REVIEW AND SYNTHESIS: CHAPTERS 16–18

Review Exercises

1. **Strategy and Solution** Since the spheres are identical, the charge will be shared evenly by the two spheres, so the spheres will have $(18.0\ \mu\text{C} + 6.0\ \mu\text{C})/2 = \boxed{12.0\ \mu\text{C}}$ of charge each.

2. **Strategy** The spheres will have the same electric potential at their surfaces. Use Eq. (17-8).

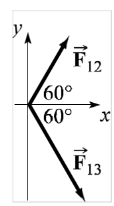
   Solution Form a proportion.

   $$\frac{V_{2r}}{V_r} = 1 = \frac{\frac{kQ_{2r}}{2r}}{\frac{kQ_r}{r}} = \frac{Q_{2r}}{2Q_r}, \text{ so } Q_{2r} = 2Q_r.$$

   So, the larger sphere will have twice the charge as the smaller, or two-thirds of the total. The total charge is $6.0\ \mu\text{C} + 18.0\ \mu\text{C} = 24.0\ \mu\text{C}$. Thus, there will be $\boxed{8.0\ \mu\text{C on the smaller sphere and 16}\ \mu\text{C on the larger sphere}}$.

3. **Strategy** The total electrical force on the upper charge is equal to the vector sum of the forces due to each of the lower charges. Let the 2.50-μC charge be 1, the 5.00-μC charge be 2, and the −7.00-μC charge be 3. Also, let $d = 0.150$ m.

   Solution Find the components of the force.



   $$F_x = F_{1x} + F_{2x} = \frac{k|q_1||q_2|}{d^2}\cos 60° + \frac{k|q_1||q_3|}{d^2}\cos(-60°) = \frac{k|q_1|}{d^2}\cos 60°(|q_2| + |q_3|)$$

   $$F_y = F_{1y} + F_{2y} = \frac{k|q_1||q_2|}{d^2}\sin 60° + \frac{k|q_1||q_3|}{d^2}\sin(-60°) = \frac{k|q_1|}{d^2}\sin 60°(|q_2| - |q_3|)$$

   Compute the magnitude.

   $$\begin{aligned} F &= \sqrt{\left[\frac{k|q_1|}{d^2}\cos 60°(|q_2| + |q_3|)\right]^2 + \left[\frac{k|q_1|}{d^2}\sin 60°(|q_2| - |q_3|)\right]^2} \\ &= \frac{k|q_1|}{d^2}\sqrt{[\cos 60°(|q_2| + |q_3|)]^2 + [\sin 60°(|q_2| - |q_3|)]^2} \\ &= \frac{(8.988\times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(2.50\ \mu\text{C})}{(0.150\ \text{m})^2}\sqrt{[\cos 60°(5.00\ \mu\text{C} + 7.00\ \mu\text{C})]^2 + [\sin 60°(5.00\ \mu\text{C} - 7.00\ \mu\text{C})]^2} \\ &= 6.24\ \text{N} \end{aligned}$$

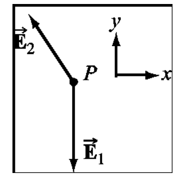
   Compute the direction.

   $$\theta = \tan^{-1}\frac{F_y}{F_x} = \tan^{-1}\frac{\sin 60°(5.00\ \mu\text{C} - 7.00\ \mu\text{C})}{\cos 60°(5.00\ \mu\text{C} + 7.00\ \mu\text{C})} = 16.1° \text{ below the } +x\text{-axis}$$

   Thus, $\vec{\mathbf{F}} = \boxed{6.24\ \text{N at } 16.1° \text{ below the } +x\text{-axis}}$.

4. (a) Strategy The electric field at P is equal to the vector sum of the fields due to each of the charges. Use Eq. (16-5).

