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Kirchhoff's Rules

PES 215 Report

Name:

Lab Station:

Objective

The purpose of this lab was to explore the rules of potential and current in a circuit as provided by Kirchhoff's Rules. This included building a circuit with resistor in series and parallel to test the various aspects of Kirchhoff's Rules.

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This day has been a long time coming, but it is finally time for you to leave the nest and try writing the reports on you own!

Data and Calculations

Part A – Checking the Components:

There were three resistors that we used for the different circuits in this lab. We used the color coded bands printed on the resistors to determine the resistance and then measured the actual resistance of the resistor using the DMM setup as an Ohmmeter.

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Resistor Number	Band Colors	Color Code Resistance [Ω]	DMM Measured Resistance [Ω]
1	Brown-Black-Yellow-Gold	100,000 Ω	100. k Ω
2	Brown-Black-Orange-Gold	10,000 Ω	10.0 k Ω
3	Brown-Black-Red-Gold	1,000 Ω	1.00 k Ω

For all calculations in Parts B – D we will use the DMM Measured Resistance of the resistors.

Part B – Resistors in Series:

For this part of the lab we were trying to prove Kirchhoff's Zeroth Rule and Kirchhoff's Loop Rule for resistors in series.

We first assembled a circuit with resistors in series. This is represented in the following circuit diagram:

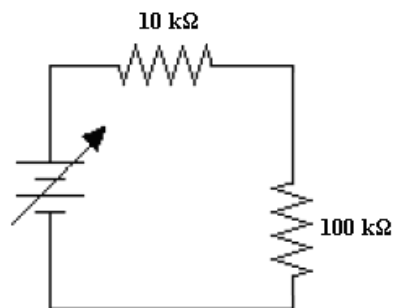


Figure 1: Circuit diagram of resistors 2 and 3 set up in series.

We used an adjustable power supply, the 10kΩ resistor, the 100kΩ resistor and a circuit board to build the circuit above.

Part B-1: Does Kirchhoff's Zeroth Rule hold?

We wanted to determine the current through various wires in the circuit above, as well as the potential drops and increases across the various components. We did this by creating three separate cases – with the ammeter positioned at various locations around the circuit. Each of these three cases is described below. We removed the short wire on the circuit board where the ammeter needed to go and connected in the ammeter to measure the current through the circuit at that part.

Case 1: Ampmeter before Both Resistors

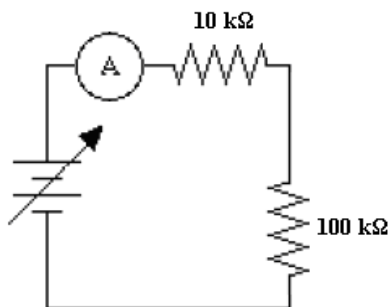


Figure 2: Circuit diagram of resistors 2 and 3 set up in series with Ampmeter measuring current before both resistors

Current through the Circuit [A]
90.91 μ A

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Case 2: Ammeter between Resistors:

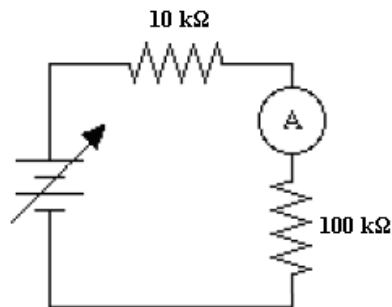


Figure 3: Circuit diagram of resistors 2 and 3 set up in series with Ammeter measuring current between the two resistors

Current through the Circuit [A]
90.90 μA

Case 3: Ammeter after Both Resistors:

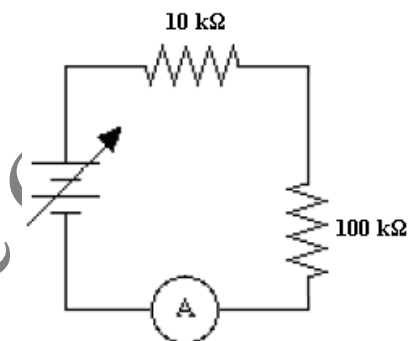


Figure 4: Circuit diagram of resistors 2 and 3 set up in series with Ammeter measuring current after both resistors

Current through the Circuit [A]
90.91 μA

Kirchhoff's Zeroth rule states: The current does not change around a corner in a circuit diagram.

