Chapter 17
Current and Resistance

Quick Quizzes

1. (d). Negative charges moving in one direction are equivalent to positive charges moving in the opposite direction. Thus, I_a, I_b, I_c, and I_d are equivalent to the movement of 5, 3, 4, and 2 charges respectively, giving $I_d < I_b < I_c < I_a$.

2. (b). Under steady-state conditions, the current is the same in all parts of the wire. Thus, the drift velocity, given by $v_d = I/nqA$, is inversely proportional to the cross-sectional area.

3. (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.

4. (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 ΔV increases, the slope (and hence $1/R$) increases. Thus, the resistance decreases.

5. (b). Consider the expression for resistance: $R = \rho\dfrac{\ell}{A} = \rho\dfrac{\ell}{\pi r^2}$. Doubling all linear dimensions increases the numerator of this expression by a factor of 2, but increases the denominator by a factor of 4. Thus, the net result is that the resistance will be reduced to one-half of its original value.

6. (a). The resistance of the shorter wire is half that of the longer wire. The power dissipated, $\mathcal{P} = (\Delta V)^2/R$, (and hence the rate of heating) will be greater for the shorter wire. Consideration of the expression $\mathcal{P} = I^2R$ 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.

7. (b). $I_a = I_b > I_c = I_d > I_e = I_f$. 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 ΔV is the same across the two bulbs and because the power delivered to a device is $\mathcal{P} = I(\Delta V)$, the 60–W bulb with the higher power rating must carry the greater current, meaning that $I_c > I_e$. 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, $I_f + I_d = I_b$.

8. **(a)** B, **(b)** B. Because the voltage across each resistor is the same, and the rate of energy delivered to a resistor is $\mathcal{P} = (\Delta V)^2 / R$, the resistor with the lower resistance (that is, B) dissipates more power. From Ohm's law, $I = \Delta V / R$. Since the potential difference is the same for the two resistors, B (having the smaller resistance) will carry the greater current.

Answers to Even Numbered Conceptual Questions

2. In the electrostatic case in which charges are stationary, the internal electric field must be zero. A nonzero field would produce a current (by interacting with the free electrons in the conductor), which would violate the condition of static equilibrium. In this chapter we deal with conductors that carry current, a nonelectrostatic situation. The current arises because of a potential difference applied between the ends of the conductor, which produces an internal electric field.

4. The number of cars would correspond to charge Q. The rate of flow of cars past a point would correspond to current.

6. The 25 W bulb has the higher resistance. Because $R = (\Delta V)^2 / \mathcal{P}$, and both operate from 120 V, the bulb dissipating the least power has the higher resistance. The 100 W bulb carries more current, because the current is proportional to the power rating of the bulb.

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. 5.21×10^{-5} m/s

4. 3.75×10^{14} electrons/s

6. 159 mA

8. 1.3×10^{-4} m/s

10. 500 mA

12. **(a)** 1.82 m **(b)** 0.280 mm

14. 0.31 Ω

16. ~ \$1 (Assumes a 400 W dryer used for about 10 min/d with electric energy costing about 10 cents/kWh.)

18. **(a)** 2.8×10^{8} A **(b)** 1.8×10^{7} A

20. 1.4×10^{3} °C

22. 9.7 Ω

24. 1.1×10^{-3} $(°\text{C})^{-1}$

26. **(a)** 0.65 mV **(b)** 1.1 mV

28. 4.90×10^{-7} m^2

30. 63.2°C

32. **(a)** \$0.29 **(b)** \$2.6

34. **(a)** 50 MW **(b)** 0.071 or 7.1%

36. **(a)** 3.2×10^{5} J **(b)** 18 min

38. **(a)** 184 W **(b)** 461°C

40. **(a)** 5.0 cents **(b)** 71%

42. **(a)** \$1.61 **(b)** 0.583 cents **(c)** 41.6 cents

44. 3.36 h/d

46. Any diameter d and length ℓ related by $d^2 = \left(4.8\times10^{-8}\text{ m}\right)\ell$, such as $\ell = 1.0\text{ m}$ and $d = 0.22\text{ mm}$. Yes.

48. **(a)** 576 Ω, 144 Ω **(b)** 4.80 s, lower potential energy
(c) 0.040 0 s, converted to internal energy and light
(d) \$1.26, energy, $\$1.94\times10^{-8}/\text{J}$

50. **(a)** $8.6\times10^{5}\text{ J}$ **(b)** 1.9 cents

52. 89 μV

54. **(a)** 18 C **(b)** 3.6 A

56. **(a)** $9.49\times10^{-7}\ \Omega$ **(b)** $8.07\times10^{-7}\ \Omega$

58. 5.6 kΩ (nichrome), 4.4 kΩ (carbon)

