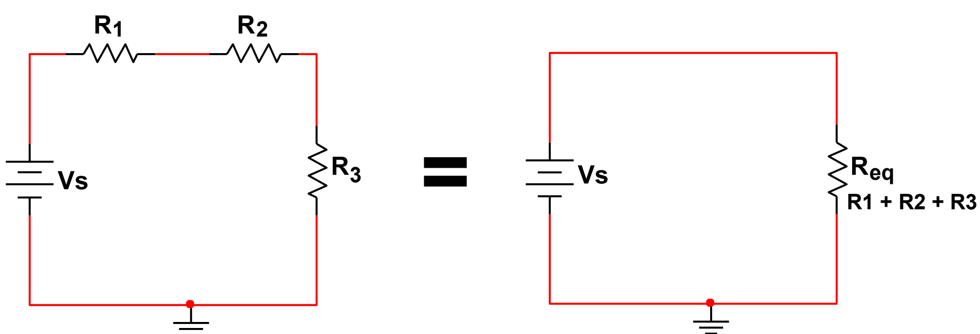

Figure 1 – Example Series Equivalent Resistance

Resistors in Parallel

Resistors in **parallel** share two common nodes. The **voltage** is the **same across all resistors** and will be equal to the applied source voltage. The total supplied current may be found by dividing the voltage source by the equivalent parallel resistance. It may also be found by summing the currents in all of the branches. The current through any resistor branch may be found by dividing the source voltage by the resistor value. The **current is the same** at all points in the loop and may be found by dividing the total voltage by the total resistance. The voltage drops across any resistor may then be found by multiplying that current by the individual resistor value. The equivalent resistance of resistors in parallel can be found by summing the reciprocal of all parallel resistors, then finding the reciprocal of that (see **Equation 3**).

$$R_{eq} = \frac{1}{\frac{1}{R1}+\frac{1}{R2}+\cdots+\frac{1}{Rn}}$$

Equation 3 – Example Parallel Equivalent Resistance

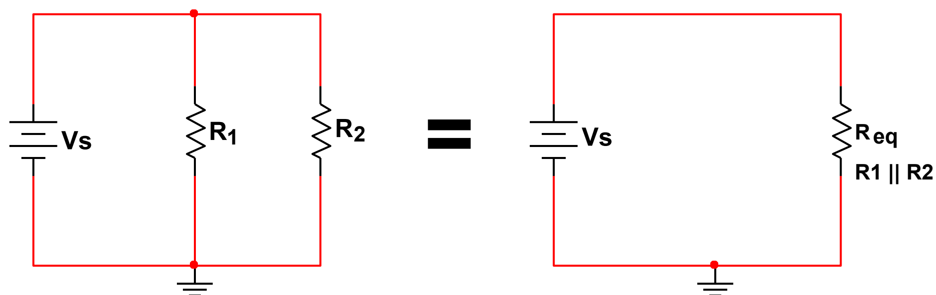

Figure 2 – Parallel Equivalent Resistance

Resistors in Series-Parallel Combination

Most circuits will use some combination of components connected in series and in parallel. Simple **series-parallel circuits** may be viewed as interconnected **series** and **parallel branches**. Each of these branches may be analyzed through basic series and parallel techniques such as the application of voltage divider and current divider rules. It is important to identify the simplest series and parallel connections in order to jump to more complex interconnections.

Measuring Voltage Across a Resistor

A Digital Multimeter (DMM) is a multi-use measurement device that we use in the lab to measure resistance, voltage, and current. The DMM was used in **Experiment #1** to measure the resistance of a resistor. In this lab, you will use the DMM to measure voltage.

Voltage is measured ***across*** an electrical device. **Figure 3** shows a series circuit with two resistors. After building the circuit on a breadboard, if we wish to measure the voltage across resistor R_2, we will do the following using the DMM:

1. **Set** the DMM to measure ***Voltage*** by pressing "**V**" on the DMM front panel.
2. **Set** the DMM to the ***range*** we expect the voltage to be (uV, mV, V, etc.).