Solution Find the components of the electric field at P.



$$E_x = E_{1x} + E_{2x} = 0 - \frac{k|Q_2|}{r_2^2}\left(\frac{2.00}{\sqrt{2.00^2 + 3.00^2}}\right) = -\frac{2.00k|Q_2|}{\sqrt{13.00}r_2^2}$$

$$E_y = E_{1y} + E_{2y} = -\frac{k|Q_1|}{r_1^2} + \frac{k|Q_2|}{r_2^2}\left(\frac{3.00}{\sqrt{2.00^2 + 3.00^2}}\right) = -\frac{k|Q_1|}{r_1^2} + \frac{3.00k|Q_2|}{\sqrt{13.00}r_2^2}$$

Compute the magnitude.

$$E = \sqrt{\left(-\frac{2.00k|Q_2|}{\sqrt{13.00}r_2^2}\right)^2 + \left(-\frac{k|Q_1|}{r_1^2} + \frac{3.00k|Q_2|}{\sqrt{13.00}r_2^2}\right)^2}$$

$$= (8.988\times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\sqrt{\left[\frac{2.00(6.0\times 10^{-6}\ \text{C})}{\sqrt{13.00}(13.00\times 10^{-4}\ \text{m}^2)}\right]^2 + \left[-\frac{4.5\times 10^{-6}\ \text{C}}{(0.0300\ \text{m})^2} + \frac{3.00(6.0\times 10^{-6}\ \text{C})}{\sqrt{13.00}(13.00\times 10^{-4}\ \text{m}^2)}\right]^2}$$

$$= 2.5\times 10^7\ \text{N/C}$$

Compute the direction.

$$\theta = \tan^{-1}\frac{E_y}{E_x} = \tan^{-1}\frac{-\frac{4.5\times 10^{-6}\ \text{C}}{(0.0300\ \text{m})^2} + \frac{3.00(6.0\times 10^{-6}\ \text{C})}{\sqrt{13.00}(13.00\times 10^{-4}\ \text{m}^2)}}{-\frac{2.00(6.0\times 10^{-6}\ \text{C})}{\sqrt{13.00}(13.00\times 10^{-4}\ \text{m}^2)}} = 24^\circ \text{ below the } -x\text{-axis}$$

Thus, $\vec{\mathbf{E}} = \boxed{2.5\times 10^7\ \text{N/C at } 24^\circ \text{ below the } -x\text{-axis}}$.

(b) Strategy Since the charge is negative, it will accelerate in the direction opposite the electric field at P. Use Newton's second law and Eq. (16-4b).

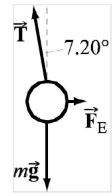
Solution Find the magnitude of the initial acceleration of the tiny particle.

$$\Sigma F = |q|E = ma, \text{ so } a = \frac{|q|E}{m} = \frac{(2.0\times 10^{-6}\ \text{C})(2.5\times 10^7\ \text{N/C})}{0.0050\ \text{kg}} = 1.0\times 10^4\ \text{m/s}^2.$$

Thus, $\vec{\mathbf{a}} = \boxed{1.0\times 10^4\ \text{m/s}^2 \text{ at } 24^\circ \text{ above the } +x\text{-axis}}$.

5. Strategy The force on charge *A* due to charge *B* is equal and opposite to the horizontal component of the tension. The sign of charge *A* is negative, since the sign of charge *B* is positive and the force is attractive. Use Newton's second law and Eq. (16-2).

Solution



(a) Find the tension.

$$\Sigma F_y = T\cos 7.20° - mg = 0, \text{ so } T = \frac{mg}{\cos 7.20°}.$$

The horizontal component of the tension is $T_x = \dfrac{mg}{\cos 7.20°}\sin 7.20° = mg\tan 7.20°.$

Solve for the second charge.

$$\frac{k|q_A||q_B|}{r^2} = mg\tan 7.20°, \text{ so}$$

$$|q_A| = \frac{r^2 mg\tan 7.20°}{k|q_B|} = \frac{(0.0500\text{ m})^2(0.0900\text{ kg})(9.80\text{ m/s}^2)\tan 7.20°}{(8.988\times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(130\times 10^{-9}\text{ C})} = 238\text{ nC}.$$

Thus, the charge on *A* is $\boxed{-238\text{ nC}}$.

(b) The tension in the thread is $T = \dfrac{mg}{\cos 7.20°} = \dfrac{(0.0900\text{ kg})(9.80\text{ m/s}^2)}{\cos 7.20°} = \boxed{0.889\text{ N}}.$

6. (a) Strategy Use Eq. (18-21b).

Solution Find the power dissipated in the light bulb immediately after it is connected to the emf.

$$P = \frac{V^2}{R} = \frac{(120\text{ V})^2}{10.0\ \Omega} = \boxed{1.4\text{ kW}}$$

(b) Strategy Use the definition of resistance.

Solution Find the resistance.

$$R = \frac{V}{I} = \frac{120\text{ V}}{0.833\text{ A}} = \boxed{140\ \Omega}$$

(c) Strategy Use Eq. (18-19).

