Introduction:

Electrical circuits are fundamental in understanding and analysing electrical and electronic systems. An electrical circuit consists of components such as resistors, capacitors, and inductors, which are connected together to form various paths for the flow of electric current. This chapter aims to study the basic parameters of electrical circuits, such as resistance, capacitance, and inductance, and how they affect the circuit's behavior and electrical characteristics. Through this chapter, students will become familiar with different methods of circuit analysis, the application of Kirchhoff's laws, and the interaction between these electrical components. This knowledge will be essential in understanding the design and implementation of complex electrical systems.

1.1. Presentation of various parameters of an electrical circuit

A. Electrical circuit

** Composition:*

All electrical circuits will consist of at least four elements.

- **The Generator:** This device provides electrical energy (such as a battery, alternator, etc.).
- **The Load:** This device receives the electrical energy and transforms it into another form of energy (all electrical appliances).
- **The Conductors:** These elements electrically connect the generator and the load (wires, switches, circuit breakers, etc.).
- **The Protections:** These are components designed to interrupt the flow of current in case of a short circuit or overload (fuses, circuit breakers)

** Representation :*

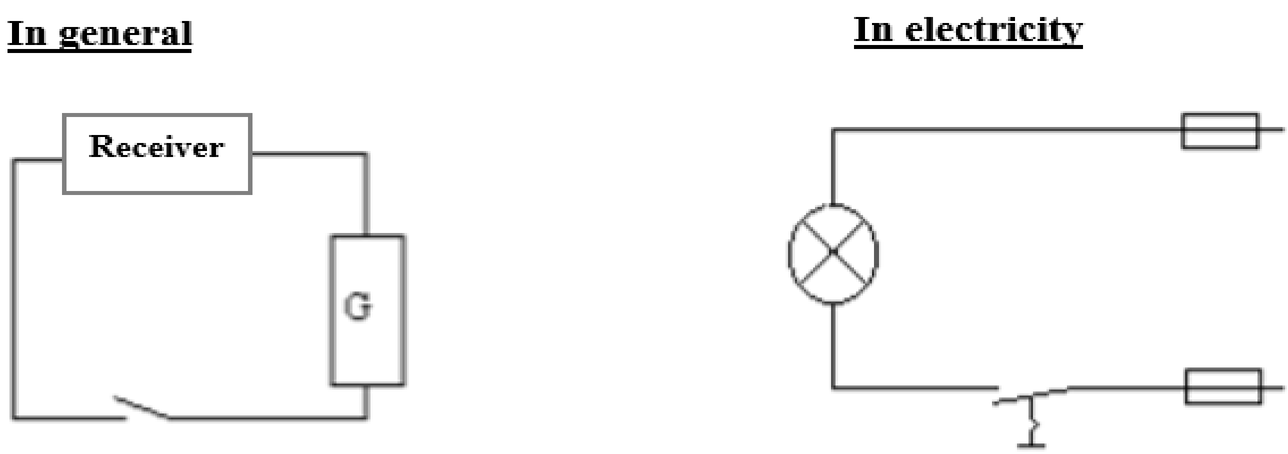


Figure 1.1. Circuit representation in general and electrically

B. Conductors and Insulators

We have learned that each atom has a specific number of electrons. In some materials, atoms tightly hold onto their electrons, while in others, electrons can easily move from one atom to another (free electrons). In the first case, electrons move with difficulty, and these materials are called insulators. In the second case, electrons move more easily, and these materials are called conductors. Note that some substances don't fit neatly into these categories; these are called semiconductors.

Examples:

Conductors include copper, aluminium, brass, and all metals.

- ***Isolators:*** These are materials that do not conduct electrical current.

Examples include PVC, rubber, paper, fabric, glass, sand, ...

- ***Conductors:*** These materials conduct electrical current.

C. Open Circuit & Closed Circuit

A circuit is considered open when electrical current cannot flow due to an interruption in the electrical connection path. In an open circuit, there is a physical break that prevents the current from flowing. This can occur, for example, when you open a switch, thereby breaking the current's path.

On the other hand, a circuit is considered closed when electrical current can flow continuously without interruption. In a closed circuit, all electrical components are connected continuously, allowing the current to flow freely. When you close an electrical switch, you create a closed circuit, enabling the current to flow through the devices and provide power.

In summary, an open circuit interrupts the flow of current due to a break, while a closed circuit allows current to flow continuously through all electrical components.

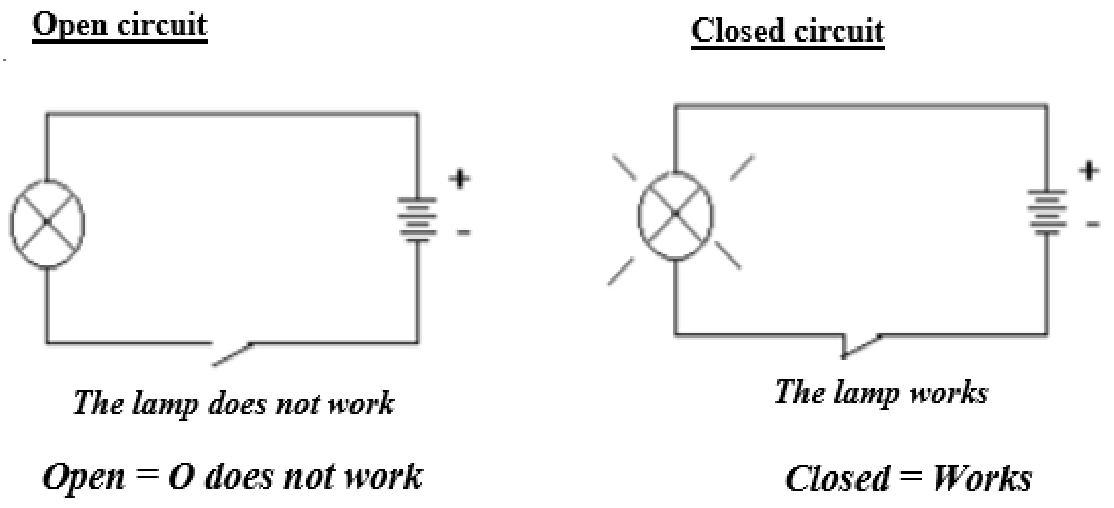


Figure 1.2. Open and closed circuit representation

1.1.1 Electric current

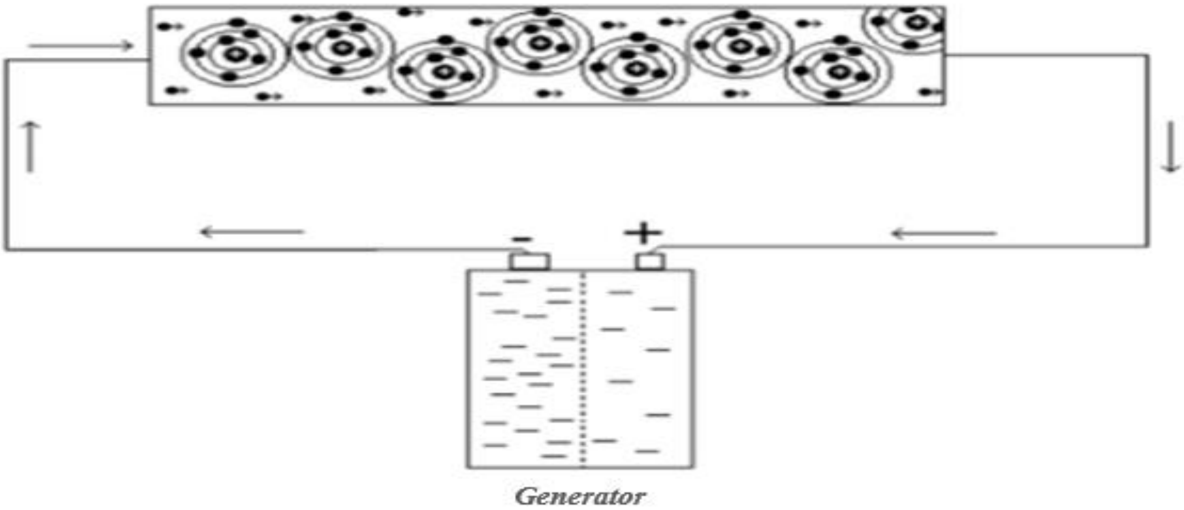


Figure 1.3. Movement of electrons from the negative pole to the positive pole

At the generator's positive + terminal, there is an electron deficiency. To rebalance, it tries to attract electrons, causing a structured flow of free electrons within the material, moving from the negative - to the positive + terminal. This electron movement gives rise to what we call the effects of electric current.

