Applied Physics

BS Software Engineering/Information Technology
1st Semester
Lecture # 16

Current and Resistance
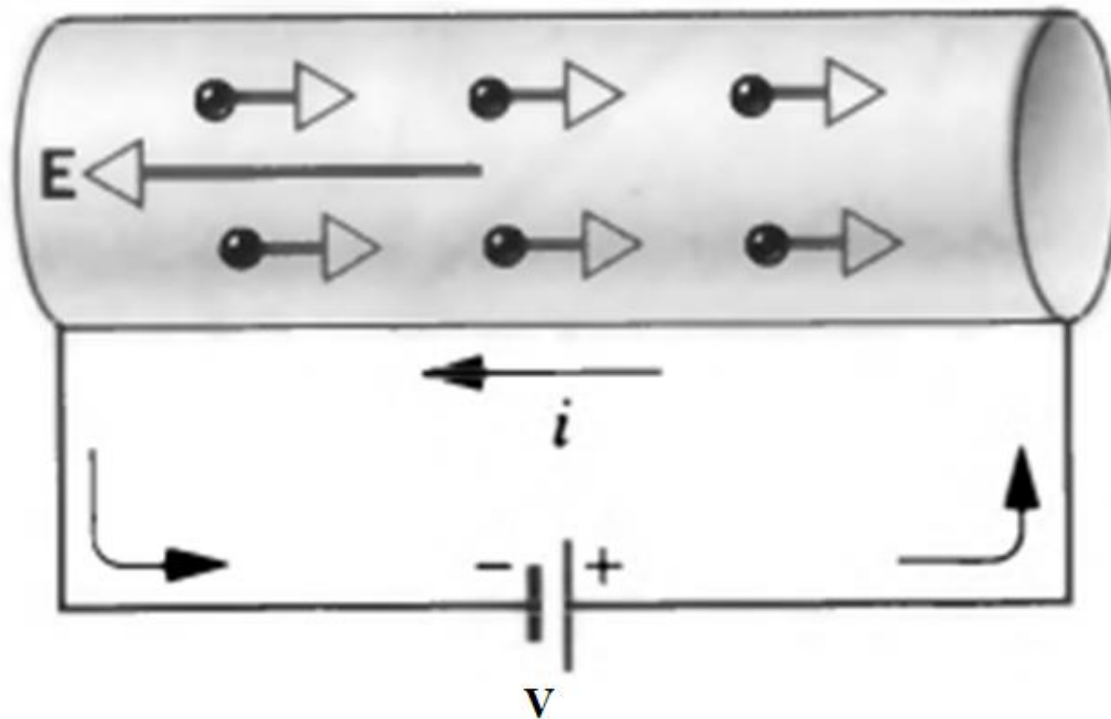
Presented By

Dr. Arifa Mirza

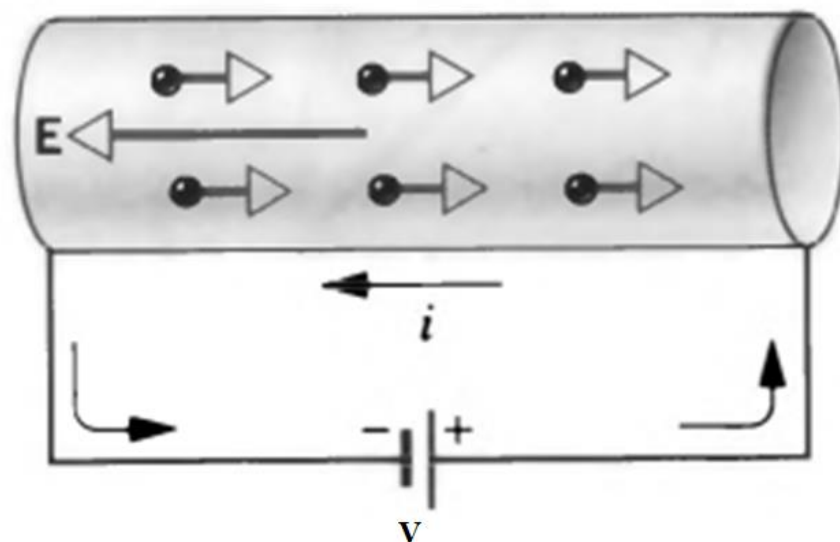**Punjab University College of Information Technology**

Lecture # 16

- Resistance
- Resistivity
- Conductivity
- Ohmic Materials
- Ohm's law
- Applications of Ohm's law

