

# CHAPTER 17

## Quick Quizzes

1. d, b = c, a. The current in (d) is equivalent to two positive charges moving to the left. Parts (b) and (c) each represent four charges moving in the same direction because negative charges moving to the left are equivalent to positive charges moving to the right. The current in (a) is equivalent to five positive charges moving to the right.
2. (c), (d). Neither circuit (a) nor circuit (b) applies a difference in potential across the bulb. Circuit (a) has both lead wires connected to the same battery terminal. Circuit (b) has a low resistance path (a "short") between the two battery terminals as well as between the bulb terminals.
3. (b). The slope of the line tangent to the curve at a point is the reciprocal of the resistance at that point. Note that as  $\Delta V$  increases, the slope (and hence  $1/R$ ) increases. Thus, the resistance decreases.
4. (b), (d). The length of the line cord will double in this event. This would tend to increase the resistance of the line cord. But the doubling of the radius of the line cord results in the increase of the cross-sectional area by a factor of 4. This would reduce the resistance more than the doubling of length increases it. The net result is a decrease in resistance. The same effect would occur for the lightbulb filament. The lowered resistance would result in a larger current in the filament, causing it to glow more brightly.
5. (a). The resistance of the shorter wire is half that of the longer wire. The power dissipated,  $\phi = (\Delta V)^2 / R$ , (and hence the rate of heating) will be greater for the shorter wire. Consideration of the expression  $\phi = I^2 R$  might initially lead one to think that the reverse would be true. However, one must realize that the currents will not be the same in the two wires.
6.  $I_a = I_b > I_c = I_d > I_e = I_f$ . Charges constituting the current  $I_a$  leave the positive terminal of the battery and then split to flow through the two bulbs; thus,  $I_a = I_c + I_e$ . Because the potential difference  $\Delta V$  is the same across the two bulbs and because the power delivered to a device is  $\phi = I(\Delta V)$ , the 60-W bulb with the higher power rating must carry the greater current. Because charge does not accumulate in the bulbs, all the charge flowing into a bulb from the left has to flow out on the right; consequently  $I_c = I_d$  and  $I_e = I_f$ . The two currents leaving the bulbs recombine to form the current back into the battery,  $I_f + I_d = I_b$ .
7. B, B. Because the voltage across each resistor is the same, and the rate of energy delivered to a resistor is  $\phi = (\Delta V)^2 / R$ , the resistor with the lower resistance exhibits the higher rate of energy transfer. In this case, the resistance of B is smaller than that for A and thus B dissipates more power. Furthermore, because  $\phi = I(\Delta V)$ , the current carried by B is larger than that of A.

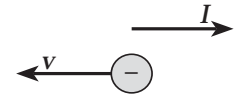
## Problem Solutions

- 17.1** The charge that moves past the cross section is  $\Delta Q = I(\Delta t)$ , and the number of electrons is

$$n = \frac{\Delta Q}{|e|} = \frac{I(\Delta t)}{|e|}$$

$$= \frac{(80.0 \times 10^{-3} \text{ C/s})[(10.0 \text{ m})(60.0 \text{ s/m})]}{1.60 \times 10^{-19} \text{ C}} = \boxed{3.00 \times 10^{20} \text{ electrons}}$$

The negatively charged electrons move in the direction opposite to the conventional current flow.



- 17.2** The period of revolution for the sphere is  $T = 2\pi/\omega$ , and the average current represented by this revolving charge is  $I = \frac{q}{T} = \boxed{\frac{q\omega}{2\pi}}$

- 17.3** The current is  $I = \frac{\Delta Q}{\Delta t} = \frac{6.0 \times 10^{-3} \text{ C}}{2.0 \text{ s}} = 3.0 \times 10^{-3} \text{ A} = \boxed{3.0 \text{ mA}}$

- 17.4**  $\Delta Q = I(\Delta t)$  and the number of electrons is

$$n = \frac{\Delta Q}{|e|} = \frac{I(\Delta t)}{|e|} = \frac{(60.0 \times 10^{-6} \text{ C/s})(1.00 \text{ s})}{1.60 \times 10^{-19} \text{ C}} = \boxed{3.75 \times 10^{14} \text{ electrons}}$$

- 17.5** The period of the electron in its orbit is  $T = 2\pi r/v$ , and the current represented by the orbiting electron is

$$I = \frac{\Delta Q}{\Delta t} = \frac{|e|}{T} = \frac{v|e|}{2\pi r}$$

$$= \frac{(2.19 \times 10^6 \text{ m/s})(1.60 \times 10^{-19} \text{ C})}{2\pi(5.29 \times 10^{-11} \text{ m})} = 1.05 \times 10^{-3} \text{ C/s} = \boxed{1.05 \text{ mA}}$$

17.6 The mass of a single gold atom is

$$m_{\text{atom}} = \frac{M}{N_A} = \frac{197 \text{ g/mol}}{6.02 \times 10^{23} \text{ atom/mol}} = 3.27 \times 10^{-22} \text{ g} = 3.27 \times 10^{-25} \text{ kg}$$

The number of atoms deposited, and hence the number of ions moving to the negative electrode, is

$$n = \frac{m}{m_{\text{atom}}} = \frac{3.25 \times 10^{-3} \text{ kg}}{3.27 \times 10^{-25} \text{ kg}} = 9.93 \times 10^{21}$$

Thus, the current in the cell is

$$I = \frac{\Delta Q}{\Delta t} = \frac{ne}{\Delta t} = \frac{(9.93 \times 10^{21})(1.60 \times 10^{-19} \text{ C})}{(2.78 \text{ h})(3600 \text{ s/h})} = 0.159 \text{ A} = \boxed{159 \text{ mA}}$$

17.7 The drift speed of electrons in the line is  $v_d = \frac{I}{nqA} = \frac{I}{n|e|(\pi d^2/4)}$ , or

$$v_d = \frac{4(1000 \text{ A})}{(8.5 \times 10^{28} \text{ /m}^3)(1.60 \times 10^{-19} \text{ C})\pi(0.020 \text{ m})^2} = 2.3 \times 10^{-4} \text{ m/s}$$

The time to travel the length of the 200-km line is then

$$\Delta t = \frac{L}{v_d} = \frac{200 \times 10^3 \text{ m}}{2.34 \times 10^{-4} \text{ m/s}} \left( \frac{1 \text{ yr}}{3.156 \times 10^7 \text{ s}} \right) = \boxed{27 \text{ yr}}$$

17.8 Assuming that, on average, each aluminum atom contributes one electron, the density of charge carriers is the same as the number of atoms per cubic meter. This is

$$n = \frac{\text{density}}{\text{mass per atom}} = \frac{\rho}{M/N_A} = \frac{N_A \rho}{M},$$

or 
$$n = \frac{(6.02 \times 10^{23} \text{ /mol})[(2.7 \text{ g/cm}^3)(10^6 \text{ cm}^3 \text{ /m}^3)]}{26.98 \text{ g/mol}} = 6.0 \times 10^{28} \text{ /m}^3$$

The drift speed of the electrons in the wire is then

$$v_d = \frac{I}{n|e|A} = \frac{5.0 \text{ C/s}}{(6.0 \times 10^{28} \text{ /m}^3)(1.60 \times 10^{-19} \text{ C})(4.0 \times 10^{-6} \text{ m}^2)} = \boxed{1.3 \times 10^{-4} \text{ m/s}}$$

- 17.9 (a) The carrier density is determined by the physical characteristics of the wire, not the current in the wire. Hence,  $n$  is unaffected.
- (b) The drift velocity of the electrons is  $v_d = I/nqA$ . Thus, the drift velocity is doubled when the current is doubled.

