

CURRENT, RESISTANCE, AND ELECTROMOTIVE FORCE

25.1. IDENTIFY and SET UP: The lightning is a current that lasts for a brief time. $I = \frac{\Delta Q}{\Delta t}$.

EXECUTE: $\Delta Q = I\Delta t = (25,000 \text{ A})(40 \times 10^{-6} \text{ s}) = 1.0 \text{ C}$.

EVALUATE: Even though it lasts for only $40 \mu\text{s}$, the lightning carries a huge amount of charge since it is an enormous current.

25.2. IDENTIFY: $I = Q/t$. Use $I = n|q|v_d A$ to calculate the drift velocity v_d .

SET UP: $n = 5.8 \times 10^{28} \text{ m}^{-3}$. $|q| = 1.60 \times 10^{-19} \text{ C}$.

EXECUTE: (a) $I = \frac{Q}{t} = \frac{420 \text{ C}}{80(60 \text{ s})} = 8.75 \times 10^{-2} \text{ A}$.

(b) $I = n|q|v_d A$. This gives $v_d = \frac{I}{n|q|A} = \frac{8.75 \times 10^{-2} \text{ A}}{(5.8 \times 10^{28})(1.60 \times 10^{-19} \text{ C})(\pi(1.3 \times 10^{-3} \text{ m})^2)} = 1.78 \times 10^{-6} \text{ m/s}$.

EVALUATE: v_d is smaller than in Example 25.1, because I is smaller in this problem.

25.3. IDENTIFY: $I = Q/t$. $J = I/A$. $J = n|q|v_d$

SET UP: $A = (\pi/4)D^2$, with $D = 2.05 \times 10^{-3} \text{ m}$. The charge of an electron has magnitude $+e = 1.60 \times 10^{-19} \text{ C}$.

EXECUTE: (a) $Q = It = (5.00 \text{ A})(1.00 \text{ s}) = 5.00 \text{ C}$. The number of electrons is $\frac{Q}{e} = 3.12 \times 10^{19}$.

(b) $J = \frac{I}{(\pi/4)D^2} = \frac{5.00 \text{ A}}{(\pi/4)(2.05 \times 10^{-3} \text{ m})^2} = 1.51 \times 10^6 \text{ A/m}^2$.

(c) $v_d = \frac{J}{n|q|} = \frac{1.51 \times 10^6 \text{ A/m}^2}{(8.5 \times 10^{28} \text{ m}^{-3})(1.60 \times 10^{-19} \text{ C})} = 1.11 \times 10^{-4} \text{ m/s} = 0.111 \text{ mm/s}$.

EVALUATE: (d) If I is the same, $J = I/A$ would decrease and v_d would decrease. The number of electrons passing through the light bulb in 1.00 s would not change.

25.4. (a) IDENTIFY: By definition, $J = I/A$ and radius is one-half the diameter.

SET UP: Solve for the current: $I = JA = J\pi(D/2)^2$

EXECUTE: $I = (1.50 \times 10^6 \text{ A/m}^2)(\pi)[(0.00102 \text{ m})/2]^2 = 1.23 \text{ A}$

EVALUATE: This is a realistic current.

(b) IDENTIFY: The current density is $J = n|q|v_d$.

SET UP: Solve for the drift velocity: $v_d = J/n|q|$

EXECUTE: Since most laboratory wire is copper, we use the value of n for copper, giving

$v_d = (1.50 \times 10^6 \text{ A/m}^2)/[(8.5 \times 10^{28} \text{ m}^{-3})(1.60 \times 10^{-19} \text{ C})] = 1.1 \times 10^{-4} \text{ m/s} = 0.11 \text{ mm/s}$.

EVALUATE: This is a typical drift velocity for ordinary currents and wires.

- 25.5. IDENTIFY and SET UP:** Use Eq. (25.3) to calculate the drift speed and then use that to find the time to travel the length of the wire.

EXECUTE: (a) Calculate the drift speed v_d :

$$J = \frac{I}{A} = \frac{I}{\pi r^2} = \frac{4.85 \text{ A}}{\pi(1.025 \times 10^{-3} \text{ m})^2} = 1.469 \times 10^6 \text{ A/m}^2$$

$$v_d = \frac{J}{n|q|} = \frac{1.469 \times 10^6 \text{ A/m}^2}{(8.5 \times 10^{28} / \text{m}^3)(1.602 \times 10^{-19} \text{ C})} = 1.079 \times 10^{-4} \text{ m/s}$$

$$t = \frac{L}{v_d} = \frac{0.710 \text{ m}}{1.079 \times 10^{-4} \text{ m/s}} = 6.58 \times 10^3 \text{ s} = 110 \text{ min.}$$

$$\text{(b) } v_d = \frac{I}{\pi r^2 n |q|}$$

$$t = \frac{L}{v_d} = \frac{\pi r^2 n |q| L}{I}$$

t is proportional to r^2 and hence to d^2 where $d = 2r$ is the wire diameter.

$$t = (6.58 \times 10^3 \text{ s}) \left(\frac{4.12 \text{ mm}}{2.05 \text{ mm}} \right)^2 = 2.66 \times 10^4 \text{ s} = 440 \text{ min.}$$

(c) EVALUATE: The drift speed is proportional to the current density and therefore it is inversely proportional to the square of the diameter of the wire. Increasing the diameter by some factor decreases the drift speed by the square of that factor.

- 25.6. IDENTIFY:** The number of moles of copper atoms is the mass of 1.00 m^3 divided by the atomic mass of copper. There are $N_A = 6.022 \times 10^{23}$ atoms per mole.

SET UP: The atomic mass of copper is 63.55 g/mole , and its density is 8.96 g/cm^3 . Example 25.1 says there are 8.5×10^{28} free electrons per m^3 .

EXECUTE: The number of copper atoms in 1.00 m^3 is

$$\frac{(8.96 \text{ g/cm}^3)(1.00 \times 10^6 \text{ cm}^3/\text{m}^3)(6.022 \times 10^{23} \text{ atoms/mole})}{63.55 \text{ g/mole}} = 8.49 \times 10^{28} \text{ atoms/m}^3.$$

EVALUATE: Since there are the same number of free electrons/ m^3 as there are atoms of copper/ m^3 , the number of free electrons per copper atom is one.

- 25.7. IDENTIFY and SET UP:** Apply Eq. (25.1) to find the charge dQ in time dt . Integrate to find the total charge in the whole time interval.

EXECUTE: (a) $dQ = I dt$

$$Q = \int_0^{8.0\text{s}} (55 \text{ A} - (0.65 \text{ A/s}^2)t^2) dt = \left[(55 \text{ A})t - (0.217 \text{ A/s}^2)t^3 \right]_0^{8.0\text{s}}$$

$$Q = (55 \text{ A})(8.0 \text{ s}) - (0.217 \text{ A/s}^2)(8.0 \text{ s})^3 = 330 \text{ C}$$

$$\text{(b) } I = \frac{Q}{t} = \frac{330 \text{ C}}{8.0 \text{ s}} = 41 \text{ A}$$

EVALUATE: The current decreases from 55 A to 13.4 A during the interval. The decrease is not linear and the average current is not equal to $(55 \text{ A} + 13.4 \text{ A})/2$.

- 25.8. IDENTIFY:** $I = Q/t$. Positive charge flowing in one direction is equivalent to negative charge flowing in the opposite direction, so the two currents due to Cl^- and Na^+ are in the same direction and add.

SET UP: Na^+ and Cl^- each have magnitude of charge $|q| = +e$.

EXECUTE: (a) $Q_{\text{total}} = (n_{\text{Cl}} + n_{\text{Na}})e = (3.92 \times 10^{16} + 2.68 \times 10^{16})(1.60 \times 10^{-19} \text{ C}) = 0.0106 \text{ C}$. Then

$$I = \frac{Q_{\text{total}}}{t} = \frac{0.0106 \text{ C}}{1.00 \text{ s}} = 0.0106 \text{ A} = 10.6 \text{ mA.}$$

(b) Current flows, by convention, in the direction of positive charge. Thus, current flows with Na^+ toward the negative electrode.

EVALUATE: The Cl^- ions have negative charge and move in the direction opposite to the conventional current direction.

- 25.9. IDENTIFY and SET UP: The number of ions that enter gives the charge that enters the axon in the specified time. $I = \frac{\Delta Q}{\Delta t}$.

EXECUTE: $\Delta Q = (5.6 \times 10^{11} \text{ ions})(1.60 \times 10^{-19} \text{ C/ion}) = 9.0 \times 10^{-8} \text{ C}$. $I = \frac{\Delta Q}{\Delta t} = \frac{9.0 \times 10^{-8} \text{ C}}{10 \times 10^{-3} \text{ s}} = 9.0 \mu\text{A}$.

EVALUATE: This current is much smaller than household currents but are comparable to many currents in electronic equipment.

- 25.10. (a) IDENTIFY: Start with the definition of resistivity and solve for E .

SET UP: $E = \rho J = \rho I / \pi r^2$

EXECUTE: $E = (1.72 \times 10^{-8} \Omega \cdot \text{m})(2.75 \text{ A}) / [\pi(0.001025 \text{ m})^2] = 1.43 \times 10^{-2} \text{ V/m}$

EVALUATE: The field is quite weak, since the potential would drop only a volt in 70 m of wire.

(b) IDENTIFY: Take the ratio of the field in silver to the field in copper.

SET UP: Take the ratio and solve for the field in silver: $E_S = E_C(\rho_S / \rho_C)$

EXECUTE: $E_S = (0.0143 \text{ V/m})[(1.47)/(1.72)] = 1.22 \times 10^{-2} \text{ V/m}$

EVALUATE: Since silver is a better conductor than copper, the field in silver is smaller than the field in copper.

- 25.11. IDENTIFY: First use Ohm's law to find the resistance at 20.0°C ; then calculate the resistivity from the resistance. Finally use the dependence of resistance on temperature to calculate the temperature coefficient of resistance.

SET UP: Ohm's law is $R = V/I$, $R = \rho L/A$, $R = R_0[1 + \alpha(T - T_0)]$, and the radius is one-half the diameter.

EXECUTE: (a) At 20.0°C , $R = V/I = (15.0 \text{ V})/(18.5 \text{ A}) = 0.811 \Omega$. Using $R = \rho L/A$ and solving for ρ gives $\rho = RA/L = R\pi(D/2)^2/L = (0.811 \Omega)\pi[(0.00500 \text{ m})/2]^2/(1.50 \text{ m}) = 1.06 \times 10^{-5} \Omega \cdot \text{m}$.

(b) At 92.0°C , $R = V/I = (15.0 \text{ V})/(17.2 \text{ A}) = 0.872 \Omega$. Using $R = R_0[1 + \alpha(T - T_0)]$ with T_0 taken as 20.0°C , we have $0.872 \Omega = (0.811 \Omega)[1 + \alpha(92.0^\circ\text{C} - 20.0^\circ\text{C})]$. This gives $\alpha = 0.00105 (\text{C}^\circ)^{-1}$.

EVALUATE: The results are typical of ordinary metals.

- 25.12. IDENTIFY: $E = \rho J$, where $J = I/A$. The drift velocity is given by $I = n|q|v_d A$.

SET UP: For copper, $\rho = 1.72 \times 10^{-8} \Omega \cdot \text{m}$. $n = 8.5 \times 10^{28}/\text{m}^3$.

EXECUTE: (a) $J = \frac{I}{A} = \frac{3.6 \text{ A}}{(2.3 \times 10^{-3} \text{ m})^2} = 6.81 \times 10^5 \text{ A/m}^2$.

(b) $E = \rho J = (1.72 \times 10^{-8} \Omega \cdot \text{m})(6.81 \times 10^5 \text{ A/m}^2) = 0.012 \text{ V/m}$.

(c) The time to travel the wire's length l is

$$t = \frac{l}{v_d} = \frac{ln|q|A}{I} = \frac{(4.0 \text{ m})(8.5 \times 10^{28}/\text{m}^3)(1.6 \times 10^{-19} \text{ C})(2.3 \times 10^{-3} \text{ m})^2}{3.6 \text{ A}} = 8.0 \times 10^4 \text{ s}$$

$$t = 1333 \text{ min} \approx 22 \text{ hrs!}$$

EVALUATE: The currents propagate very quickly along the wire but the individual electrons travel very slowly.

- 25.13. IDENTIFY: Knowing the resistivity of a metal, its geometry and the current through it, we can use Ohm's law to find the potential difference across it.

SET UP: $V = IR$. For copper, Table 25.1 gives that $\rho = 1.72 \times 10^{-8} \Omega \cdot \text{m}$ and for silver,

$$\rho = 1.47 \times 10^{-8} \Omega \cdot \text{m}. R = \frac{\rho L}{A}$$

EXECUTE: (a) $R = \frac{\rho L}{A} = \frac{(1.72 \times 10^{-8} \Omega \cdot \text{m})(2.00 \text{ m})}{\pi(0.814 \times 10^{-3} \text{ m})^2} = 1.65 \times 10^{-2} \Omega$.

$$V = (12.5 \times 10^{-3} \text{ A})(1.65 \times 10^{-2} \Omega) = 2.06 \times 10^{-4} \text{ V}.$$

(b) $V = \frac{I\rho L}{A}$. $\frac{V}{\rho} = \frac{IL}{A} = \text{constant}$, so $\frac{V_s}{\rho_s} = \frac{V_c}{\rho_c}$.

$$V_s = V_c \left(\frac{\rho_s}{\rho_c} \right) = (2.06 \times 10^{-4} \text{ V}) \left(\frac{1.47 \times 10^{-8} \Omega \cdot \text{m}}{1.72 \times 10^{-8} \Omega \cdot \text{m}} \right) = 1.76 \times 10^{-4} \text{ V}.$$

EVALUATE: The potential difference across a 2-m length of wire is less than 0.2 mV, so normally we do not need to worry about these potential drops in laboratory circuits.

25.14. IDENTIFY: The resistivity of the wire should identify what the material is.

SET UP: $R = \rho L/A$ and the radius of the wire is half its diameter.

EXECUTE: Solve for ρ and substitute the numerical values.

$$\rho = AR/L = \pi(D/2)^2 R/L = \frac{\pi[(0.00205 \text{ m}/2)^2 (0.0290 \Omega)]}{6.50 \text{ m}} = 1.47 \times 10^{-8} \Omega \cdot \text{m}$$

EVALUATE: This result is the same as the resistivity of silver, which implies that the material is silver.