RESISTANCE AND RESISTIVITY

Resistance

If we apply the same potential difference between the ends of geometrically simi-lar rods of copper and of glass, very different currents result. The characteristic of the conductor that enters here is its electrical **resistance.** We determine the re-sistance between any two points of a conductor by applying a potential difference V between those points and measuring the current i that results. The resistance R is then

$$R = \frac{V}{i} \quad \text{(definition of } R\text{)}. \tag{26-8}$$

The SI unit for resistance that follows from Eq. 26-8 is the volt per ampere. This combination occurs so often that we give it a special name, the **ohm** (symbol Ω); that is,

$$1 \text{ ohm} = 1 \ \Omega = 1 \text{ volt per ampere}$$
$$= 1 \text{ V/A}. \tag{26-9}$$

A conductor whose function in a circuit is to provide a specified resistance is called a **resistor** (see Fig. 26-7). In a circuit diagram, we represent a resistor and a resistance with the symbol ⏦. If we write Eq. 26-8 as

$$i = \frac{V}{R},$$

Resistivity
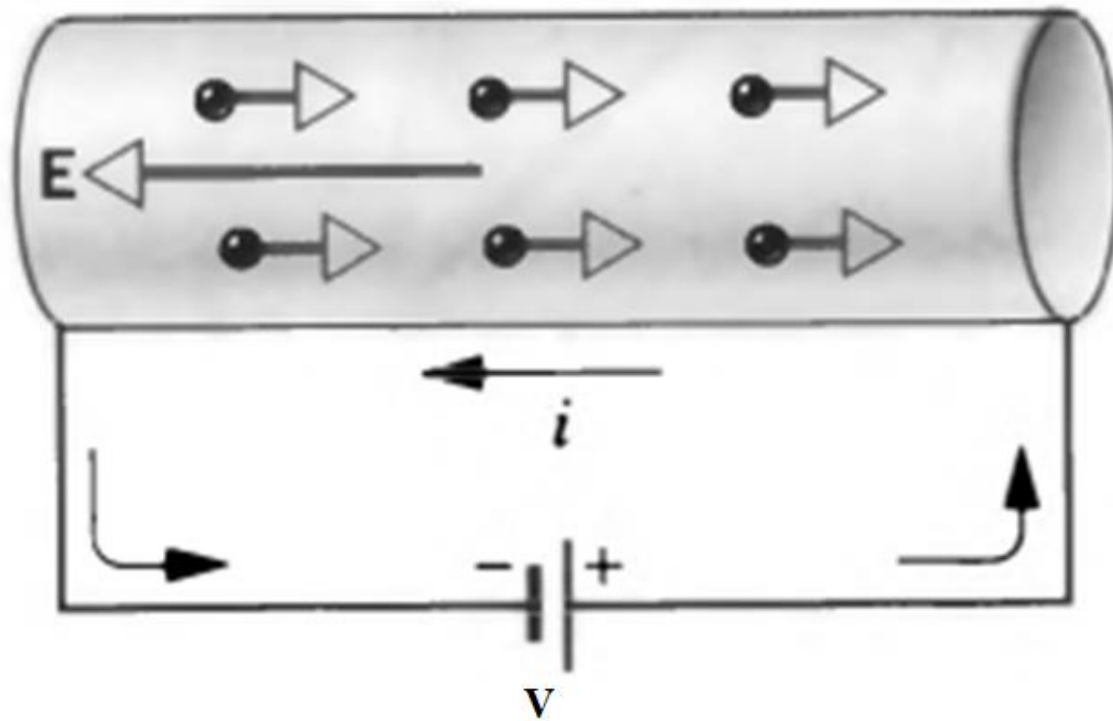
Resistivity

As we have done several times in other connections, we often wish to take a general view and deal not with particular objects but with materials. Here we do so by focusing not on the potential difference V across a particular resistor but on the electric field $\vec{E}$ at a point in a resistive material. Instead of dealing with the current i through the resistor, we deal with the current density $\vec{J}$ at the point in question. Instead of the resistance R of an object, we deal with the **resistivity** ρ of the *material*:

$$\rho = \frac{E}{J} \quad \text{(definition of } \rho\text{).} \tag{26-10}$$

(Compare this equation with Eq. 26-8.)

