

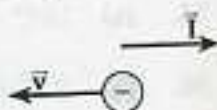
## Problem Solutions

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

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

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

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



- 17.2 The drift speed in a conductor of cross-sectional area  $A$  and carrying current  $I$  is  $v_d = I/nqA$ , where  $n$  is the number of free charge carriers per unit volume and  $q$  is the charge of each of those charge carriers. In the given conductor,

$$v_d = \frac{I}{nqA} = \frac{2.50 \text{ C/s}}{(7.50 \times 10^{28} \text{ m}^{-3})(1.60 \times 10^{-19} \text{ C})(4.00 \times 10^{-6} \text{ m}^2)} = \boxed{5.21 \times 10^{-5} \text{ m/s}}$$

- 17.3 The current is  $I = \frac{\Delta Q}{\Delta t} = \frac{\Delta V}{R}$ . Thus, the charge that passes is  $\Delta Q = \left(\frac{\Delta V}{R}\right)(\Delta t)$ , giving

$$\Delta Q = \left(\frac{1.00 \text{ V}}{10.0 \Omega}\right)(\Delta t) = (0.100 \text{ A})(20.0 \text{ s}) = \boxed{2.00 \text{ C}}$$

- 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

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

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

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

$$\text{or } n = \frac{(6.02 \times 10^{23} / \text{mol}) [(2.7 \text{ g/cm}^3)(10^6 \text{ cm}^3 / 1 \text{ m}^3)]}{26.98 \text{ g/mol}} = 6.0 \times 10^{28} / \text{m}^3$$

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.

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

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

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

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

- 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)  $R = \frac{\Delta V}{I} = \frac{12 \text{ V}}{0.40 \text{ A}} = \boxed{30 \Omega}$

(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 We assume that your hair dryer will use about 400 W of power for 10 minutes each day of the year. The estimate of the total energy used each year is

$$E = \mathcal{P}(\Delta t) = (0.400 \text{ kW}) \left[ \left( 10 \frac{\text{min}}{\text{d}} \right) \left( \frac{1 \text{ hr}}{60 \text{ min}} \right) (365 \text{ d}) \right] = 24 \text{ kWh}$$

If your cost for electrical energy is approximately ten cents per kilowatt-hour, the cost of using the hair dryer for a year is on the order of

$$\text{cost} = E \times \text{rate} = (24 \text{ kWh}) \left( 0.10 \frac{\$}{\text{kWh}} \right) = \$2.4 \quad \text{or} \quad \boxed{\sim \$1}$$

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

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

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

- 17.19 The volume of material,  $V = AL_0 = (\pi r_0^2)L_0$ , in the wire is constant. Thus, as the wire is stretched to decrease its radius, the length increases such that  $(\pi r_f^2)L_f = (\pi r_0^2)L_0$  giving

$$L_f = \left(\frac{r_0}{r_f}\right)^2 L_0 = \left(\frac{r_0}{0.25r_0}\right)^2 L_0 = (4.0)^2 L_0 = 16L_0$$

The new resistance is then

$$R_f = \rho \frac{L_f}{A_f} = \rho \frac{L_f}{\pi r_f^2} = \rho \frac{16L_0}{\pi (r_0/4)^2} = 16(4)^2 \left(\rho \frac{L_0}{\pi r_0^2}\right) = 256R_0 = 256(1.00 \Omega) = \boxed{256 \Omega}$$

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

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

- 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 The expression for the temperature variation of resistance,  $R = R_0[1 + \alpha(T - T_0)]$  with  $T_0 = 20^\circ\text{C}$ , gives the temperature coefficient of resistivity of this material as

$$\alpha = \frac{R - R_0}{R_0(T - T_0)} = \frac{10.55 \Omega - 10.00 \Omega}{(10.00 \Omega)(90^\circ\text{C} - 20^\circ\text{C})} = 7.9 \times 10^{-4} \text{ } ^\circ\text{C}^{-1}$$

Then, at  $T = -20^\circ\text{C}$ , the resistance will be

$$R = R_{20} [1 + \alpha(-20^\circ\text{C} - 20^\circ\text{C})] = (10.00 \Omega) [1 + (7.9 \times 10^{-4} \text{ } ^\circ\text{C}^{-1})(-40^\circ\text{C})] = \boxed{9.7 \Omega}$$

