CHAPTER 18: Electric Currents

Answers to Questions

1. Ampere-hours measures charge. The ampere is a charge per unit time, and the hour is a time, so the product is charge. 1 Ampere-hour of charge is 3600 Coulombs of charge.

2. In the circuit (not in the battery), electrons flow from high potential energy (at the negative terminal) to low potential energy (at the positive terminal). Inside the battery, the chemical reaction does work on the electrons to take them from low potential energy to high potential energy (to the negative terminal). A more chemical description says that the chemical reaction taking place at the negative electrode leaves electrons behind on the terminal, and the positive ions created at the negative electrode pull electrons off the positive electrode.

3. Battery energy is what is being "used up". As charges leave the battery terminal, they have a relatively high potential energy. Then as the charges move through the flashlight bulb, they lose potential energy. The battery uses a chemical reaction to replace the potential energy of the charges, by lowering the battery's chemical potential energy. When a battery is "used up", it is unable to give potential energy to charges.

4. The one terminal of the battery (usually the negative one) is connected to the metal chassis, frame, and engine block of the car. This means that all voltages used for electrical devices in the car are measured with respect to the car's frame. Also, since the frame is a large mass of metal, it can supply charges for current without significantly changing its electrical potential.

5. Water flows immediately from the spout because there is already water in the spout when you turn on the faucet. Since water is (essentially) incompressible, a push on the water from some distant location (at the valve or pump) causes all the water to move almost immediately, pushing the water out of the spout. In a battery, a similar phenomenon exists in that the wires are "full" of charges (free electrons). The voltage "push" from the battery pushes all the electrons along the wire almost immediately, and the first ones at the other end of the wire are the beginnings of the electric current.

6. Resistance is given by the relationship $R = \rho L/A$. If the ratio of resistivity to area is the same for both the copper wire and the aluminum wire, then the resistances will be the same. Thus if $\rho_{Cu}/A_{Cu} = \rho_{Al}/A_{Al}$ or $A_{Al}/A_{Cu} = \rho_{Al}/\rho_{Cu}$, the resistances will be the same.

   Also, resistance changes with temperature. By having the two wires at different temperatures, it might be possible to have their resistance the same.

7. We assume that the voltage is the same in both cases. Then if the resistance increases, the power delivered to the heater will decrease according to $P = V^2/R$. If the power decreases, the heating process will slow down.

8. Resistance is given by the relationship $R = \rho L/A$. Thus, to minimize the resistance, you should have a small length and a large cross-sectional area. Likewise, to maximize the resistance, you should have a large length and a small cross-sectional area.
   (*a*) For the least resistance, connect the wires to the faces that have dimensions of 2*a* by 3*a*, which maximizes the area ($6a^2$) and minimizes the length (*a*).

(*b*) For the greatest resistance, connect the wires to the faces that have dimensions of *a* by 2*a*, which minimizes the area ($2a^2$) and minimizes the length (3*a*).

9. To say that $P = V^2/R$ indicates a decrease in power as resistance increases implies that the voltage is constant. To say that $P = I^2R$ indicates an increase in power as resistance increases implies that the current is constant. Only one of those can be true for any given situation. If the resistance changes and the voltage is constant, then the current must also change. Likewise, if the resistance changes and the current is constant, then the voltage must also change.

10. When a light bulb burns out, its filament burns in two. Since the filament is part of the conducting path for the electricity flowing through the bulb, once the filament is broken, current can no longer flow through the bulb, and so it no longer gives off any light.

11. When a light bulb is first turned on, it will be cool and the filament will have a lower resistance than when it is hot. This lower resistance means that there will be more current through the bulb while it is cool. This momentary high current will make the filament quite hot. If the temperature is too high, the filament will vaporize, and the current will no longer be able to flow in the bulb.

12. Assuming that both light bulbs have the same voltage, then since $P = IV$, the higher power bulb will draw the most current. Likewise assuming that both light bulbs have the same voltage, since $P = V^2/R$, the higher power bulb will have the lower resistance. So the 100 W bulb will draw the most current, and the 75 W bulb will have the higher resistance.

13. Transmission lines have resistance, and therefore will change some electrical energy to thermal energy (heat) as the electrical energy is transmitted. We assume that the resistance of the transmission lines is constant. Then the "lost" power is given by $P_{\text{lost}} = I^2R$, where I is the current carried by the transmission lines. The transmitted power is given by $P_{\text{trans}} = IV$, where V is the voltage across the transmission lines. For a given value of $P_{\text{trans}} = IV$, the higher the voltage is, the lower the current has to be. As the current is decreased, $P_{\text{lost}} = I^2R$ is also decreased, and so there is a lower amount of power lost.

14. The 15-A fuse is blowing because the circuit is carrying more than 15 A of current. The circuit is probably designed to only carry 15 A, and so there might be a "short" or some other malfunction causing the current to exceed 15 A. Replacing the 15-A fuse with a 25-A fuse will allow more current to flow and thus make the wires carrying the current get hotter. A fire might result, or damage to certain kinds of electrical equipment. The blown fuse is a warning that something is wrong with the circuit.

15. At only 10 Hz, the metal filament in the wire will go on and off 20 times per second. (It has a maximum magnitude of current at the maximum current in each direction.) The metal filament has time to cool down and get dim during the low current parts of the cycle, and your eye can detect this. At 50 or 60 Hz, the filament never cools enough to dim significantly.

16. There are several factors which can be considered. As the voltage reverses with each cycle of AC, the potential energy of the electrons is raised again. Thus with each "pass" through the light, the electrons lose their potential energy, and then get it back again. Secondly, the heating of the filament (which causes the light) does not depend on the direction of the current, but only that a current exists, so the light occurs as the electrons move in both directions. Also, at 60 Hz, the current peaks 120

times per second. The small amount of time while the magnitude of the current is small is not long enough for the hot metal filament to cool down, so it stays lit the entire cycle. Finally, the human eye sees anything more rapid than about 20 Hz as continuous, even if it is not. So even if the light was to go dim during part of the cycle, our eyes would not detect it.

17. When the toaster is first turned on, the Nichrome wire is at room temperature. The wire starts to heat up almost immediately. Since the resistance increases with temperature, the resistance will be increasing as the wire heats. Assuming the voltage supplied is constant, then the current will be decreasing as the resistance increases.

18. Current is NOT used up in a resistor. The same current flows into the resistor as flows out of the resistor. If that were not the case, there would be either an increase or decrease in the charge of the resistor, but the resistor actually stays neutral, indicating equal flow in and out. What does get "used up" is potential energy. The charges that come out of a resistor have lower potential energy than the charges that go into the resistor. The amount of energy decrease per unit time is given by I^2R.

19. (*a*) With the batteries connected in series, the voltage across the bulb is higher, and so more current will flow. That will make the bulb glow brighter.
    (*b*) With the batteries connected in parallel, each battery would only have to provide half the total current to light the bulb, meaning that the device could be on longer before the batteries "ran down", as compared to a single battery. Also, if one battery should fail, the other battery can still provide the current to light the bulb.

Solutions to Problems

1. Use the definition of current, Eq. 18-1.

$$I = \frac{\Delta Q}{\Delta t} \quad \rightarrow \quad 1.30\,\text{A} = \frac{1.30\,\text{C}}{\text{s}} \times \frac{1\text{ electron}}{1.60\times10^{-19}\,\text{C}} = \boxed{8.13\times10^{18}\text{ electrons/s}}$$

2. Use the definition of current, Eq. 18-1.

$$I = \frac{\Delta Q}{\Delta t} \quad \rightarrow \quad \Delta Q = I\Delta t = (6.7\,\text{A})(5.0\,\text{h})(3600\,\text{s/h}) = \boxed{1.2\times10^{5}\,\text{C}}$$

3. Use the definition of current, Eq. 18-1.

$$I = \frac{\Delta Q}{\Delta t} = \frac{(1200\text{ ions})(1.60\times10^{-19}\text{ C/ion})}{3.5\times10^{-6}\text{s}} = \boxed{5.5\times10^{-11}\,\text{A}}$$

4. Use Eq. 18-2a for resistance.

$$R = \frac{V}{I} = \frac{120\,\text{V}}{4.2\,\text{A}} = \boxed{29\,\Omega}$$

5. Use Eq. 18-2b for the voltage.

$$V = IR = (0.25\,\text{A})(3800\,\Omega) = \boxed{950\,\text{V}}$$

6. (*a*) Use Eq. 18-2a for resistance.

