Chapter III: Electrokinetic

Course 2

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Electric circuit

An electrical circuit is a set of conductors (wires) and electrical components through which an electric current flows.

Battery (generator)

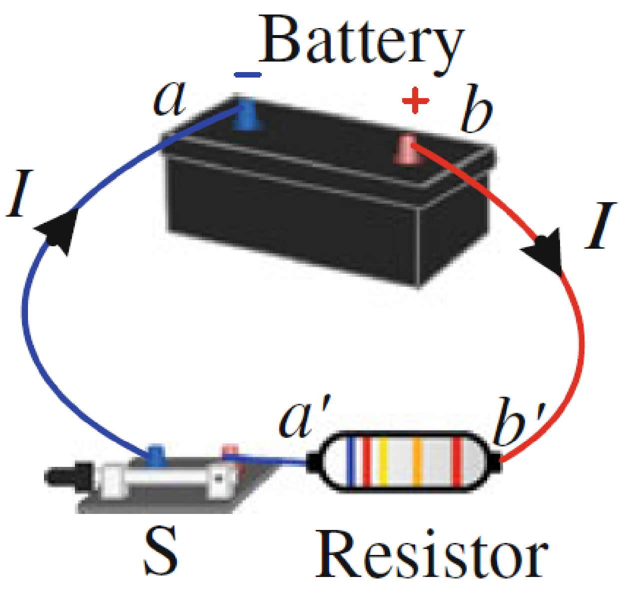
the battery as a device that produces a potential difference and causes charges to move.

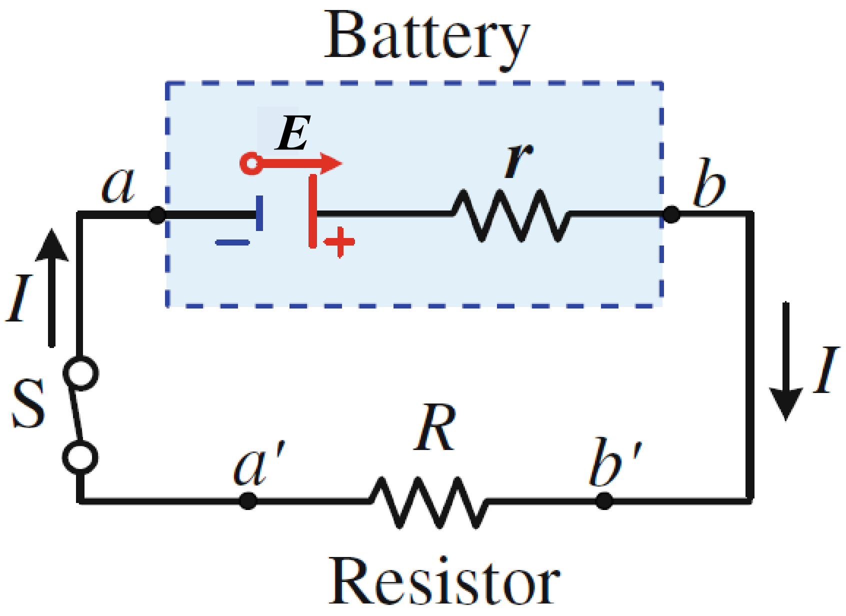
In fact, it is a device that works as an *energy converter*.

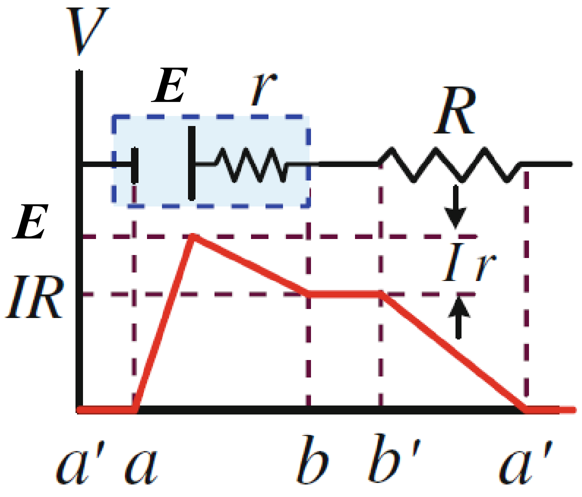
A battery is often called a *source of electromotive force* or, a *source of emf* (this unfortunate historical name describes a potential difference in volts, but not a force).

