CURRENT ELECTRICITY

DRIFT OF ELECTRONS AND THE ORIGIN OF RESISTIVITY

DRIFT SPEED:

A conductor contains a large number of loosely bound electrons which we call free electrons or conduction electrons. The remaining material is a collection of relatively heavy positive ions which we call lattice. These ions keep on vibrating about their mean positions. The average amplitude depends on the temperature. Occasionally, a free electron collides or interacts in some other fashion with the lattice. The speed and direction of the electron changes randomly at each such event. As a result, the electron moves in a zig-zag path. As there is a large number of free electrons moving in random directions, the number of electrons crossing an area ΔS from one side very nearly equals the number crossing from the other side in any given time interval. The electric current through the area is, therefore, zero.

When there is an electric field inside the conductor, a force acts on each electron in the direction opposite to the field. The electrons get biased in their random motion in favor of the force. As a result, the electrons drift slowly in this direction. At each collision, the electron starts afresh in a random direction with a random speed but gains an additional velocity v' due to the electric field. This velocity v' increases with time and suddenly becomes zero as the electron makes a collision with the lattice and starts afresh with a random velocity. As. the time, t between successive collisions is small, the electron "slowly and steadily drifts opposite to the applied field (shown figure). If the electron drifts a distance λ in a longtime t, we define drift speed as

$$V_d = \frac{l}{t}$$

If τ be the average time between successive collisions, the distance drifted during this period is

$$l = \frac{1}{2}\alpha(\tau)^2 = \frac{1}{2}\left(\frac{eE}{m}\right)(\tau)^2$$

The drift speed is $$V_d \frac{l}{\tau} = \frac{1}{2}\left(\frac{eE}{m}\right)\tau$$

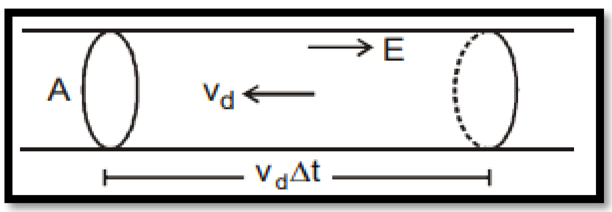
It is proportional to the electric field E and to the average collision-time τ.

The random motion of free electrons does not contribute to the drift of these electrons. Also, the average collision-time is constant for a given material at a given temperature. We, therefore, make the following assumption for our present purpose of discussing electric current.

When no electric field exists in a conductor, the free electrons stay at rest ($V_d = 0$) and when a field E exists, they move with a constant velocity

$$V_d = \frac{e\tau}{2m} E = KE$$

opposite to the field. The constant k depends on the material of the conductor and its temperature.



Let us now find the relation between the current density and the drift speed. Consider a cylindrical conductor of cross-sectional area A in which an electric field E exists. Consider a length v_d Δt of the conductor (figure shown). The volume of this portion is $Av_d\Delta t$. If there are n free electrons per unit volume of the wire, the number of free electrons in this portion is $nAv_d\Delta t$. All these electrons cross the area A in time Δt. Thus, the charge crossing this area in time Δt is

$$\Delta Q = nAv_d\ \Delta t\ e$$

Or $$i = \frac{\Delta Q}{\Delta t} = nAv_d e$$

And $$j = \frac{i}{A} = nev_d$$

Ex. Calculate the drift speed of the electrons when 1 A of current exists in a copper wire of cross- section 2 mm^2. The number of free electrons in 1 cm3 of copper is 8.5×10^{22}.

Sol. We have

$$j = nev_d$$

Or $$V_d = \frac{j}{ne} = \frac{i}{Ane} = \frac{1A}{\left(2\times10^{-6}m^2\right)\left(8.5\times10^{22}\times10^6 m^{-3}\right)\left(1.6\times10^{-19}C\right)} = 0.036 mm/s$$

We see that the drift speed is indeed small.