CIRCUIT THEORY

ΠΑΝΕΠΙΣΤΗΜΙΟ ΔΥΤΙΚΗΣ ΑΤΤΙΚΗΣ
UNIVERSITY OF WEST ATTICA

DEPARTMENT OF COMPUTER AND INFORMATION TECHNOLOGY AND COMPUTER ENGINEERING

PROJECT 1
KIRCHHOFF 'S LAWS - OHM LAW - POTENTIOMETER - RHEOSTAT

CIRCUIT THEORY

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ADDITIONAL INFORMATION:

CIRCUIT THEORY

DATE OF EXERCISE : 9/3/2022
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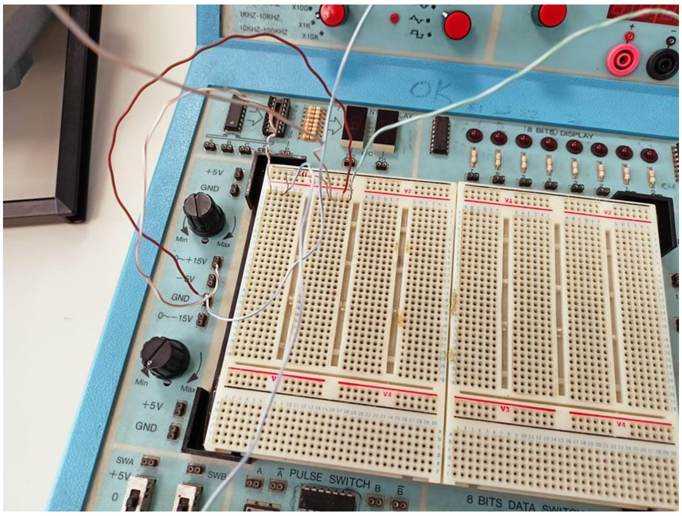
PHOTOGRAPHS OF EQUIPMENT USED IN THE LABORATORY

Breadboard/Cables



Fixed Resistance Resistor

Analog Multimeter

Digital Bench Multimeter

Potentiometer

CIRCUIT THEORY

CONTENTS

1.3.1 : Kirchhoff 's 1st law

Theoretical Solving

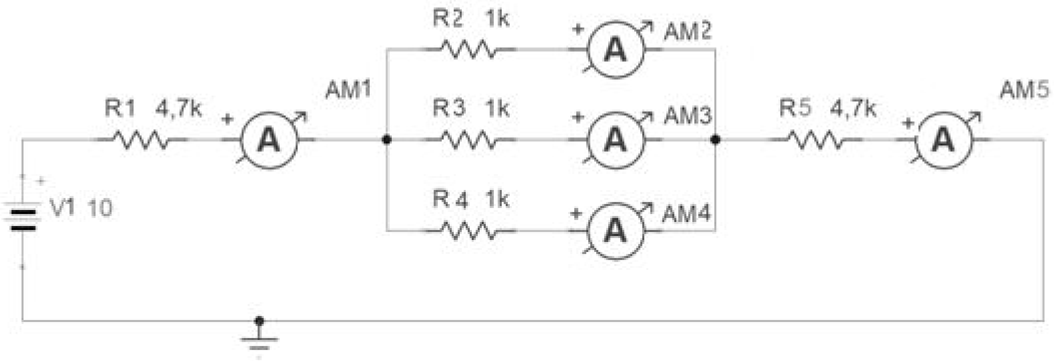


Figure 1

1 Kirchhoff 's law, or in other words Kirchhoff 's law of currents, asserts that the current entering a node is equivalent to the current leaving it. Therefore, from the chapters "Simulated Solution" and "Experimental Solution" representing the circuit in Figure 1, it can be seen that the current ammeters AM1 and AM5 give the same reading for the current. Also, the sum of the readings of ammeter AM_2, AM_3 and AM_4 is the same as the readings of ammeter AM_1 and AM_5. More specifically, the current entering the node (the point immediately after ammeter AM_1) branches into three isomeric currents and when it leaves the node (the point immediately before resistor R_5) is the same as the current before entering the node.
Therefore, Kirchhoff 's law of currents is verified and, of course, this is justified by the fact that the current that branches when it enters a node cannot have more or less intensity when it leaves it.

Simulative Resolution

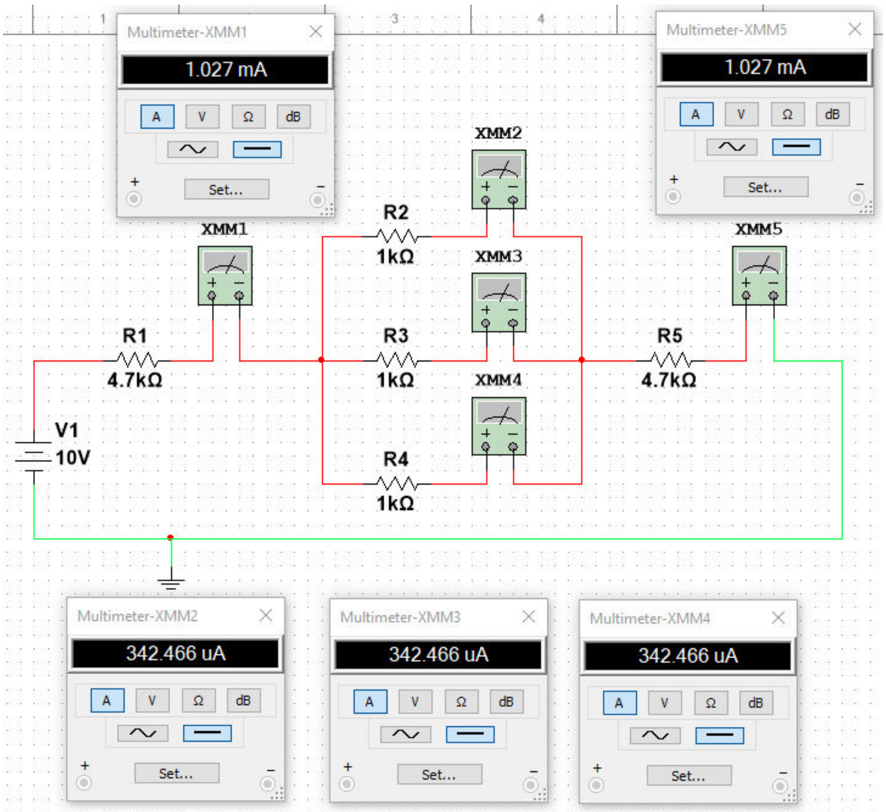


Figure 2

From the simulated solution of the circuit in the simulation software "Multisim" (Figure 2), the measurements of the multimeters (set to calculate DC current intensity) are recorded, leading to remarkable observations. In more detail, the current before entering the node (the point immediately after the ammeter XMM_1) has an intensity of 1.027 mA from the reading of the ammeter XMM_1. Once, the current enters the node, the readings of the ammeter XMM_2, XMM_3 and XMM_4 are 342.466 uA. It is worth noting that the sum of the three readings (XMM_2, XMM_3, XMM_4) is 1.027 mA which is equivalent to the reading of the ammeter XMM_1 (the current before entering the node). Finally, the reading of the ammeter XMM_5 is also 1.027 mA.
In summary, from the above readings of the ammeters XMM_1, XMM_2, XMM_3, XMM_4 and XMM_5, it is concluded that Kirchhoff's law of currents is verified, ie, that the current entering a node equals the current leaving the node .