2° Effects of electric current

The motion of free electrons within the conductor leads to reactions that, in specific circumstances, produce effects such as heat, light, magnetism, and more.

a. Calorific effect (heat effect)

When an electric current flows through a conductor, it produces heat. The amount of heat generated depends on the current's strength; the higher the current, the hotter the conductor becomes.

This effect is used in various applications, including electrical devices designed to generate heat and for safeguarding electrical systems using fuse wires

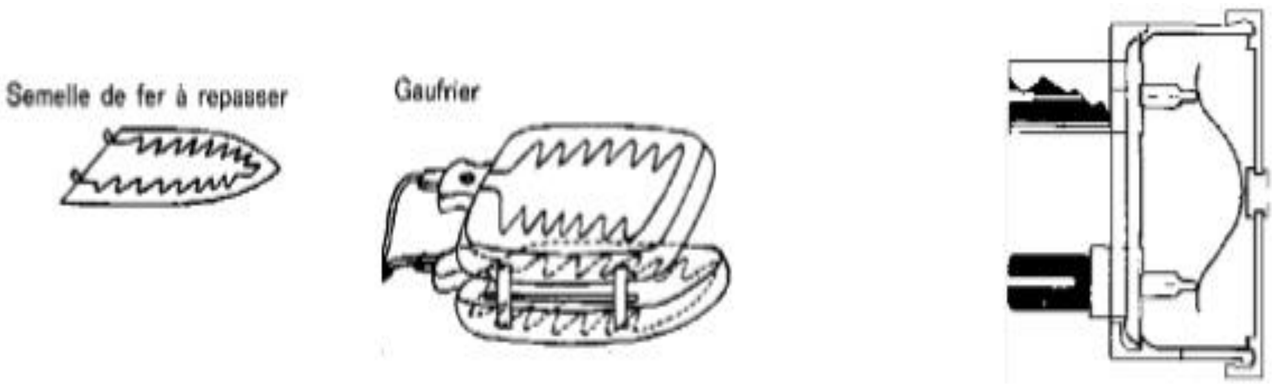


Figure 1.4. Thermal effect after current passes through

B. *Luminous effect.*

When a high electric current passes through a conductor that is too small to handle such a current, there is a significant rise in temperature, resulting in the conductor turning red or even white. The degree of this effect depends on the amount of current flowing through the wire.

This phenomenon is used in applications like incandescent lamps and others.

Figure 1.5. Optical effect after current has passed

C. *Magnetic effect*

When an electric current flows through an insulated wire wound around a metal core, the core becomes magnetised. Similarly, if I interrupt the flow of current, there is no more magnetization.

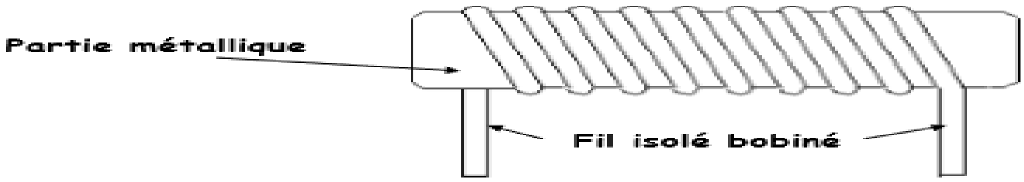


Figure 1.6. Magnetic effect after current passes through

This is called an electromagnet, which means a magnet controlled by electricity.

Applications include doorbells, relays, lifting cranes, circuit breakers, door opening mechanisms, and time switches, among others.

D. *Chemical effect.*

a. Electrolysis.

Applications: Electrolysis of metals (chromium plating, nickel plating, etc.).

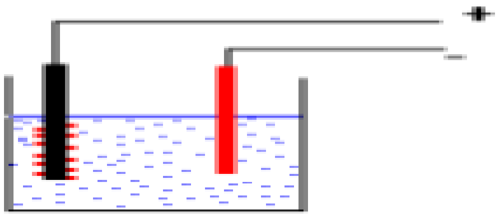


Figure 1.7. Chemical effect after current passes through

b. Battery.

Let's take a zinc casing used as the negative plate, a suspended charcoal rod in the middle of this casing serving as the positive plate, and a paste-like solution of ammonium chloride, which constitutes the electrolyte.

Figure 1.8. Chemical batteries

Note:

When we connect a voltmeter to the positive and negative terminals, its needle deflects. This indicates the production of electric current.

Applications: Batteries and cells.

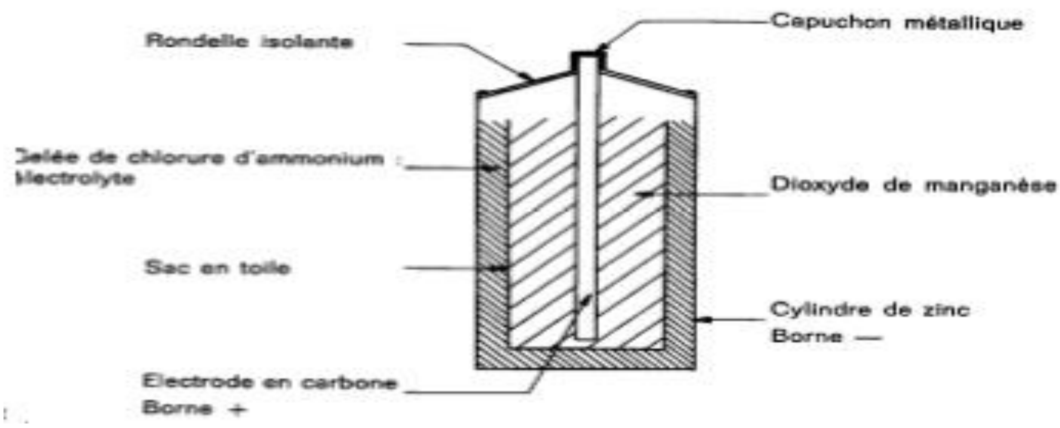


Figure 1.9. Batteries and cells

E. ***Physiological effect***

When an electric current passes through the human body, it causes muscle contractions, the severity of which depends on the current's strength.

This phenomenon has applications in pacemaker batteries, electroshock therapy, electric fences, and more.

F. *Joule Effect*

The conversion of electrical energy into heat or heat and light is called the Joule effect. When a light bulb is turned on, it consumes electrical energy and converts it into light (which illuminates) and heat (it gets hot).

This loss of energy in the form of heat reduces the efficiency of electrical devices that are not intended to provide heat. For example, the efficiency of a 100W light bulb is only 15%. This means that 15 joules out of 100 joules are used for illumination, while the rest is lost as heat.