60. No. The fuse should be rated at 3.87 A or less.

62. **(a)**

ΔV	I	$R = \Delta V/I$
-1.5 V	-0.30×10^{-5} A	$5.0\times10^{5}\ \Omega$
-1.0 V	-0.20×10^{-5} A	$5.0\times10^{5}\ \Omega$
-0.50 V	-0.10×10^{-5} A	$5.0\times10^{5}\ \Omega$
$+0.40$ V	$+0.010$ A	40 Ω
$+0.50$ V	$+0.020$ A	25 Ω
$+0.55$ V	$+0.040$ A	14 Ω
$+0.70$ V	$+0.072$ A	9.7 Ω
$+0.75$ V	$+0.10$ A	7.5 Ω

(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. **(b)** 1.420 Ω versus 1.418 Ω for the more precise equation

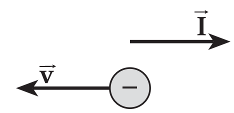
Problem Solutions

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

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

$$= \frac{(80.0\times10^{-3}\ \text{C/s})\left[(10.0\ \text{min})(60.0\ \text{s/min})\right]}{1.60\times10^{-19}\ \text{C}} = \boxed{3.00\times10^{20}\ \text{electrons}}$$

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,

$$v_d = \frac{I}{nqA} = \frac{2.50\ \text{C/s}}{(7.50\times10^{28}\ \text{m}^{-3})(1.60\times10^{-19}\ \text{C})(4.00\times10^{-6}\ \text{m}^2)} = \boxed{5.21\times10^{-5}\ \text{m/s}}$$

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

$$n = \frac{\Delta Q}{|e|} = \frac{I(\Delta t)}{|e|} = \frac{(60.0\times10^{-6}\ \text{C/s})(1.00\ \text{s})}{1.60\times10^{-19}\ \text{C}} = \boxed{3.75\times10^{14}\ \text{electrons}}$$

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

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

$$= \frac{\left(2.19\times10^{6}\ \text{m/s}\right)\left(1.60\times10^{-19}\ \text{C}\right)}{2\pi\left(5.29\times10^{-11}\ \text{m}\right)} = 1.05\times10^{-3}\ \text{C/s} = \boxed{1.05\ \text{mA}}$$

17.6 The mass of a single gold atom is

$$m_{atom} = \frac{M}{N_A} = \frac{197\ \text{g/mol}}{6.02\times10^{23}\ \text{atoms/mol}} = 3.27\times10^{-22}\ \text{g} = 3.27\times10^{-25}\ \text{kg}$$

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

$$n = \frac{m}{m_{atom}} = \frac{3.25\times10^{-3}\ \text{kg}}{3.27\times10^{-25}\ \text{kg}} = 9.93\times10^{21}$$

Thus, the current in the cell is

$$I = \frac{\Delta Q}{\Delta t} = \frac{ne}{\Delta t} = \frac{\left(9.93\times10^{21}\right)\left(1.60\times10^{-19}\ \text{C}\right)}{\left(2.78\ \text{h}\right)\left(3\,600\ \text{s/1 h}\right)} = 0.159\ \text{A} = \boxed{159\ \text{mA}}$$

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

$$v_d = \frac{4\left(1\,000\ \text{A}\right)}{\left(8.5\times10^{28}/\text{m}^3\right)\left(1.60\times10^{-19}\ \text{C}\right)\pi\left(0.020\ \text{m}\right)^2} = 2.3\times10^{-4}\ \text{m/s}$$

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

$$\Delta t = \frac{L}{v_d} = \frac{200\times10^{3}\ \text{m}}{2.34\times10^{-4}\ \text{m/s}}\left(\frac{1\ \text{yr}}{3.156\times10^{7}\ \text{s}}\right) = \boxed{27\ \text{yr}}$$

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

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

or $$n = \frac{\left(6.02\times10^{23}/\text{mol}\right)\left[\left(2.7\ \text{g/cm}^3\right)\left(10^6\ \text{cm}^3/1\ \text{m}^3\right)\right]}{26.98\ \text{g/mol}} = 6.0\times10^{28}/\text{m}^3$$

The drift speed of the electrons in the wire is then

$$v_d = \frac{I}{n|e|A} = \frac{5.0\ \text{C/s}}{\left(6.0\times10^{28}/\text{m}^3\right)\left(1.60\times10^{-19}\ \text{C}\right)\left(4.0\times10^{-6}\ \text{m}^2\right)} = \boxed{1.3\times10^{-4}\ \text{m/s}}$$

17.9 (a) The carrier density is determined by the physical characteristics of the wire, not the current in the wire. Hence, n is $\boxed{\text{unaffected}}$.

(b) The drift velocity of the electrons is $v_d = I/nqA$. Thus, the drift velocity is $\boxed{\text{doubled}}$ when the current is doubled.