$$17.10 \quad I = \frac{\Delta V}{R} = \frac{120 \text{ V}}{240 \Omega} = 0.500 \text{ A} = \boxed{500 \text{ mA}}$$

$$17.11 \quad (\Delta V)_{\max} = I_{\max} R = (80 \times 10^{-6} \text{ A}) R$$

$$\text{Thus, if } R = 4.0 \times 10^5 \Omega, (\Delta V)_{\max} = \boxed{32 \text{ V}},$$

$$\text{and if } R = 2000 \Omega, (\Delta V)_{\max} = \boxed{0.16 \text{ V}}$$

- 17.12 The volume of the copper is

$$V = \frac{m}{\text{density}} = \frac{1.00 \times 10^{-3} \text{ kg}}{8.92 \times 10^3 \text{ kg/m}^3} = 1.12 \times 10^{-7} \text{ m}^3$$

$$\text{Since, } V = A \cdot L, \text{ this gives } A \cdot L = 1.12 \times 10^{-7} \text{ m}^3. \quad (1)$$

- (a) From  $R = \frac{\rho L}{A}$ , we find that

$$A = \left( \frac{\rho}{R} \right) L = \left( \frac{1.70 \times 10^{-8} \Omega \cdot \text{m}}{0.500 \Omega} \right) L = (3.40 \times 10^{-8} \text{ m}) L.$$

Inserting this expression for  $A$  into Equation 1 gives

$$(3.40 \times 10^{-8} \text{ m}) L^2 = 1.12 \times 10^{-7} \text{ m}^3, \text{ which yields } L = \boxed{1.82 \text{ m}}$$

- (b) From equation (1),  $A = \frac{\pi d^2}{4} = \frac{1.12 \times 10^{-7} \text{ m}^3}{L}$ , or

$$d = \sqrt{\frac{4(1.12 \times 10^{-7} \text{ m}^3)}{\pi L}} = \sqrt{\frac{4(1.12 \times 10^{-7} \text{ m}^3)}{\pi(1.82 \text{ m})}}$$

$$= 2.80 \times 10^{-4} \text{ m} = \boxed{0.280 \text{ mm}}$$

**17.13** From  $R = \frac{\rho L}{A}$ , we obtain  $A = \frac{\pi d^2}{4} = \frac{\rho L}{R}$ , or

$$d = \sqrt{\frac{4\rho L}{\pi R}} = \sqrt{\frac{4(5.6 \times 10^{-8} \Omega \cdot \text{m})(2.0 \times 10^{-2} \text{ m})}{\pi(0.050 \Omega)}} = 1.7 \times 10^{-4} \text{ m} = \boxed{0.17 \text{ mm}}$$

**17.14**  $R = \frac{\rho L}{A} = \frac{\rho L}{\pi d^2/4} = \frac{4(1.7 \times 10^{-8} \Omega \cdot \text{m})(15 \text{ m})}{\pi(1.024 \times 10^{-3} \text{ m})^2} = \boxed{0.31 \Omega}$

**17.15** (a)  $R = \frac{\Delta V}{I} = \frac{12 \text{ V}}{0.40 \text{ A}} = 30 \Omega$

(b) From,  $R = \frac{\rho L}{A}$ ,

$$\rho = \frac{R \cdot A}{L} = \frac{(30 \Omega) \left[ \pi(0.40 \times 10^{-2} \text{ m})^2 \right]}{3.2 \text{ m}} = \boxed{4.7 \times 10^{-4} \Omega \cdot \text{m}}$$

**17.16** The new “wire” has length  $L = L_0/3$  and cross-section  $A = 3A_0$ . Thus, its resistance is

$$R = \frac{\rho L}{A} = \frac{\rho(L_0/3)}{3A_0} = \frac{1}{9} \left( \frac{\rho L_0}{A_0} \right) = \boxed{\frac{R_0}{9}}$$

**17.17** The resistance is  $R = \frac{\Delta V}{I} = \frac{9.11 \text{ V}}{36.0 \text{ A}} = 0.253 \Omega$ , so the resistivity of the metal is

$$\rho = \frac{R \cdot A}{L} = \frac{R \cdot (\pi d^2/4)}{L} = \frac{(0.253 \Omega) \pi (2.00 \times 10^{-3} \text{ m})^2}{4(50.0 \text{ m})} = 1.59 \times 10^{-8} \Omega \cdot \text{m}$$

Thus, the metal is seen to be silver.

**17.18** With different orientations of the block, three different values of the ratio  $L/A$  are possible. These are:

$$\left(\frac{L}{A}\right)_1 = \frac{10 \text{ cm}}{(20 \text{ cm})(40 \text{ cm})} = \frac{1}{80 \text{ cm}} = \frac{1}{0.80 \text{ m}},$$

$$\left(\frac{L}{A}\right)_2 = \frac{20 \text{ cm}}{(10 \text{ cm})(40 \text{ cm})} = \frac{1}{20 \text{ cm}} = \frac{1}{0.20 \text{ m}},$$

and  $\left(\frac{L}{A}\right)_3 = \frac{40 \text{ cm}}{(10 \text{ cm})(20 \text{ cm})} = \frac{1}{5.0 \text{ cm}} = \frac{1}{0.050 \text{ m}}$

$$(a) \quad I_{\max} = \frac{\Delta V}{R_{\max}} = \frac{\Delta V}{\rho(L/A)_{\max}} = \frac{(6.0 \text{ V})(0.80 \text{ m})}{1.7 \times 10^{-8} \Omega \cdot \text{m}} = \boxed{2.8 \times 10^8 \text{ A}}$$

$$(b) \quad I_{\max} = \frac{\Delta V}{R_{\max}} = \frac{\Delta V}{\rho(L/A)_{\max}} = \frac{(6.0 \text{ V})(0.050 \text{ m})}{1.7 \times 10^{-8} \Omega \cdot \text{m}} = \boxed{1.8 \times 10^7 \text{ A}}$$

**17.19** When the tube is stretched, the cross-sectional area decreases. Since the volume of mercury is constant,  $V = A_f \cdot L_f = A_i \cdot L_i$ , or  $\left(\frac{\pi}{4} d_f^2\right) L_f = \left(\frac{\pi}{4} d_i^2\right) L_i$ . This gives  $d_f^2 = d_i^2 (L_i/L_f)$ .

The total resistance of the circuit is

$$R = r + R_{Hg} = 1.00 \Omega + \frac{\rho_{Hg} L}{A} = 1.00 \Omega + \frac{4\rho_{Hg} L}{\pi d^2}$$

The change in current through the monitor is

$$\begin{aligned} \Delta I &= \frac{\Delta V}{R_f} - \frac{\Delta V}{R_i} = \frac{\Delta V}{1.00 \Omega + \frac{4\rho_{Hg} L_f^2}{\pi d_i^2 L_i}} - \frac{\Delta V}{1.00 \Omega + \frac{4\rho_{Hg} L_i}{\pi d_i^2}} \\ &= \frac{0.100 \text{ V}}{1.00 \Omega + \frac{4(9.4 \times 10^{-7} \Omega \cdot \text{m})(1.35 \text{ m})^2}{\pi(2.51 \times 10^{-3} \text{ m})^2(1.25 \text{ m})}} - \frac{0.100 \text{ V}}{1.00 \Omega + \frac{4(9.4 \times 10^{-7} \Omega \cdot \text{m})(1.25 \text{ m})}{\pi(2.51 \times 10^{-3} \text{ m})^2}} \end{aligned}$$

giving  $\Delta I = -2.5 \times 10^{-3} \text{ A} = \boxed{2.5 \text{ mA decrease}}$

