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Experiment No. 2

Verification of KVL & KCL

Objective

This experiment aims to use multi-loops and various branch circuits to verify Kirchhoff's voltage law (KVL) and Kirchhoff's current law (KCL).

Apparatus

- ➢ Multimeter
- ➢ Resistors ($1\ k\Omega$ x 2, $2.2\ k\Omega$, $3.3\ k\Omega$, $4.7\ k\Omega$).
- ➢ DC power supply
- ➢ Breadboard
- ➢ Jumper wires

Part 1: KVL

Theory

KVL stands for Kirchhoff's Voltage Law, which is a fundamental principle used in electrical engineering and physics. **It states that the sum of all the voltages in a closed loop in a circuit is equal to zero.** (Alternatively, it can be said that around any closed circuit the algebraic sum of the voltage rises equals the algebraic sum of the voltage drops).

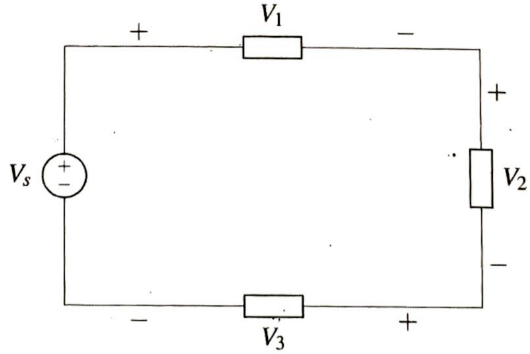


Figure 1: Illustration of KVL

To illustrate KVL, consider Fig. 1. The sign on each voltage is the polarity of the terminal encountered first as we travel around the loop. Let us start with the voltage source and go around the top, then voltages would be $-V_s + V_1 + V_2 + V_3$. Thus, KVL yields,

$$\sum \Delta V = -V_s + V_1 + V_2 + V_3 = 0$$

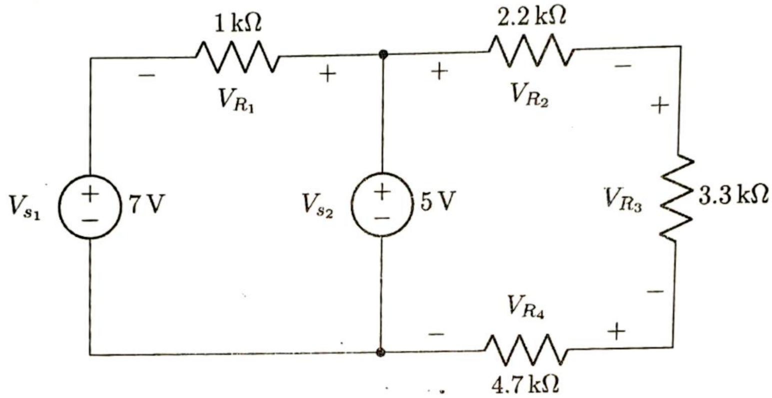
$$\Rightarrow V_s = V_1 + V_2 + V_3$$

This can be interpreted as,

Sum of voltage rises = Sum of voltage drops

Procedures

- Measure the resistances of the provided resistors and fill up the data table.
- Construct the following circuit on a breadboard. Try to use as less number of jumper wires as possible.



Circuit 1

- Measure the voltage across each resistor (V_{R_1}, V_{R_2}, V_{R_3}, V_{R_4}) as shown in the figure above. Fill up the data tables.
- Verify KVL as $\sum \Delta V = 0$ for each loop (take the polarity of the resistors clockwise).

For the left-sided loop, $\sum \Delta V = -V_{s_1} - V_{R_1} + V_{s_2}$

For the right-sided loop, $\sum \Delta V = -V_{s_2} + V_{R_2} + V_{R_3} + V_{R_4}$

- Calculate the theoretical values of V_{R_1}, V_{R_2}, V_{R_3}, V_{R_4} and note them down in the 'Theoretical Observation' row in Tables 2 & 3. For V_{R_2}, V_{R_3}, V_{R_4} use the *Voltage Divider Rule*. Relevant formulas are given below for your convenience:

$V_{R_1} = V_{s_1} - V_{s_2}$ $\qquad V_{R_2} = \frac{R_2}{R_s} \times V_{s_2}$ $\qquad V_{R_3} = \frac{R_3}{R_s} \times V_{s_2}$

$V_{R_4} = \frac{R_4}{R_s} \times V_{s_2}$ $\qquad$ where, $R_s = R_2 + R_3 + R_4$

Data Tables

Signature of Lab Faculty:	[signature]	Date:	5-3-25

** ***For all the data tables, take data up to three decimal places, round to two, then enter into the table.***

Table 0: Resistance Data

For all your future calculations, please use the observed values only **(even for theoretical calculations)**.