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

17.11 $(\Delta V)_{\text{max}} = I_{\text{max}} R = \left(80\times10^{-6}\ \text{A}\right)R$

Thus, if $R = 4.0\times10^5\ \Omega$, $(\Delta V)_{\text{max}} = \boxed{32\ \text{V}}$

and if $R = 2\,000\ \Omega$, $(\Delta V)_{\text{max}} = \boxed{0.16\ \text{V}}$

17.12 The volume of the copper is

$$V = \frac{m}{\textit{density}} = \frac{1.00\times10^{-3}\ \text{kg}}{8.92\times10^3\ \text{kg/m}^3} = 1.12\times10^{-7}\ \text{m}^3$$

Since, $V = A\cdot L$, this gives $A\cdot L = 1.12\times10^{-7}\ \text{m}^3$ (1)

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

$$A = \left(\frac{\rho}{R}\right)L = \left(\frac{1.70\times10^{-8}\ \Omega\cdot\text{m}}{0.500\ \Omega}\right)L = \left(3.40\times10^{-8}\ \text{m}\right)L$$

Inserting this expression for A into equation (1) gives

$\left(3.40\times10^{-8}\ \text{m}\right)L^2 = 1.12\times10^{-7}\ \text{m}^3$, which yields $L = \boxed{1.82\ \text{m}}$

(b) From equation (1), $A = \dfrac{\pi d^2}{4} = \dfrac{1.12\times10^{-7}\ \text{m}^3}{L}$, or

$$d = \sqrt{\frac{4\left(1.12\times10^{-7}\ \text{m}^3\right)}{\pi L}} = \sqrt{\frac{4\left(1.12\times10^{-7}\ \text{m}^3\right)}{\pi(1.82\ \text{m})}}$$

$$= 2.80\times10^{-4}\ \text{m} = \boxed{0.280\ \text{mm}}$$

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

$$d = \sqrt{\frac{4\rho L}{\pi R}} = \sqrt{\frac{4\left(5.6\times10^{-8}\ \Omega\cdot\text{m}\right)\left(2.0\times10^{-2}\ \text{m}\right)}{\pi(0.050\ \Omega)}} = 1.7\times10^{-4}\ \text{m} = \boxed{0.17\ \text{mm}}$$

17.14 $R = \dfrac{\rho L}{A} = \dfrac{\rho L}{\pi d^2/4} = \dfrac{4\left(1.7\times10^{-8}\ \Omega\cdot\text{m}\right)(15\ \text{m})}{\pi\left(1.024\times10^{-3}\ \text{m}\right)^2} = \boxed{0.31\ \Omega}$

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

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

$$\rho = \frac{R\cdot A}{L} = \frac{(30\ \Omega)\left[\pi\left(0.40\times10^{-2}\ \text{m}\right)^2\right]}{3.2\ \text{m}} = \boxed{4.7\times10^{-4}\ \Omega\cdot\text{m}}$$

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

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

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

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

Thus, the metal is seen to be $\boxed{\text{silver}}$.

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

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

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

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

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

$$T = T_0 + \frac{R - R_0}{\alpha R_0} = 20°\text{C} + \frac{140\ \Omega - 19\ \Omega}{\left[4.5\times10^{-3}\ (°\text{C})^{-1}\right](19\ \Omega)} = \boxed{1.4\times10^3\ °\text{C}}$$

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

$$I_f = I_i\left(\frac{R_i}{R_f}\right) = I_i\left(\frac{R_0\left[1+\alpha\left(T_i - T_0\right)\right]}{R_0\left[1+\alpha\left(T_f - T_0\right)\right]}\right)$$

$$= (1.00\ \text{A})\left(\frac{1+\left[3.90\times10^{-3}\ (°\text{C})^{-1}\right](58.0°\text{C} - 20.0°\text{C})}{1+\left[3.90\times10^{-3}\ (°\text{C})^{-1}\right](-88.0°\text{C} - 20.0°\text{C})}\right) = \boxed{1.98\ \text{A}}$$

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

$$\alpha = \frac{R - R_0}{R_0\left(T - T_0\right)} = \frac{10.55\ \Omega - 10.00\ \Omega}{(10.00\ \Omega)(90°\text{C} - 20°\text{C})} = 7.9\times10^{-4}\ °\text{C}^{-1}$$

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

$$R = R_{20}\left[1+\alpha\left(-20°\text{C} - 20°\text{C}\right)\right] = (10.00\ \Omega)\left[1+\left(7.9\times10^{-4}\ °\text{C}^{-1}\right)(-40°\text{C})\right] = \boxed{9.7\ \Omega}$$

17.23 At 80°C,

$$I = \frac{\Delta V}{R} = \frac{\Delta V}{R_0\left[1+\alpha\left(T-T_0\right)\right]} = \frac{5.0 \text{ V}}{(200\ \Omega)\left[1+\left(-0.5\times10^{-3}\ {}^\circ\text{C}^{-1}\right)(80^\circ\text{C}-20^\circ\text{C})\right]}$$

or $$I = 2.6\times10^{-2}\text{ A} = \boxed{26\text{ mA}}$$

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 $R = R_0\left[1+\alpha\left(T-T_0\right)\right]$ gives the temperature coefficient of resistivity of the material making up this wire as

$$\alpha = \frac{R-R_0}{R_0\left(T-T_0\right)} = \frac{41.4\ \Omega - 41.0\ \Omega}{(41.0\ \Omega)(29.0^\circ\text{C}-20^\circ\text{C})} = \boxed{1.1\times10^{-3}\ \left(^\circ\text{C}\right)^{-1}}$$