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

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

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

17.24 If  $R = 41.0 \Omega$  at  $T = 20^\circ\text{C}$  and  $R = 41.4 \Omega$  at  $T = 29.0^\circ\text{C}$ , then  $R = R_0 [1 + \alpha(T - T_0)]$  gives the temperature coefficient of resistivity of the material making up this wire as

$$\alpha = \frac{R - R_0}{R_0(T - T_0)} = \frac{41.4 \Omega - 41.0 \Omega}{(41.0 \Omega)(29.0^\circ\text{C} - 20^\circ\text{C})} = \boxed{1.1 \times 10^{-3} \text{ }^\circ\text{C}^{-1}}$$

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

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

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

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

17.26 (a) At  $20^\circ\text{C}$ , the resistance of this copper wire is  $R_0 = \rho(L/A) = \rho(L/\pi r^2)$  and the potential difference required to produce a current of  $I = 3.0 \text{ A}$  is

$$\Delta V_0 = IR_0 = I \left( \rho \frac{L}{\pi r^2} \right) = (3.0 \text{ A})(1.7 \times 10^{-8} \Omega \cdot \text{m}) \frac{(1.00 \text{ m})}{\pi (0.50 \times 10^{-2} \text{ m})^2}$$

or  $\Delta V_0 = 6.5 \times 10^{-3} \text{ V} = \boxed{6.5 \text{ mV}}$

- (b) At  $T = 200^\circ\text{C}$ , the potential difference required to maintain the same current in the copper wire is

$$\Delta V = IR = IR_0[1 + \alpha(T - T_0)] = \Delta V_0[1 + \alpha(T - T_0)]$$

$$\text{or } \Delta V = (0.65 \text{ mV})[1 + (3.9 \times 10^{-3} \text{ }^\circ\text{C}^{-1})(200^\circ\text{C} - 20^\circ\text{C})] = \boxed{1.1 \text{ mV}}$$

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

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

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

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

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

$$= (3.0 \text{ } \Omega)[1 + (3.9 \times 10^{-3} \text{ } (^\circ\text{C})^{-1})(30.0^\circ\text{C} - 20.0^\circ\text{C})] = 3.1 \text{ } \Omega$$

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

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

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

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

$$A = \frac{\rho_0 L}{R}[1 + \alpha(T - T_0)]$$

$$= \frac{(150 \times 10^{-6} \text{ } \Omega \cdot \text{m})(4.00 \text{ m})}{13.7 \text{ } \Omega} [1 + (0.40 \times 10^{-3} \text{ } (^\circ\text{C})^{-1})(320^\circ\text{C} - 20.0^\circ\text{C})]$$

$$A = \boxed{4.90 \times 10^{-7} \text{ m}^2}$$



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

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

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

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

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

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

17.32 (a) The energy used by a 100-W bulb in 24 h is

$$E = \mathcal{P} \cdot \Delta t = (100 \text{ W})(24 \text{ h}) = (0.100 \text{ kW})(24 \text{ h}) = 2.4 \text{ kWh}$$

and the cost of this energy, at a rate of \$0.12 per kilowatt-hour is

$$\text{cost} = E \cdot \text{rate} = (2.4 \text{ kWh})(\$0.12/\text{kWh}) = \boxed{\$0.29}$$

(b) The energy used by the oven in 5.0 h is

$$E = \mathcal{P} \cdot \Delta t = [I(\Delta V)] \cdot \Delta t = \left[ (20.0 \text{ C/s})(220 \text{ J/C}) \left( \frac{1 \text{ kW}}{10^3 \text{ J/s}} \right) \right] (5.0 \text{ h}) = 22 \text{ kWh}$$

and the cost of this energy, at a rate of \$0.12 per kilowatt-hour is

$$\text{cost} = E \cdot \text{rate} = (22 \text{ kWh})(\$0.12/\text{kWh}) = \boxed{\$2.6}$$

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 **18 bulbs** rated at 100 W per bulb.