Solution Find the power dissipated in the light bulb.

$$P = IV = (0.833\text{ A})(120\text{ V}) = \boxed{100\text{ W}}$$

(d) Strategy Use Eq. (18-9). The resistance is directly proportional to the resistivity.

Solution Find the temperature of the filament.

$$\frac{\rho}{\rho_0} = 1 + \alpha\Delta T = 1 + \alpha(T_\text{f} - T_\text{i}) = \frac{R}{R_0}, \text{ so}$$

$$T_\text{f} = T_\text{i} + \frac{1}{\alpha}\left(\frac{R}{R_0} - 1\right) = 20.0°\text{C} + \frac{1}{4.50\times 10^{-3}\ °\text{C}^{-1}}\left(\frac{144\ \Omega}{10.0\ \Omega} - 1\right) = \boxed{3000°\text{C}}.$$

(e) Strategy and Solution

When the bulb is first turned on, the filament is dissipating a lot more power with a lot more current flowing through it, which puts more stress on the filament and it breaks more easily.

7. **Strategy** Use conservation of energy to find the horizontal speed of electrons in the beam. Use Newton's second law to find the vertical acceleration of electrons in the beam. Let $h = 0.0110$ m and $d = 0.0850$ m.

Solution Set the electric potential energy gained by an electron while passing through the first potential difference equal to its kinetic energy to find its horizontal speed.

$$\frac{1}{2}mv_x^2 = e\Delta V_1, \text{ so } v_x = \sqrt{\frac{2e\Delta V_1}{m}}.$$

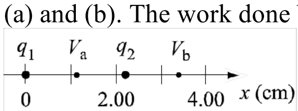
The electric field between the plates is $E = \Delta V_2/h$. According to Newton's second law,

$$ma_y = eE = e\frac{\Delta V_2}{h}, \text{ so } a_y = \frac{e\Delta V_2}{mh}.$$

The time it takes an electron in the beam to traverse the horizontal distance between the plates is $\Delta t = d/v_x$ and the vertical deflection is given by $\Delta y = \frac{1}{2}a_y(\Delta t)^2$. Find Δy.

$$\Delta y = \frac{1}{2}a_y(\Delta t)^2 = \frac{1}{2}\left(\frac{e\Delta V_2}{mh}\right)\left(\frac{d}{v_x}\right)^2 = \frac{e\Delta V_2 d^2}{2mh}\left(\frac{m}{2e\Delta V_1}\right) = \frac{\Delta V_2 d^2}{4h\Delta V_1} = \frac{(320\text{ V})(0.0850\text{ m})^2}{4(0.0110\text{ m})(12.0\times10^3\text{ V})} = \boxed{4.4\text{ mm}}$$

8. **Strategy** Draw a diagram and label the charges and potentials. Use the potential due to a point charge for parts (a) and (b). The work done by the external agent in part (c) is equal to the change in the charge's potential energy.



Solution

(a) Find the electric potential at $x = (2.20\text{ cm} - 0)/2 = 1.10\text{ cm} = 0.0110$ m.

$$V_a = \frac{kq_1}{r_1} + \frac{kq_2}{r_2} = \frac{8.988\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2}{0.0110\text{ m}}(35.0\times10^{-9}\text{ C} + 55.0\times10^{-9}\text{ C}) = \boxed{7.35\times10^4\text{ V}}$$

(b) Find the electric potential at $x = 0.0340$ m.

$$V_b = \frac{kq_1}{r_1} + \frac{kq_2}{r_2} = (8.988\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2)\left(\frac{35.0\times10^{-9}\text{ C}}{0.0340\text{ m}} + \frac{55.0\times10^{-9}\text{ C}}{0.0340\text{ m} - 0.0220\text{ m}}\right) = \boxed{5.04\times10^4\text{ V}}$$

(c) Find the work done on the charge.

$$W = \Delta U_E = q\Delta V = q(V_a - V_b) = (45.0\times10^{-9}\text{ C})(7.35\times10^4\text{ V} - 5.04\times10^4\text{ V}) = \boxed{1.04\times10^{-3}\text{ J}}$$

9. **(a)** **Strategy** Use Eqs. (18-13) and (18-17).

Solution Find the equivalent resistance.

$$R_{eq} = 15.0\ \Omega + \left(\frac{1}{40.0\ \Omega} + \frac{1}{20.0\ \Omega} + \frac{1}{40.0\ \Omega}\right)^{-1} + 10.0\ \Omega = \boxed{35.0\ \Omega}$$

(b) **Strategy** The current that flows through resistor R_1 is the current that flows through the emf.

