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Experiment No.4
Kirchhoff's Laws

1.Introduction

1.1 Objective:

You may already have become familiar with Kirchhoff's laws and power calculations in the Electrical Circuit lecture. In this lab, we will verify these laws.

1.2 Components:

1. Digital Multimeter.
2. Electrical and Electronic System Trainer Kit or power supply.
3. Breadboard.
4. Resistors (R1=470 Ω, R2=1K Ω, R3=2kΩ, R4=3kΩ, R5=1.2kΩ, R6 = 2.4 kΩ, R7 = 1.8 kΩ, R8 = 3.6 kΩ)
5. Wires.

1.3 Theory:

In the previous experiment, we learned that a single equivalent resistance, (R_T) can be found when two or more resistors are connected together in either series, parallel or combinations of both, and how these circuits obey Ohm's Law.

However, sometimes in complex circuits such as bridge or T networks, we cannot simply use Ohm's Law alone to find the voltages or currents circulating within the circuit. For these types of calculations, we need certain rules which allow us to obtain the circuit equations and for this we can use Kirchhoff's Circuit Law.

In 1845, a German physicist, Gustav Kirchhoff developed a pair or set of rules or laws which deal with the conservation of current and energy within electrical circuits. These two rules are commonly known as: *Kirchhoff's Circuit Laws*; one of Kirchhoff's laws is dealing with the current flowing around a closed circuit and it is called Kirchhoff's Current Law, (KCL) while the other law deals with the voltage sources present in a closed circuit and it is called Kirchhoff's Voltage Law, (KVL).

Kirchhoff's First Law – The Current Law, (KCL)

Kirchhoff's Current Law or KCL, states that the "*total current or charge entering a junction or node is exactly equal to the charge leaving the node as it has no other place to go except to leave, as no charge is lost within the node*". In other words, the algebraic sum of ALL the currents entering and leaving a node must be equal to zero, $I_{(exiting)} + I_{(entering)} = 0$. This idea by Kirchhoff is commonly known as the Conservation of Charge.

Kirchhoff's Current Law

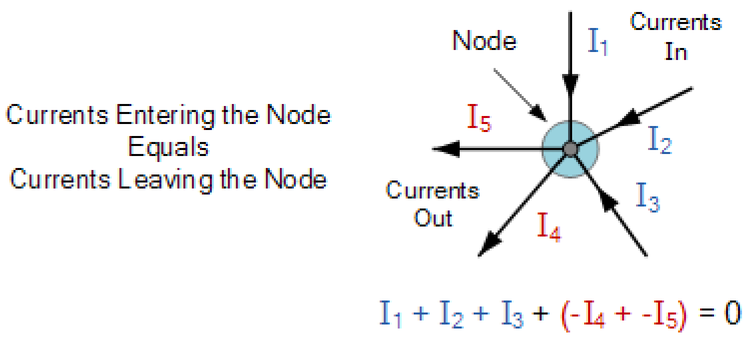


Figure 1: Kirchhoff's Current Law

In the above Figure (1), the three currents entering the node, I_1, I_2, I_3 are all positive in value and the two currents leaving the node, I_4 and I_5 are negative in value. Then this means we can also rewrite the equation as;