Notation	Expected Resistance	Observed Resistance (kΩ)
R_1	1 kΩ	0.98 kΩ
R_2	2.2 kΩ	2.15. kΩ
R_3	3.3 kΩ	3.22 kΩ
R_4	4.7 kΩ	4.66 kΩ

Table 1: Data for Loop 1 (Left-sided loop)

In the following table, V_{R1} is the voltage drop across resistor R_1. A similar syntax applies to remaining resistors. Also, calculate the percentage of error between experimental and theoretical values of $\sum\Delta V$.

Observation	V_{s_1} (V) (from dc power supply)	V_{s_1} (V) (using multimeter)	V_{s_2} (V) (from dc power supply)	V_{s_2} (V) (using multimeter)	V_{R_1} (V)	$\sum\Delta V = -V_{s_1} - V_{R_1} + V_{s_2}$ (V)
Experimental	7	7.08	5	5.	-2.07	-0.01
Theoretical					-1.96 ~~[illegible]~~	0

Absolute error = | *Experimental value* − *Theoretical value* |

Here, Absolute error in $\sum\Delta V$ calculation = 0.01

Table 2: Data for Loop 2 (Right-sided loop)

In the following table, V_{R_2} is the voltage drop across resistor R_2. A similar syntax applies to remaining resistors. Also, calculate the percentage of error between experimental and theoretical values of $\sum\Delta V$.

Observation	V_{S_2} (V) (from dc power supply)	V_{S_2} (V) (using multimeter)	V_{R_2} (V)	V_{R_3} (V)	V_{R_4} (V)	$\sum\Delta V = -V_{S_2} + V_{R_2} + V_{R_3} + V_{R_4}$ (V)
Experimental	5	5	1.07	1.6	2.32	−0.01
Theoretical			1.05	1.57	2.28	0

Here, Absolute error in $\sum\Delta V$ calculation = 0.01

Questions

1. Let us take a look at **Circuit 1** again. If we ignore the 5V voltage source (V_{S_2}) from the middle, the remaining circuitry contains only one big loop (often referred to as the outer loop). Let us examine if KVL holds for the outer loop too.

(a) Do you think KVL will apply to the outer loop?

☑ Yes ☐ No

Justify your answer.

kvl applies to every closed loops.

(b) Use the values of V_{R_1}, V_{R_2}, V_{R_3}, V_{R_4}, V_{S_1} from Tables 2 & 3 to verify your answer to the above question.

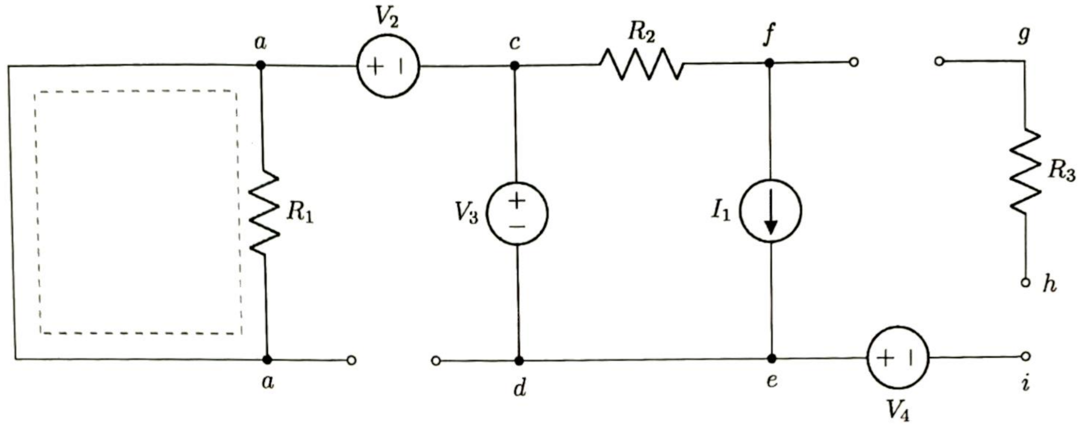
$\sum\Delta V = -V_{S_1} - V_{R_1} + V_{R_2} + V_{R_3} + V_{R_4} =$ 0.06

Did KVL hold for the outer loop?

