PHYS 111
1ST semester 1439-1440

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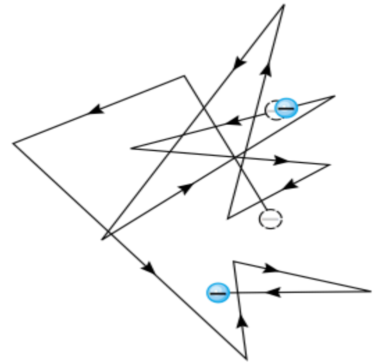
Lecture 13

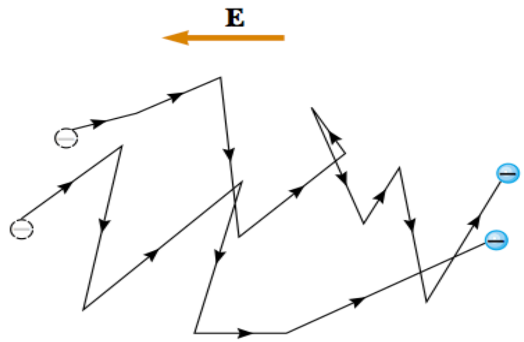
Chapter 27
Current and Resistance

27.3 A Model for Electrical Conduction

- Consider a conductor as: atoms + free electrons (*conduction* electrons).
- In the **absence** of an electric field
  - The conduction electrons move in random directions similar to the motion of gas molecules.
  - No current because the drift velocity of the free electrons is zero.
  - No net flow of charge.
- When an electric field is **applied**.
  - The free electrons drift slowly in a direction opposite that of the electric field, with an average drift speed v_d.



(a)



(b)

27.3 A Model for Electrical Conduction

- The acceleration of the electron is $\mathbf{a} = \dfrac{q\mathbf{E}}{m_e}$
- This acceleration, which occurs for only a short time interval between collisions, enables the electron to acquire a small drift velocity.
- The velocity of the electron at time *t* (at which the next collision occurs)

$$\mathbf{v}_f = \mathbf{v}_i + \mathbf{a}t = \mathbf{v}_i + \frac{q\mathbf{E}}{m_e}t$$

$$\overline{\mathbf{v}}_f = \mathbf{v}_d = \frac{q\mathbf{E}}{m_e}\tau$$

- *τ average time interval between successive collisions*.

27.3 A Model for Electrical Conduction

- The magnitude of the current density is

$$J = nqv_d = \frac{nq^2E}{m_e}\tau$$

  - where *n* is the number of charge carriers per unit volume.
- Comparing this expression with Ohm's law, $J = \sigma E$, we obtain the conductivity and resistivity of a conductor:

$$\sigma = \frac{nq^2\tau}{m_e}$$

$$\rho = \frac{1}{\sigma} = \frac{m_e}{nq^2\tau}$$

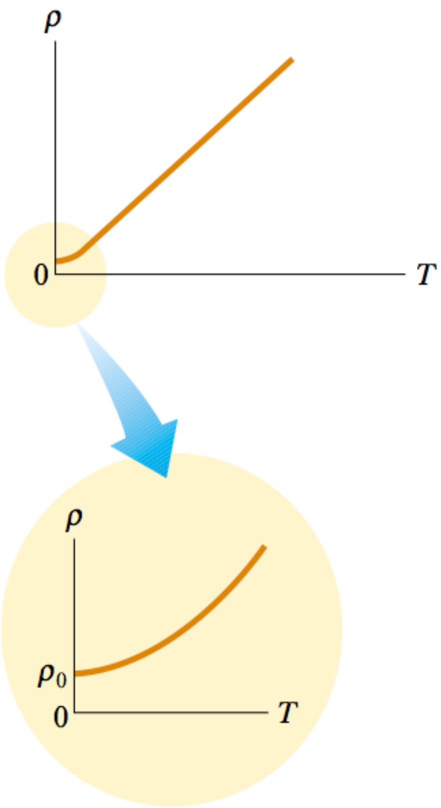
The average time interval τ between collisions is related to the average distance between collisions ℓ (that is, the *mean free path*; see Section 21.7) and the average speed $\bar{v}$ through the expression

$$\tau = \frac{\ell}{\bar{v}} \qquad (27.18)$$

27.4 Resistance and Temperature

- The resistivity of a conductor varies approximately linearly with temperature

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



- where ρ is the resistivity at some temperature *T* (in degrees Celsius), ρ_0 is the resistivity at some reference temperature T_0 (usually taken to be 20°C), and α is the **temperature coefficient of resistivity.**

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

- where $\Delta\rho = \rho - \rho_0$ is the change in resistivity in the temperature interval $\Delta T = T - T_0$.
- The unit for α is degrees Celsius^{-1} [$(°C)^{-1}$].
- Because resistance is proportional to resistivity, we can write the variation of resistance as

$$R = R_0[1 + \alpha(T - T_0)]$$

Quick Quiz 27.6 When does a lightbulb carry more current: (a) just after it is turned on and the glow of the metal filament is increasing, or (b) after it has been on for a few milliseconds and the glow is steady?

Example 27.6 A Platinum Resistance Thermometer

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 Ω at 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.