25.15. (a) IDENTIFY: Start with the definition of resistivity and use its dependence on temperature to find the electric field.

SET UP: $E = \rho J = \rho_{20}[1 + \alpha(T - T_0)] \frac{I}{\pi r^2}$

EXECUTE: $E = (5.25 \times 10^{-8} \Omega \cdot \text{m})[1 + (0.0045/\text{C}^\circ)(120^\circ\text{C} - 20^\circ\text{C})](12.5 \text{ A})/[\pi(0.000500 \text{ m})^2] = 1.21 \text{ V/m}$.

(Note that the resistivity at 120°C turns out to be $7.61 \times 10^{-8} \Omega \cdot \text{m}$.)

EVALUATE: This result is fairly large because tungsten has a larger resistivity than copper.

(b) **IDENTIFY:** Relate resistance and resistivity.

SET UP: $R = \rho L/A = \rho L/\pi r^2$

EXECUTE: $R = (7.61 \times 10^{-8} \Omega \cdot \text{m})(0.150 \text{ m})/[\pi(0.000500 \text{ m})^2] = 0.0145 \Omega$

EVALUATE: Most metals have very low resistance.

(c) **IDENTIFY:** The potential difference is proportional to the length of wire.

SET UP: $V = EL$

EXECUTE: $V = (1.21 \text{ V/m})(0.150 \text{ m}) = 0.182 \text{ V}$

EVALUATE: We could also calculate $V = IR = (12.5 \text{ A})(0.0145 \Omega) = 0.181 \text{ V}$, in agreement with part (c).

25.16. IDENTIFY: The geometry of the wire is changed, so its resistance will also change.

SET UP: $R = \frac{\rho L}{A}$. $L_{\text{new}} = 3L$. The volume of the wire remains the same when it is stretched.

EXECUTE: Volume = LA so $LA = L_{\text{new}} A_{\text{new}}$. $A_{\text{new}} = \frac{L}{L_{\text{new}}} A = \frac{A}{3}$.

$$R_{\text{new}} = \frac{\rho L_{\text{new}}}{A_{\text{new}}} = \frac{\rho(3L)}{A/3} = 9 \frac{\rho L}{A} = 9R.$$

EVALUATE: When the length increases the resistance increases and when the area decreases the resistance increases.

25.17. IDENTIFY: $R = \frac{\rho L}{A}$.

SET UP: For copper, $\rho = 1.72 \times 10^{-8} \Omega \cdot \text{m}$. $A = \pi r^2$.

EXECUTE: $R = \frac{(1.72 \times 10^{-8} \Omega \cdot \text{m})(24.0 \text{ m})}{\pi(1.025 \times 10^{-3} \text{ m})^2} = 0.125 \Omega$

EVALUATE: The resistance is proportional to the length of the piece of wire.

25.18. IDENTIFY: $R = \frac{\rho L}{A} = \frac{\rho L}{\pi d^2/4}$.

SET UP: For aluminum, $\rho_{\text{al}} = 2.63 \times 10^{-8} \Omega \cdot \text{m}$. For copper, $\rho_{\text{c}} = 1.72 \times 10^{-8} \Omega \cdot \text{m}$.

EXECUTE: $\frac{\rho}{d^2} = \frac{R\pi}{4L} = \text{constant}$, so $\frac{\rho_{\text{al}}}{d_{\text{al}}^2} = \frac{\rho_{\text{c}}}{d_{\text{c}}^2}$.

$$d_{\text{c}} = d_{\text{al}} \sqrt{\frac{\rho_{\text{c}}}{\rho_{\text{al}}}} = (3.26 \text{ mm}) \sqrt{\frac{1.72 \times 10^{-8} \Omega \cdot \text{m}}{2.63 \times 10^{-8} \Omega \cdot \text{m}}} = 2.64 \text{ mm}.$$

EVALUATE: Copper has a smaller resistivity, so the copper wire has a smaller diameter in order to have the same resistance as the aluminum wire.

25.19. IDENTIFY and SET UP: Use Eq. (25.10) to calculate A . Find the volume of the wire and use the density to calculate the mass.

EXECUTE: Find the volume of one of the wires:

$$R = \frac{\rho L}{A} \text{ so } A = \frac{\rho L}{R} \text{ and}$$

$$\text{Volume} = AL = \frac{\rho L^2}{R} = \frac{(1.72 \times 10^{-8} \Omega \cdot \text{m})(3.50 \text{ m})^2}{0.125 \Omega} = 1.686 \times 10^{-6} \text{ m}^3$$

$$m = (\text{density})V = (8.9 \times 10^3 \text{ kg/m}^3)(1.686 \times 10^{-6} \text{ m}^3) = 15 \text{ g}$$

EVALUATE: The mass we calculated is reasonable for a wire.

25.20. IDENTIFY: $R = \frac{\rho L}{A}$.

SET UP: The length of the wire in the spring is the circumference πd of each coil times the number of coils.

EXECUTE: $L = (75)\pi d = (75)\pi(3.50 \times 10^{-2} \text{ m}) = 8.25 \text{ m}$.

$$A = \pi r^2 = \pi d^2/4 = \pi(3.25 \times 10^{-3} \text{ m})^2/4 = 8.30 \times 10^{-6} \text{ m}^2.$$

$$\rho = \frac{RA}{L} = \frac{(1.74 \Omega)(8.30 \times 10^{-6} \text{ m}^2)}{8.25 \text{ m}} = 1.75 \times 10^{-6} \Omega \cdot \text{m}.$$

EVALUATE: The value of ρ we calculated is about a factor of 100 times larger than ρ for copper. The metal of the spring is not a very good conductor.

25.21. IDENTIFY: $R = \frac{\rho L}{A}$.

SET UP: $L = 1.80 \text{ m}$, the length of one side of the cube. $A = L^2$.

EXECUTE: $R = \frac{\rho L}{A} = \frac{\rho L}{L^2} = \frac{\rho}{L} = \frac{2.75 \times 10^{-8} \Omega \cdot \text{m}}{1.80 \text{ m}} = 1.53 \times 10^{-8} \Omega$

EVALUATE: The resistance is very small because A is very much larger than the typical value for a wire.

25.22. IDENTIFY: Apply $R = \frac{\rho L}{A}$ and $V = IR$.

SET UP: $A = \pi r^2$

EXECUTE: $\rho = \frac{RA}{L} = \frac{VA}{IL} = \frac{(4.50 \text{ V})\pi(6.54 \times 10^{-4} \text{ m})^2}{(17.6 \text{ A})(2.50 \text{ m})} = 1.37 \times 10^{-7} \Omega \cdot \text{m}$.

EVALUATE: Our result for ρ shows that the wire is made of a metal with resistivity greater than that of good metallic conductors such as copper and aluminum.

25.23. IDENTIFY and SET UP: Eq. (25.5) relates the electric field that is given to the current density. $V = EL$ gives the potential difference across a length L of wire and Eq. (25.11) allows us to calculate R .

EXECUTE: (a) Eq. (25.5): $\rho = E/J$ so $J = E/\rho$

From Table 25.1 the resistivity for gold is $2.44 \times 10^{-8} \Omega \cdot \text{m}$.

$$J = \frac{E}{\rho} = \frac{0.49 \text{ V/m}}{2.44 \times 10^{-8} \Omega \cdot \text{m}} = 2.008 \times 10^7 \text{ A/m}^2$$

$$I = JA = J\pi r^2 = (2.008 \times 10^7 \text{ A/m}^2)\pi(0.42 \times 10^{-3} \text{ m})^2 = 11 \text{ A}$$

$$(b) V = EL = (0.49 \text{ V/m})(6.4 \text{ m}) = 3.1 \text{ V}$$

(c) We can use Ohm's law (Eq. (25.11)): $V = IR$.

$$R = \frac{V}{I} = \frac{3.1 \text{ V}}{11 \text{ A}} = 0.28 \Omega$$

EVALUATE: We can also calculate R from the resistivity and the dimensions of the wire (Eq. 25.10):

$$R = \frac{\rho L}{A} = \frac{\rho L}{\pi r^2} = \frac{(2.44 \times 10^{-8} \Omega \cdot \text{m})(6.4 \text{ m})}{\pi(0.42 \times 10^{-3} \text{ m})^2} = 0.28 \Omega, \text{ which checks.}$$

25.24. IDENTIFY: When the ohmmeter is connected between the opposite faces, the current flows along its length, but when the meter is connected between the inner and outer surfaces, the current flows radially outward.

(a) **SET UP:** For a hollow cylinder, $R = \rho L/A$, where $A = \pi(b^2 - a^2)$.

$$\text{EXECUTE: } R = \rho L/A = \frac{\rho L}{\pi(b^2 - a^2)} = \frac{(2.75 \times 10^{-8} \Omega \cdot \text{m})(2.50 \text{ m})}{\pi[(0.0460 \text{ m})^2 - (0.0320 \text{ m})^2]} = 2.00 \times 10^{-5} \Omega$$

(b) **SET UP:** For a thin cylindrical shell of inner radius r and thickness dr , the resistance is $dR = \frac{\rho dr}{2\pi rL}$.

For radial current flow from $r = a$ to $r = b$, $R = \int dR = \frac{\rho}{2\pi L} \int_a^b \frac{1}{r} dr = (\rho/2\pi L) \ln(b/a)$ (Example 25.4).

$$\text{EXECUTE: } R = \frac{\rho}{2\pi L} \ln(b/a) = \frac{2.75 \times 10^{-8} \Omega \cdot \text{m}}{2\pi(2.50 \text{ m})} \ln\left(\frac{4.60 \text{ cm}}{3.20 \text{ cm}}\right) = 6.35 \times 10^{-10} \Omega$$

EVALUATE: The resistance is much smaller for the radial flow because the current flows through a much smaller distance and the area through which it flows is much larger.

25.25. IDENTIFY: Apply $R = R_0[1 + \alpha(T - T_0)]$ to calculate the resistance at the second temperature.

(a) **SET UP:** $\alpha = 0.0004 (\text{C}^\circ)^{-1}$ (Table 25.2). Let T_0 be 0.0°C and T be 11.5°C .

$$\text{EXECUTE: } R_0 = \frac{R}{1 + \alpha(T - T_0)} = \frac{100.0 \Omega}{1 + (0.0004 (\text{C}^\circ)^{-1})(11.5 \text{ C}^\circ)} = 99.54 \Omega$$

(b) **SET UP:** $\alpha = -0.0005 (\text{C}^\circ)^{-1}$ (Table 25.2). Let $T_0 = 0.0^\circ\text{C}$ and $T = 25.8^\circ\text{C}$.

$$\text{EXECUTE: } R = R_0[1 + \alpha(T - T_0)] = 0.0160 \Omega [1 + (-0.0005 (\text{C}^\circ)^{-1})(25.8 \text{ C}^\circ)] = 0.0158 \Omega$$

EVALUATE: Nichrome, like most metallic conductors, has a positive α and its resistance increases with temperature. For carbon, α is negative and its resistance decreases as T increases.

25.26. IDENTIFY: $R_T = R_0[1 + \alpha(T - T_0)]$

SET UP: $R_0 = 217.3 \Omega$. $R_T = 215.8 \Omega$. For carbon, $\alpha = -0.00050 (\text{C}^\circ)^{-1}$.

$$\text{EXECUTE: } T - T_0 = \frac{(R_T/R_0) - 1}{\alpha} = \frac{(215.8 \Omega/217.3 \Omega) - 1}{-0.00050 (\text{C}^\circ)^{-1}} = 13.8 \text{ C}^\circ. T = 13.8 \text{ C}^\circ + 4.0^\circ\text{C} = 17.8^\circ\text{C}.$$

EVALUATE: For carbon, α is negative so R decreases as T increases.

25.27. IDENTIFY and SET UP: Apply $R = \frac{\rho L}{A}$ to determine the effect of increasing A and L .

EXECUTE: (a) If 120 strands of wire are placed side by side, we are effectively increasing the area of the current carrier by 120. So the resistance is smaller by that factor: $R = (5.60 \times 10^{-6} \Omega)/120 = 4.67 \times 10^{-8} \Omega$.

(b) If 120 strands of wire are placed end to end, we are effectively increasing the length of the wire by 120, and so $R = (5.60 \times 10^{-6} \Omega)120 = 6.72 \times 10^{-4} \Omega$.

EVALUATE: Placing the strands side by side decreases the resistance and placing them end to end increases the resistance.