The emf **E** of a battery is the maximum possible potential difference that the battery can provide between its terminals, usually the voltage at zero current.

Because a real battery is made of matter, there is a resistance against the flow of charge within the battery. This resistance is called the battery's **internal resistance** and is usually denoted by *r*. For an ***ideal battery*** **with *zero internal resistance***.

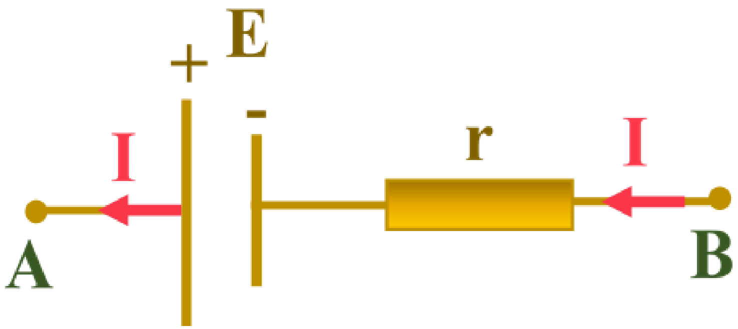






The expression for the potential difference across the terminals of a generator is given by:

$$V_{AB} = E - rI$$



La tension du générateur est E mais il délivre à l'extérieur V_{AB} une partie est dissipée par effet joule dans le générateur caractérisé par une résistance r.

b) Power (Energy) Highlighted in a battery:

Three types of energy (power) are defined in a generator.

Power supplied by the battery:

This power represents the energy provided by the electromotive force of the generator to the load to move it through the electrical circuit per unit of time.

Its expression is given by: $P_s = E.I$

Power dissipated by Joule heating in the battery:

This is the energy dissipated by Joule heating in the internal resistance, and it is given by:

$$P_d = r.I^2$$

Power used in the external circuit:

It represents the energy of the load per unit of time when it exits the generator. This power is referred to as the used power. Its expression is:

$$P_u = P_f - P_d = E.I - r.I^2$$

Generator efficiency η

It is the ratio of the electrical power used by the external circuit to the electrical power supplied by the generator.

$$\eta = \frac{E.I - r.I^2}{E.I} = 1 - \frac{r.I}{E}$$

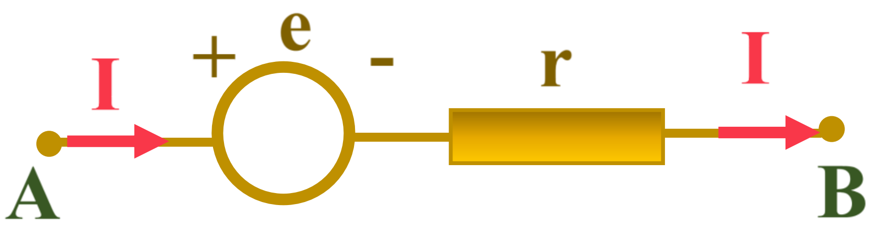
Note: If the internal resistance of the generator is zero, the generator is said to be perfect or ideal. The efficiency value will be maximum and equal to 100%.

Receivers

These are systems that, when traversed by an electric current, transform electrical energy into another form.

Equivalent diagram of a receiver:

The electric current in a receiver flows from the negative terminal (-) to the positive terminal (+). The receiver is characterized by a counter electromotive force noted as (e) which is homogeneous to a voltage, and a low internal resistance (r).



The expression for the potential difference across a receiver is given by:

$$V_{AB} = e + rI$$

Power (energy) highlighted in a receiver:

Three types of power are defined in a generator.