17.25 $$R_0 = \frac{\rho L}{A} = \frac{\left(1.7\times10^{-8}\ \Omega\cdot\text{m}\right)(10.0\text{ m})}{3.00\times10^{-6}\text{ m}^2} = 5.67\times10^{-2}\ \Omega$$

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

$$R = \left(0.056\,7\ \Omega\right)\left[1+\left(3.9\times10^{-3}\ \left(^\circ\text{C}\right)^{-1}\right)\left(30.0^\circ\text{C}-20.0^\circ\text{C}\right)\right] = \boxed{5.89\times10^{-2}\ \Omega}$$

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

$$R = \left(0.056\,7\ \Omega\right)\left[1+\left(3.9\times10^{-3}\ \left(^\circ\text{C}\right)^{-1}\right)\left(10.0^\circ\text{C}-20.0^\circ\text{C}\right)\right] = \boxed{5.45\times10^{-2}\ \Omega}$$

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

$$\Delta V_0 = IR_0 = I\left(\rho\frac{L}{\pi r^2}\right) = (3.0\text{ A})\left(1.7\times10^{-8}\ \Omega\cdot\text{m}\right)\frac{(1.00\text{ m})}{\pi\left(0.50\times10^{-2}\text{ m}\right)^2}$$

or $$\Delta V_0 = 6.5\times10^{-4}\text{ V} = \boxed{0.65\text{ mV}}$$

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

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

or $$\Delta V = (0.65\text{ mV})\left[1+\left(3.9\times10^{-3}\ °\text{C}^{-1}\right)(200°\text{C}-20°\text{C})\right] = \boxed{1.1\text{ mV}}$$

17.27 (a) The resistance at 20.0°C is

$$R_0 = \rho\frac{L}{A} = \frac{\left(1.7\times10^{-8}\ \Omega\cdot\text{m}\right)(34.5\text{ m})}{\pi\left(0.25\times10^{-3}\text{ m}\right)^2} = 3.0\ \Omega$$

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

(b) At 30.0°C,

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

$$= (3.0\ \Omega)\left[1+\left(3.9\times10^{-3}\ (°\text{C})^{-1}\right)(30.0°\text{C}-20.0°\text{C})\right] = 3.1\ \Omega$$

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

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

$$R = \frac{(\Delta V)^2}{\mathcal{P}} = \frac{(120\text{ V})^2}{1\,050\text{ W}} = 13.7\ \Omega$$

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

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

$$= \frac{\left(150\times10^{-8}\ \Omega\cdot\text{m}\right)(4.00\text{ m})}{13.7\ \Omega}\left[1+\left(0.40\times10^{-3}\ (°\text{C})^{-1}\right)(320°\text{C}-20.0°\text{C})\right]$$

$$A = \boxed{4.90\times10^{-7}\text{ m}^2}$$

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

$$R_i = \frac{\rho L_i}{A_i} = \frac{(9.4\times10^{-7}\ \Omega\cdot\text{m})(1.000\,0\text{ m})}{\pi(1.00\times10^{-3}\text{ m})^2/4} = \boxed{1.2\ \Omega}$$

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

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

$$\Delta = \left(\frac{100.04}{100.00}\right)^2 - 1 = \boxed{8.0\times10^{-4}} \text{ or } \boxed{\text{a } 0.080\% \text{ increase}}$$

17.30 The resistance at 20.0°C is

$$R_0 = \frac{R}{1+\alpha(T-T_0)} = \frac{200.0\ \Omega}{1+\left[3.92\times10^{-3}\ (°\text{C})^{-1}\right](0°\text{C}-20.0°\text{C})} = 217\ \Omega$$

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

$$T = T_0 + \frac{R-R_0}{\alpha R_0} = 20.0°\text{C} + \frac{253.8\ \Omega - 217\ \Omega}{\left[3.92\times10^{-3}\ (°\text{C})^{-1}\right](217\ \Omega)} = \boxed{63.2°\text{C}}$$

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

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

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

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

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

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

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

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

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

$$\mathcal{P}_{\max} = (\Delta V)I_{\max} = (120\ \text{V})(15\ \text{A}) = 1.8\times10^3\ \text{W}$$

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

17.34 (a) The power loss in the line is

$$\mathcal{P}_{loss} = I^2R = (1\,000\ \text{A})^2\left[(0.31\ \Omega/\text{km})(160\ \text{km})\right] = 5.0\times10^7\ \text{W} = \boxed{50\ \text{MW}}$$

(b) The total power transmitted is

$$\mathcal{P}_{input} = (\Delta V)I = (700\times10^3\ \text{V})(1\,000\ \text{A}) = 7.0\times10^8\ \text{W} = 700\ \text{MW}$$

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

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

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

$$E = mc(\Delta T) = (0.500\ \text{kg})(4\,186\ \text{J/kg}\cdot{}^\circ\text{C})(100^\circ\text{C} - 23.0^\circ\text{C}) = 1.61\times10^5\ \text{J}$$

