Applied Physics

BS Software Engineering/Information Technology

1st Semester

Lecture # 15

Current and Resistance

Presented By

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Lecture # 15 and 16

- Electric current
- Current density
- Relation between current density and drift velocity
- Resistance
- Resistivity and conductivity
- Ohm's law and its applications

Lecture # 15

- Conductor in an Electric Field
  - (Static condition)
- Conductor in an Electric Field
  - (dynamic condition)
- Electric current
- Drift Velocity
- Current density
- Relation between current density and drift velocity

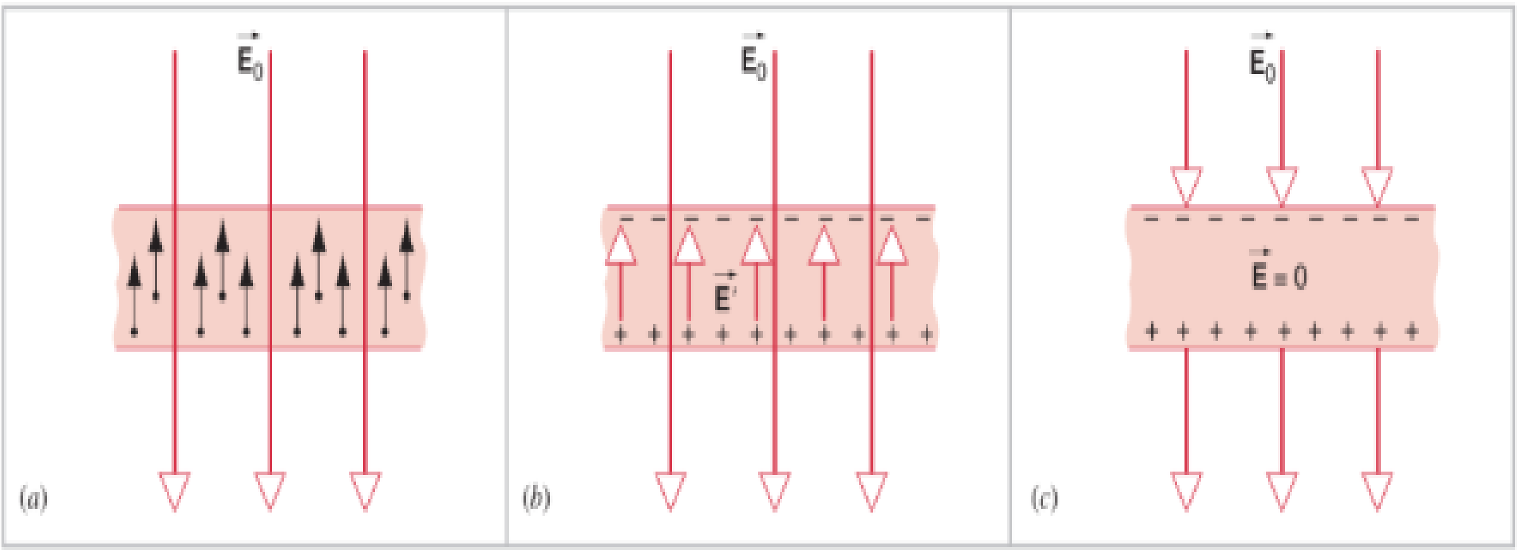
Current and Resistance

ELECTRICAL PROPERTIES OF MATERIALS

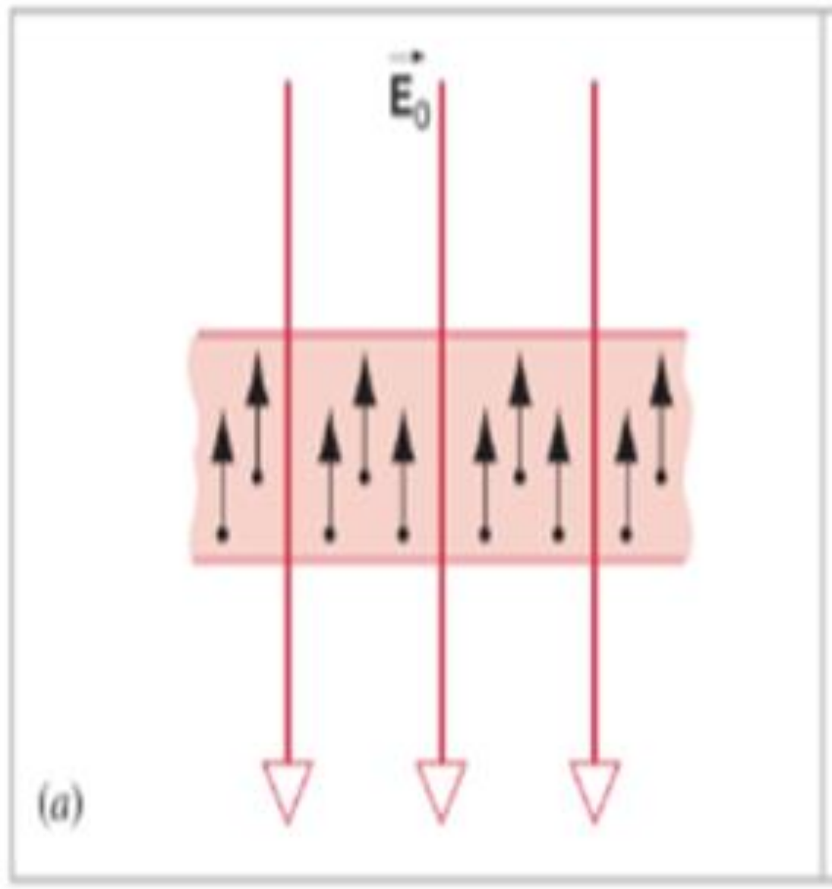
Type of Materials

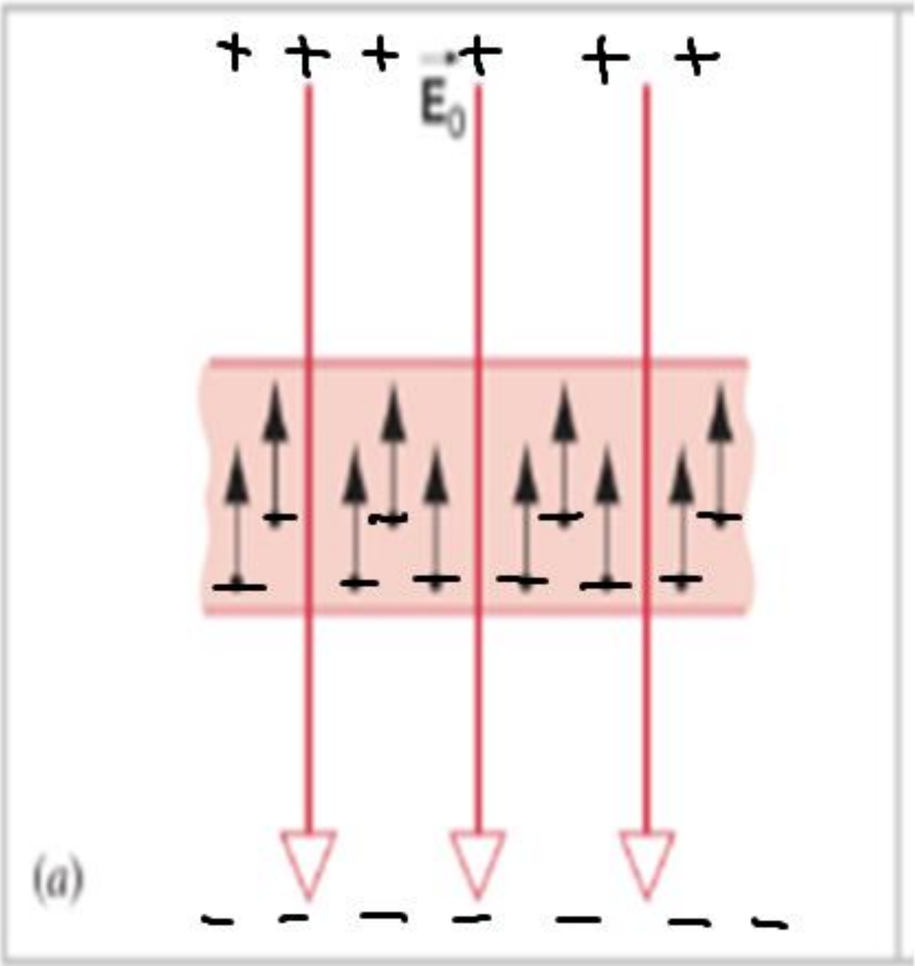
•Conductors in which electrons can move freely.

•Insulators in which electrons cannot move freely.

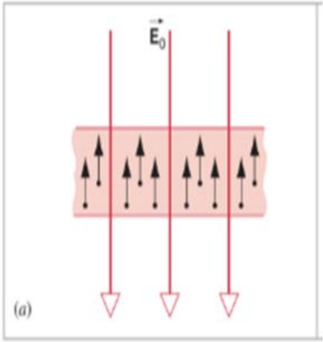


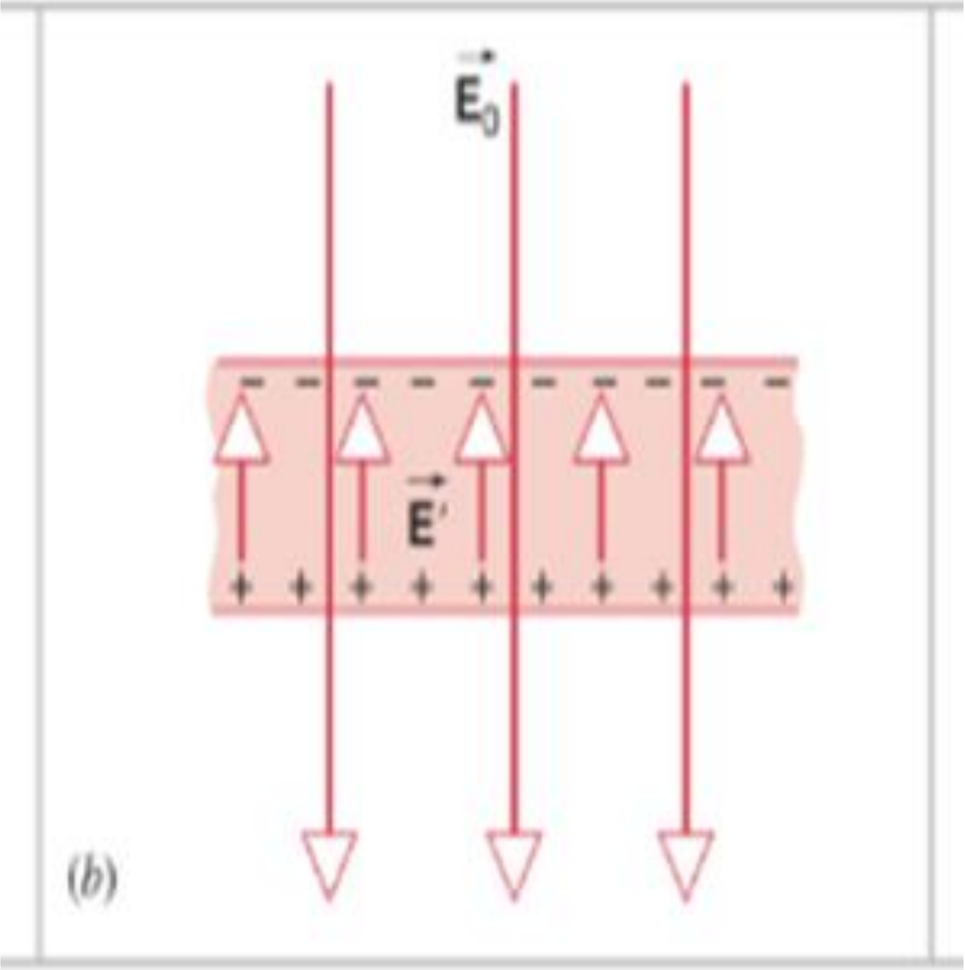
Conductor in an Electric Field (Static condition)