   Note: *In general, the **Auto-Range** setting can be used for voltage and resistance. This setting will automatically adjust the DMM to the proper range. However, there is no auto-range functionality available for measuring current.*
3. **Attach** the positive lead coming from the DMM to the positive side of R_2 and the negative lead to the negative side of R_2.
   a. In this way, the DMM is measuring ***ACROSS*** R_2.
4. **Record** the value of the voltage measured on the DMM.

These are the four conceptual steps to measuring voltage. During lab, the exact procedure will be demonstrated and explained. It is expected that you be familiar with these conceptual steps prior to the lab. If you do not understand these steps, be certain to discuss this with the GTA prior to lab.

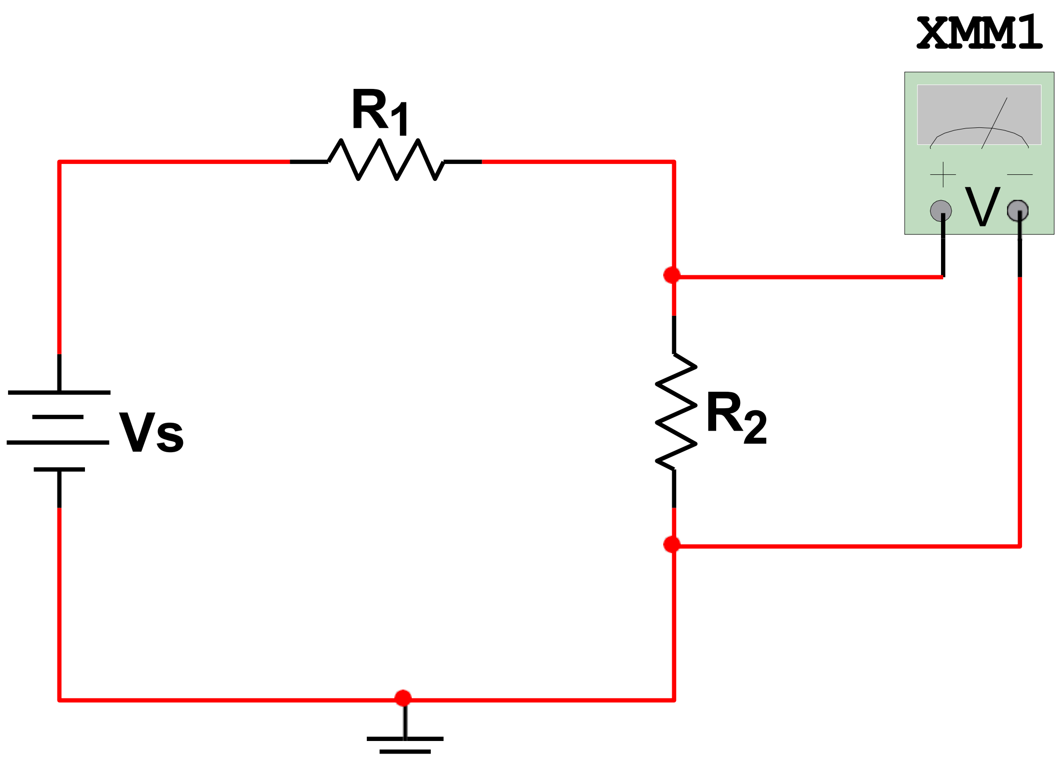

Figure 3 – DMM Measuring Voltage Across R2

Measuring Current Through a Resistor

Current is measured ***through*** an electrical device. It must be measured in an entirely different way than voltage is measured. **Figure 4** shows a circuit with two resistors. After building the circuit on a breadboard, if we wish to measure the current through resistor R_1, we need to BREAK the circuit where we wish to measure the current. We would do the following using the DMM:

1. **Set** the DMM to measure ***Current*** by pressing "**A**" (Amperes) on the DMM front panel.
2. **Set** the meter to the ***range*** we expect the current to be: (uA, mA, etc.).