The English physicist James Prescott Joule (1818-1889) was the one who demonstrated the heat-producing effect of electric current. He played a significant role in the industrial revolution of the 19th century by developing electrical machines that revolutionized work and production methods. He showed that the heat energy (W) dissipated by an electrical device is proportional to the square of the current (I) passing through it over a certain period of time. This can be expressed in a mathematical formula:

$$W = R I^2 t$$

Where:

- W = heat energy in joules (J).
- R = resistance of the conductor in ohms (Ω).
- I = current intensity flowing through the conductor in amperes (A).
- t = time of current flow through the conductor in seconds (s).

1.1.2. Electric Current Intensity

Let us take the example of a water tank placed at a height.

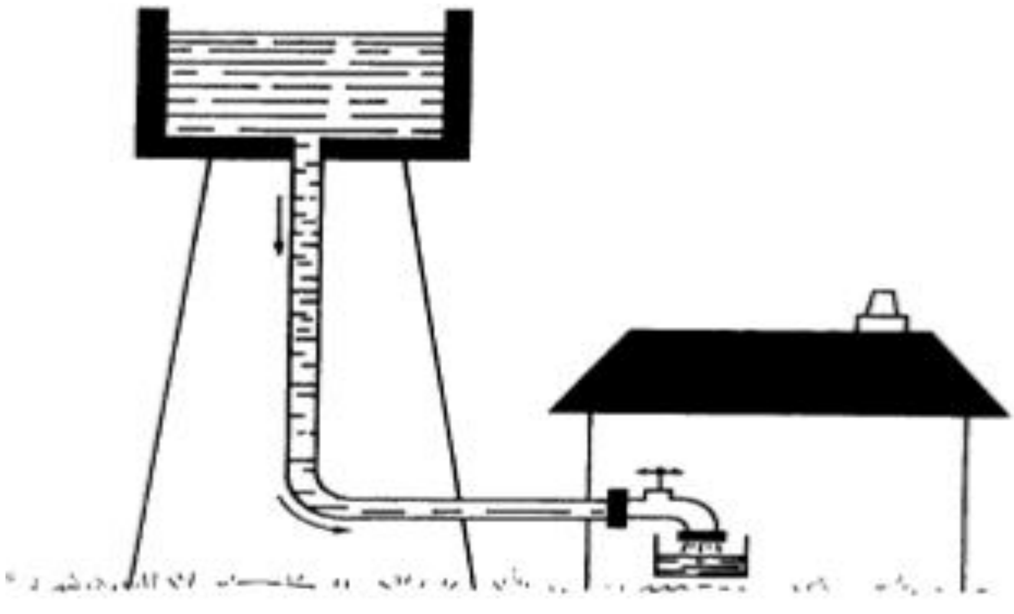


Figure 1.10. Water flow in the pipe

The number of water droplets that pass through a point in the pipeline is called:

The flow rate.

In an electrical circuit, the number of electrons that pass through a point in the circuit is called:

The electric current intensity.

Electric current intensity is the number of free electrons that flow in 1 second in a conductor.

- ***Measuring Electric Current Intensity.***

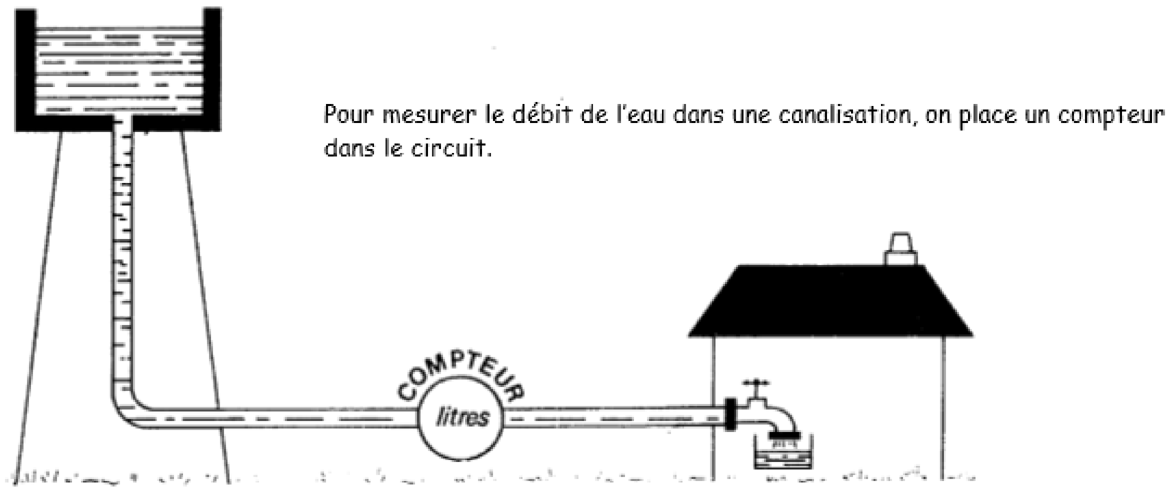
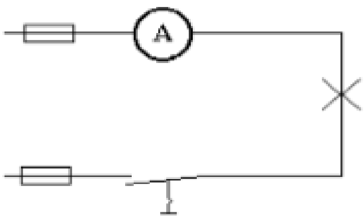


Figure 1.11. Measuring water flow in a pipe

Similarly, in electricity, to measure the number of electrons at a point in the circuit, we use an ammeter placed in series in the circuit.

Representation of the ammeter:



The measurement of electric current is the AMPERE. (French physicist 1775-1836.)

1 Ampere = $\mathbf{6.25 \times 10^{18}}$ electrons.

Examples:

Phone earpiece: 0.02A.
Flashlight: 0.3A.
Iron: 4A.
Motor: from a few tens to a few hundred amperes.

- ***The Different Types of Ammeters***

Figure 1.12. Types of analog ammeter operation

- **Summary:**

Unit of electric current measurement: **Ampere (A).**
Symbol: **I**.
Examples: **A** current with an intensity of **5A** is represented as **I = 5 A.**
Multiple: Kiloampere (**KA**) = **1000 A.**
Sub-multiple: Milliampere (**mA**) = **0.001 A**.
Measurement: Using an ammeter placed in **series**.

1.1.3. Resistance:

You know that the atoms of some materials easily release electrons from their outer orbits, while the atoms of other materials hold onto these electrons. In the latter case, we say that the material offers more opposition to the current. Every material presents some resistance to electric current, which can be either strong or weak; this opposition is called resistance. Materials with low resistance release free electrons easily. Materials with high resistance release free electrons with difficulty. Resistance is opposition to electric current.

To measure the resistance of a conductor or an electrical component, we use an ohmmeter (with the power off) connected to the terminals or ends of what we want to test. The unit of resistance measurement is the ohm (Ω), represented by the Greek letter omega (Ω).

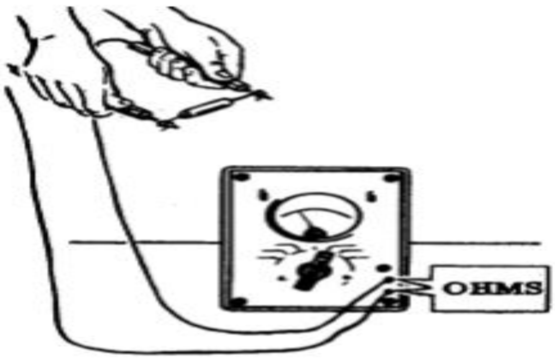


Figure 1.13. How to measure resistance

Symbol : R.

Representation : 

Multiples:

KΩ (kilo-ohm) = 1000 x 1Ω = 1000 Ohms.

MΩ (mega-ohm) = 1000000 x 1Ω = 1,000,000 Ohms.