$$R = \frac{V}{I} = \frac{120\,\text{V}}{7.5\,\text{A}} = \boxed{16\,\Omega}$$

(*b*) Use the definition of current, Eq. 18-1.

$$I = \frac{\Delta Q}{\Delta t} \rightarrow \Delta Q = I\Delta t = (7.5\,\text{A})(15\,\text{min})(60\,\text{s/min}) = \boxed{6.8\times10^{3}\,\text{C}}$$

7. (*a*) Use Eq. 18-2b to find the current.

$$V = IR \rightarrow I = \frac{V}{R} = \frac{240\,\text{V}}{9.6\,\Omega} = \boxed{25\,\text{A}}$$

(*b*) Use the definition of current, Eq. 18-1.

$$I = \frac{\Delta Q}{\Delta t} \rightarrow \Delta Q = I\Delta t = (25\,\text{A})(50\,\text{min})(60\,\text{s/min}) = \boxed{7.5\times10^{4}\,\text{C}}$$

8. Find the current from the voltage and resistance, and then find the number of electrons from the current.

$$V = IR \rightarrow I = \frac{V}{R} = \frac{9.0\,\text{V}}{1.6\,\Omega} = 5.625\,\text{A}$$

$$5.625\,\text{A} = 5.625\frac{\text{C}}{\text{s}} \times \frac{1\text{ electron}}{1.60\times10^{-19}\text{C}} \times \frac{60\,\text{s}}{1\,\text{min}} = \boxed{2.1\times10^{21}\text{ electrons/min}}$$

9. Find the potential difference from the resistance and the current.

$$R = (2.5\times10^{-5}\,\Omega/\text{m})(4.0\times10^{-2}\,\text{m}) = 1.0\times10^{-6}\,\Omega$$

$$V = IR = (2800\,\text{A})(1.0\times10^{-6}\,\Omega) = \boxed{2.8\times10^{-3}\,\text{V}}$$

10. (*a*) If the voltage drops by 15%, and the resistance stays the same, then by Eq. 18-2b, $V = IR$, the current will also drop by 15%.

$$I_{\text{final}} = 0.85 I_{\text{initial}} = 0.85(6.50\,\text{A}) = 5.525\,\text{A} \approx \boxed{5.5\,\text{A}}$$

(*b*) If the resistance drops by 15% (the same as being multiplied by 0.85), and the voltage stays the same, then by Eq. 18-2b, the current must be divided by 0.85.

$$I_{\text{final}} = \frac{I_{\text{initial}}}{0.85} = \frac{6.50\,\text{A}}{0.85} = 7.647\,\text{A} \approx \boxed{7.6\,\text{A}}$$

11. (*a*) Use Eq. 18-2a to find the resistance.

$$R = \frac{V}{I} = \frac{12\,\text{V}}{0.60\,\text{A}} = \boxed{20\,\Omega}$$

(*b*) An amount of charge ΔQ loses a potential energy of $(\Delta Q)V$ as it passes through the resistor. The amount of charge is found from Eq. 18-1.

$$\Delta\text{PE} = (\Delta Q)V = (I\Delta t)V = (0.60\,\text{A})(60\,\text{s})(12\,\text{V}) = \boxed{430\,\text{J}}$$

12. Use Eq. 18-3 to find the diameter, with the area as $A = \pi r^2 = \pi d^2/4$.

$$R = \rho \frac{L}{A} = \rho \frac{4L}{\pi d^2} \rightarrow d = \sqrt{\frac{4L\rho}{\pi R}} = \sqrt{\frac{4(1.00\,\text{m})(5.6\times10^{-8}\,\Omega\bullet\text{m})}{\pi(0.32\,\Omega)}} = \boxed{4.7\times10^{-4}\,\text{m}}$$

13. Use Eq. 18-3 to calculate the resistance, with the area as $A = \pi r^2 = \pi d^2/4$.

$$R = \rho \frac{L}{A} = \rho \frac{4L}{\pi d^2} = (1.68\times10^{-8}\,\Omega\bullet\text{m})\frac{4(3.5\,\text{m})}{\pi(1.5\times10^{-3}\,\text{m})^2} = \boxed{3.3\times10^{-2}\,\Omega}$$

14. Use Eq. 18-3 to calculate the resistances, with the area as $A = \pi r^2 = \pi d^2/4$, and so $R = \rho \frac{L}{A} = \rho \frac{4L}{\pi d^2}$.

$$\frac{R_{\text{Al}}}{R_{\text{Cu}}} = \frac{\rho_{\text{Al}} \frac{4L_{\text{Al}}}{\pi d_{\text{Al}}^2}}{\rho_{\text{Cu}} \frac{4L_{\text{Cu}}}{\pi d_{\text{Cu}}^2}} = \frac{\rho_{\text{Al}} L_{\text{Al}} d_{\text{Cu}}^2}{\rho_{\text{Cu}} L_{\text{Cu}} d_{\text{Al}}^2} = \frac{(2.65\times10^{-8}\,\Omega\bullet\text{m})(10.0\,\text{m})(2.5\,\text{mm})^2}{(1.68\times10^{-8}\,\Omega\bullet\text{m})(20.0\,\text{m})(2.0\,\text{mm})^2} = \boxed{1.2}$$

15. Use Eq. 18-3 to express the resistances, with the area as $A = \pi r^2 = \pi d^2/4$, and so $R = \rho \frac{L}{A} = \rho \frac{4L}{\pi d^2}$.

$$R_{\text{W}} = R_{\text{Cu}} \rightarrow \rho_{\text{W}} \frac{4L}{\pi d_{\text{W}}^2} = \rho_{\text{Cu}} \frac{4L}{\pi d_{\text{Cu}}^2} \rightarrow$$

$$d_{\text{W}} = d_{\text{Cu}} \sqrt{\frac{\rho_{\text{W}}}{\rho_{\text{Cu}}}} = (2.5\,\text{mm})\sqrt{\frac{5.6\times10^{-8}\,\Omega\bullet\text{m}}{1.68\times10^{-8}\,\Omega\bullet\text{m}}} = \boxed{4.6\,\text{mm}}$$

The diameter of the tungsten should be 4.6 mm.

16. Since the resistance is directly proportional to the length, the length of the long piece must be 4.0 times the length of the short piece.

$$L = L_{\text{short}} + L_{\text{long}} = L_{\text{short}} + 4.0L_{\text{short}} = 5.0L_{\text{short}} \rightarrow L_{\text{short}} = 0.20L,\ L_{\text{long}} = 0.80L$$

Make the cut at $\boxed{\text{20\% of the length of the wire}}$.

$$L_{\text{short}} = 0.20L,\ L_{\text{long}} = 0.80L \rightarrow R_{\text{short}} = 0.2R = \boxed{2.0\,\Omega},\ R_{\text{long}} = 0.8R = \boxed{8.0\,\Omega}$$

17. Use Eq. 18-4 multiplied by L/A so that it expresses resistance instead of resistivity.

$$R = R_0\left[1 + \alpha(T - T_0)\right] = 1.15R_0 \rightarrow 1 + \alpha(T - T_0) = 1.15 \rightarrow$$

$$T - T_0 = \frac{0.15}{\alpha} = \frac{0.15}{.0068(\text{C}^\circ)^{-1}} = \boxed{22\,\text{C}^\circ}$$

So raise the temperature by $22\,\text{C}^\circ$ to a final temperature of 42°C.