The power input by the heating element is

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

Therefore, the time required is

$$t = \frac{E}{\mathcal{P}_{input}} = \frac{1.61\times10^5\ \text{J}}{240\ \text{J/s}} = 672\ \text{s}\left(\frac{1\ \text{min}}{60\ \text{s}}\right) = \boxed{11.2\ \text{min}}$$

17.36 (a) $E = \mathcal{P} \cdot t = (90\text{ W})(1\text{ h}) = (90\text{ J/s})(3\,600\text{ s}) = \boxed{3.2 \times 10^5\text{ J}}$

(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

$$E = mc(\Delta T) = (1.50\text{ kg})(4\,186\text{ J/kg}\cdot{}^\circ\text{C})(50.0^\circ\text{C} - 10.0^\circ\text{C}) = 2.51 \times 10^5\text{ J}$$

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 $R = R_0\left[1 + \alpha(T - T_0)\right]$, the temperature T is given by $T = T_0 + \dfrac{R - R_0}{\alpha R_0}$. 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

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

17.39 The resistance per unit length of the cable is

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

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

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

17.40 (a) The power input to the motor is

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

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

$$cost = (Energy\ used) \cdot rate = (\mathcal{P}_{input} \cdot t) \cdot rate$$

$$= (0.210 \text{ kW})(4.0 \text{ h})(6.0 \text{ cents/kWh}) = \boxed{5.0 \text{ cents}}$$

(b) The efficiency is

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

17.41 The total power converted by the clocks is

$$\mathcal{P} = (2.50\text{ W})(270\times10^{6}) = 6.75\times10^{8}\text{ W}$$

and the energy used in one hour is

$$E = \mathcal{P}\cdot t = (6.75\times10^{8}\text{ W})(3\,600\text{ s}) = 2.43\times10^{12}\text{ J}$$

The energy input required from the coal is

$$E_{coal} = \frac{E}{efficiency} = \frac{2.43\times10^{12}\text{ J}}{0.250} = 9.72\times10^{12}\text{ J}$$

The required mass of coal is thus

$$m = \frac{E_{coal}}{heat\ of\ combustion} = \frac{9.72\times10^{12}\text{ J}}{33.0\times10^{6}\text{ J/kg}} = 2.95\times10^{5}\text{ kg}$$

or $$m = (2.95\times10^{5}\text{ kg})\left(\frac{1\text{ metric ton}}{10^{3}\text{ kg}}\right) = \boxed{295\text{ metric tons}}$$

17.42 (a) $E = \mathcal{P}\cdot t = (40.0\text{ W})(14.0\text{ d})(24.0\text{ h/d}) = 1.34\times10^{4}\text{ Wh} = 13.4\text{ kWh}$

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

(b) $E = \mathcal{P}\cdot t = (0.970\text{ kW})(3.00\text{ min})(1\text{ h}/60\text{ min}) = 4.85\times10^{-2}\text{ kWh}$

$$cost = E\cdot(rate)$$

$$= (4.85\times10^{-2}\text{ kWh})(\$0.120/\text{kWh}) = \$0.005\,83 = \boxed{0.583\text{ cents}}$$

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

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

17.43 $E = \mathcal{P}\cdot t = (0.180\text{ kW})(21\text{ h})$ and $cost = E\cdot rate = (\mathcal{P}\cdot t)(\$0.070\,0/\text{kWh})$

so $$cost = [(0.180\text{ kW})(21\text{ h})](\$0.070\,0/\text{kWh}) = \$0.26 = \boxed{26\text{ cents}}$$

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

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

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

17.45 The energy saved is

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

and the monetary savings is

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

17.46 The power required to warm the water to 100°C in 4.00 min is

$$\mathcal{P} = \frac{\Delta Q}{\Delta t} = \frac{mc(\Delta T)}{\Delta t} = \frac{(0.250\ \text{kg})(4\,186\ \text{J/kg}\cdot{}^{\circ}\text{C})(100^{\circ}\text{C} - 20^{\circ}\text{C})}{(4.00\ \text{min})(60\ \text{s/1 min})} = 3.5 \times 10^{2}\ \text{W}$$

The required resistance (at 100°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°C would be

$$R_{0} = \frac{R}{1 + \alpha(T - T_{0})} = \frac{41\ \Omega}{1 + \left(0.4 \times 10^{-3}\ {}^{\circ}\text{C}^{-1}\right)(100^{\circ}\text{C} - 20^{\circ}\text{C})} = 40\ \Omega$$

We find the needed dimensions of a Nichrome wire for this heating element from $R_{0} = \rho \ell / A = \rho \ell / \left(\pi d^{2}/4\right)$, where ℓ is the length of the wire and d is its diameter. This gives $40\ \Omega = \left(\frac{4\rho}{\pi}\right)\frac{\ell}{d^{2}}$

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

Thus,

$\boxed{\text{any combination of length and diameter satisfying the relation } d^2 = \left(4.8\times10^{-8}\ \text{m}\right)\ell}$ will be suitable. A typical combination might be

$$\ell = 1.0\ \text{m} \qquad \text{and} \qquad d = \sqrt{4.8\times10^{-8}\ \text{m}^2} = 2.2\times10^{-4}\ \text{m} = 0.22\ \text{mm}$$