- **Types of resistors:**

Every conductor, no matter what it is, offers a certain amount of resistance to the flow of electric current: motor or transformer winding wire, wire carrying electrical energy, incandescent lamps, and so on. In all cases, resistance exists, but it is not always desired. However, since a resistor inserted into a circuit reduces the current intensity flowing through it, this property is used to adjust the current passing through a load (and also the voltage) by placing a greater or lesser resistance in series with it. For example, a lamp for which we want to reduce the brightness.

Two types of resistors are used:

a) Fixed resistors (they maintain the same value).

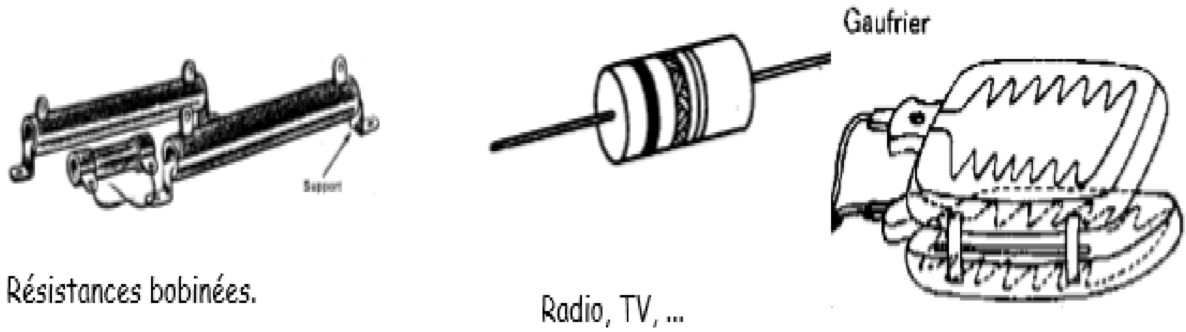


Figure 1.14. Types of fixed resistors

b) Wound resistors.

Soldering iron, electric radiators, iron, etc.

Variable resistors (their value can be adjusted).

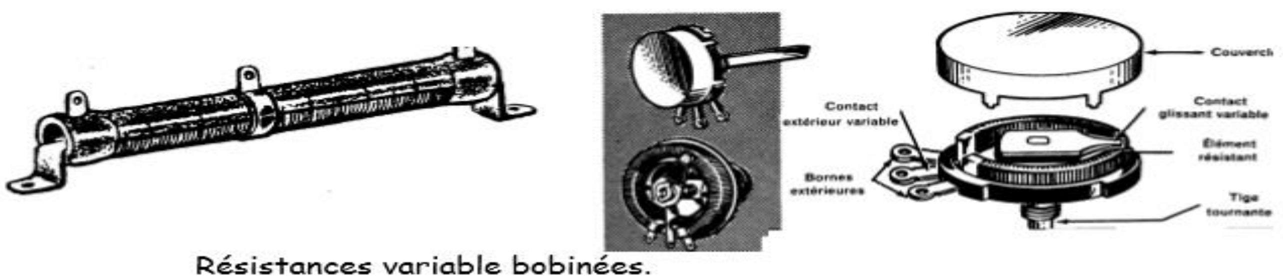


Figure 1.15. Types of variable resistors

1.1.4 - Electrical Voltage:

1- Analogy with the water circuit:

In a water circuit, a pump is required to set the water molecules in motion. Indeed, the pump must provide each water molecule with a certain amount of energy for it to traverse the circuit. When a molecule passes through the hydraulic motor, its energy is transferred from the molecule to the wheel (indeed, the wheel also requires energy, or it won't be able to turn).

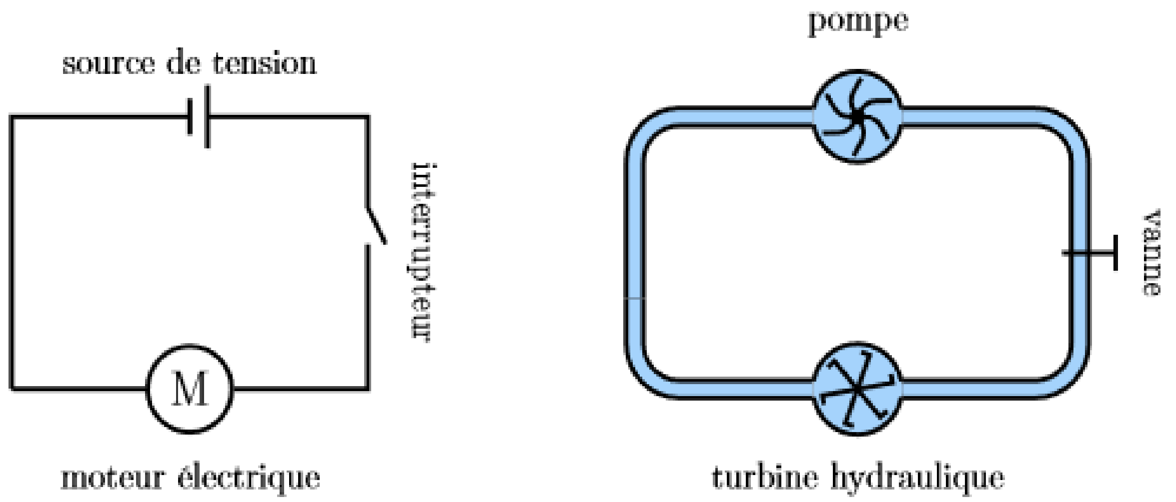


Figure 1.16. Electrical Circuit / Water Circuit

Similarly, an electron needs energy to circulate through an electrical circuit. Each charge requires a certain amount of energy that it receives from the generator and gives up when passing through the load (such as an electric motor). The amount of energy received per unit charge in an electrical source or given up per unit charge in an electrical load is called electrical voltage.

2- Definition of Electrical Voltage

The voltage of a generator is the energy transmitted from the generator to a charge of 1 Coulomb when that charge passes through the generator.

The voltage of a load is the energy transmitted from a charge of 1 Coulomb to the load when that charge passes through the load.

Symbol for electrical energy: **Eel**
SI unit of electrical energy: **J (Joule)**
Symbol for electric charge: **Q**
SI unit of electric charge: **C**
Symbol for electrical voltage: **U**
Formula: $U = \frac{E_{el}}{Q}$

The SI unit of electrical voltage is the Volt (V):

$$1V = 1\ J/C$$

So, if a charge of 1 Coulomb passes through a generator and receives 1 Joule of energy from it, we say that the generator's voltage is 1 Volt. In other words, if a charge of 1 C passes through a generator with a voltage set to 1 Volt, the charge receives 1 Joule of energy from the generator. If a 1 C charge passes through a load to which it gives 1 Joule of energy, the voltage across this load is 1 V.

3. Measurement of Electrical Voltage

The electrical voltage across the terminals of a device (generator or load) is measured using a voltmeter.

The voltmeter is always connected in parallel to the component across whose terminals we want to measure the voltage (in fact, we are measuring the difference in electrical energy possessed by a charge of 1 C after and before passing through a component).