   Note: *We **cannot** use the **auto-range** setting on the DMM to measure current. The range must be set **manually**. Pressing the auto-range button will set the DMM to measure current through the 10A (white) input.*
3. **Break the circuit** where we wish to measure the current.
   a. In **Figure 4**, we would **disconnect/break** the circuit between resistors R_1 and R_2.
   b. The DMM is then inserted **in series** between R_1 and R_2, allowing the current in the circuit to actually flow **through** the DMM, enabling it to measure the current.

      Note: *Because the DMM is in series, we know the current will be the same as it will be through R_1 and R_2.*
4. **Record** the value of the current measured on the DMM.
   a. This is the value of the current at all points through the entire series circuit.

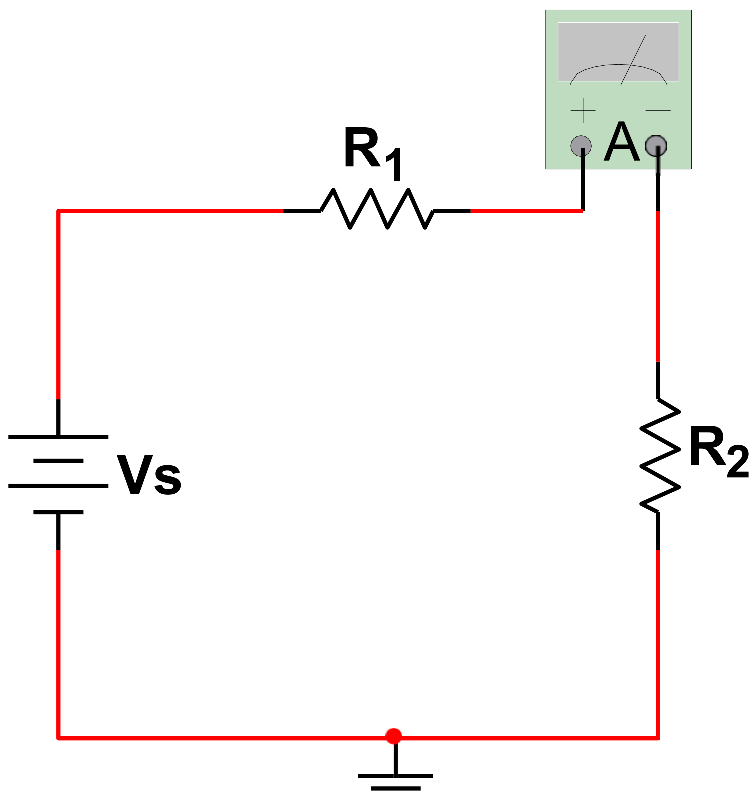

Figure 4 – DMM in Series Measuring Current Through Circuit

PRELAB

Part I – DC Series Circuit

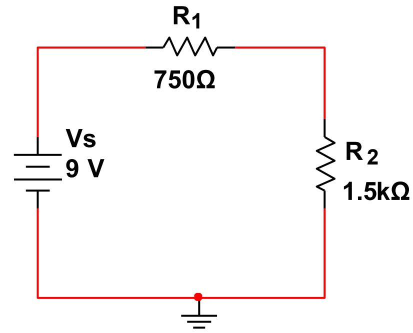

Figure P.1 – DC Series Circuit

Figure P.1 shows a DC circuit that has two resistors R_1 and R_2 connected in series with a DC Voltage Source.

1. **Analyze** the circuit in **Figure P.1**.
2. **Calculate** the nominal (expected) values for the **DC voltage**, **DC current**, and **DC power consumption** of $\mathbf{R_1}$ and $\mathbf{R_2}$ (be sure to **clearly show all calculations**).
3. **Record** your results in **Table 1.1** below.

Part II – DC Parallel Circuit

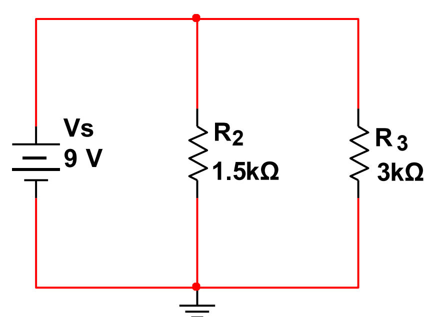

Figure P.2 – DC Parallel Circuit

Figure P.2 shows a DC circuit that has two resistors R_2 and R_3 connected in parallel with a DC Voltage Source.