18. Use Eq. 18-4 for the resistivity.

$$\rho_{\text{T Cu}} = \rho_{\text{0 Cu}}\left[1+\alpha_{\text{Cu}}\left(T-T_0\right)\right] = \rho_{\text{0 W}} \quad \rightarrow$$

$$T = T_0 + \frac{1}{\alpha_{\text{Cu}}}\left(\frac{\rho_{\text{0 W}}}{\rho_{\text{0 Cu}}}-1\right) = 20^{\circ}\text{C} + \frac{1}{0.0068\left(\text{C}^{\circ}\right)^{-1}}\left(\frac{5.6\times10^{-8}\,\Omega\bullet\text{m}}{1.68\times10^{-8}\,\Omega\bullet\text{m}}-1\right) = 363.1^{\circ}\text{C} \approx \boxed{360^{\circ}\text{C}}$$

19. Use Eq. 18-4 multiplied by L/A so that it expresses resistances instead of resistivity.

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

$$T = T_0 + \frac{1}{\alpha}\left(\frac{R}{R_0}-1\right) = 20^{\circ}\text{C} + \frac{1}{0.0060\left(\text{C}^{\circ}\right)^{-1}}\left(\frac{140\,\Omega}{12\,\Omega}-1\right) = 1798^{\circ}\text{C} \approx \boxed{1800^{\circ}\text{C}}$$

20. Calculate the voltage drop by combining Ohm's Law (Eq. 18-2b) with the expression for resistance, Eq. 18-3.

$$V = IR = I\frac{\rho L}{A} = I\frac{4\rho L}{\pi d^2} = \left(12\,\text{A}\right)\frac{4\left(1.68\times10^{-8}\,\Omega\bullet\text{m}\right)\left(26\,\text{m}\right)}{\pi\left(1.628\times10^{-3}\,\text{m}\right)^2} = \boxed{2.5\,\text{V}}$$

21. In each case calculate the resistance by using Eq. 18-3 for resistance.

(a) $$R_x = \frac{\rho L_x}{A_{yz}} = \frac{\left(3.0\times10^{-5}\,\Omega\bullet\text{m}\right)\left(1.0\times10^{-2}\,\text{m}\right)}{\left(2.0\times10^{-2}\,\text{m}\right)\left(4.0\times10^{-2}\,\text{m}\right)} = 3.75\times10^{-4}\,\Omega \approx \boxed{3.8\times10^{-4}\,\Omega}$$

(b) $$R_y = \frac{\rho L_y}{A_{xz}} = \frac{\left(3.0\times10^{-5}\,\Omega\bullet\text{m}\right)\left(2.0\times10^{-2}\,\text{m}\right)}{\left(1.0\times10^{-2}\,\text{m}\right)\left(4.0\times10^{-2}\,\text{m}\right)} = \boxed{1.5\times10^{-3}\,\Omega}$$

(c) $$R_z = \frac{\rho L_z}{A_{xy}} = \frac{\left(3.0\times10^{-5}\,\Omega\bullet\text{m}\right)\left(4.0\times10^{-2}\,\text{m}\right)}{\left(1.0\times10^{-2}\,\text{m}\right)\left(2.0\times10^{-2}\,\text{m}\right)} = \boxed{6.0\times10^{-3}\,\Omega}$$

22. The wires have the same resistance and the same resistivity.

$$R_{\text{long}} = R_{\text{short}} \quad \rightarrow \quad \frac{\rho L_{\text{long}}}{A_1} = \frac{\rho L_{\text{short}}}{A_2} \quad \rightarrow \quad \frac{(4)2L_{\text{short}}}{\pi d_{\text{long}}^2} = \frac{4L_{\text{short}}}{\pi d_{\text{short}}^2} \quad \rightarrow \quad \boxed{\frac{d_{\text{long}}}{d_{\text{short}}} = \sqrt{2}}$$

23. The original resistance is $R_0 = V/I_0$, and the high temperature resistance is $R = V/I$, where the two voltages are the same. The two resistances are related by Eq. 18-4, multiplied by L/A so that it expresses resistance instead of resistivity.

$$R = R_0\left[1+\alpha\left(T-T_0\right)\right] \quad \rightarrow \quad T = T_0 + \frac{1}{\alpha}\left(\frac{R}{R_0}-1\right) = T_0 + \frac{1}{\alpha}\left(\frac{V/I}{V/I_0}-1\right) = T_0 + \frac{1}{\alpha}\left(\frac{I_0}{I}-1\right)$$

$$= 20.0^{\circ}\text{C} + \frac{1}{0.00429\left(\text{C}^{\circ}\right)^{-1}}\left(\frac{0.4212\,\text{A}}{0.3618\,\text{A}}-1\right) = \boxed{58.3^{\circ}\text{C}}$$

24. (*a*) Calculate each resistance separately using Eq. 18-3, and then add the resistances together to find the total resistance.

$$R_{\text{Cu}} = \frac{\rho_{\text{Cu}} L}{A} = \frac{4\rho_{\text{Cu}} L}{\pi d^2} = \frac{4\left(1.68\times10^{-8}\,\Omega\bullet\text{m}\right)\left(5.0\,\text{m}\right)}{\pi\left(1.0\times10^{-3}\,\text{m}\right)^2} = 0.10695\,\Omega$$

$$R_{\text{Al}} = \frac{\rho_{\text{Al}} L}{A} = \frac{4\rho_{\text{Al}} L}{\pi d^2} = \frac{4\left(2.65\times10^{-8}\,\Omega\bullet\text{m}\right)\left(5.0\,\text{m}\right)}{\pi\left(1.0\times10^{-3}\,\text{m}\right)^2} = 0.16870\,\Omega$$

$$R_{\text{total}} = R_{\text{Cu}} + R_{\text{Al}} = 0.10695\,\Omega + 0.16870\,\Omega = 0.27565\,\Omega \approx \boxed{0.28\,\Omega}$$

(*b*) The current through the wire is the voltage divided by the total resistance.

$$I = \frac{V}{R_{\text{total}}} = \frac{85\times10^{-3}\,\text{V}}{0.27565\,\Omega} = 0.30836\,\text{A} \approx \boxed{0.31\,\text{A}}$$

(*c*) For each segment of wire, Ohm's Law is true. Both wires have the current found in (*b*) above.

$$V_{\text{Cu}} = IR_{\text{Cu}} = \left(0.30836\,\text{A}\right)\left(0.10695\,\Omega\right) \approx \boxed{0.033\,\text{V}}$$

$$V_{\text{Al}} = IR_{\text{Al}} = \left(0.30836\,\text{A}\right)\left(0.16870\,\Omega\right) \approx \boxed{0.052\,\text{V}}$$

Notice that the total voltage is 85 mV.

25. The total resistance is to be 4700 ohms $\left(R_{\text{total}}\right)$ at all temperatures. Write each resistance in terms of Eq. 18-4 (with $T_0 = 0^{\circ}\text{C}$), multiplied by L/A to express resistance instead of resistivity.

$$R_{\text{total}} = R_{0\text{C}}\left[1+\alpha_{\text{C}}T\right] + R_{0\text{N}}\left[1+\alpha_{\text{N}}T\right] = R_{0\text{C}} + R_{0\text{C}}\alpha_{\text{C}}T + R_{0\text{N}} + R_{0\text{N}}\alpha_{\text{N}}T$$
$$= R_{0\text{C}} + R_{0\text{N}} + \left(R_{0\text{C}}\alpha_{\text{C}} + R_{0\text{N}}\alpha_{\text{N}}\right)T$$

For the above to be true, the terms with a temperature dependence must cancel, and the terms without a temperature dependence must add to R_{total}. Thus we have two equations in two unknowns.

$$0 = \left(R_{0\text{C}}\alpha_{\text{C}} + R_{0\text{N}}\alpha_{\text{N}}\right)T \;\rightarrow\; R_{0\text{N}} = -\frac{R_{0\text{C}}\alpha_{\text{C}}}{\alpha_{\text{N}}}$$

$$R_{\text{total}} = R_{0\text{C}} + R_{0\text{N}} = R_{0\text{C}} - \frac{R_{0\text{C}}\alpha_{\text{C}}}{\alpha_{\text{N}}} = \frac{R_{0\text{C}}\left(\alpha_{\text{N}} - \alpha_{\text{C}}\right)}{\alpha_{\text{N}}} \;\rightarrow$$

$$R_{0\text{C}} = R_{\text{total}}\frac{\alpha_{\text{N}}}{\left(\alpha_{\text{N}} - \alpha_{\text{C}}\right)} = \left(4700\,\Omega\right)\frac{0.0004\left(\text{C}^{\circ}\right)^{-1}}{0.0004\left(\text{C}^{\circ}\right)^{-1} + 0.0005\left(\text{C}^{\circ}\right)^{-1}} = \boxed{2100\,\Omega}$$

$$R_{0\text{N}} = R_{\text{total}} - R_{0\text{C}} = \boxed{2600\,\Omega}$$

26. Use Eq. 18-6b to find the resistance from the voltage and the power.

$$P = \frac{V^2}{R} \;\rightarrow\; R = \frac{V^2}{P} = \frac{\left(240\,\text{V}\right)^2}{3300\,\text{W}} = \boxed{17\,\Omega}$$