- **Power Transformed by the Receiver:**

The counter electromotive force transforms a portion of the energy from the source into another form. For example, if the receiver is a motor, it converts electrical energy into mechanical energy. It is given by: $P_{trans} = e \cdot I$

- **Power Dissipated by Joule Effect in the Receiver:**

Power Dissipated by Joule Effect in the Receiver: This is the energy dissipated by the Joule effect in the internal resistance. It is given by: $P_d = r \cdot I^2$

- **Consumed (Used) by the Receiver:**

It represents the total power consumed by the receiver. That is, the algebraic sum of the power transformed and the power dissipated by the Joule effect in the receiver. Its expression is given by: $P_{cons} = P_{trans} + P_d = e.I + r \cdot I^2$

Receiver Efficiency η:

This is the ratio of the transformed power to the total electrical power consumed.

$$\eta = \frac{e.I}{e.I + r.I^2} = \frac{e}{e + r.I}$$

Note:

If the internal resistance of the receiver is zero, the receiver is said to be perfect or ideal, and the efficiency value will be maximum, equal to 100%.

In some cases, a generator can act as a receiver; these are called irreversible receivers. For example, the battery of a phone acts as a generator when the phone is in use, but when it discharges, we need to recharge it, and in this second case, it acts as a receiver.

Analysis of Electrical circuits:

A technique that is applied to loops in complicated circuits consists of two principles called Kirchhoff's Rules.

Junction rule: Kirchhoff's First Law (conservation of electric charge)

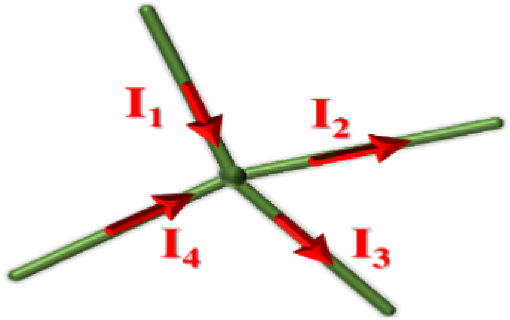
At any node or junction in a circuit, the sum of the currents entering the node is equal to the sum of the currents leaving the node.

$$\sum I_{in} = \sum I_{out}$$

Example :

Applying Kirchhoff's first law to the node

in the figure above yields: $I_1 + I_4 = I_2 + I_3$



Loop rule The Second Law of Kirchhoff (conservation of energy)

For any closed loop in a circuit, the sum of the potential differences across all elements must be zero. That is:

$$\sum_{i=1}^{n} \Delta V_i = 0$$

n : the number of elements in the loop where voltage drops occur.

Definitions

Junction: It's a point in a circuit where at least three or more wires meet.

The branch: It's a portion of an electrical circuit situated between two junctions.

Loop It's a set of branches that form a closed loop.