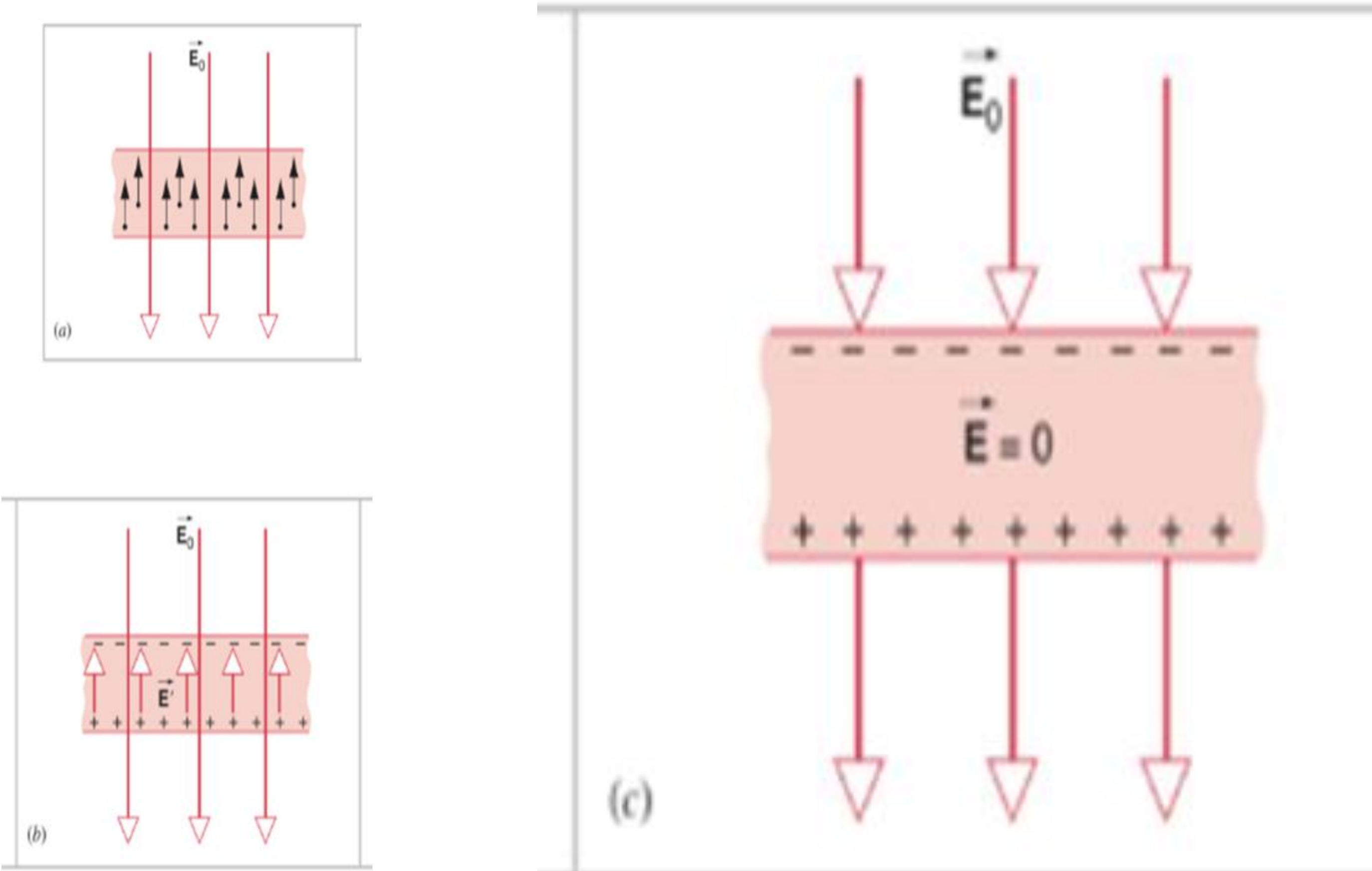




$\vec{E}_0$
(a)


