CHAPTER 25: Electric Currents and Resistance

Responses to Questions

1. A battery rating in ampere-hours gives the total amount of charge available in the battery.

2. The chemical reactions within the cell cause electrons to pile up on the negative electrode. If the terminals of the battery are connected in a circuit, then electrons flow from the negative terminal because it has an excess of electrons. Once the electrons return to the cell, the electrolyte again causes them to move to the negative terminal.

3. When a flashlight is operated, the battery energy is being used up.

4. The terminal of the car battery connected to "ground" is actually connected to the metal frame of the car. This provides a large "sink" or "source" for charge. The metal frame serves as the common ground for all electrical devices in the car, and all voltages are measured with respect to the car's frame.

5. Generally, water is already in the faucet spout, but it will not come out until the faucet valve is opened. Opening the valve provides the pressure difference needed to force water out of the spout. The same thing is essentially true when you connect a wire to the terminals of a battery. Electrons already exist in the wires. The battery provides the potential that causes them to move, producing a current.

6. Yes. They might have the same resistance if the aluminum wire is thicker. If the lengths of the wires are the same, then the ratios of resistivity to cross-sectional area must also be the same for the resistances to be the same. Aluminum has a higher resistivity than copper, so if the cross-sectional area of the aluminum is also larger by the same proportion, the two wires will have the same resistance.

7. If the emf in a circuit remains constant and the resistance in the circuit is increased, less current will flow, and the power dissipated in the circuit will decrease. Both power equations support this result. If the current in a circuit remains constant and the resistance is increased, then the emf must increase and the power dissipated in the circuit will increase. Both equations also support this result. There is no contradiction, because the voltage, current, and resistance are related to each other by $V = IR$.

8. When a lightbulb burns out, the filament breaks, creating a gap in the circuit so that no current flows.

9. If the resistance of a small immersion heater were increased, it would slow down the heating process. The emf in the circuit made up of the heater and the wires that connect it to the wall socket is maintained at a constant rms value. If the resistance in the circuit is increased, less current will flow, and the power dissipated in the circuit will decrease, slowing the heating process.

10. Resistance is proportional to length and inversely proportional to cross-sectional area.
    (*a*) For the least resistance, you want to connect the wires to maximize area and minimize length. Therefore, connect them opposite to each other on the faces that are $2a$ by $3a$.
    (*b*) For the greatest resistance, you want to minimize area and maximize length. Therefore, connect the wires to the faces that are $1a$ by $2a$.

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11. When a light is turned on, the filament is cool, and has a lower resistance than when it is hot. The current through the filament will be larger, due to the lower resistance. This momentary high current will heat the wire rapidly, possibly causing the filament to break due to thermal stress or vaporize. After the light has been on for some time, the filament is at a constant high temperature, with a higher resistance and a lower current. Since the temperature is constant, there is less thermal stress on the filament than when the light is first turned on.

12. When connected to the same potential difference, the 100-W bulb will draw more current ($P = IV$). The 75-W bulb has the higher resistance ($V = IR$ or $P = V^2/R$).

13. The electric power transferred by the lines is $P = IV$. If the voltage across the transmission lines is large, then the current in the lines will be small. The power lost in the transmission lines is $P = I^2R$. The power dissipated in the lines will be small, because I is small.

14. If the circuit has a 15-A fuse, then it is rated to carry current of no more than 15 A. Replacing the 15-A fuse with a 25-A fuse will allow the current to increase to a level that is dangerously high for the wiring, which might result in overheating and possibly a fire.

15. The human eye and brain cannot distinguish the on-off cycle of lights when they are operated at the normal 60 Hz frequency. At much lower frequencies, such as 5 Hz, the eye and brain are able to process the on-off cycle of the lights, and they will appear to flicker.

16. The electrons are not "used up" as they pass through the lamp. Their energy is dissipated as light and heat, but with each cycle of the alternating voltage, their potential energy is raised again. As long as the electrons keep moving (converting potential energy into kinetic energy, light, and heat) the lamp will stay lit.

17. Immediately after the toaster is turned on, the Nichrome wire heats up and its resistance increases. Since the (rms) potential across the element remains constant, the current in the heating element must decrease.

18. No. Energy is dissipated in a resistor but current, the rate of flow of charge, is not "used up."

19. In the two wires described, the drift velocities of the electrons will be about the same, but the current density, and therefore the current, in the wire with twice as many free electrons per atom will be twice as large as in the other wire.

20. (*a*) If the length of the wire doubles, its resistance also doubles, and so the current in the wire will be reduced by a factor of two. Drift velocity is proportional to current, so the drift velocity will be halved.
    (*b*) If the wire's radius is doubled, the drift velocity remains the same. (Although, since there are more charge carriers, the current will quadruple.)
    (*c*) If the potential difference doubles while the resistance remains constant, the drift velocity and current will also double.

21. If you turn on an electric appliance when you are outside with bare feet, and the appliance shorts out through you, the current has a direct path to ground through your feet, and you will receive a severe shock. If you are inside wearing socks and shoes with thick soles, and the appliance shorts out, the current will not have an easy path to ground through you, and will most likely find an alternate path. You might receive a mild shock, but not a severe one.

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Solutions to Problems

1. Use the definition of current, Eq. 25-1a.

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

2. Use the definition of current, Eq. 25-1a.

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

3. Use the definition of current, Eq. 25-1a.

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

4. Solve Eq. 25-2a for resistance.

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

5. (*a*) Use Eq. 25-2b to find the current.

$$V = IR \rightarrow I = \frac{V}{R} = \frac{240\,\text{V}}{8.6\,\Omega} = 27.91\,\text{A} \approx \boxed{28\,\text{A}}$$

(*b*) Use the definition of current, Eq. 25-1a.

$$I = \frac{\Delta Q}{\Delta t} \rightarrow \Delta Q = I\Delta t = (27.91\,\text{A})(50\,\text{min})(60\,\text{s/min}) = \boxed{8.4\times10^{4}\,\text{C}}$$

6. (*a*) Solve Eq. 25-2a for resistance.

$$R = \frac{V}{I} = \frac{120\,\text{V}}{9.5\,\text{A}} = 12.63\,\Omega \approx \boxed{13\,\Omega}$$

(*b*) Use the definition of average current, Eq. 25-1a.

$$I = \frac{\Delta Q}{\Delta t} \rightarrow \Delta Q = I\Delta t = (9.5\,\text{A})(15\,\text{min})(60\,\text{s/min}) = \boxed{8600\,\text{C}}$$

7. Use Ohm's Law, Eq. 25-2a, to find the current. Then use the definition of current, Eq. 25-1a, to calculate the number of electrons per minute.

$$I = \frac{V}{R} = \frac{\Delta Q}{\Delta t} = \frac{4.5\,\text{V}}{1.6\,\Omega} = \frac{2.8\,\text{C}}{\text{s}} \times \frac{1\text{ electron}}{1.60\times10^{-19}\,\text{C}} \times \frac{60\,\text{s}}{1\,\text{min}} = \boxed{1.1\times10^{21}\,\frac{\text{electrons}}{\text{minute}}}$$

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

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

$$V = IR = (3100\,\text{A})(1.0\times10^{-6}\,\Omega) = \boxed{3.1\times10^{-3}\,\text{V}}$$

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9. (*a*) Use Eq. 25-2b to find the resistance.

$$R=\frac{V}{I}=\frac{12\,\text{V}}{0.60\,\text{A}}=\boxed{20\,\Omega}\ \text{(2 sig. fig.)}$$

(*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. 25-1a.

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

10. (*a*) If the voltage drops by 15%, and the resistance stays the same, then by Eq. 25-2b, $V=IR$, the current will also drop by 15%.

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

(*b*) If the resistance drops by 15% (the same as being multiplied by 0.85), and the voltage stays the same, then by Eq. 25-2b, 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. Use Eq. 25-3 to find the diameter, with the area as $A=\pi r^2=\pi d^2/4$.