☑ Yes ☐ No

Here, absolute error in $\sum\Delta V$ calculation = 0.06

2. If a loop is defined as the *closed path formed by starting at a node, passing a* <u>*set*</u> *of nodes, and returning to the same node without passing any node more than once,* for the following circuit,



(a) Which of the pathways in the circuit shown above is/are loop(s)?

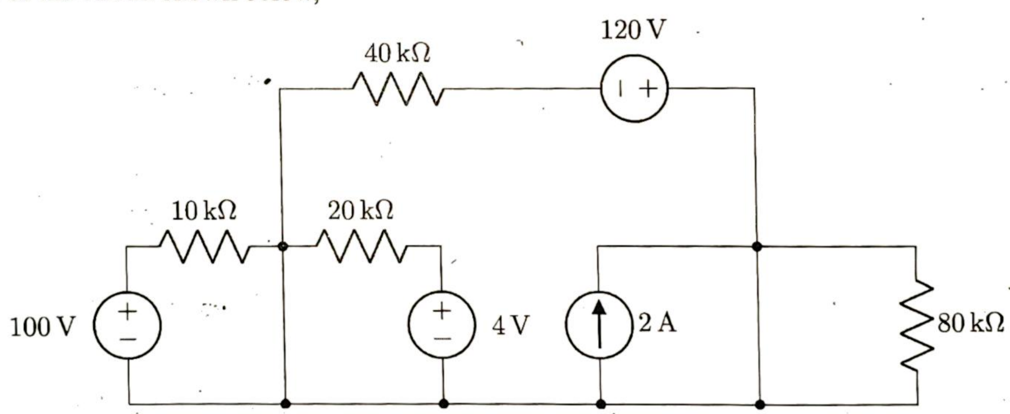
☐ path indicated by the dashed gray line.

☐ path $cdaac$.

☑ path $cfedc$.

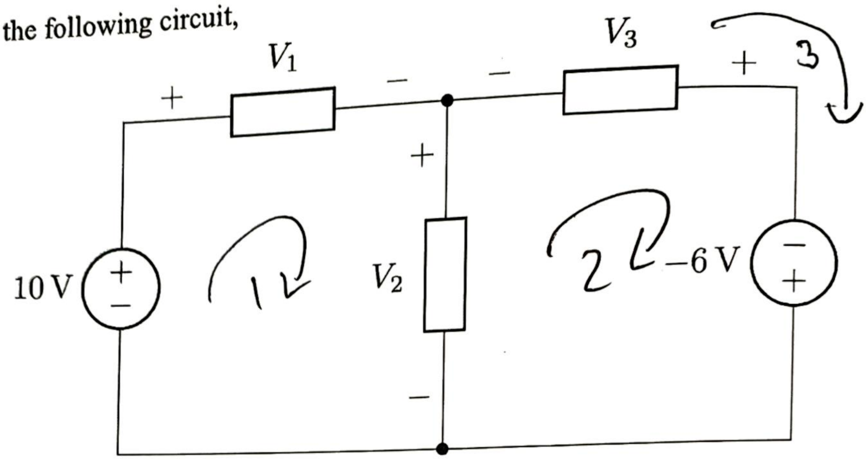
☐ path $fghief$.

3. For the circuit shown below,



Number of branches = 8
Number of elements shorted = 2
Number of nodes = 4
Number of meshes = 3
Number of independent KVL equations that are solvable = 3

4. For the following circuit,



(a) How many loops may KVL be applied along? Mark the loops in the circuit diagram.

3

(b) List all of the equations obtained by applying KVL along the number of loops mentioned in (a).

loop1 → $-10+V_1+V_2=0 \Rightarrow V_1+V_2-10=0$

loop2 → $-V_2-V_3+6=0 \Rightarrow V_2+V_3-6=0$

loop3 → $-10+V_1-V_3+6=0 \Rightarrow V_1-V_3-4=0$

(c) Can you observe any relationship among the equations or is it possible to derive any of the equations from the linear combination of the other two? If so, show the mathematical derivation.