$\vec{E}_0$
(a)


$\vec{E}_0$
$\vec{E}'$
(b)

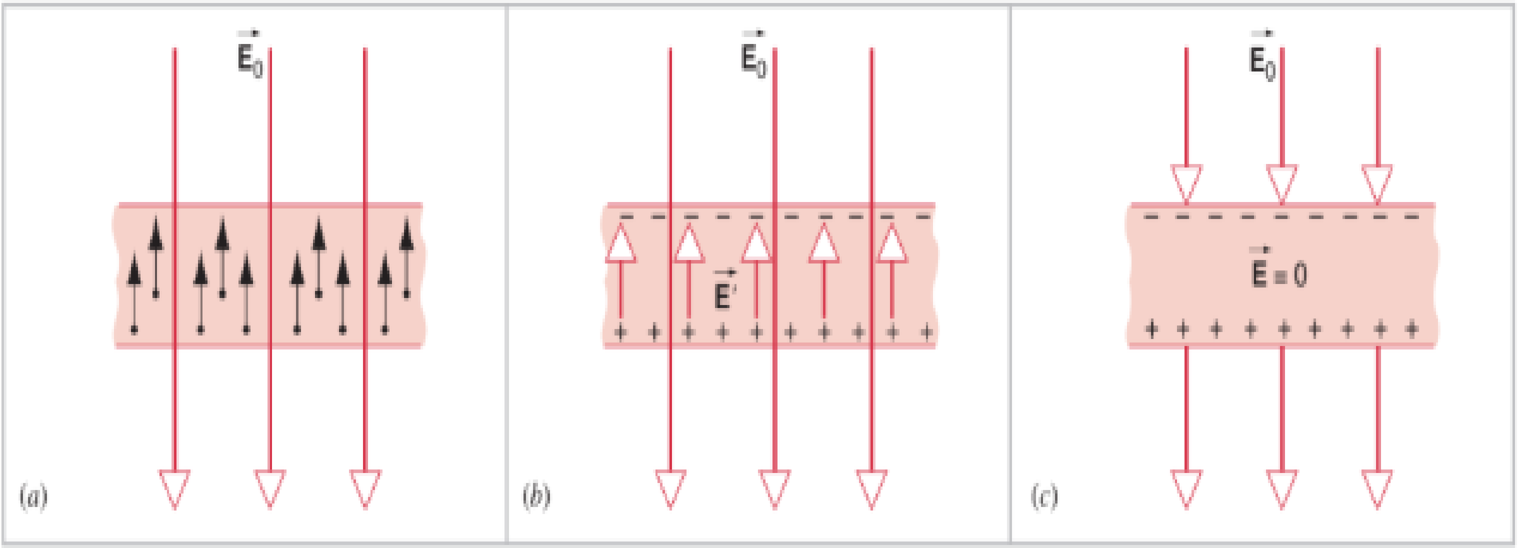


E0
(a)
E0
E'
(b)
E0
E = 0
(c)

$$E = E` + E_0$$

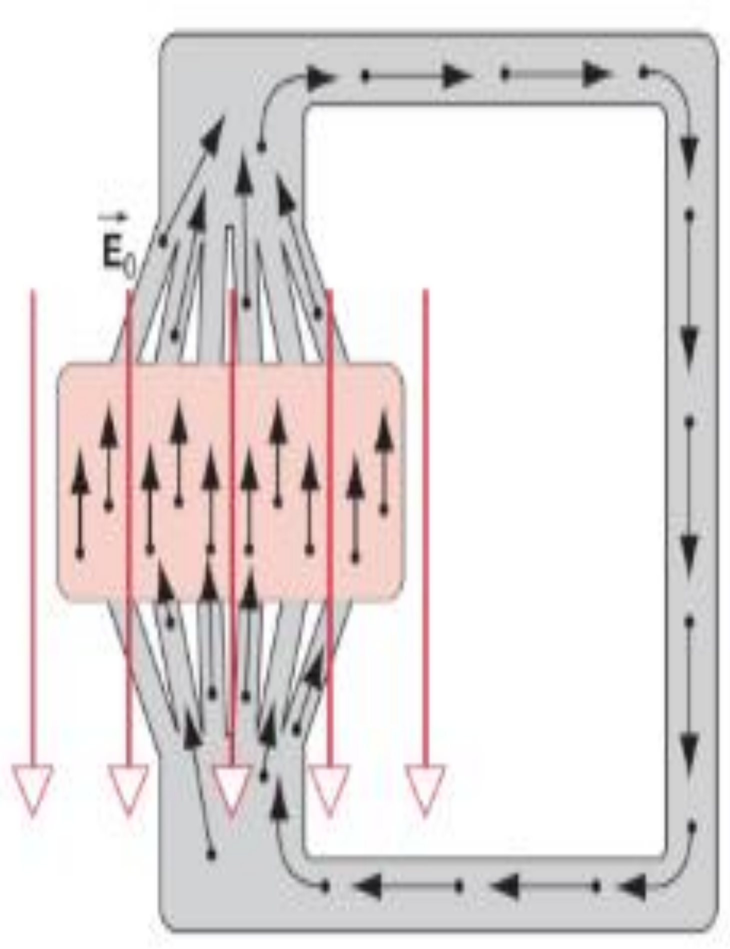
$$E = E` - E_0$$

$$E = 0$$



Conductor in an Electric Field (Dynamic condition)

