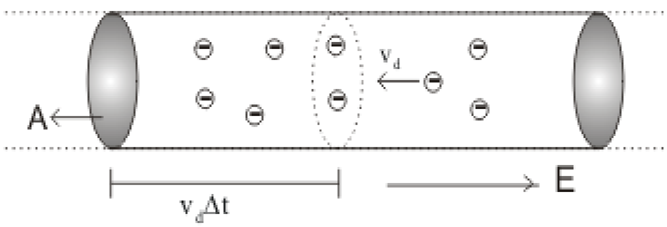
Drift Velocity

The free electrons in a conductor are randomly moving in all directions with all possible velocities like the atoms of an ideal gas. In absence of an electric field they move such that their average velocity is zero and thus the number of electrons and hence the net charge through any cross section is zero. With applications of an electric field there is a force on the electron in the direction opposite to the field and the whole free electron cloud accelerates and acquires an additional velocity in the direction opposite to electric field. In this situation during the collision with the ion cores, the electrons lose some of their kinetic energy and becomes slow, heat is produced. At a certain velocity the whole energy gained by the electrons will convert into thermal energy and thus this additional velocity of the electron cloud becomes constant. This is called drift velocity v_d.

Relation between drift velocity and electric current

Consider a conducting wire of length L and having uniform cross-section area A in which electric field is present



Let there are n free electrons per unit volume moving with the drift velocity v_d. In the time interval Δt the electron cloud advances by a distance v_d*Δt and volume of this portion is A*v_d*Δt. The number of free electrons in this portion is n*A*v_d*Δt. All these electrons cross the area A in time Δt, hence charge crossing the area in time Δt is

$$\Delta Q = neAv_d \Delta t$$

or

$$I = \Delta Q/\Delta t = neAv_d$$

This is the relation between the electric current and drift velocity

Current density

In terms of drift velocity current density is given as

$$j = I/A = nev_d$$

Average velocity of free electrons in a conductor:

There is no flow of charge through a conductor without an electric field. The free electrons in a conductor are moving randomly an all possible direction with all possible velocities and their average velocity without electric field remains zero. Mathematically

$$\frac{1}{N}\sum_{i=1}^{N}\vec{v}_i = 0 \qquad \text{---------- (1)}$$

Relaxation time:

The free elections in their random motion keep colliding with other electrons and the fixed ion cores and due to this magnitude and direction of their velocities changes. Between two collisions the electrons move with constant velocity. The time taken between two collisions will be deferent for each electron. The average of all such time is called relaxation time denoted by τ.

Now if an electric field E is present, each electron experiences a force -eE and due to which each electron accelerates in the direction of the field with an acceleration -eE/m.

Now if i_{th} electron is moving with velocity $\vec{v}_i$ just after a collision then after time t its velocity $\vec{V}_i$ will be given by

$$\vec{V}_i = \vec{v}_i - \frac{e\vec{E}}{m}\, t$$

Now after each collision the direction of velocity of electron changes and contributes to the random motion. As the average time between two collisions is τ the average velocity of the electrons in the direction of electric field i.e. drift velocity is given by

$$\frac{1}{N}\sum_{i=1}^{N}\vec{V}_i = \vec{v}_d = \frac{1}{N}\sum_{i=1}^{N}\vec{v}_i - \frac{e\vec{E}}{m}\,\tau$$

Or $\vec{v}_d = 0 - \frac{e\vec{E}}{m}\,\tau$ (using equation 1)

Or $\vec{v}_d = -\frac{e\vec{E}}{m}\,\tau$ -------------------------- (2)

Now as we know $\vec{J} = ne\vec{v}_d$ substituting value of J in equation (2) we get

$$\frac{\vec{J}}{ne} = -\frac{e\vec{E}}{m}\,\tau$$

Or $\vec{E} = -\vec{J}\,\frac{m}{ne^2\tau}$

Resistivity

Comparing it with E = j ρ (resistivity) we get

$$\rho = \frac{m}{ne^2\tau}$$

Mobility

In the conductors the drift velocity per unit electric field is called mobility of the charge carrier. Given by

$$\mu = \frac{V_d}{E}$$

Thus, the mobility of free electrons in the conductor is given by

$$\mu = \frac{V_d}{E} = \frac{e\tau}{m}$$