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

12. Use Eq. 25-3 to calculate the resistance, with the area as $A=\pi r^2=\pi d^2/4$.

$$R=\rho\frac{\ell}{A}=\rho\frac{4\ell}{\pi d^2}=(1.68\times10^{-8}\,\Omega\bullet\text{m})\frac{4(4.5\,\text{m})}{\pi(1.5\times10^{-3}\,\text{m})^2}=\boxed{4.3\times10^{-2}\,\Omega}$$

$\boxed{13.}$ Use Eq. 25-3 to calculate the resistances, with the area as $A=\pi r^2=\pi d^2/4$.

$$R=\rho\frac{\ell}{A}=\rho\frac{4\ell}{\pi d^2}.$$

$$\frac{R_{\text{Al}}}{R_{\text{Cu}}}=\frac{\rho_{\text{Al}}\dfrac{4\ell_{\text{Al}}}{\pi d_{\text{Al}}^2}}{\rho_{\text{Cu}}\dfrac{4\ell_{\text{Cu}}}{\pi d_{\text{Cu}}^2}}=\frac{\rho_{\text{Al}}\ell_{\text{Al}}d_{\text{Cu}}^2}{\rho_{\text{Cu}}\ell_{\text{Cu}}d_{\text{Al}}^2}=\frac{(2.65\times10^{-8}\,\Omega\bullet\text{m})(10.0\,\text{m})(1.8\,\text{mm})^2}{(1.68\times10^{-8}\,\Omega\bullet\text{m})(20.0\,\text{m})(2.0\,\text{mm})^2}=\boxed{0.64}$$

14. Use Eq. 25-3 to express the resistances, with the area as $A=\pi r^2=\pi d^2/4$, and so $R=\rho\frac{\ell}{A}=\rho\frac{4\ell}{\pi d^2}$.

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

$$d_{\text{W}}=d_{\text{Cu}}\sqrt{\frac{\rho_{\text{W}}}{\rho_{\text{Cu}}}}=(2.2\,\text{mm})\sqrt{\frac{5.6\times10^{-8}\,\Omega\bullet\text{m}}{1.68\times10^{-8}\,\Omega\bullet\text{m}}}=\boxed{4.0\,\text{mm}}$$

The diameter of the tungsten should be 4.0 mm.

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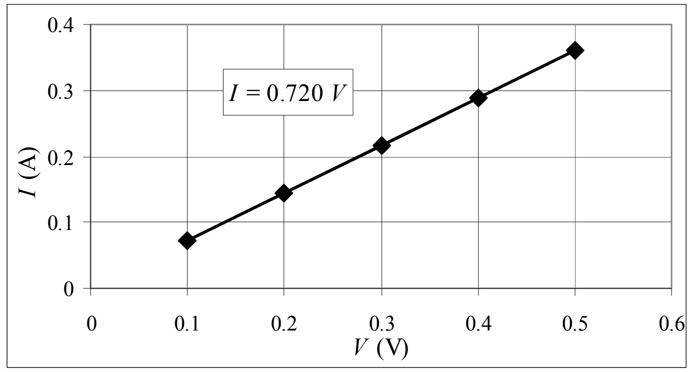
15. (*a*) If the wire obeys Ohm's law, then $V = IR$ or $I = \frac{1}{R}V$, showing a linear relationship between I and V. A graph of I vs. V should give a straight line with a slope of $\frac{1}{R}$ and a y-intercept of 0.

(*b*) From the graph and the calculated linear fit, we see that the wire obeys Ohm's law.



$$\text{slope} = \frac{1}{R} \rightarrow$$

$$R = \frac{1}{0.720}\,\text{A/V} = \boxed{1.39\,\Omega}$$

The spreadsheet used for this problem can be found on the Media Manager, with filename "PSE4_ISM_CH25.XLS," on tab "Problem 25.15b."

(*c*) Use Eq. 25-3 to find the resistivity.

$$R = \rho\frac{\ell}{A} \rightarrow \rho = \frac{AR}{\ell} = \frac{\pi d^2 R}{4\ell} = \frac{\pi\left(3.2\times10^{-4}\,\text{m}\right)^2\left(1.39\,\Omega\right)}{4\left(0.11\,\text{m}\right)} = \boxed{1.0\times10^{-6}\,\Omega\bullet\text{m}}$$

From Table 25-1, the material is $\boxed{\text{nichrome}}$.

16. Use Eq. 25-5 multiplied by ℓ/A so that it expresses resistance instead of resistivity.

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

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

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

17. 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.

$$\ell = \ell_{\text{short}} + \ell_{\text{long}} = \ell_{\text{short}} + 4.0\ell_{\text{short}} = 5.0\ell_{\text{short}} \rightarrow \ell_{\text{short}} = 0.20\ell\,,\ \ell_{\text{long}} = 0.80\ell$$

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

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

18. Use Eq. 25-5 for the resistivity.

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

$$T = T_0 + \frac{1}{\alpha_{\text{Al}}}\left(\frac{\rho_{\text{0 W}}}{\rho_{\text{0 Al}}} - 1\right) = 20^\circ\text{C} + \frac{1}{0.00429\left(\text{C}^\circ\right)^{-1}}\left(\frac{5.6\times10^{-8}\,\Omega\bullet\text{m}}{2.65\times10^{-8}\,\Omega\bullet\text{m}} - 1\right) = 279.49^\circ\text{C} \approx \boxed{280^\circ\text{C}}$$

$\boxed{19.}$ Use Eq. 25-5 multiplied by ℓ/A so that it expresses resistances instead of resistivity.

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

$$T = T_0 + \frac{1}{\alpha}\left(\frac{R}{R_0} - 1\right) = 20^\circ\text{C} + \frac{1}{0.0045\left(\text{C}^\circ\right)^{-1}}\left(\frac{140\,\Omega}{12\,\Omega} - 1\right) = 2390^\circ\text{C} \approx \boxed{2400^\circ\text{C}}$$

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20. Calculate the voltage drop by combining Ohm's Law (Eq. 25-2b) with the expression for resistance, Eq. 25-3.

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

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

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

22. In each case calculate the resistance by using Eq. 25-3 for resistance.

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

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

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

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. 25-5, multiplied by ℓ/A so that it expresses resistance instead of resistivity.

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

$$= 20.0^\circ\text{C} + \frac{1}{0.00429\left(\text{C}^\circ\right)^{-1}}\left(\frac{0.4212\,\text{A}}{0.3818\,\text{A}}-1\right) = \boxed{44.1^\circ\text{C}}$$

24. For the cylindrical wire, its (constant) volume is given by $V = \ell_0 A_0 = \ell A$, and so $A = \frac{V}{\ell}$. Combine this relationship with Eq. 25-3. We assume that $\Delta\ell \ll \ell_0$.

$$R_0 = \rho\frac{\ell_0}{A_0} = \rho\frac{\ell_0^2}{V_0} \;;\; R = \rho\frac{\ell}{A} = \rho\frac{\ell^2}{V_0} \;;\; \frac{dR}{d\ell} = 2\rho\frac{\ell}{V_0}$$

$$\Delta R \approx \frac{dR}{d\ell}\Delta\ell = 2\rho\frac{\ell}{V_0}\Delta\ell \rightarrow \Delta\ell = \frac{V_0\Delta R}{2\rho\ell} \rightarrow \frac{\Delta\ell}{\ell} = \frac{V_0\Delta R}{2\rho\ell^2} = \frac{\Delta R}{2\frac{\rho\ell^2}{V_0}} = \tfrac{1}{2}\frac{\Delta R}{R}$$

This is true for any initial conditions, and so $\boxed{\frac{\Delta\ell}{\ell_0} = \tfrac{1}{2}\frac{\Delta R}{R_0}}$

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25. The resistance depends on the length and area as $R = \rho\ell/A$. Cutting the wire and running the wires side by side will halve the length and double the area.

$$R_2 = \frac{\rho\left(\frac{1}{2}\ell\right)}{2A} = \frac{1}{4}\frac{\rho\ell}{A} = \boxed{\frac{1}{4}R_1}$$

26. The total resistance is to be 3700 ohms $\left(R_{\text{total}}\right)$ at all temperatures. Write each resistance in terms of Eq.25-5 (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.