~~loop2 → $V_2=V_3-6$ loop 3 → $V_1=V_3+4$~~

loop 1 − loop2 ⇒

$V_1+V_2-10-V_2-V_3+6=0$

$\Rightarrow V_1-V_3-4=0$ — loop 3

(d) Now, have you been able to solve the simultaneous equations to get V_1, V_2, and V_3?

☐ Yes ☑ No

If yes, what are they? If not, why are the equations not solvable, and what is your conclusion? *[Hint: think of the relation between number of meshes and the number of independent KVL equations that are solvable]*

$V_1 =$ The third equatio here is redundant,
$V_2 =$ So using 2 equation ~~solving~~ finding
$V_3 =$ three variable is not possible.

Part 2: KCL

Theory

KCL stands for Kirchhoff's Current Law, which is another fundamental principle used in electrical engineering and physics. It states that the total current entering a node in a circuit must equal the total current leaving the node. In other words, **KCL states that the algebraic sum of currents entering and exiting a node is equal to zero.** This law is also essential for analyzing circuits and predicting the behavior of electrical systems.

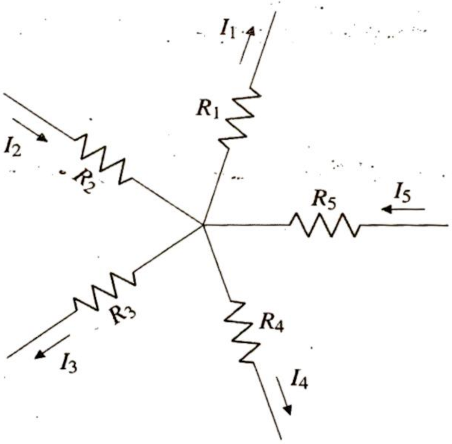


Figure 2: Illustration of KCL

To illustrate KCL, consider Fig. 2. Here, we can see 5 branches connected to 1 node. The exiting currents are I_1, I_3, I_4 and the entering currents are I_2, I_5. Applying KCL gives,

$$\Sigma i = I_1 + (-I_2) + I_3 + I_4 + (-I_5) = 0$$

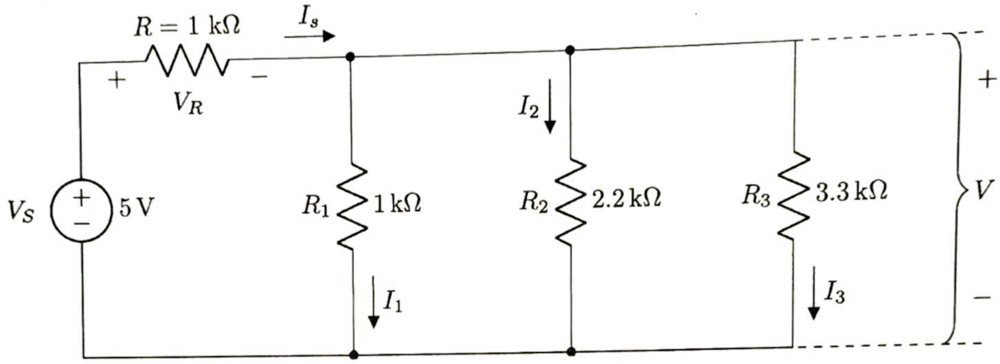
$$\Rightarrow I_1 + I_3 + I_4 = I_2 + I_5$$

Which can be interpreted as,

Sum of currents entering a node = Sum of currents leaving the node

Procedures

- Measure the resistances of the provided resistors and fill up the data table.
- Construct the following circuit on a breadboard. Try to use minimum number of jumper wires:



Circuit 2

- Measure the voltage and current across each resistor (V_R, V, I_s, I_1, I_2, & I_3) as shown in the figure above. Use a multimeter to measure the voltage, and use Ohm's law to calculate the current through each resistor. Fill up the data tables.

- Verify KCL as $\sum i = 0$ for the node connecting R to R_1, R_2, & R_3 (Assume positive exiting currents).