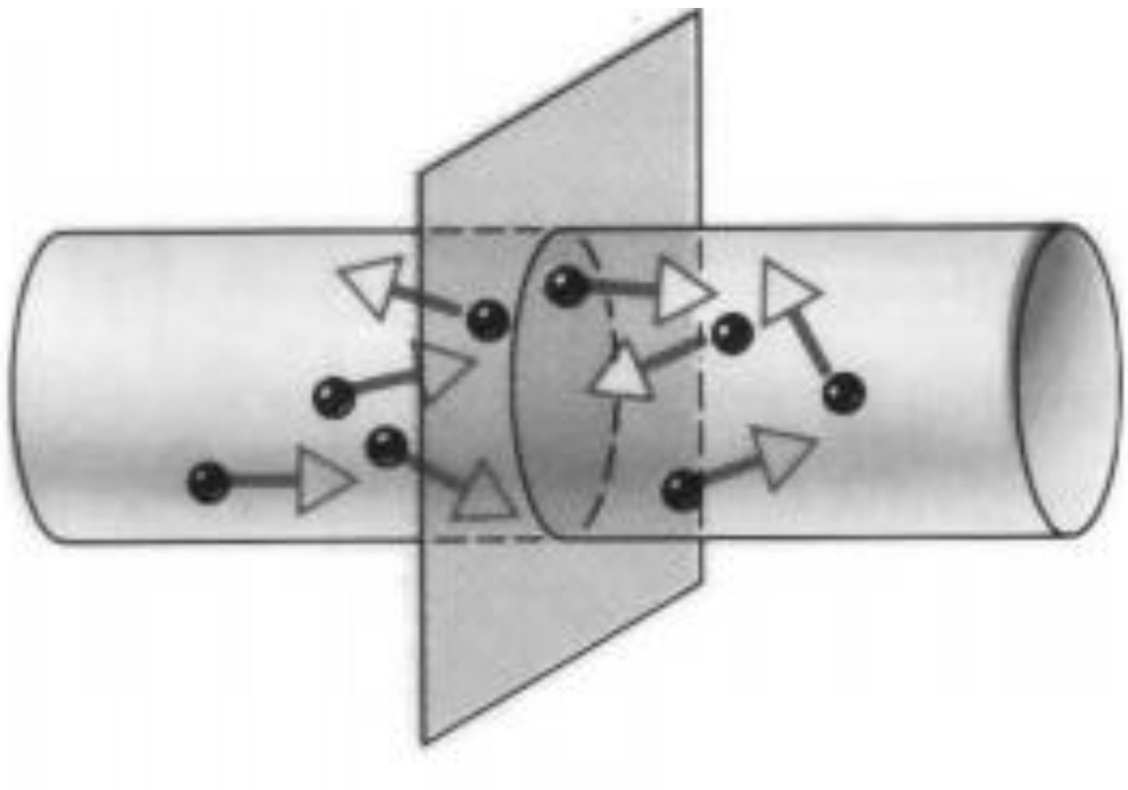
$I = dq/dt$

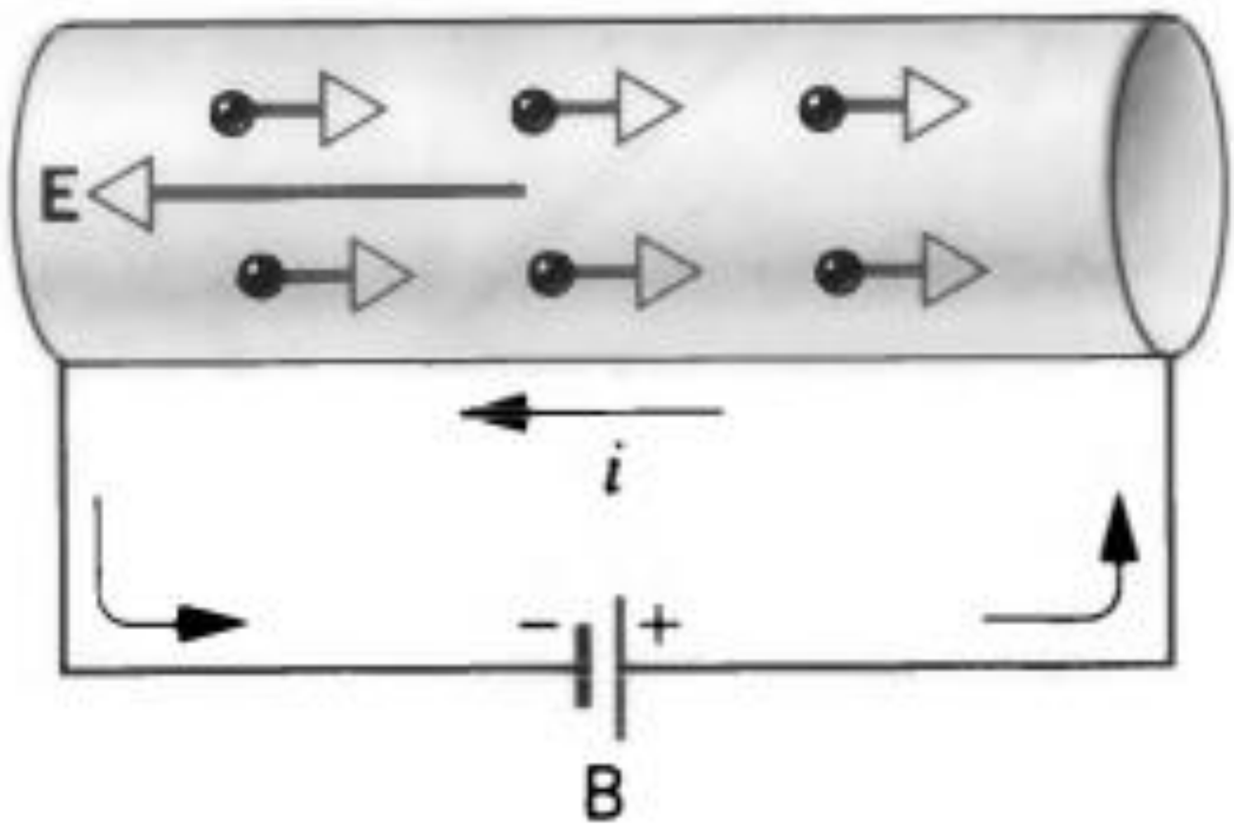


Electric Current

Although an electric current is a stream of moving charges, not all moving charges constitute an electric current. If there is to be an electric current through a given surface, there must be a net flow of charge through that surface. Two examples clarify our meaning.

1. The free electrons (conduction electrons) in an isolated length of copper wire are in random motion at speeds of the order of 10^6 m/s. If you pass a hypothetical plane through such a wire, conduction electrons pass through it *in both directions* at the rate of many billions per second—but there is *no net transport* of charge and thus *no current* through the wire. However, if you connect the ends of the wire to a battery, you slightly bias the flow in one direction, with the result that there now is a net transport of charge and thus an electric current through the wire.