27. Use Eq. 18-5 to find the power from the voltage and the current.

$$P = IV = \left(0.32\,\text{A}\right)\left(3.0\,\text{V}\right) = \boxed{0.96\,\text{W}}$$

28. Use Eq. 18-6b to find the voltage from the power and the resistance.

$$P=\frac{V^2}{R} \quad\rightarrow\quad V=\sqrt{RP}=\sqrt{(2700\,\Omega)(0.25\,\text{W})}=\boxed{26\,\text{V}}$$

29. Use Eq. 18-6b to find the resistance, and Eq. 18-5 to find the current.

(*a*) $$P=\frac{V^2}{R} \quad\rightarrow\quad R=\frac{V^2}{P}=\frac{(120\,\text{V})^2}{75\,\text{W}}=192\,\Omega\approx\boxed{190\,\Omega}$$

$$P=IV \quad\rightarrow\quad I=\frac{P}{V}=\frac{75\,\text{W}}{120\,\text{V}}=0.625\,\text{A}\approx\boxed{0.63\,\text{A}}$$

(*b*) $$P=\frac{V^2}{R} \quad\rightarrow\quad R=\frac{V^2}{P}=\frac{(120\,\text{V})^2}{440\,\text{W}}=32.73\,\Omega\approx\boxed{33\,\Omega}$$

$$P=IV \quad\rightarrow\quad I=\frac{P}{V}=\frac{440\,\text{W}}{120\,\text{V}}=3.667\,\text{A}\approx\boxed{3.7\,\text{A}}$$

30. (*a*) Use Eq. 18-5 to find the current.

$$P=IV \quad\rightarrow\quad I=\frac{P}{V}=\frac{110\,\text{W}}{115\,\text{V}}=\boxed{0.96\,\text{A}}$$

(*b*) Use Eq. 18-6b to find the resistance.

$$P=\frac{V^2}{R} \quad\rightarrow\quad R=\frac{V^2}{P}=\frac{(115\,\text{V})^2}{110\,\text{W}}\approx\boxed{120\,\Omega}$$

31. (*a*) Since $P=\frac{V^2}{R} \rightarrow R=\frac{V^2}{P}$ says that the resistance is inversely proportional to the power for a constant voltage, we predict that the 850 W setting has the higher resistance.

(*b*) $$R=\frac{V^2}{P}=\frac{(120\,\text{V})^2}{850\,\text{W}}=\boxed{17\,\Omega}$$

(*c*) $$R=\frac{V^2}{P}=\frac{(120\,\text{V})^2}{1250\,\text{W}}=\boxed{12\,\Omega}$$

32. The power (and thus the brightness) of the bulb is proportional to the square of the voltage, according to Eq. 18-6a, $P=\frac{V^2}{R}$. Since the resistance is assumed to be constant, if the voltage is cut in half from 240 V to 120V, the power will be reduced by a factor of 4. Thus the bulb will appear only about $\boxed{\text{1/4 as bright}}$ in the United States as in Europe.

$\boxed{33.}$ To find the kWh of energy, multiply the kilowatts of power consumption by the number of hours in operation.

$$\text{Energy}=P(\text{in kW})\,t(\text{in h})=(550\,\text{W})\left(\frac{1\text{kW}}{1000\,\text{W}}\right)(15\,\text{min})\left(\frac{1\,\text{h}}{60\,\text{min}}\right)=0.1375\,\text{kWh}\approx\boxed{0.14\,\text{kWh}}$$

To find the cost of the energy used in a month, multiply times 4 days per week of usage, times 4 weeks per month, times the cost per kWh.

$$\text{Cost} = \left(0.1375\frac{\text{kWh}}{\text{d}}\right)\left(\frac{4\,\text{d}}{1\,\text{week}}\right)\left(\frac{4\,\text{week}}{1\,\text{month}}\right)\left(\frac{9.0\,\text{cents}}{\text{kWh}}\right) \approx \boxed{20\,\text{cents/month}}$$

34. To find the cost of the energy, multiply the kilowatts of power consumption by the number of hours in operation times the cost per kWh.

$$\text{Cost} = (25\,\text{W})\left(\frac{1\,\text{kW}}{1000\,\text{W}}\right)(365\,\text{day})\left(\frac{24\,\text{h}}{1\,\text{day}}\right)\left(\frac{\$0.095}{\text{kWh}}\right) \approx \boxed{\$21}$$

35. (*a*) Calculate the resistance from Eq. 18-2a, and the power from Eq. 18-5.

$$R = \frac{V}{I} = \frac{3.0\,\text{V}}{0.45\,\text{A}} = 6.667\,\Omega \approx \boxed{6.7\,\Omega} \qquad P = IV = (0.45\,\text{A})(3.0\,\text{V}) = 1.35\,\text{W} \approx \boxed{1.4\,\text{W}}$$

(*b*) If four D-cells are used, the voltage will be doubled to 6.0 V. Assuming that the resistance of the bulb stays the same (by ignoring heating effects in the filament), the power that the bulb would need to dissipate is given by Eq. 18-6b, $P = \frac{V^2}{R}$. A doubling of the voltage means the power is increased by a factor of $\boxed{4}$. This should not be tried because the bulb is probably not rated for such a high wattage. The filament in the bulb would probably burn out, and the glass bulb might even explode if the filament burns violently.

36. The A•h rating is the amount of charge that the battery can deliver. The potential energy of the charge is the charge times the voltage.

$$\text{PE} = QV = (85\,\text{A}\bullet\text{h})\left(\frac{3600\,\text{s}}{1\,\text{h}}\right)(12\,\text{V}) = \boxed{3.7\times10^{6}\,\text{J}}$$

37. Each bulb will draw an amount of current found from Eq. 18-5.

$$P = IV \quad\rightarrow\quad I_{\text{bulb}} = \frac{P}{V}$$

The number of bulbs to draw 15 A is the total current divided by the current per bulb.

$$I_{\text{total}} = nI_{\text{bulb}} = n\frac{P}{V} \quad\rightarrow\quad n = \frac{VI_{\text{total}}}{P} = \frac{(120\,\text{V})(15\,\text{A})}{100\,\text{W}} = \boxed{18\text{ bulbs}}$$

38. Find the power dissipated in the cord by Eq. 18-6a, using Eq. 18-3 for the resistance.

$$P = I^2R = I^2\rho\frac{2L}{A} = (15.0\,\text{A})^2\left(1.68\times10^{-8}\,\Omega\bullet\text{m}\right)\frac{8(2.7\,\text{m})}{\pi\left(0.129\times10^{-2}\,\text{m}\right)^2} = \boxed{16\,\text{W}}$$

39. Find the current used to deliver the power in each case, and then find the power dissipated in the resistance at the given current.

$$P = IV \quad\rightarrow\quad I = \frac{P}{V} \qquad P_{\text{dissipated}} = I^2R = \frac{P^2}{V^2}R$$

$$P_{\substack{\text{dissipated}\\12{,}000\,\text{V}}} = \frac{\left(6.20\times10^{5}\,\text{W}\right)^2}{\left(1.2\times10^{4}\,\text{V}\right)^2}(3.0\,\Omega) = 8008\,\text{W}$$

$$P_{\substack{\text{dissipated}\\50,000\,\text{V}}} = \frac{\left(6.20\times10^5\,\text{W}\right)^2}{\left(5\times10^4\,\text{V}\right)^2}\left(3.0\,\Omega\right) = 461\,\text{W} \qquad \text{difference} = 8008\,\text{W} - 461\,\text{W} = \boxed{7.5\times10^3\,\text{W}}$$

40. The water temperature rises by absorbing the heat energy that the electromagnet dissipates. Express both energies in terms of power, which is energy per unit time.

$$P_{\text{electric}} = P_{\substack{\text{to heat}\\\text{water}}} \rightarrow IV = \frac{Q_{\text{heat water}}}{t} = \frac{mc\Delta T}{t} \rightarrow$$

$$\frac{m}{t} = \frac{IV}{c\Delta T} = \frac{\left(17.5\,\text{A}\right)\left(240\,\text{V}\right)}{\left(4186\,\text{J/kg}\bullet{}^{\text{o}}\text{C}\right)\left(7.50\,\text{C}^{\text{o}}\right)} = 0.134\ \text{kg/s} \approx \boxed{0.13\,\text{kg/s}}$$

This is about 134 ml per second.