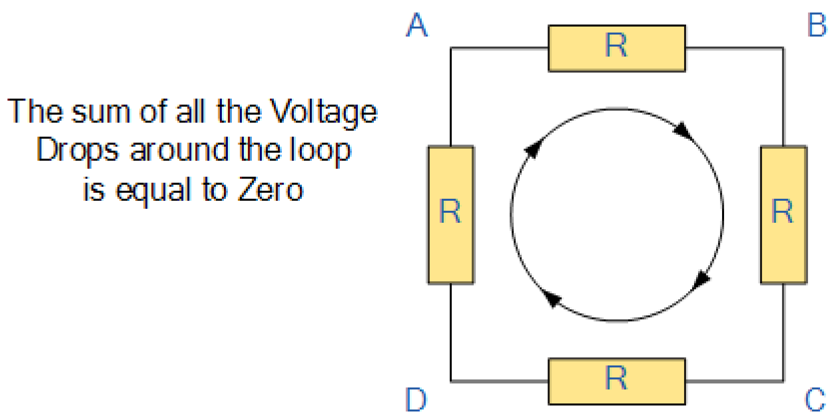
$$I_1 + I_2 + I_3 - I_4 - I_5 = 0$$

The term Node in an electrical circuit generally refers to a connection or junction of two or more current carrying paths or elements such as cables and components. Also, for current to flow either in or out of a node a closed-circuit path must exist. We can use Kirchhoff's current law when analyzing parallel circuits.

Kirchhoff's Second Law – The Voltage Law, (KVL)

Kirchhoff's Voltage Law or KVL, states that "*in any closed loop network, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop*" which is also equal to zero. In other words, the algebraic sum of all voltages within the loop must be equal to zero. This idea by Kirchhoff is known as the Conservation of Energy.

Kirchhoff's Voltage Law



$$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$$

Figure 2: Kirchhoff's Voltage Law

From Figure (2), starting at any point in the loop continue in the same direction noting the direction of all the voltage drops, either positive or negative, and returning back to the same starting point. It is important to maintain the same direction either clockwise or anti-clockwise or the final voltage sum will not be equal to zero. We can use Kirchhoff's voltage law when analyzing series circuits.

Power Consumption:

The power absorbed by an element is equal to the product of the voltage across it and the current passing through it (in the direction from high to low potential), i.e. $P = V \times I$. For a resistor, this value is always positive (implying that the resistor "absorbs" power). The value will be negative if an element "delivers" power (which is usually but not always the case for a power source).

When analyzing either DC circuits or AC circuits using Kirchhoff's Circuit Laws a number of definitions and terminologies are used to describe the parts of the circuit being analyzed such as: node, paths, branches, loops and meshes. These terms are used frequently in circuit analysis so it is important to understand them.

Common DC Circuit Theory Terms:

• Circuit – a circuit is a closed loop conducting path in which an electrical current flows.

• Path – a single line of connecting elements or sources.

• Node – a node is a junction, connection or terminal within a circuit were two or more circuit elements are connected or joined together giving a connection point between two or more branches. A node is indicated by a dot.

• Branch – a branch is a single or group of components such as resistors or a source which are connected between two nodes.

• Loop – a loop is a simple closed path in a circuit in which no circuit element or node is encountered more than once.

• Mesh – a mesh is a single open loop that does not have a closed path. There are no components inside a mesh.

Note that:

Components are said to be connected together in Series if the same current value flows through all the components.

Components are said to be connected together in Parallel if they have the same voltage applied across them.

2.Experiments:

2.1 Exercise 1:

Connect the circuit as shown in Figure (3) With DC voltage = 12V and R1 = 470 Ω, R2 = 1 KΩ, R3 = 2 KΩ, R4 = 3 KΩ, R5 = 1.2 KΩ. then using the digital multimeter, measure the voltage value at Vab, Vbc, Vcd, and voltage across R2 with polarity and verify KVL in loop 1,2 and fill in Table (1).