34 (a) The power loss in the line is

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

(b) The total power transmitted is

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

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

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

7.35 The energy required to bring the water to the boiling point is

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

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

(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

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

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

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

(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

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

and the energy used in one hour is

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

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)  $E = \mathcal{P}t = (40.0 \text{ W})(14.0 \text{ d})(24.0 \text{ h/d}) = 1.34 \times 10^4 \text{ Wh} = 13.4 \text{ kWh}$

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

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

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

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

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

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

17.43  $E = \mathcal{P}t = (0.180 \text{ kW})(21 \text{ h})$  and  $\text{cost} = E \cdot \text{rate} = (\mathcal{P}t)(\$0.0700/\text{kWh})$

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

17.44 The energy used was  $E = \frac{\text{cost}}{\text{rate}} = \frac{\$200}{\$0.080/\text{kWh}} = 2.50 \times 10^3 \text{ kWh}$

The total time the furnace operated was  $t = \frac{E}{\mathcal{P}} = \frac{2.50 \times 10^3 \text{ kWh}}{24.0 \text{ kW}} = 104 \text{ h}$ , and since January has 31 days, the average time per day was

$$\text{average daily operation} = \frac{104 \text{ h}}{31.0 \text{ d}} = \boxed{3.36 \text{ h/d}}$$

17.45 The energy saved is

$$\Delta E = (\mathcal{P}_{\text{high}} - \mathcal{P}_{\text{low}}) \cdot t = (40 \text{ W} - 11 \text{ W})(100 \text{ h}) = 2.9 \times 10^3 \text{ Wh} = 2.9 \text{ kWh}$$

and the monetary savings is

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

17.46 The power required to warm the water to  $100^\circ\text{C}$  in 4.00 min is

$$\mathcal{P} = \frac{\Delta Q}{\Delta t} = \frac{mc(\Delta T)}{\Delta t} = \frac{(0.250 \text{ kg})(4186 \text{ J/kg}\cdot^\circ\text{C})(100^\circ\text{C} - 20^\circ\text{C})}{(4.00 \text{ min})(60 \text{ s/1 min})} = 3.5 \times 10^2 \text{ W}$$

The required resistance (at  $100^\circ\text{C}$ ) of the heating element is then

$$R = \frac{(\Delta V)^2}{\mathcal{P}} = \frac{(120 \text{ V})^2}{3.5 \times 10^2 \text{ W}} = 41 \Omega$$

so the resistance at  $20^\circ\text{C}$  would be

$$R_0 = \frac{R}{1 + \alpha(T - T_0)} = \frac{41 \Omega}{1 + (0.4 \times 10^{-3} \text{ }^\circ\text{C}^{-1})(100^\circ\text{C} - 20^\circ\text{C})} = 40 \Omega$$

We find the needed dimensions of a Nichrome wire for this heating element from  $R_0 = \rho \ell / A = \rho \ell / (\pi d^2 / 4)$ , where  $\ell$  is the length of the wire and  $d$  is its diameter. This

$$\text{gives } 40 \Omega = \left( \frac{4\rho}{\pi} \right) \frac{\ell}{d^2}$$

$$\text{or } d^2 = \left[ \frac{\rho}{\pi(40 \Omega)} \right] \ell = \left[ \frac{150 \times 10^{-8} \Omega \cdot \text{m}}{\pi(40 \Omega)} \right] \ell = (4.8 \times 10^{-8} \text{ m}) \ell$$

Thus,  $\text{any combination of length and diameter satisfying the relation } d^2 = (4.8 \times 10^{-8} \text{ m})\ell$  will be suitable. A typical combination might be

$$\ell = 1.0 \text{ m} \quad \text{and} \quad d = \sqrt{4.8 \times 10^{-8} \text{ m}^2} = 2.2 \times 10^{-4} \text{ m} = 0.22 \text{ mm}$$

Yes, such heating elements could easily be made from less than  $0.5 \text{ cm}^3$  of Nichrome. The volume of material required for the typical wire given above is

$$V = A\ell = (\pi d^2)\ell = \pi (2.2 \times 10^{-4} \text{ m})^2 (1.0 \text{ m}) = (1.5 \times 10^{-7} \text{ m}^3) \left( \frac{10^6 \text{ cm}^3}{1 \text{ m}^3} \right) = 0.15 \text{ cm}^3$$

17.47 The energy that must be added to the water is

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

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

17.48 (a) From  $\mathcal{P} = (\Delta V)^2/R$ , the resistance of each bulb is

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

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

(b) The current in the dim bulb is

$$I = \frac{\mathcal{P}_{\text{dim}}}{\Delta V} = \frac{25.0 \text{ W}}{120 \text{ V}} = 0.208 \text{ A}$$

so the time for  $1.00 \text{ C}$  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 lower potential energy