- 25.28. IDENTIFY:** When current passes through a battery in the direction from the $-$ terminal toward the $+$ terminal, the terminal voltage V_{ab} of the battery is $V_{ab} = \mathcal{E} - Ir$. Also, $V_{ab} = IR$, the potential across the circuit resistor.
- SET UP:** $\mathcal{E} = 24.0 \text{ V}$. $I = 4.00 \text{ A}$.
- EXECUTE: (a)** $V_{ab} = \mathcal{E} - Ir$ gives $r = \frac{\mathcal{E} - V_{ab}}{I} = \frac{24.0 \text{ V} - 21.2 \text{ V}}{4.00 \text{ A}} = 0.700 \Omega$.
- (b)** $V_{ab} - IR = 0$ so $R = \frac{V_{ab}}{I} = \frac{21.2 \text{ V}}{4.00 \text{ A}} = 5.30 \Omega$.
- EVALUATE:** The voltage drop across the internal resistance of the battery causes the terminal voltage of the battery to be less than its emf. The total resistance in the circuit is $R + r = 6.00 \Omega$.
- $I = \frac{24.0 \text{ V}}{6.00 \Omega} = 4.00 \text{ A}$, which agrees with the value specified in the problem.
- 25.29. IDENTIFY:** Use $R = \frac{\rho L}{A}$ to calculate R and then apply $V = IR$. $P = VI$ and energy $= Pt$.
- SET UP:** For copper, $\rho = 1.72 \times 10^{-8} \Omega \cdot \text{m}$. $A = \pi r^2$, where $r = 0.050 \text{ m}$.
- EXECUTE: (a)** $R = \frac{\rho L}{A} = \frac{(1.72 \times 10^{-8} \Omega \cdot \text{m})(100 \times 10^3 \text{ m})}{\pi(0.050 \text{ m})^2} = 0.219 \Omega$. $V = IR = (125 \text{ A})(0.219 \Omega) = 27.4 \text{ V}$.
- (b)** $P = VI = (27.4 \text{ V})(125 \text{ A}) = 3422 \text{ W} = 3422 \text{ J/s}$ and energy $= Pt = (3422 \text{ J/s})(3600 \text{ s}) = 1.23 \times 10^7 \text{ J}$.
- EVALUATE:** The rate of electrical energy loss in the cable is large, over 3 kW.
- 25.30. (a) IDENTIFY:** The *idealized* ammeter has no resistance so there is no potential drop across it. Therefore it acts like a short circuit across the terminals of the battery and removes the $4.00\text{-}\Omega$ resistor from the circuit. Thus the only resistance in the circuit is the $2.00\text{-}\Omega$ internal resistance of the battery.
- SET UP:** Use Ohm's law: $I = \mathcal{E}/r$.
- EXECUTE:** $I = (10.0 \text{ V})/(2.00 \Omega) = 5.00 \text{ A}$.
- (b)** The zero-resistance ammeter is in parallel with the $4.00\text{-}\Omega$ resistor, so all the current goes through the ammeter. If no current goes through the $4.00\text{-}\Omega$ resistor, the potential drop across it must be zero.
- (c)** The terminal voltage is zero since there is no potential drop across the ammeter.
- EVALUATE:** An ammeter should *never* be connected this way because it would seriously alter the circuit!
- 25.31. IDENTIFY:** The terminal voltage of the battery is $V_{ab} = \mathcal{E} - Ir$. The voltmeter reads the potential difference between its terminals.
- SET UP:** An ideal voltmeter has infinite resistance.
- EXECUTE: (a)** Since an ideal voltmeter has infinite resistance, so there would be NO current through the 2.0Ω resistor.
- (b)** $V_{ab} = \mathcal{E} = 5.0 \text{ V}$; Since there is no current there is no voltage lost over the internal resistance.
- (c)** The voltmeter reading is therefore 5.0 V since with no current flowing there is no voltage drop across either resistor.
- EVALUATE:** This not the proper way to connect a voltmeter. If we wish to measure the terminal voltage of the battery in a circuit that does not include the voltmeter, then connect the voltmeter across the terminals of the battery.
- 25.32. IDENTIFY:** The sum of the potential changes around the circuit loop is zero. Potential decreases by IR when going through a resistor in the direction of the current and increases by \mathcal{E} when passing through an emf in the direction from the $-$ to $+$ terminal.
- SET UP:** The current is counterclockwise, because the 16-V battery determines the direction of current flow.
- EXECUTE:** $+16.0 \text{ V} - 8.0 \text{ V} - I(1.6 \Omega + 5.0 \Omega + 1.4 \Omega + 9.0 \Omega) = 0$
- $$I = \frac{16.0 \text{ V} - 8.0 \text{ V}}{1.6 \Omega + 5.0 \Omega + 1.4 \Omega + 9.0 \Omega} = 0.47 \text{ A}$$
- (b)** $V_b + 16.0 \text{ V} - I(1.6 \Omega) = V_a$, so $V_a - V_b = V_{ab} = 16.0 \text{ V} - (1.6 \Omega)(0.47 \text{ A}) = 15.2 \text{ V}$.
- (c)** $V_c + 8.0 \text{ V} + I(1.4 \Omega + 5.0 \Omega) = V_a$ so $V_{ac} = (5.0 \Omega)(0.47 \text{ A}) + (1.4 \Omega)(0.47 \text{ A}) + 8.0 \text{ V} = 11.0 \text{ V}$.

(d) The graph is sketched in Figure 25.32.

EVALUATE: $V_{cb} = (0.47 \text{ A})(9.0 \Omega) = 4.2 \text{ V}$. The potential at point b is 15.2 V below the potential at point a and the potential at point c is 11.0 V below the potential at point a , so the potential of point c is $15.2 \text{ V} - 11.0 \text{ V} = 4.2 \text{ V}$ above the potential of point b .

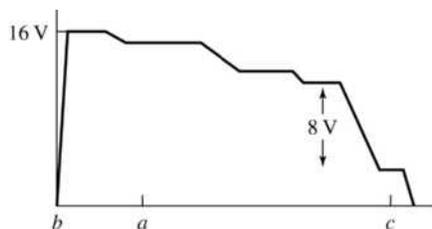
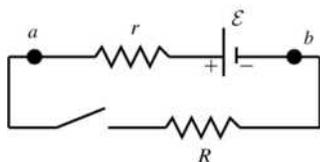


Figure 25.32

25.33. **IDENTIFY:** The voltmeter reads the potential difference V_{ab} between the terminals of the battery.

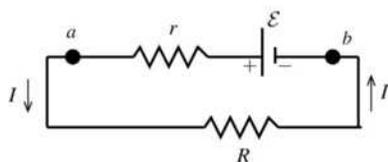
SET UP: open circuit $I = 0$. The circuit is sketched in Figure 25.33a.



EXECUTE: $V_{ab} = \mathcal{E} = 3.08 \text{ V}$

Figure 25.33a

SET UP: switch closed The circuit is sketched in Figure 25.33b.



EXECUTE: $V_{ab} = \mathcal{E} - Ir = 2.97 \text{ V}$

$$r = \frac{\mathcal{E} - 2.97 \text{ V}}{I}$$

$$r = \frac{3.08 \text{ V} - 2.97 \text{ V}}{1.65 \text{ A}} = 0.067 \Omega$$

Figure 25.33b

And $V_{ab} = IR$ so $R = \frac{V_{ab}}{I} = \frac{2.97 \text{ V}}{1.65 \text{ A}} = 1.80 \Omega$.

EVALUATE: When current flows through the battery there is a voltage drop across its internal resistance and its terminal voltage V is less than its emf.

25.34. **IDENTIFY:** The sum of the potential changes around the loop is zero.

SET UP: The voltmeter reads the IR voltage across the $9.0\text{-}\Omega$ resistor. The current in the circuit is counterclockwise because the 16-V battery determines the direction of the current flow.

EXECUTE: (a) $V_{bc} = 1.9 \text{ V}$ gives $I = V_{bc}/R_{bc} = 1.9 \text{ V}/9.0 \Omega = 0.21 \text{ A}$.

(b) $16.0 \text{ V} - 8.0 \text{ V} = (1.6 \Omega + 9.0 \Omega + 1.4 \Omega + R)(0.21 \text{ A})$ and $R = \frac{5.48 \text{ V}}{0.21 \text{ A}} = 26.1 \Omega$.

(c) The graph is sketched in Figure 25.34.

EVALUATE: In Exercise 25.32 the current is 0.47 A. When the $5.0\text{-}\Omega$ resistor is replaced by the $26.1\text{-}\Omega$ resistor the current decreases to 0.21 A.

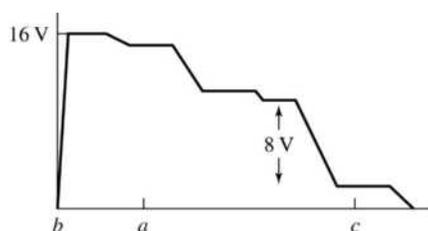


Figure 25.34

- 25.35. (a) **IDENTIFY and SET UP:** Assume that the current is clockwise. The circuit is sketched in Figure 25.35a.

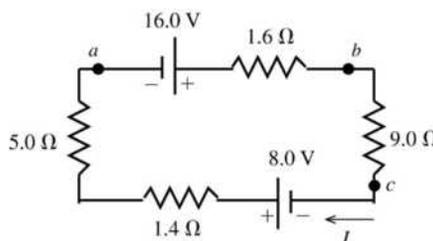


Figure 25.35a

Add up the potential rises and drops as travel clockwise around the circuit.

EXECUTE: $16.0 \text{ V} - I(1.6 \Omega) - I(9.0 \Omega) + 8.0 \text{ V} - I(1.4 \Omega) - I(5.0 \Omega) = 0$

$$I = \frac{16.0 \text{ V} + 8.0 \text{ V}}{9.0 \Omega + 1.4 \Omega + 5.0 \Omega + 1.6 \Omega} = \frac{24.0 \text{ V}}{17.0 \Omega} = 1.41 \text{ A, clockwise}$$

EVALUATE: The 16.0-V battery and the 8.0-V battery both drive the current in the same direction.

(b) **IDENTIFY and SET UP:** Start at point a and travel through the battery to point b , keeping track of the potential changes. At point b the potential is V_b .

EXECUTE: $V_a + 16.0 \text{ V} - I(1.6 \Omega) = V_b$

$$V_a - V_b = -16.0 \text{ V} + (1.41 \text{ A})(1.6 \Omega)$$

$V_{ab} = -16.0 \text{ V} + 2.3 \text{ V} = -13.7 \text{ V}$ (point a is at lower potential; it is the negative terminal). Therefore,

$$V_{ba} = 13.7 \text{ V}.$$

EVALUATE: Could also go counterclockwise from a to b :

$$V_a + (1.41 \text{ A})(5.0 \Omega) + (1.41 \text{ A})(1.4 \Omega) - 8.0 \text{ V} + (1.41 \text{ A})(9.0 \Omega) = V_b$$

$$V_{ab} = -13.7 \text{ V, which checks.}$$

(c) **IDENTIFY and SET UP:** Start at point a and travel through the battery to point c , keeping track of the potential changes.

EXECUTE: $V_a + 16.0 \text{ V} - I(1.6 \Omega) - I(9.0 \Omega) = V_c$

$$V_a - V_c = -16.0 \text{ V} + (1.41 \text{ A})(1.6 \Omega + 9.0 \Omega)$$

$$V_{ac} = -16.0 \text{ V} + 15.0 \text{ V} = -1.0 \text{ V} \text{ (point } a \text{ is at lower potential than point } c)$$

EVALUATE: Could also go counterclockwise from a to c :

$$V_a + (1.41 \text{ A})(5.0 \Omega) + (1.41 \text{ A})(1.4 \Omega) - 8.0 \text{ V} = V_c$$

$$V_{ac} = -1.0 \text{ V, which checks.}$$

(d) Call the potential zero at point a . Travel clockwise around the circuit. The graph is sketched in Figure 25.35b.

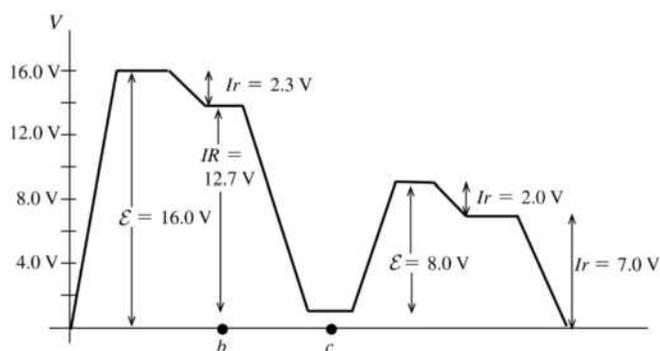


Figure 25.35b

25.36. IDENTIFY: Ohm's law says $R = \frac{V_{ab}}{I}$ is a constant.

SET UP: (a) The graph is given in Figure 25.36a.

EXECUTE: (b) No. The graph of V_{ab} versus I is not a straight line so thyrite does not obey Ohm's law.

(c) The graph of R versus I is given in Figure 25.36b. R is not constant; it decreases as I increases.

EVALUATE: Not all materials obey Ohm's law.

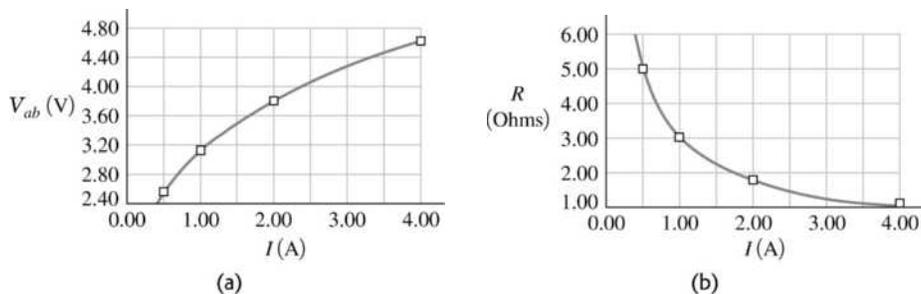


Figure 25.36

25.37. IDENTIFY: Ohm's law says $R = \frac{V_{ab}}{I}$ is a constant.

SET UP: (a) The graph is given in Figure 25.37.

EXECUTE: (b) The graph of V_{ab} versus I is a straight line so nichrome obeys Ohm's law.

(c) R is the slope of the graph in part (a). $R = \frac{15.52 \text{ V} - 1.94 \text{ V}}{4.00 \text{ A} - 0.50 \text{ A}} = 3.88 \Omega$.

EVALUATE: V_{ab}/I for every I gives the same result for R , $R = 3.88 \Omega$.