Experimental Solution

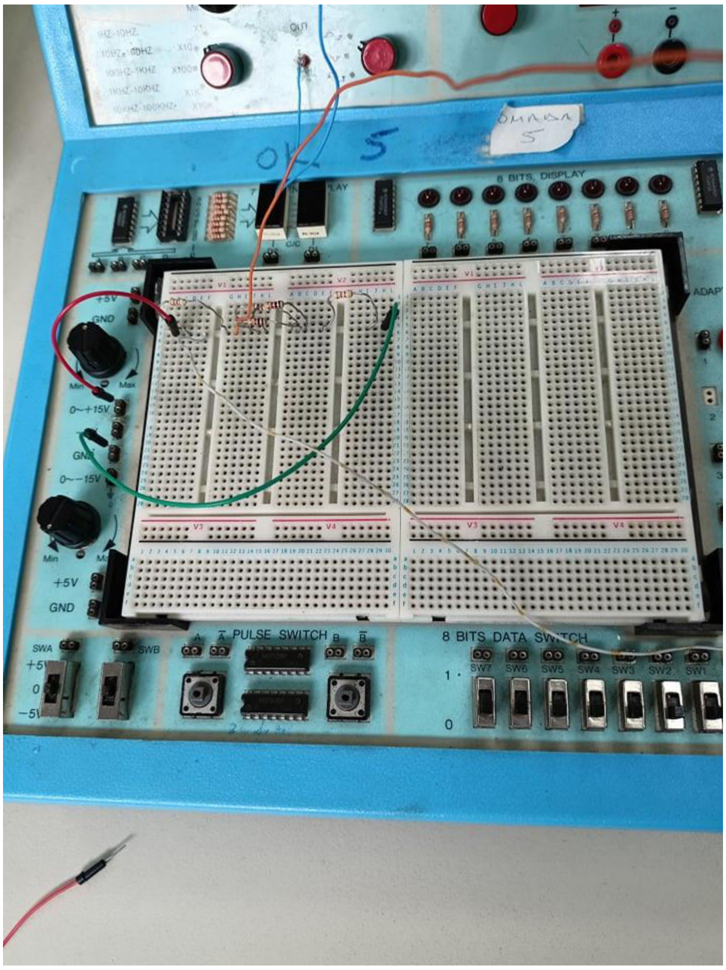


Figure 3

Figure 4

For the experimental solution of the circuit carried out inside the laboratory, the " breadboard " interface board (Figure 3), two constant value resistors with 4.7 kΩ resistance, three constant value resistors with 1 kΩ resistance, a digital bench-top multimeter set to calculate the DC voltage (voltmeter), an analog multimeter set to calculate the DC intensity (ammeter, Figure 4) and two cables were used.

Initially, the digital bench-top multimeter configured to calculate DC voltage was used , ie, configured to be a voltmeter on a 1 volt scale. The positive end was connected to the DC source and the negative end to ground in order to set the source to 10 Volts . After, the source is set at 10 Volts, the voltmeter is disconnected and the circuit assembly begins.

First of all, one constant value resistor with a resistance of 4.7 kΩ is connected in series and to the left of the node containing three equivalent constant value resistors with a resistance of 1 kΩ each connected in parallel with each other. Also connected in series with the node and to its right is the second constant value resistor with a resistance of 4.7 kΩ .

Next, the analog multimeter set to calculate the DC current intensity is used, ie, set to be an ammeter on a 10 mA scale. In the circuit of Figure 3, the ammeter is connected in series at each of the five points and immediately to the right of each resistor, just as represented in the circuit of Figure 1 in the "Theoretical Solution" section.

In summary, the ammeter readings at each point are identical to those recorded in the "Simulated Solution" chapter with infinitesimal differences that do not affect the conclusion recorded for the circuit (Theoretical Solution chapter, Figure 1), ie, that Kirchhoff 's 1 the law is verified.

1.3.2 : Kirchhoff 's 2nd law

Theoretical Solving

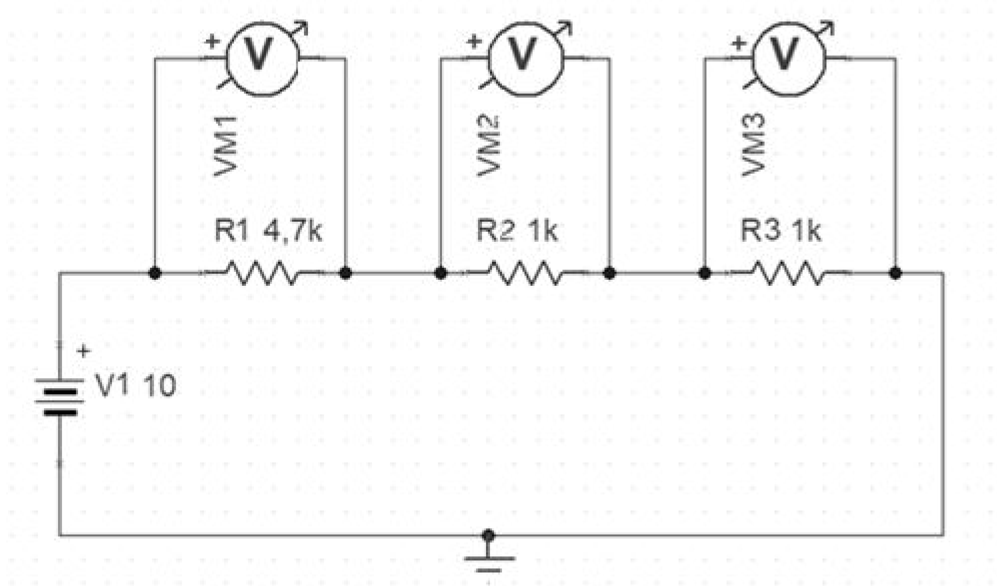


Figure 5

Kirchhoff 's 2nd law , or in other words Kirchhoff 's law of trends, asserts that the sum of all potential differences in the individual branches equals zero.
Therefore, from the chapters "Simulated Solution" and "Experimental Solution" representing the circuit of Figure 5,
it is found that the sum of the voltmeter readings VM_1, VM_2 and VM_3 equals the potential difference of the DC voltage source V_1 (10 volts).
The circuit operates as a voltage divider, ie, the potential difference of the source V_1, is distributed to the three resistors R_1, R_2 and R_3.
To summarize, Kirchhoff 's law of voltages is also verified by the excuse that the current in a closed circuit has a certain direction and therefore does not make it possible to have a voltage drop or more.