$\boxed{\text{Yes}}$, 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

$$V = A\ell = \left(\pi d^2\right)\ell = \pi\left(2.2\times10^{-4}\ \text{m}\right)^2(1.0\ \text{m}) = \left(1.5\times10^{-7}\ \text{m}^3\right)\left(\frac{10^6\ \text{cm}^3}{1\ \text{m}^3}\right) = 0.15\ \text{cm}^3$$

17.47 The energy that must be added to the water is

$$E = mc(\Delta T) = (200\ \text{kg})\left(4\,186\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)(80^\circ\text{C} - 15^\circ\text{C})\left(\frac{1\ \text{kWh}}{3.60\times10^6\ \text{J}}\right) = 15\ \text{kWh}$$

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

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

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

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

(b) The current in the dim bulb is

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

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 $\boxed{\text{lower potential energy}}$

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

$$\Delta t = \frac{\Delta E}{\mathcal{P}_{dim}} = \frac{1.00\text{ J}}{25.0\text{ W}} = \boxed{0.040\,0\text{ s}}$$

Electrical potential energy is $\boxed{\text{transformed into internal energy and light}}$

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

$$E = \mathcal{P}_{dim} \cdot t = (25.0\text{ W})(30.0\text{ d})(24.0\text{ h/d}) = 1.80\times10^4\text{ Wh} = 18.0\text{ kWh}$$

and the cost is $cost = E \cdot rate = (18.0\text{ kWh})(\$0.070\,0/\text{kWh}) = \boxed{\$1.26}$

The electric company sells $\boxed{\text{energy}}$, and the unit cost is

$$unit\ cost = \left(\frac{\$0.070\,0}{\text{kWh}}\right)\left(\frac{1\text{ kWh}}{3.60\times10^6\text{ J}}\right) = \boxed{\$1.94\times10^{-8}/\text{Joule}}$$

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

$$L = \frac{R\cdot A}{\rho} = \frac{(8.3\ \Omega)(4.0\times10^{-6}\text{ m}^2)}{3.0\times10^{-8}\ \Omega\cdot\text{m}} = 1.1\times10^3\text{ m} = \boxed{1.1\text{ km}}$$

17.50 (a) The power required by the iron is

$$\mathcal{P} = (\Delta V)I = (120\text{ V})(6.0\text{ A}) = 7.2\times10^2\text{ W}$$

and the energy transformed in 20 minutes is

$$E = \mathcal{P}\cdot t = \left(7.2\times10^2\ \frac{\text{J}}{\text{s}}\right)\left[(20\text{ min})\left(\frac{60\text{ s}}{1\text{ min}}\right)\right] = \boxed{8.6\times10^5\text{ J}}$$

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

$$cost = E \cdot rate$$

$$= \left[\left(8.6\times10^{5}\ \text{J}\right)\left(\frac{1\ \text{kWh}}{3.60\times10^{6}\ \text{J}}\right)\right]\left(\$0.080/\text{kWh}\right) = \$0.019 = \boxed{1.9\ \text{cents}}$$

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 (Ω)	ρ ($\Omega\cdot$m)
0.540	10.4	1.41×10^{-6}
1.028	21.1	1.50×10^{-6}
1.543	31.8	1.50×10^{-6}

The average value found for the resistivity is

$$\rho_{\text{av}} = \frac{\Sigma\rho_i}{3} = \boxed{1.47\times10^{-6}\ \Omega\cdot\text{m}}$$

which differs from the value of $\rho = 150\times10^{-8}\ \Omega\cdot\text{m} = 1.50\times10^{-6}\ \Omega\cdot\text{m}$ 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

$$R = \frac{\rho L}{A} = \frac{\left(1.7\times10^{-8}\ \Omega\cdot\text{m}\right)(0.040\ \text{m})}{\pi(0.011\ \text{m})^2} = 1.79\times10^{-6}\ \Omega,$$

so the potential difference is

$$\Delta V = IR = (50\ \text{A})\left(1.79\times10^{-6}\ \Omega\right) = 8.9\times10^{-5}\ \text{V} = \boxed{89\ \mu\text{V}}$$

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

$$\mathcal{P} = (1\,200 + 500)\ \text{W} = 1.70\ \text{kW}$$

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

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

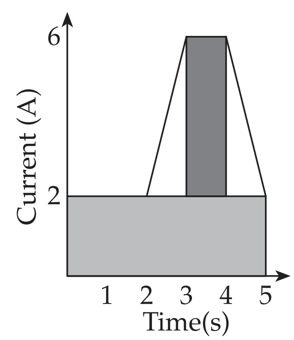
(b) If you upgraded, the new power requirement would be:

$$\mathcal{P} = (2\,400 + 500)\ \text{W=2}\,900\ \text{W}$$

and the required current would be $I = \dfrac{\mathcal{P}}{\Delta V} = \dfrac{2\,900\ \text{W}}{110\ \text{V}} = 26.4\ \text{A} > 20\ \text{A}$

$\boxed{\text{No}}$, your present circuit breaker cannot handle the upgrade.

