

Electric Current and Current Density

by

Dr P A Sunny Dayal

Associate Professor, Dept of ECE

Centurion University of Technology and Management

Andhra Pradesh

Classification of Materials

❑ Based on Electrical Properties:

- ❖ Conductivity measured in Siemens per meter S/m
- ❖ Depending on conductivity values, materials are classified as:
 - ❖ Conductors
 - ❖ Insulators or dielectrics
 - ❖ Semiconductors
- ❖ Typically conductivity for conductors $\sim 10^7$ S/m
- ❖ For semiconductors: $10^0 - 10^{-4}$ S/m
- ❖ And for Insulators: $< 10^{-4}$ S/m

Electric Current

- The current through a given medium is defined as charge passing through the medium per unit time. It is a scalar.

That is, $I \equiv \frac{dQ}{dt}$

Units: Amperes

- The currents are of three types.
 - Convection current
 - Conduction current
 - Displacement current

- **Convection current** : It is defined as the current produced by a beam of electrons flowing through an insulating medium.
Ex : The current through a vacuum, liquid etc. is the convection current.
This does not obey Ohm's law.
- **Conduction current** : It is defined as the current produced due to flow of electrons in a conductor. This obeys Ohm's law.
Ex : The current in a conductor like copper is conduction current.
- **Displacement current** : It is defined as the current which flows as a result of time-varying electric field in a dielectric material.
Ex : The current through a capacitor when the time-varying voltage is applied.

Current Density

- It is defined as the current at a given point through a unit normal area at that point. It is a vector and it has the units of Ampere/m². It is represented by \mathbf{J} .
- In electromagnetic field theory, it is of interest to describe the events at a point instead of in a large region. This is the reason why, the current densities are considered.
- The types of current densities are of three types.
 - ❑ Convection current density
 - ❑ Conduction current density
 - ❑ Displacement current density

- **Convection Current Density :**

It is defined as the convection current at a given point through a unit normal area at that point.

- **Conduction Current Density:**

It is defined as conduction current at a given point through a unit normal area at that point.

- **Displacement Current Density:**

It is defined as the rate of displacement electric flux density with time.

Electric Current and Current Density

■ Convection and Conduction Currents

❖ The current (in amperes) through a given area is the amount of charge passing through the area per unit time.

❖ i.e $I = dQ/dt$

❖ Similarly, if a current ΔI flows through a planar surface ΔS , the current density is :

$$\text{❖ } J = \Delta I / \Delta S$$

$$\text{❖ } \Delta I = J \Delta S$$

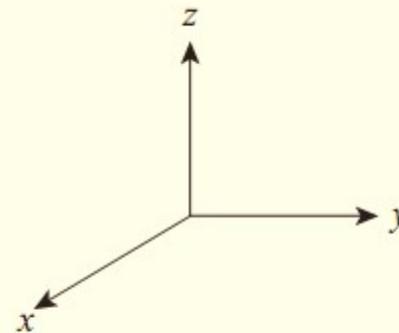
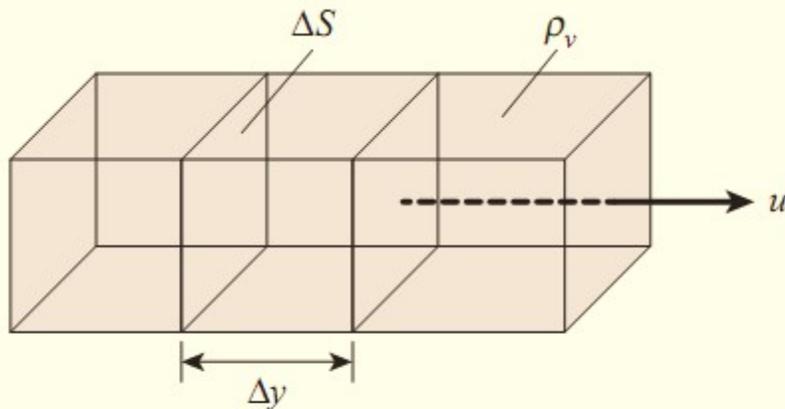
$$\Delta I = \mathbf{J} \cdot \Delta \mathbf{S}$$