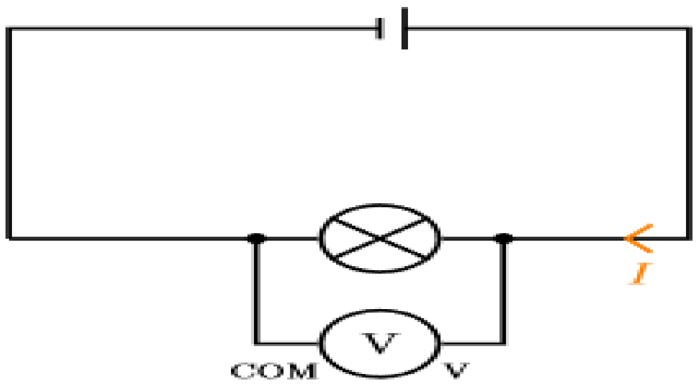


Figure 1.17. A Voltmeter Connected Correctly

The V+ terminal is connected on the side where the current arrives. The COM terminal is the negative pole of the measuring instrument

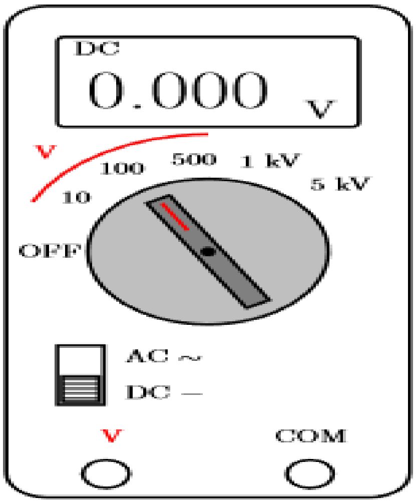


Figure 1.18. A Digital Voltmeter

The selection of the range and the type of current is done in the same way as for the ammeter.

1.1.5 Electrical Energy.

Every electrical circuit has a generator that provides electrical energy to set the charges in motion. The unit of measurement for energy is the joule (symbol J), and its symbol is W. For example, the potential energy contained in a thundercloud represents about 1 trillion joules.

Electrical devices consume electrical energy and convert it into useful energy and heat.

For example:

A fan converts electrical energy supplied by the mains (220 volts) into mechanical energy (it rotates) and heat (it also produces some heat).

A toaster converts electrical energy into heat. In this case, the dissipated heat is useful, whereas in the case of the fan, the dissipated heat is lost energy (Joule effect). Just as we evaluate the energy of a waterfall by multiplying the quantity of liquid by the height of the fall, we evaluate electrical energy by multiplying the quantity of electricity (Q) by the potential difference (U).

1.1.6. Electrical Power.

The electrical power of a device is the energy consumed by that device per unit of time (in one second). Power is expressed in watts (symbol **W**).

The electrical energy consumed by a device = the power of the device (in watts) x the duration of use (in seconds).

So, $\mathbf{P = W/t = (I.\ t.\ U)/t = I.U}$

Where:

P = power in watts (W)
U = voltage in volts (V).
I = current intensity in amperes (A)
$\mathbf{P = U \times I}$
Power is the amount of energy that can be produced or consumed per unit of time.

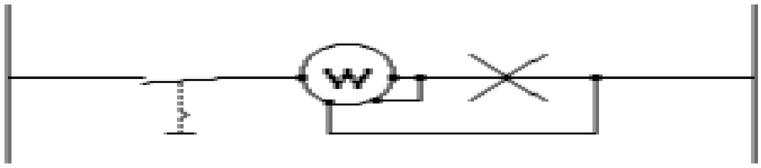
Examples: 2W, 6W, 25W, 100W, 1000W lamps...

736W, 200W motors...
1000W, 2000W heaters...
For electrical consumption, we use the kilowatt-hour (kWh).

It is the consumed power multiplied by the time during which it was consumed

2.2. Measurement of Power.

It is carried out using a voltmeter and an ammeter (2 devices).



We can also use a wattmeter (a single device) that includes a voltmeter coil and an ammeter coil. The product U x I can be read directly on the instrument's dial.

2.2. Reading nameplates on electrical appliances.

All electrical appliances have an identification plate. This plate contains various symbols. Discover

Figure 1.19. Movement of electrons from the negative pole to the positive pole

Characteristics:

- CE

This symbol indicates that the manufacturer or importer guarantees the compliance of the device with the standards in force within the European Union. The CE marking is not a quality mark; it is intended for market control services and not for consumers to guide their choices.

- **Double Insulation:**

When a device displays this symbol, it means that no live parts are accessible without the use of a tool. These devices do not have an earth connection.

- **Standards:(Les norms)**

Compliance with the applicable French standards for a device is attested by the presence of one of the symbols above.

Different numbers indicate: - Operating voltage (230V), Frequency (50Hz), Absorbed power (example: 1010W).

6. Efficiency. (EXT)

In an engine, the nominal electrical power required to produce mechanical power will never be equal to that mechanical power. Indeed, a small portion of the electrical power will be needed to overcome the friction of the engine's moving parts. Mechanical losses. Additionally, the electric current passing through the motor's electrical coils will generate heat. Electrical losses. Useful power = absorbed power + losses.

$$\eta = \frac{useful\ power}{absorbed\ power} = \frac{P_u}{P_a}$$

η = efficiency.
Pu = useful power.
Pa = absorbed power (the power supplied to it)

Le rendement est toujours plus petit que 1

Noticed

Horsepower is equal to 736 Watts.

1.2. Presentation of an Electric Circuit ***(Direct Current)***

1.2.1 The Different Principles:

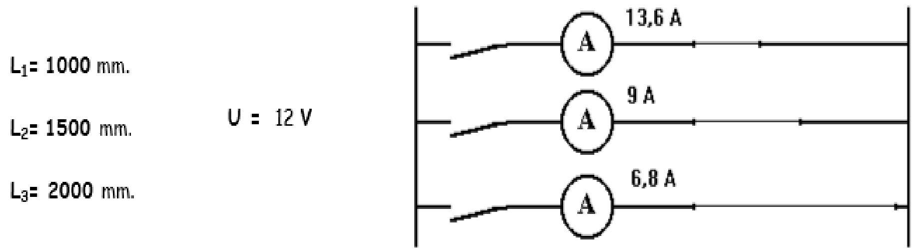
1.2.1.1 Pouillet's Law

Claude Pouillet: French physicist (1790 - 1868)

Even though they are classified as "good conductors," electrical wires, and, in general, various conducting materials, offer a certain resistance to the flow of electric current.

- **Experiment #1**.

Let's insert a wire made of ferronickel with various lengths into the circuit and measure the current with the same cross-section.

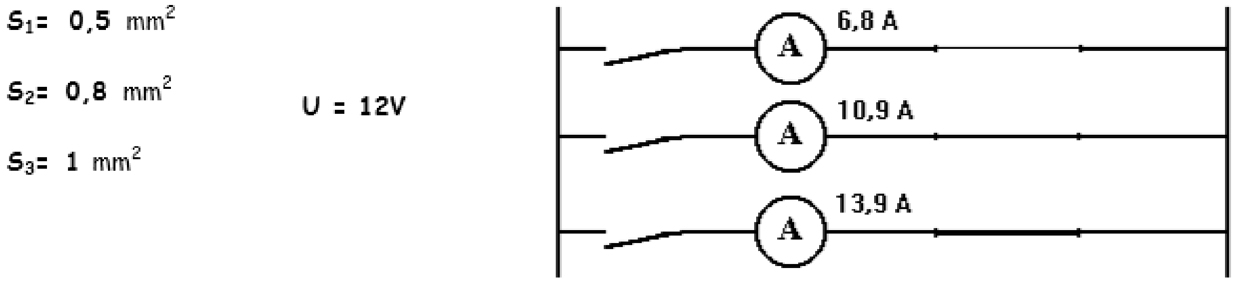


Conclusion:

The electrical resistance of a conductor is directly proportional to its length. (The longer a conductor is, the more it offers resistance to the flow of current)

- ***Experiment #2.***

Now, let's insert a wire made of ferronickel with the same length but different cross-sections into the circuit and measure the current

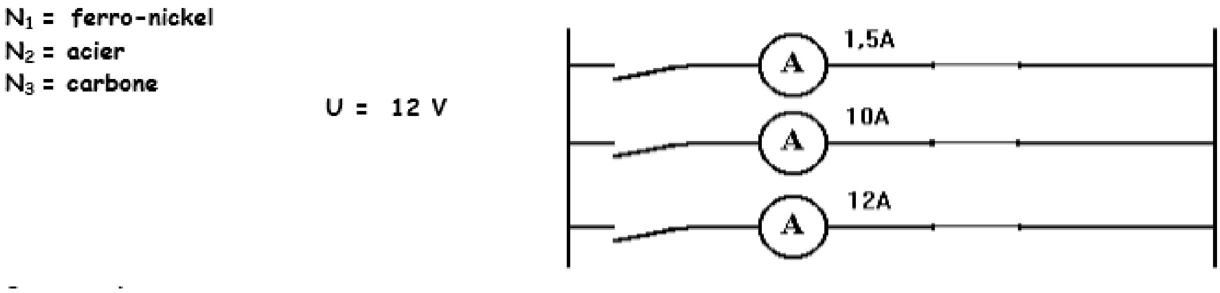


Conclusion:

The electrical resistance of a conductor is inversely proportional to its length. (The larger the conductor, the less resistance it offers to the flow of current, as it allows more electrons to pass through).