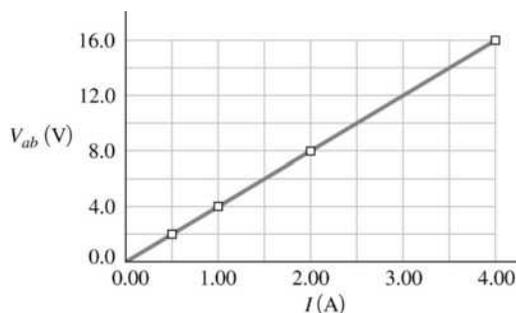


Figure 25.37

- 25.38. IDENTIFY and SET UP:** There is a single current path so the current is the same at all points in the circuit. Assume the current is counterclockwise and apply Kirchoff's loop rule.
EXECUTE: (a) Apply the loop rule, traveling around the circuit in the direction of the current.
 $+16.0 \text{ V} - I(1.6 \Omega + 5.0 \Omega + 1.4 \Omega + 9.0 \Omega) - 8.0 \text{ V} = 0$. $I = \frac{16.0 \text{ V} - 8.0 \text{ V}}{17.0 \Omega} = 0.471 \text{ A}$. Our calculated I is positive so I is counterclockwise, as we assumed.
 (b) $V_b + 16.0 \text{ V} - I(1.6 \Omega) = V_a$. $V_{ab} = 16.0 \text{ V} - (0.471 \text{ A})(1.6 \Omega) = 15.2 \text{ V}$.
EVALUATE: If we traveled around the circuit in the direction opposite to the current, the final answers would be the same.
- 25.39. IDENTIFY:** The bulbs are each connected across a 120-V potential difference.
SET UP: Use $P = V^2/R$ to solve for R and Ohm's law ($I = V/R$) to find the current.
EXECUTE: (a) $R = V^2/P = (120 \text{ V})^2/(100 \text{ W}) = 144 \Omega$.
 (b) $R = V^2/P = (120 \text{ V})^2/(60 \text{ W}) = 240 \Omega$
 (c) For the 100-W bulb: $I = V/R = (120 \text{ V})/(144 \Omega) = 0.833 \text{ A}$
 For the 60-W bulb: $I = (120 \text{ V})/(240 \Omega) = 0.500 \text{ A}$
EVALUATE: The 60-W bulb has *more* resistance than the 100-W bulb, so it draws less current.
- 25.40. IDENTIFY:** Across 120 V, a 75-W bulb dissipates 75 W. Use this fact to find its resistance, and then find the power the bulb dissipates across 220 V.
SET UP: $P = V^2/R$, so $R = V^2/P$
EXECUTE: Across 120 V: $R = (120 \text{ V})^2/(75 \text{ W}) = 192 \Omega$. Across a 220-V line, its power will be
 $P = V^2/R = (220 \text{ V})^2/(192 \Omega) = 252 \text{ W}$.
EVALUATE: The bulb dissipates much more power across 220 V, so it would likely blow out at the higher voltage. An alternative solution to the problem is to take the ratio of the powers.
 $\frac{P_{220}}{P_{120}} = \frac{V_{220}^2/R}{V_{120}^2/R} = \left(\frac{V_{220}}{V_{120}}\right)^2 = \left(\frac{220}{120}\right)^2$. This gives $P_{220} = (75 \text{ W})\left(\frac{220}{120}\right)^2 = 252 \text{ W}$.
- 25.41. IDENTIFY:** A "100-W" European bulb dissipates 100 W when used across 220 V.
(a) SET UP: Take the ratio of the power in the U.S. to the power in Europe, as in the alternative method for Problem 25.40, using $P = V^2/R$.
EXECUTE: $\frac{P_{\text{US}}}{P_{\text{E}}} = \frac{V_{\text{US}}^2/R}{V_{\text{E}}^2/R} = \left(\frac{V_{\text{US}}}{V_{\text{E}}}\right)^2 = \left(\frac{120 \text{ V}}{220 \text{ V}}\right)^2$. This gives $P_{\text{US}} = (100 \text{ W})\left(\frac{120 \text{ V}}{220 \text{ V}}\right)^2 = 29.8 \text{ W}$.
(b) SET UP: Use $P = IV$ to find the current.
EXECUTE: $I = P/V = (29.8 \text{ W})/(120 \text{ V}) = 0.248 \text{ A}$
EVALUATE: The bulb draws considerably less power in the U.S., so it would be much dimmer than in Europe.
- 25.42. IDENTIFY:** $P = VI$. Energy = Pt .
SET UP: $P = (9.0 \text{ V})(0.13 \text{ A}) = 1.17 \text{ W}$
EXECUTE: Energy = $(1.17 \text{ W})(1.5 \text{ h})(3600 \text{ s/h}) = 6320 \text{ J}$
EVALUATE: The energy consumed is proportional to the voltage, to the current and to the time.
- 25.43. IDENTIFY and SET UP:** By definition $p = \frac{P}{LA}$. Use $P = VI$, $E = VL$ and $I = JA$ to rewrite this expression in terms of the specified variables.
EXECUTE: (a) E is related to V and J is related to I , so use $P = VI$. This gives $p = \frac{VI}{LA}$.
 $\frac{V}{L} = E$ and $\frac{I}{A} = J$ so $p = EJ$.

(b) J is related to I and ρ is related to R , so use $P = IR^2$. This gives $p = \frac{I^2 R}{LA}$.

$$I = JA \text{ and } R = \frac{\rho L}{A} \text{ so } p = \frac{J^2 A^2 \rho L}{LA^2} = \rho J^2$$

(c) E is related to V and ρ is related to R , so use $P = V^2/R$. This gives $p = \frac{V^2}{RLA}$.

$$V = EL \text{ and } R = \frac{\rho L}{A} \text{ so } p = \frac{E^2 L^2}{LA} \left(\frac{A}{\rho L} \right) = \frac{E^2}{\rho}$$

EVALUATE: For a given material (ρ constant), p is proportional to J^2 or to E^2 .

25.44. IDENTIFY: Knowing the current and potential difference, we can find the power.

SET UP: $P = VI$ and energy is the product of power and time.

EXECUTE: $P = (500 \text{ V})(80 \times 10^{-3} \text{ A}) = 40 \text{ W}$.

Energy = $Pt = (40 \text{ W})(10 \times 10^{-3} \text{ s}) = 0.40 \text{ J}$.

EVALUATE: The energy delivered depends not only on the voltage and current but also on the length of the pulse. The pulse is short but the voltage is large.

25.45. IDENTIFY: We know the current, voltage and time the current lasts, so we can calculate the power and the energy delivered.

SET UP: Power is energy per unit time. The power delivered by a voltage source is $P = V_{ab} I$.

EXECUTE: (a) $P = (25 \text{ V})(12 \text{ A}) = 300 \text{ W}$.

(b) Energy = $Pt = (300 \text{ W})(3.0 \times 10^{-3} \text{ s}) = 0.90 \text{ J}$.

EVALUATE: The energy is not very great, but it is delivered in a short time (3 ms) so the power is large, which produces a short shock.

25.46. IDENTIFY: Calculate the current in the circuit. The power output of a battery is its terminal voltage times the current through it. The power dissipated in a resistor is $I^2 R$.

SET UP: The sum of the potential changes around the circuit is zero.

EXECUTE: (a) $I = \frac{8.0 \text{ V}}{17 \Omega} = 0.47 \text{ A}$. Then $P_{5\Omega} = I^2 R = (0.47 \text{ A})^2 (5.0 \Omega) = 1.1 \text{ W}$ and

$P_{9\Omega} = I^2 R = (0.47 \text{ A})^2 (9.0 \Omega) = 2.0 \text{ W}$, so the total is 3.1 W.

(b) $P_{16\text{V}} = \mathcal{E}I - I^2 r = (16 \text{ V})(0.47 \text{ A}) - (0.47 \text{ A})^2 (1.6 \Omega) = 7.2 \text{ W}$.

(c) $P_{8\text{V}} = \mathcal{E}I + I^2 r = (8.0 \text{ V})(0.47 \text{ A}) + (0.47 \text{ A})^2 (1.4 \Omega) = 4.1 \text{ W}$.

EVALUATE: (d) (b) = (a) + (c). The rate at which the 16.0-V battery delivers electrical energy to the circuit equals the rate at which it is consumed in the 8.0-V battery and the 5.0- Ω and 9.0- Ω resistors.

25.47. (a) IDENTIFY and SET UP: $P = VI$ and energy = (power) \times (time).

EXECUTE: $P = VI = (12 \text{ V})(60 \text{ A}) = 720 \text{ W}$

The battery can provide this for 1.0 h, so the energy the battery has stored is

$U = Pt = (720 \text{ W})(3600 \text{ s}) = 2.6 \times 10^6 \text{ J}$.

(b) IDENTIFY and SET UP: For gasoline the heat of combustion is $L_c = 46 \times 10^6 \text{ J/kg}$. Solve for the mass m required to supply the energy calculated in part (a) and use density $\rho = m/V$ to calculate V .

EXECUTE: The mass of gasoline that supplies $2.6 \times 10^6 \text{ J}$ is $m = \frac{2.6 \times 10^6 \text{ J}}{46 \times 10^6 \text{ J/kg}} = 0.0565 \text{ kg}$.

The volume of this mass of gasoline is

$$V = \frac{m}{\rho} = \frac{0.0565 \text{ kg}}{900 \text{ kg/m}^3} = 6.3 \times 10^{-5} \text{ m}^3 \left(\frac{1000 \text{ L}}{1 \text{ m}^3} \right) = 0.063 \text{ L}.$$

(c) **IDENTIFY and SET UP:** Energy = (power) × (time); the energy is that calculated in part (a).

$$\text{EXECUTE: } U = Pt, t = \frac{U}{P} = \frac{2.6 \times 10^6 \text{ J}}{450 \text{ W}} = 5800 \text{ s} = 97 \text{ min} = 1.6 \text{ h.}$$

EVALUATE: The battery discharges at a rate of 720 W (for 60 A) and is charged at a rate of 450 W, so it takes longer to charge than to discharge.

25.48. IDENTIFY: The rate of conversion of chemical to electrical energy in an emf is $\mathcal{E}I$. The rate of dissipation of electrical energy in a resistor R is I^2R .

SET UP: Example 25.9 finds that $I = 1.2 \text{ A}$ for this circuit. In Example 25.8, $\mathcal{E}I = 24 \text{ W}$ and $I^2r = 8 \text{ W}$. In Example 25.9, $I^2R = 12 \text{ W}$, or 11.5 W if expressed to three significant figures.

EXECUTE: (a) $P = \mathcal{E}I = (12 \text{ V})(1.2 \text{ A}) = 14.4 \text{ W}$. This is less than the previous value of 24 W.

(b) The energy dissipated in the battery is $P = I^2r = (1.2 \text{ A})^2(2.0 \Omega) = 2.9 \text{ W}$. This is less than 8 W, the amount found in Example (25.8).

(c) The net power output of the battery is $14.4 \text{ W} - 2.9 \text{ W} = 11.5 \text{ W}$. This is the same as the power dissipated in the 8.0- Ω resistor.

EVALUATE: With the larger circuit resistance the current is less and the power input and power consumption are less.

25.49. IDENTIFY: Some of the power generated by the internal emf of the battery is dissipated across the battery's internal resistance, so it is not available to the bulb.

SET UP: Use $P = I^2R$ and take the ratio of the power dissipated in the internal resistance r to the total power.

$$\text{EXECUTE: } \frac{P_r}{P_{\text{Total}}} = \frac{I^2r}{I^2(r+R)} = \frac{r}{r+R} = \frac{3.5 \Omega}{28.5 \Omega} = 0.123 = 12.3\%$$

EVALUATE: About 88% of the power of the battery goes to the bulb. The rest appears as heat in the internal resistance.

25.50. IDENTIFY: The voltmeter reads the terminal voltage of the battery, which is the potential difference across the appliance. The terminal voltage is less than 15.0 V because some potential is lost across the internal resistance of the battery.

(a) SET UP: $P = V^2/R$ gives the power dissipated by the appliance.

$$\text{EXECUTE: } P = (11.3 \text{ V})^2/(75.0 \Omega) = 1.70 \text{ W}$$

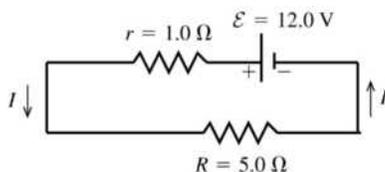
(b) SET UP: The drop in terminal voltage ($\mathcal{E} - V_{ab}$) is due to the potential drop across the internal resistance r . Use $Ir = \mathcal{E} - V_{ab}$ to find the internal resistance r , but first find the current using $P = IV$.

$$\text{EXECUTE: } I = P/V = (1.70 \text{ W})/(11.3 \text{ V}) = 0.151 \text{ A. Then } Ir = \mathcal{E} - V_{ab} \text{ gives } (0.151 \text{ A})r = 15.0 \text{ V} - 11.3 \text{ V} \text{ and } r = 24.5 \Omega.$$

EVALUATE: The full 15.0-V of the battery would be available only when no current (or a very small current) is flowing in the circuit. This would be the case if the appliance had a resistance much greater than 24.5 Ω .

25.51. IDENTIFY: Solve for the current I in the circuit. Apply Eq. (25.17) to the specified circuit elements to find the rates of energy conversion.

SET UP: The circuit is sketched in Figure 25.51



EXECUTE: Compute I :

$$\mathcal{E} - Ir - IR = 0$$

$$I = \frac{\mathcal{E}}{r+R} = \frac{12.0 \text{ V}}{1.0 \Omega + 5.0 \Omega} = 2.00 \text{ A}$$

Figure 25.51

(a) The rate of conversion of chemical energy to electrical energy in the emf of the battery is
 $P = \mathcal{E}I = (12.0 \text{ V})(2.00 \text{ A}) = 24.0 \text{ W}$.

(b) The rate of dissipation of electrical energy in the internal resistance of the battery is
 $P = I^2r = (2.00 \text{ A})^2(1.0 \Omega) = 4.0 \text{ W}$.

(c) The rate of dissipation of electrical energy in the external resistor
 R is $P = I^2R = (2.00 \text{ A})^2(5.0 \Omega) = 20.0 \text{ W}$.

EVALUATE: The rate of production of electrical energy in the circuit is 24.0 W. The total rate of consumption of electrical energy in the circuit is $4.00 \text{ W} + 20.0 \text{ W} = 24.0 \text{ W}$. Equal rate of production and consumption of electrical energy are required by energy conservation.

25.52. IDENTIFY: The power delivered to the bulb is I^2R . Energy = Pt .

SET UP: The circuit is sketched in Figure 25.52. r_{total} is the combined internal resistance of both batteries.

EXECUTE: (a) $r_{\text{total}} = 0$. The sum of the potential changes around the circuit is zero, so

$1.5 \text{ V} + 1.5 \text{ V} - I(17 \Omega) = 0$. $I = 0.1765 \text{ A}$. $P = I^2R = (0.1765 \text{ A})^2(17 \Omega) = 0.530 \text{ W}$. This is also $(3.0 \text{ V})(0.1765 \text{ A})$.

(b) Energy = $(0.530 \text{ W})(5.0 \text{ h})(3600 \text{ s/h}) = 9540 \text{ J}$

(c) $P = \frac{0.530 \text{ W}}{2} = 0.265 \text{ W}$. $P = I^2R$ so $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{0.265 \text{ W}}{17 \Omega}} = 0.125 \text{ A}$.

The sum of the potential changes around the circuit is zero, so $1.5 \text{ V} + 1.5 \text{ V} - IR - Ir_{\text{total}} = 0$.

$r_{\text{total}} = \frac{3.0 \text{ V} - (0.125 \text{ A})(17 \Omega)}{0.125 \text{ A}} = 7.0 \Omega$.