41. (*a*) By conservation of energy and the efficiency claim, 60% of the electrical power dissipated by the heater must be the rate at which energy is absorbed by the water.

$$0.6P_{\substack{\text{emitted by}\\\text{electromagnet}}} = P_{\substack{\text{absorbed}\\\text{by water}}} \rightarrow 0.6\left(IV\right) = \frac{Q_{\text{heat water}}}{t} = \frac{mc\Delta T}{t} \rightarrow$$

$$I = \frac{mc\Delta T}{0.6Vt} = \frac{\left(0.120\,\text{kg}\right)\left(4186\,\text{J/kg}\right)\left(95^{\text{o}}\text{C} - 25^{\text{o}}\text{C}\right)}{\left(0.6\right)\left(12\,\text{V}\right)\left(480\,\text{s}\right)} = 10.17\,\text{A} \approx \boxed{10\,\text{A}}$$

(*b*) Use Ohm's Law to find the resistance of the heater.

$$V = IR \rightarrow R = \frac{V}{I} = \frac{12\,\text{V}}{10.17\,\text{A}} = \boxed{1.2\,\Omega}$$

42. Use Ohm's law and the relationship between peak and rms values.

$$I_{\text{peak}} = \sqrt{2}I_{\text{rms}} = \sqrt{2}\frac{V_{\text{rms}}}{R} = \sqrt{2}\frac{220\,\text{V}}{2.2\times10^3\,\Omega} = \boxed{0.14\,\text{A}}$$

43. Find the peak current from Ohm's law, and then find the rms current from the relationship between peak and rms values.

$$I_{\text{peak}} = \frac{V_{\text{peak}}}{R} = \frac{180\,\text{V}}{330\,\Omega} = 0.54545\,\text{A} \simeq \boxed{0.55\,\text{A}} \qquad I_{\text{rms}} = I_{\text{peak}}/\sqrt{2} = \left(0.54545\,\text{A}\right)/\sqrt{2} = \boxed{0.39\,\text{A}}$$

44. (*a*) When everything electrical is turned off, no current will be flowing into the house, even though a voltage is being supplied. Since for a given voltage, the more resistance, the lower the current, a zero current corresponds to an infinite resistance.

(b) Assuming that the voltage is 120 V, use Eq. 18-6a to calculate the resistance.

$$P = \frac{V^2}{R} \rightarrow R = \frac{V^2}{P} = \frac{\left(120\,\text{V}\right)^2}{75\,\text{W}} = 192\,\Omega \approx \boxed{1.9\times10^2\,\Omega}$$

45. The power and current can be used to find the peak voltage, and then the rms voltage can be found from the peak voltage.

$$\overline{P} = I_{\text{rms}}V_{\text{rms}} = \frac{I_{\text{peak}}}{\sqrt{2}}V_{\text{rms}} \rightarrow V_{\text{rms}} = \frac{\sqrt{2}\overline{P}}{I_{\text{peak}}} = \frac{\sqrt{2}\left(1500\,\text{W}\right)}{5.4\,\text{A}} = \boxed{3.9\times10^2\,\text{V}}$$

46. Use the average power and rms voltage to calculate the peak voltage and peak current.

(*a*) $V_{\text{peak}} = \sqrt{2}V_{\text{rms}} = \sqrt{2}\left(660\,\text{V}\right) = 933.4\,\text{V} \approx \boxed{9.3\times10^{2}\text{V}}$

(b) $\overline{P} = I_{\text{rms}}V_{\text{rms}} = \dfrac{I_{\text{peak}}}{\sqrt{2}}V_{\text{rms}} \quad\rightarrow\quad I_{\text{peak}} = \dfrac{\sqrt{2}\overline{P}}{V_{\text{rms}}} = \dfrac{\sqrt{2}\left(1800\,\text{W}\right)}{660\,\text{V}} = \boxed{3.9\,\text{A}}$

47. (*a*) We assume that the 3.0 hp is the average power, so the maximum power is twice that, or 6.0 hp, as seen in Figure 18-22.

$$6.0\,\text{hp}\left(\frac{746\,\text{W}}{1\,\text{hp}}\right) = 4476\,\text{W} \approx \boxed{4.5\times10^{3}\text{W}}$$

(*b*) Use the average power and the rms voltage to find the peak current.

$$\overline{P} = I_{\text{rms}}V_{\text{rms}} = \frac{I_{\text{peak}}}{\sqrt{2}}V_{\text{rms}} \quad\rightarrow\quad I_{\text{peak}} = \frac{\sqrt{2}\overline{P}}{V_{\text{rms}}} = \frac{\sqrt{2}\left[\frac{1}{2}\left(4476\,\text{W}\right)\right]}{240\,\text{V}} = \boxed{13\,\text{A}}$$

48. (*a*) The average power used can be found from the resistance and the rms voltage by Eq. 18-9c.

$$\overline{P} = \frac{V_{\text{rms}}^2}{R} = \frac{\left(240\,\text{V}\right)^2}{34\,\Omega} = 1694\,\text{W} \approx \boxed{1.7\times10^{3}\,\text{W}}$$

(*b*) The maximum power is twice the average power, and the minimum power is 0.

$$P_{\text{max}} = 2\overline{P} = 2\left(1694\,\text{W}\right) \approx \boxed{3.4\times10^{3}\text{W}} \qquad P_{\text{min}} = \boxed{0\,\text{W}}$$

49. We follow exactly the derivation in Example 18-14, which results in an expression for the drift velocity.

$$v_{\text{d}} = \frac{I}{neA} = \frac{I}{\dfrac{N\left(1\text{ mole}\right)}{m\left(1\text{ mole}\right)}\rho_{\text{D}}e\pi\left(\frac{1}{2}d\right)^2} = \frac{4I\,m}{N\rho_{\text{D}}e\pi d^2}$$

$$= \frac{4\left(2.3\times10^{-6}\,\text{A}\right)\left(63.5\times10^{-3}\,\text{kg}\right)}{\left(6.02\times10^{23}\right)\left(8.9\times10^{3}\,\text{kg/m}^3\right)\left(1.60\times10^{-19}\,\text{C}\right)\pi\left(0.65\times10^{-3}\,\text{m}\right)^2} = \boxed{5.1\times10^{-10}\,\text{m/s}}$$

50. (a) Use Ohm's Law to find the resistance.

$$V = IR \quad\rightarrow\quad R = \frac{V}{I} = \frac{22.0\times10^{-3}\,\text{V}}{0.75\,\text{A}} = 0.02933\,\Omega \approx \boxed{0.029\,\Omega}$$

(b) Find the resistivity from Eq. 18-3.

$$R = \frac{\rho L}{A} \quad\rightarrow\quad \rho = \frac{RA}{L} = \frac{R\pi r^2}{L} = \frac{\left(0.02933\,\Omega\right)\pi\left(1.0\times10^{-3}\,\text{m}\right)^2}{\left(5.80\,\text{m}\right)} = \boxed{1.6\times10^{-8}\,\Omega\bullet\text{m}}$$

(c) Find the number of electrons per unit volume from Eq. 18-10.

$I = neAv_{\text{d}} \quad\rightarrow$

$$n = \frac{I}{eAv_{\text{d}}} = \frac{I}{e\pi r^2 v_{\text{d}}} = \frac{\left(0.75\,\text{A}\right)}{\left(1.60\times10^{-19}\,\text{C}\right)\pi\left(1.0\times10^{-3}\,\text{m}\right)^2\left(1.7\times10^{-5}\,\text{m/s}\right)} = \boxed{8.8\times10^{28}\,\text{e}^-/\text{m}^3}$$

51. We are given a charge density and a speed (like the drift speed) for both types of ions. From that we can use Eq. 18-10 to determine the current per unit area. Both currents are in the same direction in terms of conventional current – positive charge moving north has the same effect as negative charge moving south – and so they can be added.

$$I = neAv_{\text{d}} \quad \rightarrow$$

$$\frac{I}{A} = \left(nev_{\text{d}}\right)_{\text{He}} + \left(nev_{\text{d}}\right)_{\text{O}} = \left[\left(2.8\times10^{12}\ \text{ions/m}^3\right)2\left(1.60\times10^{-19}\ \text{C/ion}\right)\left(2.0\times10^{6}\ \text{m/s}\right)\right] + \left[\left(7.0\times10^{11}\ \text{ions/m}^3\right)\left(1.60\times10^{-19}\ \text{C/ion}\right)\left(7.2\times10^{6}\ \text{m/s}\right)\right]$$

$$= \boxed{2.6\ \text{A/m}^2\text{, North}}$$

52. The magnitude of the electric field is the voltage change per unit meter.

$$\left|E\right| = \frac{\Delta V}{\Delta x} = \frac{70\times10^{-3}\ \text{V}}{1.0\times10^{-8}\ \text{m}} = \boxed{7.0\times10^{6}\ \text{V/m}}$$

53. The speed is the change in position per unit time.

$$v = \frac{\Delta x}{\Delta t} = \frac{7.20\times10^{-2}\ \text{m} - 3.40\times10^{-2}\ \text{m}}{0.0063\ \text{s} - 0.0052\ \text{s}} = \boxed{35\ \text{m/s}}$$

Two measurements are needed because there may be a time delay from the stimulation of the nerve to the generation of the action potential.