**17.20** Solving  $R = R_0[1 + \alpha(T - T_0)]$  for the final temperature gives

$$T = T_0 + \frac{R - R_0}{\alpha R_0} = 20^\circ\text{C} + \frac{140\ \Omega - 19\ \Omega}{[4.5 \times 10^{-3}\ (\text{°C})^{-1}](19\ \Omega)} = \boxed{1.4 \times 10^3\ \text{°C}}$$

**17.21** From Ohm's law,  $\Delta V = I_i R_i = I_f R_f$ , so the current in Antarctica is

$$\begin{aligned} I_f &= I_i \left( \frac{R_i}{R_f} \right) = I_i \left( \frac{R_0 [1 + \alpha(T_i - T_0)]}{R_0 [1 + \alpha(T_f - T_0)]} \right) \\ &= (1.00\ \text{A}) \left( \frac{1 + [3.90 \times 10^{-3}\ (\text{°C})^{-1}](58.0^\circ\text{C} - 20.0^\circ\text{C})}{1 + [3.90 \times 10^{-3}\ (\text{°C})^{-1}](-88.0^\circ\text{C} - 20.0^\circ\text{C})} \right) = \boxed{1.98\ \text{A}} \end{aligned}$$

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

$$= (10.0\ \Omega) \left[ 1 + (3.80 \times 10^{-3}\ (\text{°C})^{-1})(40.0^\circ\text{C} - 20.0^\circ\text{C}) \right] = \boxed{10.8\ \Omega}$$

**17.23** At  $80^\circ\text{C}$ ,

$$I = \frac{\Delta V}{R} = \frac{\Delta V}{R_0 [1 + \alpha(T - T_0)]} = \frac{5.0\ \text{V}}{(200\ \Omega) [1 + (-0.5 \times 10^{-3}\ \text{°C}^{-1})(80^\circ\text{C} - 20^\circ\text{C})]},$$

or  $I = 2.6 \times 10^{-2}\ \text{A} = 26\ \text{mA}$

**17.24** If  $R = 100\ \Omega$  at  $T = 40.0^\circ\text{C}$ , then  $R = R_0[1 + \alpha(T - T_0)]$  gives

$$R_0 = \frac{R}{1 + \alpha(T - T_0)} = \frac{100\ \Omega}{1 + [3.40 \times 10^{-3}\ (\text{°C})^{-1}](40.0^\circ\text{C} - 20.0^\circ\text{C})} = 93.6\ \Omega$$

$$T = T_0 + \frac{R - R_0}{\alpha R_0} = 20.0^\circ\text{C} + \frac{97.0\ \Omega - 93.6\ \Omega}{[3.40 \times 10^{-3}\ (\text{°C})^{-1}](93.6\ \Omega)} = \boxed{30.6^\circ\text{C}}$$

**17.25**  $R_0 = \frac{\rho L}{A} = \frac{(1.7 \times 10^{-8}\ \Omega \cdot \text{m})(10.0\ \text{m})}{3.00 \times 10^{-6}\ \text{m}^2} = 5.67 \times 10^{-2}\ \Omega$

(a) At  $T = 30.0^\circ\text{C}$ ,  $R = R_0[1 + \alpha(T - T_0)]$  gives a resistance of

$$R = (0.0567 \, \Omega) \left[ 1 + (3.9 \times 10^{-3} \, (^\circ\text{C})^{-1})(30.0^\circ\text{C} - 20.0^\circ\text{C}) \right] = \boxed{5.89 \times 10^{-2} \, \Omega}$$

(b) At  $T = 10.0^\circ\text{C}$ ,  $R = R_0[1 + \alpha(T - T_0)]$  yields

$$R = (0.0567 \, \Omega) \left[ 1 + (3.9 \times 10^{-3} \, (^\circ\text{C})^{-1})(10.0^\circ\text{C} - 20.0^\circ\text{C}) \right] = \boxed{5.45 \times 10^{-2} \, \Omega}$$

**17.26** For aluminum, the coefficient of linear expansion is  $\alpha = 24 \times 10^{-6} \, (^\circ\text{C})^{-1}$  and the temperature coefficient of resistivity is  $\alpha_e = 3.9 \times 10^{-3} \, (^\circ\text{C})^{-1}$ . At temperature  $T$ , the length and cross-sectional area may be expressed as  $L = L_0[1 + \alpha(T - T_0)]$  and  $A = A_0[1 + \alpha(T - T_0)]^2$ , respectively.

$$\text{Thus, } R = \rho \frac{L}{A} = \rho_0 [1 + \alpha_e(T - T_0)] \frac{L_0 [1 + \alpha(T - T_0)]}{A_0 [1 + \alpha(T - T_0)]^2} = \left( \rho_0 \frac{L_0}{A_0} \right) \frac{[1 + \alpha_e(T - T_0)]}{[1 + \alpha(T - T_0)]}.$$

At  $T = 120^\circ\text{C}$ , this gives

$$R = R_0 \frac{[1 + \alpha_e(T - T_0)]}{[1 + \alpha(T - T_0)]} = (1.234 \, \Omega) \frac{[1 + 3.9 \times 10^{-3} \, (^\circ\text{C})^{-1}(120 - 20.0)^\circ\text{C}]}{[1 + 24 \times 10^{-6} \, (^\circ\text{C})^{-1}(120 - 20.0)^\circ\text{C}]} = \boxed{1.71 \, \Omega}$$

**17.27** (a) The resistance at  $20.0^\circ\text{C}$  is

$$R_0 = \rho \frac{L}{A} = \frac{(1.7 \times 10^{-8} \, \Omega \cdot \text{m})(34.5 \, \text{m})}{\pi(0.25 \times 10^{-3} \, \text{m})^2} = 3.0 \, \Omega,$$

$$\text{and the current will be } I = \frac{\Delta V}{R_0} = \frac{9.0 \, \text{V}}{3.0 \, \Omega} = \boxed{3.0 \, \text{A}}$$

(b) At  $30.0^\circ\text{C}$ ,

$$\begin{aligned} R &= R_0 [1 + \alpha(T - T_0)] \\ &= (3.0 \, \Omega) \left[ 1 + (3.9 \times 10^{-3} \, (^\circ\text{C})^{-1})(30.0^\circ\text{C} - 20.0^\circ\text{C}) \right] = 3.1 \, \Omega \end{aligned}$$

$$\text{Thus, the current is } I = \frac{\Delta V}{R} = \frac{9.0 \, \text{V}}{3.1 \, \Omega} = \boxed{2.9 \, \text{A}}$$



**17.28** The resistance of the heating element when at its operating temperature is

$$R = \frac{(\Delta V)^2}{\mathcal{P}} = \frac{(120 \text{ V})^2}{1050 \text{ W}} = 13.7 \, \Omega$$

From  $R = R_0[1 + \alpha(T - T_0)] = \frac{\rho_0 L}{A}[1 + \alpha(T - T_0)]$ , the cross-sectional area is

$$\begin{aligned} A &= \frac{\rho_0 L}{R}[1 + \alpha(T - T_0)] \\ &= \frac{(150 \times 10^{-8} \, \Omega \cdot \text{m})(4.00 \text{ m})}{13.7 \, \Omega} \left[ 1 + (0.40 \times 10^{-3} \, (^{\circ}\text{C})^{-1})(320^{\circ}\text{C} - 20.0^{\circ}\text{C}) \right] \\ A &= \boxed{4.90 \times 10^{-7} \text{ m}^2} \end{aligned}$$

**17.29** (a) From  $R = \rho L/A$ , the initial resistance of the mercury is

$$R_i = \frac{\rho L_i}{A_i} = \frac{(9.4 \times 10^{-7} \, \Omega \cdot \text{m})(1.0000 \text{ m})}{\pi(1.00 \times 10^{-3} \text{ m})^2/4} = \boxed{1.2 \, \Omega}$$