EVALUATE: When the power to the bulb has decreased to half its initial value, the total internal resistance of the two batteries is nearly half the resistance of the bulb. Compared to a single battery, using two identical batteries in series doubles the emf but also doubles the total internal resistance.

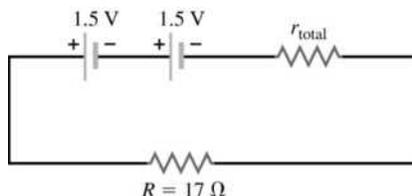


Figure 25.52

25.53. IDENTIFY: $P = I^2R = \frac{V^2}{R} = VI$. $V = IR$.

SET UP: The heater consumes 540 W when $V = 120 \text{ V}$. Energy = Pt .

EXECUTE: (a) $P = \frac{V^2}{R}$ so $R = \frac{V^2}{P} = \frac{(120 \text{ V})^2}{540 \text{ W}} = 26.7 \Omega$

(b) $P = VI$ so $I = \frac{P}{V} = \frac{540 \text{ W}}{120 \text{ V}} = 4.50 \text{ A}$

(c) Assuming that R remains 26.7Ω , $P = \frac{V^2}{R} = \frac{(110 \text{ V})^2}{26.7 \Omega} = 453 \text{ W}$. P is smaller by a factor of $(110/120)^2$.

EVALUATE: (d) With the lower line voltage the current will decrease and the operating temperature will decrease. R will be less than 26.7Ω and the power consumed will be greater than the value calculated in part (c).

25.54. IDENTIFY: From Eq. (25.24), $\rho = \frac{m}{ne^2\tau}$.

SET UP: For silicon, $\rho = 2300 \Omega \cdot \text{m}$.

EXECUTE: (a) $\tau = \frac{m}{ne^2\rho} = \frac{9.11 \times 10^{-31} \text{ kg}}{(1.0 \times 10^{16} \text{ m}^{-3})(1.60 \times 10^{-19} \text{ C})^2(2300 \Omega \cdot \text{m})} = 1.55 \times 10^{-12} \text{ s}$.

EVALUATE: (b) The number of free electrons in copper ($8.5 \times 10^{28} \text{ m}^{-3}$) is much larger than in pure silicon ($1.0 \times 10^{16} \text{ m}^{-3}$). A smaller density of current carriers means a higher resistivity.

25.55. (a) IDENTIFY and SET UP: Use $R = \frac{\rho L}{A}$.

EXECUTE: $\rho = \frac{RA}{L} = \frac{(0.104 \Omega)\pi(1.25 \times 10^{-3} \text{ m})^2}{14.0 \text{ m}} = 3.65 \times 10^{-8} \Omega \cdot \text{m}$

EVALUATE: This value is similar to that for good metallic conductors in Table 25.1.

(b) IDENTIFY and SET UP: Use $V = EL$ to calculate E and then Ohm's law gives I .

EXECUTE: $V = EL = (1.28 \text{ V/m})(14.0 \text{ m}) = 17.9 \text{ V}$

$I = \frac{V}{R} = \frac{17.9 \text{ V}}{0.104 \Omega} = 172 \text{ A}$

EVALUATE: We could do the calculation another way:

$E = \rho J$ so $J = \frac{E}{\rho} = \frac{1.28 \text{ V/m}}{3.65 \times 10^{-8} \Omega \cdot \text{m}} = 3.51 \times 10^7 \text{ A/m}^2$

$I = JA = (3.51 \times 10^7 \text{ A/m}^2)\pi(1.25 \times 10^{-3} \text{ m})^2 = 172 \text{ A}$, which checks.

(c) IDENTIFY and SET UP: Calculate $J = I/A$ or $J = E/\rho$ and then use Eq. (25.3) for the target variable v_d .

EXECUTE: $J = n|q|v_d = nev_d$

$v_d = \frac{J}{ne} = \frac{3.51 \times 10^7 \text{ A/m}^2}{(8.5 \times 10^{28} \text{ m}^{-3})(1.602 \times 10^{-19} \text{ C})} = 2.58 \times 10^{-3} \text{ m/s} = 2.58 \text{ mm/s}$

EVALUATE: Even for this very large current the drift speed is small.

25.56. IDENTIFY: Use $R = \frac{\rho L}{A}$ to calculate the resistance of the silver tube. Then $I = V/R$.

SET UP: For silver, $\rho = 1.47 \times 10^{-8} \Omega \cdot \text{m}$. The silver tube is sketched in Figure 25.56. Since the thickness $T = 0.100 \text{ mm}$ is much smaller than the radius, $r = 2.00 \text{ cm}$, the cross-sectional area of the silver is $2\pi rT$. The length of the tube is $l = 25.0 \text{ m}$.

EXECUTE: $I = \frac{V}{R} = \frac{V}{\rho l/A} = \frac{VA}{\rho l} = \frac{V(2\pi rT)}{\rho l} = \frac{(12 \text{ V})(2\pi)(2.00 \times 10^{-2} \text{ m})(0.100 \times 10^{-3} \text{ m})}{(1.47 \times 10^{-8} \Omega \cdot \text{m})(25.0 \text{ m})} = 410 \text{ A}$

EVALUATE: The resistance is small, $R = 0.0292 \Omega$, so 12.0 V produces a large current.

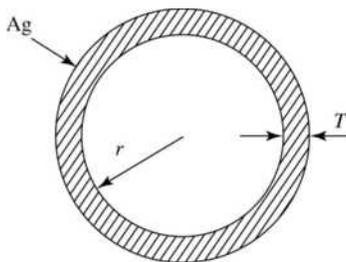


Figure 25.56

- 25.57. IDENTIFY and SET UP:** With the voltmeter connected across the terminals of the battery there is no current through the battery and the voltmeter reading is the battery emf; $\mathcal{E} = 12.6 \text{ V}$.

With a wire of resistance R connected to the battery current I flows and $\mathcal{E} - Ir - IR = 0$, where r is the internal resistance of the battery. Apply this equation to each piece of wire to get two equations in the two unknowns.

EXECUTE: Call the resistance of the 20.0-m piece R_1 ; then the resistance of the 40.0-m piece is

$$R_2 = 2R_1.$$

$$\mathcal{E} - I_1 r - I_1 R_1 = 0; \quad 12.6 \text{ V} - (7.00 \text{ A})r - (7.00 \text{ A})R_1 = 0$$

$$\mathcal{E} - I_2 r - I_2 (2R_1) = 0; \quad 12.6 \text{ V} - (4.20 \text{ A})r - (4.20 \text{ A})(2R_1) = 0$$

Solving these two equations in two unknowns gives $R_1 = 1.20 \Omega$. This is the resistance of 20.0 m, so the resistance of one meter is $[1.20 \Omega / (20.0 \text{ m})](1.00 \text{ m}) = 0.060 \Omega$.

EVALUATE: We can also solve for r and we get $r = 0.600 \Omega$. When measuring small resistances, the internal resistance of the battery has a large effect.

- 25.58. IDENTIFY:** Conservation of charge requires that the current is the same in both sections. The voltage drops across each section add, so $R = R_{\text{Cu}} + R_{\text{Ag}}$. The total resistance is the sum of the resistances of each

section. $E = \rho J = \frac{\rho I}{A}$, so $E = \frac{IR}{L}$, where R is the resistance of a section and L is its length.

SET UP: For copper, $\rho_{\text{Cu}} = 1.72 \times 10^{-8} \Omega \cdot \text{m}$. For silver, $\rho_{\text{Ag}} = 1.47 \times 10^{-8} \Omega \cdot \text{m}$.

EXECUTE: (a) $I = \frac{V}{R} = \frac{V}{R_{\text{Cu}} + R_{\text{Ag}}}$. $R_{\text{Cu}} = \frac{\rho_{\text{Cu}} L_{\text{Cu}}}{A_{\text{Cu}}} = \frac{(1.72 \times 10^{-8} \Omega \cdot \text{m})(0.8 \text{ m})}{(\pi/4)(6.0 \times 10^{-4} \text{ m})^2} = 0.049 \Omega$ and

$$R_{\text{Ag}} = \frac{\rho_{\text{Ag}} L_{\text{Ag}}}{A_{\text{Ag}}} = \frac{(1.47 \times 10^{-8} \Omega \cdot \text{m})(1.2 \text{ m})}{(\pi/4)(6.0 \times 10^{-4} \text{ m})^2} = 0.062 \Omega. \text{ This gives } I = \frac{5.0 \text{ V}}{0.049 \Omega + 0.062 \Omega} = 45 \text{ A}.$$

The current in the copper wire is 45 A.

(b) The current in the silver wire is 45 A, the same as that in the copper wire or else charge would build up at their interface.

$$(c) E_{\text{Cu}} = J \rho_{\text{Cu}} = \frac{IR_{\text{Cu}}}{L_{\text{Cu}}} = \frac{(45 \text{ A})(0.049 \Omega)}{0.8 \text{ m}} = 2.76 \text{ V/m}.$$

$$(d) E_{\text{Ag}} = J \rho_{\text{Ag}} = \frac{IR_{\text{Ag}}}{L_{\text{Ag}}} = \frac{(45 \text{ A})(0.062 \Omega)}{1.2 \text{ m}} = 2.33 \text{ V/m}.$$

$$(e) V_{\text{Ag}} = IR_{\text{Ag}} = (45 \text{ A})(0.062 \Omega) = 2.79 \text{ V}.$$

EVALUATE: For the copper section, $V_{\text{Cu}} = IR_{\text{Cu}} = 2.21 \text{ V}$. Note that $V_{\text{Cu}} + V_{\text{Ag}} = 5.0 \text{ V}$, the voltage applied across the ends of the composite wire.

- 25.59. IDENTIFY:** Conservation of charge requires that the current be the same in both sections of the wire.

$E = \rho J = \frac{\rho I}{A}$. For each section, $V = IR = JAR = \left(\frac{EA}{\rho}\right)\left(\frac{\rho L}{A}\right) = EL$. The voltages across each section add.

SET UP: $A = (\pi/4)D^2$, where D is the diameter.

EXECUTE: (a) The current must be the same in both sections of the wire, so the current in the thin end is 2.5 mA.

$$(b) E_{1.6 \text{ mm}} = \rho J = \frac{\rho I}{A} = \frac{(1.72 \times 10^{-8} \Omega \cdot \text{m})(2.5 \times 10^{-3} \text{ A})}{(\pi/4)(1.6 \times 10^{-3} \text{ m})^2} = 2.14 \times 10^{-5} \text{ V/m}.$$

$$(c) E_{0.8 \text{ mm}} = \rho J = \frac{\rho I}{A} = \frac{(1.72 \times 10^{-8} \Omega \cdot \text{m})(2.5 \times 10^{-3} \text{ A})}{(\pi/4)(0.80 \times 10^{-3} \text{ m})^2} = 8.55 \times 10^{-5} \text{ V/m}. \text{ This is } 4E_{1.6 \text{ mm}}.$$

$$(d) V = E_{1.6 \text{ mm}} L_{1.6 \text{ mm}} + E_{0.8 \text{ mm}} L_{0.8 \text{ mm}} = (2.14 \times 10^{-5} \text{ V/m})(1.20 \text{ m}) + (8.55 \times 10^{-5} \text{ V/m})(1.80 \text{ m}) = 1.80 \times 10^{-4} \text{ V}.$$

EVALUATE: The currents are the same but the current density is larger in the thinner section and the electric field is larger there.

25.60. IDENTIFY: $I = JA$.

SET UP: From Example 25.1, an 18-gauge wire has $A = 8.17 \times 10^{-3} \text{ cm}^2$.

EXECUTE: (a) $I = JA = (1.0 \times 10^5 \text{ A/cm}^2)(8.17 \times 10^{-3} \text{ cm}^2) = 820 \text{ A}$

(b) $A = I/J = (1000 \text{ A})/(1.0 \times 10^6 \text{ A/cm}^2) = 1.0 \times 10^{-3} \text{ cm}^2$. $A = \pi r^2$ so

$$r = \sqrt{A/\pi} = \sqrt{(1.0 \times 10^{-3} \text{ cm}^2)/\pi} = 0.0178 \text{ cm} \text{ and } d = 2r = 0.36 \text{ mm.}$$

EVALUATE: These wires can carry very large currents.

25.61. IDENTIFY: The current generates heat in the nichrome heating element. This heat increases the temperature of the water and its aluminum container.

SET UP: The rate of heating in the nichrome is $P = I^2R$, the power is Q/t , and the current in the circuit

is $I = \frac{\mathcal{E}}{R+r}$, where \mathcal{E} is the internal emf of the battery.

$$\text{EXECUTE: } I = \frac{\mathcal{E}}{R+r} = \frac{96.0 \text{ V}}{28.0 \Omega + 1.2 \Omega} = 3.288 \text{ A.}$$

$P = I^2R = (3.288 \text{ A})^2(28.0 \Omega) = 302.6 \text{ W}$. The total heat needed is:

Cup: $Q = mc\Delta T = (0.130 \text{ kg})(910 \text{ J/(kg} \cdot \text{K)})(34.5^\circ\text{C} - 21.2^\circ\text{C}) = 1573 \text{ J}$.

Water: $Q = mc\Delta T = (0.200 \text{ kg})(4190 \text{ J/(kg} \cdot \text{K)})(34.5^\circ\text{C} - 21.2^\circ\text{C}) = 11,145 \text{ J}$.

$$\text{Total: } Q = 12,718 \text{ J. } t = \frac{Q}{P} = \frac{12,718 \text{ J}}{302.6 \text{ W}} = 42.0 \text{ s.}$$

EVALUATE: A current of about 3 A is rather large and would generate heat at a considerable rate. It could reasonably change the temperature of the water and aluminum by about 13 C° in 42 s.

25.62. IDENTIFY: The current in the circuit depends on R and on the internal resistance of the battery, as well as the emf of the battery. It is only the current in R that dissipates energy in the resistor R .