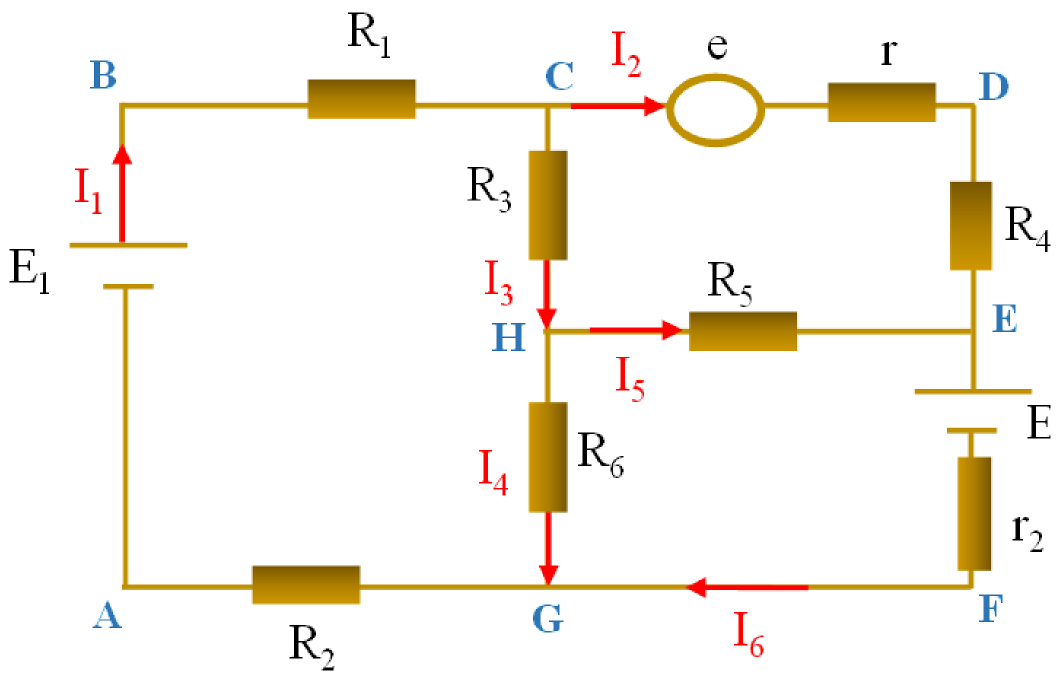
The dipole: An element of the circuit, such as a generator, resistor, motor, etc.

Example

Consider the circuit in the figure below.

Determine the junctions of the circuit.

Name the branches and loops of this circuit.



Note :

-In an electrical circuit with J Junctions, there are (J-1) independent junctions.

-Number of independent loops (L) = Number of branches (B) - (Number of junctions (J) – 1

$$L = B - (J - 1)$$

For each independent loop and junction, we apply Kirchhoff's law to solve for the unknowns.

Exercise 1

We give the circuit in Figure below with:

$E = 40V$, $r = 1\ \Omega$, $R_1 = R_3 = R_4 = 4\ \Omega$, $R_2 = 3\ \Omega$, $R5 = 5\ \Omega$, $R = 10\Omega$

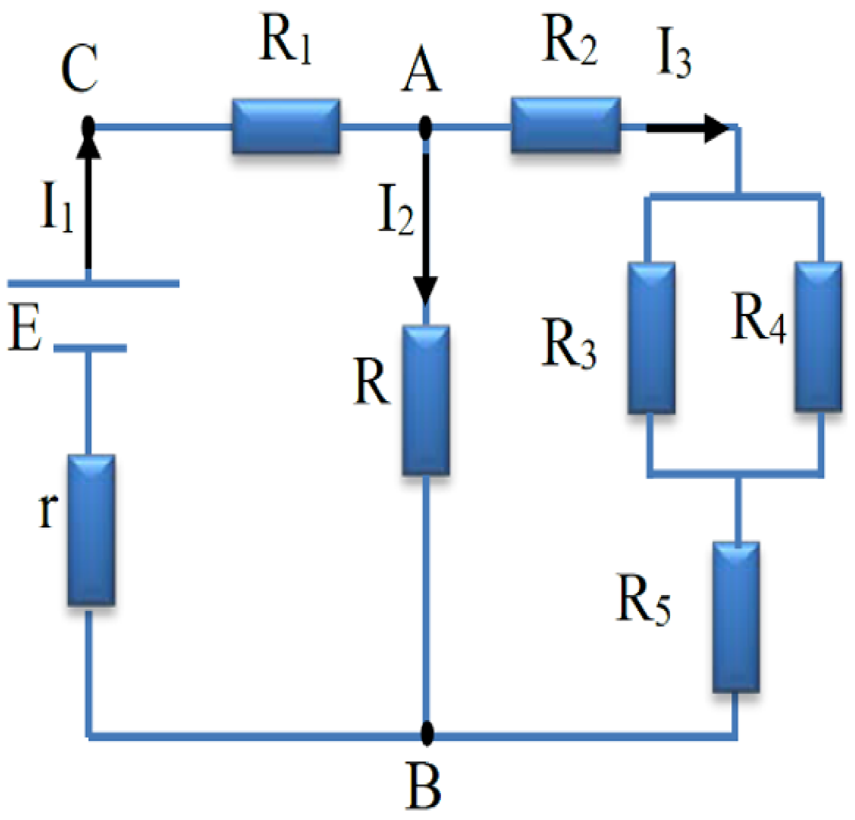
1) Simplify the circuit by calculating the equivalent resistance of all the resistors: R, R_2, R_3, R_4 and R_5.

