Pre-Lab 2

Carefully read the entirety of Lab 2, then answer the following questions. Attach a separate sheet of paper, if necessary, to show all work and calculations.

1. Explain the difference between a short circuit and an open circuit.

2. Why can short circuits be dangerous?

3. Are all short circuits dangerous? Why or why not?

4. When using 1/4 W resistors, what is the smallest single resistor value that can be used given a supply of...
   (a) ... 6 V?

   (b) ... 8 V?

   (c) ... 10 V?

   (d) ... 12 V?

5. Assume that you have access to all possible values of 1/4 W resistors. You need to use them to create an equivalent resistance of 50 Ω with a voltage source of 5 V. How can you accomplish this without burning out any resistors?

Lab 2: Ohm's Law and Kirchhoff's Circuit Laws

Ohm's law and Kirchhoff's circuit laws are two very powerful tools that can be used to analyze and design analog circuits. Ohm's law gives a relationship between voltage, current, and resistance. Kirchhoff's circuit laws can be used to determine the voltage and current at various parts in a circuit.

For lab resources and information, go to the following URL or scan the QR code. doctor-pasquale.com/circuit-analysis-lab-2

2.1 Series and Parallel Circuits

Circuit components can be wired together in different ways. Depending on how components are connected at nodes (a point where two or more circuit elements meet), they can be said to be either series or parallel. (Note: many circuits are not purely series or purely parallel but may contain elements of both configurations. Some circuits are neither. This section discusses the two specific sets of circuits that are purely series or purely parallel.)

2.1.1 Series Circuits

Circuit elements are said to be connected in series when they all exist within a single branch. There is only one path connecting each circuit component together, so electrons must travel through each and every one. In a circuit composed of a source and series resistors, current must flow through all of the resistors. Therefore, when resistors are connected in series, the equivalent resistance of the circuit goes up, as described by equation 2.1.

$$R_{EQ} = \sum_i R_i \tag{2.1}$$

2.1.2 Parallel Circuits

Circuit elements are said to be connected in parallel when they connect at both nodes (which causes each element to be within its own branch). This creates multiple branches for electrons to travel through. Therefore, when resistors are connected in parallel, the equivalent resistance of the circuit goes down, as described by equation 2.2.

$$\frac{1}{R_{EQ}} = \sum_i \frac{1}{R_i} \tag{2.2}$$

Circuit 1: With the resistors that are available to you, design a series circuit that has an equivalent resistance of 5,400 Ω. More than one resistor must be used. All resistors must be connected in series. Draw the circuit diagram. Build the circuit, then demonstrate its functionality to your instructor to receive a stamp.

Instructor Stamp: ______

Circuit 2: With the resistors that are available to you, design a series circuit that has an equivalent resistance of 195 kΩ. More than one resistor must be used. All resistors must be connected in series. Draw the circuit diagram. Build the circuit, then demonstrate its functionality to your instructor to receive a stamp.

Instructor Stamp: ______

Circuit 3: With the resistors that are available to you, design a parallel circuit that has an equivalent resistance of 250 Ω. More than one resistor must be used. All resistors must be connected in parallel. Draw the circuit diagram. Build the circuit, then demonstrate its functionality to your instructor to receive a stamp.

Instructor Stamp: ______

Circuit 4: With the resistors that are available to you, design a parallel circuit that has an equivalent resistance of 330 Ω. More than one resistor must be used. All resistors must be connected in parallel. Draw the circuit diagram. Build the circuit, then demonstrate its functionality to your instructor to receive a stamp.

Instructor Stamp: ______

2.2 Ohm's Law

Ohm's describes the relationship between voltage and current in a resistor. This relationship is defined by equation 2.3.

$$V = IR \tag{2.3}$$

The power consumed by a resistor can be determined by solving the equation for power ($P = IV$) simultaneously with Ohm's law. Equations 2.4 and 2.5 are used to determine the power consumed by a resistor if only voltage or current are known along with the value of the resistor.

$$P = \frac{V^2}{R} \tag{2.4}$$

$$P = I^2 R \tag{2.5}$$

It is important to note that resistors are rated with a particular power level. Exceeding this amount of power in a resistor will cause it to melt. Most of the resistors used in this class are 1/4 W resistors. Circuits must therefore be designed not to exceed 1/4 W on any individual resistor!

2.2.1 Short Circuits

Ideally, wires are highly conducting and have an effective resistance of 0 Ω. Because their resistance is 0, if you were to measure the voltage drop over a wire, it would be 0 V.