(b) Since the volume of mercury is constant,  $V = A_f \cdot L_f = A_i \cdot L_i$  gives the final cross-sectional area as  $A_f = A_i \cdot (L_i/L_f)$ . Thus, the final resistance is given by

$$R_f = \frac{\rho L_f}{A_f} = \frac{\rho L_f^2}{A_i \cdot L_i}. \text{ The fractional change in the resistance is then}$$

$$\Delta = \frac{R_f - R_i}{R_i} = \frac{R_f}{R_i} - 1 = \frac{\rho L_f^2 / (A_i \cdot L_i)}{\rho L_i / A_i} - 1 = \left( \frac{L_f}{L_i} \right)^2 - 1,$$

$$\Delta = \left( \frac{100.04}{100.00} \right)^2 - 1 = \boxed{8.0 \times 10^{-4}} \text{ or } \boxed{\text{a } 0.080\% \text{ increase}}$$

**17.30** The resistance at  $20.0^\circ\text{C}$  is

$$R_0 = \frac{R}{1 + \alpha(T - T_0)} = \frac{200.0 \, \Omega}{1 + [3.92 \times 10^{-3} \, (^{\circ}\text{C})^{-1}](0^\circ\text{C} - 20.0^\circ\text{C})} = 217 \, \Omega$$

Solving  $R = R_0[1 + \alpha(T - T_0)]$  for  $T$  gives the temperature of the melting potassium as

$$T = T_0 + \frac{R - R_0}{\alpha R_0} = 20.0^\circ\text{C} + \frac{253.8 \, \Omega - 217 \, \Omega}{[3.92 \times 10^{-3} \, (^{\circ}\text{C})^{-1}](217 \, \Omega)} = \boxed{63.2^\circ\text{C}}$$

**17.31**  $I = \frac{\mathcal{P}}{\Delta V} = \frac{600 \, \text{W}}{120 \, \text{V}} = \boxed{5.00 \, \text{A}}$

and  $R = \frac{\Delta V}{I} = \frac{120 \, \text{V}}{5.00 \, \text{A}} = \boxed{24.0 \, \Omega}$

**17.32** The energy produced by the Sun in 1.0 second is

$$\begin{aligned} E &= \mathcal{P} \cdot t = (4.0 \times 10^{26} \, \text{W})(1.0 \, \text{s}) \\ &= 4.0 \times 10^{26} \, \text{W} \cdot \text{s} \left( \frac{1 \, \text{kW}}{10^3 \, \text{W}} \right) \left( \frac{1 \, \text{h}}{3600 \, \text{s}} \right) = 1.1 \times 10^{20} \, \text{kW} \cdot \text{h} \end{aligned}$$

At a rate of 8.0¢ per kilowatt-hour, the cost of this energy is

$$\text{cost} = (1.1 \times 10^{20} \, \text{kW} \cdot \text{h}) \left( \frac{\$0.08}{\text{kW} \cdot \text{h}} \right) = \boxed{8.8 \times 10^{18} \, \text{dollars}}$$

**17.33** The maximum power that can be dissipated in the circuit is

$$\mathcal{P}_{\text{max}} = (\Delta V) I_{\text{max}} = (120 \, \text{V})(15 \, \text{A}) = 1.8 \times 10^3 \, \text{W}$$

Thus, one can operate at most  $\boxed{18 \, \text{bulbs}}$  rated at 100 W per bulb.

**17.34** (a) The power loss in the line is

$$\mathcal{P}_{\text{loss}} = I^2 R = (1000 \, \text{A})^2 [(0.31 \, \Omega/\text{km})(160 \, \text{km})] = 5.0 \times 10^7 \, \text{W} = \boxed{50 \, \text{MW}}$$

(b) The total power transmitted is

$$\mathcal{P}_{\text{input}} = (\Delta V) I = (700 \times 10^3 \text{ V})(1000 \text{ A}) = 7.0 \times 10^8 \text{ W} = 700 \text{ M W}$$

Thus, the fraction of the total transmitted power represented by the line losses is

$$\text{fraction loss} = \frac{\mathcal{P}_{\text{loss}}}{\mathcal{P}_{\text{input}}} = \frac{50 \text{ M W}}{700 \text{ M W}} = 0.071 \text{ or } \boxed{7.1\%}$$

**17.35** The energy required to bring the water to the boiling point is

$$E = m c (\Delta T) = (0.500 \text{ kg})(4186 \text{ J/kg} \cdot ^\circ\text{C})(100^\circ\text{C} - 23.0^\circ\text{C}) = 1.61 \times 10^5 \text{ J}$$

The power input by the heating element is

$$\mathcal{P}_{\text{input}} = (\Delta V) I = (120 \text{ V})(2.00 \text{ A}) = 240 \text{ W} = 240 \text{ J/s}$$

Therefore, the time required is

$$t = \frac{E}{\mathcal{P}_{\text{input}}} = \frac{1.61 \times 10^5 \text{ J}}{240 \text{ J/s}} = 672 \text{ s} \left( \frac{1 \text{ min}}{60 \text{ s}} \right) = \boxed{11.2 \text{ min}}$$

**17.36** (a)  $E = \mathcal{P} \cdot t = (90 \text{ W})(1 \text{ h}) = (90 \text{ J/s})(3600 \text{ s}) = 3.2 \times 10^5 \text{ J}$

(b) The power consumption of the color set is

$$\mathcal{P} = (\Delta V) I = (120 \text{ V})(2.50 \text{ A}) = 300 \text{ W}$$

Therefore, the time required to consume the energy found in (a) is

$$t = \frac{E}{\mathcal{P}} = \frac{3.2 \times 10^5 \text{ J}}{300 \text{ J/s}} = 1.1 \times 10^3 \text{ s} \left( \frac{1 \text{ min}}{60 \text{ s}} \right) = \boxed{18 \text{ min}}$$

**17.37** The energy input required is

$$E = mc(\Delta T) = (1.50 \text{ kg})(4186 \text{ J/kg} \cdot ^\circ\text{C})(50.0^\circ\text{C} - 10.0^\circ\text{C}) = 2.51 \times 10^5 \text{ J}$$

and, if this is to be added in  $\Delta t = 10.0 \text{ min} = 600 \text{ s}$ , the power input needed is

$$\mathcal{P} = \frac{E}{\Delta t} = \frac{2.51 \times 10^5 \text{ J}}{600 \text{ s}} = 419 \text{ W}$$

The power input to the heater may be expressed as  $\mathcal{P} = (\Delta V)^2/R$ , so the needed resistance is

$$R = \frac{(\Delta V)^2}{\mathcal{P}} = \frac{(120 \text{ V})^2}{419 \text{ W}} = \boxed{34.4 \Omega}$$

**17.38** (a) At the operating temperature,

$$\mathcal{P} = (\Delta V)I = (120 \text{ V})(1.53 \text{ A}) = \boxed{184 \text{ W}}$$

(b) From  $R = R_0[1 + \alpha(T - T_0)]$ , the temperature  $T$  is given by  $T = T_0 + \frac{R - R_0}{\alpha R_0}$ . The resistances are given by Ohm's law as

$$R = \frac{(\Delta V)}{I} = \frac{120 \text{ V}}{1.53 \text{ A}}, \text{ and } R_0 = \frac{(\Delta V)_0}{I_0} = \frac{120 \text{ V}}{1.80 \text{ A}}$$

Therefore, the operating temperature is

$$T = 20.0^\circ\text{C} + \frac{(120/1.53) - (120/1.80)}{(0.400 \times 10^{-3} \text{ } ^\circ\text{C}^{-1})(120/1.80)} = \boxed{461^\circ\text{C}}$$