Solution Find the current.

$$I = \frac{V}{R_{eq}} = \frac{24.0\text{ V}}{35.0\ \Omega} = \boxed{0.686\text{ A}}$$

(c) Strategy Use Eq. (18-21b).

Solution Find the power dissipated in the circuit.

$$P=\frac{V^2}{R_{\text{eq}}}=\frac{(24.0\text{ V})^2}{35.0\ \Omega}=\boxed{16.5\text{ W}}$$

(d) Strategy R_2, R_3, and R_4 are in parallel, so the potential difference across each is the same. Use Kirchhoff's loop rule.

Solution Find the potential difference across R_3, V_3.

$$V-IR_1-V_3-IR_5=0,\text{ so } V_3=V-IR_1-IR_5=24.0\text{ V}-(0.686\text{ A})(15.0\ \Omega+10.0\ \Omega)=\boxed{6.9\text{ V}}.$$

(e) Strategy Use the definition of resistance.

Solution Find the current through R_3, I_3.

$$I_3=\frac{V_3}{R_3}=\frac{6.86\text{ V}}{20.0\ \Omega}=\boxed{0.34\text{ A}}$$

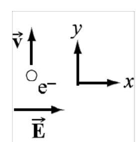
(f) Strategy Use Eq. (18-21b).

Solution Find the power dissipated in R_3.

$$P=\frac{V_3^{\,2}}{R_3}=\frac{(6.9\text{ V})^2}{20.0\ \Omega}=\boxed{2.4\text{ W}}$$

10. Strategy Use Newton's second law to find the horizontal acceleration of the electron.

Solution The y-component of the particle's displacement is



$$\Delta y=v_y\Delta t=(10.0\text{ m/s})(2.40\times10^{-6}\text{ s})=\boxed{24\ \mu\text{m}}.$$

According to Newton's second law, $\Sigma F_x=-eE=ma_x$, so $a_x=-\frac{eE}{m}$.

Thus, the x-component of the particle's displacement is

$$\Delta x=\frac{1}{2}a_x(\Delta t)^2=\frac{1}{2}\left(-\frac{eE}{m}\right)(\Delta t)^2=-\frac{eE(\Delta t)^2}{2m}=-\frac{(1.602\times10^{-19}\text{ C})(200\text{ V/m})(2.40\times10^{-6}\text{ m})^2}{2(9.109\times10^{-31}\text{ kg})}=\boxed{-100\text{ m}}.$$

11. Strategy The force between the particles is repulsive since they both have positive charge. Use conservation of energy.

Solution Find the closest distance that the proton approaches the lithium nucleus.

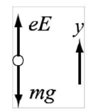
$$U_{\text{f}}=\frac{kq_1q_2}{r}=K_{\text{i}}=\frac{1}{2}m_{\text{p}}v_{\text{i}}^{\,2},\text{ so}$$

$$r=\frac{2kq_{\text{Li}}q_{\text{p}}}{m_{\text{p}}v_{\text{i}}^{\,2}}=\frac{2k(3e)(e)}{m_{\text{p}}v_{\text{i}}^{\,2}}=\frac{6(8.988\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(1.602\times10^{-19}\text{ C})^2}{(1.673\times10^{-27}\text{ kg})(5.24\times10^5\text{ m/s})^2}=\boxed{3.01\times10^{-12}\text{ m}}.$$

12. (a) Strategy and Solution The electron has negative charge, so it is attracted to the positively charged plate. Since gravity acts on the electron with a force in the downward direction, the electric force on the electron must be upward to counterbalance it. Therefore, the $\boxed{\text{upper plate is positively charged}}$ and $\boxed{\text{the lower plate is negatively charged}}$.

(b) Strategy The voltage across the plates is given by $\Delta V = Ed$, where d is the plate separation. Use Newton's second law.

Solution Find the magnitude of the electric field.



$$\Sigma F_y = eE - mg = 0, \text{ so } E = \frac{mg}{e}.$$

Compute the voltage across the plates.

$$\Delta V = \frac{mgd}{e} = \frac{(9.109\times10^{-31}\text{ kg})(9.80\text{ m/s}^2)(0.00300\text{ m})}{1.602\times10^{-19}\text{ C}} = \boxed{1.67\times10^{-13}\text{ V}}$$

13. (a) Strategy After the switch has been closed for a long time, the capacitor is fully charged and acts like a resistor with infinite resistance. Thus, all of the current passes through the 12-Ω resistor, thereby bypassing the capacitor. Therefore, the current through the 12-Ω resistor is equal to the current through the emf.