1. **Analyze** the circuit in **Figure P.2**.
2. **Calculate** the nominal (expected) values for the **DC voltage**, **DC current**, and **power consumption** of $\mathbf{R_2}$ and $\mathbf{R_3}$ (be sure to **clearly show all calculations**).
3. **Record** your results in **Table 2.1** below.

Part III – DC Series-Parallel Combination Circuit

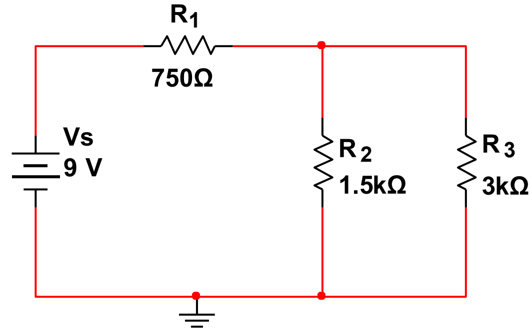

Figure P.3 – DC Series-Parallel Combination Circuit

Many circuits have a combination of series and parallel resistors. **Figure P.3** shows a DC circuit that has two resistors R_2 and R_3 connected in parallel with one another. R_2 and R_3 together are connected in series with resistor R1 and the DC Voltage Source.

1. **Analyze** the circuit in **Figure P.3**.
2. **Calculate** the nominal (expected) values for the **DC voltage**, **DC current**, and **power consumption** of **R_1**, **R_2**, and **R_3** (be sure to **clearly show all calculations**).
3. **Record** your results in **Table 3.1** below.

Part IV – How to Measure Voltage and Current

During the lab, you will build the three circuits you have analyzed in the prelab. You will then measure the **voltage across** and the **current through** each resistor to compare these experimental results to your calculated values. In order to make the measurements, it is **essential** that you know how to connect the measurement equipment to the circuits you will build.

1. **Review** the **Introduction** to today's lab and ensure you are familiar with the proper way to measure **voltage across** and **current through** resistors.

   Note: *It is imperative that you understand that you must change the way your DMM is connected to the circuit* ***before*** *switching between measuring voltage and measuring current. If you attempt to measure current across a resistor, you will pull a dangerous amount of current and likely blow the fuse on the DMM. Setting a* ***current limit*** *on the power supply will at least help to prevent blowing the fuse on the DMM.*
2. **Question:** What is the overload protection (maximum current allowed) for the mA current input on the Keithley 175 DMM? Use the specification sheet for the Keithley 175 to determine the answer.
3. **Question:** Can the auto-range feature of the DMM be used when measuring current? **Explain**.
4. **Redraw** the circuit in **Figure P.3** showing how you would attach the DMM to measure the current through R_2.

LAB

Part I – DC Series Circuit Measurements

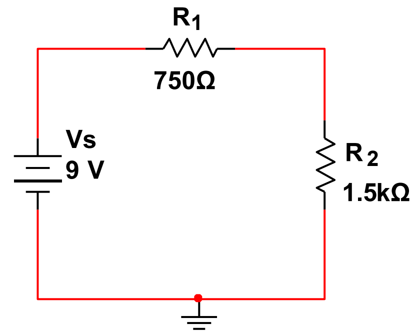

Figure 1.1 – DC Series Circuit

1. **Build** the **DC Series Circuit** in **Figure 1.1** on your breadboard.
2. **Set** the **+25V Output (Channel 2)** on the KEYSIGHT DC power supply to **9V** using the following procedure:
    a. **Do not** connect the power supply to your circuit until it is properly configured.
    b. **Turn on** the power supply.
    c. Press the right arrow button to move the selection over to Channel 2's voltage. **Change** the display value to **9V**.
    d. **Ensure** the output is **OFF** while you connect the circuit.
    e. **Connect** the banana end of the banana to alligator test leads to the **+25V terminals** and the alligator ends to the circuit.
    f. If your circuit configuration is correct, press **Output On/Off** to apply 9V to your circuit.
3. **Measure** the **voltage across** R_1 and R_2 with the DMM and **record** it in **Table 1.1** using the following procedure:
    a. **Turn on** the Keithley 175 DMM.
    b. Ensure the DMM is set to measure **DC** values and not AC.
    c. **Enable auto-range** on the DMM to get the maximum number of significant figures available during measurements.
    d. **Connect** the DMM to your circuit.

