Chapter 27

Current and Resistance

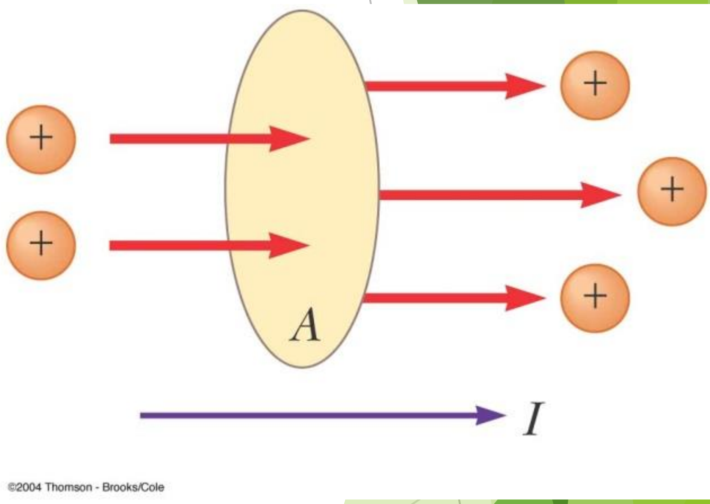
Outline

- 27.1 Electric Current
- 27.2 Resistance and Ohm's Law
- 27.3 Resistance and Temperature
- 27.6 Electrical Energy and Power

27.1 Electric Current

- Whenever there is a net flow of charge through some region, an electric current is said to exist.

- The current is the rate at which charge flows through this surface.



$$I_{ave} = \frac{\Delta Q}{\Delta t}$$ ***Average Current***

$$I \equiv \frac{dq}{dt}$$ ***Instantaneous Current***

27.1 Electric Current

- The SI unit of current is the ampere (A): $1A = \dfrac{1C}{1s}$

1 A of current is equivalent to 1 C of charge passing through the surface area in 1 s.

- It is conventional to assign to the current the same direction as the flow of positive charge

- The direction of the current is opposite the direction of flow of electrons.

- Moving charge (positive or negative) are commonly named as a *mobile charge carrier*. For example, the mobile charge carriers in a metal are electrons.

27.1 Electric Current

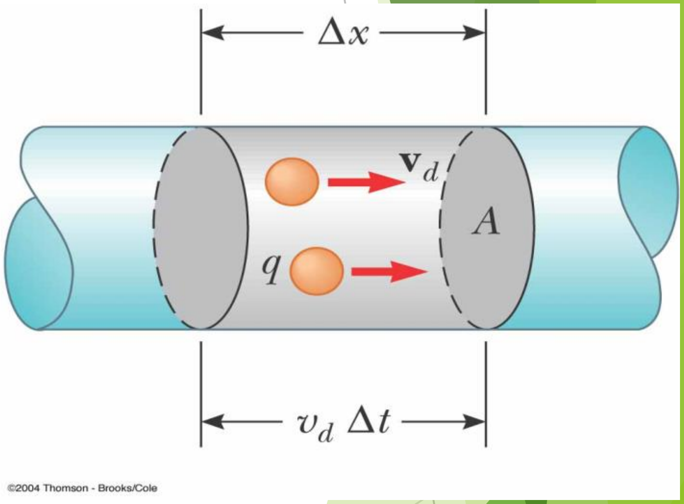
Microscopic Model of Current:

ΔQ = number of carriers in section x charge per carrier

$\Delta Q = (n A \, \Delta x) q$

$\Delta Q = (n A v_d \, \Delta t) \, q$

$$I_{ave} = \frac{\Delta Q}{\Delta t} = n A q v_d \, A$$



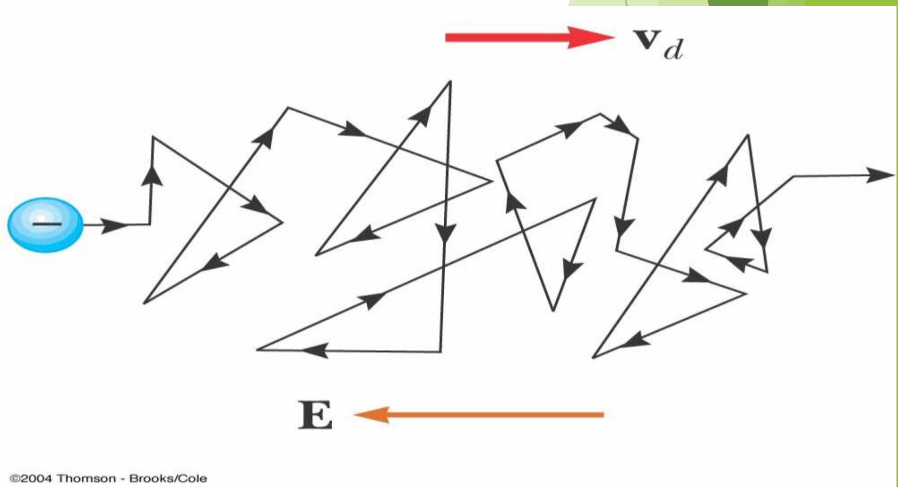
The speed of the charge carriers v_d is an average speed called *the drift speed*.

27.1 Electric Current

Microscopic Model of Current:

- When a potential difference is applied across the conductor (for example, by means of a battery), an electric field is set up in the conductor; this field exerts an electric force on the electrons, producing a current.

- However, the electrons do not move in straight lines along the conductor. Instead, they collide repeatedly with the metal atoms, and their resultant motion is complicated and ***zigzag***



27.1 Electric Current

➢ ***Quick Quiz 27.1***

Quick Quiz 27.1 Consider positive and negative charges moving horizontally through the four regions shown in Figure 27.4. Rank the current in these four regions, from lowest to highest.

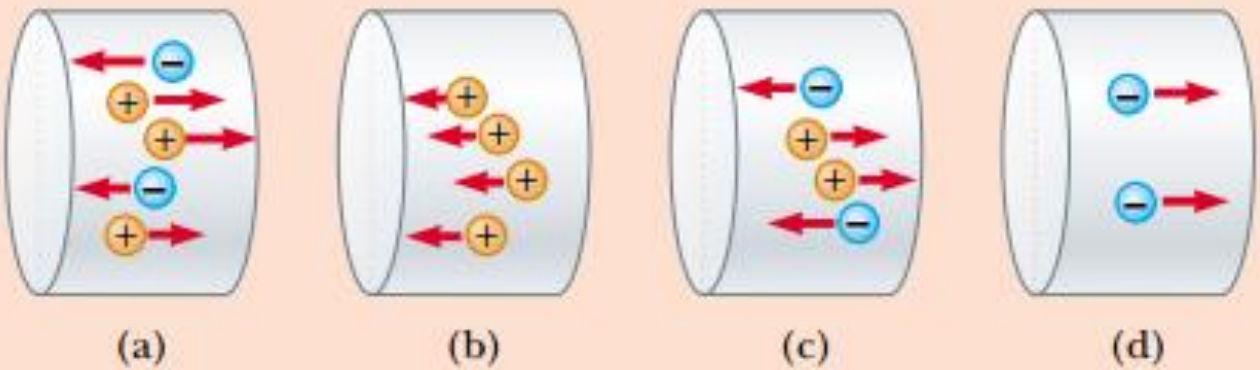


Figure 27.4 (Quick Quiz 27.1) Charges move through four regions.

27.1 Electric Current

- ***Example 27.1***

A copper wire in a typical residential building has a cross sectional area of 3.31x 10^{-6} m^2. If it carries a current of 10.0 A, what is the drift speed of the electrons? Assume that each copper atom contributes one free electron to the current. The density of copper is 8.95 g/cm^3. (Atomic mass of cupper is 63.5 g/mol.