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

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

Electrical potential energy is **transformed into internal energy and light**

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

$$E = \mathcal{P}_{\text{dim}} \cdot t = (25.0 \text{ W})(30.0 \text{ d})(24.0 \text{ h/d}) = 1.80 \times 10^4 \text{ Wh} = 18.0 \text{ kWh}$$

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

The electric company sells **energy**, and the unit cost is

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

- 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

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

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

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

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

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 (a) The total power you now use while cooking breakfast is

$$P = (1200 + 500) \text{ W} = 1.70 \text{ kW}$$

The cost to use this power for 0.500 h each day for 30.0 days is

$$\text{cost} = [P \times (\Delta t)] \times \text{rate} = \left[ (1.70 \text{ kW}) \left( 0.500 \frac{\text{h}}{\text{day}} \right) (30.0 \text{ days}) \right] (\$0.120/\text{kWh}) = \boxed{\$3.06}$$

- (b) If you upgraded, the new power requirement would be:

$$P = (2400 + 500) \text{ W} = 2900 \text{ W}$$

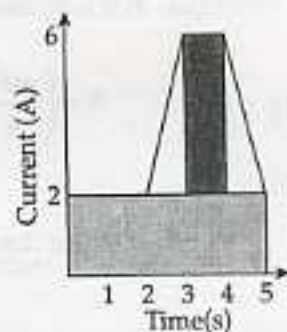
and the required current would be  $I = \frac{P}{\Delta V} = \frac{2900 \text{ W}}{110 \text{ V}} = 26.4 \text{ A} > 20 \text{ A}$

**No**, your present circuit breaker cannot handle the upgrade.

- 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  $\mathcal{P} = (\Delta V)I$ , the current is  $I = \frac{\mathcal{P}}{\Delta V} = \frac{8.00 \times 10^3 \text{ W}}{12.0 \text{ V}} = \boxed{667 \text{ A}}$

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

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

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

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

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

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

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

(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  $\alpha = 4.5 \times 10^{-5} (\text{°C})^{-1}$ , the length at  $T_0 = 20^\circ\text{C}$  is

$$L_0 = \frac{L}{1 + \alpha(T - T_0)} = \frac{26 \text{ m}}{1 + (4.5 \times 10^{-5} (\text{°C})^{-1})(2600^\circ\text{C} - 20^\circ\text{C})} = \boxed{25 \text{ m}}$$

17.60 Each speaker has a resistance of  $R = 4.00 \Omega$  and can handle 60.0 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 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 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.

17.63 The power the beam delivers to the target is

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

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  $\mathcal{P} = (\Delta m/\Delta t)c(\Delta T)$  as

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

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  $\rho = \rho_0 [1 + \alpha(T - T_0)]$ ,  
 $L = L_0 [1 + \alpha'(T - T_0)]$ , and  $A = A_0 [1 + \alpha'(T - T_0)]^2 \approx A_0 [1 + 2\alpha'(T - T_0)]$

Thus,

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

$$(b) R_0 = \frac{\rho_0 L_0}{A_0} = \frac{(1.70 \times 10^{-8} \Omega \cdot \text{m})(2.00 \text{ m})}{\pi(0.100 \times 10^{-2})^2} = 1.082 \Omega$$

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

$$R = (1.082 \Omega) [1 + (3.90 \times 10^{-3} / ^\circ\text{C})(80.0^\circ\text{C})] = \boxed{1.420 \Omega}$$

The more complex formula gives

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

**Note:** Some rules for handling significant figures have been deliberately violated in this solution in order to illustrate the very small difference in the results obtained with these two expressions.

17.67 Note that all potential differences in this solution have a value of  $\Delta V = 120 \text{ V}$ . First, we shall do a symbolic solution for many parts of the problem, and then enter the specified numeric values for the cases of interest.