Simulative Resolution

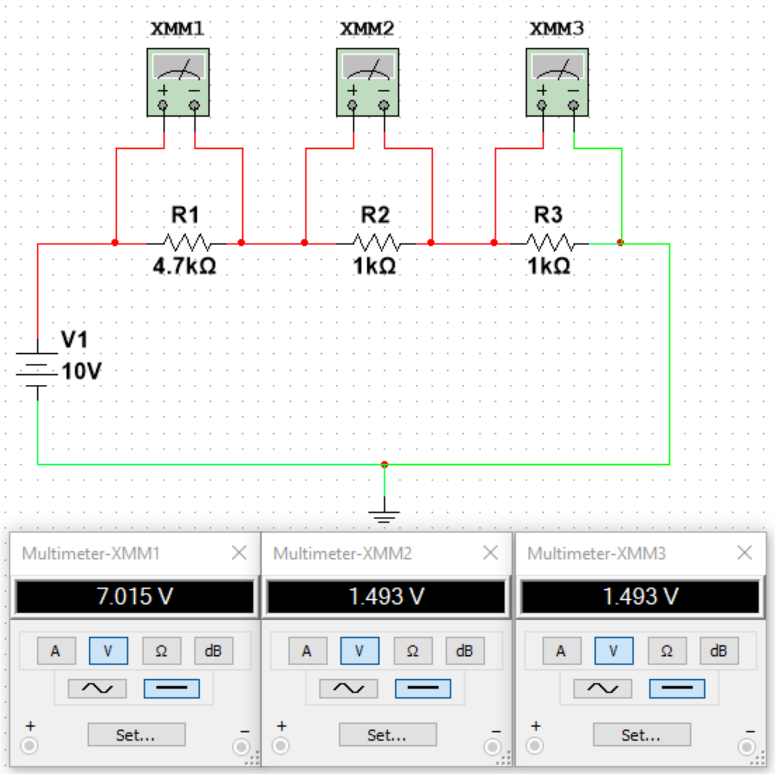


Figure 6

From the simulated analysis of the circuit in the "Multisim" software (Figure 6), the measurements of the multimeters (set to calculate DC voltage) are recorded, leading to notable observations. In more detail, the reading of the XMM $_1$ voltmeter is 7.015 Volts equivalent to the potential difference at the ends of the R $_1$ resistor (4.7 kΩ). Then, the reading of the XMM $_2$ voltmeter is 1,493 Volts equivalent to the potential difference at the ends of the R $_2$ resistor (1 kΩ). Finally, the reading of the voltmeter XMM $_3$ is 1.493 Volts which is equivalent to the potential difference at the ends of the resistor R $_3$ (1 kΩ). Assume that the direction of the current is clockwise. Kirchhoff's law of voltages asserts that the sum of all potential differences in the individual branches of a loop equals zero. Therefore, we have:

$-V_1 + V_{R1} + V_{R2} + V_{R3} = 0$ **=> =>**

$-10 + 7.015 + 1.493 + 1.493 = 0$ **=>**

$0 = 0$

In summary, from the above readings of the XMM $_1$, XMM $_2$ and XMM $_3$ voltmeters, it is concluded that Kirchhoff's law of stresses is verified.

Experimental Solution

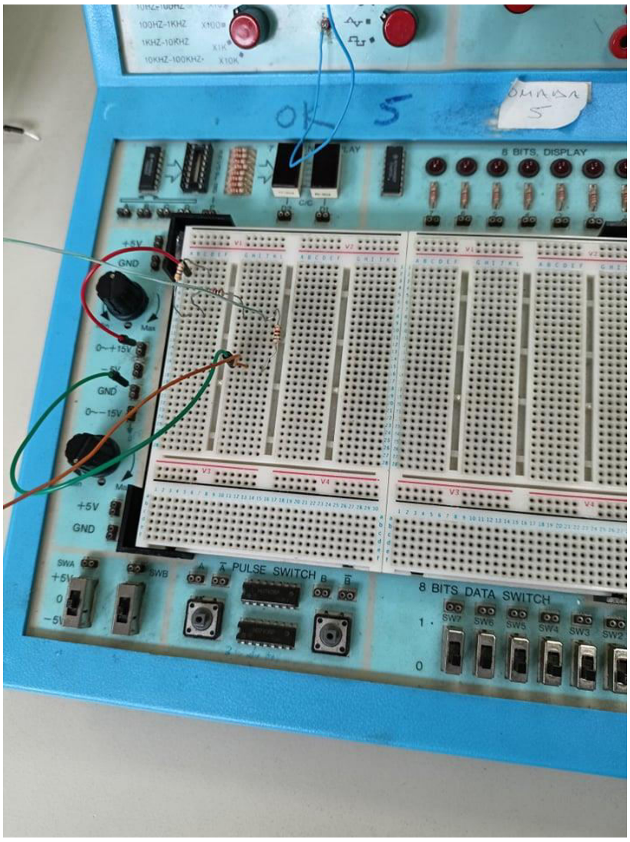


Figure 7

Figure 8

For the experimental solution of the circuit carried out inside the laboratory, the " breadboard " interface board (Figure 7), a constant value resistor with a resistance of 4.7 kΩ , two constant value resistors with a resistance of 1 kΩ and an analog multimeter set to calculate the DC voltage (voltmeter, Figure 8) were used.

Initially, the analog multimeter configured to calculate DC voltage
was used , ie, configured to be a voltmeter in the 1 volt range. The positive end was connected to the DC voltage source and the negative end to ground in order to set the source to 10 Volts . After, the source is set at 10 Volts, the voltmeter is disconnected and the circuit assembly begins.

First of all, the constant value resistors with a resistance of 4.7 kΩ, 1 kΩ and 1 kΩ are connected from left to right respectively and in series.

Next, the analog multimeter
is used again set to calculate the DC voltage, ie, set to be a voltmeter in the 1 volt range. In the circuit of Figure 7, the voltmeter is connected at each of the three points and in parallel with each resistor, exactly as represented in the circuit of Figure 5 in the "Theoretical Solution" section.