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

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

$$R_{0\text{C}} = R_{\text{total}}\frac{\alpha_{\text{N}}}{\left(\alpha_{\text{N}} - \alpha_{\text{C}}\right)} = \left(3700\,\Omega\right)\frac{0.0004\left(\text{C}^\circ\right)^{-1}}{0.0004\left(\text{C}^\circ\right)^{-1} + 0.0005\left(\text{C}^\circ\right)^{-1}} = 1644\,\Omega \approx \boxed{1600\,\Omega}$$

$$R_{0\text{N}} = R_{\text{total}} - R_{0\text{C}} = 3700\,\Omega - 1644\,\Omega = 2056\,\Omega \approx \boxed{2100\,\Omega}$$

27. We choose a spherical shell of radius *r* and thickness *dr* as a differential element. The area of this element is $4\pi r^2$. Use Eq. 25-3, but for an infinitesimal resistance. Then integrate over the radius of the sphere.

$$R = \rho\frac{\ell}{A} \rightarrow dR = \rho\frac{d\ell}{A} = \frac{dr}{4\pi\sigma r^2} \rightarrow R = \int dR = \int_{r_1}^{r_2}\frac{dr}{4\pi\sigma r^2} = \frac{1}{4\pi\sigma}\left(-\frac{1}{r}\right)_{r_1}^{r_2} = \boxed{\frac{1}{4\pi\sigma}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)}$$

28. (*a*) Let the values at the lower temperature be indicated by a subscript "0". Thus $R_0 = \rho_0\frac{\ell_0}{A_0}$ $= \rho_0\frac{4\ell_0}{\pi d_0^2}$. The change in temperature results in new values for the resistivity, the length, and the diameter. Let α represent the temperature coefficient for the resistivity, and α_{T} represent the thermal coefficient of expansion, which will affect the length and diameter.

$$R = \rho\frac{\ell}{A} = \rho\frac{4\ell}{\pi d^2} = \rho_0\left[1+\alpha\left(T-T_0\right)\right]\frac{4\ell_0\left[1+\alpha_{\text{T}}\left(T-T_0\right)\right]}{\pi\left\{d_0\left[1+\alpha_{\text{T}}\left(T-T_0\right)\right]\right\}^2} = \rho_0\frac{4\ell_0}{\pi d_0^2}\frac{\left[1+\alpha\left(T-T_0\right)\right]}{\left[1+\alpha_{\text{T}}\left(T-T_0\right)\right]}$$
$$= R_0\frac{\left[1+\alpha\left(T-T_0\right)\right]}{\left[1+\alpha_{\text{T}}\left(T-T_0\right)\right]} \rightarrow R\left[1+\alpha_{\text{T}}\left(T-T_0\right)\right] = R_0\left[1+\alpha\left(T-T_0\right)\right] \rightarrow$$

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$$T = T_0 + \frac{(R - R_0)}{(R_0\alpha - R\alpha_T)} = 20°\text{C} + \frac{(140\,\Omega - 12\,\Omega)}{\left[(12\,\Omega)(0.0045\,\text{C}^{\circ -1}) - (140\,\Omega)(5.5\times10^{-6}\,\text{C}^{\circ -1})\right]}$$

$$= 20°\text{C} + 2405°\text{C} = 2425°\text{C} \approx \boxed{2400°\text{C}}$$

(*b*) The net effect of thermal expansion is that both the length and diameter increase, which lowers the resistance.

$$\frac{R}{R_0} = \frac{\rho_0 \frac{4\ell}{\pi d^2}}{\rho_0 \frac{4\ell_0}{\pi d_0^2}} = \frac{\ell d_0^2}{\ell_0 d^2} = \frac{\ell_0\left[1 + \alpha_T (T - T_0)\right]}{\ell_0} \frac{d_0^2}{\left\{d_0\left[1 + \alpha_T (T - T_0)\right]\right\}^2} = \frac{1}{\left[1 + \alpha_T (T - T_0)\right]}$$

$$= \frac{1}{\left[1 + (5.5\times10^{-6}\,\text{C}^{\circ -1})(2405°\text{C})\right]} = 0.9869$$

$$\%\,\text{change} = \left(\frac{R - R_0}{R_0}\right)100 = \left(\frac{R}{R_0} - 1\right)100 = -1.31 \approx \boxed{-1.3\%}$$

The net effect of resistivity change is that the resistance increases.

$$\frac{R}{R_0} = \frac{\rho \frac{4\ell_0}{\pi d_0^2}}{\rho_0 \frac{4\ell_0}{\pi d_0^2}} = \frac{\rho}{\rho_0} = \frac{\rho_0\left[1 + \alpha(T - T_0)\right]}{\rho_0} = \left[1 + \alpha(T - T_0)\right] = \left[1 + (0.0045\,\text{C}^{\circ -1})(2405°\text{C})\right]$$

$$= 11.82$$

$$\%\,\text{change} = \left(\frac{R - R_0}{R_0}\right)100 = \left(\frac{R}{R_0} - 1\right)100 = 1082 \approx \boxed{1100\%}$$

29. (*a*) Calculate each resistance separately using Eq. 25-3, and then add the resistances together to find the total resistance.

$$R_{Cu} = \frac{\rho_{Cu}\ell}{A} = \frac{4\rho_{Cu}\ell}{\pi d^2} = \frac{4(1.68\times10^{-8}\,\Omega\bullet\text{m})(5.0\,\text{m})}{\pi(1.4\times10^{-3}\,\text{m})^2} = 0.054567\,\Omega$$

$$R_{Al} = \frac{\rho_{Al}\ell}{A} = \frac{4\rho_{Al}\ell}{\pi d^2} = \frac{4(2.65\times10^{-8}\,\Omega\bullet\text{m})(5.0\,\text{m})}{\pi(1.4\times10^{-3}\,\text{m})^2} = 0.086074\,\Omega$$

$$R_{total} = R_{Cu} + R_{Al} = 0.054567\,\Omega + 0.086074\,\Omega = 0.140641\,\Omega \approx \boxed{0.14\,\Omega}$$

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

$$I = \frac{V}{R_{total}} = \frac{85\times10^{-3}\,\text{V}}{0.140641\,\Omega} = 0.60438\,\text{A} \approx \boxed{0.60\,\text{A}}$$

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

$$V_{Cu} = IR_{Cu} = (0.60438\,\text{A})(0.054567\,\Omega) \approx \boxed{0.033\,\text{V}}$$

$$V_{Al} = IR_{Al} = (0.60438\,\text{A})(0.086074\,\Omega) \approx \boxed{0.052\,\text{V}}$$

Notice that the total voltage is 85 mV.

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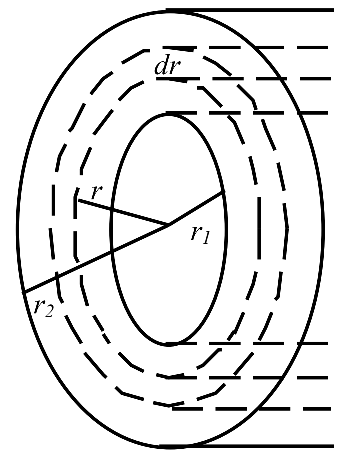
30. (*a*) Divide the cylinder up into concentric cylindrical shells of radius *r*, thickness *dr*, and length ℓ. See the diagram. The resistance of one of those shells, from Eq. 25-3, is found. Note that the "length" in Eq. 25-3 is in the direction of the current flow, so we must substitute in *dr* for the "length" in Eq. 25-3. The area is the surface area of the thin cylindrical shell. Then integrate over the range of radii to find the total resistance.



$$R = \rho\frac{"\ell"}{A} \rightarrow dR = \rho\frac{dr}{2\pi r\ell} \ ;$$

$$R = \int dR = \int_{r_1}^{r_2} \rho\frac{dr}{2\pi r\ell} = \boxed{\frac{\rho}{2\pi\ell}\ln\frac{r_2}{r_1}}$$

(*b*) Use the data given to calculate the resistance from the above formula.

$$R = \frac{\rho}{2\pi\ell}\ln\frac{r_2}{r_1} = \frac{15\times10^{-5}\,\Omega\bullet\text{m}}{2\pi(0.024\,\text{m})}\ln\left(\frac{1.8\,\text{mm}}{1.0\,\text{mm}}\right) = \boxed{5.8\times10^{-4}\,\Omega}$$

(*c*) For resistance along the axis, we again use Eq. 25-3, but the current is flowing in the direction of length ℓ. The area is the cross-sectional area of the face of the hollow cylinder.

$$R = \frac{\rho\ell}{A} = \frac{\rho\ell}{\pi\left(r_2^2 - r_1^2\right)} = \frac{\left(15\times10^{-5}\,\Omega\bullet\text{m}\right)(0.024\,\text{m})}{\pi\left[\left(1.8\times10^{-3}\,\text{m}\right)^2 - \left(1.0\times10^{-3}\,\text{m}\right)^2\right]} = \boxed{0.51\,\Omega}$$