Short circuits can be dangerous. If a voltage source is directly connected at both nodes with a wire, as shown in figure 2.1, the effective resistance of the circuit is 0, causing the current $I \to \infty$. All of this current flows through the wire until it melts or a fuse blows in the power supply. For this reason it is imperative that the exposed contacts of red (wires that are reserved for connections to high potential) and black (wires that are reserved for connections to low potential) wires never touch each other! Furthermore, because the internal resistance of an ammeter is close to zero, this dangerous short circuit will occur if current is measured in parallel with a voltage source.

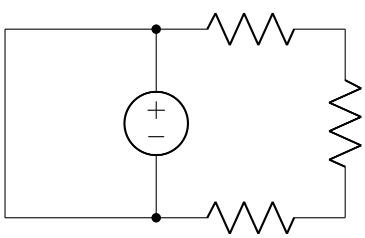

Figure 2.1: A short circuit with a low-resistance path, which will cause overheating.

Not all short circuits are inherently dangerous, however. It is possible to short out an individual circuit element while still maintaining a high enough resistance within a circuit to prevent any of the other elements from melting. An example circuit diagram of this scenario is shown in figure 2.2. Only a single resistor in figure 2.2 is shorted out; assuming that the two other resistors are high enough to withstand the current flowing through the circuit, everything will be fine. While this circuit might not cause catastrophic damage to the breadboard, power supply, and other circuit components, it still may lead to undesirable side effects (incorrect voltage and current values throughout the circuit) if the short circuit isn't part of the circuit design.

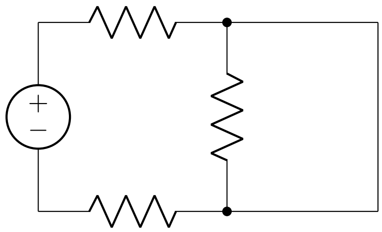

Figure 2.2: A short circuit with a resistance in the short circuit path, which may not cause overheating.

2.2.2 Open Circuits

An ideal insulator (for example, air) is a material that offers infinite resistance ($R \to \infty$ Ω) to current. In other words, electrons cannot flow through the material and current is zero ($I = 0$ A), even in the presence of a potential difference. The circuit diagram in figure 2.3 depicts a circuit that contains a branch with an open.

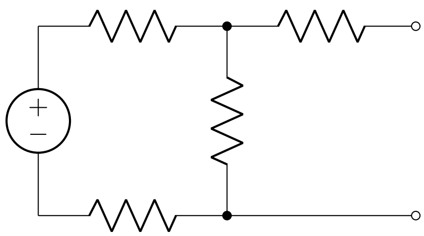

Figure 2.3: An circuit featuring a branch with an open.

Circuit 5: Use one or more resistors to generate a current of 1.5 mA with a voltage source of 10 V. Ensure that the power consumed by any individual resistor is less than 1/4 W. Draw the circuit diagram (include the placement of the ammeter in your diagram). Build the circuit, then demonstrate its functionality to your instructor to receive a stamp.

Instructor Stamp: ______

Circuit 6: Use one or more resistors to generate a current of 4.5 mA with a voltage source of 6 V. Ensure that the power consumed by any individual resistor is less than 1/4 W. Draw the circuit diagram (include the placement of the ammeter in your diagram). Build the circuit, then demonstrate its functionality to your instructor to receive a stamp.

Instructor Stamp: ______

2.3 Kirchhoff's Voltage Law (KVL) and the Voltage Divider Rule

KVL states that all voltage drops in a loop have to sum to zero (conservation of energy). A consequence of this is the voltage divider rule, which applies when all resistors are connected in series. The voltage divider rule is described by equation 2.6, where V_i is the voltage dropped over the i^{th} resistor, V_s is the source voltage, R_i is the resistance of the i^{th} resistor, and R_{EQ} is the equivalent series resistance of the circuit.

$$V_i = V_s \left(\frac{R_i}{R_{EQ}} \right) \tag{2.6}$$

Circuit 7: Connect 8 V to the red and black binding posts of the voltage divider circuit, shown in figure 2.4 (left). This circuit contains three unknown resistors, which are labeled in the diagram as R_1, R_2, and R_3.

- Connect the voltmeter between nodes `a` and `b` to measure and record voltage V_{ab}.

- Connect the voltmeter between nodes `b` and `c` to measure and record voltage V_{bc}.

- Connect the voltmeter between nodes `c` and `d` to measure and record voltage V_{cd}.

- Verify that these three voltages add up to 8 V.

