Lab 1: Ohm's Law, KVL, and Voltage Divider Rule using Series Circuit

1.1 Objectives

- Find the resistance of a resistor from its color code.
- Measure voltage, current and resistance values using a digital multimeter.
- Verify the validity of Ohm's Law.
- Test the voltage divider rule in a series circuit.

1.2 Introduction

The digital multimeter (DMM) is one of the most useful devices to measure voltage, current and resistance. Most DMMs have three terminals and two probes.

(i) One black terminal - zero potential/ Ground

(ii) One red terminal - for measuring voltage

(iii) One red terminal - for measuring current

One probe is continuously connected to the black terminal and another probe connects to one of the two red terminals depending on the measurement mode. Some advanced DMMs can also measure capacitance, inductance, detect terminals of transistors, diodes, etc.

PRECAUTION

To avoid **damage of the DMM**:

- Keep it switched off while not in use.
- Before connecting the DMM, the measurement mode must be selected and its meter range should be placed to its highest value.
- The red probe must be connected to the correct terminal.

1.3 Theoretical Background

Ohm's Law
Voltage Divider
Resistor Color Code
Breadboard
DMM
Percentage Error

1.3.1 Voltage Measurement

Voltage is measured across the circuit elements / components. That is - a parallel connection is made with DMM and the desired element. Voltage measurement requires negative and positive polarity consideration. If the reading gives a positive value the the polarity consideration is correct.

1.3.2 Current Measurement

Current is measured through the circuit components. So, current measurement requires series connection with the DMM. Current measurement also requires polarity consideration. Similar to voltage measurement a positive reading will indicate right current flow consideration.

1.3.3 Resistance Measurement

Resistances are the simplest form of circuit components. Commercially resistors come in many shapes, sizes. Most common types of resistors are color-coded carbon composition or cabin film resistors. Color codes are multi-colored bands that determine the resistor’s value and tolerance. To measure the resistance two probes of DMM are connected to the two ends of the resistor. Again, resistance mode (Ohmmeter) must be selected before starting measurement.

PRECAUTION

Do **not** connect an **Ohmmeter to a live circuit**. Only connect the component of which the resistance is to be measured.

Another way of measuring resistance is reading color codes (printed colored rings) on the resistors.

Resistors Color Code:

Resistors use colored painted bands to indicate both their resistive value and their tolerance with the physical size of the resistor indicating its wattage rating. These colored painted bands produce a system of identification generally known as a **Resistors Color Code**.

An international and universally accepted resistor color code scheme was developed many years ago as a simple and quick way of identifying a resistors ohmic value no matter what its size or condition. It consists of a set of individual colored rings or bands in spectral order representing each digit of the resistors value.
The resistor color code markings are always read one band at a time starting from the left to the right, with the larger width tolerance band oriented to the right side indicating its tolerance. By matching the color of the first band with its associated number in the digit column of the color chart below the first digit is identified and this represents the first digit of the resistance value.

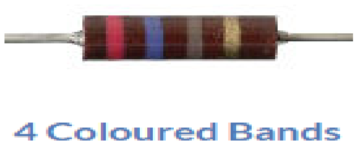


Fig 1: 4 Bands Resistor

Again, by matching the color of the second band with its associated number in the digit column of the color chart we get the second digit of the resistance value and so on. The fourth and fifth bands are used to determine the percentage tolerance of the resistor. Resistor tolerance is a measure of the resistors variation from the specified resistive value and is a consequence of the manufacturing process and is expressed as a percentage of its “nominal” or preferred value.

Then the resistor color code is read from left to right as illustrated below:

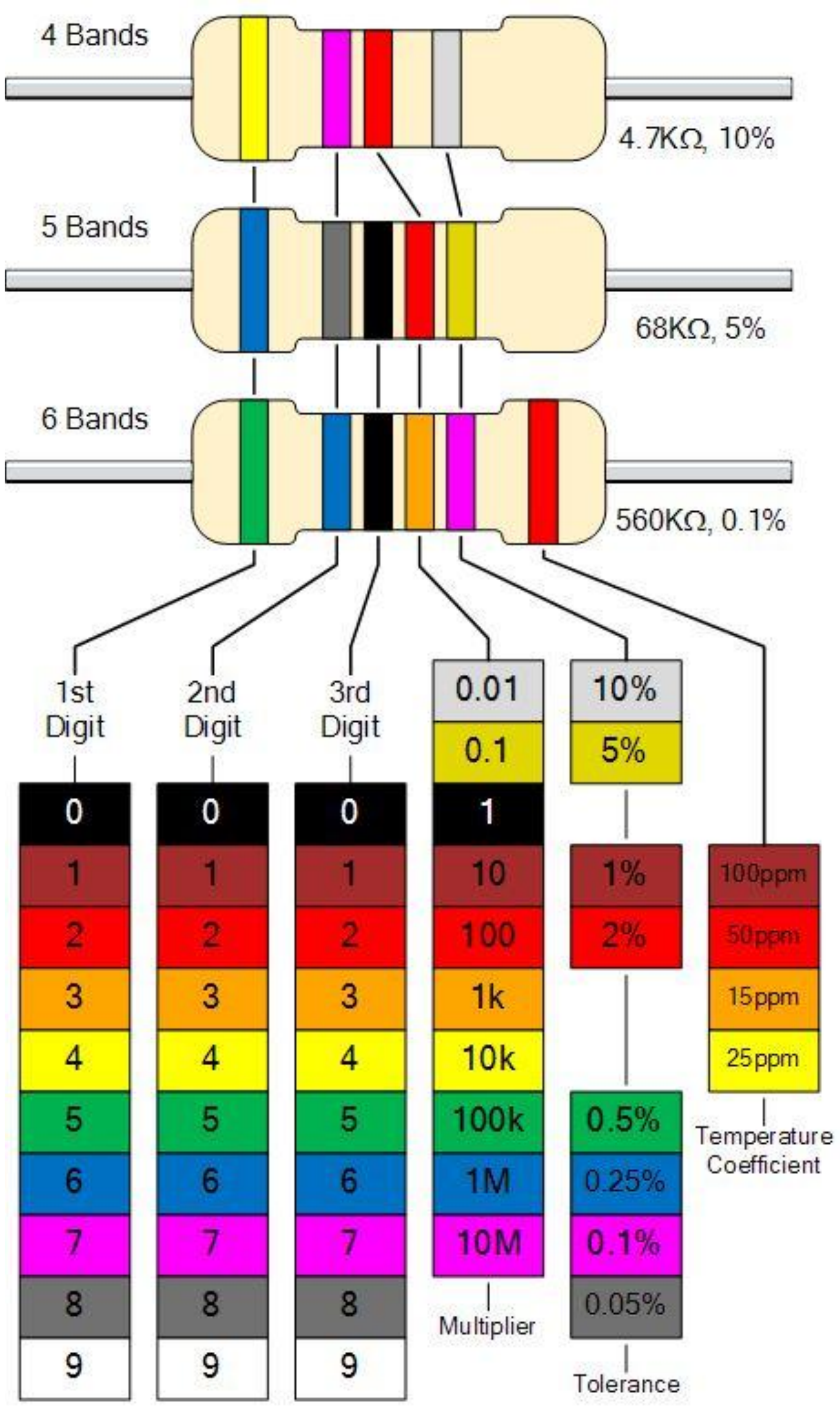


Fig 2: The Standard Resistor Color Code Chart

Colour	Digit	Multiplier	Tolerance
Black	0	1	
Brown	1	10	± 1%
Red	2	100	± 2%
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	± 0.5%
Blue	6	1,000,000	± 0.25%
Violet	7	10,000,000	± 0.1%
Grey	8		± 0.05%
White	9		
Gold		0.1	± 5%
Silver		0.01	± 10%
None			± 20%

Fig 3: The Resistor Color Code Table

The **Resistor Color Code** system is all well and good but we need to understand how to apply it in order to get the correct value of the resistor. The "left-hand" or the most significant colored band is the band which is nearest to a connecting lead with the color coded bands being read from left-to-right as follows:

Digit, Digit, Multiplier ± tolerance = Color, Color x 10^{color} in Ohm's (Ω) ± tolerance

For example, a resistor has the following colored markings:

Yellow Violet Red Golden = 4 7 2 = 4 7 x 10^2 = 4700Ω or 4.7 KΩ ± 5%

1.4 Breadboard (http://wiring.org.co/learning/tutorials/breadboard/)

A breadboard is a solder less device for temporary prototype with electronics and test circuit designs. Most electronic components in electronic circuits can be interconnected by inserting their leads or terminals into the holes and then making connections through wires where appropriate. The breadboard has strips of metal underneath the board and connects the holes on the top of the board. The metal strips are laid out as shown below. Note that the top and bottom rows of holes are connected horizontally and split in the middle while the remaining holes are connected vertically.

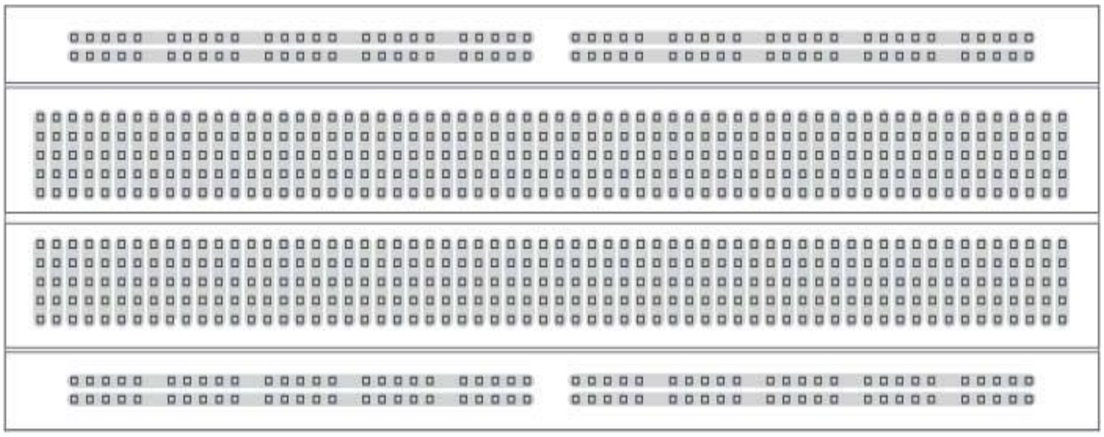


Fig 4: The metal strips connections of a breadboard

The top and bottom of a breadboard are shown below with the bottom insulation stripped off to clearly show metal strip connections corresponding to the holes. Please note that the orientation of the boards in the diagram below have been rotated by 90° compared to the diagram above.