- ***Experiment #3.***

Finally, let's insert wires of the same length and the same cross-section but of different materials into the circuit and measure the currents.



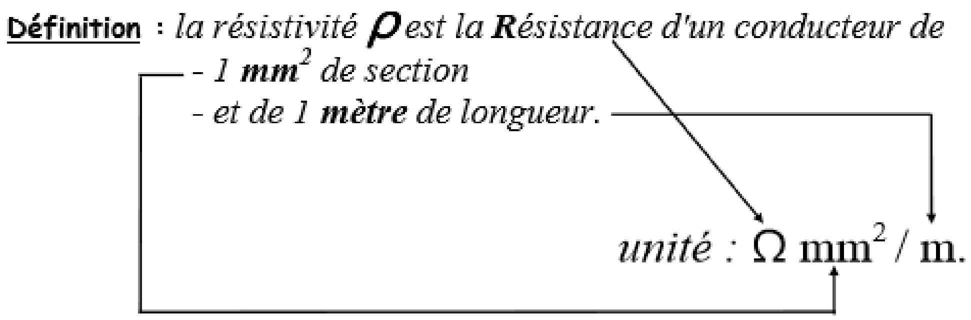
Conclusion:

The electrical resistance of a conductor is directly proportional to its nature. This is resistivity (ρ or Rho), as some materials allow electrons to flow more easily.

- ***Definition:***

Resistivity (ρ) is the resistance of a conductor with:

1 mm² of cross-section
and 1 meter in length.
Unit: **Ω** mm²/m.



$$R = \frac{\rho\, L}{S}$$

R = resistance in **Ω** (ohms).
L = length in meters.
ρ = resistivity in **Ω**·mm²/m (ohm millimeters squared per meter).
The resistance of a conductor is equal to the resistivity (ρ) of the conductor multiplied by the length (L) of the conductor and divided by the cross-sectional area (S) of the conductor.

R = ρ * (L / S)

Transformation de la formule :

$$R = \frac{\rho\, L}{S}$$

$\Rightarrow R\, S = \rho\, L$

$\Longrightarrow\ \rho = \dfrac{R\, S}{L}$

$\Longrightarrow\quad L = \cdots \ldots$

$\Longrightarrow\ S = \cdots \ldots \ldots \ldots$

Note:

Most conductors have a circular cross-section. You can calculate the cross-sectional area when you know the diameter or radius.

To calculate the cross-sectional area (**S**) of a circular conductor when you know the diameter (**D**) or the radius (**R**), you can use the following formulas:

If you know the diameter (**D**) of the conductor:

$$\mathbf{S = (\pi/4) * D^2}$$

If you know the radius (**R)** of the conductor:

$$\mathbf{S = \pi * R^2}$$

Where **π (pi)** is a mathematical constant with an approximate value of **3.14159**.

These formulas will allow you to calculate the cross-sectional area of a circular conductor based on the diameter or radius.

S = cross-sectional in mm2

π = 3,14

D= ∅ in mm

r = radius in mm

1.2.1.2 Ohm's Laws: George Ohm: German physicist (1789 – 1854)

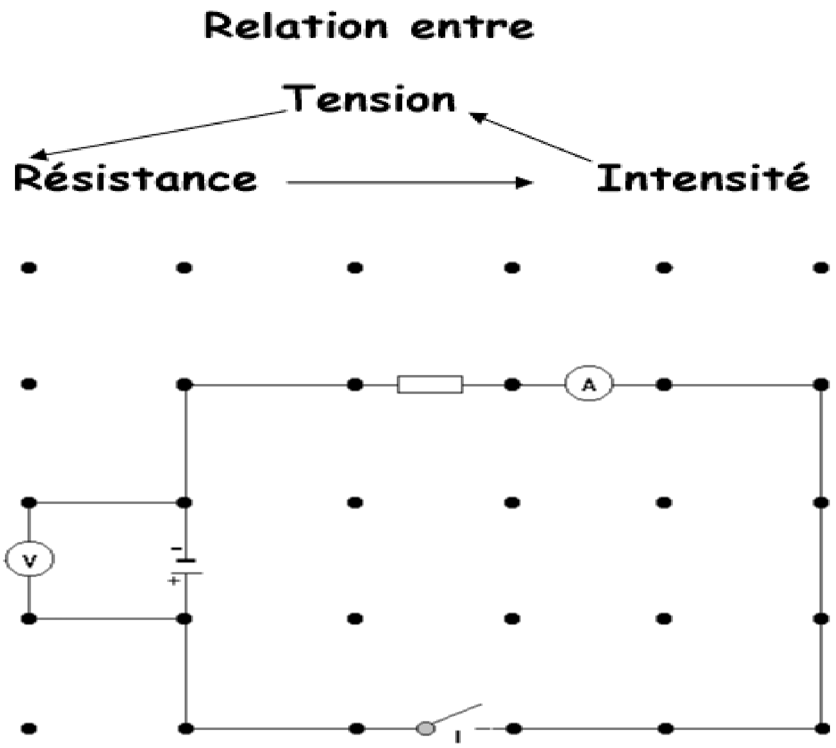


Figure 1.20. Movement of electrons from the negative pole to the positive pole

- ***Experiment #1.***

Place resistors of different values one after the other in the 1.5 V powered circuit and record the readings

U (V)	R (Ω)	I (A)	R x I
....	4,7 Ω	....	....
....	10 Ω	....	....
....	22 Ω	....	....
....	47 Ω	....	....