In summary, the voltmeter
readings at each point are identical to those recorded in the "Simulation Solution" chapter with infinitesimal differences that do not affect the conclusion recorded for the circuit (Theoretical Solution chapter, Figure 5), ie, that Kirchhoff 's 2 the law is verified

1.3.3 : Ohm's law

Theoretical Solution

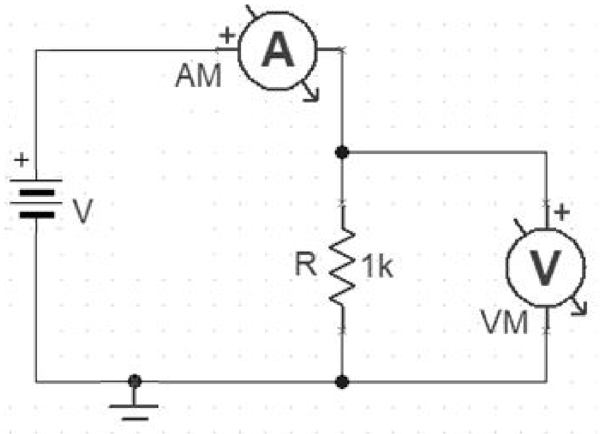


Figure 9

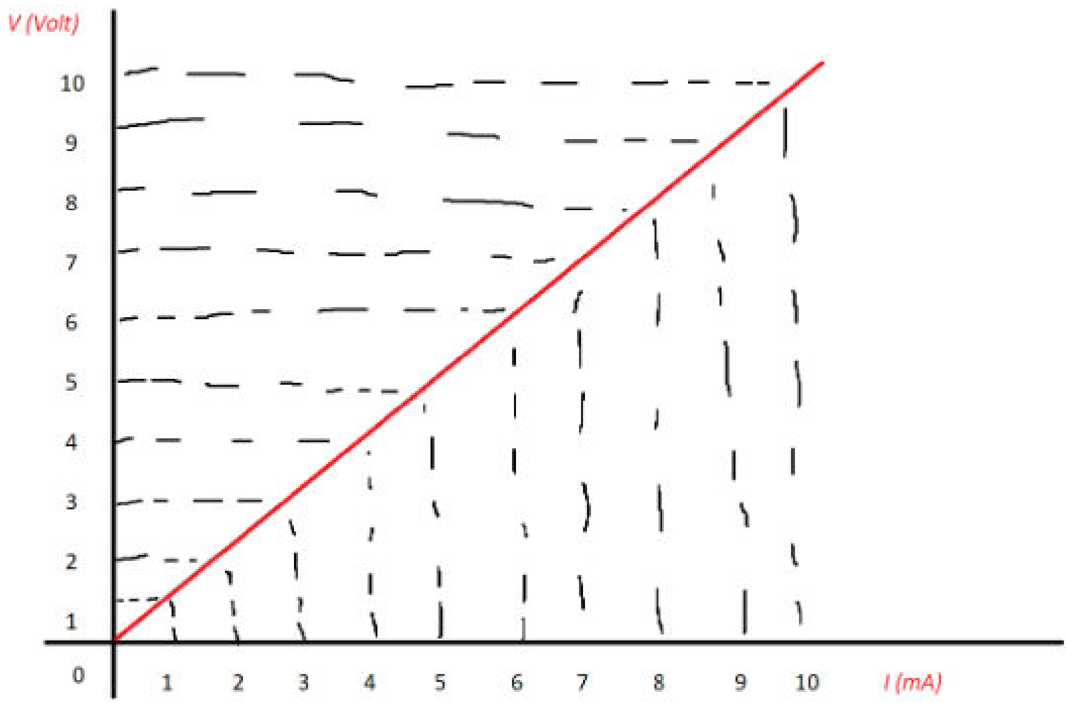


Figure 10

From the IV graph (Figure 10), it is observed that the current intensity I and voltage V have a linear relationship with each other. In other words, they are proportional to each other, ie, as the current intensity increases, the voltage increases and vice versa, verifying Ohm's law (I = V / R). The voltage is the cause and the current is the effect, so as the cause increases, so does the effect. Conversely, resistance decreases the intensity of the current and therefore they are inversely proportional quantities, ie, the greater the resistance R , the smaller the intensity of the current I.