If we combine the SI units of E and J according to Eq. 26-10, we get, for the unit of ρ, the ohm-meter ($\Omega \cdot m$):

$$\frac{\text{unit } (E)}{\text{unit } (J)} = \frac{V/m}{A/m^2} = \frac{V}{A} \, m = \Omega \cdot m.$$

We can write Eq. 26-10 in vector form as

$$\vec{E} = \rho\vec{J}. \qquad (26\text{-}11)$$

Equations 26-10 and 26-11 hold only for *isotropic* materials—materials whose electrical properties are the same in all directions.
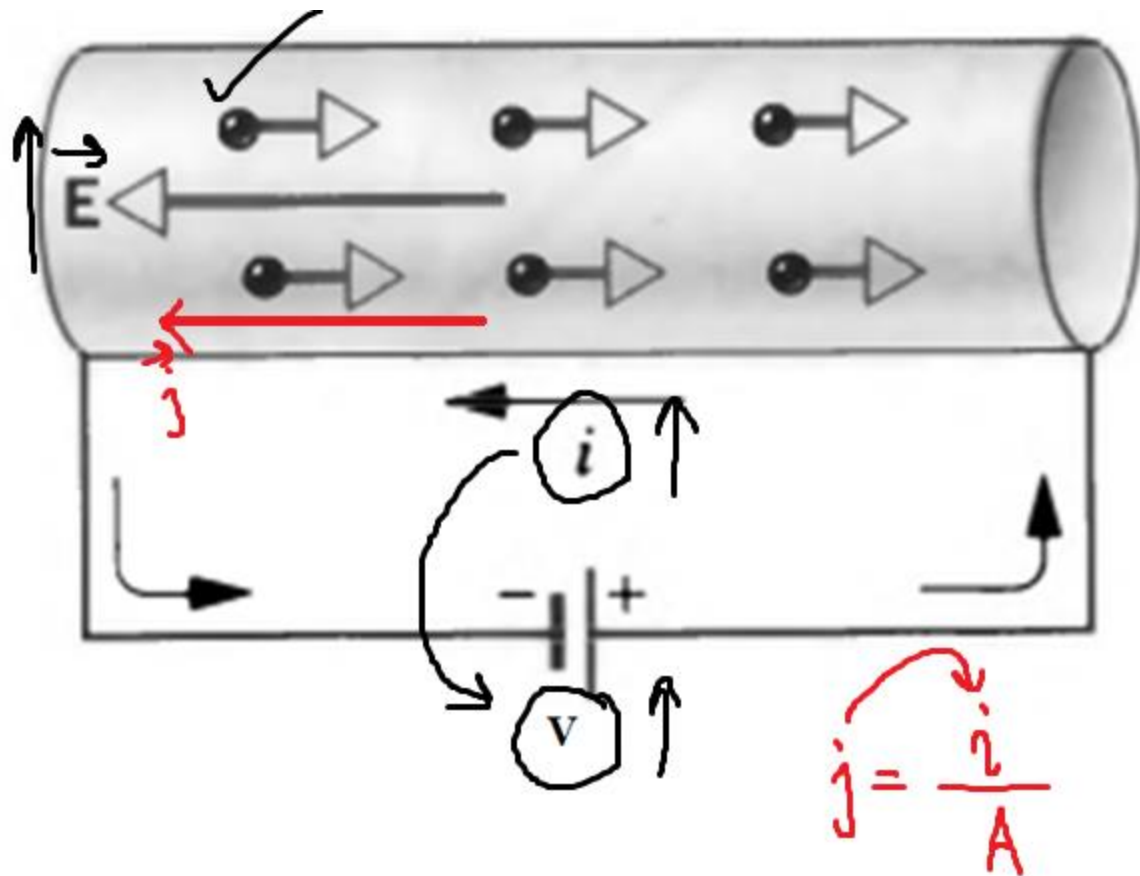
Conductivity

We often speak of the **conductivity** σ of a material. This is simply the reciprocal of its resistivity, so

$$\sigma = \frac{1}{\rho} \quad \text{(definition of } \sigma\text{).} \tag{26-12}$$

