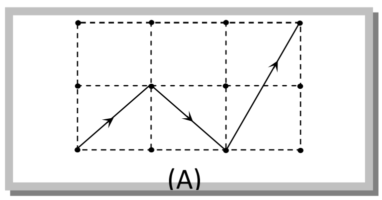
Conduction of Current in Metals.

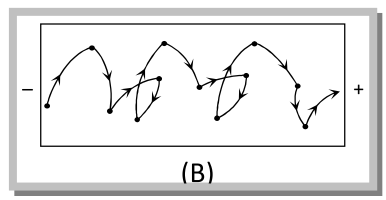
According to modern views, a metal consists of a 'lattice' of fixed positively charged ions in which billions and billions of free electrons are moving randomly at speed which at room temperature (i.e. 300 K) in accordance with kinetic theory of gases is given by

$$v_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3\times(1.38\times10^{-23})\times300}{9.1\times10^{-31}}} \simeq 10^5\ m/s$$

The randomly moving free electrons inside the metal collide with the lattice and follow a zig-zag path as shown in figure (A).



(A)

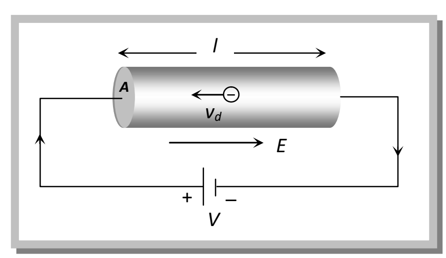


(B)

However, in absence of any electric field due to this random motion, the number of electrons crossing from left to right is equal to the number of electrons crossing from right to left (otherwise metal will not remain equipotential) so the net current through a cross-section is zero.

When an electric field is applied, inside the conductor due to electric force the path of electron in general becomes curved (parabolic) instead of straight lines and electrons drift opposite to the field figure (B). Due to this drift the random motion of electrons get modified and there is a net transfer of electrons across a cross-section resulting in current.

(1) Drift velocity : Drift velocity is the average uniform velocity acquired by free electrons inside a metal by the application of an electric field which is responsible for current through it. Drift velocity is very small it is of the order of 10–4 m/s as compared to thermal speed $(\simeq 10^5\ m/s)$ of electrons at room temperature.



If suppose for a conductor

n = Number of electron per unit volume of the conductor

A = Area of cross-section

V = potential difference across the conductor

E = electric field inside the conductor

i = current, J = current density, ρ = specific resistance, σ = conductivity $\left(\sigma = \frac{1}{\rho}\right)$ then current relates with drift velocity as $i = neAv_d$ we can also write $v_d = \frac{i}{neA} = \frac{J}{ne} = \frac{\sigma E}{ne} = \frac{E}{\rho ne} = \frac{V}{\rho l n e}$.

Note: The direction of drift velocity for electron in a metal is opposite to that of applied electric field (i.e. current density $\vec{J}$).

$v_d \propto E$ i.e., greater the electric field, larger will be the drift velocity.

When a steady current flows through a conductor of non-uniform cross-section drift velocity varies inversely with area of cross-section $\left(v_d \propto \frac{1}{A}\right)$

If diameter of a conductor is doubled, then drift velocity of electrons inside it will not change.

(2) Relaxation time (τ) : The time interval between two successive collisions of electrons with the positive ions in the metallic lattice is defined as relaxation time

$\tau = \frac{\text{mean free path}}{\text{r.m.s. velocity of electrons}} = \frac{\lambda}{v_{rms}}$ with rise in temperature vrms increases consequently τ decreases.

(3) Mobility: Drift velocity per unit electric field is called mobility of electron i.e. $\mu = \frac{v_d}{E}$. Its unit is $\frac{m^2}{volt - \sec}$.

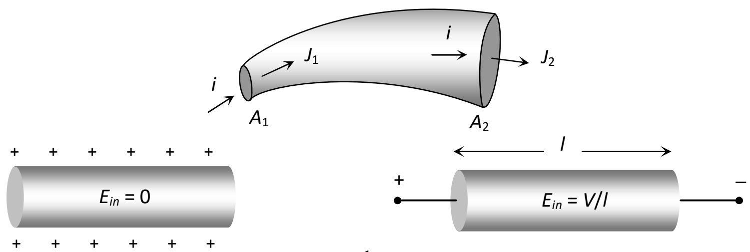
Concepts

Human body, though has a large resistance of the order of kΩ (say 10 kΩ), is very sensitive to minute currents even as low as a few mA. Electrocution, excites and disorders the nervous system of the body and hence one fails to control the activity of the body.

1 ampere of current means the flow of 6.25 × 1018 electrons per second through any cross-section of the conductors.

dc flows uniformly throughout the cross-section of conductor while ac mainly flows through the outer surface area of the conductor. This is known as skin effect.

It is worth noting that electric field inside a charged conductor is zero, but it is non zero inside a current carrying conductor and is given by $E = \frac{V}{l}$ where V = potential difference across the conductor and l = length of the conductor. Electric field outside the current carrying is zero.



For a given conductor JA = i = constant so that $J \propto \frac{1}{A}$ i.e., J1 A1 = J2 A2 ; this is called equation of continuity

If cross-section is constant, I ∝ J i.e. for a given cross-sectional area, greater the current density, larger will be current.

The drift velocity of electrons is small because of the frequent collisions suffered by electrons.

The small value of drift velocity produces a large amount of electric current, due to the presence of extremely large number of free electrons in a conductor. The propagation of current is almost at the speed of light and involves electromagnetic process. It is due to this reason that the electric bulb glows immediately when switch is on.

In the absence of electric field, the paths of electrons between successive collisions are straight line while in presence of electric field the paths are generally curved.

Free electron density in a metal is given by $n = \frac{N_A x\, d}{A}$ where NA = Avogrado number, x = number of free electrons per atom, d = density of metal and A = Atomic weight of metal.