

## Fundamentals of Physics in Engineering I

### Unit 7.- ELECTRIC CURRENT

#### • Introduction

A conductor is a material which allows charged particles to move freely through it and these particles carry the charge on the conductor. For example, a metal may be considered to be a structure of positive ions occupying fixed positions on a lattice with the free electrons moving between them. The charge of all the free electrons is equal and opposite to the charge of all the ions, thus giving rise to a neutral material. The free electrons can move freely within the lattice of ions and carry the charge through the metal.

#### • Current and charge motion. Current density

An *electric current* is a flow of charged particles. The intensity  $I$  of the electric current characterises the charge flowing through a circuit element:

$$I = \frac{dQ}{dt}$$

The direction of the current is the same as the direction of the drift velocity  $\mathbf{v}$  of the positive charge carriers. In the SI, the intensity  $I$  is expressed in amperes (A). The *current density*  $\mathbf{J}$  is the charge flow at a point inside a conducting medium:

$$\mathbf{J} = nq\mathbf{v}$$

where  $n$  is the number of charge carriers per unit of volume (concentration of particles) and  $\mathbf{v}$  is the drift velocity of the charge carriers. Successive collisions with the ions in the lattice cause the drift velocity of the charge carriers to be a constant average. If  $\mathbf{j}$  is uniform, its module  $j$  is given by:

$$J = \frac{I}{S}$$

and in the general case:

$$I = \int_S \mathbf{J} \cdot d\mathbf{S}$$

Conventionally, the direction of the electric current is taken to be that of the positive charge carriers. When the charge carriers are negative, the direction of the current is contrary to the direction of movement of these negative charge carriers.

#### • Ohm's law. Conductivity, resistivity and resistance

For a conductor at a constant temperature, Ohm's law states that the quotient between the potential difference  $V$  between two points on a conductor and the electric current  $I$  circulating through the conductor is a constant known as *electrical resistance*,  $R$ :

$$\frac{V}{I} = R \quad \Rightarrow \quad V = RI$$

In this case the conductor is said to be ohmic. In the SI, the resistance  $R$  is expressed in ohms ( $\Omega$ ).

For a conductor of length  $l$  and section  $S$ , Ohm's law may be written as:

$$J = \frac{l}{RS} E = \frac{1}{\rho} E = \sigma E$$

where  $\sigma = 1/\rho$  is the *conductivity* of the material and  $\rho$  its *resistivity*.  $\rho$  is expressed in  $\Omega^{-1}\text{m}^{-1}$  and:

$$R = \frac{\rho l}{S}$$

The resistivity of metals increases with temperature. Ohm's law may be written in general as:

$$\mathbf{J} = \sigma \mathbf{E}$$

and the drift velocity of the electrons may be written as:

$$\mathbf{v} = -\frac{\sigma}{en} \mathbf{E}$$

#### • Resistances in series and in parallel

The equivalent resistance of resistances connected in series is given by:

$$R_{eq} = \sum_i R_i$$

and of resistances connected in parallel:

$$\frac{1}{R_{eq}} = \sum_i \frac{1}{R_i}$$

#### • Energy aspects of an electric current. Joule's law

A supply of energy is necessary to maintain an electric current since the charges must be accelerated by an electric field. The energy per unit of time, or power, required to maintain a current is given by  $P = IV$ . In the SI, power  $P$  is expressed in watts (W). For conductors that obey Ohm's law  $V = RI$  and so:

$$P = IV = IR^2 = \frac{V^2}{R} \quad (\text{Joule's law})$$