The SI unit of conductivity is the reciprocal ohm-meter, $(\Omega \cdot m)^{-1}$. The unit name mhos per meter is sometimes used (mho is ohm backwards). The definition of σ allows us to write Eq. 26-11 in the alternative form

$$\vec{J} = \sigma \vec{E}. \tag{26-13}$$

$$i \propto V$$

$$i = \frac{1}{R} V$$

$$\boxed{iR = V}$$

$$V_d \propto E$$

$$\vec{j} \propto \vec{E}$$

$$\vec{j} = \frac{1}{\rho} \vec{E}$$

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

Ohmic Materials

- Homogeneous:
  - Same composition.
- Isotropic
  - Same electrical properties in all the directions.
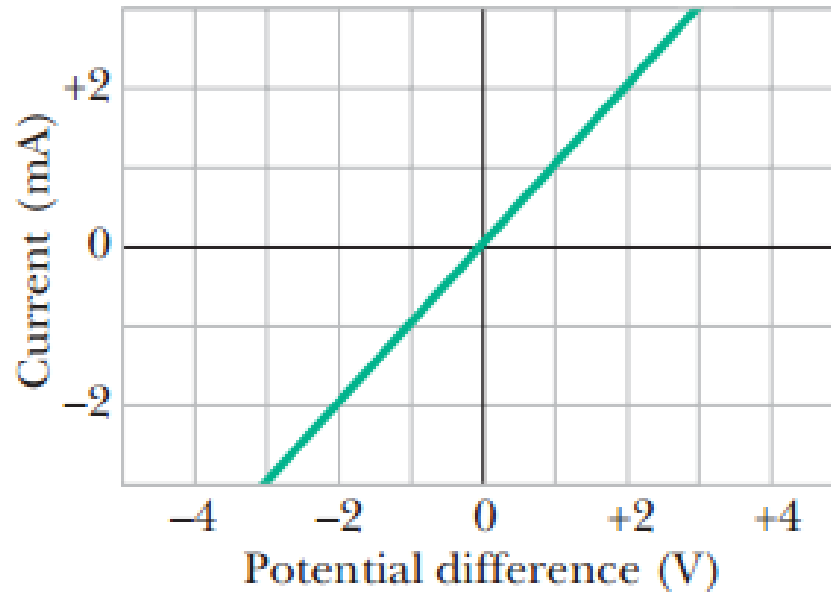
OHM'S LAW

- Macroscopic Form:

$$V = IR$$

- Microscopic Form:

$$E = \rho J$$

$$J = \sigma E$$

The macroscopic quantities V, i, and R are of greatest interest when we are making electrical measurements on specific conductors. They are the quantities that we read directly on meters. We turn to the microscopic quantities E, J, and ρ when we are interested in the fundamental electrical properties of materials.

Ohm's law is an assertion that the current through a device is *always* directly proportional to the potential difference applied to the device.

A conducting device obeys Ohm's law when the resistance of the device is independent of the magnitude and polarity of the applied potential difference.

It is often contended that $V = iR$ is a statement of Ohm's law. That is not true! This equation is the defining equation for resistance, and it applies to all conducting devices, whether they obey Ohm's law or not. If we measure the potential difference V across, and the current i through, any device, even a *pn* junction diode, we can find its resistance *at that value of* V as $R = V/i$. The essence of Ohm's law, however, is that a plot of i versus V is linear; that is, R is independent of V. We can generalize this for conducting materials by using Eq. 26-11 ($\vec{E} = \rho\vec{J}$):

A conducting material obeys Ohm's law when the resistivity of the material is independent of the magnitude and direction of the applied electric field.
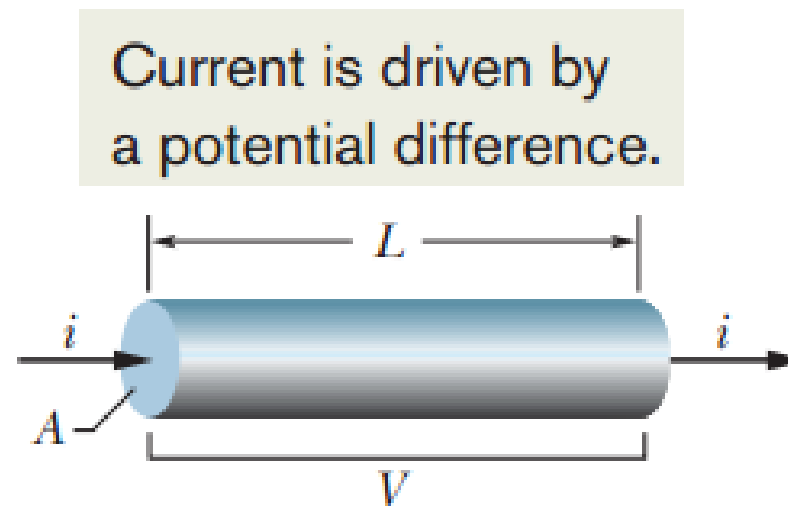
Calculating Resistance from Resistivity

Current is driven by
a potential difference.