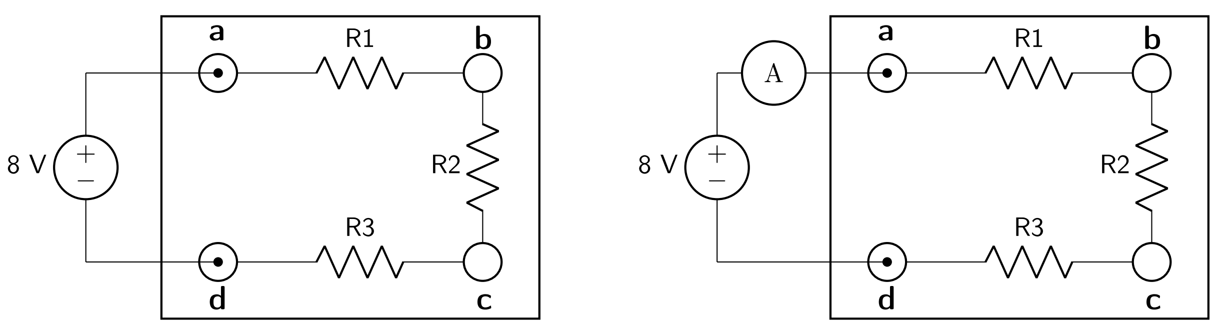

Figure 2.4: KVL circuit layout, without an ammeter (left) and with an ammeter (right).

Finally, connect an ammeter in series between your power supply and the circuit, shown in figure 2.4 (right), to measure the current that flows through all three resistors. Record the current below.

When you have finished recording and verifying your data, show the results to your instructor to receive a stamp.

Instructor Stamp: ______

Circuit 8: Design the circuit in figure 2.5 to give an output voltage equal to your group number divided by two. (Therefore, if you are in group 8, the output voltage should be 4 V.) Ensure that the power consumed by any one resistor will be less than one quarter watt.

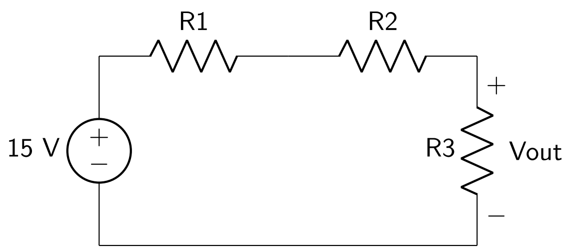

Figure 2.5: Circuit diagram for the group number voltage divider circuit.

Record your resistor values (include units!) in table 2.1.

Resistor	**Value**
R1	
R2	
R3	

Table 2.1: Table of resistor values.

Build the circuit on your breadboard, and verify your results with your instructor to receive a stamp.

Instructor Stamp: ______

2.4 Kirchhoff's Current Law (KCL) and the Current Divider Rule

KCL states that the sum of all currents entering a node is equal to zero (conservation of charge). A consequence of this is the current divider rule, which applies when all resistors are connected in parallel. The current divider rule is described by equation 2.7, where I_i is the current flowing through the i^{th} resistor, I_s is the source current, R_i is the resistance of the i^{th} resistor, and R_{EQ} is the equivalent parallel resistance of the circuit.

$$I_i = I_s \left(\frac{R_{EQ}}{R_i} \right) \tag{2.7}$$

Circuit 9: Design the circuit in figure 2.6 to give an output current equal to your group number divided by two. (Therefore, if you are in group 6, the output current should be 3 mA.) Ensure that the power consumed by any one resistor will be less than one quarter watt.

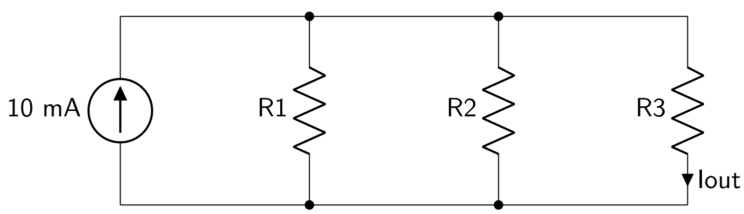

Figure 2.6: Circuit diagram for the group number current divider circuit.

Record your resistor values (include units!) in table 2.2.

Resistor	Value
R1	
R2	
R3	

Table 2.2: Table of resistor values.

Build the circuit on your breadboard, and verify your results with your instructor to receive a stamp.

Instructor Stamp: ______

Circuit 10: Follow the instructions as given below. When you have finished measuring all of your data, verify your results with your instructor to receive a stamp. The circuit board diagram is shown in figure 2.7.