54. The energy required to transmit one pulse is equivalent to the energy stored by charging the axon capacitance to full voltage. In Example 18-15, the capacitance is estimated at $1.0\times10^{-8}\,\text{F}$, and the potential difference is about 0.1 V.

$$E = \tfrac{1}{2}CV^2 = 0.5\left(10^{-8}\,\text{F}\right)\left(0.1\,\text{V}\right)^2 = \boxed{5\times10^{-11}\,\text{J}}$$

The power is the energy per unit time, for 10,000 neutrons transmitting 100 pulses each per second.

$$P = \frac{E}{t} = \frac{\left(5\times10^{-11}\ \text{J/neuron}\right)\left(1.0\times10^{4}\,\text{neurons}\right)}{0.01\text{s}} = \boxed{5\times10^{-5}\,\text{W}}$$

55. The power is the work done per unit time. The work done to move a charge through a potential difference is the charge times the potential difference. The charge density must be multiplied by the surface area of the cell (the surface area of an open tube, length times circumference) to find the actual charge moved.

$$P = \frac{W}{t} = \frac{QV}{t} = \frac{Q}{t}V$$

$$= \left(3\times10^{-7}\ \frac{\text{mol}}{\text{m}^2\bullet\text{s}}\right)\left(6.02\times10^{23}\ \frac{\text{ions}}{\text{mol}}\right)\left(1.6\times10^{-19}\ \frac{\text{C}}{\text{ion}}\right)\left(0.10\,\text{m}\right)\pi\left(20\times10^{-6}\,\text{m}\right)\left(0.030\,\text{V}\right)$$

$$= \boxed{5.4\times10^{-9}\,\text{W}}$$

56. $\left(1.00\text{A}\bullet\text{h}\right)\left(\frac{1\text{C/s}}{1\text{A}}\right)\left(\frac{3600\,\text{s}}{1\ \text{h}}\right) = \boxed{3600\,\text{C}}$

57. Use Eq. 18-5 to calculate the current.

$$P = IV \quad \rightarrow \quad I = \frac{P}{V} = \frac{746\,\text{W}}{120\,\text{V}} = \boxed{6.22\,\text{A}}$$

58. The energy supplied by the battery is the energy consumed by the lights.

$$E_{\text{supplied}} = E_{\text{consumed}} \quad \rightarrow \quad Q\Delta V = Pt \quad \rightarrow$$

$$t = \frac{Q\Delta V}{P} = \frac{(95\,\text{A}\bullet\text{h})(3600\,\text{s/h})(12\,\text{V})}{92\,\text{W}} = 44609\,\text{s}\left(\frac{1\,\text{h}}{3600\,\text{s}}\right) = 12.39\,\text{h} \approx \boxed{12\,\text{h}}$$

59. Use Eq. 18-6 to express the resistance in terms of the power, and Eq. 18-3 to express the resistance in terms of the wire geometry.

$$P = \frac{V^2}{R} \quad \rightarrow \quad R = \frac{V^2}{P} \qquad R = \rho\frac{L}{A} = \rho\frac{L}{\pi r^2} = 4\rho\frac{L}{\pi d^2}$$

$$4\rho\frac{L}{\pi d^2} = \frac{V^2}{P} \quad \rightarrow \quad d = \sqrt{\frac{4\rho LP}{\pi V^2}} = \sqrt{\frac{4(9.71\times10^{-8}\,\Omega\bullet\text{m})(5.4\,\text{m})(1500\,\text{W})}{\pi(110\,\text{V})^2}} = \boxed{2.9\times10^{-4}\,\text{m}}$$

60. From Eq. 18-2a, if $R = V/I$, then $G = I/V$

$$G = \frac{I}{V} = \frac{0.73\,\text{A}}{3.0\,\text{V}} = \boxed{0.24\,\text{S}}$$

61. To deliver 10 MW of power at 120 V requires a current of $I = \frac{P}{V} = \frac{10^7\,\text{W}}{120\,\text{V}} = 83,300\,\text{A}$. Calculate the power dissipated in the resistors using the current and the resistance.

$$P = I^2R = I^2\rho\frac{L}{A} = I^2\rho\frac{L}{\pi r^2} = 4I^2\rho\frac{L}{\pi d^2} = 4(83,300\,\text{A})^2(1.68\times10^{-8}\,\Omega\bullet\text{m})\frac{2(1.0\,\text{m})}{\pi(5.0\times10^{-3}\,\text{m})^2}$$

$$= 1.187\times10^7\,\text{W}$$

$$\text{Cost} = (\text{Power})(\text{time})(\text{rate per kWh}) = (1.187\times10^7\,\text{W})\left(\frac{1\,\text{kW}}{1000\,\text{W}}\right)(1\,\text{h})\left(\frac{\$0.10}{\text{kWh}}\right)$$

$$= \$1187 \approx \boxed{\$1,200 \text{ per hour per meter}}$$

62. (*a*) Calculate the total kWh used per day, and then multiply by the number of days and the cost per kWh.

$$(1.8\,\text{kW})(3.0\,\text{h/d}) + 4(0.1\,\text{kW})(6.0\,\text{h/d}) + (3.0\,\text{kW})(1.4\,\text{h/d}) + (2.0\,\text{kWh/d})$$

$$= 14.0\,\text{kWh/d}$$

$$\text{Cost} = (14.0\,\text{kWh/d})(30\,\text{d})\left(\frac{\$0.105}{\text{kWh}}\right) = \boxed{\$44.10 \text{ per month}}$$

(*b*) The energy required by the household is 35% of the energy that needs to be supplied by the power plant.

$$\text{Household Energy} = 0.35(\text{coal mass})(\text{coal energy per mass}) \rightarrow$$

$$\text{coal mass} = \frac{\text{Household Energy}}{(0.35)(\text{coal energy per mass})} = \frac{(14.0\,\text{kWh/d})(365\,\text{d})\left(\frac{1000\,\text{W}}{\text{kW}}\right)\left(\frac{3600\,\text{s}}{1\,\text{h}}\right)}{(0.35)\left(7000\frac{\text{kcal}}{\text{kg}}\right)\left(\frac{4186\,\text{J}}{1\,\text{kcal}}\right)}$$

$$= 1794\,\text{kg} \approx \boxed{1800\,\text{kg of coal}}$$

63. The length of the new wire is half the length of the original wire, and the cross-sectional area of the new wire is twice that of the original wire. Use Eq. 18-3.

$$R_0 = \rho\frac{L_0}{A_0} \quad L = \tfrac{1}{2}L_0 \quad A = 2A_0 \quad R = \rho\frac{L}{A} = \rho\frac{\tfrac{1}{2}L_0}{2A_0} = \tfrac{1}{4}\rho\frac{L_0}{A_0} = \tfrac{1}{4}R_0$$

The new resistance is $\boxed{\text{one-fourth}}$ of the original resistance.

64. (*a*) Use Eq. 18-6 to relate the power to the voltage for a constant resistance.

$$P = \frac{V^2}{R} \rightarrow \frac{P_{105}}{P_{117}} = \frac{(105\,\text{V})^2/R}{(117\,\text{V})^2/R} = \frac{(105\,\text{V})^2}{(117\,\text{V})^2} = 0.805 \text{ or a } \boxed{19.5\%\text{ decrease}}$$

(*b*) The lower power output means that the resistor is generating less heat, and so the resistor's temperature would be lower. The lower temperature results in a lower value of the resistance, which would increase the power output at the lower voltages. Thus the decrease would be somewhat smaller than the value given in the first part of the problem.