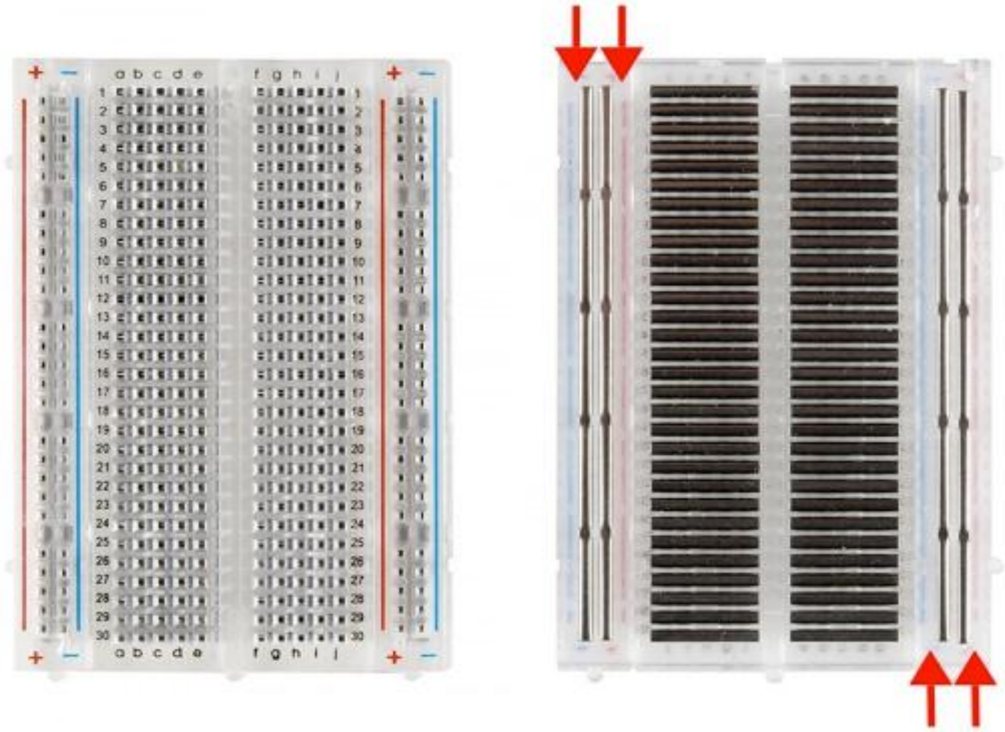


Fig 5: The top and bottom level of a breadboard

Note how all holes in the selected row are connected together, so the holes in the selected column. The set of connected holes can be called a node:

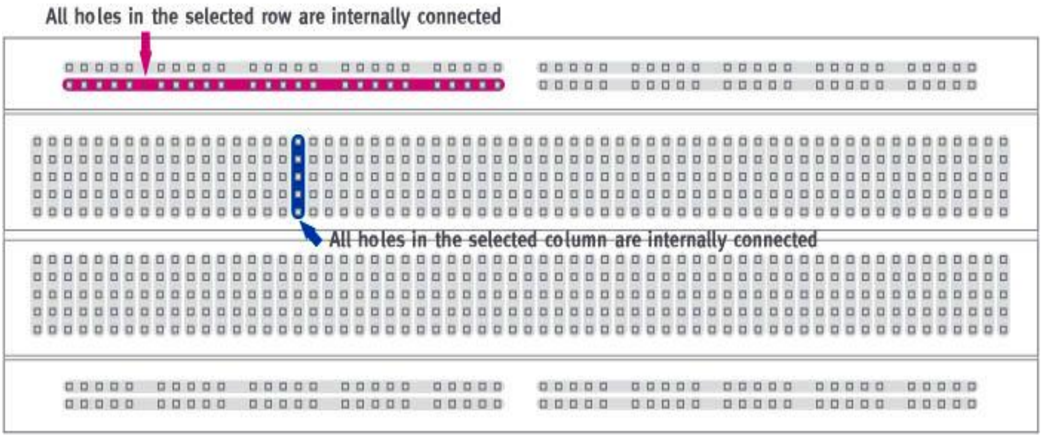
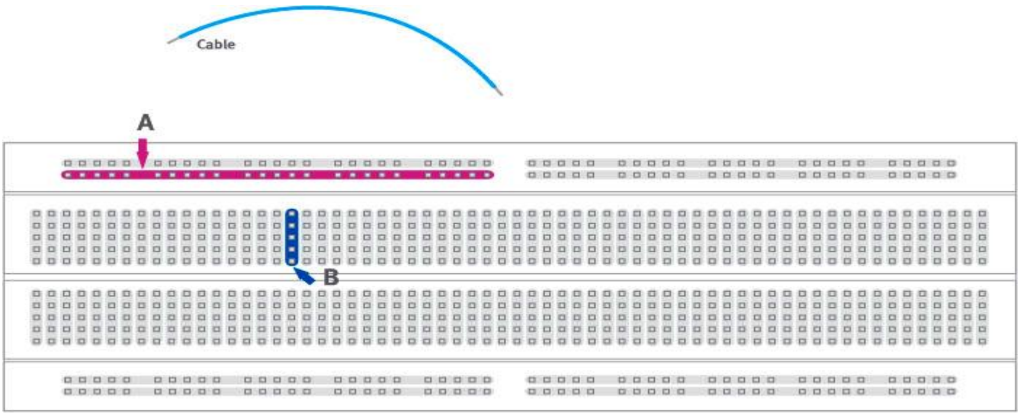