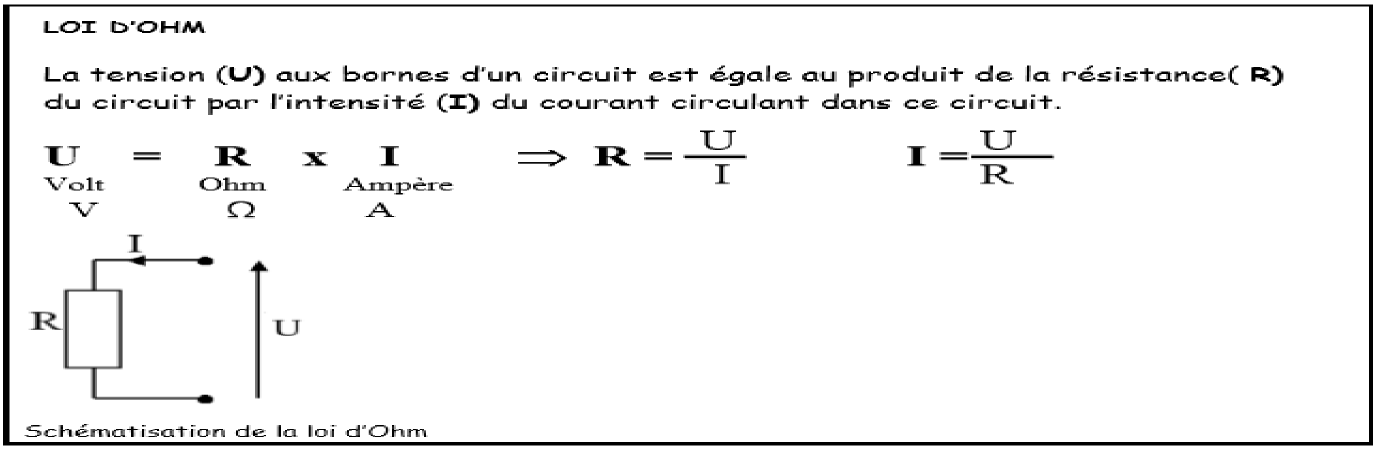
Observations:

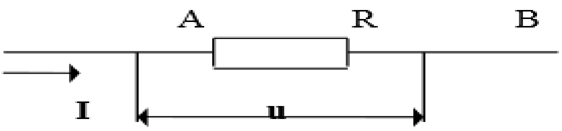
If R increases, I ....

What is the value of R x I for the four tests? ....

Conclusion:

For a specific generator, the product R x I is constant and corresponds to the potential difference (Voltage and Voltage difference). The product R x I: - is the voltage or potential difference across the generator's terminals. - is represented by U and is expressed in volts.





Potentiel A > Potentiel B

V_A > V_B = <u>chute de tension</u>

Voltage drop is the result of electrons passing through a resistor and is defined by the equation:

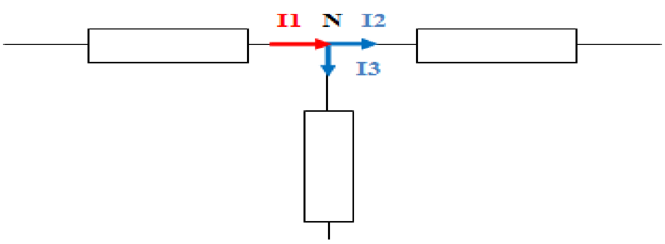
U = R × I.

Any circuit that has a resistor will experience a voltage drop.

3- Fundamental Laws of Circuits: Kirchhoff's Laws

3.1- Nodal Law

A node is a junction point where at least three branches of the network meet. There is no accumulation of charges at the node. All the charges that arrive at the node through one of the branches are immediately redistributed across all the other branches of the node. Thus, the sum of the incoming currents at the node is equal to the sum of the outgoing currents from the node.



Generalizing:

$$\sum_k I_k = 0 \quad (algebraic\ sum)\ or\ \sum_i I_{Incoming_i} = \sum_j I_{sOutgoing_j}$$

The orientation 'incoming' or 'outgoing' of each current can be arbitrarily chosen if not imposed. It makes no assumptions regarding the actual positive direction of flow. Indeed, if all currents are oriented as 'incoming', then at least one of the currents will have a negative value.

3-2- Mesh Law

A mesh is a closed loop consisting of several branches. Any given branch can often be common to two or more neigh-boring meshes. When a branch belongs to only one mesh, the mesh is called independent, and the equation that governs it is an independent and unique equation. As seen in 1.2, the work (or energy input) required to move a charge q from one node A to another node B is independent of the path taken.

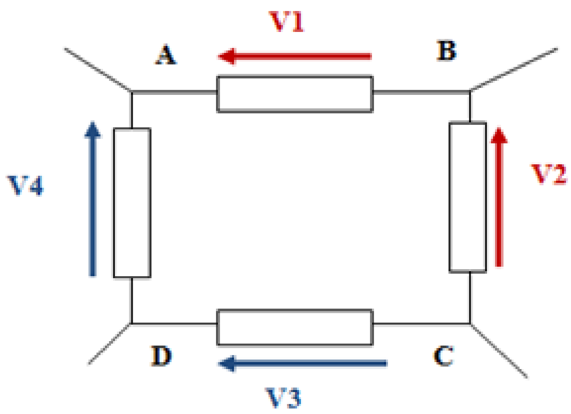
$$W = q(V_A - V_B)$$

In particular, the sum of the work done during a closed loop is zero:

$$W_{A\rightarrow A} = q(V_A - V_A) = 0$$

Thus, the algebraic sum of potential differences along a closed loop is zero.

Exemples



$$-V1 - V2 + V3 + V4 = 0$$

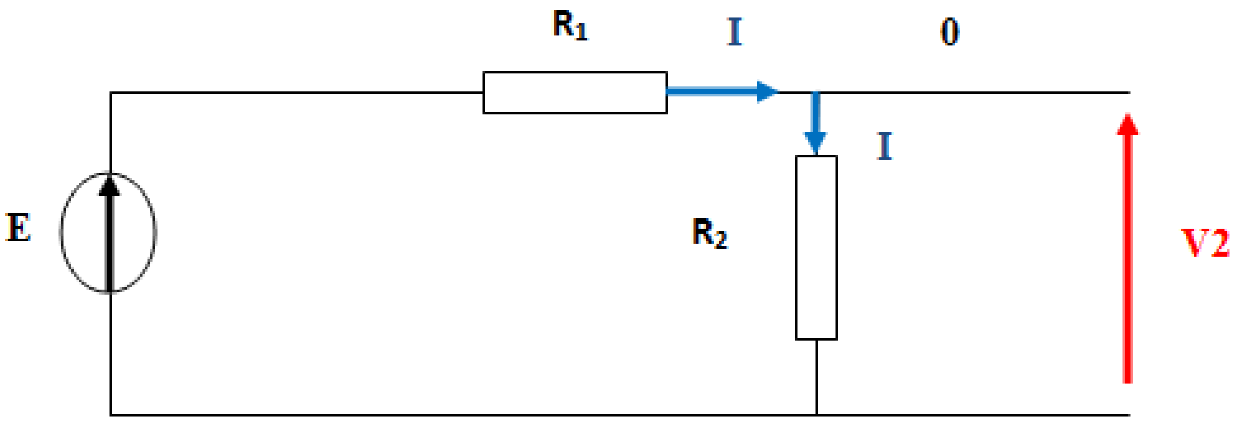
Generalization:

$\sum_k V_k = 0$ (The algebraic sum along a closed loop)

4- Fundamental Theorems

4-1- Laws of Dividers

4-1-1- Voltage Divider Law

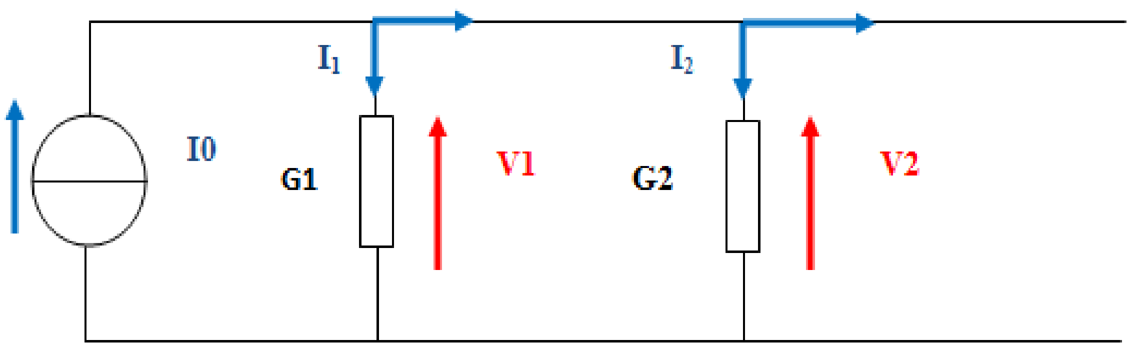


The two resistances of the bridge in Figure 1 being traversed by the same current, the voltage V_2 is a fraction of the voltage E:

$$V_2 = E\frac{R_2}{R_1 + R_2}$$

When the divider is loaded, R_2 is then traversed by a fraction of I, and the voltage divider law is no longer satisfied.