Solution The resistors are in series, so the equivalent resistance of the circuit is 27 Ω. Compute the current.

$$I = \frac{V}{R_{\text{eq}}} = \frac{12\text{ V}}{27\ \Omega} = \boxed{0.44\text{ A}}$$

(b) Strategy The capacitor and 12-Ω resistor are in parallel, so the voltage across each is the same.

Solution Find the voltage across the capacitor.

$$V_{\text{cap}} = V_R = IR = \frac{V}{R_{\text{eq}}}R = \frac{(12\text{V})(12\ \Omega)}{27\ \Omega} = \boxed{5.3\text{ V}}$$

14. Strategy Refer to the figure. Use Kirchhoff's rules.

Solution Use the junction and loop rules.

(1) $I_1 = I_2 + I_3$

(2) $V_1 - I_1R_1 - I_2R_2 = 0$

(3) $V_2 + I_2R_2 - I_3R_3 = 0$

(a) Solve (2) for I_2.

$$I_2 = \frac{V_1 - I_1R_1}{R_2} = \frac{30.0\text{ V} - (2.50\text{ A})(8.00\ \Omega)}{5.00\ \Omega} = \boxed{2.00\text{ A}}.$$

(b) Solve (1) for I_3.

$$I_3 = I_1 - I_2 = 2.50\text{ A} - 2.00\text{ A} = \boxed{0.50\text{ A}}$$

(c) Solve (3) for R_3.

$$R_3 = \frac{V_2 + I_2R_2}{I_3} = \frac{9.00\text{ V} + (2.00\text{ A})(5.00\ \Omega)}{0.50\text{ A}} = \boxed{38\ \Omega}$$

15. Strategy The charge on the plates is directly proportional to the capacitance and the capacitance is directly proportional to the dielectric constant, so the charge on the plates is directly proportional to the dielectric constant.

Solution Since the dielectric constants of air and strontium titanate are 1.00054 and 310, respectively, $\kappa_{st} > \kappa_{air}$ and $\boxed{\text{the charge on the plates increases}}$. Form a proportion.

$$\frac{Q_{st}}{Q_{air}} = \frac{C_{st}\Delta V}{C_{air}\Delta V} = \frac{C_{st}}{C_{air}} = \frac{\kappa_{st}}{\kappa_{air}} = \frac{310}{1.00054} = 310$$

The charge on the plates increases $\boxed{\text{by a factor of 310}}$.

16. (a) Strategy Use the definition of resistance.

Solution S_1 closed, S_2 open:

Since no current flows through the galvanometer, the current flows only through R_1, R, and the 20.0-V battery. The voltage across R_1 is $\%_s = 2.00$ V. The voltage across R is $\% = 20.0$ V. The current is $I = \frac{\%_s}{R_1} = \frac{\%}{R}$. Solve for R.

$$R = \frac{\%}{\%_s} R_1 = \frac{20.0\text{ V}}{2.00\text{ V}}(20.0\ \Omega) = 2.00\times10^2\ \Omega$$

S_1 open, S_2 closed:

Since no current flows through the galvanometer, the current flows only through R_2, R, and the 20.0-V battery. The voltage across R_2 is $\%_x$. The voltage across R is $\% = 20.0$ V. The current is $I = \frac{\%_x}{R_2} = \frac{\%}{R}$.

Solve for $\%_x$.

$$\%_x = \% \frac{R_2}{R} = \frac{80.0\ \Omega}{2.00\times10^2\ \Omega}(20.0\text{ V}) = \boxed{8.00\text{ V}}$$

(b) Strategy and Solution $\boxed{\text{Since no current passes through the source, its internal resistance is irrelevant.}}$

17. Strategy Use the definition of resistance.

Solution No current flows through the upper branch of the circuit, since V_x is open. The voltage across R is $\% = 45.0$ V. So, the current is $I = \%/R$. The voltage across R_x is V_x, and the current is I. Find R_x.

$$R_x = \frac{V_x}{I} = \frac{V_x}{\%}R = \frac{30.0\text{ V}}{45.0\text{ V}}(100.0\ \Omega) = \boxed{66.7\ \Omega}$$

18. Strategy Use the definition of capacitance and Eqs. (17-5) and (17-18b).

Solution

(a) The final charge on the capacitor is $Q = CV = \boxed{C\%}$.