Solution Solving Equation 27.21 for ΔT and using the α value for platinum given in Table 27.1, we obtain

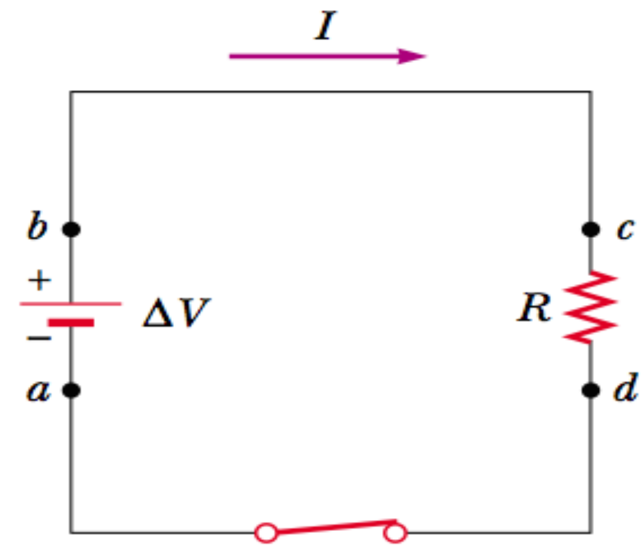
$$\Delta T = \frac{R - R_0}{\alpha R_0} = \frac{76.8\ \Omega - 50.0\ \Omega}{[3.92 \times 10^{-3}(°\mathrm{C})^{-1}](50.0\ \Omega)}$$

$$= 137°\mathrm{C}$$

Because $T_0 = 20.0°\mathrm{C}$, we find that T, the temperature of the melting indium sample, is 157°C.

27.6 Electrical Power

- If a **battery** is used to establish a **current** in a conductor, there is a continuous transformation of **chemical energy** in the battery to **kinetic energy** of the electrons to **internal energy** in the conductor, resulting in an increase in the **temperature** of the conductor.
- Imagine a positive charge *Q* 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. ($\Delta U = q\,\Delta V$)



27.6 Electrical Power

- The charge moves from *c* to *d* through the resistor, the system ***loses*** this electric potential energy during collisions of electrons with atoms in the resistor.
- Because we have neglected the resistance of the interconnecting wires, no energy transformation occurs for paths *bc* and *da.*
- The rate at which the system loses electric potential energy as the charge *Q* passes through the resistor:

$$\frac{dU}{dt} = \frac{d}{dt}(Q\Delta V) = \frac{dQ}{dt}\Delta V = I\Delta V$$

- The rate at which the system **loses** potential energy as the charge passes through the resistor = the rate at which the system **gains** internal energy in the resistor.

27.6 Electrical Power

- The **power**, is the rate at which energy is delivered to the resistor, is

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

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

- The SI unit of power is the **Watt**.

Quick Quiz 27.7 The same potential difference is applied to the two lightbulbs shown in Figure 27.14. 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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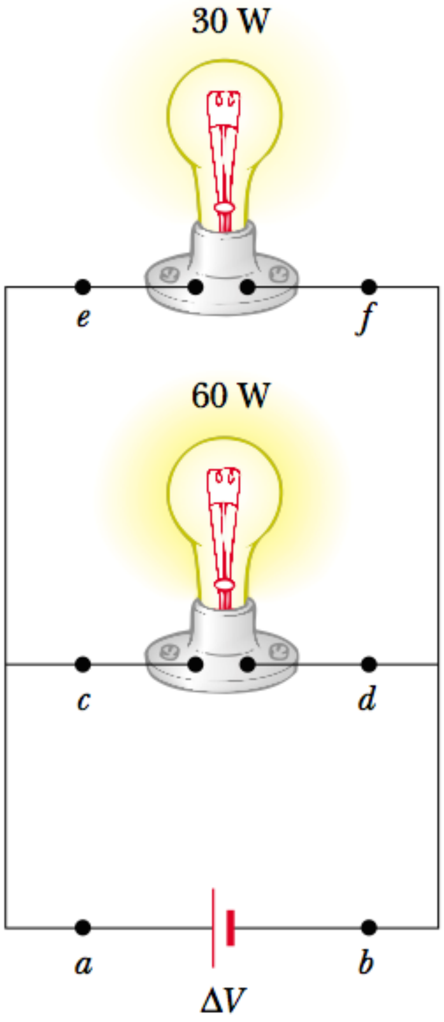

Example 27.7 Power in an Electric Heater

An electric heater is constructed by applying a potential difference of 120 V 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.

Solution Because $\Delta V = IR$, we have

$$I = \frac{\Delta V}{R} = \frac{120\ \text{V}}{8.00\ \Omega} = 15.0\ \text{A}$$

We can find the power rating using the expression $\mathcal{P} = I^2R$:

$$\mathcal{P} = I^2R = (15.0\ \text{A})^2(8.00\ \Omega) = 1.80 \times 10^3\ \text{W}$$

$$\mathcal{P} = 1.80\ \text{kW}$$

What If? What if the heater were accidentally connected to a 240-V supply? (This is difficult to do because the shape and orientation of the metal contacts in 240-V plugs are different from those in 120-V plugs.) How would this affect the current carried by the heater and the power rating of the heater?

Answer If we doubled the applied potential difference, Equation 27.8 tells us that the current would double. According to Equation 27.23, $\mathcal{P} = (\Delta V)^2/R$, the power would be four times larger.