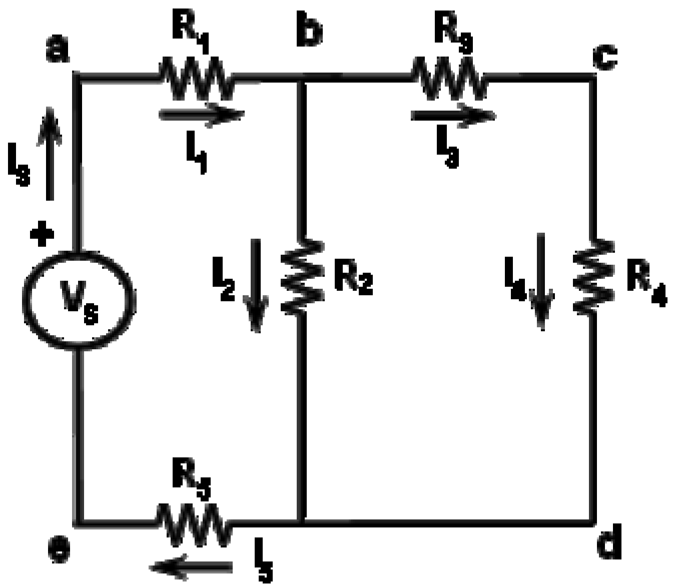


Figure 3: The Circuit For Exercise 1

Voltage Values	
Vab	
Vbc	
Vcd	
V across R2	

Table 1: Voltage Values to verify KVL

Also, measure I1, I2 and I3 and verify KCL at node b and fill in Table (2).

Current Values	
I1	

I2	
I3	

Table 2: Current Values to verify KCL

2.2 Exercise 2:

Build the circuit shown in Figure (4) using resistors: R1 = 2.4 kΩ, R2 = 3 kΩ, R3 = 1.8 kΩ, R4 = 1.2 kΩ and R5 = 3.6 kΩ (measure their resistances and write them in the first column of Table 5. Use the 5V source for Vs2 and use a 15V source for Vs1.

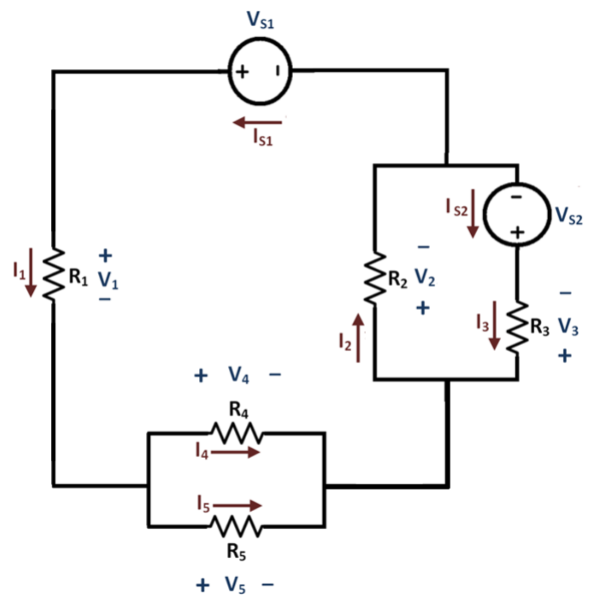


Figure 4: The Circuit For Exercise 2

It is strongly recommended that you show your circuit to the TA/instructor before proceeding further (if the circuit is built wrong, all subsequent measurements and calculations will be invalid).

Now your goal is to find out all the voltages, Vs1, Vs2, V1, V2, V3 … V5, using the minimum number of voltmeter measurements. Some of these voltages may be equal. Find out how many different voltages there are in the circuit. If there are x different voltages, you don't necessarily need to take x measurements. You can deduce some of the voltages from others using KVL. Fill in Table 3. Enter the voltages across each of the elements in the second column of Table 5.

What is x, the number of different voltages	

in this circuit? What are these voltages? [do not assume that the supply voltages are exactly the same as their nominal values; measure or calculate them]	
What is the minimum number of voltmeter measurements that you need to deduce all x voltage values? Which values did you measure and how did you calculate the rest?	

Table 3: Number of Voltages

Your next goal is to find all the currents using the minimum number of ammeter measurements (you WILL NOT use Ohm's law to calculate them from the resistances and voltages; you will rely only on ammeter readings and KCL). Some of these currents are the same. Find out how many different currents there are in the circuit. If there are y different currents, you don't necessarily need to take y ammeter measurements. As before, you can deduce some of the currents from others. Fill in Table 4. Enter the values of all currents in the third column of Table 5.

What is y, the number of different currents in this circuit? What are these currents?	
What is the minimum number of ammeter measurements that you need to deduce all y current values? Which values did you measure and how did you calculate the rest?	