  For this node, $\sum i = -I_s + I_1 + I_2 + I_3$

- Calculate the theoretical values of I, I_1, I_2, I_3 and note them down in the 'Theoretical Observation' row in Table 5. For I_1, I_2, & I_3 use the *Current Divider Rule*. Relevant formulas are given below for your convenience:

$$I = \frac{V_s}{R+R_p} \qquad I_1 = \frac{(R_1)^{-1}}{(R_p)^{-1}} \times I_s \qquad I_2 = \frac{(R_2)^{-1}}{(R_p)^{-1}} \times I_s$$

$$I_3 = \frac{(R_3)^{-1}}{(R_p)^{-1}} \times I_s \qquad \text{where } R_p = \left((R_1)^{-1} + (R_2)^{-1} + (R_3)^{-1}\right)^{-1}$$

Data Tables

Signature of Lab Faculty:	[signature]	Date:	5-3-25

** ***For all the data tables, take data up to three decimal places, round to two, then enter into the table.***

Table 3: Resistance Data

For all your future calculations, please use the observed values only **(even for theoretical calculations)**.

Notation	Expected Resistance	Observed Resistance (kΩ)
R	1 kΩ	0.98
R_1	1 kΩ	0.98
R_2	2.2 kΩ	2.15
R_3	3.3 kΩ	3.22

Table 4: Data from Circuit 2

In the following table, I_1 is the current through resistor R_1. Similar syntax applies to remaining resistors. The voltage supplied to the complete circuit is denoted by V_s and the current being supplied to the whole network is denoted as I_s.

Observations	V_s (V) (from dc power supply)	V_s (V) (using multimeter)	V_R (V)	$I_s = \frac{V_R}{R}$ (mA)	V (V)	$I_1 = \frac{V}{R_1}$ (mA)	$I_2 = \frac{V}{R_2}$ (mA)	$I_3 = \frac{V}{R_3}$ (mA)	$\Sigma i = -I_s + I_1 + I_2 + I_3$ (mA)
Experimental	5	5	3.18	3.24	1.81	1.84	0.84	0.56	0
Theoretical			3.25	3.25	1.79	1.82	0.83	0.56	0

Here, Absolute error in $\sum i$ calculation = 0

Questions

5. Kirchoff's current law (KCL) states that *the algebraic sum of branch currents flowing into and out of a node is equal to zero*. This is a consequence of another principle.

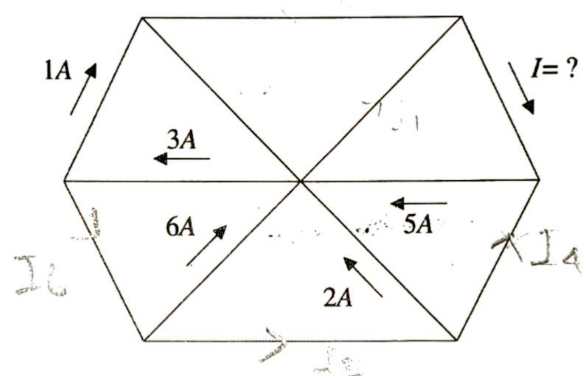
Which principle is it?

☐ Conservation of Energy ☑ Conservation of Electric Charge ☐ None of them

Why is your selection valid?