Fig 6: The holes connection of a breadboard

To interconnect the selected row (node A) and column (node B) a cable going from any hole in the row to any hole in the column is needed:



Now the selected column (node B) and row (node A) are interconnected:

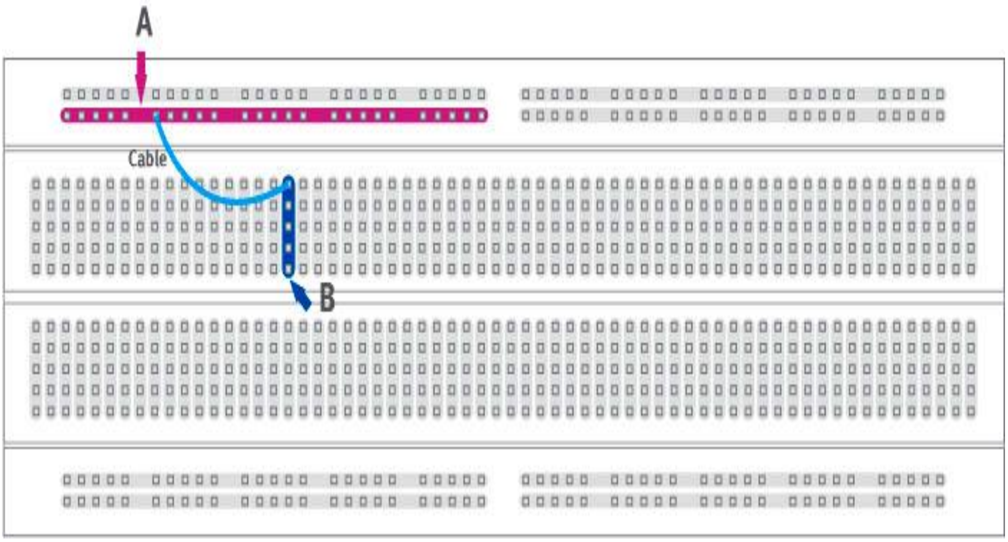


Fig 7: Different nodes connection on a breadboard

1.5 From electronic diagrams to actual circuit connections

(http://wiring.org.co/learning/tutorials/diagrams/index.html)

i. Trainer board
ii. LED
iii. 1kΩ Resistor
iv. Digital Multimeter (DMM)

A circuit diagram makes use of standardized symbols that represent electrical components or devices. It is easier to draw these symbols than drawing the actual pictures of the components. The actual components might change appearance as the electronics industry revises them or renders them obsolete. The diagrams describe the way in which the components are connected together electrically. There are drawn lines that represent wires or conductors between the appropriate connection points on the symbols; no particular type of wire or physical distance between components is implied; two components might be separated by a few inches or centimeters or a meter or feet.

The following tutorial translates from a circuit diagram to actually connecting components on a breadboard. Note that the circuit diagrams are the universal way of representing circuits; books, on-line resources, and materials use them to communicate the circuit connections. They are very useful compared with pictorial diagrams of the connections.

Let us consider the following circuit diagram:

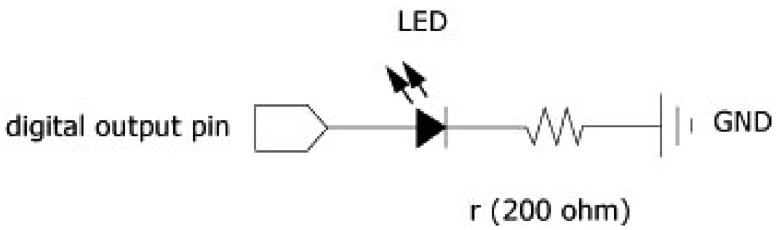


Fig 8: Simple DC Circuit

The next step would be to identify the components and their terminals:

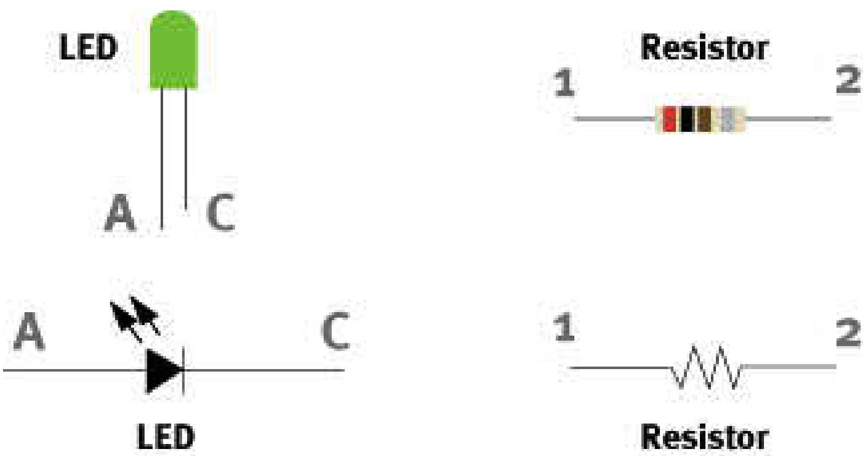


Fig 9: Circuit Components and their terminals

Next, identify the connection nodes between components, connections between different components are formed by putting their legs (or terminals) in a common node:

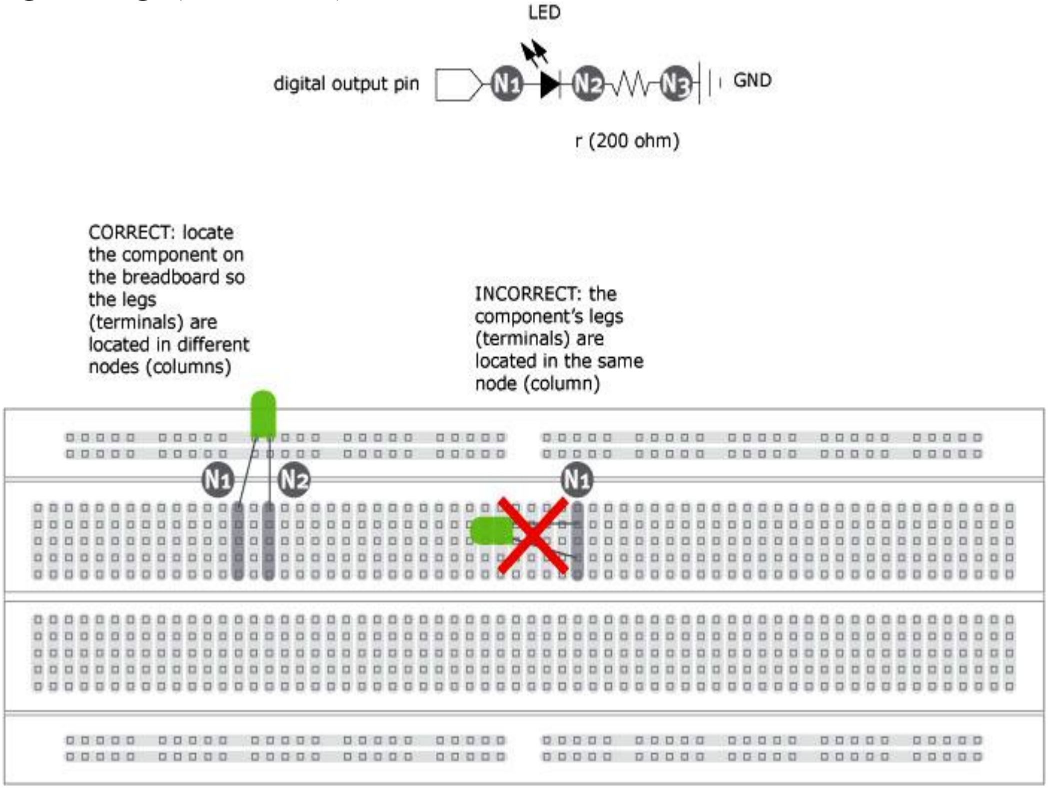


Fig 10: Component Connections process on breadboard

Note the difference between the correct and incorrect connections. In the correct version the two legs are on different columns (nodes), in the incorrect version the two legs are connected to the same column (node) which is equivalent to solder or tie together the two legs of the LED.