Simulated Solution

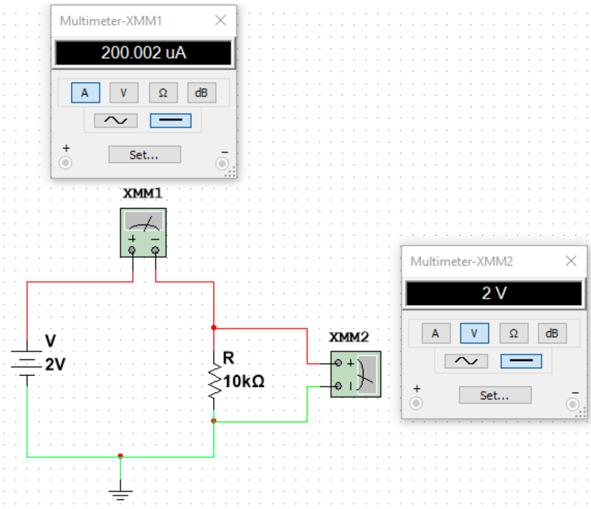


Figure 11

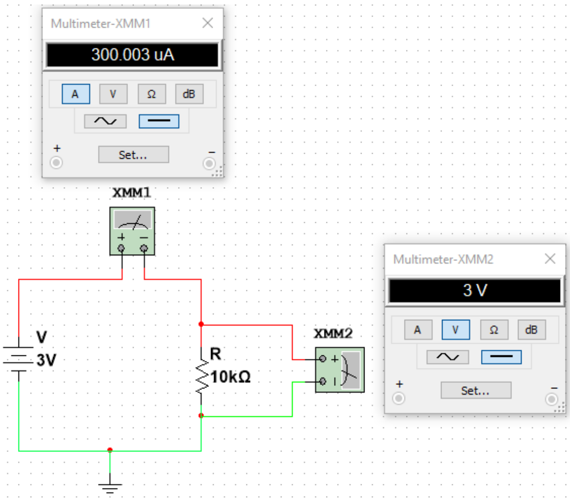


Figure 12

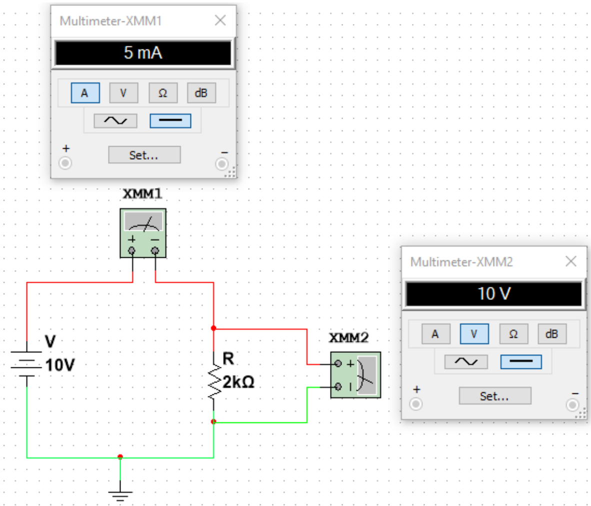


Figure 13

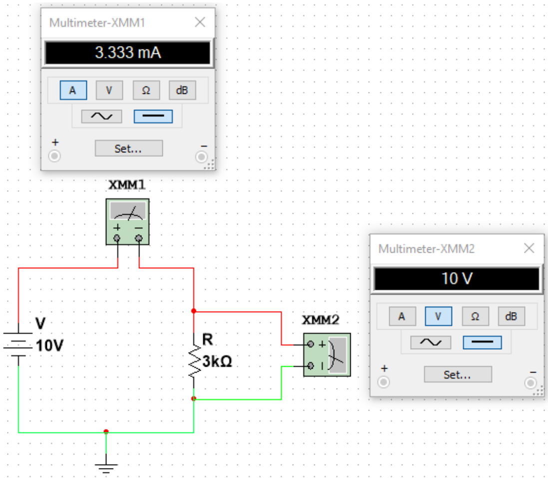


Figure 14

Contraction R = 1K											
Source voltage (V) (volts)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Voltage (I) (A)	0	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.01
Voltage drop in R (V) (Volt)	0	1	2	3	4	5	6	7	8	9	10

Sou volt											
Res (K		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Vol (A)		0.01	0.005	0.00333	0.0025	0.002	0.001667	0.001429	0.00125	0.001111	0.001
Voltage drop in R (V) (Volt)	1u	10	10	10	10	10	10	10	10	10	10

Table 1

Table 2

From the simulated solution of the circuit in the simulation software "Multisim" (Figures 11, 12, 13, 14), the measurements of the multimeters (configured to calculate DC current and voltage) are recorded, leading to remarkable observations.

Figures 11 and 12 are two snapshots from Table 1 for the case where the current intensity in Ampere and the voltage drop across resistor R (1 kΩ) in Volts are

recorded for various source voltage values in Volts. The observation is that as the source voltage increases, so does the current intensity, verifying Ohm's law (I and V being analogous quantities). The voltage drop across R takes the same value as the source voltage as it changes in each measurement recorded, verifying Kirchhoff 's law of voltages.

Figures 13 and 14 are two snapshots from Table 2 for the case where the current intensity in Ampere and the voltage drop across resistor R in Volt are recorded with the source voltage (10 Volt) constant and for various values of resistor R in kΩ . The observation is that as the resistance at R increases, the current intensity decreases, again verifying Ohm's law (I and R are inversely proportional quantities). The voltage drop across R takes the same value as the source voltage, verifying Kirchhoff 's law of voltages.

Experimental Solution

Figure 15

For the experimental solution of the circuit carried out in the laboratory, the " breadboard " interface board (Figure 15), a fixed-value resistor with a resistance of 1 kΩ, a digital bench-top multimeter configured to calculate the DC voltage (voltmeter, left of the breadboard in Figure 15) and an analog multimeter configured to calculate the DC current (ammeter, right of the breadboard in Figure 15) were used.
Initially, the digital bench top multimeter configured to calculate DC voltage was used, ie, configured to be

voltmeter in 1 Volt scale . The positive end was connected to the voltage source and the negative end to ground in order to set the source to 10 Volts . After, the source is set at 10 Volts, the voltmeter is disconnected and the circuit assembly begins.
First of all, the constant value resistor with a resistance of 1 kΩ is connected. Next, the digital bench multimeter is used again set to calculate the DC voltage, ie, set to be a voltmeter in the 1 Volt range. In the circuit represented in Figure 15, the voltmeter is connected in parallel with the resistor. The analog multimeter set to measure the current intensity on a 10 mA scale is connected in series before the resistor and after the positive end of the source.
In summary, the voltmeter and ammeter readings are the same as captured in the "Simulation Solution" section in Tables 1 and 2, verifying Ohm 's Law.

1.3.4 : Resistance connection as potentiometer

Theoretical solution

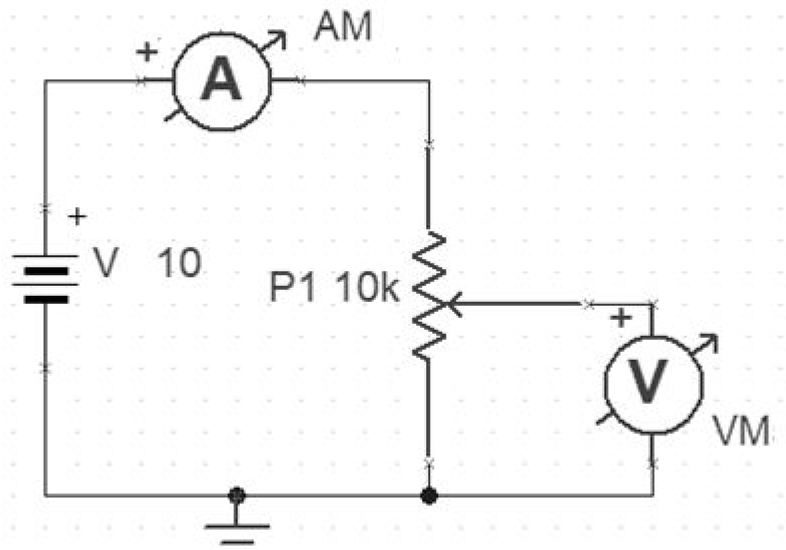


Figure 16

The circuit in Figure 16 takes advantage of the voltage divider connection. In other words, the source voltage is divided at the ends of the variable resistance resistor P_1, depending on its resistance.
Therefore, from the chapter "Simulated Solution" that

representing the circuit of Figure 16, it is seen that the reading of the AM ammeter is the same at each resistance value of the variable resistor, while the reading of the voltmeter changes depending on the resistance of the resistor. As can be seen in Table 3 in the "Simulated Solution" section, the potential difference at the ends of the resistor takes a proportional percentage of the source potential difference, verifying the voltage divider connection and Ohm's law.
The resistor is connected as a potentiometer and the resistance values range from 0 to 10 kΩ (0 - 100%). Therefore, the voltage at the ends of the potentiometer cannot exceed the voltage at the ends of the source and is therefore transferred in proportion to the value of the resistance taken by the potentiometer.