2. The flow of water through a garden hose represents the directed flow of positive charge (the protons in the water molecules) at a rate of perhaps several million coulombs per second. There is no net transport of charge, however, because there is a parallel flow of negative charge (the electrons in the water molecules) of exactly the same amount moving in exactly the same direction.

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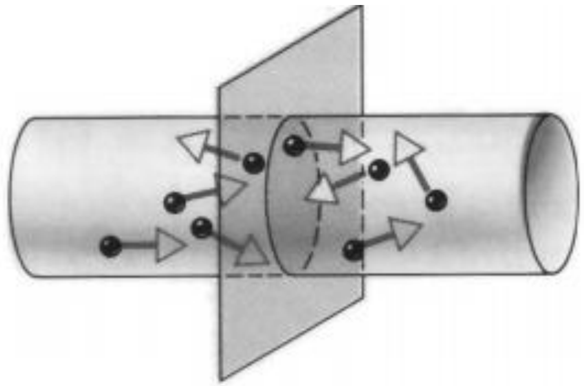


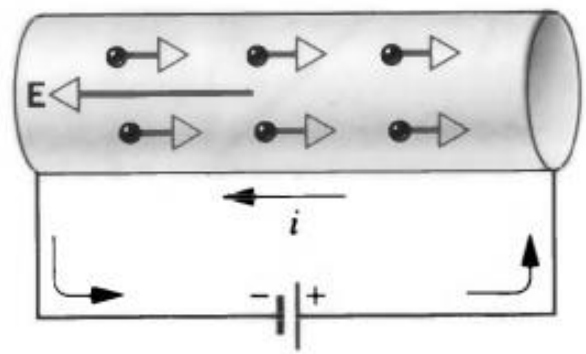


Figure 1 (*a*) In an isolated conductor, the electrons are in random motion. The net flow of charge across an arbitrary plane is zero. (*b*) A battery B connected across the conductor sets up an electric field **E**, and the electrons acquire a net motion due to the field.

If a net charge dq passes through any surface in a time interval dt, we say that an electric current i has been established, where

$$i = \frac{dq}{dt} \quad \text{(definition of current).}$$

We can find the charge that passes through the plane in a time interval extending from 0 to t by integration:

$$q = \int dq = \int_0^t i\,dt,$$

in which the current i may vary with time.

The SI unit of current is the ampere

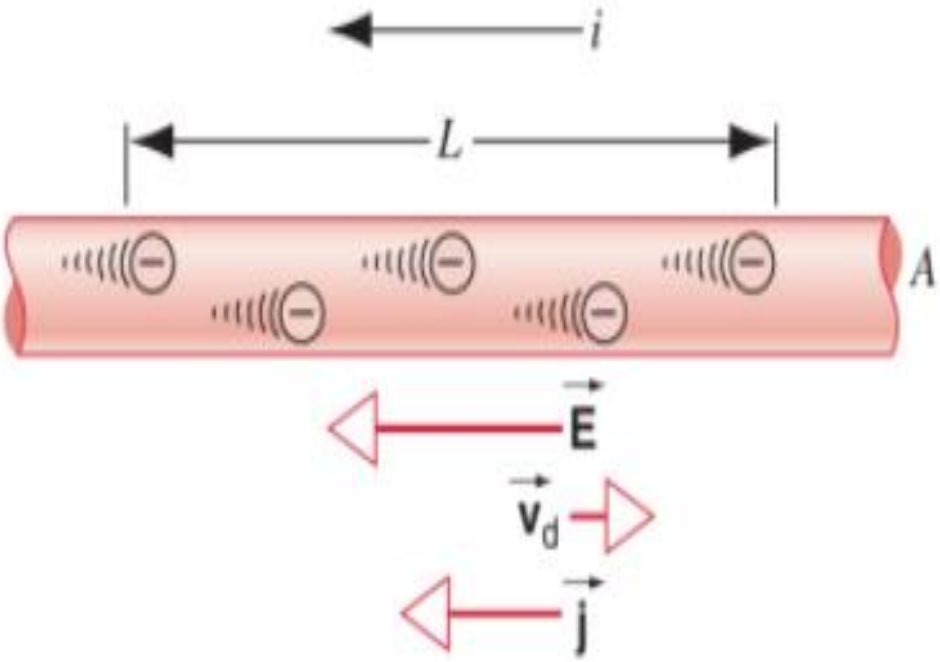
(abbreviation A).