(b) The final energy stored in the capacitor is $U = \frac{1}{2}CV^2 = \boxed{\frac{1}{2}C\%^2}$.

(c) The total energy supplied by the emf is $U = qV = Q$%%%(%%%) $= \boxed{C\ ^2}$, since the emf is constant.

(d) During the charging process, while current flows through the resistor, electrical energy is converted into internal energy of the resistor. In other words, $\boxed{\text{energy is dissipated by the resistor}}$.

19. (a) Strategy Use Eqs. (17-14) and (17-15). The maximum potential difference is given by $\Delta V = Ed_{\text{sep}}$, where E is the dielectric strength of dry air and d_{sep} is the plate separation.

Solution Find the maximum charge that can be on the capacitor.

$$Q = C\Delta V = \frac{A}{4\pi kd_{\text{sep}}}\Delta V = \frac{\frac{1}{4}\pi d^2 Ed_{\text{sep}}}{4\pi kd_{\text{sep}}} = \frac{d^2 E}{16k} = \frac{(0.100\text{ m})^2(3\times10^6\text{ V/m})}{16(8.988\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2)} = \boxed{200\text{ nC}}$$

(b) Strategy Use Eqs. (17-14) and (17-16). The maximum potential difference is given by $\Delta V = Ed_{\text{sep}}$, where E is the dielectric strength of neoprene and d_{sep} is the plate separation.

Solution Find the maximum charge that can be on the capacitor.

$$Q = C\Delta V = \kappa\frac{A}{4\pi kd_{\text{sep}}}\Delta V = \kappa\frac{\frac{1}{4}\pi d^2 Ed_{\text{sep}}}{4\pi kd_{\text{sep}}} = \frac{\kappa d^2 E}{16k} = \frac{6.7(0.100\text{ m})^2(12\times10^6\text{ V/m})}{16(8.988\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2)} = \boxed{5.6\ \mu\text{C}}$$

20. Strategy Let D = mass density. Use Eq. (18-8).

Solution Compute the ratios of resistances.

$$D = \frac{m}{V} = \frac{m}{AL},\ \text{so}\ A = \frac{m}{DL}.\ \text{Thus,}\ \frac{R_1}{R_2} = \frac{\rho_1 L/A_1}{\rho_2 L/A_2} = \frac{\rho_1 A_2}{\rho_2 A_1} = \frac{\rho_1[m/(D_2 L)]}{\rho_2[m/(D_1 L)]} = \frac{\rho_1 D_1}{\rho_2 D_2}.$$

(a) $\frac{R_{\text{Ag}}}{R_{\text{Cu}}} = \frac{(1.59\times10^{-8})(10.1\times10^3)}{(1.67\times10^{-8})(8.9\times10^3)} = \boxed{1.1}$

(b) $\frac{R_{\text{Al}}}{R_{\text{Cu}}} = \frac{(2.65\times10^{-8})(2.7\times10^3)}{(1.67\times10^{-8})(8.9\times10^3)} = \boxed{0.48}$

(c) Since 0.48 < 1.1, $\boxed{\text{aluminum}}$ is the best conductor for wires of equal length and equal mass.

21. (a) Strategy Use Eq. (17-18b).

Solution Find the capacitance.

$$U = \frac{1}{2}C(\Delta V)^2,\ \text{so}\ C = \frac{2U}{(\Delta V)^2} = \frac{2(32\text{ J})}{(300\text{ V})^2} = \boxed{710\ \mu\text{F}}.$$

(b) Strategy Use Eq. (17-16).

Solution Find the dielectric constant.

$$C = \frac{\kappa A}{4\pi kd},\ \text{so}\ \kappa = \frac{4\pi kdC}{A} = \frac{4\pi(8.988\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(1.1\times10^{-6}\text{ m})(710\times10^{-6}\text{ F})}{9.0\text{ m}^2} = \boxed{9.8}.$$

(c) Strategy The average power produced is equal to the energy stored in the capacitor divided by the time it takes to discharge it.