**17.39** The resistance per unit length of the cable is

$$\frac{R}{L} = \frac{\rho / I^2}{L} = \frac{\rho / L}{I^2} = \frac{2.00 \text{ W/m}}{(300 \text{ A})^2} = 2.22 \times 10^{-5} \text{ } \Omega/\text{m}$$

From  $R = \rho L / A$ , the resistance per unit length is also given by  $R/L = \rho / A$ . Hence, the cross-sectional area is  $\pi r^2 = A = \frac{\rho}{R/L}$ , and the required radius is

$$r = \sqrt{\frac{\rho}{\pi(R/L)}} = \sqrt{\frac{1.7 \times 10^{-8} \text{ } \Omega \cdot \text{m}}{\pi(2.22 \times 10^{-5} \text{ } \Omega/\text{m})}} = 0.016 \text{ m} = \boxed{1.6 \text{ cm}}$$

**17.40** (a) The power input to the motor is

$$\mathcal{P}_{\text{input}} = (\Delta V) I = (120 \text{ V})(1.75 \text{ A}) = 210 \text{ W} = 0.210 \text{ kW}.$$

At a rate of \$0.06/kWh, the cost of operating this motor for 4.0 h is

$$\begin{aligned} \text{cost} &= (\text{Energy used}) \cdot \text{rate} = (\mathcal{P}_{\text{input}} \cdot t) \cdot \text{rate} \\ &= (0.210 \text{ kW})(4.0 \text{ h})(6.0 \text{ cents/kW h}) = \boxed{5.0 \text{ cents}} \end{aligned}$$

(b) The efficiency is

$$\text{Eff} = \frac{\mathcal{P}_{\text{output}}}{\mathcal{P}_{\text{input}}} = \frac{(0.20 \text{ hp})(0.746 \text{ kW/hp})}{0.210 \text{ kW}} = 0.71 \text{ or } \boxed{71\%}$$

**17.41** The total power converted by the clocks is

$$\wp = (2.50 \text{ W})(270 \times 10^6) = 6.75 \times 10^8 \text{ W} ,$$

and the energy used in one hour is

$$E = \wp \cdot t = (6.75 \times 10^8 \text{ W})(3600 \text{ s}) = 2.43 \times 10^{12} \text{ J}.$$

The energy input required from the coal is

$$E_{\text{coal}} = \frac{E}{\text{efficiency}} = \frac{2.43 \times 10^{12} \text{ J}}{0.250} = 9.72 \times 10^{12} \text{ J}$$

The required mass of coal is thus

$$m = \frac{E_{\text{coal}}}{\text{heat of combustion}} = \frac{9.72 \times 10^{12} \text{ J}}{33.0 \times 10^6 \text{ J/kg}} = 2.95 \times 10^5 \text{ kg}$$

$$\text{or } m = (2.95 \times 10^5 \text{ kg}) \left( \frac{1 \text{ metric ton}}{10^3 \text{ kg}} \right) = \boxed{295 \text{ metric tons}}$$

**17.42** (a)  $E = \wp \cdot t = (40.0 \text{ W})(14.0 \text{ d})(24.0 \text{ h/d}) = 1.34 \times 10^4 \text{ W h} = 13.4 \text{ kW h}$

$$\text{cost} = E \cdot (\text{rate}) = (13.4 \text{ kW h})(\$0.120/\text{kW h}) = \boxed{\$1.61}$$

(b)  $E = \wp \cdot t = (0.970 \text{ kW})(3.00 \text{ min})(1 \text{ h}/60 \text{ min}) = 4.85 \times 10^{-2} \text{ kW h}$

$$\text{cost} = E \cdot (\text{rate})$$

$$= (4.85 \times 10^{-2} \text{ kW h})(\$0.120/\text{kW h}) = \$0.00583 = \boxed{0.583 \text{ cents}}$$

(c)  $E = \wp \cdot t = (5.20 \text{ kW})(40.0 \text{ min})(1 \text{ h}/60 \text{ min}) = 3.47 \text{ kW h}$

$$\text{cost} = E \cdot (\text{rate}) = (3.47 \text{ kW h})(\$0.120/\text{kW h}) = \$0.416 = \boxed{41.6 \text{ cents}}$$

$$17.43 \quad E = \phi \cdot t = (0.180 \text{ kW})(21 \text{ h}) \quad \text{and} \quad \text{cost} = E \cdot \text{rate} = (\phi \cdot t)(\$0.0700/\text{kW h}),$$

$$\text{so} \quad \text{cost} = [(0.180 \text{ kW})(21 \text{ h})](\$0.0700/\text{kW h}) = \$0.26 = \boxed{26 \text{ cents}}$$

$$17.44 \quad \text{The energy used was } E = \frac{\text{cost}}{\text{rate}} = \frac{\$200}{\$0.080/\text{kW h}} = 2.5 \times 10^3 \text{ kW h}.$$

The total time the furnace operated was  $t = \frac{E}{\phi} = \frac{2.5 \times 10^3 \text{ kW h}}{24 \text{ kW}} = 104 \text{ h}$ , and since January has 31 days, the average time per day was

$$\text{average daily operation} = \frac{104 \text{ h}}{31 \text{ d}} = \boxed{3.4 \text{ h/d}}$$

17.45 The energy saved is

$$\Delta E = (\phi_{\text{high}} - \phi_{\text{low}}) \cdot t = (40 \text{ W} - 11 \text{ W})(100 \text{ h}) = 2.9 \times 10^3 \text{ W h} = 2.9 \text{ kW h},$$

and the monetary savings is

$$\text{savings} = \Delta E \cdot \text{rate} = (2.9 \text{ kW h})(\$0.080/\text{kW h}) = \$0.23 = \boxed{23 \text{ cents}}$$

$$17.46 \quad \text{The power needed is } \phi = 1500 \frac{\text{kcal}}{\text{h}} \left( \frac{4186 \text{ J}}{1 \text{ kcal}} \right) \left( \frac{1 \text{ h}}{3600 \text{ s}} \right) = 1744 \text{ W},$$

$$\text{so the current required is } I = \frac{\phi}{\Delta V} = \frac{1744 \text{ W}}{110 \text{ V}} = 15.9 \text{ A}$$

Thus, you should use the 20-A fuse.

17.47 The energy that must be added to the water is

$$E = mc(\Delta T) = (200 \text{ kg}) \left( 4186 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}} \right) (80^\circ\text{C} - 15^\circ\text{C}) \left( \frac{1 \text{ kW h}}{3.60 \times 10^6 \text{ J}} \right) = 15 \text{ kW h}$$

$$\text{and the cost is } \text{cost} = E \cdot \text{rate} = (15 \text{ kW h})(\$0.080/\text{kW h}) = \boxed{\$1.2}$$

**17.48** (a) From  $\phi = (\Delta V)^2 / R$ , the resistance of each bulb is

$$R_{dim} = \frac{(\Delta V)^2}{\phi_{dim}} = \frac{(120 \text{ V})^2}{25.0 \text{ W}} = \boxed{576 \Omega} \text{ and}$$

$$R_{bright} = \frac{(\Delta V)^2}{\phi_{bright}} = \frac{(120 \text{ V})^2}{100 \text{ W}} = \boxed{144 \Omega}$$

(b) The current in the dim bulb is

$$I = \frac{\phi_{dim}}{\Delta V} = \frac{25.0 \text{ W}}{120 \text{ V}} = 0.208 \text{ A},$$

so the time for 1.00 C to pass through the bulb is

$$\Delta t = \frac{\Delta Q}{I} = \frac{1.00 \text{ C}}{0.208 \text{ A}} = \boxed{4.80 \text{ s}}$$