Simulated Solution

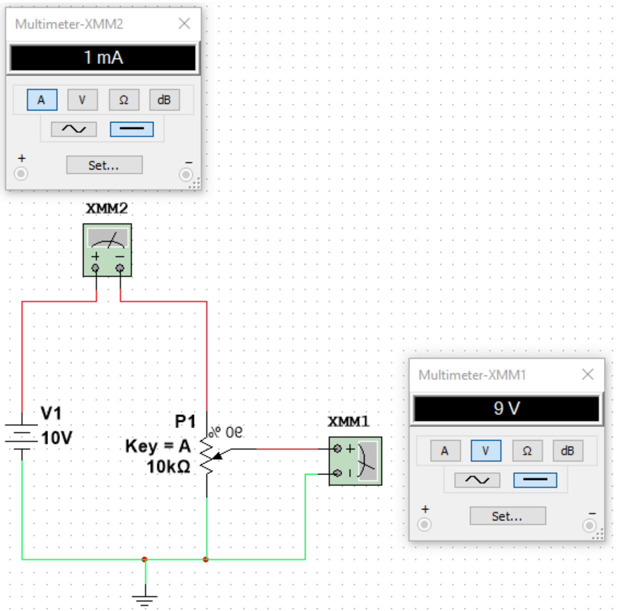


Figure 17

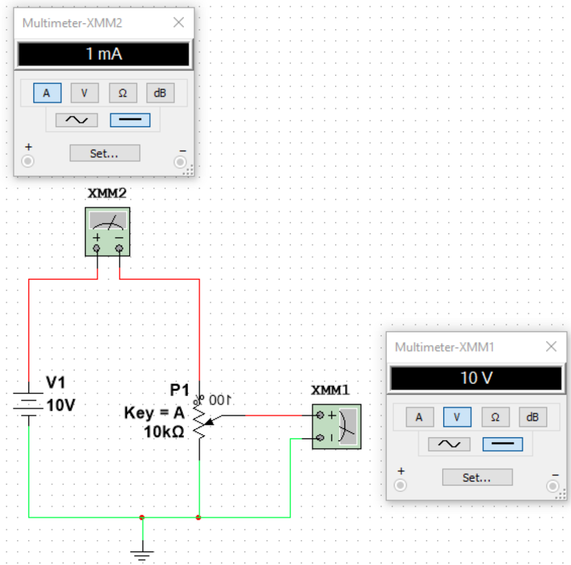


Figure 18

Resistance (R) %	10	20	30	40	50	60	70	80	90	100
Voltage (V) (Volts)	0.999999	2	3	4	5	6	7	8	9	10

Table 3

From the simulated solution of the circuit in the simulation software "Multisim" (Figures 17, 18), the measurements of the multimeters (configured to calculate DC current and voltage) are recorded, leading to remarkable observations. From Table 3 it is observed that as the value of the resistance varies, the potential difference at its ends varies the same, but does not exceed the potential difference at the ends of the source V. The circuit works like a voltage divider, ie, the potential difference at the ends of the resistor is a percentage of the potential difference at the source ends (the percentage varies).
The XMM $_2$
multimeter (ammeter) is connected in series with one end at the positive pole of the source and the other at the top end of the potentiometer, while the XMM $_1$ multimeter (voltmeter) is connected in parallel with the potentiometer with one end at the middle wire of the potentiometer and the other at ground.
Figures 17 and 18 are two snapshots from Table 3 and are comparable for 90% (Figure 17) and 100% (Figure 18) of the potentiometer resistance (10 kΩ) and as observed the voltage is transferred entirely to the ends of the potentiometer when it is at 100% of the resistance value (10 kΩ), verifying the voltage divider connection.

1.3.5 : Resistance connection as a dimmer

Theoretical solution

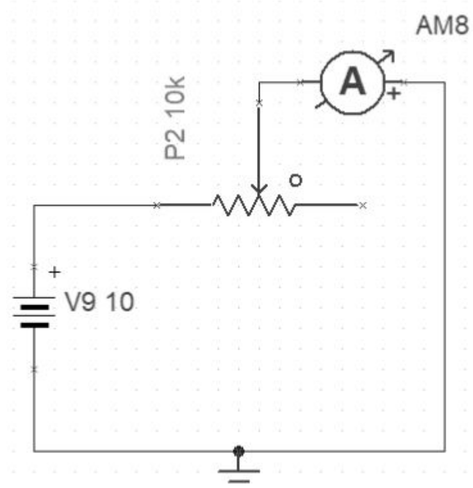


Figure 19

The circuit in Figure 19 takes advantage of the current divider wiring. In other words, the intensity of the current flowing through the ends of the variable resistance resistor P_2 is inversely proportional to the value the resistor takes.
Therefore, from the "Simulation Solution" section representing the circuit of Figure 19, it can be seen that the reading of the ammeter AM changes at each resistance value taken by the variable resistance resistor. As, it is found in Table 3 in the "Simulated solution" section, the current intensity takes an inversely proportional rate from the resistance of the variable resistance resistor, verifying the current divider connection and Ohm's law.
The resistor is connected as a rheostat and the resistance values range from 0 to 10 kΩ (0 - 100%). Therefore, according to Ohm's law, the intensity of the current flowing through the rheostat will decrease as the resistance in the rheostat increases.

Simulated Solution

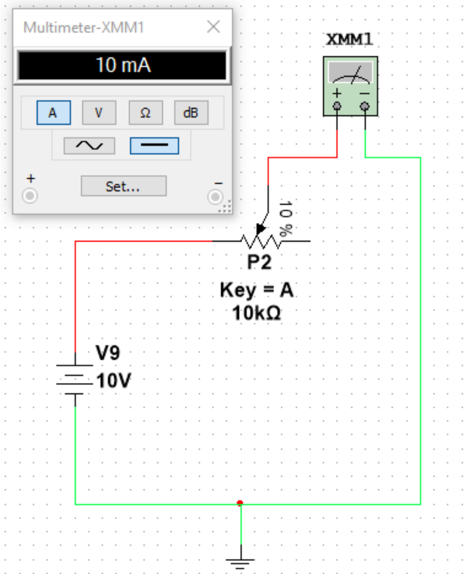


Figure 20

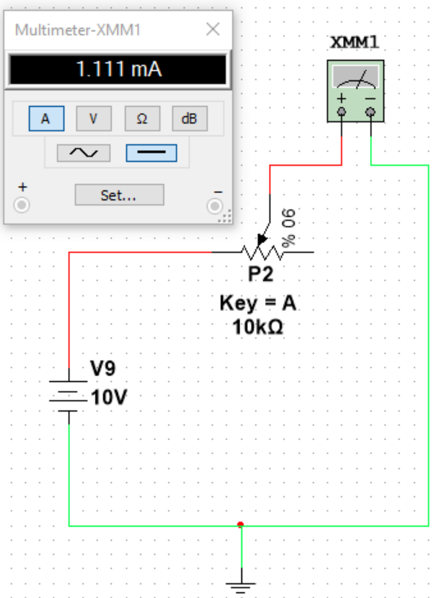


Figure 21

Resistance (R) %	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Voltage (I) (mA)	10	5	3.33	2.5	2	1,667	1,429	1.25	1.111	1

Table 4

From the simulated solution of the circuit in the simulation software "Multisim" (Figures 20, 21), the measurements of the multimeter (set to calculate the DC current intensity) are recorded, leading to remarkable observations. From Table 4 it is observed that as the value of the resistance varies, the intensity of the current flowing through the ends of the rheostat varies inversely. The circuit works like a current divider, ie, the intensity of the current flowing through the ends of the rheostat is an inverse percentage of the resistance of the rheostat (the percentage varies).