2) Calculate the current I_1 delivered by the generator.

3) Calculate the voltage VA-VB and deduce the currents I_2 (circulating in R) and I_3 (circulating in R_2).

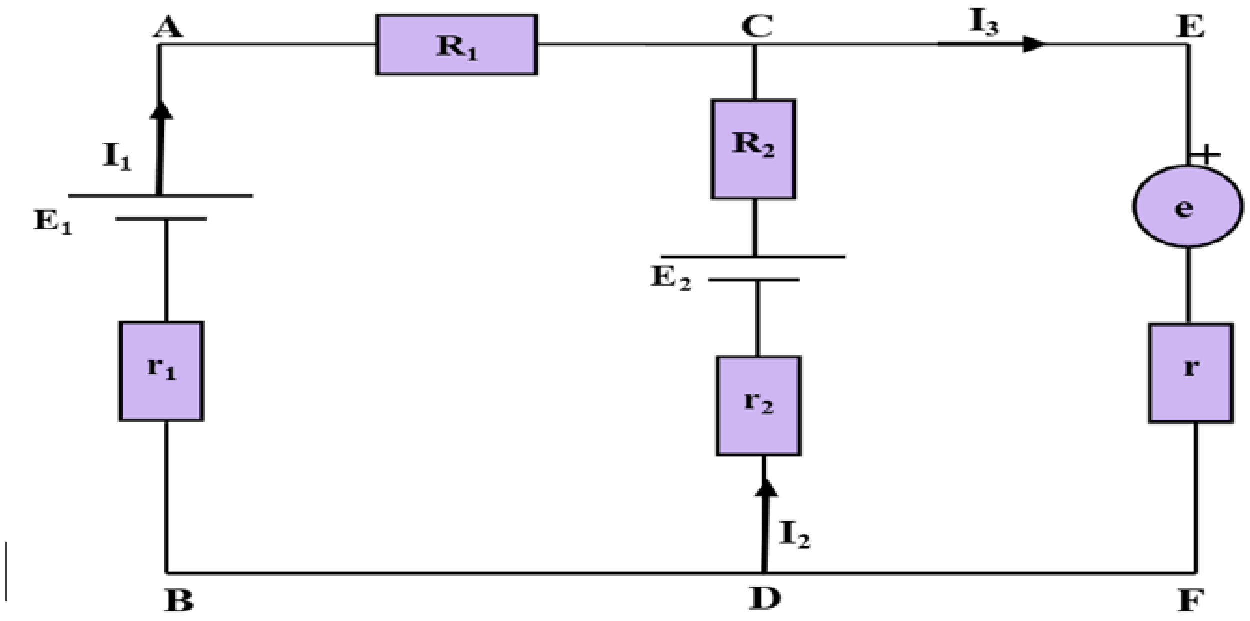
4) Calculate VC-VB and deduce the efficiency of the generator E.

5) Calculate the total power dissipated by Joule effect throughout the circuit.



Exercise2

Consider the following electrical circuit:



as given:

(E_1=12V, r_1= 1Ω),

(E_2=6V, r_2=2Ω),

(e=3V ,r=2Ω),

R_1=5Ω,

R_2=4Ω

1- Calculate I_1, I_2, and I_3, the currents flowing through each branch.

2- Determine the power dissipated by Joule effect in generator E_2.

3- Calculate the voltage drops: V_{AB} and V_{CA} .

4- Calculate the efficiency of generator E1 and receiver e.