When the charge emerges from the bulb, it has low electrical energy

(c) The time for the dim bulb to dissipate 1.00 J of energy is

$$\Delta t = \frac{\Delta E}{\phi_{dim}} = \frac{1.00 \text{ J}}{25.0 \text{ W}} = \boxed{0.0400 \text{ s}}$$

Electrical potential energy is transformed into internal energy and light

(d) In 30.0 days, the energy used by the dim bulb is

$$E = \phi_{dim} \cdot t = (25.0 \text{ W})(30.0 \text{ d})(24.0 \text{ h/d}) = 1.80 \times 10^4 \text{ W h} = 18.0 \text{ kW h}$$

and the cost is  $cost = E \cdot rate = (18.0 \text{ kW h})(\$0.0700/\text{kW h}) = \boxed{\$1.26}$

The electric company sells energy, and the unit cost is

$$unit \text{ cost} = \left( \frac{\$0.0700}{\text{kW h}} \right) \left( \frac{1 \text{ kW h}}{3.60 \times 10^6 \text{ J}} \right) = \boxed{\$1.94 \times 10^{-8} / \text{Joule}}$$



**17.49** From  $\mathcal{P} = (\Delta V)^2 / R$ , the total resistance needed is

$$R = \frac{(\Delta V)^2}{\mathcal{P}} = \frac{(20 \text{ V})^2}{48 \text{ W}} = 8.3 \, \Omega$$

Thus, from  $R = \rho L / A$ , the length of wire required is

$$L = \frac{R \cdot A}{\rho} = \frac{(8.3 \, \Omega)(4.0 \times 10^{-6} \text{ m}^2)}{3.0 \times 10^{-8} \, \Omega \cdot \text{m}} = 1.1 \times 10^3 \text{ m} = \boxed{1.1 \text{ km}}$$

**17.50** (a) The power required by the iron is

$$\mathcal{P} = (\Delta V) I = (120 \text{ V})(6.0 \text{ A}) = 7.2 \times 10^2 \text{ W} ,$$

and the energy transformed in 20 minutes is

$$E = \mathcal{P} \cdot t = \left( 7.2 \times 10^2 \frac{\text{J}}{\text{s}} \right) \left[ (20 \text{ min}) \left( \frac{60 \text{ s}}{1 \text{ min}} \right) \right] = \boxed{8.6 \times 10^5 \text{ J}}$$

(b) The cost of operating the iron for 20 minutes is

$$\text{cost} = E \cdot \text{rate}$$

$$= \left[ (8.6 \times 10^5 \text{ J}) \left( \frac{1 \text{ kW h}}{3.60 \times 10^6 \text{ J}} \right) \right] (\$0.080/\text{kW h}) = \$0.019 = \boxed{1.9 \text{ cents}}$$

**17.51** Ohm's law gives the resistance as  $R = (\Delta V) / I$ . From  $R = \rho L / A$ , the resistivity is given by  $\rho = R \cdot (A / L)$ . The results of these calculations for each of the three wires are summarized in the table below.

$L$ (m)	$R$ ( $\Omega$ )	$\rho$ ( $\Omega \cdot \text{m}$ )
0.540	10.4	$1.41 \times 10^{-6}$
1.028	21.1	$1.50 \times 10^{-6}$
1.543	31.8	$1.50 \times 10^{-6}$

The average value found for the resistivity is

$$\bar{\rho} = \frac{\sum \rho_i}{3} = \boxed{1.47 \times 10^{-6} \Omega \cdot \text{m}}$$

which differs from the value of  $\rho = 150 \times 10^{-8} \Omega \cdot \text{m} = 1.50 \times 10^{-6} \Omega \cdot \text{m}$  given in Table 17.1 by  $\boxed{2.0\%}$ .

**17.52** The resistance of the 4.0 cm length of wire between the feet is

$$R = \frac{\rho L}{A} = \frac{(1.7 \times 10^{-8} \Omega \cdot \text{m})(0.040 \text{ m})}{\pi(0.011 \text{ m})^2} = 1.79 \times 10^{-6} \Omega,$$

so the potential difference is

$$\Delta V = IR = (50 \text{ A})(1.79 \times 10^{-6} \Omega) = 8.9 \times 10^{-5} \text{ V} = \boxed{89 \mu\text{V}}$$

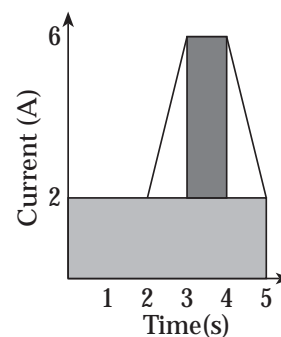
**17.53** The period of the revolving charge is  $T = \frac{2\pi}{\omega} = \frac{2\pi}{100\pi \text{ rad/s}} = 2.00 \times 10^{-2} \text{ s}$ , so the average current is

$$I = \frac{\Delta Q}{\Delta t} = \frac{q}{T} = \frac{8.00 \times 10^{-9} \text{ C}}{2.00 \times 10^{-2} \text{ s}} = 4.00 \times 10^{-7} \text{ A} = \boxed{0.400 \mu\text{A}}$$

**17.54** (a) The charge passing through the conductor in the interval  $0 \leq t \leq 5.0 \text{ s}$  is represented by the area under the  $I$  vs  $t$  graph given in Figure P17.54. This area consists of two rectangles and two triangles. Thus,

$$\begin{aligned} \Delta Q &= A_{\text{rectangle 1}} + A_{\text{rectangle 2}} + A_{\text{triangle 1}} + A_{\text{triangle 2}} \\ &= (5.0 \text{ s} - 0)(2.0 \text{ A} - 0) + (4.0 \text{ s} - 3.0 \text{ s})(6.0 \text{ A} - 2.0 \text{ A}) \\ &\quad + \frac{1}{2}(3.0 \text{ s} - 2.0 \text{ s})(6.0 \text{ A} - 2.0 \text{ A}) + \frac{1}{2}(5.0 \text{ s} - 4.0 \text{ s})(6.0 \text{ A} - 2.0 \text{ A}) \end{aligned}$$

$$\Delta Q = \boxed{18 \text{ C}}$$



(b) The constant current that would pass the same charge in 5.0 s is

$$I = \frac{\Delta Q}{\Delta t} = \frac{18 \text{ C}}{5.0 \text{ s}} = \boxed{3.6 \text{ A}}$$

17.55 (a) From  $\phi = (\Delta V)I$ , the current is  $I = \frac{\phi}{\Delta V} = \frac{8.00 \times 10^3 \text{ W}}{12.0 \text{ V}} = \boxed{667 \text{ A}}$

(b) The time before the stored energy is depleted is

$$t = \frac{E_{\text{storage}}}{\phi} = \frac{2.00 \times 10^7 \text{ J}}{8.00 \times 10^3 \text{ J/s}} = 2.50 \times 10^3 \text{ s}$$

Thus, the distance traveled is

$$d = v \cdot t = (20.0 \text{ m/s})(2.50 \times 10^3 \text{ s}) = 5.00 \times 10^4 \text{ m} = \boxed{50.0 \text{ km}}$$

17.56 The volume of aluminum available is

$$V = \frac{\text{mass}}{\text{density}} = \frac{115 \times 10^{-3} \text{ kg}}{2.70 \times 10^3 \text{ kg/m}^3} = 4.26 \times 10^{-5} \text{ m}^3$$

(a) For a cylinder whose height equals the diameter, the volume is

$$V = \left( \frac{\pi d^2}{4} \right) d = \frac{\pi d^3}{4},$$

and the diameter is  $d = \left( \frac{4V}{\pi} \right)^{1/3} = \left[ \frac{4(4.26 \times 10^{-5} \text{ m}^3)}{\pi} \right]^{1/3} = 0.03785 \text{ m}$