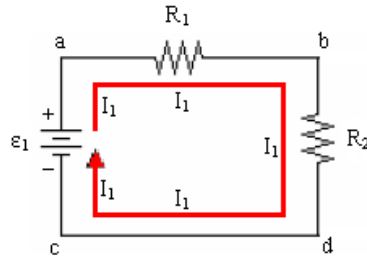


Figure 5: Circuit diagram of two resistors set up in series with current flowing through the circuit following Kirchhoff's Zeroth Rule

$$I_{case1} = I_{case2} = I_{case3}$$

In our case, the circuit diagram for resistors in series does not have any junctions (only corners); thus, Kirchhoff's Zeroth rule would appear to be applicable for this circuit. So, for Kirchhoff's Zeroth rule to hold, all the currents (assuming the resistors are not changed and the EMF is relatively the same) should be equal.

$$I_{case1} \stackrel{?}{=} I_{case2} \stackrel{?}{=} I_{case3}$$

Case 1: Current through the Circuit [A]	Case 2: Current through the Circuit [A]	Case 3: Current through the Circuit [A]
90.91 μ A	90.90 μ A	90.91 μ A

To prove Kirchhoff's Zeroth rule, we check to see if the 3 currents measured around the circuit are equal:

$$90.91 [\mu\text{A}] \stackrel{?}{=} 90.90 [\mu\text{A}] \stackrel{?}{=} 90.91 [\mu\text{A}]$$

$$90.91 [\mu\text{A}] \cong 90.90 [\mu\text{A}] \cong 90.91 [\mu\text{A}]$$

Note that since the values we obtained are VERY NEARLY equal, we can confidently state that Kirchhoff's Zeroth Rule holds. Note that if we had "more accurate" readings that the answer would likely be even closer to equality – but due to rounding and other mechanical random errors (e.g. resistors' errors) it may not be equal *exactly*. (Another likely error could be from small changes in the EMF from case 1 to case 3.)

Part B-2: Does Kirchhoff's Loop Rule hold?

Kirchhoff's Loop rule states: The sum of the potential increases and drops around a closed loop add up to zero.

$$\sum_{i=1}^n \Delta V_i = 0$$

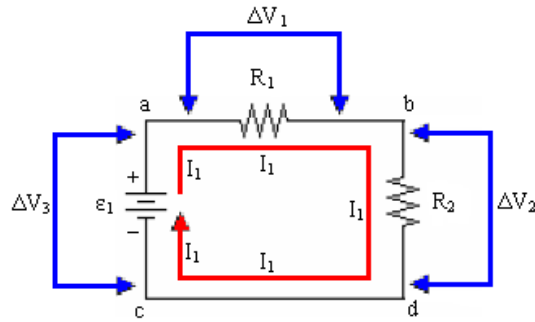


Figure 6: Circuit diagram of two resistors with Kirchhoff's Rule problem-solving techniques applies

Potential Rise from Voltage Supplied (EMF) [V]	Potential Drop Across 10kΩ [V]	Potential Drop Across 100kΩ [V]
10.00 V	-0.9091 V	-9.091 V

(Note: Recall that Potential increases (e.g., EMF) typically have a "+" sign to indicate increase where potential drops typically have a "-" sign to indicate decrease when traversing around a closed circuit in the same direction as the current.)

In our case, we have one potential rise (the voltage supplied) and two separate potential drops (the drop across the 10kΩ and 100kΩ resistors). So, for Kirchhoff's Loop Rule to hold, the sum of the potential rises and decreases around a closed loop must be (very nearly) zero.

$$\sum_{i=1}^3 \Delta V_i = \mathcal{E} + \Delta V_{10k\Omega} + \Delta V_{100k\Omega} = 0$$

Plugging in the numbers I have in the table above:

$$\mathcal{E} + \Delta V_{10k\Omega} + \Delta V_{100k\Omega} = 0$$

$$10.00 [V] - 0.9091 [V] - 9.091 [V] = -0.0001 [V] = 0$$

$$-0.0001 [V] \approx 0$$

Since the value of the sum we obtained is VERY NEARLY zero, we can confidently state that Kirchhoff's Loop Rule holds. Note that if we had "more accurate" readings that the answer

would likely be even closer to zero – but due to rounding and other mechanical random errors (e.g. resistors' errors) it may not be zero *exactly*.

Another method for proving Kirchhoff's Loop Rule is by using the Problem Solving Techniques from the pre-lab. This gives the following relationship:

$$\varepsilon = I_1(R_1 + R_2)$$

$$10.00 \text{ V} = 90.905 \mu\text{A}(10000 \Omega + 100000 \Omega) = 9.99955 \text{ V}$$

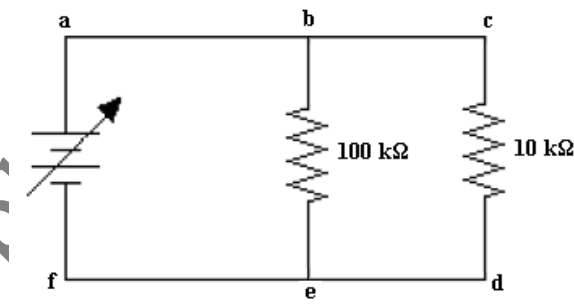
$$10.00 \text{ V} \approx 9.99955 \text{ V}$$

Since the evaluation provided by analyzing this circuit provides VERY NEARLY equal values, we can confidently state that Kirchhoff's Loop Rule holds.