17.54 (a) The charge passing through the conductor in the interval $0 \le t \le 5.0\ \text{s}$ 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,



$$\Delta Q = A_{rectangle\,1} + A_{rectangle\,2} + A_{triangle\,1} + A_{triangle\,2}$$

$$= (5.0\ \text{s} - 0)(2.0\ \text{A} - 0) + (4.0\ \text{s} - 3.0\ \text{s})(6.0\ \text{A} - 2.0\ \text{A})$$

$$+ \frac{1}{2}(3.0\ \text{s} - 2.0\ \text{s})(6.0\ \text{A} - 2.0\ \text{A}) + \frac{1}{2}(5.0\ \text{s} - 4.0\ \text{s})(6.0\ \text{A} - 2.0\ \text{A})$$

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

(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 $I = \dfrac{\mathcal{P}}{\Delta V} = \dfrac{8.00 \times 10^3 \text{ W}}{12.0 \text{ V}} = \boxed{667 \text{ A}}$

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

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

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

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

(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 $d = \left(\dfrac{4V}{\pi}\right)^{1/3} = \left[\dfrac{4(4.26 \times 10^{-5} \text{ m}^3)}{\pi}\right]^{1/3} = 0.037\,85 \text{ m}$

The resistance between ends is then

$$R = \frac{\rho L}{A} = \frac{\rho d}{(\pi d^2/4)} = \frac{4\rho}{\pi d} = \frac{4(2.82 \times 10^{-8} \ \Omega \cdot \text{m})}{\pi (0.037\,85 \text{ m})} = \boxed{9.49 \times 10^{-7} \ \Omega}$$

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

$$L = (V)^{1/3} = (4.26 \times 10^{-5} \text{ m})^{1/3} = 0.034\,9 \text{ m}$$

The resistance between opposite faces is

$$R = \frac{\rho L}{A} = \frac{\rho L}{L^2} = \frac{\rho}{L} = \frac{2.82 \times 10^{-8} \ \Omega \cdot \text{m}}{0.034\,9 \text{ m}} = \boxed{8.07 \times 10^{-7} \ \Omega}$$

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

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

$$n = \frac{I}{v_d e\left(\pi r^2\right)} = \frac{150 \text{ A}}{\left(3.17\times10^{-4} \text{ m/s}\right)\left(1.60\times10^{-19} \text{ C}\right)\pi\left(5.00\times10^{-3} \text{ m}\right)^2}$$

or $\quad n = \boxed{3.77\times10^{28}/\text{m}^3}$

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

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

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

$$R_{0c} + R_{0n} = 10.0 \text{ k}\Omega \tag{1}$$

and
$$R_{0c}\alpha_c + R_{0n}\alpha_n = 0 \tag{2}$$

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

$$\left(10.0 \text{ k}\Omega - R_{0n}\right)\left[-0.50\times10^{-3}\ (^\circ\text{C})^{-1}\right] + R_{0n}\left[0.40\times10^{-3}\ (^\circ\text{C})^{-1}\right] = 0$$

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

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

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

$$L = \frac{R\cdot A}{\rho} = \frac{(144\ \Omega)\left(0.010 \text{ mm}^2\right)}{5.6\times10^{-8}\ \Omega\cdot\text{m}}\left(\frac{1 \text{ m}^2}{10^6 \text{ mm}^2}\right) = \boxed{26 \text{ m}}$$

(c) The filament is tightly coiled $\boxed{\text{to fit the required length into a small space}}$

(d) From $L = L_0\left[1+\alpha\left(T-T_0\right)\right]$, where $\alpha = 4.5\times10^{-6}\ (°\text{C})^{-1}$, the length at $T_0 = 20°\text{C}$ is

$$L_0 = \frac{L}{1+\alpha\left(T-T_0\right)} = \frac{26\ \text{m}}{1+\left(4.5\times10^{-6}\ (°\text{C})^{-1}\right)\left(2\,600°\text{C}-20°\text{C}\right)} = \boxed{25\ \text{m}}$$

17.60 Each speaker has a resistance of $R = 4.00\ \Omega$ and can handle 60.0 W of power. From $\mathcal{P} = I^2R$, 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 $\boxed{\text{is not adequately protected}}$ by a 4.00 A fuse.