as $\Sigma I_{in} = \Sigma I_{out}$
I is rate of charge flowing in a circuit

6. Using KCL, determine the current *I* for the following circuit.



$~~I_1+I_2+3=13~~$
$~~\Rightarrow I_1+I_2=10~~$

$~~I_2+1=I_3~~$
$~~\Rightarrow I_2-I_3=-1~~$

$\Rightarrow I$

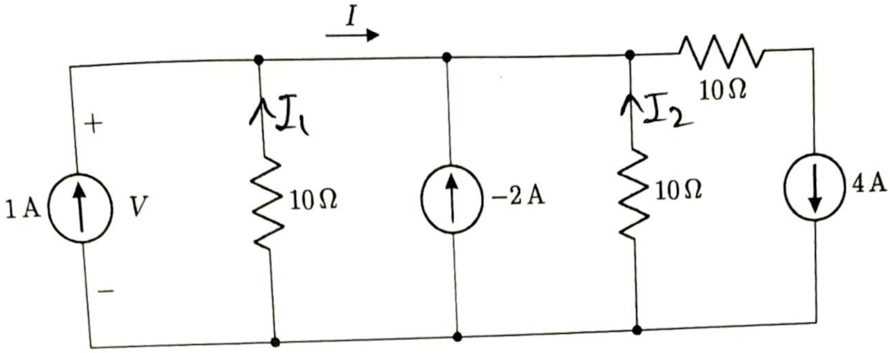
$I_6+1=3$
$\Rightarrow I_6=2\,A$

$I_6=6+I_5$
$\Rightarrow I_5=-4\,A$

$I_5=2+I_4$
$\Rightarrow I_4=-6\,A$

$I_4+I=5$
$\Rightarrow I=11\,A$

7. For the following circuit, determine the current I using only KCL and Ohm's Law.



$-1 - I_1 + 2 - I_2 + 4 = 0$

$\Rightarrow I_1 + I_2 = 5$

$\Rightarrow \frac{V}{10} + \frac{V}{10} = 5 \Rightarrow V = 25\ V$

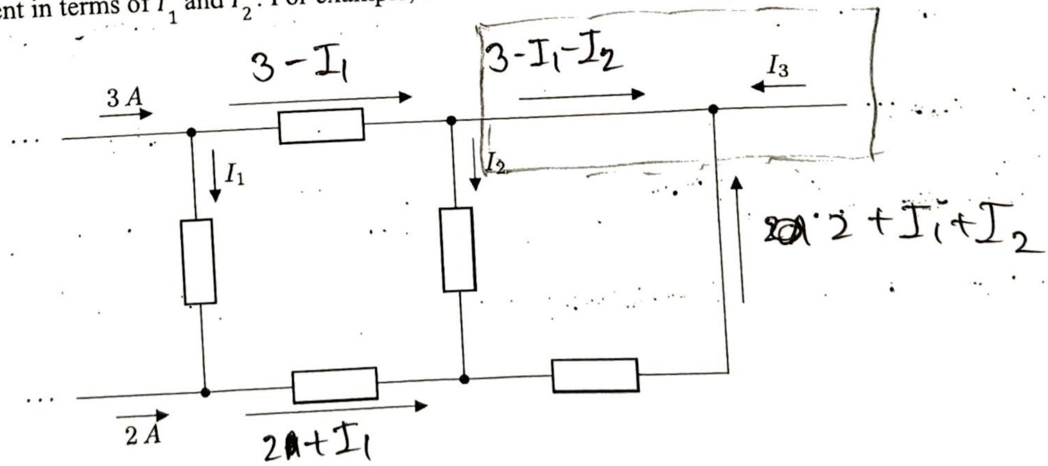
$\therefore I_1 = \frac{25}{10} = 2.5A \quad \therefore I = 2.5 + 1 = 3.5\ A$

8.

(a) The statement '*KCL can also be applied to any area and volume as the sum of currents leaving an area or a volume is equal to the sum of currents entering the area or the volume*' is—

☑ True ☐ False

(b) Apply KCL and write beside each of the large arrows in the following circuit the current in terms of I_1 and I_2. For example, one of those will be: $2 + I_1 + I_2$.



(c) Based on the current labels in (b), apply KCL to a suitable connection indicating dot (•) to determine the current I_3.

$I_3 + 3 - I_1 - I_2 + 2 + I_1 + I_2 = 0$

$\Rightarrow I_3 = -5\,A$

(d) Now in the same circuit, form an area (or surface) so that you can determine I_3 by applying KCL only once. Circle the area in the diagram. You are not allowed to write or apply more than one KCL equation.

The best place to apply kcl for I_3 is in the juction where I_3 entering. It takes only one equation.

(e) Based on the concept you get from (d), look again at your choice in (a) and evaluate yourself below–

☐ My choice in (a) was wrong

☑ My choice in (a) was correct

☐ It's gone over my head

Report

1. Fill up the theoretical parts of all the data tables.
2. Answer to the questions.
3. Discussion *[your overall experience, accuracy of the measured data, difficulties experienced, and your thoughts on those]*. Start writing from below the line.

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cussion

This experiment was about ~~va~~ verification of KVL & KCL.

This experiment was really special as we got to experience these theories in real life. The circuit building was easy. We build ~~the~~ ~~cir~~ two circuit to see if they follow KCL and KVL. Our results say they do follow these theories.

It was a great experiment as we could learn about these topics in details and solve our confusions.