1 ampere = 1 coulomb/second.

A current arrow is drawn in the direction in which positive charge carriers would move, even if the actual charge carriers are negative and move in the opposite direction.

CURRENT DENSITY

$$J = \frac{i}{A},$$



Sometimes we are interested in the current i in a particular conductor. At other times we take a localized view and study the flow of charge through a cross section of the conductor at a particular point. To describe this flow, we can use the **current density** $\vec{J}$, which has the same direction as the velocity of the moving charges if they are positive and the opposite direction if they are negative. For each element of the cross section, the magnitude J is equal to the current per unit area through that element. We can write the amount of current through the element as $\vec{J} \cdot d\vec{A}$, where $d\vec{A}$ is the area vector of the element, perpendicular to the element. The total current through the surface is then

$$i = \int \vec{J} \cdot d\vec{A}. \tag{26-4}$$

If the current is uniform across the surface and parallel to $d\vec{A}$, then $\vec{J}$ is also uniform and parallel to $d\vec{A}$. Then Eq. 26-4 becomes

$$i = \int J\,dA = J \int dA = JA,$$

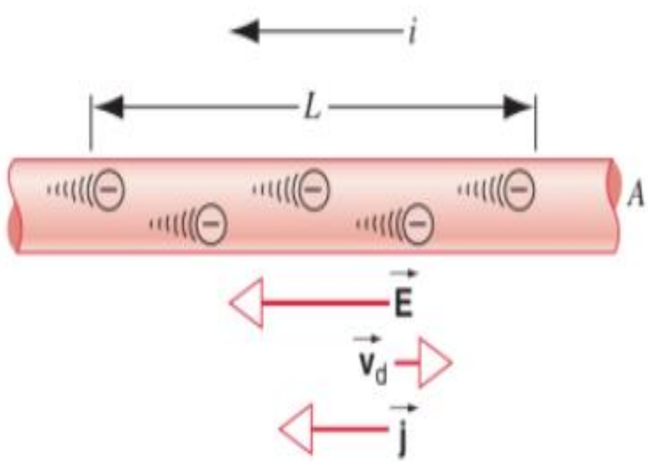
so

$$J = \frac{i}{A}, \tag{26-5}$$

Drift Velocity

Drift Speed

When a conductor does not have a current through it, its conduction electrons move randomly, with no net motion in any direction. When the conductor does have a current through it, these electrons actually still move randomly, but now they tend to *drift* with a **drift speed** v_d in the direction opposite that of the applied electric field that causes the current. The drift speed is tiny compared with the speeds in the random motion. For example, in the copper conductors of household wiring, electron drift speeds are perhaps 10^{-5} or 10^{-4} m/s, whereas the random-motion speeds are around 10^6 m/s.



Relation between Current Density and Drift velocity

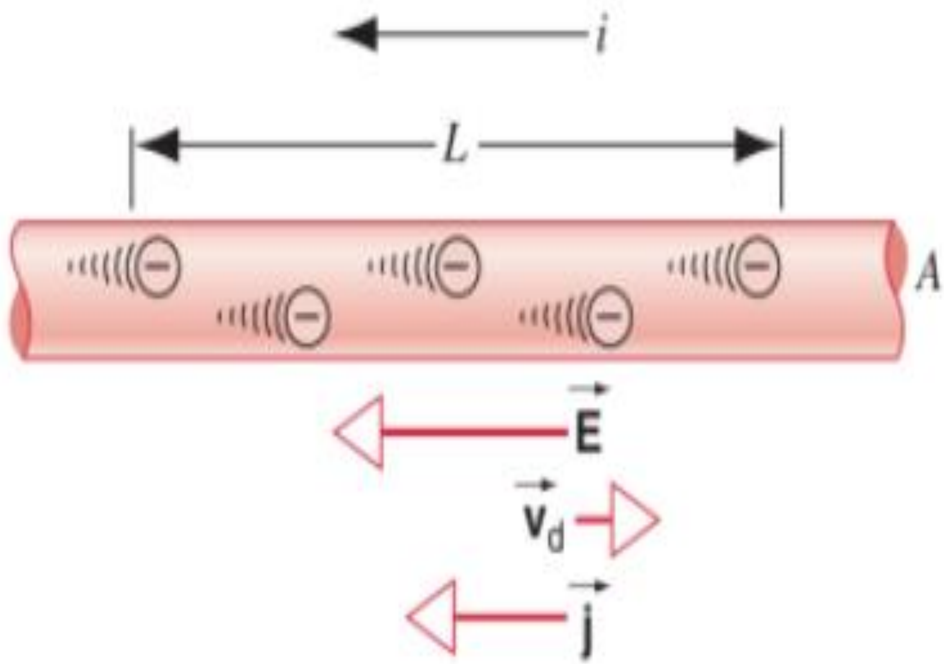


Fig. 26-5 shows the equivalent drift of *positive* charge carriers in the direction of the applied electric field $\vec{E}$. Let us assume that these charge carriers all move with the same drift speed v_d and that the current density J is uniform across the wire's cross-sectional area A. The number of charge carriers in a length L of the wire is nAL, where n is the number of carriers per unit volume. The total charge of the carriers in the length L, each with charge e, is then