Solution Compute the average power.

$$P_{\text{av}} = \frac{U}{\Delta t} = \frac{32\text{ J}}{4.0\times 10^{-3}\text{ s}} = \boxed{8.0\text{ kW}}$$

(d) Strategy The capacitance of a parallel plate capacitor is inversely proportional to the plate separation, and the energy stored in a capacitor is directly proportional to its capacitance. Thus, the energy stored in a capacitor is inversely proportional to the plate separation.

Solution Form a proportion to find the new energy capacity of the capacitor.

$$\frac{U_2}{U_1} = \frac{d_1}{d_2},\text{ so } U_2 = \frac{d_1}{d_2}U_1 = \frac{d_1}{\frac{1}{2}d_1}U_1 = 2U_1 = 2(32\text{ J}) = \boxed{64\text{ J}}.$$

22. (a) Strategy Use Eq. (18-26) and the definition of capacitance.

Solution Find the charge as a function of time.

$$Q = C\Delta V = CV_{\text{C}}(t) = Q(t),\text{ so } V_{\text{C}}(t) = \frac{Q(t)}{C} = \%@\%^{/\tau}\text{ or } Q(t) = C\ \ e^{-t/\tau} = Q_0e^{-t/\tau}.$$

Find the time constant.

$$\frac{Q(t)}{Q_0} = 0.010 = e^{-t/\tau},\text{ so } \tau = -\frac{t}{\ln 0.010} = -\frac{4.0\times 10^{-3}\text{ s}}{\ln 0.010} = \boxed{8.7\times 10^{-4}\text{ s}}.$$

(b) Strategy Use Eq. (17-18b) and (18-24).

Solution Find the capacitance of the flash bulb.

$$U = \frac{1}{2}C(\Delta V)^2,\text{ so } C = \frac{2U}{(\Delta V)^2}.$$

Find the resistance of the flash bulb.

$$\tau = RC,\text{ so } R = \frac{\tau}{C} = \frac{-\frac{t}{\ln 0.010}}{\frac{2U}{(\Delta V)^2}} = -\frac{t(\Delta V)^2}{2U\ln 0.010} = -\frac{(4.0\times 10^{-3}\text{ s})(300\text{ V})^2}{2(32\text{ J})\ln 0.010} = \boxed{1.2\ \Omega}.$$

(c) Strategy When the capacitor begins to discharge, its voltage is 300 V. Use Eq. (18-21b).

Solution Compute the maximum power.

$$P_{\max} = \frac{V^2}{R} = \frac{(300\text{ V})^2}{1.22\ \Omega} = \boxed{74\text{ kW}}$$

23. Strategy Use Newton's second law and Eqs. (9-7), (9-16), and (16-4b).

Solution

(a) Find R, the radius of a droplet.

$$\Sigma F_x = 0\text{ and }\Sigma F_y = F_{\text{D}} + F_{\text{B}} - m_{\text{oil}}g = 6\pi\eta Rv_{\text{t}} + m_{\text{air}}g - m_{\text{oil}}g = 6\pi\eta Rv_{\text{t}} - \frac{4}{3}\pi R^3(\rho_{\text{oil}} - \rho_{\text{air}})g = 0,\text{ so}$$

$$R = \boxed{\sqrt{\frac{9\eta v_{\text{t}}}{2(\rho_{\text{oil}} - \rho_{\text{air}})g}}}.$$

(b) Find q, the charge of a droplet.

$\Sigma F_x = 0$ and $\Sigma F_y = F_E + F_B - m_{oil}g = qE + \rho_{air}Vg - \rho_{oil}Vg = qE - \frac{4}{3}\pi R^3(\rho_{oil} - \rho_{air})g = 0,$ so

$$q = \boxed{\frac{4\pi R^3(\rho_{oil} - \rho_{air})g}{3E}}.$$

MCAT Review

1. Strategy and Solution At a given temperature, the resistance R of a wire to direct current is given by $R = \rho L/A$, where ρ is the resistivity, L is the length, and A is the cross-sectional area. Therefore, the correct answer is $\boxed{\text{D}}$.

2. Strategy There are ten electric immersion heaters that each use 5 kW of power. Use Eq. (18-19).

Solution The total power requirement to run all ten heaters is 50 kW. Find the current.

$P = I\Delta V$, so $I = \frac{P}{\Delta V} = \frac{50\times 10^3\text{ W}}{600\text{ V}} = 83\text{ A}.$

The correct answer is $\boxed{\text{C}}$.

3. Strategy Each heater draws 20 A, so five heaters draw 100 A. Use Eq. (18-19).

Solution Find the total power usage of the heaters.

