ANSWER KEY

CHAPTER 1

CHECK YOUR UNDERSTANDING

1.1. The actual amount (mass) of gasoline left in the tank when the gauge hits "empty" is less in the summer than in the winter. The gasoline has the same volume as it does in the winter when the "add fuel" light goes on, but because the gasoline has expanded, there is less mass.

1.2. Not necessarily, as the thermal stress is also proportional to Young's modulus.

1.3. To a good approximation, the heat transfer depends only on the temperature difference. Since the temperature differences are the same in both cases, the same 25 kJ is necessary in the second case. (As we will see in the next section, the answer would have been different if the object had been made of some substance that changes phase anywhere between $30\,°\text{C}$ and $50\,°\text{C}$.)

1.4. The ice and liquid water are in thermal equilibrium, so that the temperature stays at the freezing temperature as long as ice remains in the liquid. (Once all of the ice melts, the water temperature will start to rise.)

1.5. Snow is formed from ice crystals and thus is the solid phase of water. Because enormous heat is necessary for phase changes, it takes a certain amount of time for this heat to be transferred from the air, even if the air is above $0\,°\text{C}$.

1.6. Conduction: Heat transfers into your hands as you hold a hot cup of coffee. Convection: Heat transfers as the barista "steams" cold milk to make hot cocoa. Radiation: Heat transfers from the Sun to a jar of water with tea leaves in it to make "Sun tea." A great many other answers are possible.

1.7. Because area is the product of two spatial dimensions, it increases by a factor of four when each dimension is doubled $\left(A_{\text{fina}} = (2d)^2 = 4d^2 = 4A_{\text{initial}}\right)$. The distance, however, simply doubles. Because the temperature difference and the coefficient of thermal conductivity are independent of the spatial dimensions, the rate of heat transfer by conduction increases by a factor of four divided by two, or two:

$$P_{\text{fina}} = \frac{kA_{\text{fina}}\left(T_{\text{h}} - T_{\text{c}}\right)}{d_{\text{fina}}} = \frac{k\left(4A_{\text{fina}}\left(T_{\text{h}} - T_{\text{c}}\right)\right)}{2d_{\text{initial}}} = 2\frac{kA_{\text{fina}}\left(T_{\text{h}} - T_{\text{c}}\right)}{d_{\text{initial}}} = 2P_{\text{initial}}.$$

1.8. Using a fan increases the flow of air: Warm air near your body is replaced by cooler air from elsewhere. Convection increases the rate of heat transfer so that moving air "feels" cooler than still air.

1.9. The radiated heat is proportional to the fourth power of the *absolute temperature*. Because $T_1 = 293\text{ K}$ and $T_2 = 313\text{ K}$, the rate of heat transfer increases by about 30% of the original rate.

CONCEPTUAL QUESTIONS

1. They are at the same temperature, and if they are placed in contact, no net heat flows between them.

3. The reading will change.

5. The cold water cools part of the inner surface, making it contract, while the rest remains expanded. The strain is too great for the strength of the material. Pyrex contracts less, so it experiences less strain.

7. In principle, the lid expands more than the jar because metals have higher coefficients of expansion than glass. That should make unscrewing the lid easier. (In practice, getting the lid and jar wet may make gripping them more difficult.)

9. After being heated, the length is ($1 + 300\alpha$) (1 m). After being cooled, the length is $(1 - 300\,\alpha)(1 + 300\,\alpha)(1\text{ m})$. That answer is not 1 m, but it should be. The explanation is that even if α is exactly constant, the relation $\Delta L = \alpha L \Delta T$ is strictly true only in the limit of small ΔT. Since α values are small, the discrepancy is unimportant in practice.

11. Temperature differences cause heat transfer.

13. No, it is stored as thermal energy. A thermodynamic system does not have a well-defined quantity of heat.

15. It raises the boiling point, so the water, which the food gains heat from, is at a higher temperature.

17. Yes, by raising the pressure above 56 atm.

19. work

21. $0\,°\text{C}$ (at or near atmospheric pressure)

23. Condensation releases heat, so it speeds up the melting.

25. Because of water's high specific heat, it changes temperature less than land. Also, evaporation reduces temperature rises. The air tends to stay close to equilibrium with the water, so its temperature does not change much where there's a lot of water around, as in San Francisco but not Sacramento.

27. The liquid is oxygen, whose boiling point is above that of nitrogen but whose melting point is below the boiling point of liquid nitrogen. The crystals that sublime are carbon dioxide, which has no liquid phase at atmospheric pressure. The crystals that melt are water, whose melting point is above carbon dioxide's sublimation point. The water came from the instructor's breath.

29. Increasing circulation to the surface will warm the person, as the temperature of the water is warmer than human body temperature. Sweating will cause no evaporative cooling under water or in the humid air immediately above the tub.

31. It spread the heat over the area above the heating elements, evening the temperature there, but does not spread the heat much beyond the heating elements.

33. Heat is conducted from the fire through the fire box to the circulating air and then convected by the air into the room (forced convection).
35. The tent is heated by the Sun and transfers heat to you by all three processes, especially radiation.
37. If shielded, it measures the air temperature. If not, it measures the combined effect of air temperature and net radiative heat gain from the Sun.
39. Turn the thermostat down. To have the house at the normal temperature, the heating system must replace all the heat that was lost. For all three mechanisms of heat transfer, the greater the temperature difference between inside and outside, the more heat is lost and must be replaced. So the house should be at the lowest temperature that does not allow freezing damage.
41. Air is a good insulator, so there is little conduction, and the heated air rises, so there is little convection downward.