31. Use Eq. 25-6 to find the power from the voltage and the current.

$$P = IV = (0.27\,\text{A})(3.0\,\text{V}) = \boxed{0.81\,\text{W}}$$

32. Use Eq. 25-7b to find the resistance from the voltage and the power.

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

33. Use Eq. 25-7b to find the voltage from the power and the resistance.

$$P = \frac{V^2}{R} \rightarrow V = \sqrt{RP} = \sqrt{(3300\,\Omega)(0.25\,\text{W})} = \boxed{29\,\text{V}}$$

34. Use Eq. 25-7b to find the resistance, and Eq. 25-6 to find the current.

(*a*) $$P = \frac{V^2}{R} \rightarrow R = \frac{V^2}{P} = \frac{(110\,\text{V})^2}{75\,\text{W}} = 161.3\,\Omega \approx \boxed{160\,\Omega}$$

$$P = IV \rightarrow I = \frac{P}{V} = \frac{75\,\text{W}}{110\,\text{V}} = 0.6818\,\text{A} \approx \boxed{0.68\,\text{A}}$$

(*b*) $$P = \frac{V^2}{R} \rightarrow R = \frac{V^2}{P} = \frac{(110\,\text{V})^2}{440\,\text{W}} = 27.5\,\Omega \approx \boxed{28\,\Omega}$$

$$P = IV \rightarrow I = \frac{P}{V} = \frac{440\,\text{W}}{110\,\text{V}} = \boxed{4.0\,\text{A}}$$

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35. (*a*) From Eq. 25-6, if power P is delivered to the transmission line at voltage V, there must be a current $I = P/V$. As this current is carried by the transmission line, there will be power losses of I^2R due to the resistance of the wire. This power loss can be expressed as $\Delta P = I^2R$ $= \boxed{P^2R/V^2}$. Equivalently, there is a voltage drop across the transmission lines of $V' = IR$. Thus the voltage available to the users is $V - V'$, and so the power available to the users is $P' = (V - V')I = VI - V'I = VI - I^2R = P - I^2R$. The power loss is $\Delta P = P - P' = P - (P - I^2R)$ $= I^2R = \boxed{P^2R/V^2}$.

(*b*) Since $\Delta P \propto \dfrac{1}{V^2}$, V should be $\boxed{\text{as large as possible}}$ to minimize ΔP.

36. (*a*) Since $P = \dfrac{V^2}{R} \rightarrow R = \dfrac{V^2}{P}$ 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*) $R = \dfrac{V^2}{P} = \dfrac{(120\,\text{V})^2}{850\,\text{W}} = \boxed{17\,\Omega}$

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

37. (*a*) Use Eq. 25-6 to find the current.

$$P = IV \rightarrow I = \frac{P}{V} = \frac{95\,\text{W}}{115\,\text{V}} = \boxed{0.83\,\text{A}}$$

(*b*) Use Eq. 25-7b to find the resistance.

$$P = \frac{V^2}{R} \rightarrow R = \frac{V^2}{P} = \frac{(115\,\text{V})^2}{95\,\text{W}} \approx \boxed{140\,\Omega}$$

38. The power (and thus the brightness) of the bulb is proportional to the square of the voltage, according to Eq. 25-7b, $P = \dfrac{V^2}{R}$. 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.

39. To find the kWh of energy, multiply the kilowatts of power consumption by the number of hours in operation.

$$\text{Energy} = P(\text{in kW})\,t(\text{in h}) = (550\,\text{W})\left(\frac{1\,\text{kW}}{1000\,\text{W}}\right)(6.0\,\text{min})\left(\frac{1\,\text{h}}{60\,\text{min}}\right) = \boxed{0.055\,\text{kWh}}$$

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.

$$\text{Cost} = \left(0.055\frac{\text{kWh}}{\text{d}}\right)\left(\frac{4\,\text{d}}{1\,\text{week}}\right)\left(\frac{4\,\text{week}}{1\,\text{month}}\right)\left(\frac{9.0\,\text{cents}}{\text{kWh}}\right) = \boxed{7.9\,\text{cents/month}}$$

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40. 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.

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

41. The $\text{A}\bullet\text{h}$ rating is the amount of charge that the battery can deliver. The potential energy of the charge is the charge times the voltage.

$$U = QV = (75\,\text{A}\bullet\text{h})\left(\frac{3600\,\text{s}}{1\,\text{h}}\right)(12\,\text{V}) = \boxed{3.2\times10^{6}\,\text{J}} = 0.90\,\text{kWh}$$

42. (*a*) Calculate the resistance from Eq. 25-2b and the power from Eq. 25-6.

$$R = \frac{V}{I} = \frac{3.0\,\text{V}}{0.38\,\text{A}} = 7.895\,\Omega \approx \boxed{7.9\,\Omega} \qquad P = IV = (0.38\,\text{A})(3.0\,\text{V}) = 1.14\,\text{W} \approx \boxed{1.1\,\text{W}}$$

(*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. 25-7b, $P = \frac{V^2}{R}$. 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.

$\boxed{43.}$ Each bulb will draw an amount of current found from Eq. 25-6.

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

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

$$I_{\text{total}} = nI_{\text{bulb}} = n\frac{P}{V} \quad \rightarrow \quad n = \frac{VI_{\text{total}}}{P} = \frac{(120\,\text{V})(15\,\text{A})}{75\,\text{W}} = \boxed{24\ \text{bulbs}}$$

44. Find the power dissipated in the cord by Eq. 25-7a, using Eq. 25-3 for the resistance.

$$P = I^2R = I^2\rho\frac{\ell}{A} = I^2\rho\frac{\ell}{\pi d^2/4} = I^2\rho\frac{4\ell}{\pi d^2} = (15.0\,\text{A})^2\left(1.68\times10^{-8}\,\Omega\bullet\text{m}\right)\frac{4(5.4\,\text{m})}{\pi\left(0.129\times10^{-2}\,\text{m}\right)^2}$$

$$= 15.62\,\text{W} \approx \boxed{16\,\text{W}}$$

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

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

$$P_{\substack{\text{dissipated}\\ 12{,}000\,\text{V}}} = \frac{\left(7.5\times10^{5}\,\text{W}\right)^2}{\left(1.2\times10^{4}\,\text{V}\right)^2}(3.0\,\Omega) = 11719\,\text{W}$$

$$P_{\substack{\text{dissipated}\\ 50{,}000\,\text{V}}} = \frac{\left(7.5\times10^{5}\,\text{W}\right)^2}{\left(5\times10^{4}\,\text{V}\right)^2}(3.0\,\Omega) = 675\,\text{W} \qquad \text{difference} = 11719\,\text{W} - 675\,\text{W} = \boxed{1.1\times10^{4}\,\text{W}}$$

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46. (*a*) By conservation of energy and the efficiency claim, 75% of the electrical power dissipated by the heater must be the rate at which energy is absorbed by the water.

$$0.75_{\substack{\text{emitted by}\\ \text{electromagnet}}} = P_{\substack{\text{absorbed}\\ \text{by water}}} \rightarrow 0.75(IV) = \frac{Q_{\text{heat water}}}{t} = \frac{mc\Delta T}{t} \rightarrow$$

$$I = \frac{mc\Delta T}{0.75Vt} = \frac{(0.120\,\text{kg})(4186\,\text{J/kg})(95°\text{C} - 25°\text{C})}{(0.75)(12\,\text{V})(480\,\text{s})} = 8.139\,\text{A} \approx \boxed{8.1\,\text{A}}$$

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

$$V = IR \rightarrow R = \frac{V}{I} = \frac{12\,\text{V}}{8.139\,\text{A}} = \boxed{1.5\,\Omega}$$

47. 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.

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

$$\frac{m}{t} = \frac{IV}{c\Delta T} = \frac{(17.5\,\text{A})(240\,\text{V})}{(4186\,\text{J/kg}\bullet°\text{C})(6.50\,\text{C}°)} = 0.154\ \text{kg/s} \approx \boxed{0.15\,\text{kg/s}}$$

This is $154\,\text{mL/s}$.