Part C – Resistors in Parallel:

For this part of the lab we were trying to prove Kirchhoff's Zeroth Rule, Kirchhoff's Loop Rule, and Kirchhoff's Junction Rule for resistors in parallel.

We first assembled a circuit with resistors in parallel. This is represented in the following circuit diagram:



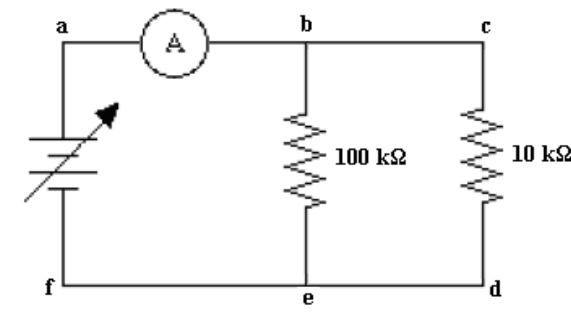
Note that there are two distinct junctions in the circuit diagram above. These occur at: 1) junction b and 2) junction e. We will test Kirchhoff's Junction Rule for currents at both of these junctions for the current(s) flowing into the junction and the current(s) flowing out of the junction.

Again, we used an adjustable power supply, a 10kΩ resistor, a 100kΩ resistor, and the circuit board to build the circuit above.

Part C-1: Does Kirchhoff's Zeroth Rule hold?

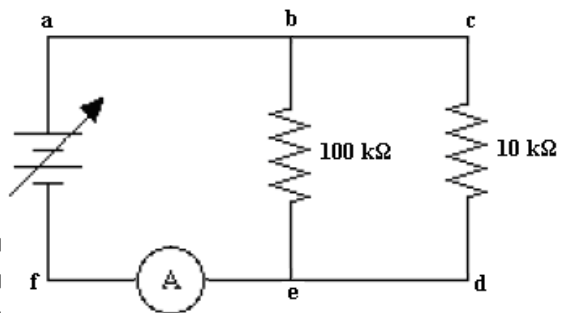
We wanted to determine the current through various wires in the circuit above, as well as the potential drops and increases across the various components. We did this by creating four separate cases – with the ammeter positioned at various locations around the circuit. Each of these four cases is described below.

Case 1: Ampmeter before Both Resistors:



Current through the Circuit [A]
1.1 mA

Case 4: Ampmeter after Both Resistors:

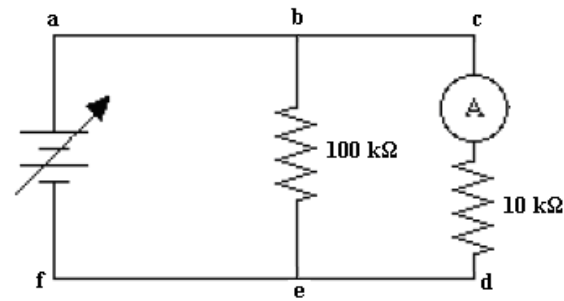


Current through the Circuit [A]
1.1 mA

Part C-2: Does Kirchhoff's Junction Rule hold?

Case 3: Ampmeter before/after 10kΩ Resistor:

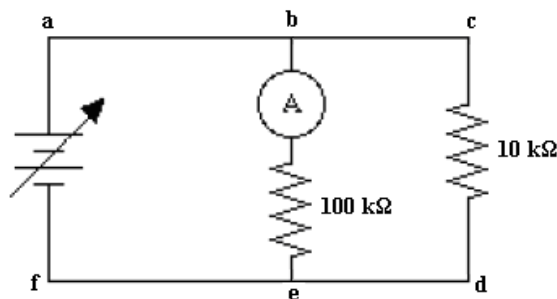
<Add descriptive text about what you had to do to build the following circuit. Was there anything special you needed to do? Did you have to completely re-build the circuit?>



Current through the Circuit [A]
1.0 mA

Case 3: Ammeter before/after 100kΩ Resistor:

<Add descriptive text about what you had to do to build the following circuit. Was there anything special you needed to do? Did you have to completely re-build the circuit?>



Current through the Circuit [A]
0.09 mA

<Notice anything in particular about the potential drop across resistors in parallel? Maybe something related to the EMF?>

Part C Further Analysis:

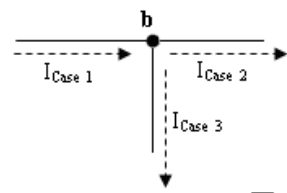
<Overall does Kirchhoff's Junction Rule hold for resistors in parallel? Does the current through the circuit case 1 = case 2 + case 3 and case 4 = case 2 + case 3?>

Kirchhoff's Junction Rule states: The sum of the currents into a junction point must equal the sum of the current out of a junction point.

$$\sum_{j=1}^n I_{In,j} = \sum_{k=1}^m I_{Out,k}$$

In our case, we have two distinct junction points (junction b and junction e). So, for Kirchhoff's Junction Rule to hold, the sum of the currents into junction b (or junction e) must equal the sum of the currents out of junction b (or junction e).