Figure 26-9 A potential difference V is applied
between the ends of a wire of length L and
cross section A, establishing a current i.

Calculating Resistance from Resistivity

Resistance is a property of an object. Resistivity is a property of a material.

If we know the resistivity of a substance such as copper, we can calculate the resistance of a length of wire made of that substance. Let A be the cross-sectional area of the wire, let L be its length, and let a potential difference V exist between its ends (Fig. 26-9). If the streamlines representing the current density are uniform throughout the wire, the electric field and the current density will be constant for all points within the wire and, from Eqs. 24-42 and 26-5, will have the values

$$E = V/L \quad \text{and} \quad J = i/A. \qquad (26\text{-}14)$$

We can then combine Eqs. 26-10 and 26-14 to write

$$\rho = \frac{E}{J} = \frac{V/L}{i/A}. \qquad (26\text{-}15)$$

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However, V/i is the resistance R, which allows us to recast Eq. 26-15 as

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Equation 26-16 can be applied only to a homogeneous isotropic conductor of uniform cross section, with the potential difference applied as in Fig. 26-8b.

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☑ Checkpoint 3

The figure here shows three cylindrical copper conductors along with their face areas and lengths. Rank them according to the current through them, greatest first, when the same potential difference V is placed across their lengths.

(a)   (b)   (c)
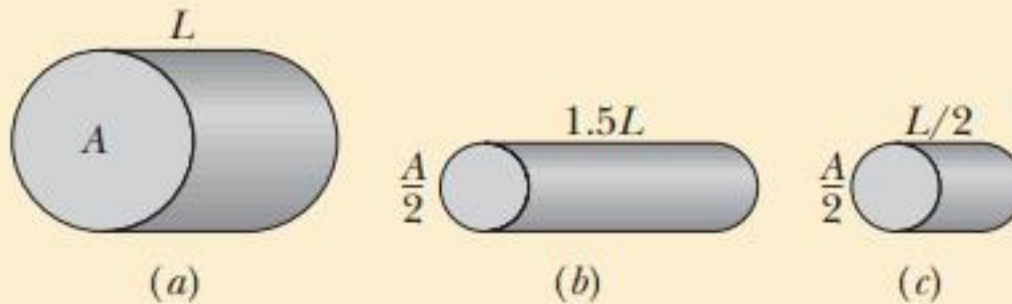
Sample Problem A rectangular block of iron has dimensions 1.2 cm × 1.2 cm × 15 cm. (*a*) What is the resistance of the block measured between the two square ends? (*b*) What is the resistance between two opposing rectangular faces? The resistivity of iron at room temperature is $9.68 \times 10^{-8}\ \Omega \cdot m$.

Solution (*a*) The area of a square end is $(1.2 \times 10^{-2}\ m)^2$ or $1.44 \times 10^{-4}\ m^2$. From Eq. 13,

$$R = \frac{\rho L}{A} = \frac{(9.68 \times 10^{-8}\ \Omega \cdot m)(0.15\ m)}{1.44 \times 10^{-4}\ m^2}$$

$$= 1.0 \times 10^{-4}\ \Omega = 100\ \mu\Omega.$$
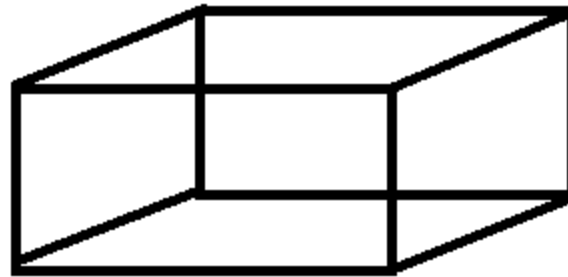
(b) The area of a rectangular face is $(1.2 \times 10^{-2} \text{ m})(0.15 \text{ m})$ or $1.80 \times 10^{-3} \text{ m}^2$. From Eq. 13,

$$R = \frac{\rho L}{A} = \frac{(9.68 \times 10^{-8} \; \Omega \cdot \text{m})(1.2 \times 10^{-2} \text{ m})}{1.80 \times 10^{-3} \text{ m}^2}$$

$$= 6.5 \times 10^{-7} \; \Omega = 0.65 \; \mu\Omega.$$