48. For the wire to stay a constant temperature, the power generated in the resistor is to be dissipated by radiation. Use Eq. 25-7a and 19-18, both expressions of power (energy per unit time). We assume that the dimensions requested and dimensions given are those at the higher temperature, and do not take any thermal expansion effects into account. We also use Eq. 25-3 for resistance.

$$I^2R = \varepsilon\sigma A\left(T_{\text{high}}^4 - T_{\text{low}}^4\right) \rightarrow I^2\frac{4\rho\ell}{\pi d^2} = \varepsilon\sigma\pi d\ell\left(T_{\text{high}}^4 - T_{\text{low}}^4\right) \rightarrow$$

$$d = \left(\frac{4I^2\rho}{\pi^2\varepsilon\sigma\left(T_{\text{high}}^4 - T_{\text{low}}^4\right)}\right)^{1/3} = \left(\frac{4(15.0\,\text{A})^2(5.6\times10^{-8}\,\Omega\bullet\text{m})}{\pi^2(1.0)(5.67\times10^{-8}\,\text{W/m}^2\bullet\text{K}^4)\left[(3100\,\text{K})^4 - (293\,\text{K})^4\right]}\right)^{1/3}$$

$$= 9.92\times10^{-5}\,\text{m} \approx \boxed{0.099\,\text{mm}}$$

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

$$I_{\text{peak}} = \sqrt{2}I_{\text{rms}} = \sqrt{2}\frac{V_{\text{rms}}}{R} = \sqrt{2}\frac{220\,\text{V}}{2700\,\Omega} = \boxed{0.12\,\text{A}}$$

50. Find the peak current from Ohm's law, and then find the rms current from Eq. 25-9a.

$$I_{\text{peak}} = \frac{V_{\text{peak}}}{R} = \frac{180\,\text{V}}{380\,\Omega} = 0.47368\,\text{A} \approx \boxed{0.47\,\text{A}} \qquad I_{\text{rms}} = I_{\text{peak}}/\sqrt{2} = (0.47368\,\text{A})/\sqrt{2} = \boxed{0.33\,\text{A}}$$

51. (*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*) Use Eq. 25-7a to calculate the resistance.

$$P = \frac{V^2}{R} \rightarrow R = \frac{V^2}{P} = \frac{(120\,\text{V})^2}{2(75\,\text{W})} = \boxed{96\,\Omega}$$

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

$$\overline{P} = I_{\text{rms}}V_{\text{rms}} = \frac{I_{\text{peak}}}{\sqrt{2}}V_{\text{rms}} \rightarrow V_{\text{rms}} = \frac{\sqrt{2}\overline{P}}{I_{\text{peak}}} = \frac{\sqrt{2}\left(1500\,\text{W}\right)}{5.4\,\text{A}} = \boxed{390\,\text{V}}$$

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

(*a*) $V_{\text{peak}} = \sqrt{2}V_{\text{rms}} = \sqrt{2}\left(660\,\text{V}\right) = 933.4\,\text{V} \approx \boxed{930\,\text{V}}$

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

54. (*a*) We assume that the 2.5 hp is the average power, so the maximum power is twice that, or 5.0 hp, as seen in Figure 25-22.

$$5.0\,\text{hp}\left(\frac{746\,\text{W}}{1\,\text{hp}}\right) = 3730\,\text{W} \approx \boxed{3700\,\text{W}}$$

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

$$\overline{P} = I_{\text{rms}}V_{\text{rms}} = \frac{I_{\text{peak}}}{\sqrt{2}}V_{\text{rms}} \rightarrow I_{\text{peak}} = \frac{\sqrt{2}\overline{P}}{V_{\text{rms}}} = \frac{\sqrt{2}\left[\frac{1}{2}\left(3730\,\text{W}\right)\right]}{240\,\text{V}} = \boxed{11\,\text{A}}$$

55. (*a*) The average power used can be found from the resistance and the rms voltage by Eq. 25-10c.

$$\overline{P} = \frac{V_{\text{rms}}^2}{R} = \frac{\left(240\,\text{V}\right)^2}{44\,\Omega} = 1309\,\text{W} \approx \boxed{1300\,\text{W}}$$

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

$$P_{\text{max}} = 2\overline{P} = 2\left(1309\,\text{W}\right) \approx \boxed{2600\,\text{W}} \qquad P_{\text{min}} = \boxed{0\,\text{W}}$$

56. (*a*) Find V_{rms}. Use an integral from Appendix B-4, page A-7.

$$V_{\text{rms}} = \left[\frac{1}{T}\int_0^T \left(V_0 \sin\frac{2\pi t}{T}\right)^2 dt\right]^{1/2} = \left[\frac{V_0^2}{T}\left(\frac{t}{2} - \frac{\sin\left(\frac{4\pi t}{T}\right)}{\frac{8\pi}{T}}\right)\Bigg|_0^T\right]^{1/2} = \left(\frac{V_0^2}{2}\right)^{1/2} = \boxed{\frac{V_0}{\sqrt{2}}}$$

(*b*) Find V_{rms}.

$$V_{\text{rms}} = \left[\frac{1}{T}\int_0^T V^2 dt\right]^{1/2} = \left[\frac{1}{T}\int_0^{T/2} V_0^2 dt + \frac{1}{T}\int_{T/2}^{T} \left(0\right)^2 dt\right]^{1/2} = \left[\frac{V_0^2}{T}\frac{T}{2} + 0\right]^{1/2} = \boxed{\frac{V_0}{\sqrt{2}}}$$

57. (*a*) We follow the derivation in Example 25-14. Start with Eq. 25-14, in absolute value.

$$j = nev_{\text{d}} \rightarrow v_{\text{d}} = \frac{j}{ne} = \frac{I}{neA} = \frac{I}{\left(\frac{N\left(1\text{ mole}\right)}{m\left(1\text{ mole}\right)}\rho_{\text{D}}\right)e\left[\pi\left(\frac{1}{2}d\right)^2\right]} = \frac{4Im}{N\rho_{\text{D}}e\pi d^2}$$

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

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(*b*) Calculate the current density from Eq. 25-11.

$$j = \frac{I}{A} = \frac{I}{\pi r^2} = \frac{4I}{\pi d^2} = \frac{4\left(2.3\times10^{-6}\,\text{A}\right)}{\pi\left(6.5\times10^{-4}\,\text{m}\right)^2} = 6.931\,\text{A/m}^2 \approx \boxed{6.9\,\text{A/m}^2}$$

(*c*) The electric field is calculated from Eq. 25-17.

$$j = \frac{1}{\rho}E \;\rightarrow\; E = \rho j = \left(1.68\times10^{-8}\,\Omega\bullet\text{m}\right)\left(6.931\,\text{A/m}^2\right) = \boxed{1.2\times10^{-7}\,\text{V/m}}$$

58. (*a*) Use Ohm's law to find the resistance.

$$V = IR \;\rightarrow\; R = \frac{V}{I} = \frac{0.0220\,\text{V}}{0.75\,\text{A}} = 0.02933\,\Omega \approx \boxed{0.029\,\Omega}$$

(*b*) Find the resistivity from Eq. 25-3.

$$R = \frac{\rho\ell}{A} \;\rightarrow$$

$$\rho = \frac{RA}{\ell} = \frac{R\pi r^2}{\ell} = \frac{\left(0.02933\,\Omega\right)\pi\left(1.0\times10^{-3}\,\text{m}\right)^2}{\left(5.80\,\text{m}\right)} = 1.589\times10^{-8}\,\Omega\bullet\text{m} \approx \boxed{1.6\times10^{-8}\,\Omega\bullet\text{m}}$$

(*c*) Use Eq. 25-11 to find the current density.

$$j = \frac{I}{A} = \frac{I}{\pi r^2} = \frac{0.75}{\pi\left(0.0010\,\text{m}\right)^2} = 2.387\times10^{5}\,\text{A/m}^2 \approx \boxed{2.4\times10^{5}\,\text{A/m}^2}$$

(*d*) Use Eq. 25-17 to find the electric field.

$$j = \frac{1}{\rho}E \;\rightarrow$$

$$E = \rho j = \left(1.589\times10^{-8}\,\Omega\bullet\text{m}\right)\left(2.387\times10^{5}\,\text{A/m}^2\right) = 3.793\times10^{-3}\,\text{V/m} \approx \boxed{3.8\times10^{-3}\,\text{V/m}}$$

(*e*) Find the number of electrons per unit volume from the absolute value of Eq. 25-14.

$$j = nev_\text{d} \;\rightarrow\; n = \frac{j}{v_\text{d}e} = \frac{2.387\times10^{5}\,\text{A/m}^2}{\left(1.7\times10^{-5}\,\text{m/s}\right)\left(1.60\times10^{-19}\,\text{C}\right)} = \boxed{8.8\times10^{28}\,\text{e}^-/\text{m}^3}$$

59. We are given a charge density and a speed (like the drift speed) for both types of ions. From that we can use Eq. 25-13 (without the negative sign) 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.