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

Thus,

$$R = \frac{\rho L}{A} = \frac{\left(3.5\times10^{5}\ \Omega\cdot\text{m}\right)\left(4.0\times10^{-2}\ \text{m}\right)}{\pi\left[\left(1.2\times10^{-2}\ \text{m}\right)^2 - \left(0.50\times10^{-2}\ \text{m}\right)^2\right]} = 3.7\times10^{7}\ \Omega = \boxed{37\ \text{M}\Omega}$$

17.62 (a)

ΔV	I	$R = \Delta V/I$
−1.5 V	-0.30×10^{-5} A	$5.0\times10^{5}\ \Omega$
−1.0 V	-0.20×10^{-5} A	$5.0\times10^{5}\ \Omega$
−0.50 V	-0.10×10^{-5} A	$5.0\times10^{5}\ \Omega$
+0.40 V	+0.010 A	40 Ω
+0.50 V	+0.020 A	25 Ω
+0.55 V	+0.040 A	14 Ω
+0.70 V	+0.072 A	9.7 Ω
+0.75 V	+0.10 A	7.5 Ω

(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

$$\mathcal{P} = (\Delta V)I = \left(4.0\times10^{6}\ \text{V}\right)\left(25\times10^{-3}\ \text{A}\right) = 1.0\times10^{5}\ \text{W}$$

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°C is found from $\mathcal{P} = \left(\Delta m/\Delta t\right)c(\Delta T)$ as

$$\frac{\Delta m}{\Delta t} = \frac{\mathcal{P}}{c(\Delta T)} = \frac{1.0\times10^{5}\ \text{J/s}}{(4\,186\ \text{J/kg}\cdot{}^\circ\text{C})(50^\circ\text{C})} = \boxed{0.48\ \text{kg/s}}$$

17.64 The volume of the material is

$$V = \frac{mass}{density} = \frac{50.0\ \text{g}}{7.86\ \text{g/cm}^{3}}\left(\frac{1\ \text{m}^{3}}{10^{6}\ \text{cm}^{3}}\right) = 6.36\times10^{-6}\ \text{m}^{3}$$

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

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

$$L = \sqrt{\frac{R\cdot V}{\rho}} = \sqrt{\frac{(1.5\ \Omega)\left(6.36\times10^{-6}\ \text{m}^{3}\right)}{11\times10^{-8}\ \Omega\cdot\text{m}}} = \boxed{9.3\ \text{m}}$$

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

$$d = \sqrt{\frac{4V}{\pi L}} = \sqrt{\frac{4\left(6.36\times10^{-6}\ \text{m}^{3}\right)}{\pi(9.3\ \text{m})}} = 9.3\times10^{-4}\ \text{m} = \boxed{0.93\ \text{mm}}$$

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

$$A = (circumference)\cdot(thickness) = (0.080\ \text{m})\left(2.0\times10^{-3}\ \text{m}\right) = 1.6\times10^{-4}\ \text{m}^{2}$$

Thus, the resistance of this tube is

$$R = \frac{\rho L}{A} = \frac{\left(1.7\times10^{-8}\ \Omega\cdot\text{m}\right)(0.24\ \text{m})}{1.6\times10^{-4}\ \text{m}^{2}} = \boxed{2.6\times10^{-5}\ \Omega}$$

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

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

$$m = (density)\cdot\frac{\rho L^2}{R} = \left(8\,920\ \text{kg/m}^3\right)\cdot\frac{\left(1.7\times10^{-8}\ \Omega\cdot\text{m}\right)\left(1\,500\ \text{m}\right)^2}{4.5\ \Omega} = \boxed{76\ \text{kg}}$$

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

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

Thus,

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

(b) $$R_0 = \frac{\rho_0 L_0}{A_0} = \frac{\left(1.70\times10^{-8}\ \Omega\cdot\text{m}\right)\left(2.00\ \text{m}\right)}{\pi\left(0.100\times10^{-3}\right)^2} = 1.082\ \Omega$$

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

$$R = (1.082\ \Omega)\left[1+\left(3.90\times10^{-3}/^\circ\text{C}\right)(80.0^\circ\text{C})\right] = \boxed{1.420\ \Omega}$$

The more complex formula gives

$$R = \frac{(1.420\ \Omega)\cdot\left[1+\left(17\times10^{-6}/^\circ\text{C}\right)(80.0^\circ\text{C})\right]}{\left[1+2\left(17\times10^{-6}/^\circ\text{C}\right)(80.0^\circ\text{C})\right]} = \boxed{1.418\ \Omega}$$

Note: Some rules for handing 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

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

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

$$R_t = R_i + 2R_c \qquad \textbf{Equation (2)}$$

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

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

The resistance of a copper conductor of length ℓ 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 $R_{c,\max}$ is the maximum allowed value of R_c, the minimum acceptable diameter of the conductor is

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

(a) If $R_c = 0.900\ \Omega$, 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

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

(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

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

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

and, from Equation (4), $d_{\min} = \sqrt{\dfrac{4\left(1.7\times10^{-8}\ \Omega\cdot\text{m}\right)(15.0\text{ m})}{\pi(0.128\ \Omega)}} = \boxed{1.60\text{ mm}}$

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

$$R_{c,\,\max} = \frac{(120\text{ V})^2}{2}\left[\frac{1}{\sqrt{(532\text{ W})(535\text{ W})}} - \frac{1}{535\text{ W}}\right] = 0.037\,9\ \Omega$$

and, $\qquad d_{\min} = \sqrt{\dfrac{4\left(1.7\times10^{-8}\ \Omega\cdot\text{m}\right)(15.0\text{ m})}{\pi(0.037\,9\ \Omega)}} = \boxed{2.93\text{ mm}}$