Junction b:



There is one current going into junction b. This is the current from case 1 above. Likewise, there are two currents going out of junction b. These are the currents from case 2 and case 3 respectively. Thus, according to Kirchhoff's Junction Rule:

$$I_{Case1} = I_{Case2} + I_{Case3}$$

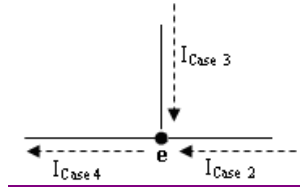
<u>Case 1: Current through the Circuit [A]</u>	<u>Case 2: Current through the Circuit [A]</u>	<u>Case 3: Current through the Circuit [A]</u>
<u>1.1 mA</u>	<u>0.09 mA</u>	<u>1.0 mA</u>

$$1.1 [mA] \stackrel{?}{=} 0.09 [mA] + 1.0 [mA]$$

$$1.1 [mA] \cong 1.09 [mA]$$

<Again note that since the values we obtained are VERY NEARLY equal, we can confidently state that Kirchhoff's Junction Rule holds. Note that if we had "more accurate" readings that the answer would likely be even closer to equality – but due to rounding and other mechanical random errors (e.g. resistors' errors) it may not be equal exactly. Another likely error could be from changing the EMF from case 1, to case 2, to case 3.>

Junction e:



There are two currents going into junction e. This is the current from case 3 and case 3 above. Likewise, there is one current going out of junction e. This is the currents from case 4. Thus, according to Kirchhoff's Junction Rule:

$$I_{Case2} + I_{Case3} = I_{Case4}$$

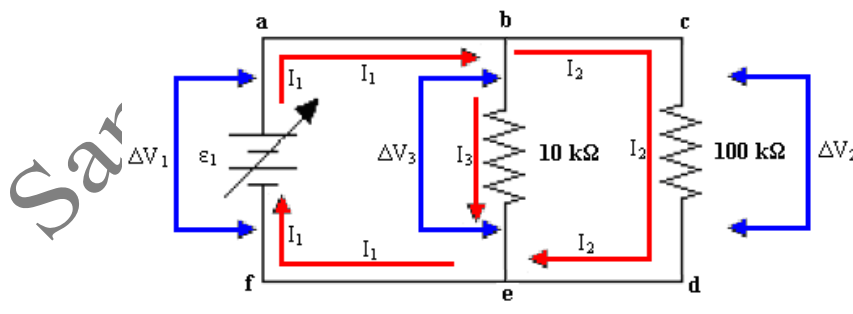
Case 2: Current through the Circuit [A]	Case 3: Current through the Circuit [A]	Case 4: Current through the Circuit [A]
0.09 mA	1.0 mA	1.1 mA

$$1.1 \text{ [mA]} = 0.09 \text{ [mA]} + 1.0 \text{ [mA]}$$

$$1.1 \text{ [mA]} \approx 1.09 \text{ [mA]}$$

<Again note that since the values we obtained are VERY NEARLY equal, we can confidently state that Kirchhoff's Junction Rule holds. Note that if we had "more accurate" readings that the answer would likely be even closer to equality – but due to rounding and other mechanical random errors (e.g. resistors' errors) it may not be equal exactly. Another likely error could be from changing the EMF from case 1, to case 2, to case 3.>

Part C-3: Does Kirchhoff's Loop Rule hold?



Potential Rise from Voltage Supplied (EMF) [V]	Potential Drop Across 10kΩ [V]	Potential Drop Across 100kΩ [V]
10.07 V	-10.07 V	-10.07 V

Kirchhoff's Loop rule states: The sum of the potential rises and decreases around a closed loop must be zero.

$$\sum_{i=1}^n \Delta V_i = 0$$

In our case, we have three separate loops (a-b-e-f-a, a-b-c-d-e-f-a, and b-d-c-e-b). So, for Kirchhoff's Loop Rule to hold, the sum of the potential rises and decreases around a closed loop must be (very nearly) zero.

For loop a-b-e-f-a:

$$\sum_{i=1}^2 \Delta V_i = \mathcal{E} + \Delta V_{10k\Omega} \stackrel{?}{=} 0$$

$$\mathcal{E} + \Delta V_{10k\Omega} \stackrel{?}{=} 0$$

$$10.07 \text{ [V]} - 10.07 \text{ [V]} = 0.0 \text{ [V]} \stackrel{?}{=} 0$$

$$0.0 \text{ [V]} \cong 0$$

For loop a-b-c-d-e-f-a:

$$\sum_{i=1}^2 \Delta V_i = \mathcal{E} + \Delta V_{10k\Omega} \stackrel{?}{=} 0$$

$$\mathcal{E} + \Delta V_{10k\Omega} \stackrel{?}{=} 0$$

$$10.07 \text{ [V]} - 10.07 \text{ [V]} = 0.0 \text{ [V]} \stackrel{?}{=} 0$$

$$0.0 \text{ [V]} \cong 0$$

For loop b-c-d-e-b:

$$\sum_{i=1}^2 \Delta V_i = -\Delta V_{10k\Omega} + \Delta V_{10k\Omega} \stackrel{?}{=} 0$$