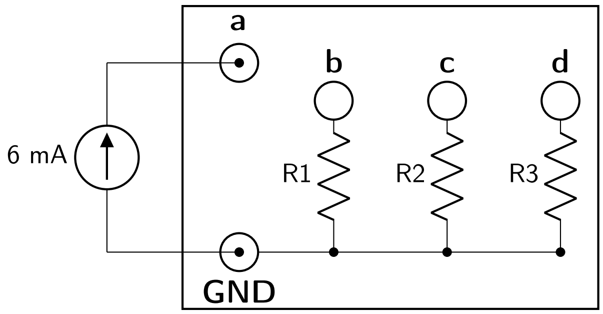

Figure 2.7: KCL circuit board layout.

- Connect the power supply to the appropriate terminals on the constant current source. Slowly and carefully dial the power supply to 15 V.
- If you would like, you may connect the output of the current source to the ammeter to verify that the current is actually 6 mA as you dial the potentiometer on the current source. Once you have finished this optional step, connect the current supply to the KCL board as shown below. (Note: the current source will not display any current reading until it is connected to a load or to the ammeter.)
- Connect the ammeter between the current source and resistor R_1 (between binding posts `a` and `b`). Then, connect banana plugs between the power supply and resistor R_2 (between binding posts `a` and `c`), and between the power supply and resistor R_3 (between binding posts `a` and `d`). Record I_a below.
- Connect the ammeter between the current source and resistor R_2 (between binding posts `a` and `c`). Then, connect banana plugs between the power supply and resistor R_1 (between binding posts `a` and `b`), and between the power supply and resistor R_3 (between binding posts `a` and `d`). Record I_b below.
- Connect the ammeter between the current source and resistor R_3 (between binding posts `a` and `d`). Then, connect banana plugs between the power supply and resistor R_1 (between binding posts `a` and `b`), and between the power supply and resistor R_2 (between binding posts `a` and `c`). Record I_c below.
- Disconnect the power supply and current source. Then, connect banana plugs along the top rails (between `a` and `b`, between `b` and `c`, and between `c` and `d`). Connect the multimeter to measure resistance between the red and black binding posts (this is the equivalent resistance of the circuit). Record R_{EQ} below.

Instructor Stamp: ______

Lab 2 Homework

Carefully read each question before answering. Show all work or justify your answers to receive credit. Attach a separate sheet of paper, if necessary, to show all work and calculations.

1. The following questions pertain to lab Circuit 7. You will also need to refer to equation 2.6 describing the voltage divider.

   (a) Explain how this circuit verifies KVL.

   (b) Use Ohm's Law to calculate the total resistance of the circuit.

   (c) Use the voltage divider equation to determine the value of resistor R_1.

   (d) Use the voltage divider equation to determine the value of resistor R_2.

   (e) Use the voltage divider equation to determine the value of resistor R_3.

   (f) Which resistor has the largest voltage drop? Is this the resistor with the highest or lowest resistance value?

   (g) Which resistor has the smallest voltage drop? Is this the resistor with the highest or lowest resistance value?

2. The following questions pertain to lab Circuit 8.

   (a) Calculate the total current flowing through all three resistors.

   (b) Calculate the voltage drop over resistor R_1.

   (c) Calculate the power consumed by resistor R_1.

   (d) Calculate the voltage drop over resistor R_2.

   (e) Calculate the power consumed by resistor R_2.

   (f) Calculate the power consumed by resistor R_3. (There is no need to calculate the voltage drop, as you engineered the circuit specifically to have a particular voltage drop over this circuit element.)

3. The following questions pertain to lab Circuit 9.

   (a) Calculate the total voltage drop over all three resistors.

   (b) Calculate the current flow through resistor R_1.

   (c) Calculate the power consumed by resistor R_1.

   (d) Calculate the current flow through resistor R_2.

   (e) Calculate the power consumed by resistor R_2.

   (f) Calculate the power consumed by resistor R_3. (There is no need to calculate the current flow, as you engineered the circuit specifically to have a particular current flow through this circuit element.)

4. The following questions pertain to lab Circuit 10. You will also need to refer to equation 2.7 describing the current divider.

   (a) Explain how this circuit verifies KCL.

   (b) Use the current divider equation to determine the value of resistor R_1.

   (c) Use the current divider equation to determine the value of resistor R_2.

   (d) Use the current divider equation to determine the value of resistor R_3.

   (e) Which resistor has the largest current flow? Is this the resistor with the highest or lowest resistance value?

   (f) Which resistor has the smallest current flow? Is this the resistor with the highest or lowest resistance value?