65. Assume that we have a meter of wire, carrying 35 A of current, and dissipating 1.8 W of heat. The power dissipated is $P_R = I^2R$, and the resistance is $R = \frac{\rho L}{A}$.

$$P_R = I^2R = I^2\frac{\rho L}{A} = I^2\frac{\rho L}{\pi r^2} = I^2\frac{4\rho L}{\pi d^2} \rightarrow$$

$$d = \sqrt{I^2\frac{4\rho L}{P_R\pi}} = 2I\sqrt{\frac{\rho L}{P_R\pi}} = 2(35\,\text{A})\sqrt{\frac{(1.68\times10^{-8}\,\Omega\bullet\text{m})(1.0\,\text{m})}{(1.8\,\text{W})\pi}} = \boxed{3.8\times10^{-3}\,\text{m}}$$

66. (*a*) The angular frequency is $\omega = 210\,\text{rad/s}$.

$$f = \frac{\omega}{2\pi} = \frac{210\,\text{rad/s}}{2\pi} = \boxed{33.4\,\text{Hz}}$$

(*b*) The maximum current is 1.80 A.

$$I_{\text{rms}} = \frac{I_{\max}}{\sqrt{2}} = \frac{1.80\,\text{A}}{\sqrt{2}} = \boxed{1.27\,\text{A}}$$

(*c*) For a resistor, $V = IR$.

$$V = IR = (1.80\,\text{A})(\sin 210t)(42.0\,\Omega) = \boxed{(75.6\sin 210t)\,\text{V}}$$

67. (*a*) The power delivered to the interior is 65% of the power drawn from the source.

$$P_{\text{interior}} = 0.65P_{\text{source}} \rightarrow P_{\text{source}} = \frac{P_{\text{interior}}}{0.65} = \frac{950\text{ W}}{0.65} = 1462\text{ W} \approx \boxed{1500\text{ W}}$$

(*b*) The current drawn is current from the source, and so the source power is used to calculate the current.

$$P_{\text{source}} = IV_{\text{source}} \rightarrow I = \frac{P_{\text{source}}}{V_{\text{source}}} = \frac{1462\text{ W}}{120\text{ V}} = 12.18\text{ A} \approx \boxed{12\text{ A}}$$

68. The volume of wire is unchanged by the stretching. The volume is equal to the length of the wire times its cross-sectional area, and so since the length was increased by a factor of 3, the area was decreased by a factor of 3. Use Eq. 18-3.

$$R_0 = \rho\frac{L_0}{A_0} \quad L = 3L_0 \quad A = \tfrac{1}{3}A_0 \quad R = \rho\frac{L}{A} = \rho\frac{3L_0}{\tfrac{1}{3}A_0} = 9\rho\frac{L_0}{A_0} = 9R_0 = \boxed{9.00\,\Omega}$$

69. The long, thick conductor is labeled as conductor number 1, and the short, thin conductor is labeled as number 2. The power transformed by a resistor is given by Eq. 18-6, $P = \frac{V^2}{R}$,and both have the same voltage applied.

$$R_1 = \rho\frac{L_1}{A_1} \quad R_2 = \rho\frac{L_2}{A_2} \quad L_1 = 2L_2 \quad A_1 = 4A_2 \quad (\text{diameter}_1 = 2\text{diameter}_2)$$

$$\frac{P_1}{P_2} = \frac{V_1^2/R_1}{V_2^2/R_2} = \frac{R_2}{R_1} = \frac{\rho\frac{L_2}{A_2}}{\rho\frac{L_1}{A_1}} = \frac{L_2}{L_1}\frac{A_1}{A_2} = \frac{1}{2}\times 4 = 2 \qquad \boxed{P_1 : P_2 = 2:1}$$

70. The heater must heat 124 m^3 of air per hour from 5°C to 20°C, and also replace the heat being lost at a rate of 850 kcal/h. Use Eq. 14-2 to calculate the energy needed to heat the air. The density of air is found in Table 10-1.

$$Q = mc\Delta T \rightarrow \frac{Q}{t} = \frac{m}{t}c\Delta T = \left(124\frac{\text{m}^3}{\text{h}}\right)\left(1.29\frac{\text{kg}}{\text{m}^3}\right)\left(0.17\frac{\text{kcal}}{\text{kg}\bullet\text{C}^\circ}\right)(15\text{C}^\circ) = 408\frac{\text{kcal}}{\text{h}}$$

$$\text{Power required} = 408\frac{\text{kcal}}{\text{h}} + 850\frac{\text{kcal}}{\text{h}} = 1258\frac{\text{kcal}}{\text{h}}\left(\frac{4186\text{ J}}{\text{kcal}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right) = 1463\text{ W} \approx \boxed{1500\text{ W}}$$

71. (*a*) Use Eq. 18-6.

$$P = \frac{V^2}{R} \rightarrow R = \frac{V^2}{P} = \frac{(240\text{ V})^2}{2200\text{ W}} = 26.18\,\Omega \approx \boxed{26\,\Omega}$$

(*b*) Only 75% of the heat from the oven is used to heat the water.

$$0.75(P_{\text{oven}})t = \text{Heat absorbed by water} = mc\Delta T \rightarrow$$

$$t = \frac{mc\Delta T}{0.75(P_{\text{oven}})} = \frac{(0.120\text{ L})\left(\frac{1\text{kg}}{1\text{L}}\right)(4186\text{ J/kg}\bullet\text{C}^\circ)(85\text{ C}^\circ)}{0.75(2200\text{ W})} = 25.88\text{ s} \approx \boxed{26\text{ s}}$$

(*c*) $\dfrac{11\,\text{cents}}{\text{kWh}}(2.2\,\text{kW})(25.88\,\text{s})\dfrac{1\,\text{h}}{3600\,\text{s}} = \boxed{0.17\ \text{cents}}$

72. (*a*) The horsepower required is the power dissipated by the frictional force, since we are neglecting the energy used for acceleration.

$$P = Fv = (240\,\text{N})(45\,\text{km/hr})\left(\frac{1\,\text{m/s}}{3.6\,\text{km/hr}}\right) = 3000\,\text{W}\left(\frac{1\,\text{hp}}{746\,\text{W}}\right) = \boxed{4.0\,\text{hp}}$$

(*b*) The charge available by each battery is $Q = 95\,\text{A}\bullet\text{h} = 95\,\text{C/s}\bullet 3600\,\text{s} = 3.42\times10^{5}\,\text{C}$, and so the total charge available is 24 times that. The potential energy of that charge is the charge times the voltage. That energy must be delivered (batteries discharged) in a certain amount of time to produce the 3000 W necessary. The speed of the car times the discharge time is the range of the car between recharges.

$$P = \frac{\text{PE}}{t} = \frac{QV}{t} \quad\to\quad t = \frac{QV}{P} = \frac{d}{v} \quad\to$$

$$d = vt = v\frac{QV}{P} = v\frac{QV}{Fv} = \frac{QV}{F} = \frac{24(3.42\times10^{5}\,\text{C})(12\,\text{V})}{240\,\text{N}} = \boxed{410\,\text{km}}$$

73. The mass of the wire is the density of copper times the volume of the wire, and the resistance of the wire is given by Eq. 18-3. We represent the mass density by ρ_{m} and the resistivity by ρ.

$$R = \rho\frac{L}{A} \quad\to\quad A = \frac{\rho L}{R} \qquad m = \rho_{\text{m}}LA = \rho_{\text{m}}L\frac{\rho L}{R} \quad\to$$

$$L = \sqrt{\frac{mR}{\rho_{\text{m}}\rho}} = \sqrt{\frac{(0.018\,\text{kg})(12.5\,\Omega)}{(8.9\times10^{3}\,\text{kg/m}^{3})(1.68\times10^{-8}\,\Omega\bullet\text{m})}} = 38.79\,\text{m} \approx \boxed{38.8\,\text{m}}$$

$$A = \frac{\rho L}{R} = \pi\left(\tfrac{1}{2}d\right)^{2} \quad\to\quad d = \sqrt{\frac{4\rho L}{\pi R}} = \sqrt{\frac{4(1.68\times10^{-8}\,\Omega\bullet\text{m})(38.79\,\text{m})}{\pi(12.5\,\Omega)}} = \boxed{2.58\times10^{-4}\,\text{m}}$$

74. Use Eq. 18-6.

(*a*) $P = \dfrac{V^{2}}{R} = \dfrac{(120\,\text{V})^{2}}{12\,\Omega} = \boxed{1200\,\text{W}}$