4-1-2- Current Divider Law



Au nœud A du réseau de la figure 2, le courant I_0 se repartit entre les deux branches, le courant I_1 (ouI_2) est une fraction de I_0 :

$$I_1 = I_0\frac{G_1}{G_1+G_2} \Longrightarrow I_1 = I_0\frac{\frac{1}{R_1}}{\frac{1}{R_1}+\frac{1}{R_2}} = I_0\frac{R_2}{R_1+R_2} \qquad => \quad I_1 = I_0\frac{R_2}{R_1+R_2}$$

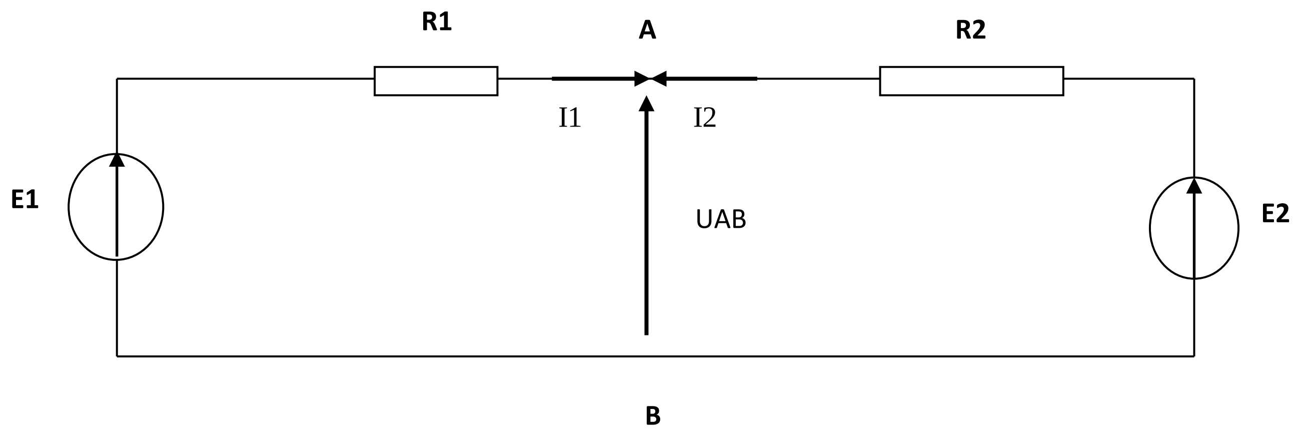
4-2- Superposition Theorems

Consider a linear network powered by multiple independent voltage and/or current sources denoted by respective electromotive forces (EMFs) E_1, E_2, ... and short-circuit currents I_{01}, I_{02}, ...

The current I_k in any arbitrary branch k of the network is equal to the algebraic sum of the currents individually created in that branch by each source acting alone, with the others being neutralized.

The superposition theorem applies similarly to calculate the potential difference between any two arbitrary nodes in the network.

Examples

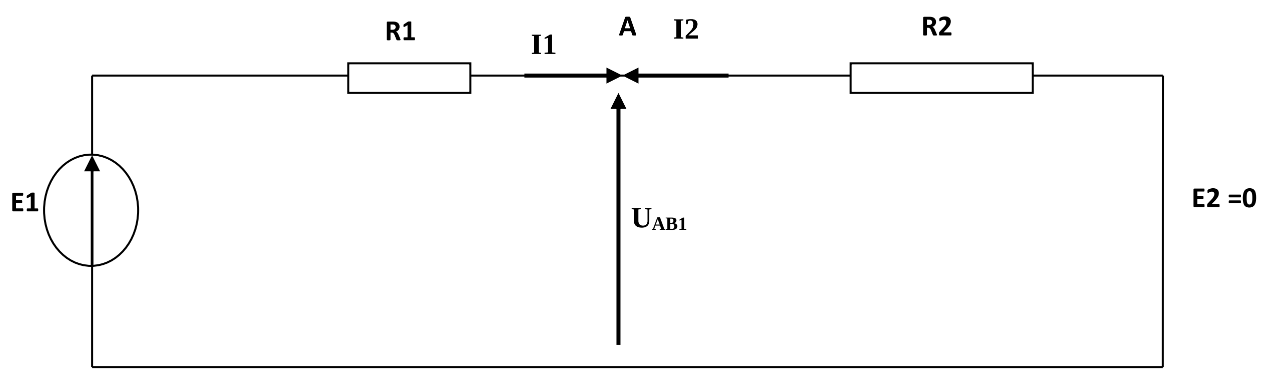


Let's calculate the voltage U_{AB} in the circuit shown in Figure 3 by applying the superposition theorem.

E1 and E2 are two independent sources.

The calculation is done in two steps:

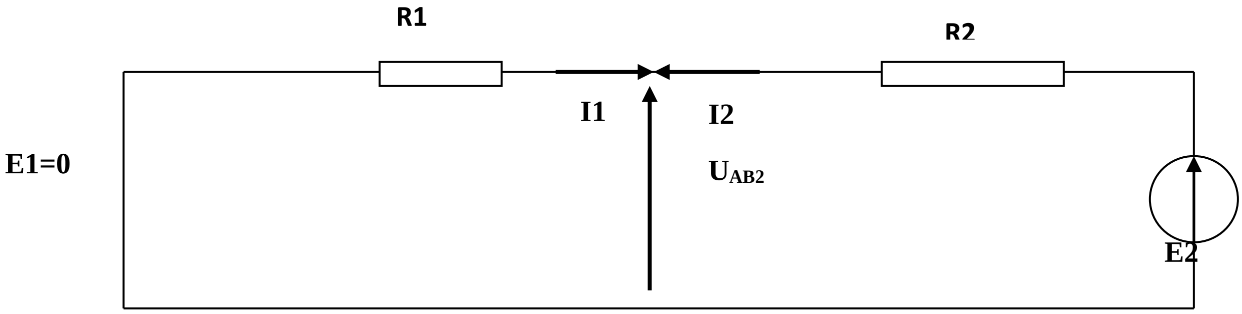
- ***Step 1 :***



The independent source E_2 is neutralised, and only the source E_1 is active:

$$U_{AB1} = E_1 \frac{R_2}{R_1 + R_2}$$

- ***Step 2:***



The independent source E_1 is neutralised, and only the source E_2 is active:

$$U_{AB2} = E_2 \frac{R_1}{R_1 + R_2}$$

- ***Final result :***

$$U_{AB} = U_{AB1} + U_{AB2} = E_1 \frac{R_2}{R_1 + R_2} + E_2 \frac{R_1}{R_1 + R_2}$$

The superposition theorem applies to a network that includes dependent sources, i.e., active components, provided that their operation is linear.

This theorem is very useful, but its application becomes challenging when the network involves numerous sources. In certain cases, it is preferable to use the Millman theorem.

Conclusion

In conclusion, understanding the basic parameters of electrical circuits, such as resistance, capacitance, and inductance, is essential in the field of electrical engineering. This knowledge enables us to analyse and design electrical circuits efficiently and provides the tools necessary to understand the impact of each component on the performance of the system. Learning these principles and applying them practically is a crucial step towards working with electrical circuits in various engineering applications, whether in the design of electronic devices or the development of advanced electrical systems.