$$q = (nAL)e.$$

Because the carriers all move along the wire with speed v_d, this total charge moves through any cross section of the wire in the time interval

$$t = \frac{L}{v_d}.$$

Equation 26-1 tells us that the current i is the time rate of transfer of charge across a cross section, so here we have

$$i = \frac{q}{t} = \frac{nALe}{L/v_d} = nAev_d. \qquad (26\text{-}6)$$

Solving for v_d and recalling Eq. 26-5 ($J = i/A$), we obtain

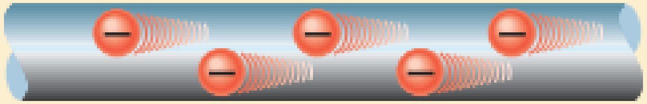
$$v_d = \frac{i}{nAe} = \frac{J}{ne}$$

or, extended to vector form,

$$\vec{J} = (ne)\vec{v}_d. \qquad (26\text{-}7)$$

Checkpoint 2

The figure shows conduction electrons moving leftward in a wire. Are the following leftward or rightward: (a) the current i, (b) the current density $\vec{J}$, (c) the electric field $\vec{E}$ in the wire?



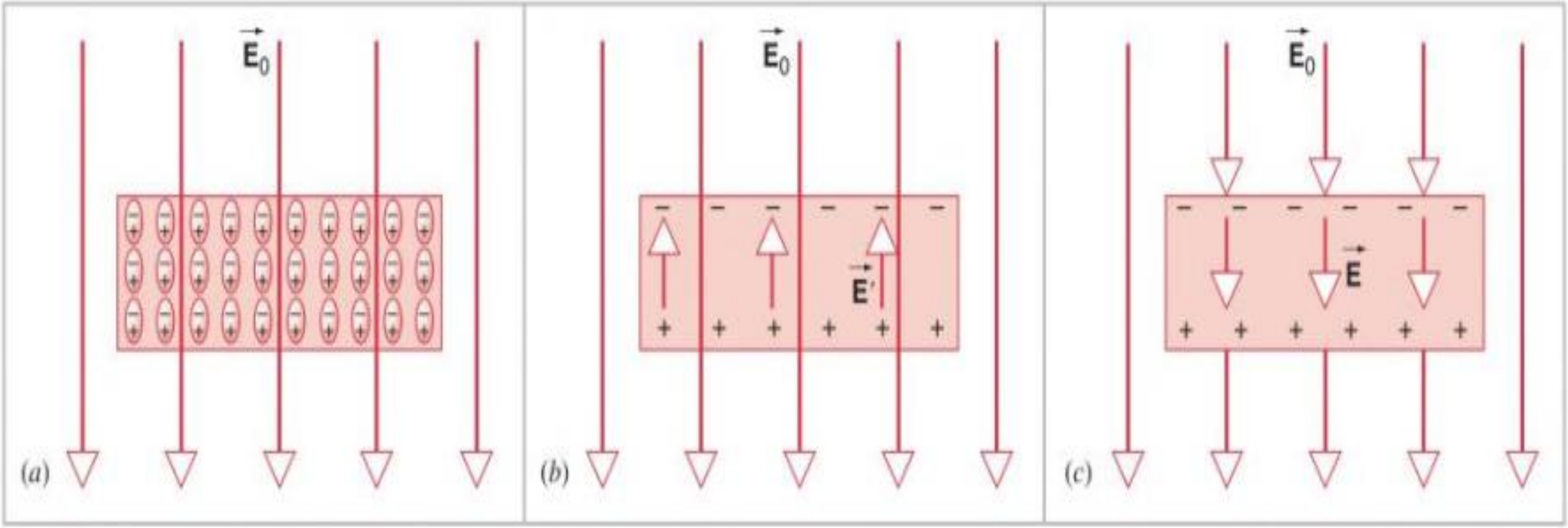
Insulator in the Electric Field

In insulator Electrons are tightly bound with their atomic sites

In insulator $E` < E_0$

$\mathbf{E = E_0 - E`}$

E is not equal to zero.



Home Work

PROBLEMS

Section 32-2 Current Density

1. A current of 4.82 A exists in a 12.4-Ω resistor for 4.60 min. (*a*) How much charge and (*b*) how many electrons pass through any cross section of the resistor in this time?
2. The current in the electron beam of a typical video display terminal is 200 μA. How many electrons strike the screen each minute?
3. Suppose that we have 2.10×10^8 doubly charged positive ions per cubic centimeter, all moving north with a speed of 1.40×10^5 m/s. (*a*) Calculate the current density, in magnitude and direction. (*b*) Can you calculate the total current in this ion beam? If not, what additional information is needed?
4. A small but measurable current of 123 pA exists in a copper wire whose diameter is 2.46 mm. Calculate (*a*) the current density and (*b*) the electron drift speed. See Sample Problem 2.
5. Suppose that the material composing a fuse (see Question 21) melts once the current density rises to 440 A/cm^2. What diameter of cylindrical wire should be used for the fuse to limit the current to 0.552 A?