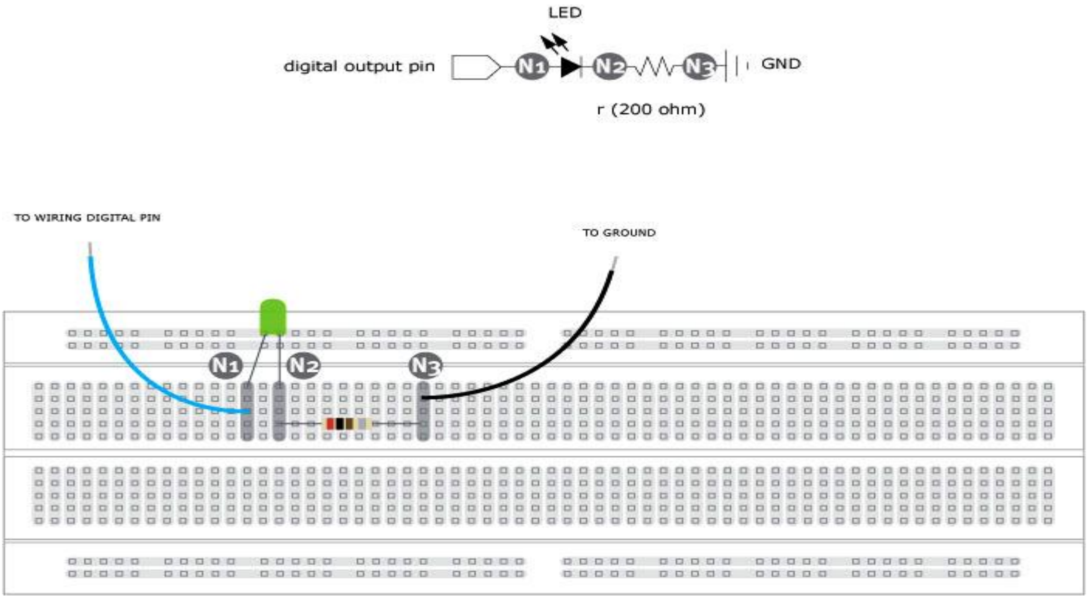


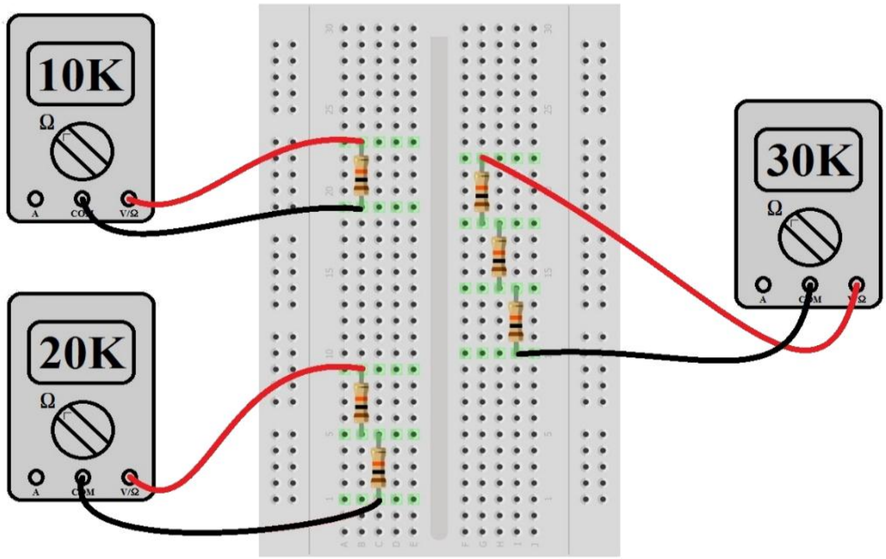
Fig 11: Full Circuit Connections process on breadboard

The LED has two legs, from Fig 7 the leg marked as A is connected to Node N1, the leg marked C is connected to the leg marked 1 on the resistor (Node N2) and the leg marked 2 on the resistor is connected to GROUND (Node N3). The LED is a polarized device, which means it matters the way it is connected, the resistor is not polarized so pins can be inverted with no effect on the circuit's behavior. To learn more about a specific component try to find its datasheet. Search on the Web using the component's reference number to become familiar with its functions, terminals and specs.

Equivalent resistance:

Source: https://learn.sparkfun.com/tutorials/series-and-parallel-circuits

Series:



Parallel:

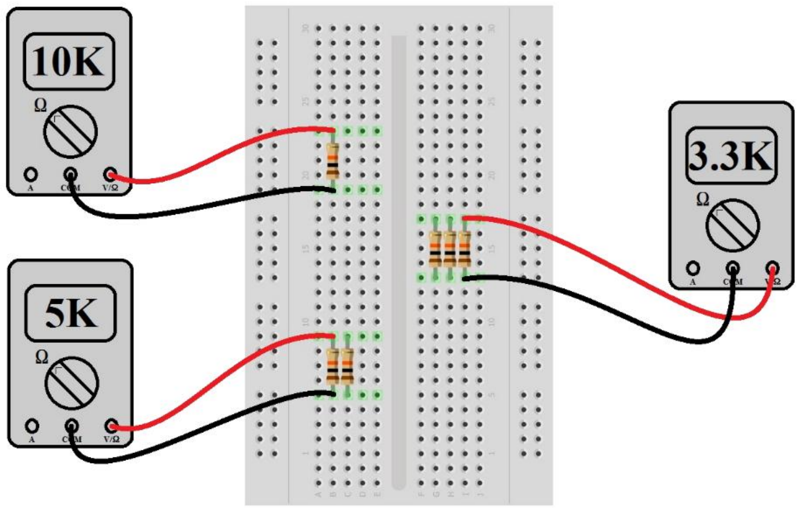
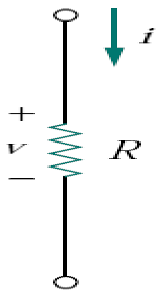


Fig 12: Resistors Connections process on breadboard

Exp1.1: Verification of Ohm's Law

Theory: The relationship between current and voltage for a resistor is known as **Ohm's law.**
Ohm's law states that the current through a conductor between two points is directly proportional to the voltage across the two points.
Or, we can say that the voltage v across a resistor is directly proportional to the current i flowing through the resistor.