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

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

$$\left[\left(7.0\times10^{11}\,\text{ions/m}^3\right)\left(1.60\times10^{-19}\,\text{C/ion}\right)\left(6.2\times10^{6}\,\text{m/s}\right)\right]$$

$$= 2.486\,\text{A/m}^2 \approx \boxed{2.5\,\text{A/m}^2\text{, North}}$$

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

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

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61. 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.

62. 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.

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

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

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

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

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

$$t = \frac{Q\Delta V}{P} = \frac{(85\text{A}\bullet\text{h})(3600\,\text{s/h})(12\text{V})}{92\,\text{W}} = 39913\,\text{s}\left(\frac{1\,\text{h}}{3600\,\text{s}}\right) = 11.09\,\text{h} \approx \boxed{11\,\text{h}}$$

64. The ampere-hour is a unit of charge.

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

65. Use Eqs. 25-3 and 25-7b.

$$R = \rho\frac{\ell}{A} = \rho\frac{\ell}{\pi r^2} = \frac{4\rho\ell}{\pi d^2} \;;\; P = \frac{V^2}{R} = \frac{V^2}{\frac{4\rho\ell}{\pi d^2}} \rightarrow$$

$$\ell = \frac{V^2\pi d^2}{4\rho P} = \frac{(1.5\,\text{V})^2\pi\left(5.0\times10^{-4}\,\text{m}\right)^2}{4\left(1.68\times10^{-8}\,\Omega\bullet\text{m}\right)(15\,\text{W})} = 1.753\,\text{m} \approx \boxed{1.8\,\text{m}}$$

If the voltage increases by a factor of 6 without the resistance changing, the power will increase by a factor of 36. The blanket would theoretically be able to deliver 540 W of power, which might make the material catch on fire or burn the occupant.

66. Use Eq. 25-6 to calculate the current.

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

67. From Eq. 25-2b, if $R = V/I$, then $G = I/V$

$$G = \frac{I}{V} = \frac{0.48\,\text{A}}{3.0\,\text{V}} = \boxed{0.16\,\text{S}}$$

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68. Use Eq. 25-7b to express the resistance in terms of the power, and Eq. 25-3 to express the resistance in terms of the wire geometry.

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

$$4\rho\frac{\ell}{\pi d^2}=\frac{V^2}{P}\ \rightarrow\ d=\sqrt{\frac{4\rho\ell P}{\pi V^2}}=\sqrt{\frac{4\left(9.71\times10^{-8}\Omega\bullet\text{m}\right)(3.5\,\text{m})(1500\,\text{W})}{\pi(110\,\text{V})^2}}=\boxed{2.3\times10^{-4}\,\text{m}}$$

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

$$(1.8\,\text{kW})(2.0\,\text{h/d})+4(0.1\,\text{kW})(6.0\,\text{h/d})+(3.0\,\text{kW})(1.0\,\text{h/d})+(2.0\,\text{kWh/d})$$
$$=11.0\,\text{kWh/d}$$

$$\text{Cost}=(11.0\,\text{kWh/d})(30\,\text{d})\left(\frac{\$0.105}{\text{kWh}}\right)=\$34.65\approx\boxed{\$35\text{ per month}}$$

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

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

$$\text{coal mass}=\frac{\text{Household Energy}}{(0.35)(\text{coal energy per mass})}=\frac{(11.0\,\text{kWh/d})(365\,\text{d})\left(\frac{1000\,\text{W}}{\text{kW}}\right)\left(\frac{3600\,\text{s}}{1\,\text{h}}\right)}{(0.35)\left(7500\frac{\text{kcal}}{\text{kg}}\right)\left(\frac{4186\,\text{J}}{1\,\text{kcal}}\right)}$$

$$=1315\,\text{kg}\approx\boxed{1300\,\text{kg of coal}}$$

70. To deliver 15 MW of power at 120 V requires a current of $I=\frac{P}{V}=\frac{15\times10^6\,\text{W}}{120\,\text{V}}=1.25\times10^5\,\text{A}$.

Calculate the power dissipated in the resistors using the current and the resistance.

$$P=I^2R=I^2\rho\frac{L}{A}=I^2\rho\frac{L}{\pi r^2}=4I^2\rho\frac{L}{\pi d^2}=4\left(1.25\times10^5\,\text{A}\right)^2\left(1.68\times10^{-8}\Omega\bullet\text{m}\right)\frac{2(1.0\,\text{m})}{\pi\left(5.0\times10^{-3}\,\text{m}\right)^2}$$
$$=2.674\times10^7\,\text{W}$$

$$\text{Cost}=(\text{Power})(\text{time})(\text{rate per kWh})=\left(2.674\times10^7\,\text{W}\right)\left(\frac{1\,\text{kW}}{1000\,\text{W}}\right)(1\,\text{h})\left(\frac{\$0.090}{\text{kWh}}\right)$$
$$=\$2407\approx\boxed{\$2,400\text{ per hour per meter}}$$

71. (*a*) Use Eq. 25-7b 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 smaller than the value given in the first part of the problem.

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72. Assume that we have a meter of wire, carrying 35 A of current, and dissipating 1.5 W of heat. The power dissipated is $P_R = I^2 R$, and the resistance is $R = \frac{\rho\ell}{A}$.

$$P_R = I^2 R = I^2 \frac{\rho\ell}{A} = I^2 \frac{\rho\ell}{\pi r^2} = I^2 \frac{4\rho\ell}{\pi d^2} \quad \to$$

$$d = \sqrt{I^2 \frac{4\rho\ell}{P_R \pi}} = 2I\sqrt{\frac{\rho\ell}{P_R\pi}} = 2(35\,\text{A})\sqrt{\frac{(1.68\times 10^{-8}\,\Omega\bullet\text{m})(1.0\,\text{m})}{(1.5\,\text{W})\pi}} = \boxed{4.2\times 10^{-3}\,\text{m}}$$

$\boxed{73.}$ (*a*) The resistance at the operating temperature can be calculated directly from Eq. 25-7.

$$P = \frac{V^2}{R} \quad \to \quad R = \frac{V^2}{P} = \frac{(120\,\text{V})^2}{75\,\text{W}} = \boxed{190\,\Omega}$$

(*b*) The resistance at room temperature is found by converting Eq. 25-5 into an equation for resistances and solving for R_0.

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

$$R_0 = \frac{R}{\left[1+\alpha\left(T-T_0\right)\right]} = \frac{192\,\Omega}{\left[1+\left(0.0045\,\text{K}^{-1}\right)\left(3000\,\text{K} - 293\,\text{K}\right)\right]} = \boxed{15\,\Omega}$$

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

$$f = \frac{\omega}{2\pi} = \frac{210\,\text{rad/s}}{2\pi} = 33.42\,\text{Hz} \approx \boxed{33\,\text{Hz}}$$

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

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

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

$$V = IR = (1.80\,\text{A})(\sin 210\,t)(24.0\,\Omega) = \boxed{(43.2\sin 210\,t)\,\text{V}}$$

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

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

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

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

76. 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 since the length was increased by a factor of 1.20, the area was decreased by a factor of 1.20. Use Eq. 25-3.

$$R_0 = \rho\frac{\ell_0}{A_0} \qquad \ell = 1.20\ell_0 \qquad A = \frac{A_0}{1.20} \qquad R = \rho\frac{\ell}{A} = \rho\frac{1.20\ell_0}{\frac{A_0}{1.20}} = (1.20)^2\rho\frac{\ell_0}{A_0} = 1.44R_0 = \boxed{1.44\,\Omega}$$

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77. 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. 25-7b, $P = V^2/R$, and both have the same voltage applied.

$$R_1 = \rho\frac{\ell_1}{A_1} \quad R_2 = \rho\frac{\ell_2}{A_2} \quad \ell_1 = 2\ell_2 \quad A_1 = 4A_2 \ \left(\text{diameter}_1 = 2\text{diameter}_2\right)$$

$$\frac{P_1}{P_2} = \frac{V_1^2/R_1}{V_2^2/R_2} = \frac{R_2}{R_1} = \frac{\rho\ell_2/A_2}{\rho\ell_1/A_1} = \frac{\ell_2}{\ell_1}\frac{A_1}{A_2} = \frac{1}{2}\times 4 = 2 \quad \boxed{P_1 : P_2 = 2:1}$$