From the marked specifications on the cleaner, its internal resistance (assumed constant) is

$$R_i = \frac{(\Delta V)^2}{\mathcal{P}_1} \quad \text{where } \mathcal{P}_1 = 535 \text{ W} \quad \text{Equation (1)}$$

If each of the two conductors in the extension cord has resistance  $R_c$ , the total resistance in the path of the current (outside of the power source) is

$$R_t = R_i + 2R_c \quad \text{Equation (2)}$$

so the current which will exist is  $I = \Delta V/R_t$ , and the power that is delivered to the cleaner is

$$\mathcal{P}_{\text{delivered}} = I^2 R_i = \left(\frac{\Delta V}{R_t}\right)^2 R_i = \left(\frac{\Delta V}{R_i + 2R_c}\right)^2 \frac{(\Delta V)^2}{\mathcal{P}_1} = \frac{(\Delta V)^4}{R_i^2 \mathcal{P}_1} \quad \text{Equation (3)}$$

The resistance of a copper conductor of length  $\ell$  and diameter  $d$  is

$$R_c = \rho_{\text{Cu}} \frac{\ell}{A} = \rho_{\text{Cu}} \frac{\ell}{(\pi d^2/4)} = \frac{4\rho_{\text{Cu}} \ell}{\pi d^2}$$

Thus, if  $R_{c, \text{max}}$  is the maximum allowed value of  $R_c$ , the minimum acceptable diameter of the conductor is

$$d_{\text{min}} = \sqrt{\frac{4\rho_{\text{Cu}} \ell}{\pi R_{c, \text{max}}}} \quad \text{Equation (4)}$$

(a) If  $R_i = 0.900 \Omega$ , then from Equations (2) and (1),

$$R_t = R_i + 2(0.900 \Omega) = \frac{(\Delta V)^2}{\mathcal{P}_1} + 1.80 \Omega = \frac{(120 \text{ V})^2}{535 \text{ W}} + 1.80 \Omega$$

and, from Equation (3), the power delivered to the cleaner is

$$\mathcal{P}_{\text{delivered}} = \frac{(120 \text{ V})^4}{\left[\frac{(120 \text{ V})^2}{535 \text{ W}} + 1.80 \Omega\right]^2 (535 \text{ W})} = \boxed{470 \text{ W}}$$



- (b) If the minimum acceptable power delivered to the cleaner is  $\mathcal{P}_{\min}$ , then Equations (2) and (3) give the maximum allowable total resistance as

$$R_{t,\max} = R_i + 2R_{c,\max} = \sqrt{\frac{(\Delta V)^4}{\mathcal{P}_{\min} \mathcal{P}_1}} = \frac{(\Delta V)^2}{\sqrt{\mathcal{P}_{\min} \mathcal{P}_1}}$$

so

$$R_{c,\max} = \frac{1}{2} \left[ \frac{(\Delta V)^2}{\sqrt{\mathcal{P}_{\min} \mathcal{P}_1}} - R_i \right] = \frac{1}{2} \left[ \frac{(\Delta V)^2}{\sqrt{\mathcal{P}_{\min} \mathcal{P}_1}} - \frac{(\Delta V)^2}{\mathcal{P}_1} \right] = \frac{(\Delta V)^2}{2} \left[ \frac{1}{\sqrt{\mathcal{P}_{\min} \mathcal{P}_1}} - \frac{1}{\mathcal{P}_1} \right]$$

$$\text{When } \mathcal{P}_{\min} = 525 \text{ W, then } R_{c,\max} = \frac{(120 \text{ V})^2}{2} \left[ \frac{1}{\sqrt{(525 \text{ W})(535 \text{ W})}} - \frac{1}{535 \text{ W}} \right] = 0.128 \Omega$$

$$\text{and, from Equation (4), } d_{\min} = \sqrt{\frac{4(1.7 \times 10^{-8} \Omega \cdot \text{m})(15.0 \text{ m})}{\pi(0.128 \Omega)}} = \boxed{1.60 \text{ mm}}$$

When  $\mathcal{P}_{\min} = 532 \text{ W}$ , then

$$R_{c,\max} = \frac{(120 \text{ V})^2}{2} \left[ \frac{1}{\sqrt{(532 \text{ W})(535 \text{ W})}} - \frac{1}{535 \text{ W}} \right] = 0.0379 \Omega$$

$$\text{and, } d_{\min} = \sqrt{\frac{4(1.7 \times 10^{-8} \Omega \cdot \text{m})(15.0 \text{ m})}{\pi(0.0379 \Omega)}} = \boxed{2.93 \text{ mm}}$$