    Note: *Make sure the DMM is connected in* ***parallel*** *with the resistor across which you are going to measure the voltage!*

    e. **Record** the voltage in **Table 1.1**.
4. **Measure** the **current through** R_1 and R_2 with the DMM and **record** it in **Table 1.1**.
    a. **Disconnect** the alligator leads from your circuit before adjusting the DMM.
    b. **Press** the **A** button to switch to current mode.
    c. **Break the circuit** at the point you wish to measure current.
    d. **Connect** the DMM in **series** with your circuit as discussed in the **Prelab**.
    e. **Select** the appropriate **current range** by pressing one of the range buttons.

    Note: *As explained in the prelab, there is no auto-range feature for current measurement. You must set it to the correct range based on the expected value from your calculations.* f.

    Record the current in **Table 1.1**.
5. **Calculate** the **power consumption** of R_1 and R_2 from the measured DC voltage and DC current of R_1 and R_2 and **record** it in **Table 1.1**.

6. **Multisim Simulation**:
    a. **Simulate** the circuit from **Figure 1.1** in **Multisim**.
    b. **Find** the **simulated voltage**, **current**, and **power consumption** for each resistor by performing a **DC Operating Point Analysis**.

    Note: *The GTA will give a brief overview of how to setup the circuit in Multisim and perform the necessary analysis. You should be familiar with Multisim from the introductory labs, so this overview will be short and focused on the simulation itself. The analysis can be found under **Simulate → Analyses → DC Operating Point**.*

    c. **Record** your simulated results in **Table 1.1**.
7. **Calculate** the **percent error** between your **calculated** and **measured** results and **record** it in **Table 1.1**. Compare and discuss your results in the analysis section of the lab report.

Electrical Quantity		***Resistor***	
		$\boldsymbol{R_1}$	$\boldsymbol{R_2}$
***Voltage* (V)**	***Calculated***		
	Measured		
	Simulated		
***Current* (mA)**	***Calculated***		
	Measured		
	Simulated		
***Power* (mW)**	***Calculated***		
	Measured		
	Simulated		
***Percent Error* (%)**	***Voltage***		
	Current		
	Power		

Table 1.1 – DC Series Circuit Data

Part II – DC Parallel Circuit Measurements

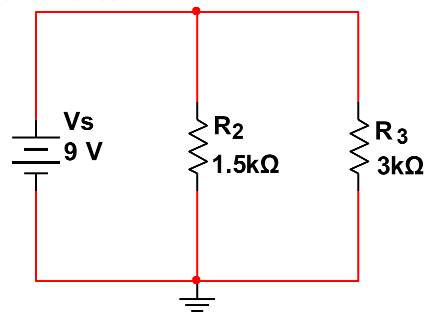

Figure 2.1 – DC Parallel Circuit

1. **Build** the **DC Parallel Circuit** in **Figure 2.1** on your breadboard.
2. **Ensure Channel 2** on the KEYSIGHT DC power supply is still set to **9V**.
3. **Measure** the **voltage across** R_2 and R_3 with the DMM and **record** it in **Table 2.1**.
4. **Measure** the **current through** R_2 and R_3 with the DMM and **record** it in **Table 2.1**.
5. **Calculate** the **power consumption** of R_2 and R_3 from the measured DC voltage and DC current of R_2 and R_3 and **record** it in **Table 2.1**.
6. **Multisim Simulation**:
   a. **Build** the circuit from **Figure 2.1** in **Multisim**.
   b. **Find** the **simulated voltage**, **current**, and **power consumption** for each resistor by performing a **DC Operating Point Analysis**.
   c. **Record** your simulated results in **Table 2.1**.
7. **Calculate** the **percent error** between your **calculated** and **measured** results and **record** it in **Table 2.1**. Compare and discuss your results in the analysis section of the lab report.