The resistance between ends is then

$$R = \frac{\rho L}{A} = \frac{\rho d}{(\pi d^2/4)} = \frac{4\rho}{\pi d} = \frac{4(2.82 \times 10^{-8} \Omega \cdot \text{m})}{\pi(0.03785 \text{ m})} = \boxed{9.49 \times 10^{-7} \Omega}$$

(b) For a cube,  $V = L^3$ , so the length of an edge is

$$L = (V)^{1/3} = (4.26 \times 10^{-5} \text{ m}^3)^{1/3} = 0.0349 \text{ m}$$

The resistance between opposite faces is

$$R = \frac{\rho L}{A} = \frac{\rho L}{L^2} = \frac{\rho}{L} = \frac{2.82 \times 10^{-8} \Omega \cdot \text{m}}{0.0349 \text{ m}} = \boxed{8.07 \times 10^{-7} \Omega}$$

**17.57** The current in the wire is  $I = \frac{\Delta V}{R} = \frac{15.0 \text{ V}}{0.100 \Omega} = 150 \text{ A}$

Then, from  $v_d = I/nqA$ , the density of free electrons is

$$n = \frac{I}{v_d e (\pi r^2)} = \frac{150 \text{ A}}{(3.17 \times 10^{-4} \text{ m/s})(1.60 \times 10^{-19} \text{ C})\pi(5.00 \times 10^{-3} \text{ m})^2},$$

or  $n = \boxed{3.77 \times 10^{28} / \text{m}^3}$

**17.58** At temperature  $T$ , the resistance of the carbon wire is  $R_c = R_{0c}[1 + \alpha_c(T - T_0)]$ , and that of the nichrome wire is  $R_n = R_{0n}[1 + \alpha_n(T - T_0)]$ . When the wires are connected end to end, the total resistance is

$$R = R_c + R_n = (R_{0c} + R_{0n}) + (R_{0c}\alpha_c + R_{0n}\alpha_n)(T - T_0)$$

If this is to have a constant value of  $10.0 \text{ k}\Omega$  as the temperature changes, it is necessary that

$$R_{0c} + R_{0n} = 10.0 \text{ k}\Omega \quad (1)$$

and  $R_{0c}\alpha_c + R_{0n}\alpha_n = 0 \quad (2)$

From equation (1),  $R_{0c} = 10.0 \text{ k}\Omega - R_{0n}$ , and substituting into equation (2) gives

$$(10.0 \text{ k}\Omega - R_{0n})[-0.50 \times 10^{-3} (\text{°C})^{-1}] + R_{0n}[0.40 \times 10^{-3} (\text{°C})^{-1}] = 0$$

Solving this equation gives  $R_{0n} = \boxed{5.6 \text{ k}\Omega \text{ (nichrome wire)}}$

Then,  $R_{0c} = 10.0 \text{ k}\Omega - 5.6 \text{ k}\Omega = \boxed{4.4 \text{ k}\Omega \text{ (carbon wire)}}$

**17.59** (a) From  $\phi = \frac{(\Delta V)^2}{R}$ , the resistance is  $R = \frac{(\Delta V)^2}{\phi} = \frac{(120 \text{ V})^2}{100 \text{ W}} = 144 \Omega$

(b) Solving  $R = \frac{\rho L}{A}$  for the length gives

$$L = \frac{R \cdot A}{\rho} = \frac{(144 \Omega)(0.010 \text{ m}^2)}{5.6 \times 10^{-8} \Omega \cdot \text{m}} \left( \frac{1 \text{ m}^2}{10^6 \text{ m}^2} \right) = 26 \text{ m}$$

(c) The filament is tightly coiled to fit the required length into a small space

(d) From  $L = L_0[1 + \alpha(T - T_0)]$ , where  $\alpha = 4.5 \times 10^{-6} (\text{°C})^{-1}$ , the length at  $T_0 = 20^\circ\text{C}$  is

$$L_0 = \frac{L}{1 + \alpha(T - T_0)} = \frac{26 \text{ m}}{1 + (4.5 \times 10^{-6} (\text{°C})^{-1})(2600^\circ\text{C} - 20^\circ\text{C})} = \boxed{25 \text{ m}}$$

**17.60** Each speaker has a resistance of  $R = 4.00 \, \Omega$  and can handle  $60.0 \text{ W}$  of power. From  $\mathcal{P} = I^2 R$ , the maximum safe current is

$$I_{\max} = \sqrt{\frac{\mathcal{P}}{R}} = \sqrt{\frac{60.0 \text{ W}}{4.00 \, \Omega}} = 3.87 \text{ A}$$

Thus, the system is not adequately protected by a  $4.00 \text{ A}$  fuse.

**17.61** The cross-sectional area of the conducting material is  $A = \pi(r_{\text{outer}}^2 - r_{\text{inner}}^2)$ .

Thus,

$$R = \frac{\rho L}{A} = \frac{(3.5 \times 10^5 \, \Omega \cdot \text{m})(4.0 \times 10^{-2} \text{ m})}{\pi[(1.2 \times 10^{-2} \text{ m})^2 - (0.50 \times 10^{-2} \text{ m})^2]} = 3.7 \times 10^7 \, \Omega = \boxed{37 \text{ M}\, \Omega}$$

**17.62** (a)

$\Delta V$	$I$	$R = \Delta V / I$
$-1.5 \text{ V}$	$-0.30 \times 10^{-5} \text{ A}$	$5.0 \times 10^5 \, \Omega$
$-1.0 \text{ V}$	$-0.20 \times 10^{-5} \text{ A}$	$5.0 \times 10^5 \, \Omega$
$-0.50 \text{ V}$	$-0.10 \times 10^{-5} \text{ A}$	$5.0 \times 10^5 \, \Omega$
$+0.40 \text{ V}$	$+0.010 \text{ A}$	$40 \, \Omega$
$+0.50 \text{ V}$	$+0.020 \text{ A}$	$25 \, \Omega$
$+0.55 \text{ V}$	$+0.040 \text{ A}$	$14 \, \Omega$
$+0.70 \text{ V}$	$+0.072 \text{ A}$	$9.7 \, \Omega$
$+0.75 \text{ V}$	$+0.10 \text{ A}$	$7.5 \, \Omega$

(b) The resistance of the diode is very large when the applied potential difference has one polarity, and is rather small when the potential difference has the opposite polarity.

**17.63** The power the beam delivers to the target is

$$\wp = (\Delta V)I = (4.0 \times 10^6 \text{ V})(25 \times 10^{-3} \text{ A}) = 1.0 \times 10^5 \text{ W}.$$

The mass of cooling water that must flow through the tube each second if the rise in the water temperature is not to exceed  $50^\circ\text{C}$  is found from  $\wp = (\Delta m / \Delta t)c(\Delta T)$  as

$$\frac{\Delta m}{\Delta t} = \frac{\wp}{c(\Delta T)} = \frac{1.0 \times 10^5 \text{ J/s}}{(4186 \text{ J/kg} \cdot ^\circ\text{C})(50^\circ\text{C})} = \boxed{0.48 \text{ kg/s}}$$

**17.64** The volume of the material is

$$V = \frac{\text{mass}}{\text{density}} = \frac{50.0 \text{ g}}{7.86 \text{ g/cm}^3} \left( \frac{1 \text{ m}^3}{10^6 \text{ cm}^3} \right) = 6.36 \times 10^{-6} \text{ m}^3$$

Since  $V = A \cdot L$ , the cross-sectional area of the wire is  $A = V/L$ .