Table 4: Number of Currents

In the fourth column of Table 5, calculate (with proper sign) the power absorbed or delivered by each of the seven components of the circuit. Then see if the "total power dissipated" is equal to the "total power generated" in the circuit (as it should according to the law of conservation of energy).

Element	Voltage (V)	Current (I)	Power (W)
R1=	V1=	I1=	P1=
R2=	V2=	I2=	P2=
R3=	V3=	I3=	P3=

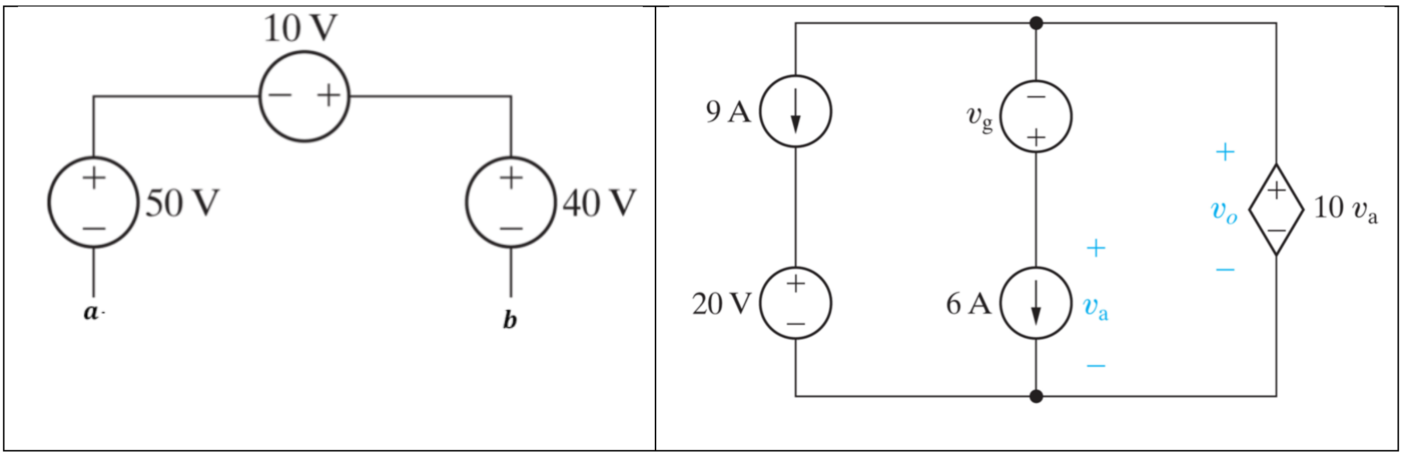
R4=	V4=	I4=	P4=
R5=	V5=	I5=	P5=
15V Supply	VS1=	IS1=	PS1=
5V Supply	VS2=	IS2=	PS2=
Total power dissipated in the circuit (sum of all positive quantities) =			
Total power generated in the circuit (sum of all negative quantities) =			

Table 5: Exercise 2 Calculations

3.Discussion:

1. calculate all the voltages and currents theoretically and compare them with the measured voltages and currents of exercise 1.
2. verify KVL and KCL on the circuit as shown in Figure (3)
3. a) In the circuit in Figure 1(a), find vab, the voltage between nodes a and b.

   b) In the circuit in Figure 1(b), write an equation relating vg and va by applying KVL to the right loop. Then write an expression for the voltage across the 9A source in terms of vg and va by applying KVL to the left loop.