27.2 Resistance and Ohm's Law

- Consider a conductor of cross-sectional area **A** carrying a current ***I***.
- The current density **J** in the conductor is

$$I_{ave} = nqv_d A$$

$$J = \frac{I}{A} = nqv_d \qquad (A/m^2)$$

- The current density **J** is a vector quantity and is ***in the direction of*** charge motion for **positive charge** carriers and ***opposite*** the direction of motion for negative charge carriers
- **J** and **E** are established in a conductor whenever a potential difference is maintained across the conductor

27.2 Resistance and Ohm's Law

➢ Ohm's law:

For many materials (including most metals), the ratio of the current density to the electric field is a constant σ that is independent of the electric field producing the current.

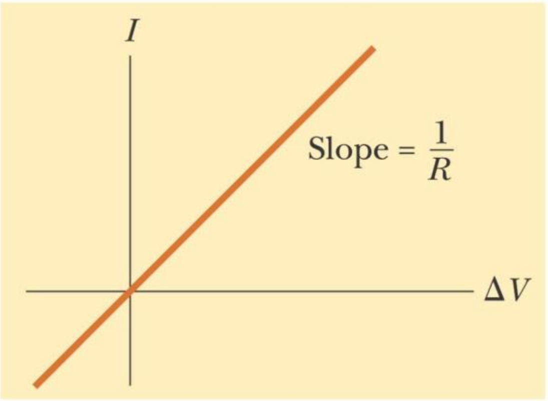
$$J = \sigma E$$

➢ **σ** is called the ***conductivity*** of the conductor.

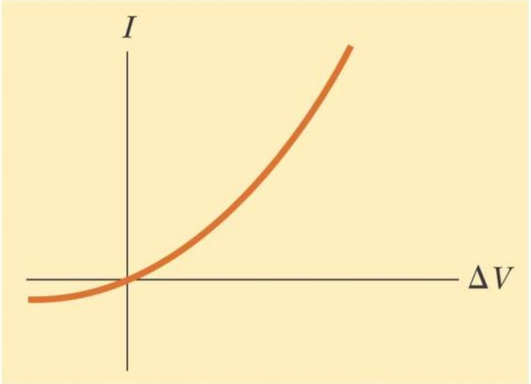
➢ Materials that obey Ohm's law said to be ***ohmic***,

➢ Materials that do not obey Ohm's law

are said to be ***non-ohmic***

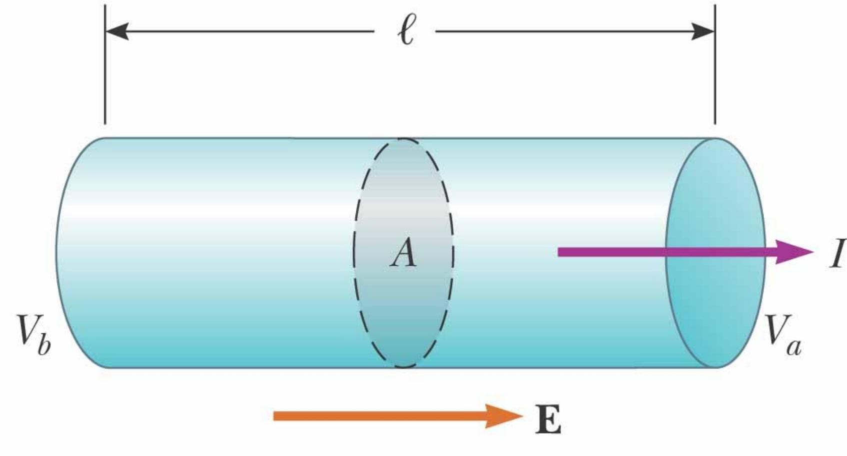


(a)



27.2 Resistance and Ohm’s Law

- **Ohm’s law:**



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$$\Delta V = E\ell$$

$$J = \sigma E = \sigma \frac{\Delta V}{\ell}$$

$$\Delta V = \frac{\ell}{\sigma} J = \left(\frac{\ell}{\sigma A}\right) I$$

$$R \equiv \frac{\ell}{\sigma A} \equiv \frac{\Delta V}{I}$$

- **Unit of Resistance R:** $1\,\Omega \equiv \frac{1\text{ V}}{1\text{ A}}$

27.2 Resistance and Ohm's Law

- **Resistivity and Conductivity :**

$$\rho = \frac{1}{\sigma}$$

Unit: ***Ohm.meters***

Resistance of a uniform material along the length *l*

$$R = \rho \frac{l}{A}$$

Important Notes:

Resistivity is property of a substance

Resistance is a property of an object

27.2 Resistance and Ohm’s Law

Resistivities and Temperature Coefficients of Resistivity for Various Materials

Material	Resistivity[a] ($\Omega \cdot m$)	Temperature Coefficient[b] $\alpha[(°C)^{-1}]$
Silver	1.59×10^{-8}	3.8×10^{-3}
Copper	1.7×10^{-8}	3.9×10^{-3}
Gold	2.44×10^{-8}	3.4×10^{-3}
Aluminum	2.82×10^{-8}	3.9×10^{-3}
Tungsten	5.6×10^{-8}	4.5×10^{-3}
Iron	10×10^{-8}	5.0×10^{-3}
Platinum	11×10^{-8}	3.92×10^{-3}
Lead	22×10^{-8}	3.9×10^{-3}
Nichrome[c]	1.50×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}
Silicon	640	-75×10^{-3}
Glass	10^{10} to 10^{14}	
Hard rubber	$\sim 10^{13}$	
Sulfur	10^{15}	
Quartz (fused)	75×10^{16}	

The negative values of resistivity indicates that the resistivity of these materials decreases with increasing temperature (Semiconductors)

27.2 Resistance and Ohm’s Law

➢ ***Example 27.2***

Calculate the resistance of an aluminum cylinder that has a length of 10.0 cm and a cross-sectional area of 2.00×10^{-4} m^2

Repeat the calculation for a cylinder of the same dimensions and made of glass having a resistivity of 3.00×10^{10} Ω.m

27.2 Resistance and Ohm’s Law

- ***Example 27.3***

A) Calculate the resistance per unit length of a 22-gauge Nichrome wire, which has a radius of 0.321mm

B) If a potential difference of 10V is maintained across a 1.0-m length of the Nichrome wire, what is the current in the wire?

27.4 Resistance and Temperature

- The resistivity of a conductor varies approximately linearly with temperature as:

$$\rho = \rho_0[1 + \alpha(T - T_0)]$$

where

ρ isthe resistivity at some temperature T *(in degrees Celsius)*

ρ_0 *is the resistivity* at some reference temperature T_0 *(usually 20°C),*

α is the temperature coefficient of resistivity.

$$\alpha = \frac{1}{\rho_0}\frac{\Delta\rho}{\Delta T}$$

Unit: C^{-1}

$$\Delta\rho = \rho - \rho_0$$

$$\Delta T = T - T_0.$$

27.4 Resistance and Temperature

- Because resistance is proportional to resistivity

$$R = R_o\left[1 + \alpha\left(T - T_0\right)\right]$$

- ***Quick Quiz 27.6***

When does a lightbulb carry more current:

1) just after it is turned on and the glow of the metal filament is increasing

2) after it has been on for a few milliseconds and the glow is steady

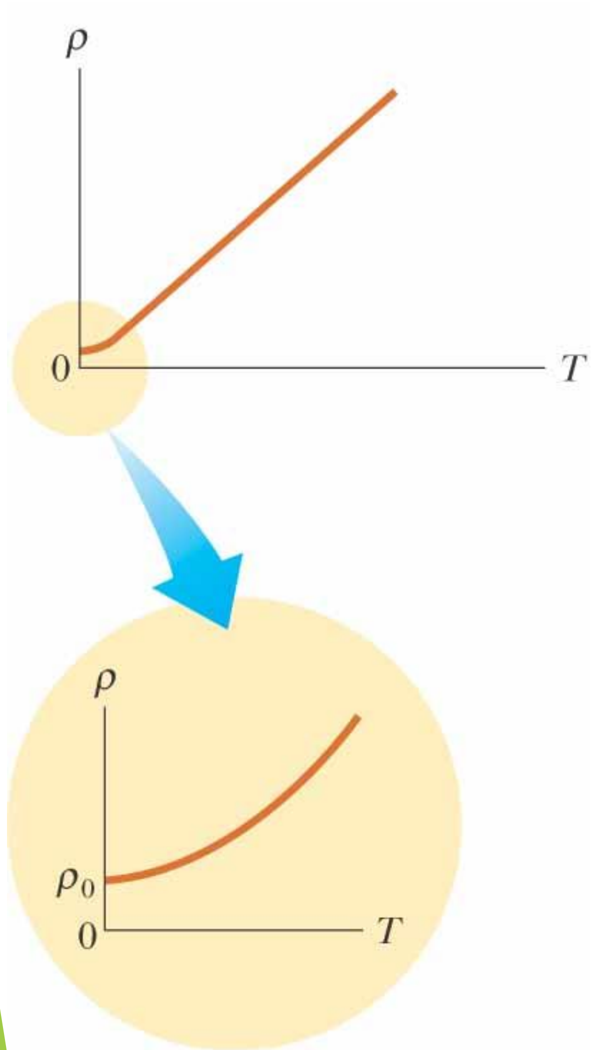
27.4 Resistance and Temperature

- ***Example 27.6***

A resistance thermometer, which measures temperature by measuring the change in resistance of a conductor, is made from platinum and has a resistance of 50.0 Cat 20.0°C. When immersed in a vessel containing melting indium, its resistance increases to 76.8 Ω ***Calculate the melting point of the indium***

27.4 Resistance and Temperature

Resistivity versus temperature for a metal



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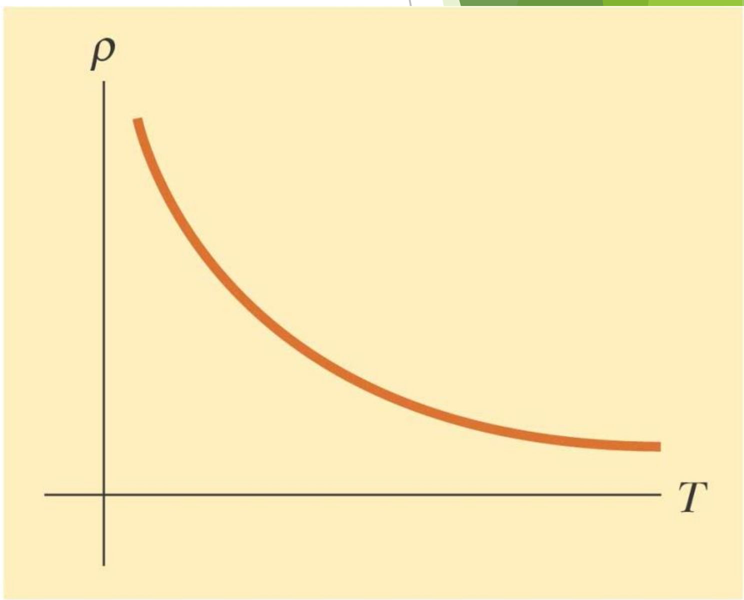

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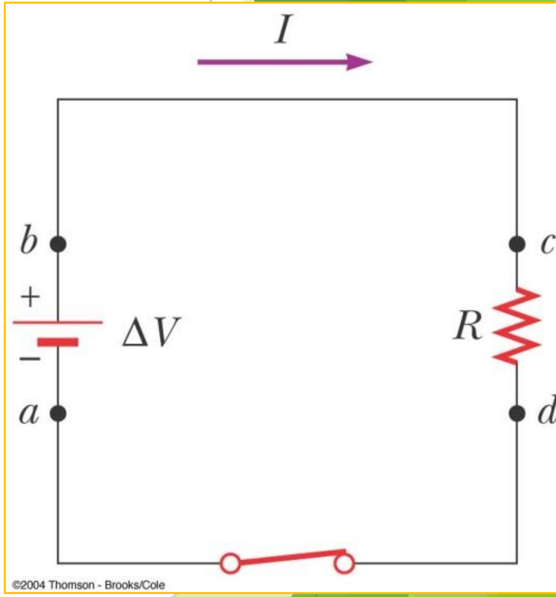
27.6 Electrical Power