(a) From  $R = \frac{\rho L}{A} = \frac{\rho L}{V/L} = \frac{\rho L^2}{V}$ , the length of the wire is given by

$$L = \sqrt{\frac{R \cdot V}{\rho}} = \sqrt{\frac{(1.5 \Omega)(6.36 \times 10^{-6} \text{ m}^3)}{11 \times 10^{-8} \Omega \cdot \text{m}}} = \boxed{9.3 \text{ m}}$$

(b) The cross-sectional area of the wire is  $A = \frac{\pi d^2}{4} = \frac{V}{L}$ . Thus, the diameter is

$$d = \sqrt{\frac{4V}{\pi L}} = \sqrt{\frac{4(6.36 \times 10^{-6} \text{ m}^3)}{\pi(9.3 \text{ m})}} = 9.3 \times 10^{-4} \text{ m} = \boxed{0.93 \text{ mm}}$$

**17.65** (a) The cross-sectional area of the copper in the hollow tube is

$$A = (\text{circumference}) \cdot (\text{thickness}) = (0.080 \text{ m})(2.0 \times 10^{-3} \text{ m}) = 1.6 \times 10^{-4} \text{ m}^2$$

Thus, the resistance of this tube is

$$R = \frac{\rho L}{A} = \frac{(1.7 \times 10^{-8} \Omega \cdot \text{m})(0.24 \text{ m})}{1.6 \times 10^{-4} \text{ m}^2} = \boxed{2.6 \times 10^{-5} \Omega}$$

(b) The mass may be written as  $m = (\text{density}) \cdot \text{Volume} = (\text{density}) \cdot A \cdot L$ .

From  $R = \rho L / A$ , the cross-sectional area is  $A = \rho L / R$ , so the expression for the mass becomes

$$m = (\text{density}) \cdot \frac{\rho L^2}{R} = (8920 \text{ kg/m}^3) \cdot \frac{(1.7 \times 10^{-8} \Omega \cdot \text{m})(1500 \text{ m})^2}{4.5 \Omega} = \boxed{76 \text{ kg}}$$

**17.66** (a) At temperature  $T$ , the resistance is  $R = \frac{\rho L}{A}$ , where  $\rho = \rho_0 [1 + \alpha(T - T_0)]$ ,

$$L = L_0 [1 + \alpha'(T - T_0)], \text{ and } A = A_0 [1 + \alpha'(T - T_0)]^2 \approx A_0 [1 + 2\alpha'(T - T_0)]$$

Thus,

$$R = \left( \frac{\rho_0 L_0}{A_0} \right) \frac{[1 + \alpha(T - T_0)] \cdot [1 + \alpha'(T - T_0)]}{[1 + 2\alpha'(T - T_0)]} = \boxed{\frac{R_0 [1 + \alpha(T - T_0)] \cdot [1 + \alpha'(T - T_0)]}{[1 + 2\alpha'(T - T_0)]}}$$

$$(b) \quad R_0 = \frac{\rho_0 L_0}{A_0} = \frac{(1.7 \times 10^{-8} \Omega \cdot \text{m})(2.00 \text{ m})}{\pi (0.100 \times 10^{-3})^2} = 1.082 \Omega$$

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

$$R = (1.082 \Omega) [1 + (3.9 \times 10^{-3} / ^\circ\text{C})(80.0^\circ\text{C})] = \boxed{1.420 \Omega}$$

The more complex formula gives

$$R = \frac{(1.420 \Omega) \cdot [1 + (17 \times 10^{-6} / ^\circ\text{C})(80.0^\circ\text{C})]}{[1 + 2(17 \times 10^{-6} / ^\circ\text{C})(80.0^\circ\text{C})]} = \boxed{1.418 \Omega}$$

**Answers to Even Numbered Conceptual Questions**

2. It is a moderate electrical conductor. Its resistivity of  $\rho = 3.5 \times 10^5 \Omega \cdot \text{m}$  falls between that of metallic conductors ( $\sim 10^{-8} \Omega \cdot \text{m}$ ) and good insulators ( $\sim 10^{13} \Omega \cdot \text{m}$  and higher).
4. The number of cars would correspond to charge  $Q$ . The rate of flow of cars past a point would correspond to current.
6. A voltmeter measures potential difference, not resistance. More likely, the instrument applied a known potential difference across the nerve, and measured the current through it. From this information, the resistance could be determined.
8. An electrical shock occurs when your body serves as a conductor between two points having a difference in potential. The concept behind the admonition is to avoid simultaneously touching points that are at different potentials.
10. The knob is connected to a variable resistor. As you increase the magnitude of the resistance in the circuit, the current is reduced and the bulb dims.
12. Superconducting devices are expensive to operate primarily because they must be kept at very low temperatures. As the onset temperature for superconductivity is increased toward room temperature, it becomes easier to accomplish this reduction in temperature. In fact, if room temperature superconductors could be achieved, this requirement would disappear altogether.
14. The amplitude of atomic vibrations increases with temperature, thereby scattering electrons more efficiently.



**Answers to Even Numbered Problems**

2.  $\alpha\omega/2\pi$
4.  $3.75 \times 10^{14}$  electrons/s
6. 159 mA
8.  $1.3 \times 10^{-4}$  m/s
10. 500 mA
12. (a) 1.82 m (b) 0.280 mm
14.  $0.31 \Omega$
16.  $R_0/9$
18. (a)  $2.8 \times 10^8$  A (b)  $1.8 \times 10^7$  A
20.  $1.4 \times 10^3$  °C
22.  $10.8 \Omega$
24.  $30.6^\circ\text{C}$
26.  $1.71 \Omega$
28.  $4.90 \times 10^{-7}$  m<sup>2</sup>
30.  $63.2^\circ\text{C}$
32.  $8.8 \times 10^{18}$  dollars
34. (a) 50 MW (b) 0.071 or 7.1%
36. (a)  $3.2 \times 10^5$  J (b) 18 min
38. (a) 184 W (b)  $461^\circ\text{C}$
40. (a) 5.0 cents (b) 71%
42. (a) \$1.61 (b) 0.583 cents (c) 41.6 cents
44. 3.4 h/d
46. use a 20-A fuse

48. (a)  $576\ \Omega, 144\ \Omega$  (b) 4.80 s, lower potential energy  
 (c) 0.0400 s, converted to internal energy and light  
 (d) \$1.26, energy,  $1.94 \times 10^{-8}\ \text{J}$
50. (a)  $8.6 \times 10^5\ \text{J}$  (b) 1.9 cents
52.  $89\ \mu\text{V}$
54. (a) 18 C (b) 3.6 A
56. (a)  $9.49 \times 10^{-7}\ \Omega$  (b)  $8.07 \times 10^{-7}\ \Omega$
58.  $5.6\ \text{k}\Omega$  (nichrome),  $4.4\ \text{k}\Omega$  (carbon)
60. No. The fuse should be rated at 3.87 A or less.
62. (a)

$\Delta V$	$I$	$R = \Delta V / I$
-1.5 V	$-0.30 \times 10^{-5}\ \text{A}$	$5.0 \times 10^5\ \Omega$
-1.0 V	$-0.20 \times 10^{-5}\ \text{A}$	$5.0 \times 10^5\ \Omega$
-0.50 V	$-0.10 \times 10^{-5}\ \text{A}$	$5.0 \times 10^5\ \Omega$
+0.40 V	+0.010 A	40 $\Omega$
+0.50 V	+0.020 A	25 $\Omega$
+0.55 V	+0.040 A	14 $\Omega$
+0.70 V	+0.072 A	9.7 $\Omega$
+0.75 V	+0.10 A	7.5 $\Omega$

- (b) The resistance of the diode is very large when the applied potential difference has one polarity, and is rather small when the potential difference has the opposite polarity.
64. (a) 9.3 m (b) 0.93 mm
66.  $1.42\ \Omega$  is less precise than  $1.418\ \Omega$