Electrical Quantities		***Resistor***	
		R₂	***R₃***
***Voltage* (V)**	***Calculated***		
	Measured		
	Simulated		
***Current* (mA)**	***Calculated***		
	Measured		
	Simulated		
***Power* (mW)**	***Calculated***		
	Measured		
	Simulated		
***Percent Error* (%)**	***Voltage***		
	Current		
	Power		

Table 2.1 – DC Parallel Circuit Data

Part III – DC Series-Parallel Combination Circuit

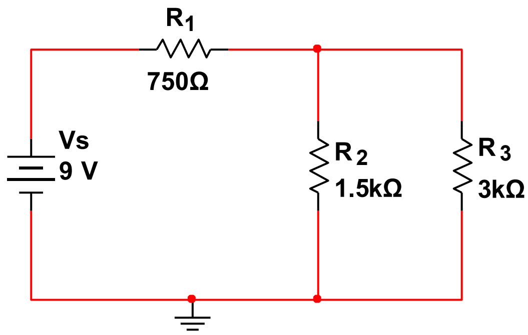

Figure 3.1 – DC Series-Parallel Combination Circuit

1. **Build** the **DC Series-Parallel Circuit** in **Figure 3.1** on your breadboard.
2. **Ensure that Channel 2** on the KEYSIGHT DC power supply is still set to **9V**.
3. **Measure** the **voltage across** R_1, R_2, and R_3 with the DMM and **record** it in **Table 3.1**.
4. **Measure** the **current through** R_1, R_2, and R_3 with the DMM and **record** it in **Table 3.1**.
5. **Calculate** the **power consumption** of R_1, R_2, and R_3 from the measured DC voltage and DC current and **record** it in **Table 3.1**.
6. **Multisim Simulation**:
   a. **Build** the circuit from **Figure 3.1** in **Multisim**.
   b. **Find** the **simulated voltage**, **current**, and **power consumption** for each resistor by performing a **DC Operating Point Analysis**.
   c. **Record** your simulated results in **Table 3.1**.
7. **Calculate** the **percent error** between your **calculated** and **measured** results and **record** it in **Table 3.1**. Compare and discuss your results in the analysis section of the lab report.

Electrical Quantities		***Resistor***		
		R_1	***R_2***	***R_3***
***Voltage* (V)**	***Calculated***			
	Measured			
	Simulated			
***Current* (mA)**	***Calculated***			
	Measured			
	Simulated			
***Power* (mW)**	***Calculated***			
	Measured			
	Simulated			
***Percent Error* (%)**	***Voltage***			
	Current			
	Power			

Table 3.1 – DC Series-Parallel Combination Circuit Data

POST-LAB ANALYSIS

1. **Analyze** and **interpret** the data collected in **each** of the Data Tables throughout the lab. **Explain** any interesting pieces of data, outliers, or important considerations.
2. **Describe** the relationship between the total voltage and current in the whole circuit and the voltage across and current through every resistor in each part of the lab.
    a. **Part I – DC Series Circuit**
        i. Is the total voltage across R_1 and R_2 equal to the 9V source? Why or why not?
        ii. Are the currents flowing through R_1 and R_2 equal? Why or why not?
    b. **Part II – DC Parallel Circuit**
        i. What is the total current through the whole circuit? What are the currents through R_2 and R_3? What is the relationship between the total current and the currents flowing through each resistor?
        ii. What are voltages across R_2 and R_3? Are they equal? Why or why not?
    c. **Part III – DC Series-Parallel Combination Circuit**
        i. What is the mathematical relationship of the currents through R_1, R_2, and R_3?
        ii. What is the mathematical relationship of the voltages across R_1, R_2, and R_3?
3. **Compare** the **calculated** (nominal) results with the **measured** results in **Table 1.1**, **Table 2.1**, and **Table 3.1**. Be sure to complete the **percent error** section for each table and **analyze** the error. **Explain** any possible reasons for the error.