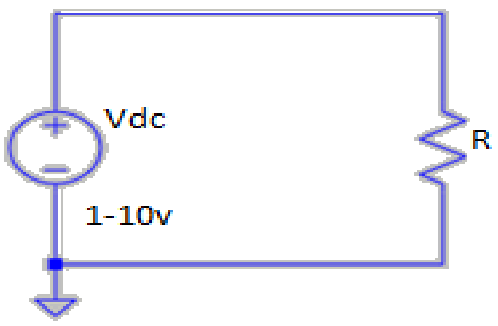
$$\boldsymbol{V \propto I} \qquad \textbf{(1)}$$

Ohm defined the constant of proportionality for a resistor to be the resistance, **R.** The resistance R of an element denotes its ability to resist the flow of electric current; it is measured in ohms (Ω).
Now the equation (1) becomes

$$\textbf{Or, } \boldsymbol{V = IR}$$

$$\textbf{Or, I} = \boldsymbol{\frac{V}{R}}$$

Circuit Diagram:



Circuit 1

List of Components:
- Trainer board
- Resistors (3.3 KΩ, 5.6 KΩ)
- Digital Multimeter (DMM)
- Connecting Wire

Procedure:

1. Identify the given resistors using color coding and fill in the required columns in Table 1.
2. Measure the resistances of the resistors using the DMM and fill in the required column in Table 1.
3. Calculate the percentage error of the resistance values.

Percentage Error = |(Practical value – Theoretical value)| / Theoretical value

4. Build circuit 1 using the 3.3 KΩ resistor.
5. Set the voltage source to 2 V. Check the voltage across the supply using the DMM. Open circuit before taking source voltage reading to avoid loading effect of internal resistance.
   (i) Measure the current flowing through the resistor. Note it down in Table 2.
   (ii) Calculate IR using the experimental values of I and R. Note it down in Table 2.
   (iii) Calculate the power using the experimental values of I and R (Power = I^2R).
   (iv) Repeat the above steps for 2 V to 10 V in steps of 2 V (2 V, 4 V, 6 V, 8 V, 10 V).
6. Repeat step 5-7 for the 5.6K resistor. Record data in Table 3

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Data Collection for Exp1.1:

Lab 1: Exp1
Group No. ________
Instructor's Signature ___________

Table 1:

Resistance using colour coding					Resistance using DMM	% Error
Band 1	**Band 2**	**Band 3**	**Band 4**	**Resistance ± tol**		

Table 2:

3.3 KΩ Voltage	Experimental readings		
	Current, I	**Voltage, I R**	**Power,** I^2R
2			
4			
6			
8			
10			

Table 3

5.6 KΩ Voltage	Experimental readings		
	Current, I	**Voltage, I R**	**Power,** I^2R
2			
4			
6			
8			
10			

Exp1.2: Series Circuit

Objectives

- Learn how to connect a series circuit on a breadboard.
- Validate the voltage divider rules.
- Verify Kirchhoff's voltage law.

Theory: Consider the circuit given below.

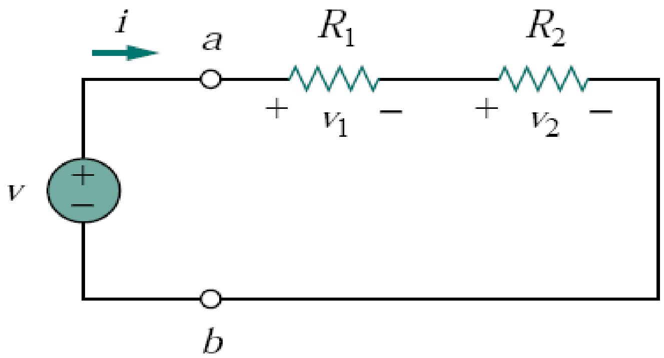


Fig 1: A single-loop circuit with two resistors in series

The two resistors are in series, since the same current i flows in both of them. Applying Ohm's law to each of the resistors, we obtain,

$$v_1 = iR_1,\ v2 = iR_2$$

The Principle of voltage division is that the source voltage v is divided among the resistors in direct proportion to their resistances; the larger the resistance, the larger the voltage drop. The circuit in Fig.1 is called **a voltage divider.**

$$\boldsymbol{v_n = \frac{R_n}{R_1 + R_2 + \cdots + R_N}\, v}$$

Applying the voltage division rule we can now determine the voltage across each resistor in Fig 1

$$\boldsymbol{v_1 = \frac{R_1}{R_1 + R_2}\, v}$$

$$\boldsymbol{v_2 = \frac{R_2}{R_1 + R_2}\, v}$$

Kirchhoff's voltage law (KVL): Kirchhoff's voltage law states that the algebraic sum of all voltages around a closed path (or loop) is zero.