<Notice since the traverse of the 10k Ω resistor is in the opposite direction of the current flowing through that resistor we must have a negative sign in there. Using the numbers I have in the example above:>

$$-\Delta V_{10k\Omega} + \Delta V_{100k\Omega} \stackrel{?}{=} 0$$

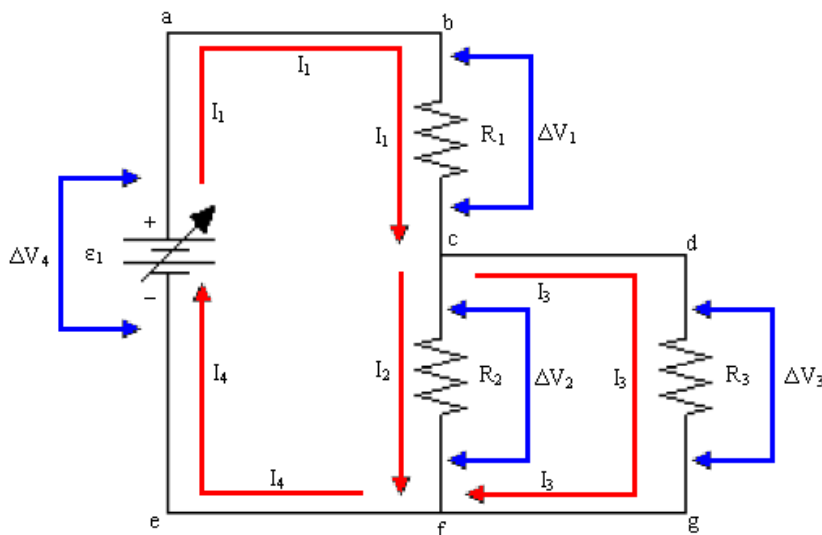
$$-(-10.07 [V]) - 10.07 [V] = 0.0 [V] \stackrel{?}{=} 0$$

$$0.0 [V] \cong 0$$

<And since ALL the values we obtained are all VERY NEARLY zero, we can confidently state that Kirchhoff's Loop Rule holds. Note that if we had "more accurate" readings that the answer would likely be even closer to zero – but due to rounding and other mechanical random errors (e.g. resistors' errors) it may not be zero *exactly*.>

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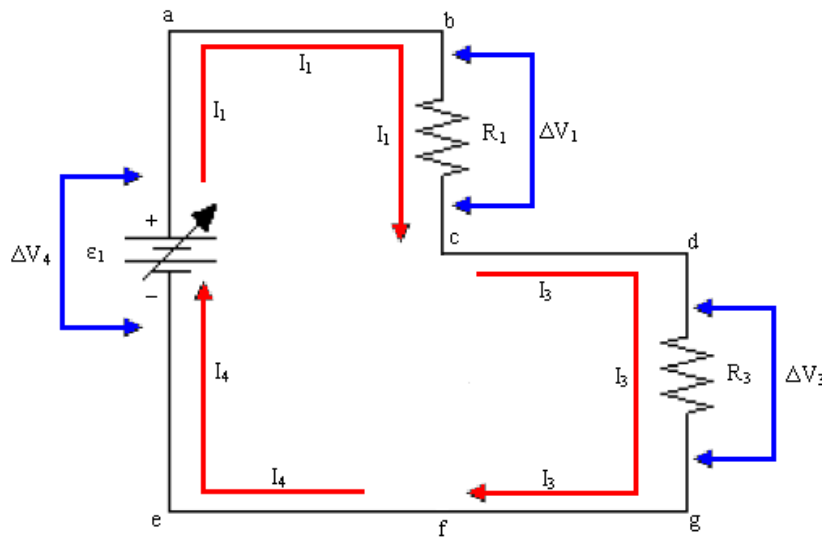
Part D – A Little Bit of Everything:



PST 9 - Apply the Loop Rule for each closed loop in the circuit diagram (use Ohm's Law as described at the beginning of this pre-lab):

We have 3 loops that we need to consider each individually. These three loops are (using the letters to describe the loops):

Loop 1 = a-b-c-d-g-f-e-a:



** NOTE: we did not “get rid” of the wire connecting c to f, we just are “selectively ignoring” it at the moment since it plays no part in the loop we are concerned with. **

Applying Ohm’s Law using the convention set up at the beginning of the pre-lab:

From a to b:

$$\Delta V = 0$$

From b to c:

$$\Delta V_1 = -I_1 R_1$$

(** NOTICE THAT IT IS NEGATIVE SINCE WE ARE TRAVERSING IN THE SAME DIRECTION AS THE CURRENT! **)