(*b*) $P = \dfrac{V^{2}}{R} = \dfrac{(120\,\text{V})^{2}}{140\,\Omega} = 103\,\text{W} \approx \boxed{100\,\text{W}}$

75. Model the protons as moving in a continuous beam of cross-sectional area *A*. Then by Eq. 18-10, $I = neAv_{\text{d}}$. The variable *n* is the number of protons per unit volume, so $n = \dfrac{N}{Al}$, where *N* is the number of protons in the beam and *l* is the circumference of the ring. The "drift" velocity in this case is the speed of light.

$$I = neAv_{\text{d}} = \frac{N}{Al}eAv_{\text{d}} = \frac{N}{l}ev_{\text{d}} \quad\to$$

$$N = \frac{Il}{ev_d} = \frac{(11\times10^{-3}\,\text{A})(6300\,\text{m})}{(1.60\times10^{-19}\,\text{C})(3.00\times10^{8}\,\text{m/s})} = \boxed{1.4\times10^{12}\,\text{protons}}$$

76. (*a*) The power is given by $P = IV$.

$$P = IV = (12\,\text{A})(220\,\text{V}) = 2640\,\text{W} \approx \boxed{2600\,\text{W}}$$

(*b*) The power dissipated is given by $P_R = I^2R$, and the resistance is $R = \dfrac{\rho L}{A}$.

$$P_R = I^2R = I^2\frac{\rho L}{A} = I^2\frac{\rho L}{\pi r^2} = I^2\frac{4\rho L}{\pi d^2} = (12\,\text{A})^2\frac{4(1.68\times10^{-8}\,\Omega\bullet\text{m})(15\,\text{m})}{\pi(1.628\times10^{-3}\,\text{m})^2} = 17.433\,\text{W}$$

$$\approx \boxed{17\,\text{W}}$$

(*c*) $$P_R = I^2\frac{4\rho L}{\pi d^2} = (12\,\text{A})^2\frac{4(1.68\times10^{-8}\,\Omega\bullet\text{m})(15\,\text{m})}{\pi(2.053\times10^{-3}\,\text{m})^2} = 10.962\,\text{W} \approx \boxed{11\,\text{W}}$$

(*d*) The savings is due to the power difference.

$$\text{Savings} = (17.433\,\text{W} - 10.962\,\text{W})\left(\frac{1\,\text{kW}}{1000\,\text{W}}\right)(30\,\text{d})\left(\frac{12\,\text{h}}{1\,\text{d}}\right)\left(\frac{\$0.12}{1\,\text{kWh}}\right)$$

$$= \$0.2795/\text{month} \approx \boxed{28\,\text{cents per month}}$$

77. The resistance can be calculated from the power and voltage, and then the diameter of the wire can be calculated from the resistance.

$$P = \frac{V^2}{R} \rightarrow R = \frac{V^2}{P} \qquad R = \frac{\rho L}{A} = \frac{\rho L}{\pi\left(\frac{1}{2}d\right)^2} \rightarrow \frac{V^2}{P} = \frac{\rho L}{\pi\left(\frac{1}{2}d\right)^2} \rightarrow$$

$$d = \sqrt{\frac{4\rho LP}{\pi V^2}} = \sqrt{\frac{4(100\times10^{-8}\,\Omega\bullet\text{m})(3.8\,\text{m})(95\,\text{W})}{\pi(120\,\text{V})^2}} = \boxed{1.8\times10^{-4}\,\text{m}}$$

78. Use Eq. 18-6 for the power in each case, assuming the resistance is constant.

$$\frac{P_{13.8\,\text{V}}}{P_{12.0\,\text{V}}} = \frac{(V^2/R)_{13.8\,\text{V}}}{(V^2/R)_{12.0\,\text{V}}} = \frac{13.8^2}{12.0^2} = 1.3225 = \boxed{32\%\ \text{increase}}$$

79. (*a*) The current can be found from Eq. 18-5.

$$I = P/V \qquad I_A = P_A/V_A = 40\,\text{W}/120\,\text{V} = \boxed{0.33\,\text{A}} \qquad I_B = P_B/V_B = 40\,\text{W}/12\,\text{V} = \boxed{3.3\,\text{A}}$$

(*b*) The resistance can be found from Eq. 18-6.

$$R = \frac{V^2}{P} \qquad R_A = \frac{V_A^2}{P_A} = \frac{(120\,\text{V})^2}{40\,\text{W}} = \boxed{360\,\Omega} \qquad R_B = \frac{V_B^2}{P_B} = \frac{(12\,\text{V})^2}{40\,\text{W}} = \boxed{3.6\,\Omega}$$

(*c*) The charge is the current times the time.

$$Q = It \qquad Q_A = I_At = (0.33\,\text{A})(3600\,\text{s}) = \boxed{1200\,\text{C}}$$

$$Q_B = I_Bt = (3.3\,\text{A})(3600\,\text{s}) = \boxed{12{,}000\,\text{C}}$$

(*d*) The energy is the power times the time, and the power is the same for both bulbs.

$$E = Pt \qquad E_A = E_B = (40\,\text{W})(3600\,\text{s}) = \boxed{1.44\times10^5\,\text{J}}$$

(*e*) $\boxed{\text{Bulb B}}$ requires a larger current, and so should have larger diameter connecting wires to avoid overheating the connecting wires.

80. The current in the wire can be found by $I = P/V$.

(*a*) $$P_R = I^2R = \frac{P^2}{V^2}R = \frac{P^2}{V^2}\frac{\rho L}{A} = \frac{P^2}{V^2}\frac{\rho L}{\pi r^2} = \frac{P^2}{V^2}\frac{4\rho L}{\pi d^2}$$

$$= \frac{(2250\,\text{W})^2}{(120\,\text{V})^2}\frac{4(1.68\times10^{-8}\,\Omega\bullet\text{m})(25.0\,\text{m})}{\pi(2.59\times10^{-3}\,\text{m})^2} = \boxed{28.0\,\text{W}}$$

(*b*) $$P_R = \frac{P^2}{V^2}\frac{4\rho L}{\pi d^2} = \frac{(2250\,\text{W})^2}{(120\,\text{V})^2}\frac{4(1.68\times10^{-8}\,\Omega\bullet\text{m})(25.0\,\text{m})}{\pi(4.12\times10^{-3}\,\text{m})^2} = \boxed{11.1\,\text{W}}$$

81. Eq. 18-3 can be used. The area to be used is the cross-sectional area of the pipe.

$$R = \frac{\rho L}{A} = \frac{\rho L}{\pi\left(r_{\text{outside}}^2 - r_{\text{inside}}^2\right)} = \frac{(1.68\times10^{-8}\,\Omega\bullet\text{m})(10.0\,\text{m})}{\pi\left[(2.50\times10^{-2}\,\text{m})^2 - (1.50\times10^{-2}\,\text{m})^2\right]} = \boxed{1.34\times10^{-4}\,\Omega}$$

82. The volume of wire $(\text{Volume} = \text{length}\times\text{cross-sectional area})$ remains constant as the wire is stretched from the original length of L_0 to the final length of $2L_0$. Thus the cross-sectional area changes from A_0 to $\frac{1}{2}A_0$. Use Eq. 18-3 for the resistance and 18-6 for the power dissipated.

$$R_0 = \frac{\rho L_0}{A_0} \qquad R = \frac{\rho L}{A} = \frac{\rho 2L_0}{\frac{1}{2}A_0} = 4\frac{\rho L_0}{A_0} = 4R_0$$

$$P_0 = \frac{V^2}{R_0} \qquad P = \frac{V^2}{R} = \frac{V^2}{4R_0} = \frac{1}{4}\frac{V^2}{R_0} = \frac{1}{4}P_0$$

The $\boxed{\text{power is reduced by a factor of 4}}$.

83. The resistance of the filament when the flashlight is on is $R = \frac{V}{I} = \frac{3.2\,\text{V}}{0.20\,\text{A}} = 16\,\Omega$. That can be used with a combination of Eqs. 18-3 and 18-4 to find the temperature.

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

$$T = T_0 + \frac{1}{\alpha}\left(\frac{R}{R_0} - 1\right) = 20^\circ\text{C} + \frac{1}{0.0045(\text{C}^\circ)^{-1}}\left(\frac{16\,\Omega}{1.5\,\Omega} - 1\right) = 2168^\circ\text{C} \approx \boxed{2200^\circ\text{C}}$$