78. The heater must heat $108\,\text{m}^3$ 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. 19-2 to calculate the energy needed to heat the air. The density of air is found in Table 13-1.

$$Q = mc\Delta T \quad \rightarrow \quad \frac{Q}{t} = \frac{m}{t}c\Delta T = \left(108\frac{\text{m}^3}{\text{h}}\right)\left(1.29\frac{\text{kg}}{\text{m}^3}\right)\left(0.17\frac{\text{kcal}}{\text{kg•C}^\circ}\right)\left(15\text{C}^\circ\right) = 355\frac{\text{kcal}}{\text{h}}$$

$$\text{Power required} = 355\frac{\text{kcal}}{\text{h}} + 850\frac{\text{kcal}}{\text{h}} = 1205\frac{\text{kcal}}{\text{h}}\left(\frac{4186\,\text{J}}{\text{kcal}}\right)\left(\frac{1\,\text{h}}{3600\,\text{s}}\right) = 1401\,\text{W} \approx \boxed{1400\,\text{W}}$$

79. (*a*) Use Eq. 25-7b.

$$P = \frac{V^2}{R} \quad \rightarrow \quad R = \frac{V^2}{P} = \frac{(240\,\text{V})^2}{2800\,\text{W}} = 20.57\,\Omega \approx \boxed{21\,\Omega}$$

(*b*) Only 75% of the heat from the oven is used to heat the water. Use Eq. 19-2.

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

$$t = \frac{mc\Delta T}{0.75\left(P_{\text{oven}}\right)} = \frac{(0.120\,\text{L})\left(\frac{1\,\text{kg}}{1\,\text{L}}\right)(4186\,\text{J/kg•C}^\circ)(85\,\text{C}^\circ)}{0.75(2800\,\text{W})} = 20.33\,\text{s} \approx \boxed{20\,\text{s}}\ (2\text{ sig. fig.})$$

(*c*) $$\frac{11\,\text{cents}}{\text{kWh}}(2.8\,\text{kW})(20.33\,\text{s})\frac{1\,\text{h}}{3600\,\text{s}} = \boxed{0.17\,\text{cents}}$$

80. (*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 $Q = 95\,\text{A•h} = 95\,\text{C/s•}3600\,\text{s} = 3.42\times10^5\,\text{C}$, 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.

$$P = \frac{U}{t} = \frac{QV}{t} \quad \rightarrow \quad t = \frac{QV}{P} = \frac{d}{v} \quad \rightarrow$$

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

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81. 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. 25-3. We represent the mass density by ρ_{m} and the resistivity by ρ.

$$R=\rho\frac{\ell}{A} \rightarrow A=\frac{\rho\ell}{R} \qquad m=\rho_{\mathrm{m}}\ell A=\rho_{\mathrm{m}}\ell\frac{\rho\ell}{R} \rightarrow$$

$$\ell=\sqrt{\frac{mR}{\rho_{\mathrm{m}}\rho}}=\sqrt{\frac{(0.0155\,\mathrm{kg})(12.5\,\Omega)}{(8.9\times10^{3}\,\mathrm{kg/m^{3}})(1.68\times10^{-8}\,\Omega\bullet\mathrm{m})}}=35.997\,\mathrm{m}\approx\boxed{36.0\,\mathrm{m}}$$

$$A=\frac{\rho\ell}{R}=\pi\left(\tfrac{1}{2}d\right)^{2} \rightarrow d=\sqrt{\frac{4\rho\ell}{\pi R}}=\sqrt{\frac{4(1.68\times10^{-8}\,\Omega\bullet\mathrm{m})(35.997\,\mathrm{m})}{\pi(12.5\,\Omega)}}=\boxed{2.48\times10^{-4}\,\mathrm{m}}$$

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

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

$$d=\sqrt{\frac{4\rho LP}{\pi V^{2}}}=\sqrt{\frac{4(100\times10^{-8}\,\Omega\bullet\mathrm{m})(3.8\,\mathrm{m})(95\,\mathrm{W})}{\pi(120\,\mathrm{V})^{2}}}=1.787\times10^{-4}\,\mathrm{m}\approx\boxed{1.8\times10^{-4}\,\mathrm{m}}$$

83. Use Eq. 25-7b.

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

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

84. Use Eq. 25-7b for the power in each case, assuming the resistance is constant.

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

85. Model the protons as moving in a continuous beam of cross-sectional area *A*. Then by Eq. 25-13, $I=neAv_{\mathrm{d}}$, where we only consider the absolute value of the current. The variable *n* is the number of protons per unit volume, so $n=\dfrac{N}{A\ell}$, 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.

$$I=neAv_{\mathrm{d}}=\frac{N}{A\ell}eAv_{\mathrm{d}}=\frac{N}{\ell}ev_{\mathrm{d}} \rightarrow$$

$$N=\frac{I\ell}{ev_{\mathrm{d}}}=\frac{(11\times10^{-3})(6300\,\mathrm{m})}{(1.60\times10^{-19}\,\mathrm{C})(3.00\times10^{8}\,\mathrm{m/s})}=\boxed{1.4\times10^{12}\text{ protons}}$$

86. (*a*) The current can be found from Eq. 25-6.

$$I=P/V \qquad I_{A}=P_{A}/V_{A}=40\mathrm{W}/120\,\mathrm{V}=\boxed{0.33\,\mathrm{A}} \qquad I_{B}=P_{B}/V_{B}=40\mathrm{W}/12\,\mathrm{V}=\boxed{3.3\,\mathrm{A}}$$

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(*b*) The resistance can be found from Eq. 25-7b.

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

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

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

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

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

$$E = Pt \qquad E_A = E_B = (40\,\text{W})(3600\,\text{s}) = \boxed{1.4\times10^5\,\text{J}}$$

(*e*) Bulb B requires a larger current, and so should have larger diameter connecting wires to avoid overheating the connecting wires.

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

$$P = IV = (14\,\text{A})(220\,\text{V}) = 3080\text{W} \approx \boxed{3100\,\text{W}}$$

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

$$P_R = I^2R = I^2\frac{\rho\ell}{A} = I^2\frac{\rho\ell}{\pi r^2} = I^2\frac{4\rho\ell}{\pi d^2} = (14\,\text{A})^2\frac{4(1.68\times10^{-8}\Omega\text{•m})(15\,\text{m})}{\pi(1.628\times10^{-3}\text{m})^2} = 23.73\,\text{W}$$

$$\approx \boxed{24\,\text{W}}$$

(*c*) $$P_R = I^2\frac{4\rho L}{\pi d^2} = (14\,\text{A})^2\frac{4(1.68\times10^{-8}\Omega\text{•m})(15\,\text{m})}{\pi(2.053\times10^{-3}\text{m})^2} = 14.92\,\text{W} \approx \boxed{15\,\text{W}}$$

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

$$\text{Savings} = (23.73\,\text{W} - 14.92\,\text{W})\left(\frac{1\,\text{kW}}{1000\,\text{W}}\right)(30\,\text{d})\left(\frac{12\,\text{h}}{1\,\text{d}}\right)\left(\frac{\$0.12}{1\,\text{kWh}}\right)$$

$$= \$0.3806/\text{month} \approx \boxed{38\,\text{cents per month}}$$

88. The wasted power is due to losses in the wire. The current in the wire can be found by $I = P/V$.

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

$$= \frac{(1750\,\text{W})^2}{(120\,\text{V})^2}\frac{4(1.68\times10^{-8}\Omega\text{•m})(25.0\,\text{m})}{\pi(2.59\times10^{-3}\text{m})^2} = 16.954\,\text{W} \approx \boxed{17.0\,\text{W}}$$

(*b*) $$P_R = \frac{P^2}{V^2}\frac{4\rho L}{\pi d^2} = \frac{(1750\,\text{W})^2}{(120\,\text{V})^2}\frac{4(1.68\times10^{-8}\Omega\text{•m})(25.0\,\text{m})}{\pi(4.12\times10^{-3}\text{m})^2} = \boxed{6.70\,\text{W}}$$

89. (*a*) The D-cell provides 25 mA at 1.5 V for 820 h, at a cost of \$1.70.

$$\text{Energy} = Pt = VIt = (1.5\,\text{V})(0.025\,\text{A})(820\,\text{h})\left(\frac{1\,\text{kW}}{1000\,\text{W}}\right) = 0.03075\,\text{kWh}$$

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$$\text{Cost/kWh} = \frac{\$1.70}{0.03075\,\text{kWh}} = \$55.28/\text{kWh} \approx \boxed{\$55/\text{kWh}}$$

(*b*) The AA-cell provides 25 mA at 1.5 V for 120 h, at a cost of $1.25.

$$\text{Energy} = Pt = VIt = (1.5\,\text{V})(0.025\,\text{A})(120\,\text{h})\left(\frac{1\,\text{kW}}{1000\,\text{W}}\right) = 0.0045\,\text{kWh}$$

$$\text{Cost/kWh} = \frac{\$1.25}{0.0045\,\text{kWh}} = \$277.78/\text{kWh} \approx \boxed{\$280/\text{kWh}}$$

The D-cell is $\frac{\$55.28/\text{kWh}}{\$0.10/\text{kWh}} \approx \boxed{550\times\text{as costly}}$. The AA-cell is $\frac{\$277.78/\text{kWh}}{\$0.10/\text{kWh}} \approx \boxed{2800\times\text{as costly}}$.