The XMM $_1$ multimeter (ammeter) is connected in series with one end connected to the middle wire of the rheostat and the other to ground.

Figures 20 and 21 are two snapshots from Table 4 and are comparable for 10% (Figure 20) and 90% (Figure 21) of the rheostat resistance (10 kΩ) and as observed the current decreases in a manner proportional to the rheostat resistance increasing , verifying the connectivity of the current divider and Ohm 's law.

1.6 : Questions

Question 1

What will happen in Figure 19 if the variable resistance goes to 0%? Calculate the current that will flow through the resistor. Is there a way to solve this particular problem?

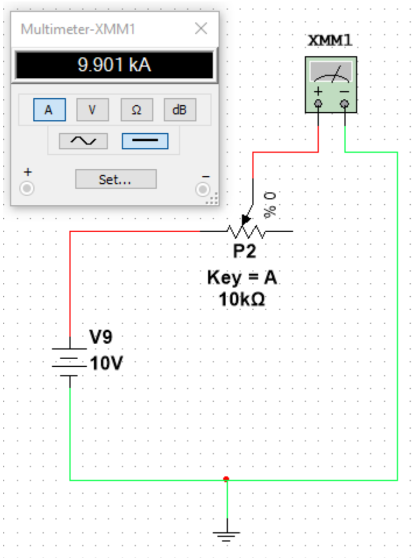


Figure 22

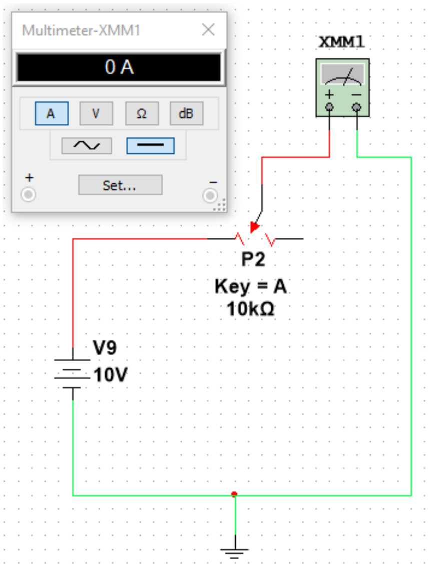


Figure 23

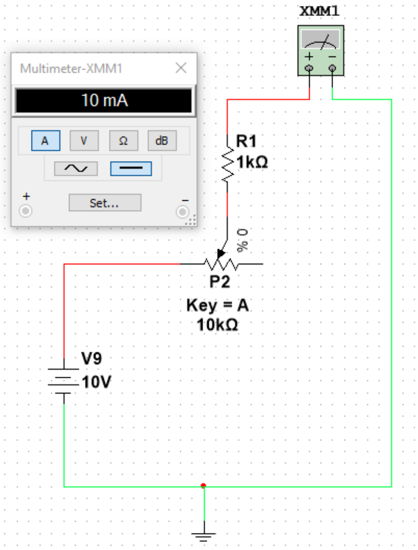


Figure 24

In Figure 19 (section 1.3.5 : Resistance connection as a dimmer, chapter "Theoretical Solution"), if the variable resistance goes to 0%, then, initially the ammeter reading will be 9.901 kA (Figure 22). The reading, clearly, is too high, with the consequence that the resistance connection to the ammeter is cut and the circuit becomes open (Figure 23). Ammeters have very little internal resistance and it is known from Ohm's law that current intensity and resistance are inversely proportional quantities. Therefore, the smaller the value of resistance, the larger the value of current intensity, which justifies the very high reading of the ammeter when the variable resistance goes to 0%. The problem is corrected by placing a fixed value resistor (1 kΩ) at the end where the variable resistance value is changed (Figure 24). So, when the variable resistance goes to 0%, then the problem of high current intensity will not arise due to the very low internal resistance of the ammeter, which leads to an open circuit.

Question 2

The voltage measurement in Figure 9, would it be more correct to include the voltage drop at the ends of resistor R and the ammeter? Justify.

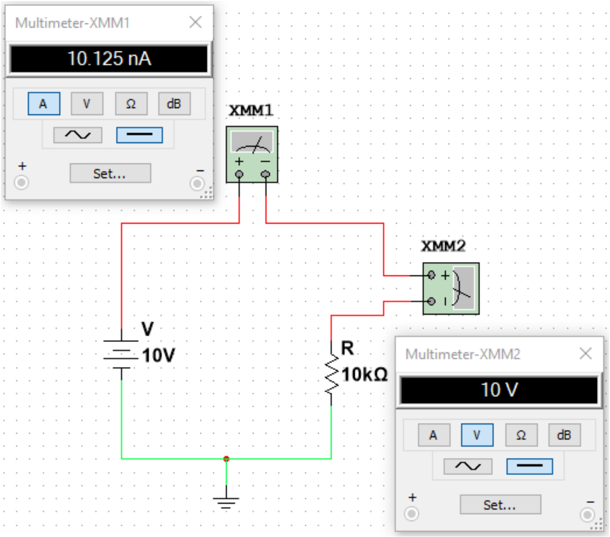


Figure 25

The voltage measurement in Figure 9 (section 1.3.3 : Ohm 's law, chapter "Theoretical solution"), would not be more correct to include the voltage drop at the ends of the resistor R and the ammeter.
From Figure 25, the reading of the voltmeter XMM $_2$ is correct and the same for the voltage drop at the ends of resistor R (10 kΩ) for a 10 volt voltage source. However, the reading of the XMM amperometer $_1$ is 10.125 nA, a value that is far from the correct reading of the current intensity (10 mA) for a 10 Volt voltage source. The reason is that the ammeter measures the intensity of the current from the source to the voltmeter. The voltmeter has a large internal resistance and by Ohm's law (I = V/R), where resistance (R) and current intensity (I) are inversely proportional quantities. Therefore, the greater the resistance, the smaller the current intensity.

