CURRENT ELECTRICITY

ELECTRIC CURRENT

INTRODUCTION

Conductor:

In some materials, the outer electrons of each atom or molecules are only weakly bound to it. These electrons are almost free to move throughout the body of the material and are called free electrons. They are also known as conduction electrons. When such a material is placed in an electric field, the free electrons move in a direction opposite to the field. Such materials are called conductors.

Insulator:

Another class of materials is called insulators in which all the electrons are tightly bound to their respective atoms or molecules. Effectively, there are no free electrons. When such a material is placed in an electric field, the electrons may slightly shift opposite to the field but they can't leave their parent atoms or molecules and hence can't move through long distances. Such materials are also called dielectrics.

Semiconductor:

In semiconductors, the behavior is like an insulator at low levels of temperature. But at higher temperatures, a small number of electrons are able to free themselves and they respond to the applied electric field. As the number of free electrons in a semiconductor is much smaller than that in a conductor, its behavior is in between a conductor and an insulator and hence, the name semiconductor. A freed electron in a semiconductor leaves a vacancy in its normal bound position. These vacancies also help in conduction.

Electric current and current density

When there is a transfer of charge from one side of an area to the other, we say that there is an electric current through the area. If the moving charges are positive, the current is in the direction of motion, if they are negative, the current is opposite to the direction of motion.

If a charge ΔQ crosses an area in time Δt, we define the average electric current through the area during this time as.

$$i = \frac{\Delta Q}{\Delta t}$$

The current at time t is. $$i = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$$

Thus, electric current through an area is the rate of transfer of charge from one side of the area to the other. The SI unit of current is ampere. If one coulomb of charge crosses an area in one second, the current is one ampere. It is one of the seven base units accepted in SI.

Ex. If $q = 2t^2 + 3$, find current at $t = 2$ sec? **(For Competitive Exam)**

Sol.
$$i = \frac{dq}{dt}$$

$$i = 4t$$

$$\therefore \text{ i at 2 sec} = 4 \times 2 = 8 \text{ A}$$

We shall now define a vector quantity known as electric current density at a point. To define the current density at a point P, we draw a small area ΔS through P perpendicular to the flow of charges (shown in figure) If Δi be the current through the area ΔS, the average current density is

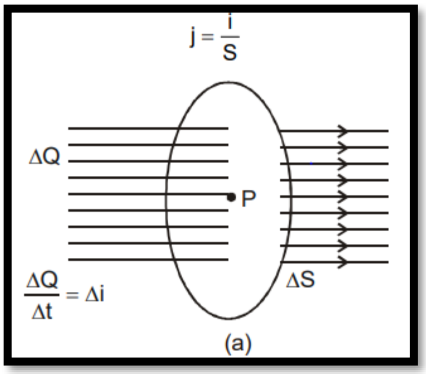
$$\vec{j} = \frac{\Delta i}{\Delta \vec{S}}$$

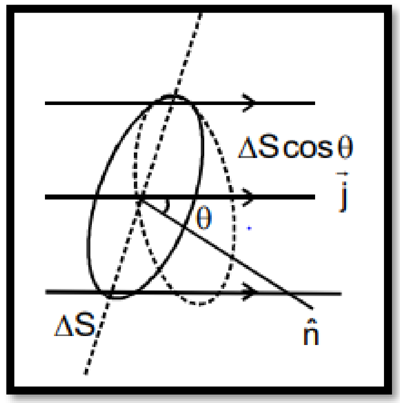
The current density at the point P is

$$j = \lim_{\Delta S \to 0} \frac{\Delta i}{\Delta S} = \frac{di}{dS}$$

The direction of the current density is the same as the direction of the current. Thus, it is along the motion of the moving charges, if the charges are positive and opposite to the motion of the charges, if

The charges are negative. If a current i is uniformly distributed over an area S and is perpendicular to it,





Now let us consider an area ΔS which is not necessarily perpendicular to the current (figure shown) If the normal to the area makes an angle θ with the direction of the current, the current density is,

$$j = \frac{\Delta i}{\Delta S \cos\theta}$$

Or, $\Delta i = j\, \Delta S \cos \theta$

Where Δi is the current through ΔS, If $\Delta\vec{S}$ be the area vector corresponding to the area ΔS, we have

$$\Delta i = \vec{j}.\Delta\vec{S}$$

For a finite area,

$$i = \int \vec{j}.\Delta d\vec{S}$$

Note carefully that an electric current has direction as well as magnitude but it is not a vector quantity. It does not add like vectors. Therefore, current is neither a vector quantity nor a scalar quantity but a tensor quantity. The current density is a vector quantity.

Ex. An electron beam has an aperture 1.0 mm^2. A total of 6.0×10^{10} electrons go through any perpendicular cross-section per second. Find (a) the current and (b) the current density in the beam.

Sol. The total charge crossing a perpendicular cross-section in one second is

q = ne

6.0 × 10 16 × 1.6 × 10 ñ19 C

9.6 × 10 ñ3 C

The current is

$$i = \frac{q}{t} = \frac{9.6 \times 10^{-3} C}{1s} = 9.6 \times 10^{-3} A$$

As the charge is negative, the current is opposite to be direction of motion of the beam. (b) The current density is

$$j = \frac{i}{S} = \frac{9.6 \times 10^{-3} A}{(1.0mm)^2} = \frac{9.6 \times 10^{-3} A}{1.0 \times 10^{-6} m^2} = 9.6 \times 10^3 A/m^2$$