90. The electrons are assumed to be moving with simple harmonic motion. During one cycle, an object in simple harmonic motion will move a distance equal to the amplitude from its equilibrium point. From Eq. 14-9a, we know that $v_{\max} = A\omega$, where ω is the angular frequency of oscillation. From Eq. 25-13 in absolute value, we see that $I_{\max} = neAv_{\max}$. Finally, the maximum current can be related to the power by Eqs. 25-9 and 25-10. The charge carrier density, *n*, is calculated in Example 25-14.

$$\overline{P} = I_{\text{rms}}V_{\text{rms}} = \tfrac{1}{\sqrt{2}}I_{\max}V_{\text{rms}}$$

$$A = \frac{v_{\max}}{\omega} = \frac{I_{\max}}{\omega neA} = \frac{\sqrt{2}\overline{P}}{\omega ne\frac{\pi d^2}{4}V_{\text{rms}}}$$

$$= \frac{4\sqrt{2}(550\,\text{W})}{2\pi(60\,\text{Hz})(8.4\times10^{28}\,\text{m}^{-3})(1.60\times10^{-19}\,\text{C})\pi(1.7\times10^{-3}\,\text{m})^2(120\,\text{V})} = \boxed{5.6\times10^{-7}\,\text{m}}$$

The electron will move this distance in both directions from its equilibrium point.

$\boxed{91.}$ Eq. 25-3 can be used. The area to be used is the cross-sectional area of the pipe.

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

92. We assume that all of the current that enters at *a* leaves at *b*, so that the current is the same at each end. The current density is given by Eq. 25-11.

$$j_{\text{a}} = \frac{I}{A_{\text{a}}} = \frac{I}{\pi\left(\frac{1}{2}a\right)^2} = \frac{4I}{\pi a^2} = \frac{4(2.0\,\text{A})}{\pi(2.5\times10^{-3}\,\text{m})^2} = \boxed{4.1\times10^5\,\text{A/m}^2}$$

$$j_{\text{b}} = \frac{I}{A_{\text{b}}} = \frac{I}{\pi\left(\frac{1}{2}b\right)^2} = \frac{4I}{\pi b^2} = \frac{4(2.0\,\text{A})}{\pi(4.0\times10^{-3}\,\text{m})^2} = \boxed{1.6\times10^5\,\text{A/m}^2}$$

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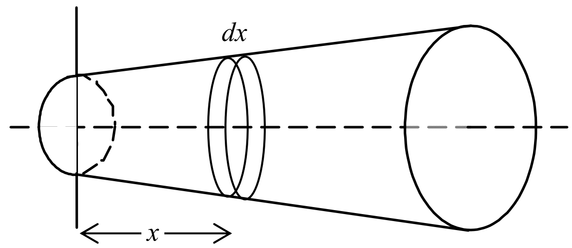
93. Using Eq. 25-3, we find the infinitesimal resistance first of a thin vertical slice at a horizontal distance x from the center of the left side towards the center of the right side. Let the thickness of that slice be dx. That thickness corresponds to the variable ℓ in Eq. 25-3. The diameter of this slice is $a+\frac{x}{\ell}(b-a)$. Then integrate over all the slices to find the total resistance.



$$R=\rho\frac{\ell}{A} \rightarrow dR=\rho\frac{dx}{\pi\frac{1}{4}\left(a+\frac{x}{\ell}(b-a)\right)^2} \rightarrow$$

$$R=\int dR=\int_0^{\ell}\rho\frac{dx}{\pi\frac{1}{4}\left(a+\frac{x}{\ell}(b-a)\right)^2}=-\frac{4\rho}{\pi}\frac{\ell}{b-a}\frac{1}{\left(a+\frac{x}{\ell}(b-a)\right)}\Bigg|_0^{\ell}=\boxed{\frac{4\rho}{\pi}\frac{\ell}{ab}}$$

94. 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. 25-3 and 25-5 to find the temperature.

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

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

95. When the tank is empty, the entire length of the wire is in a non-superconducting state, and so has a non-zero resistivity, which we call ρ. Then the resistance of the wire when the tank is empty is given by $R_0=\rho\frac{\ell}{A}=\frac{V_0}{I}$. When a length x of the wire is superconducting, that portion of the wire has 0 resistance. Then the resistance of the wire is only due to the length $\ell-x$, and so $R=\rho\frac{\ell-x}{A}=\rho\frac{\ell}{A}\frac{\ell-x}{\ell}=R_0\frac{\ell-x}{\ell}$. This resistance, combined with the constant current, gives $V=IR$.

$$V=IR=\left(\frac{V_0}{R_0}\right)R_0\frac{\ell-x}{\ell}=V_0\left(1-\frac{x}{\ell}\right)=V_0\left(1-f\right) \rightarrow \boxed{f=1-\frac{V}{V_0}}$$

Thus a measurement of the voltage can give the fraction of the tank that is filled with liquid helium.

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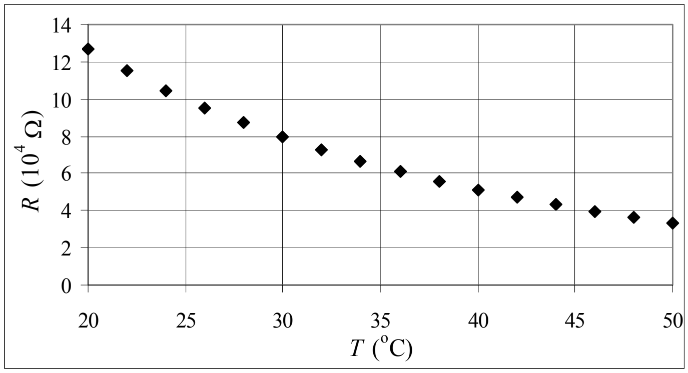
96. We plot resistance vs. temperature. The graph is shown as follows, with no curve fitted to it. It is apparent that a linear fit will not be a good fit to this data. Both quadratic and exponential equations fit the data well, according to the R-squared coefficient as given by Excel. The equations and the predictions are given below.



$$R_{\text{exp}} = \left(30.1\times10^4 e^{-0.0442T}\right)\Omega$$

$$R_{\text{quad}} = \left[\left(7.39\times10^4\right)T^2 - 8200T + 25.9\times10^4\right]\Omega$$

Solving these expressions for $R = 57,641\,\Omega$ (using the spreadsheet) gives $T_{\text{exp}} = 37.402°\text{C}$ and $T_{\text{quad}} = 37.021°\text{C}$. So the temperature is probably in the range between those two values: $\boxed{37.021°\text{C} < T < 37.402°\text{C}}$. The average of those two values is $\boxed{T = 37.21°\text{C}}$. The spreadsheet used for this problem can be found on the Media Manager, with filename "PSE4_ISM_CH25.XLS," on tab "Problem 25.96."

As an extra comment, how might you choose between the exponential and quadratic fits? While they both give almost identical predictions for this intermediate temperature, they differ significantly at temperatures near $0°\text{C}$. The exponential fit would give a resistance of about $301,000\,\Omega$ at $0°\text{C}$, while the quadratic fit would give a resistance of about 259,000 Ω at $0°\text{C}$. So a measurement of resistance near $0°\text{C}$ might be very useful.

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