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

Electric Current and Current Density

■ Convection Currents

- ❖ Convection current does not involve conductors and therefore does not obey Ohm's law
- ❖ It occurs when current flows through an insulating medium such as liquid, gas or vacuum.
- ❖ *For example: A beam of electrons passing through a vacuum tube constitutes a convection current.*



$$J_y = \frac{\Delta I}{\Delta S} = \rho_v u_y$$

$$\boxed{\mathbf{J} = \rho_v \mathbf{u}}$$

Figure 1 Current in a filament.

Electric Current and Current Density

❖ Conduction current – due to free electrons

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

A **perfect conductor** ($\sigma = \infty$) cannot contain an electrostatic field within it.

$$\frac{I}{S} = \sigma E = \frac{\sigma V}{\ell}$$

$$R = \frac{V}{I} = \frac{\ell}{\sigma S}$$

$$R = \frac{\rho_c \ell}{S}$$

Polarization in Dielectrics

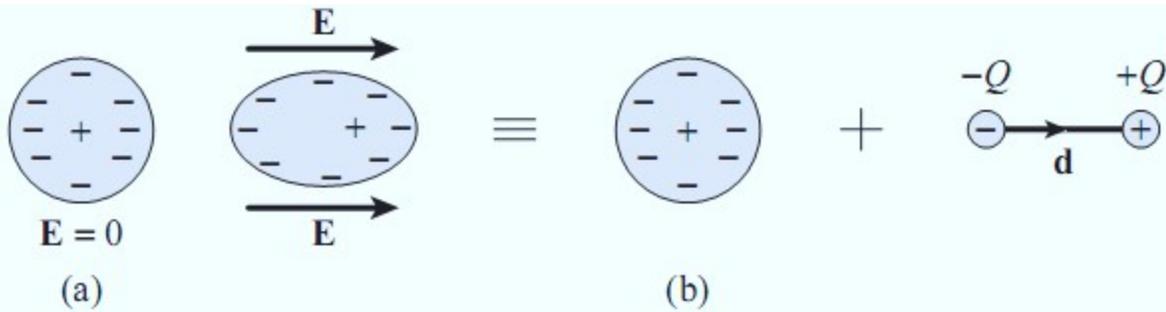


Figure 2 Polarization of a nonpolar atom or molecule.

$$\mathbf{p} = Q\mathbf{d}$$

$$\mathbf{P} = \chi_e \epsilon_0 \mathbf{E}$$

$$\mathbf{D} = \epsilon_0 \mathbf{E} + \mathbf{P}$$

$$\mathbf{D} = \epsilon_0 (1 + \chi_e) \mathbf{E} = \epsilon_0 \epsilon_r \mathbf{E}$$

$$\mathbf{D} = \epsilon \mathbf{E}$$

$$\epsilon_r = 1 + \chi_e = \frac{\epsilon}{\epsilon_0}$$

$$\epsilon = \epsilon_0 \epsilon_r$$

■ Linear, Isotropic and Homogeneous Dielectrics

- ❖ Linear: If D varies linearly with E
- ❖ Homogenous : ϵ is constant within the medium independent of (x,y,z)
- ❖ Isotropic: the dielectric constant is same along different directions

Anisotropic materials:

$$\begin{bmatrix} D_x \\ D_y \\ D_z \end{bmatrix} = \begin{bmatrix} \epsilon_{xx} & \epsilon_{xy} & \epsilon_{xz} \\ \epsilon_{yz} & \epsilon_{yy} & \epsilon_{yz} \\ \epsilon_{zx} & \epsilon_{zy} & \epsilon_{zz} \end{bmatrix} \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix}$$