SET UP: $I = \frac{\mathcal{E}}{R+r}$, where \mathcal{E} is the emf of the battery, and $P = I^2R$.

$$\text{EXECUTE: } P = I^2R = \frac{\mathcal{E}^2}{(R+r)^2}R, \text{ which gives } \mathcal{E}^2R = (R^2 + 2Rr + r^2)P.$$

$$R^2 + \left(2r - \frac{\mathcal{E}^2}{P}\right)R + r^2 = 0. \quad R = \frac{1}{2} \left[\left(\frac{\mathcal{E}^2}{P} - 2r \right) \pm \sqrt{\left(\frac{\mathcal{E}^2}{P} - 2r \right)^2 - 4r^2} \right].$$

$$R = \frac{1}{2} \left[\left(\frac{(12.0 \text{ V})^2}{80.0 \text{ W}} - 2(0.40 \Omega) \right) \pm \sqrt{\left(\frac{(12.0 \text{ V})^2}{80.0 \text{ W}} - 2(0.40 \Omega) \right)^2 - 4(0.40 \Omega)^2} \right].$$

$$R = 0.50 \Omega \pm 0.30 \Omega. \quad R = 0.20 \Omega \text{ and } R = 0.80 \Omega.$$

EVALUATE: There are two values for R because there are two ways for the power dissipated in R to be 80 W. The power is $P = I^2R$, so we can have a small $R(0.20 \Omega)$ and large current, or a larger $R(0.80 \Omega)$ and a smaller current.

25.63. IDENTIFY: Knowing the current and the time for which it lasts, plus the resistance of the body, we can calculate the energy delivered.

SET UP: Electrical energy is deposited in his body at the rate $P = I^2R$. Heat energy Q produces a temperature change ΔT according to $Q = mc\Delta T$, where $c = 4190 \text{ J/kg} \cdot \text{C}^\circ$.

EXECUTE: (a) $P = I^2R = (25,000 \text{ A})^2(1.0 \text{ k} \Omega) = 6.25 \times 10^{11} \text{ W}$. The energy deposited is

$$Pt = (6.15 \times 10^{11} \text{ W})(40 \times 10^{-6} \text{ s}) = 2.5 \times 10^7 \text{ J. Find } \Delta T \text{ when } Q = 2.5 \times 10^7 \text{ J.}$$

$$\Delta T = \frac{Q}{mc} = \frac{2.5 \times 10^7 \text{ J}}{(75 \text{ kg})(4190 \text{ J/kg} \cdot \text{C}^\circ)} = 80 \text{ C}^\circ.$$

(b) An increase of only 63°C brings the water in the body to the boiling point; part of the person's body will be vaporized.

EVALUATE: Even this approximate calculation shows that being hit by lightning is very dangerous.

25.64. IDENTIFY: The moving electron carries its charge around the nucleus and therefore produces a current.

SET UP: $I = \frac{\Delta Q}{\Delta t}$. In 1.00 s the electron passes a point on the orbit 6.0×10^{15} times. The charge of an electron has magnitude e .

EXECUTE: The magnitude of the average current is

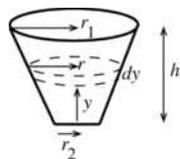
$$I = \frac{(6.0 \times 10^{15})e}{1.00 \text{ s}} = \frac{(6.0 \times 10^{15})(1.60 \times 10^{-19} \text{ C})}{1.00 \text{ s}} = 9.6 \times 10^{-4} \text{ A} = 0.96 \text{ mA.}$$

The direction of the current is opposite to the direction of circulation of the electron, since the electron has negative charge.

EVALUATE: This current is comparable to currents in electronic equipment.

25.65. (a) IDENTIFY: Apply Eq. (25.10) to calculate the resistance of each thin disk and then integrate over the truncated cone to find the total resistance.

SET UP:



EXECUTE: The radius of a truncated cone a distance y above the bottom is given by $r = r_2 + (y/h)(r_1 - r_2) = r_2 + y\beta$ with $\beta = (r_1 - r_2)/h$.

Figure 25.65

Consider a thin slice a distance y above the bottom. The slice has thickness dy and radius r (see

Figure 25.65.) The resistance of the slice is $dR = \frac{\rho dy}{A} = \frac{\rho dy}{\pi r^2} = \frac{\rho dy}{\pi(r_2 + \beta y)^2}$.

The total resistance of the cone if obtained by integrating over these thin slices:

$$R = \int dR = \frac{\rho}{\pi} \int_0^h \frac{dy}{(r_2 + \beta y)^2} = \frac{\rho}{\pi} \left[-\frac{1}{\beta} (r_2 + \beta y)^{-1} \right]_0^h = -\frac{\rho}{\pi\beta} \left[\frac{1}{r_2 + h\beta} - \frac{1}{r_2} \right]$$

But $r_2 + h\beta = r_1$

$$R = \frac{\rho}{\pi\beta} \left[\frac{1}{r_2} - \frac{1}{r_1} \right] = \frac{\rho}{\pi} \left(\frac{h}{r_1 - r_2} \right) \left(\frac{r_1 - r_2}{r_1 r_2} \right) = \frac{\rho h}{\pi r_1 r_2}$$

(b) EVALUATE: Let $r_1 = r_2 = r$. Then $R = \rho h / \pi r^2 = \rho L / A$ where $A = \pi r^2$ and $L = h$. This agrees with Eq. (25.10).

25.66. IDENTIFY: Divide the region into thin spherical shells of radius r and thickness dr . The total resistance is the sum of the resistances of the thin shells and can be obtained by integration.

SET UP: $I = V/R$ and $J = I/4\pi r^2$, where $4\pi r^2$ is the surface area of a shell of radius r .

EXECUTE: (a) $dR = \frac{\rho dr}{4\pi r^2} \Rightarrow R = \frac{\rho}{4\pi} \int_a^b \frac{dr}{r^2} = -\frac{\rho}{4\pi} \frac{1}{r} \Big|_a^b = \frac{\rho}{4\pi} \left(\frac{1}{a} - \frac{1}{b} \right) = \frac{\rho}{4\pi} \left(\frac{b-a}{ab} \right)$.

(b) $I = \frac{V_{ab}}{R} = \frac{V_{ab} 4\pi ab}{\rho(b-a)}$ and $J = \frac{I}{A} = \frac{V_{ab} 4\pi ab}{\rho(b-a) 4\pi r^2} = \frac{V_{ab} ab}{\rho(b-a)r^2}$.

(c) If the thickness of the shells is small, then $4\pi ab \approx 4\pi a^2$ is the surface area of the conducting material.

$$R = \frac{\rho}{4\pi} \left(\frac{1}{a} - \frac{1}{b} \right) = \frac{\rho(b-a)}{4\pi ab} \approx \frac{\rho L}{4\pi a^2} = \frac{\rho L}{A}, \text{ where } L = b - a.$$

EVALUATE: The current density in the material is proportional to $1/r^2$.

25.67. **IDENTIFY:** Apply $R = \frac{\rho L}{A}$.

SET UP: For mercury at 20°C , $\rho = 9.5 \times 10^{-7} \Omega \cdot \text{m}$, $\alpha = 0.00088 (\text{C}^\circ)^{-1}$ and $\beta = 18 \times 10^{-5} (\text{C}^\circ)^{-1}$.

EXECUTE: (a) $R = \frac{\rho L}{A} = \frac{(9.5 \times 10^{-7} \Omega \cdot \text{m})(0.12 \text{ m})}{(\pi/4)(0.0016 \text{ m})^2} = 0.057 \Omega$.

(b) $\rho(T) = \rho_0(1 + \alpha\Delta T)$ gives

$$\rho(60^\circ\text{C}) = (9.5 \times 10^{-7} \Omega \cdot \text{m})(1 + (0.00088 (\text{C}^\circ)^{-1})(40 \text{ C}^\circ)) = 9.83 \times 10^{-7} \Omega \cdot \text{m}, \text{ so } \Delta\rho = 3.34 \times 10^{-8} \Omega \cdot \text{m}.$$

(c) $\Delta V = \beta V_0 \Delta T$ gives $A\Delta L = A(\beta L_0 \Delta T)$. Therefore

$\Delta L = \beta L_0 \Delta T = (18 \times 10^{-5} (\text{C}^\circ)^{-1})(0.12 \text{ m})(40 \text{ C}^\circ) = 8.64 \times 10^{-4} \text{ m} = 0.86 \text{ mm}$. The cross-sectional area of the mercury remains constant because the diameter of the glass tube doesn't change. All of the change in volume of the mercury must be accommodated by a change in length of the mercury column.

(d) $R = \frac{\rho L}{A}$ gives $\Delta R = \frac{L\Delta\rho}{A} + \frac{\rho\Delta L}{A}$.

$$\Delta R = \frac{(3.34 \times 10^{-8} \Omega \cdot \text{m})(0.12 \text{ m})}{(\pi/4)(0.0016 \text{ m})^2} + \frac{(9.5 \times 10^{-7} \Omega \cdot \text{m})(0.86 \times 10^{-3} \text{ m})}{(\pi/4)(0.0016 \text{ m})^2} = 2.40 \times 10^{-3} \Omega.$$

EVALUATE: (e) From Eq. (25.12),

$$\alpha = \frac{1}{\Delta T} \left(\frac{R}{R_0} - 1 \right) = \frac{1}{40 \text{ C}^\circ} \left(\frac{0.057 \Omega + 2.40 \times 10^{-3} \Omega}{0.057 \Omega} - 1 \right) = 1.1 \times 10^{-3} (\text{C}^\circ)^{-1}.$$

This value is 25% greater than the temperature coefficient of resistivity and the length increase is important.

25.68. **IDENTIFY:** Consider the potential changes around the circuit. For a complete loop the sum of the potential changes is zero.

SET UP: There is a potential drop of IR when you pass through a resistor in the direction of the current.

EXECUTE: (a) $I = \frac{8.0 \text{ V} - 4.0 \text{ V}}{24.0 \Omega} = 0.167 \text{ A}$. $V_d + 8.00 \text{ V} - I(0.50 \Omega + 8.00 \Omega) = V_a$, so

$$V_{ad} = 8.00 \text{ V} - (0.167 \text{ A})(8.50 \Omega) = 6.58 \text{ V}.$$

(b) The terminal voltage is $V_{bc} = V_b - V_c$. $V_c + 4.00 \text{ V} + I(0.50 \Omega) = V_b$ and

$$V_{bc} = +4.00 \text{ V} + (0.167 \text{ A})(0.50 \Omega) = +4.08 \text{ V}.$$

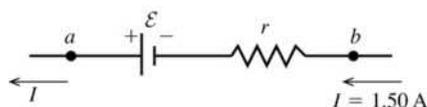
(c) Adding another battery at point d in the opposite sense to the 8.0-V battery produces a counterclockwise current with magnitude $I = \frac{10.3 \text{ V} - 8.0 \text{ V} + 4.0 \text{ V}}{24.5 \Omega} = 0.257 \text{ A}$. Then $V_c + 4.00 \text{ V} - I(0.50 \Omega) = V_b$ and

$$V_{bc} = 4.00 \text{ V} - (0.257 \text{ A})(0.50 \Omega) = 3.87 \text{ V}.$$

EVALUATE: When current enters the battery at its negative terminal, as in part (c), the terminal voltage is less than its emf. When current enters the battery at the positive terminal, as in part (b), the terminal voltage is greater than its emf.

25.69. **IDENTIFY:** In each case write the terminal voltage in terms of \mathcal{E} , I and r . Since I is known, this gives two equations in the two unknowns \mathcal{E} and r .

SET UP: The battery with the 1.50-A current is sketched in Figure 25.69a.



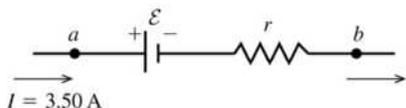
$$V_{ab} = 8.4 \text{ V}$$

$$V_{ab} = \mathcal{E} - Ir$$

$$\mathcal{E} - (1.50 \text{ A})r = 8.4 \text{ V}$$

Figure 25.69a

The battery with the 3.50-A current is sketched in Figure 25.69b.



$$\begin{aligned}V_{ab} &= 9.4 \text{ V} \\V_{ab} &= \mathcal{E} + Ir \\ \mathcal{E} + (3.5 \text{ A})r &= 9.4 \text{ V}\end{aligned}$$

Figure 25.69b

EXECUTE: (a) Solve the first equation for \mathcal{E} and use that result in the second equation:

$$\mathcal{E} = 8.4 \text{ V} + (1.50 \text{ A})r$$

$$8.4 \text{ V} + (1.50 \text{ A})r + (3.50 \text{ A})r = 9.4 \text{ V}$$

$$(5.00 \text{ A})r = 1.0 \text{ V} \text{ so } r = \frac{1.0 \text{ V}}{5.00 \text{ A}} = 0.20 \Omega$$

(b) Then $\mathcal{E} = 8.4 \text{ V} + (1.50 \text{ A})r = 8.4 \text{ V} + (1.50 \text{ A})(0.20 \Omega) = 8.7 \text{ V}$

EVALUATE: When the current passes through the emf in the direction from $-$ to $+$, the terminal voltage is less than the emf and when it passes through from $+$ to $-$, the terminal voltage is greater than the emf.

25.70. IDENTIFY: $V = IR$. $P = I^2R$.

SET UP: The total resistance is the resistance of the person plus the internal resistance of the power supply.

EXECUTE: (a) $I = \frac{V}{R_{\text{tot}}} = \frac{14 \times 10^3 \text{ V}}{10 \times 10^3 \Omega + 2000 \Omega} = 1.17 \text{ A}$

(b) $P = I^2R = (1.17 \text{ A})^2(10 \times 10^3 \Omega) = 1.37 \times 10^4 \text{ J} = 13.7 \text{ kJ}$

(c) $R_{\text{tot}} = \frac{V}{I} = \frac{14 \times 10^3 \text{ V}}{1.00 \times 10^{-3} \text{ A}} = 14 \times 10^6 \Omega$. The resistance of the power supply would need to be

$$14 \times 10^6 \Omega - 10 \times 10^3 \Omega = 14 \times 10^6 \Omega = 14 \text{ M}\Omega.$$

EVALUATE: The current through the body in part (a) is large enough to be fatal.

25.71. IDENTIFY: $R = \frac{\rho L}{A}$. $V = IR$. $P = I^2R$.

SET UP: The area of the end of a cylinder of radius r is πr^2 .

EXECUTE: (a) $R = \frac{(5.0 \Omega \cdot \text{m})(1.6 \text{ m})}{\pi(0.050 \text{ m})^2} = 1.0 \times 10^3 \Omega$

(b) $V = IR = (100 \times 10^{-3} \text{ A})(1.0 \times 10^3 \Omega) = 100 \text{ V}$

(c) $P = I^2R = (100 \times 10^{-3} \text{ A})^2(1.0 \times 10^3 \Omega) = 10 \text{ W}$

EVALUATE: The resistance between the hands when the skin is wet is about a factor of ten less than when the skin is dry (Problem 25.70).