From c to d:

$$\Delta V = 0$$

From d to g:

$$\Delta V_3 = -I_3 R_3$$

From g to f:

$$\Delta V = 0$$

From f to e:

$$\Delta V = 0$$

From e to a:

$$\underline{\Delta V_4 = +\varepsilon}$$

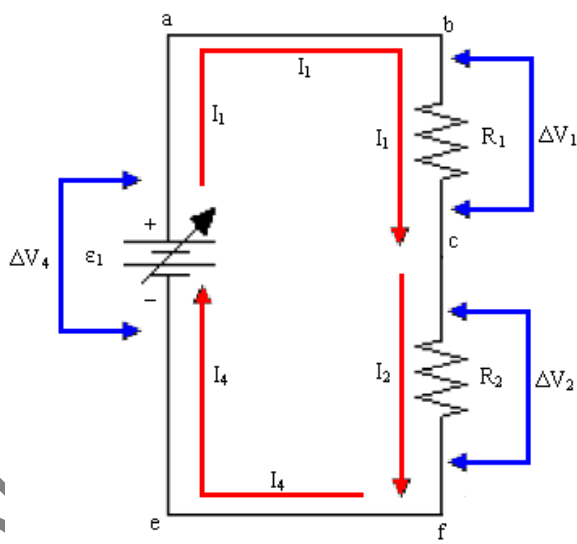
According to the loop rule, the sum of the potential rises and decreases around a closed loop must be zero.

$$\underline{\sum_{i=1}^n \Delta V_i = 0}$$

$$\underline{\sum_{i=1}^7 \Delta V_i = 0 - I_1 R_1 + 0 - I_3 R_3 + 0 + 0 + \varepsilon = 0}$$

$$\underline{-I_1 R_1 - I_3 R_3 + \varepsilon = 0 \text{ (eq. 1)}}$$

Loop 2 = a-b-c-f-e-a:



Applying Ohm's Law using the convention set up at the beginning of the pre-lab:

From a to b:

$$\underline{\Delta V = 0}$$

From b to c:

$$\underline{\Delta V_1 = -I_1 R_1}$$

From c to f:

$$\underline{\Delta V_2 = -I_2 R_2}$$

From f to e:

$$\underline{\Delta V = 0}$$

From e to a:

$$\underline{\Delta V_4 = +\varepsilon}$$

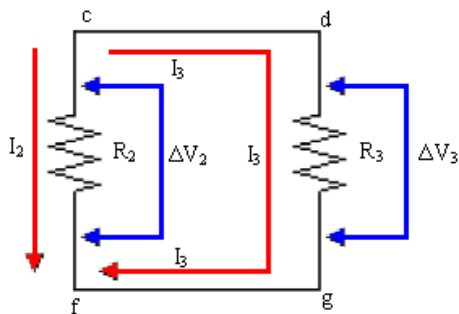
According to the loop rule, the sum of the potential rises and decreases around a closed loop must be zero.

$$\underline{\sum_{i=1}^n \Delta V_i = 0}$$

$$\underline{\sum_{i=1}^5 \Delta V_i = 0 - I_1 R_1 - I_2 R_2 + 0 + \varepsilon = 0}$$

$$\underline{-I_1 R_1 - I_2 R_2 + \varepsilon = 0 \text{ (eq. 2)}}$$

Loop 3 = c-d-g-f-c:



Applying Ohm's Law using the convention set up at the beginning of the pre-lab:

From c to d:

$$\underline{\Delta V = 0}$$

From d to g:

$$\underline{\Delta V_3 = -I_3 R_3}$$

From g to f:

$$\underline{\Delta V = 0}$$

From f to c:

$$\underline{\Delta V_2 = +I_2 R_2}$$

(** NOTICE THAT IT IS POSTIVE SINCE WE ARE TRAVERSING IN THE OPPOSITE DIRECTION THAN THE CURRENT! **)

According to the loop rule, the sum of the potential rises and decreases around a closed loop must be zero.

$$\sum_{i=1}^n \Delta V_i = 0$$

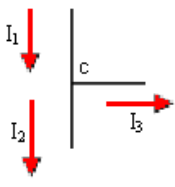
$$\sum_{i=1}^4 \Delta V_i = 0 - I_3 R_3 + 0 + I_2 R_2 = 0$$

$$\underline{-I_3 R_3 + I_2 R_2 = 0 \text{ (eq. 3)}}$$

PST 10 - Apply the Junction Rule for each junction in the circuit diagram:

We have 2 junctions that we need to consider each individually. These two junctions are (using the letters to describe the junctions):

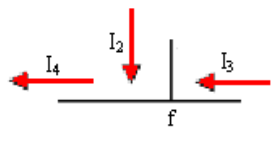
Junction 1 @ c:



According to the junction rule, the sum of the currents into a junction point must equal the sum of the current out of a junction point.

$$\underline{I_1 = I_2 + I_3 \text{ (eq. 4)}}$$

Junction 1 @ f:



According to the junction rule, the sum of the currents into a junction point must equal the sum of the current out of a junction point.

$$\underline{I_2 + I_3 = I_4 \text{ (eq.5)}}$$

PST 11 - Solve the system of equations for the knowns and unknowns:

We are given the following information from the beginning of the problem:

ε	R_1	R_2	R_3
<u>10 V</u>	<u>10 kΩ</u>	<u>100 kΩ</u>	<u>1 kΩ</u>

That means that the unknowns are:

$$\underline{I_1, I_2, I_3, \text{ and } I_4}$$

Here is the list of consolidated equations we found using the loop rule and junction rule on the circuit:

$$\underline{-I_1 R_1 - I_3 R_3 + \varepsilon = 0 \text{ (eq. 1)}}$$

$$\underline{-I_1 R_1 - I_2 R_2 + \varepsilon = 0 \text{ (eq. 2)}}$$

$$\underline{-I_3 R_3 + I_2 R_2 = 0 \text{ (eq. 3)}}$$

$$\underline{I_1 = I_2 + I_3 \text{ (eq. 4)}}$$

$$\underline{I_2 + I_3 = I_4 \text{ (eq. 5)}}$$

First, start by solving equation 3 for I_3 :

$$\underline{I_3 = \frac{I_2 R_2}{R_3} \text{ (eq. 6)}}$$

Plug equation 6 into equation 1:

$$\underline{-I_1 R_1 - \left(\frac{I_2 R_2}{R_3} \right) R_3 + \varepsilon = 0}$$

$$\underline{-I_1 R_1 - I_2 R_2 + \varepsilon = 0}$$

Notice that this is exactly the same as equation 2! So at least we did the loop rules right! ☺

Look at equation 4 and equation 5. Notice that the sums are the same for both of those equations. This must mean that:

$$I_1 = I_4 \text{ (eq. 7)}$$

Use equation 4 and plug the value for I_1 into equation 2:

$$-(I_2 + I_3)R_1 - I_2R_2 + \varepsilon = 0$$

$$-I_2R_1 - I_3R_1 - I_2R_2 + \varepsilon = 0 \text{ (eq. 8)}$$

Use equation 6 and plug in the value of I_3 into equation 8, then solve for I_2 :

$$-I_2R_1 - \left(\frac{I_2R_2}{R_3}\right)R_1 - I_2R_2 + \varepsilon = 0$$

$$-I_2\left(R_1 + \frac{R_1R_2}{R_3} + R_2\right) = -\varepsilon$$

$$I_2 = \frac{\varepsilon}{\left(R_1 + \frac{R_1R_2}{R_3} + R_2\right)}$$

$$I_2 = \frac{\varepsilon(R_3)}{(R_1R_3 + R_1R_2 + R_2R_3)}$$

Use the value we just found for I_2 and plug it into equation 3, then solve for I_3 :

$$-I_3R_3 + \left(\frac{\varepsilon(R_3)}{(R_1R_3 + R_1R_2 + R_2R_3)}\right)R_2 = 0$$

$$-I_3R_3 = -\frac{\varepsilon(R_2R_3)}{(R_1R_3 + R_1R_2 + R_2R_3)}$$

$$I_3 = \frac{\varepsilon(R_2)}{(R_1R_3 + R_1R_2 + R_2R_3)}$$

Use the values we have found for I_2 and for I_3 and plug them into equation 4, then solve for I_1 :

$$I_1 = I_2 + I_3 = \frac{\varepsilon(R_3)}{(R_1R_3 + R_1R_2 + R_2R_3)} + \frac{\varepsilon(R_2)}{(R_1R_3 + R_1R_2 + R_2R_3)}$$

$$I_1 = \frac{\varepsilon(R_3) + \varepsilon(R_2)}{(R_1 R_3 + R_1 R_2 + R_2 R_3)}$$

$$I_1 = \frac{\varepsilon(R_2 + R_3)}{(R_1 R_3 + R_1 R_2 + R_2 R_3)}$$

Use the value we have found for I_1 and plug it into equation 7, then solve for I_4 :

$$I_1 = I_4$$

$$I_4 = \frac{\varepsilon(R_2 + R_3)}{(R_1 R_3 + R_1 R_2 + R_2 R_3)}$$

Now we have expressions for all four currents in the original circuit.

$$\begin{aligned} I_1 &= \frac{\varepsilon(R_2 + R_3)}{(R_1 R_3 + R_1 R_2 + R_2 R_3)} & I_2 &= \frac{\varepsilon(R_3)}{(R_1 R_3 + R_1 R_2 + R_2 R_3)} \\ I_3 &= \frac{\varepsilon(R_2)}{(R_1 R_3 + R_1 R_2 + R_2 R_3)} & I_4 &= \frac{\varepsilon(R_2 + R_3)}{(R_1 R_3 + R_1 R_2 + R_2 R_3)} \end{aligned}$$