- **Battery → Conductor → Electric current → transformation of chemical energy in the battery to kinetic energy of the electrons → Internal energy in the conductor → increase in the temperature of the conductor**

- **Imagine following a positive quantity of charge Q that is moving clockwise around the circuit.**

  - As the charge moves from **a** to **b** through the battery, the ***electric potential energy*** of the system ***increases*** by an amount **$Q\Delta V$** while the ***chemical potential energy*** in the battery ***decreases*** by the same amount.

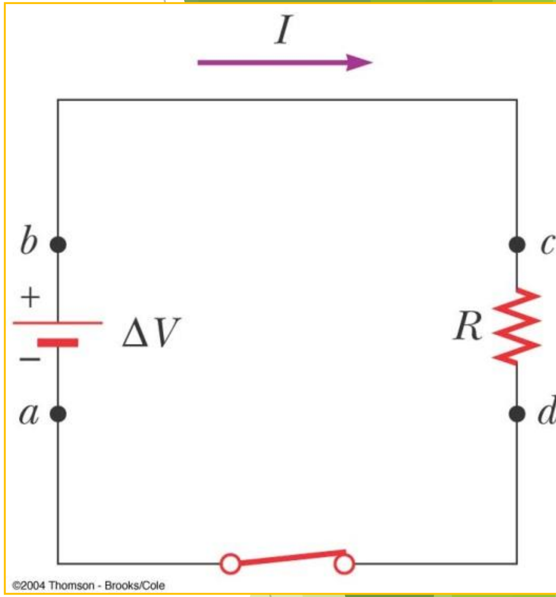
  - As the charge moves from d to c through the battery **the system loses** this electric potential energy during collisions of electrons with atoms in the resistor.



27.6 Electrical Power

- **No loss in energy occurs for paths bc and da (resistance of the connecting wires is neglected)**

- Power : ***The rate at which energy is delivered to the resistor***



$$\mathcal{P} = I\Delta V$$

$$\mathcal{P} = I^2R = \frac{(\Delta V)^2}{R}$$

The SI unit of power is the ***watt***

27.6 Electrical Power

➢ ***Quick Quiz 27.7***

The same potential difference is applied to the two lightbulbs shown in the figure below. Which one of the following statements is true?

(a) The 30-W bulb carries the greater current and has the higher resistance.

(b) The 30-W bulb carries the greater current, but the 60-W bulb has the higher resistance.

(c) The 30-W bulb has the higher resistance, but the 60-W bulb carries the greater current.

(d) The 60-W bulb carries the greater current and has the higher resistance.

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27.6 Electrical Power

- ***Example 27.7***

An electric heater is constructed by applying a potential difference

of 120V to a Nichrome wire that has a total resistance of 8.00 Ω.

Find the current carried by the wire and the power rating of the heater

What if the heater were accidentally connected to a 240-V supply?

Chapter Problems

Problem 1 page 852

In a particular cathode ray tube, the measured beam current is 30.0μA. How many electrons strike the tube Screen every 40.0s

Problem 12 page 852

Calculate the current density in a gold wire at 20°C, if an electric field of 0.740V/m exists in the wire?

Problem 33 page 853

What is the fractional change in the resistance of an iron filament when its temperature changes from 25.0°C to 50.0°C?

Chapter Problems

Problem 54 page 854

One light bulb is marked "25W 120 V" and the other is marked "100W 120V". This means that each bulb converts its respective power to heat and light when plugged into a constant 120V potential difference.

a. What is the resistance of each bulb?

b. How long does it take for 2.20 Coulomb to pass through the 25W bulb?

c. How long does it take for 1.80 Joule to pass through the 100W bulb?

D. What is the cost of running the 25W bulb continuously for 30 days if the electric company sells electricity at $0.07/kWhr?