25.72. IDENTIFY: The cost of operating an appliance is proportional to the amount of energy consumed. The energy depends on the power the item consumes and the length of time for which it is operated.

SET UP: At a constant power, the energy is equal to Pt , and the total cost is the cost per kilowatt-hour (kWh) times the energy (in kWh).

EXECUTE: (a) Use the fact that $1.00 \text{ kWh} = (1000 \text{ J/s})(3600 \text{ s}) = 3.60 \times 10^6 \text{ J}$, and one year contains $3.156 \times 10^7 \text{ s}$.

$$(75 \text{ J/s}) \left(\frac{3.156 \times 10^7 \text{ s}}{1 \text{ yr}} \right) \left(\frac{\$0.120}{3.60 \times 10^6 \text{ J}} \right) = \$78.90$$

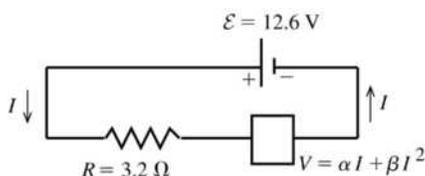
(b) At 8 h/day, the refrigerator runs for 1/3 of a year. Using the same procedure as above gives

$$(400 \text{ J/s})\left(\frac{1}{3}\right)\left(\frac{3.156 \times 10^7 \text{ s}}{1 \text{ yr}}\right)\left(\frac{\$0.120}{3.60 \times 10^6 \text{ J}}\right) = \$140.27$$

EVALUATE: Electric lights can be a substantial part of the cost of electricity in the home if they are left on for a long time!

25.73. IDENTIFY: Set the sum of the potential rises and drops around the circuit equal to zero and solve for I .

SET UP: The circuit is sketched in Figure 25.73.



EXECUTE: $\mathcal{E} - IR - V = 0$

$$\mathcal{E} - IR - \alpha I - \beta I^2 = 0$$

$$\beta I^2 + (R + \alpha)I - \mathcal{E} = 0$$

Figure 25.73

The quadratic formula gives $I = (1/2\beta)\left[-(R + \alpha) \pm \sqrt{(R + \alpha)^2 + 4\beta\mathcal{E}}\right]$

I must be positive, so take the + sign

$$I = (1/2\beta)\left[-(R + \alpha) + \sqrt{(R + \alpha)^2 + 4\beta\mathcal{E}}\right]$$

$$I = -2.692 \text{ A} + 4.116 \text{ A} = 1.42 \text{ A}$$

EVALUATE: For this I the voltage across the thermistor is 8.0 V. The voltage across the resistor must then be 12.6 V – 8.0 V = 4.6 V, and this agrees with Ohm’s law for the resistor.

25.74. (a) IDENTIFY: The rate of heating (power) in the cable depends on the potential difference across the cable and the resistance of the cable.

SET UP: The power is $P = V^2/R$ and the resistance is $R = \rho L/A$. The diameter D of the cable is twice its

radius. $P = \frac{V^2}{R} = \frac{V^2}{(\rho L/A)} = \frac{AV^2}{\rho L} = \frac{\pi r^2 V^2}{\rho L}$. The electric field in the cable is equal to the potential

difference across its ends divided by the length of the cable: $E = V/L$.

EXECUTE: Solving for r and using the resistivity of copper gives

$$r = \sqrt{\frac{P\rho L}{\pi V^2}} = \sqrt{\frac{(50.0 \text{ W})(1.72 \times 10^{-8} \Omega \cdot \text{m})(1500 \text{ m})}{\pi(220.0 \text{ V})^2}} = 9.21 \times 10^{-5} \text{ m}. \quad D = 2r = 0.184 \text{ mm}$$

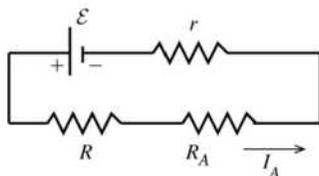
(b) SET UP: $E = V/L$

$$\mathbf{EXECUTE:} \quad E = (220 \text{ V})/(1500 \text{ m}) = 0.147 \text{ V/m}$$

EVALUATE: This would be an extremely thin (and hence fragile) cable.

25.75. IDENTIFY: The ammeter acts as a resistance in the circuit loop. Set the sum of the potential rises and drops around the circuit equal to zero.

(a) SET UP: The circuit with the ammeter is sketched in Figure 25.75a.

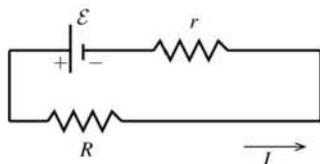


$$\mathbf{EXECUTE:} \quad I_A = \frac{\mathcal{E}}{r + R + R_A}$$

$$\mathcal{E} = I_A(r + R + R_A)$$

Figure 25.75a

SET UP: The circuit with the ammeter removed is sketched in Figure 25.75b.



EXECUTE: $I = \frac{\mathcal{E}}{R+r}$

Figure 25.75b

Combining the two equations gives

$$I = \left(\frac{1}{R+r} \right) I_A (r + R + R_A) = I_A \left(1 + \frac{R_A}{r+R} \right)$$

(b) Want $I_A = 0.990I$. Use this in the result for part (a).

$$I = 0.990I \left(1 + \frac{R_A}{r+R} \right)$$

$$0.010 = 0.990 \left(\frac{R_A}{r+R} \right)$$

$$R_A = (r+R)(0.010/0.990) = (0.45 \Omega + 3.80 \Omega)(0.010/0.990) = 0.0429 \Omega$$

(c) $I - I_A = \frac{\mathcal{E}}{r+R} - \frac{\mathcal{E}}{r+R+R_A}$

$$I - I_A = \mathcal{E} \left(\frac{r+R+R_A - r - R}{(r+R)(r+R+R_A)} \right) = \frac{\mathcal{E}R_A}{(r+R)(r+R+R_A)}$$

EVALUATE: The difference between I and I_A increases as R_A increases. If R_A is larger than the value calculated in part (b) then I_A differs from I by more than 1.0%.

25.76. IDENTIFY: Since the resistivity is a function of the position along the length of the cylinder, we must integrate to find the resistance.

(a) **SET UP:** The resistance of a cross-section of thickness dx is $dR = \rho dx/A$.

EXECUTE: Using the given function for the resistivity and integrating gives

$$R = \int \frac{\rho dx}{A} = \int_0^L \frac{(a + bx^2) dx}{\pi r^2} = \frac{aL + bL^3/3}{\pi r^2}$$

Now get the constants a and b : $\rho(0) = a = 2.25 \times 10^{-8} \Omega \cdot \text{m}$ and $\rho(L) = a + bL^2$ gives

$8.50 \times 10^{-8} \Omega \cdot \text{m} = 2.25 \times 10^{-8} \Omega \cdot \text{m} + b(1.50 \text{ m})^2$ which gives $b = 2.78 \times 10^{-8} \Omega/\text{m}$. Now use the above result to find R .

$$R = \frac{(2.25 \times 10^{-8} \Omega \cdot \text{m})(1.50 \text{ m}) + (2.78 \times 10^{-8} \Omega/\text{m})(1.50 \text{ m})^3/3}{\pi(0.0110 \text{ m})^2} = 1.71 \times 10^{-4} \Omega = 171 \mu\Omega$$

(b) **IDENTIFY:** Use the definition of resistivity to find the electric field at the midpoint of the cylinder, where $x = L/2$.

SET UP: $E = \rho J$. Evaluate the resistivity, using the given formula, for $x = L/2$.

EXECUTE: At the midpoint, $x = L/2$, giving $E = \frac{\rho I}{\pi r^2} = \frac{[a + b(L/2)^2]I}{\pi r^2}$.

$$E = \frac{[2.25 \times 10^{-8} \Omega \cdot \text{m} + (2.78 \times 10^{-8} \Omega/\text{m})(0.750 \text{ m})^2](1.75 \text{ A})}{\pi(0.0110 \text{ m})^2} = 1.76 \times 10^{-4} \text{ V/m}$$

(c) **IDENTIFY:** For the first segment, the result is the same as in part (a) except that the upper limit of the integral is $L/2$ instead of L .

SET UP: Integrating using the upper limit of $L/2$ gives $R_1 = \frac{a(L/2) + (b/3)(L^3/8)}{\pi r^2}$.

EXECUTE: Substituting the numbers gives

$$R_1 = \frac{(2.25 \times 10^{-8} \Omega \cdot \text{m})(0.750 \text{ m}) + (2.78 \times 10^{-8} \Omega/\text{m})/3((1.50 \text{ m})^3/8)}{\pi(0.0110 \text{ m})^2} = 5.47 \times 10^{-5} \Omega$$

The resistance R_2 of the second half is equal to the total resistance minus the resistance of the first half.

$$R_2 = R - R_1 = 1.71 \times 10^{-4} \Omega - 5.47 \times 10^{-5} \Omega = 1.16 \times 10^{-4} \Omega$$

EVALUATE: The second half has a greater resistance than the first half because the resistance increases with distance along the cylinder.

- 25.77. IDENTIFY:** The power supplied to the house is $P = VI$. The rate at which electrical energy is dissipated in the wires is I^2R , where $R = \frac{\rho L}{A}$.

SET UP: For copper, $\rho = 1.72 \times 10^{-8} \Omega \cdot \text{m}$.

EXECUTE: (a) The line voltage, current to be drawn, and wire diameter are what must be considered in household wiring.

(b) $P = VI$ gives $I = \frac{P}{V} = \frac{4200 \text{ W}}{120 \text{ V}} = 35 \text{ A}$, so the 8-gauge wire is necessary, since it can carry up to 40 A.

(c) $P = I^2R = \frac{I^2 \rho L}{A} = \frac{(35 \text{ A})^2 (1.72 \times 10^{-8} \Omega \cdot \text{m})(42.0 \text{ m})}{(\pi/4)(0.00326 \text{ m})^2} = 106 \text{ W}$.

(d) If 6-gauge wire is used, $P = \frac{I^2 \rho L}{A} = \frac{(35 \text{ A})^2 (1.72 \times 10^{-8} \Omega \cdot \text{m})(42 \text{ m})}{(\pi/4)(0.00412 \text{ m})^2} = 66 \text{ W}$. The decrease in energy

consumption is $\Delta E = \Delta Pt = (40 \text{ W})(365 \text{ days/yr})(12 \text{ h/day}) = 175 \text{ kWh/yr}$ and the savings is $(175 \text{ kWh/yr})(\$0.11/\text{kWh}) = \19.25 per year.

EVALUATE: The cost of the 4200 W used by the appliances is \$2020. The savings is about 1%.

- 25.78. IDENTIFY:** Compact fluorescent bulbs draw much less power than incandescent bulbs and last much longer. Hence they cost less to operate.

SET UP: A kWh is power of 1 kW for a time of 1 h. $P = \frac{V^2}{R}$.

EXECUTE: (a) In 3.0 yr the bulbs are on for $(3.0 \text{ yr})(365.24 \text{ days/yr})(4.0 \text{ h/day}) = 4.38 \times 10^3 \text{ h}$.

Compact bulb: The energy used is $(23 \text{ W})(4.38 \times 10^3 \text{ h}) = 1.01 \times 10^5 \text{ Wh} = 101 \text{ kWh}$. The cost of this energy is $(\$0.080/\text{kWh})(101 \text{ kWh}) = \8.08 . One bulb will last longer than this. The bulb cost is \$11.00, so the total cost is \$19.08.

Incandescent: The energy used is $(100 \text{ W})(4.38 \times 10^3 \text{ h}) = 4.38 \times 10^5 \text{ Wh} = 438 \text{ kWh}$. The cost of this energy is $(\$0.080/\text{kWh})(438 \text{ kWh}) = \35.04 . Six bulbs will be used during this time and the bulb cost will be \$4.50. The total cost will be \$39.54.

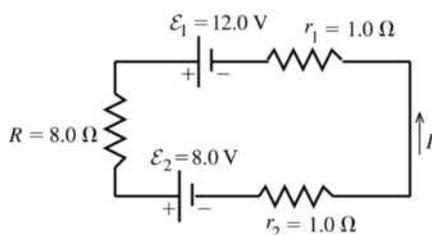
(b) The compact bulb will save $\$39.54 - \$19.08 = \$20.46$.

(c) $R = \frac{V^2}{P} = \frac{(120 \text{ V})^2}{23 \text{ W}} = 626 \Omega$.

EVALUATE: The initial cost of the bulb is much greater for the compact fluorescent bulb but the savings soon repay the cost of the bulb. The compact bulb should last for over six years, so over a 6-year period the savings per year will be even greater. The cost of compact fluorescent bulbs has come down dramatically, so the savings today would be considerably greater than indicated here.

- 25.79. (a) IDENTIFY:** Set the sum of the potential rises and drops around the circuit equal to zero and solve the resulting equation for the current I . Apply Eq. (25.17) to each circuit element to find the power associated with it.

SET UP: The circuit is sketched in Figure 25.79.



$$\text{EXECUTE: } \mathcal{E}_1 - \mathcal{E}_2 - I(r_1 + r_2 + R) = 0$$

$$I = \frac{\mathcal{E}_1 - \mathcal{E}_2}{r_1 + r_2 + R}$$

$$I = \frac{12.0 \text{ V} - 8.0 \text{ V}}{1.0 \Omega + 1.0 \Omega + 8.0 \Omega}$$

$$I = 0.40 \text{ A}$$

Figure 25.79

$$(b) P = I^2 R + I^2 r_1 + I^2 r_2 = I^2 (R + r_1 + r_2) = (0.40 \text{ A})^2 (8.0 \Omega + 1.0 \Omega + 1.0 \Omega)$$

$$P = 1.6 \text{ W}$$

(c) Chemical energy is converted to electrical energy in a battery when the current goes through the battery from the negative to the positive terminal, so the electrical energy of the charges increases as the current passes through. This happens in the 12.0-V battery, and the rate of production of electrical energy is $P = \mathcal{E}_1 I = (12.0 \text{ V})(0.40 \text{ A}) = 4.8 \text{ W}$.