We can now plug in the value of the given information and solve for the numerical value of each of the currents.

$$I_1 = \frac{10 \text{ V}(100\text{k}\Omega + 1\text{k}\Omega)}{((10\text{k}\Omega)(1\text{k}\Omega) + (10\text{k}\Omega)(100\text{k}\Omega) + (100\text{k}\Omega)(1\text{k}\Omega))}$$

$$I_1 = \frac{10 \text{ V}(101000\Omega)}{((1 \times 10^7 \Omega^2) + (1 \times 10^9 \Omega^2) + (1 \times 10^8 \Omega^2))} = \frac{10 \text{ V}(101000\Omega)}{(1110000000\Omega^2)}$$

$$I_1 = 9.0991 \times 10^{-4} \text{ A} = 0.90991 \text{ mA}$$

$$I_2 = \frac{10 \text{ V}(1\text{k}\Omega)}{((10\text{k}\Omega)(1\text{k}\Omega) + (10\text{k}\Omega)(100\text{k}\Omega) + (100\text{k}\Omega)(1\text{k}\Omega))}$$

$$I_2 = \frac{10 \text{ V}(1000\Omega)}{((1 \times 10^7 \Omega^2) + (1 \times 10^9 \Omega^2) + (1 \times 10^8 \Omega^2))} = \frac{10 \text{ V}(1000\Omega)}{(1110000000\Omega^2)}$$

$$I_2 = 9.009 \times 10^{-6} \text{ A} = 9.009 \mu\text{A}$$

$$I_3 = \frac{10 \text{ V}(100k\Omega)}{((10k\Omega)(1k\Omega) + (10k\Omega)(100k\Omega) + (100k\Omega)(1k\Omega))}$$

$$I_1 = \frac{10 \text{ V}(100000\Omega)}{((1 \times 10^7 \Omega^2) + (1 \times 10^9 \Omega^2) + (1 \times 10^8 \Omega^2))} = \frac{10 \text{ V}(100000\Omega)}{(1110000000\Omega^2)}$$

$$I_3 = 9.009 \times 10^{-4} \text{ A} = 0.9009 \text{ mA}$$

$$I_4 = \frac{10 \text{ V}(100k\Omega + 1k\Omega)}{((10k\Omega)(1k\Omega) + (10k\Omega)(100k\Omega) + (100k\Omega)(1k\Omega))}$$

$$I_4 = \frac{10 \text{ V}(101000\Omega)}{((1 \times 10^7 \Omega^2) + (1 \times 10^9 \Omega^2) + (1 \times 10^8 \Omega^2))} = \frac{10 \text{ V}(101000\Omega)}{(1110000000\Omega^2)}$$

$$I_4 = 9.0991 \times 10^{-4} \text{ A} = 0.90991 \text{ mA}$$

Finally, we can determine the potentials (voltages) across each of the components by Ohm's Law.

$$\Delta V_1 = -I_1 R_1$$

$$\Delta V_1 = -(0.90991 \text{ mA})(10k\Omega) = -(0.90991 \times 10^{-3} \text{ A})(1 \times 10^4 \Omega)$$

$$\Delta V_1 = -9.0991 \text{ V}$$

$$\Delta V_2 = -I_2 R_2$$

$$\Delta V_2 = -(9.009 \mu\text{A})(100k\Omega) = -(9.009 \times 10^{-6} \text{ A})(1 \times 10^5 \Omega)$$

$$\Delta V_2 = -0.9009 \text{ V}$$

$$\Delta V_3 = -I_3 R_3$$

$$\Delta V_3 = -(0.9009 \text{ mA})(1k\Omega) = -(0.9009 \times 10^{-3} \text{ A})(1 \times 10^3 \Omega)$$

$$\Delta V_3 = -0.9009 \text{ V}$$

$$\Delta V_4 = \mathcal{E} = 10 \text{ V}$$



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Additional Questions

•question 1

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Conclusion

You write the details. ← Include your answer here. Use complete sentences!!!!

** NOTE: There are several components of error which could significantly modify the results of this experiment. Some of these are listed below:

- Heat
- Age
- Humidity
- Short circuit
- Fuse
- Bad power supply (recall we used the DMM to attempt to alleviate this problem.)
- Bad connections (in protoboard)
- Insulation
- Length of wire and Gauge accuracy of wire (copper) ** Think lab 7 **
- Bad power supply (recall we used the DMM to attempt to alleviate this problem.)
- Buckling, bending, etc... of wire
- Elemental components/material makeup of the wire ** Think lab 7 **
- ??

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It is recommended that you take these and explain the “why” part of each for your results and conclusions sections – and possibly what could have been done (if anything) to minimize the effects of these errors.