Expressed mathematically, KVL states that,

$$\boldsymbol{\sum_{m=1}^{M} v_m = 0}$$

Where M is the number of voltages in the loop and v_m is the *mth* voltage.

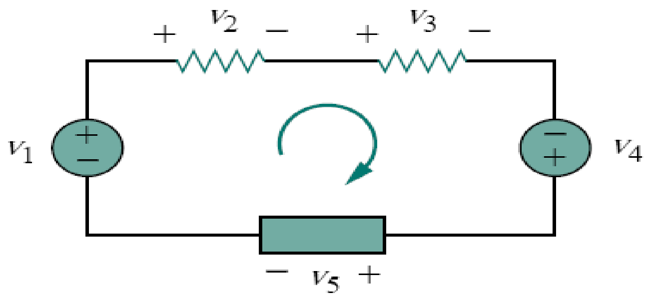


Fig 2: A single-loop circuit illustrating KVL

Applying KVL, we can find that,

$$-v_1 + v_2 + v_3 - v_4 + v_5 = 0$$

Rearranging terms gives,

$$v_2 + v_3 + v_5 = v_1 + v_4$$

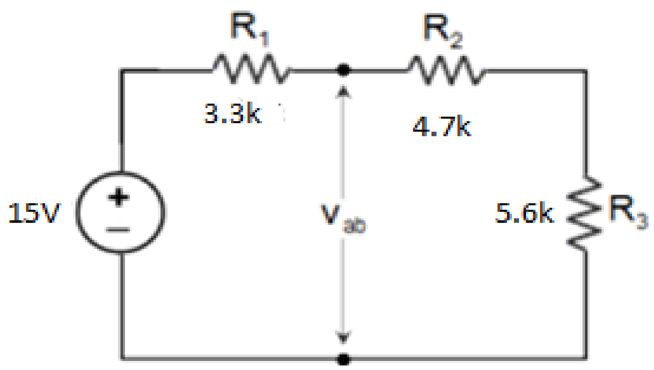
which may be interpreted as

Sum of voltage drops = Sum of voltage rises

List of Components:

i. Trainer board
ii. Resistors (3.3 KΩ, 4.7 KΩ, 5.6K)
iii. Digital Multimeter (DMM)
iv. Connecting Wire

Circuit Diagram:



Circuit 2

Procedure:

1. Identify the given resistors using color coding and fill in the required columns in Table 1.
2. Measure the resistances of the resistors using the DMM and fill in the required column in Table 1.
3. Calculate the percentage error of the resistance values.

   Percentage Error = |(Practical value – Theoretical value)| / Theoretical value
4. Build the circuit 2.
5. Using the DMM, find the potential differences across the source V_S and resistors R_1, R_2 and R_3. Record the readings in Table 2.
6. Fill in Table 3.
7. Measure V_{ab}. Calculate V_{ab} using voltage division rule. Note down values in Table 4.
8. Now, disconnect the voltage source from the circuit and measure the total load resistance, R_{eq} of the circuit using DMM. Note down values in Table 4.

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Data Collection for Exp1.2:

Lab 1: Exp2
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Table 1:

Resistance using colour coding					Resistance using DMM	% Error
Band 1	**Band 2**	**Band 3**	**Band 4**	**Resistance ± tol**		

Table 2:

Experimental readings				Theoretical values			
V_S	V_{R1}	V_{R2}	V_{R3}	V_S	V_{R1}	V_{R2}	V_{R3}
% Error							
V_S		V_{R1}		V_{R2}		V_{R3}	

Table 3:

Potential rise V_S		**Are the voltage rises and drops equal?**
Potential drops ($V_{R1} + V_{R1} + V_{R3}$)		

Table 4

Experimental readings		Theoretical values	
V_{ab}	R_{eq}	V_{ab}	R_{eq}
% Error			
V_{ab}		R_{eq}	

Questions

Experiment 1.1:

1. Plot V vs. I graph for each resistor value in same graph.
2. Does your experimental circuit follow ohm's law? Explain how you figured it out.
3. Calculate the resistance of each circuit using the slope of your V vs. I graphs. Compare these R graph values to the measured R values using DMM. Find the percent difference.

Experiment 1.2:

1. Showing all steps, calculate the theoretical values in Table 2. Compare theoretical values to your experimental values and explain whether your circuit follows KVL or not.
2. Showing all the calculations, theoretically calculate V_{ab}. Compare with the experimental value and verify the voltage division rule at the terminal a-b.
3. Showing all the steps, calculate R_{eq}. Compare with the experimental value.

Useful Formula:

Voltage Divider Rule: $V_X = E\ R_X / R_T$

% Error = (Theoretical value – Experimental Value) / Theoretical Value