$P = I\Delta V = (100\text{ A})(800\text{ V}) = 80\text{ kW}$

The correct answer is $\boxed{\text{C}}$.

4. Strategy Use Kirchhoff's rules and the definition of resistance.

Solution Find the current flowing through R_L. According to the loop rule,

$I_L R_L - I_S R_S = 0,$ so $I_S = \frac{R_L}{R_S} I_L = \frac{1.0\ \Omega}{2.0\ \Omega} I_L = 0.50 I_L$. According to the junction rule,

$I = I_L + I_S = I_L + 0.50 I_L = 1.50 I_L$, so $I_L = \frac{I}{1.50}$. Thus, the voltage drop across R_L is

$V_L = I_L R_L = \frac{IR_L}{1.50} = \frac{(0.5\text{ A})(1.0\ \Omega)}{1.50} = 0.33\text{ V}.$ The correct answer is $\boxed{\text{B}}$.

5. Strategy Use Kirchhoff's rules and Eq. (18-21a).

Solution Find the current flowing through R_S. According to the loop rule,

$I_L R_L - I_S R_S = 0,$ so $I_L = \frac{R_S}{R_L} I_S = \frac{3.0\ \Omega}{1.0\ \Omega} I_S = 3.0 I_S$. According to the junction rule,

$I = I_L + I_S = 3.0 I_S + I_S = 4.0 I_S$, so $I_S = 0.25I$. Thus, the power dissipated in R_S is

$P_S = I_S{}^2 R_S = (0.25I)^2 R_S = [0.25(1.2\text{ A})]^2(3.0\ \Omega) = 0.27\text{ W}.$ The correct answer is $\boxed{\text{A}}$.

6. Strategy and Solution As current flows through R_L, power is dissipated at a constant rate by R_L as heat that enters the water, increasing its energy and raising its temperature (and the temperature of the system). Thus, the entropy of the system increases, as well. The correct answer is $\boxed{\text{D}}$.

7. Strategy and Solution Energy is stored in the battery as chemical energy. This energy is converted into electrical energy when the current flows. The electrical energy is dissipated as heat by the resistor. The correct answer is $\boxed{\text{A}}$.

8. Strategy and Solution As R_L increases with time, the amount of the current I passing through it decreases and the amount passing through R_S increases. The correct answer is $\boxed{\text{C}}$.

9. Strategy Use Eq. (14-4).

Solution The water is heated at a rate of $Q/\Delta t = mc\Delta T/\Delta t = 1.0\text{ W}.$ So, the time it takes for the temperature of the water to increase 1.0°C is $\Delta t = \dfrac{mc\Delta T}{1.0\text{ W}} = \dfrac{(1.0\text{ kg})[4.2\times 10^3\text{ J/(kg}\cdot{}^\circ\text{C)}](1.0^\circ\text{C})}{1.0\text{ W}} = 4200\text{ s}.$

The correct answer is $\boxed{\text{D}}$.

10. Strategy Use Eq. (18-19).

Solution Compute the current required.

$P = I\Delta V,$ so $I = \dfrac{P}{\Delta V} = \dfrac{1.2\times 10^4\text{ W}}{120\text{ V}} = 100\text{ A}.$ The correct answer is $\boxed{\text{C}}$.

11. Strategy Refer to the table to compute the initial and final resistances.

Solution Compute the resistances.

$R_i = (10^5\text{ m})\dfrac{3.4\times 10^{-1}\ \Omega}{10^3\text{ m}} = 34\ \Omega$ and $R_f = (10^5\text{ m})\dfrac{3.8\times 10^{-1}\ \Omega}{10^3\text{ m}} = 38\ \Omega.$

The change in resistance is $R_f - R_i = 38\ \Omega - 34\ \Omega = 4\ \Omega.$ The correct answer is $\boxed{\text{C}}$.

12. Strategy Use Eq. (18-21a).

Solution Compute the power lost as heat.

$P = I^2R = (2\text{ A})^2(3\ \Omega) = 12\text{ W},$ so the correct answer is $\boxed{\text{C}}$.

13. Strategy and Solution The ten residences require $10\times 10^4\text{ W} = 10^5\text{ W}$ of power and $5\times 10^3\text{ W}$ of power is lost as heat, so the total power requirement is $10^5\text{ W} + 5\times 10^3\text{ W} = 1.05\times 10^5\text{ W}.$ The correct answer is $\boxed{\text{C}}$.