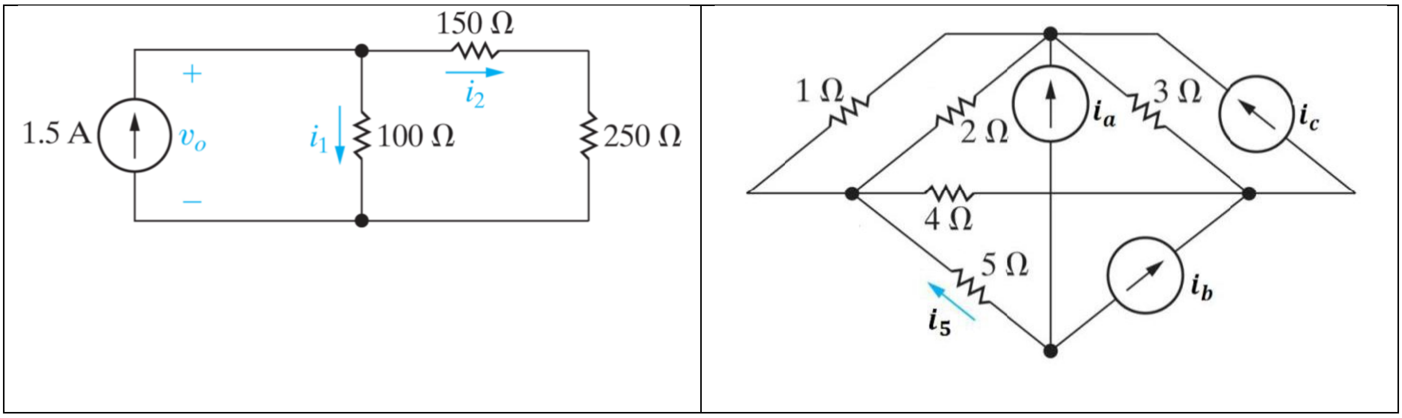


a b

Figure 5: Circuits of Problem 3

4. a) In the circuit in Figure 2(a), find $i2$ if $i1$ = 1.2 A.

   b) In the circuit in Figure 2(b), what is the value of $i5$ if ia, ib and ic are 1, 2 and 3 A, respectively?



a b

Figure 6: Circuits of Problem 4

5. In the following circuits, state whether the 5V power source is "absorbing power from" or "delivering power to" the circuit. Find this power.

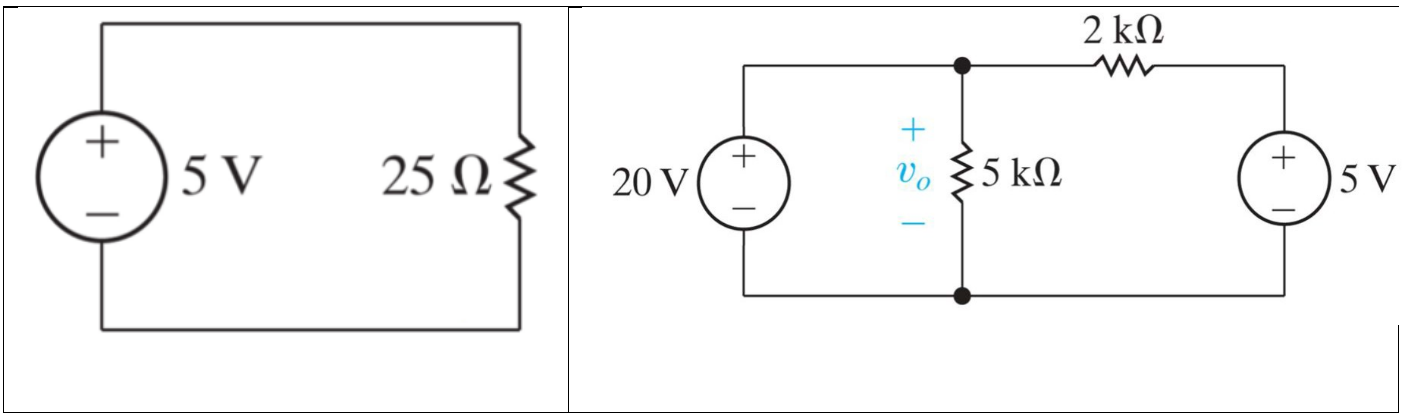


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Figure 7: Circuits of Problem 5