Question 3

Consider a voltage divider with $R_1 = R_2 = 1$ kΩ . Connect a load R_L = 10 Ω. What will happen? Suggest a way to solve it.

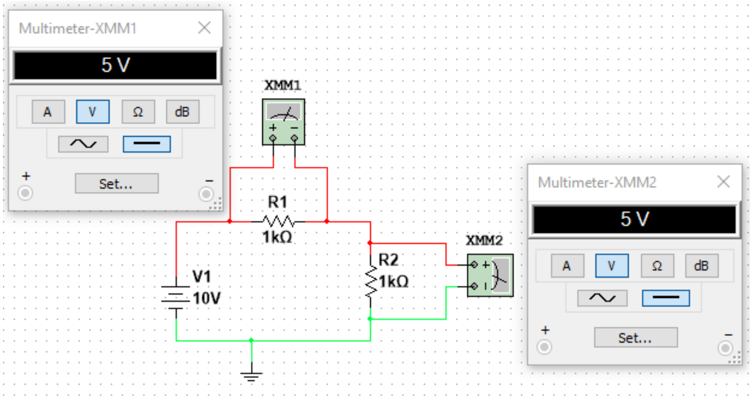


Figure 26

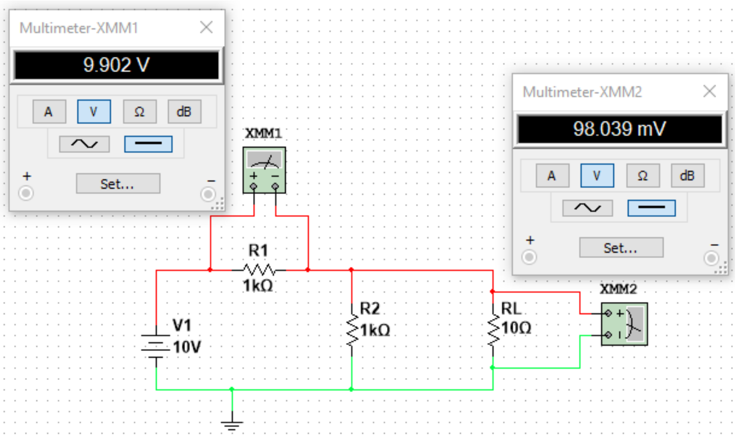


Figure 27

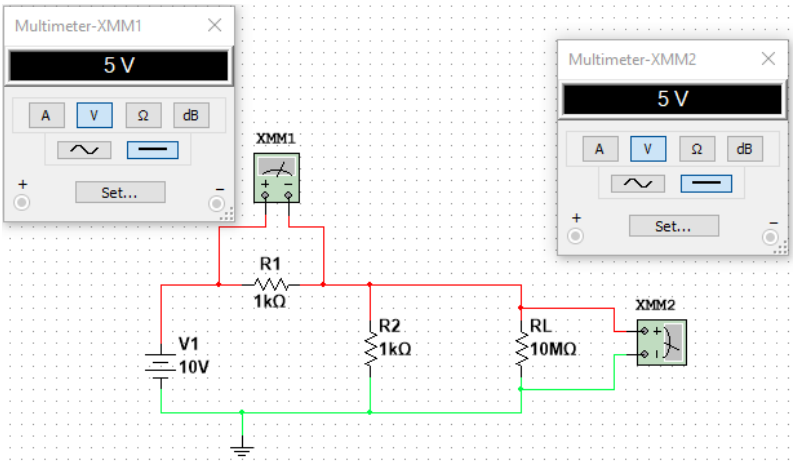


Figure 28

By connecting in the voltage divider circuit (Figure 26), a load resistor R_L (10 Ω) in parallel with resistor R_2 (1 KΩ), it is observed that the source voltage is not equally divided between the two resistors R_1 (1 KΩ) and R_2 (Figure 27). Specifically, the reading of the multimeter XMM_1 in Figure 27, which is set to measure DC voltage (voltmeter) and connected in parallel with resistor R_1 , is 9.902 V. In contrast, the reading of the multimeter XMM_2 in Figure 27, which is also, configured to measure DC voltage (voltmeter) and connected in parallel with resistor R_2 , is 98.039 mV. In Figure 26, ie, in the circuit of the voltage divider, it is observed that the source voltage (10 V) is equally divided at the ends of the two resistors R_1 and R_2.
This consideration is analyzed by resistor connection theory and with the help of Ohm's law. The two resistors R_2 (1 kΩ) and R_L (10 Ω) are connected in parallel with each other. Therefore, from the mathematical formula of parallel connection of resistors we have :

$R_2 // R_L$ **=>** $R_{2L} = R_2 * R_L / R_2 + R_L$ **=>** $R_{2L} = 1000 * 10 / 1000 + 10$ **=>** $R_{2L} = 10000 / 1010$ **=>** $R_{2L} = 9.9$ OHMS

From Ohm
's law for resistor R_{2L} and for resistor R_1 the following conclusion is recorded:

$R_1 : I = VR_1 / R_1$ 1

$R_{2L} : I = VR_{2L} / R_{2L}$ **2**

1 , **2** **=>** $VR_1 = VR_{2L}$ **=>** $I * R_1 = I * R_{2L}$ **=>** $I * 1000 = I * 9.9$ **3**

From relation **3** it can be seen that the voltage at the ends of R_1 is much higher than the voltage at the ends of R_{2L}.
The solution to the problem is realized if the load resistance R_L is much higher than the resistance of R_2 (Figure 28). In Figure 28, the load resistance R_L is 10 MΩ and by re-running the same diode the following is recorded :

$R_2 // R_L$ **=>** $R_{2L} = R_2 * R_L / R_2 + R_L$ **=>** $R_{2L} = 1000 * 10000000 / 1000 + 10000000$ **=>** $R_{2L} = 10000000000000 / 10001000$ **=>** $R_{2L} = 999.9\ \Omega$

R_1 : $I = VR_1 / R_1$ 1

R_{2L} : $I = VR_{2L} / R_{2L}$ **2**

1 , 2 => $VR_1 = VR_{2L}$ **=>** $I * R_1 = I * R_{2L}$ **=>** $I * 1000 = I * 999.9$ **3**

From relation **3,** it can be seen that the voltage at the ends of R_1 is almost equal to the voltage at the ends of R_{2L}, verifying the operation of the voltage divider. According to Ohm's law, the greater the resistance in a closed loop the greater the voltage at its ends and according to parallel resistor wiring the greater the deviation of the resistances of the two resistors, the greater the equivalent resistance. The voltage divider is not affected if the load resistance is much greater than the resistance of the resistor connected in parallel (R_L = 10 MΩ // R_2 = 1 kΩ) and as correctly observed in Figure 28 and noted in Figure 27, when the load resistance R_L is less than or equal to or greater than R_2.