(d) Electrical energy is converted to chemical energy in a battery when the current goes through the battery from the positive to the negative terminal, so the electrical energy of the charges decreases as the current passes through. This happens in the 8.0-V battery, and the rate of consumption of electrical energy is $P = \mathcal{E}_2 I = (8.0 \text{ V})(0.40 \text{ V}) = 3.2 \text{ W}$.

(e) **EVALUATE:** Total rate of production of electrical energy = 4.8 W. Total rate of consumption of electrical energy = 1.6 W + 3.2 W = 4.8 W, which equals the rate of production, as it must.

25.80. **IDENTIFY:** Apply $R = \frac{\rho L}{A}$ for each material. The total resistance is the sum of the resistances of the rod

and the wire. The rate at which energy is dissipated is $I^2 R$.

SET UP: For steel, $\rho = 2.0 \times 10^{-7} \Omega \cdot \text{m}$. For copper, $\rho = 1.72 \times 10^{-8} \Omega \cdot \text{m}$.

$$\text{EXECUTE: (a) } R_{\text{steel}} = \frac{\rho L}{A} = \frac{(2.0 \times 10^{-7} \Omega \cdot \text{m})(2.0 \text{ m})}{(\pi/4)(0.018 \text{ m})^2} = 1.57 \times 10^{-3} \Omega \text{ and}$$

$$R_{\text{Cu}} = \frac{\rho L}{A} = \frac{(1.72 \times 10^{-8} \Omega \cdot \text{m})(35 \text{ m})}{(\pi/4)(0.008 \text{ m})^2} = 0.012 \Omega. \text{ This gives}$$

$$V = IR = I(R_{\text{steel}} + R_{\text{Cu}}) = (15000 \text{ A})(1.57 \times 10^{-3} \Omega + 0.012 \Omega) = 204 \text{ V}.$$

$$(b) E = Pt = I^2 R t = (15000 \text{ A})^2 (0.0136 \Omega)(65 \times 10^{-6} \text{ s}) = 199 \text{ J}.$$

EVALUATE: $I^2 R$ is large but t is very small, so the energy deposited is small. The wire and rod each have a mass of about 1 kg, so their temperature rise due to the deposited energy will be small.

25.81. **IDENTIFY and SET UP:** The terminal voltage is $V_{ab} = \mathcal{E} - Ir = IR$, where R is the resistance connected to the battery. During the charging the terminal voltage is $V_{ab} = \mathcal{E} + Ir$. $P = VI$ and energy is $E = Pt$. $I^2 r$ is the rate at which energy is dissipated in the internal resistance of the battery.

$$\text{EXECUTE: (a) } V_{ab} = \mathcal{E} + Ir = 12.0 \text{ V} + (10.0 \text{ A})(0.24 \Omega) = 14.4 \text{ V}.$$

$$(b) E = Pt = IVt = (10 \text{ A})(14.4 \text{ V})(5)(3600 \text{ s}) = 2.59 \times 10^6 \text{ J}.$$

$$(c) E_{\text{diss}} = P_{\text{diss}} t = I^2 r t = (10 \text{ A})^2 (0.24 \Omega)(5)(3600 \text{ s}) = 4.32 \times 10^5 \text{ J}.$$

$$(d) \text{ Discharged at } 10 \text{ A: } I = \frac{\mathcal{E}}{r + R} \Rightarrow R = \frac{\mathcal{E} - Ir}{I} = \frac{12.0 \text{ V} - (10 \text{ A})(0.24 \Omega)}{10 \text{ A}} = 0.96 \Omega.$$

$$(e) E = Pt = IVt = (10 \text{ A})(9.6 \text{ V})(5)(3600 \text{ s}) = 1.73 \times 10^6 \text{ J}.$$

(f) Since the current through the internal resistance is the same as before, there is the same energy dissipated as in (c): $E_{\text{diss}} = 4.32 \times 10^5 \text{ J}$.

EVALUATE: (g) Part of the energy originally supplied was stored in the battery and part was lost in the internal resistance. So the stored energy was less than what was supplied during charging. Then when discharging, even more energy is lost in the internal resistance, and only what is left is dissipated by the external resistor.

- 25.82. IDENTIFY and SET UP:** The terminal voltage is $V_{ab} = \mathcal{E} - Ir = IR$, where R is the resistance connected to the battery. During the charging the terminal voltage is $V_{ab} = \mathcal{E} + Ir$. $P = VI$ and energy is $E = Pt$. I^2r is the rate at which energy is dissipated in the internal resistance of the battery.

EXECUTE: (a) $V_{ab} = \mathcal{E} + Ir = 12.0 \text{ V} + (30 \text{ A})(0.24 \Omega) = 19.2 \text{ V}$.

(b) $E = Pt = IVt = (30 \text{ A})(19.2 \text{ V})(1.7)(3600 \text{ s}) = 3.53 \times 10^6 \text{ J}$.

(c) $E_{\text{diss}} = P_{\text{diss}}t = I^2Rt = (30 \text{ A})^2(0.24 \Omega)(1.7)(3600 \text{ s}) = 1.32 \times 10^6 \text{ J}$.

(d) Discharged at 30 A: $I = \frac{\mathcal{E}}{r + R}$ gives $R = \frac{\mathcal{E} - Ir}{I} = \frac{12.0 \text{ V} - (30 \text{ A})(0.24 \Omega)}{30 \text{ A}} = 0.16 \Omega$.

(e) $E = Pt = I^2Rt = (30 \text{ A})^2(0.16 \Omega)(1.7)(3600 \text{ s}) = 8.81 \times 10^5 \text{ J}$.

(f) Since the current through the internal resistance is the same as before, there is the same energy dissipated as in (c): $E_{\text{diss}} = 1.32 \times 10^6 \text{ J}$.

EVALUATE: (g) Again, part of the energy originally supplied was stored in the battery and part was lost in the internal resistance. So the stored energy was less than what was supplied during charging. Then when discharging, even more energy is lost in the internal resistance, and what is left is dissipated over the external resistor. This time, at a higher current, much more energy is lost in the internal resistance. Slow charging and discharging is more energy efficient.

- 25.83. IDENTIFY:** No current flows through the capacitor when it is fully charged.

SET UP: With the capacitor fully charged, $I = \frac{\mathcal{E}}{R_1 + R_2}$. $V_R = IR$ and $V_C = Q/C$.

EXECUTE: $V_C = \frac{Q}{C} = \frac{36.0 \mu\text{C}}{9.00 \mu\text{F}} = 4.00 \text{ V}$. $V_{R_1} = V_C = 4.00 \text{ V}$ and $I = \frac{V_{R_1}}{R_1} = \frac{4.00 \text{ V}}{6.00 \Omega} = 0.667 \text{ A}$.

$V_{R_2} = IR_2 = (0.667 \text{ A})(4.00 \Omega) = 2.668 \text{ V}$. $\mathcal{E} = V_{R_1} + V_{R_2} = 4.00 \text{ V} + 2.668 \text{ V} = 6.67 \text{ V}$.

EVALUATE: When a capacitor is fully charged, it acts like an open circuit and prevents any current from flowing through it.

- 25.84. IDENTIFY:** No current flows to the capacitors when they are fully charged.

SET UP: $V_R = RI$ and $V_C = Q/C$.

EXECUTE: (a) $V_{C_1} = \frac{Q_1}{C_1} = \frac{18.0 \mu\text{C}}{3.00 \mu\text{F}} = 6.00 \text{ V}$. $V_{C_2} = V_{C_1} = 6.00 \text{ V}$.

$Q_2 = C_2V_{C_2} = (6.00 \mu\text{F})(6.00 \text{ V}) = 36.0 \mu\text{C}$.

(b) No current flows to the capacitors when they are fully charged, so $\mathcal{E} = IR_1 + IR_2$.

$V_{R_2} = V_{C_1} = 6.00 \text{ V}$. $I = \frac{V_{R_2}}{R_2} = \frac{6.00 \text{ V}}{2.00 \Omega} = 3.00 \text{ A}$.

$R = \frac{\mathcal{E} - IR_2}{I} = \frac{60.0 \text{ V} - 6.00 \text{ V}}{3.00 \text{ A}} = 18.0 \Omega$.

EVALUATE: When a capacitor is fully charged, it acts like an open circuit and prevents any current from flowing through it.

- 25.85. IDENTIFY and SET UP:** Follow the steps specified in the problem.

EXECUTE: (a) $\Sigma F = ma = |q|E$ gives $\frac{|q|}{m} = \frac{a}{E}$.

(b) If the electric field is constant, $V_{bc} = EL$ and $\frac{|q|}{m} = \frac{aL}{V_{bc}}$.

(c) The free charges are “left behind” so the left end of the rod is negatively charged, while the right end is positively charged. Thus the right end, point c , is at the higher potential.

$$(d) a = \frac{V_{bc}|q|}{mL} = \frac{(1.0 \times 10^{-3} \text{ V})(1.6 \times 10^{-19} \text{ C})}{(9.11 \times 10^{-31} \text{ kg})(0.50 \text{ m})} = 3.5 \times 10^8 \text{ m/s}^2.$$

EVALUATE: (e) Performing the experiment in a rotational way enables one to keep the experimental apparatus in a localized area—whereas an acceleration like that obtained in (d), if linear, would quickly have the apparatus moving at high speeds and large distances. Also, the rotating spool of thin wire can have many turns of wire and the total potential is the sum of the potentials in each turn, the potential in each turn times the number of turns.

25.86. IDENTIFY: The power output of the source is $VI = (\mathcal{E} - Ir)I$.

SET UP: The short-circuit current is $I_{\text{short circuit}} = \mathcal{E}/r$.

EXECUTE: (a) $P = \mathcal{E}I - I^2r$, so $\frac{dP}{dI} = \mathcal{E} - 2Ir = 0$ for maximum power output and

$$I_{P \text{ max}} = \frac{1}{2} \frac{\mathcal{E}}{r} = \frac{1}{2} I_{\text{short circuit}}.$$

(b) For the maximum power output of part (a), $I = \frac{\mathcal{E}}{r + R} = \frac{1}{2} \frac{\mathcal{E}}{r}$. $r + R = 2r$ and $R = r$.

$$\text{Then, } P = I^2R = \left(\frac{\mathcal{E}}{2r}\right)^2 r = \frac{\mathcal{E}^2}{4r}.$$

EVALUATE: When R is smaller than r , I is large and the I^2r losses in the battery are large. When R is larger than r , I is small and the power output $\mathcal{E}I$ of the battery emf is small.

25.87. IDENTIFY: Apply $R = \frac{\rho L}{A}$ to find the resistance of a thin slice of the rod and integrate to find the total R .

$V = IR$. Also find $R(x)$, the resistance of a length x of the rod.

SET UP: $E(x) = \rho(x)J$

EXECUTE: (a) $dR = \frac{\rho dx}{A} = \frac{\rho_0 \exp[-x/L] dx}{A}$ so

$$R = \frac{\rho_0}{A} \int_0^L \exp[-x/L] dx = \frac{\rho_0}{A} [-L \exp[-x/L]]_0^L = \frac{\rho_0 L}{A} (1 - e^{-1}) \quad \text{and} \quad I = \frac{V_0}{R} = \frac{V_0 A}{\rho_0 L (1 - e^{-1})}.$$

limit of x rather than L in the integration, $R(x) = \frac{\rho_0 L}{A} (1 - e^{-x/L})$.

$$(b) E(x) = \rho(x)J = \frac{I \rho_0 e^{-x/L}}{A} = \frac{V_0 e^{-x/L}}{L(1 - e^{-1})}.$$

$$(c) V = V_0 - IR(x). \quad V = V_0 - \left(\frac{V_0 A}{\rho_0 L [1 - e^{-1}]}\right) \left(\frac{\rho_0 L}{A}\right) (1 - e^{-x/L}) = V_0 \frac{(e^{-x/L} - e^{-1})}{(1 - e^{-1})}$$

(d) Graphs of resistivity, electric field and potential from $x = 0$ to L are given in Figure 25.87. Each quantity is given in terms of the indicated unit.

EVALUATE: The current is the same at all points in the rod. Where the resistivity is larger the electric field must be larger, in order to produce the same current density.

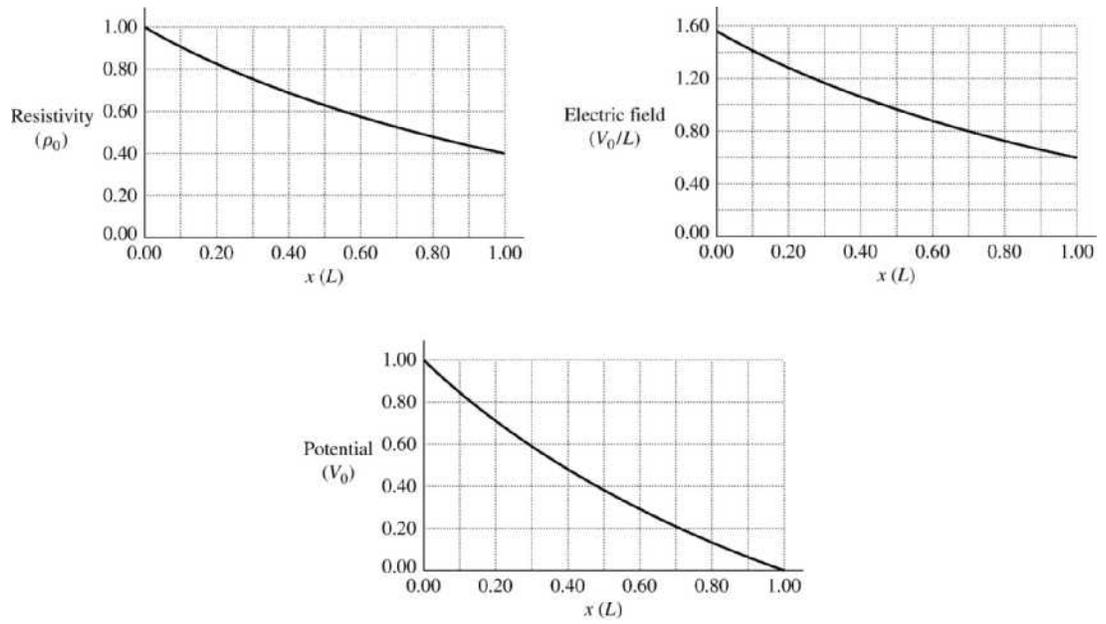


Figure 25.87