PROBLEMS

43. That must be Celsius. Your Fahrenheit temperature is $102\ °\text{F}$. Yes, it is time to get treatment.

45. a. $\Delta T_{\text{C}} = 22.2\ °\text{C}$; b. We know that $\Delta T_{\text{F}} = T_{\text{F2}} - T_{\text{F1}}$. We also know that $T_{\text{F2}} = \frac{9}{5}T_{\text{C2}} + 32$ and $T_{\text{F1}} = \frac{9}{5}T_{\text{C1}} + 32$. So, substituting, we have $\Delta T_{\text{F}} = \left(\frac{9}{5}T_{\text{C2}} + 32\right) - \left(\frac{9}{5}T_{\text{C1}} + 32\right)$. Partially solving and rearranging the equation, we have $\Delta T_{\text{F}} = \frac{9}{5}(T_{\text{C2}} - T_{\text{C1}})$. Therefore, $\Delta T_{\text{F}} = \frac{9}{5}\Delta T_{\text{C}}$.

47. a. $-40°$; b. 575 K

49. Using **Table 1.2** to find the coefficient of thermal expansion of marble:

$$L = L_0 + \Delta L = L_0(1 + \alpha\Delta T) = 170\ \text{m}\left[1 + \left(2.5 \times 10^{-6}/°\text{C}\right)(-45.0\ °\text{C})\right] = 169.98\ \text{m}.$$

(Answer rounded to five significant figures to show the slight difference in height.)

51. Using **Table 1.2** to find the coefficient of thermal expansion of mercury:

$$\Delta L = \alpha L\Delta T = \left(6.0 \times 10^{-5}/°\text{C}\right)(0.0300\ \text{m})(3.00\ °\text{C}) = 5.4 \times 10^{-6}\ \text{m}.$$

53. On the warmer day, our tape measure will expand linearly. Therefore, each measured dimension will be smaller than the actual dimension of the land. Calling these measured dimensions l' and w', we will find a new area, *A*. Let's calculate these measured dimensions:

$$l' = l_0 - \Delta l = (20\ \text{m}) - (20\ °\text{C})(20\ \text{m})\left(\frac{1.2 \times 10^{-5}}{°\text{C}}\right) = 19.9952\ \text{m};$$

$$A' = l \times w' = (29.9928\ \text{m})(19.9952\ \text{m}) = 599.71\ \text{m}^2;$$

$$\text{Cost change} = (A - A')\left(\frac{\$60{,}000}{\text{m}^2}\right) = \left((600 - 599.71)\text{m}^2\right)\left(\frac{\$60{,}000}{\text{m}^2}\right) = \$17{,}000.$$

Because the area gets smaller, the price of the land *decreases* by about $17,000.

55. a. Use **Table 1.2** to find the coefficients of thermal expansion of steel and aluminum. Then $\Delta L_{\text{Al}} - \Delta L_{\text{steel}} = (\alpha_{\text{Al}} - \alpha_{\text{steel}})L_0\,\Delta T = \left(\frac{2.5 \times 10^{-5}}{°\text{C}} - \frac{1.2 \times 10^{-5}}{°\text{C}}\right)(1.00\ \text{m})(22\ °\text{C}) = 2.9 \times 10^{-4}\ \text{m}$.

b. By the same method with $L_0 = 30.0\ \text{m}$, we have $\Delta L = 8.6 \times 10^{-3}\ \text{m}$.

57. $\Delta V = 0.475\ \text{L}$

59. If we start with the freezing of water, then it would expand to $\left(1\ \text{m}^3\right)\left(\frac{1000\ \text{kg/m}^3}{917\ \text{kg/m}^3}\right) = 1.09\ \text{m}^3 = 1.98 \times 10^8\ \text{N/m}^2$ of ice.

61. $m = 5.20 \times 10^8\ \text{J}$

63. $Q = mc\Delta T \quad \Rightarrow \Delta T = \frac{Q}{mc}$; a. $21.0\ °\text{C}$; b. $25.0\ °\text{C}$; c. $29.3\ °\text{C}$; d. $50.0\ °\text{C}$

65. $Q = mc\Delta T \quad \Rightarrow c = \frac{Q}{m\Delta T} = \frac{1.04\ \text{kcal}}{(0.250\ \text{kg})(45.0\ °\text{C})} = 0.0924\ \text{kcal/kg}\cdot°\text{C}$. It is copper.

67. a. $Q = m_{\text{w}}c_{\text{w}}\Delta T + m_{\text{A1}}c_{\text{A1}}\Delta T = (m_{\text{w}}c_{\text{w}} + m_{\text{A1}}c_{\text{A1}})\Delta T$;

$$Q = \begin{bmatrix}(0.500\ \text{kg})(1.00\ \text{kcal/kg}\cdot°\text{C}) + \\ (0.100\ \text{kg})(0.215\ \text{kcal/kg}\cdot°\text{C})\end{bmatrix}(54.9\ °\text{C}) = 28.63\ \text{kcal};$$

$\frac{Q}{m_p} = \frac{28.63\ \text{kcal}}{5.00\ \text{g}} = 5.73\ \text{kcal/g}$; b. $\frac{Q}{m_p} = \frac{200\ \text{kcal}}{33\ \text{g}} = 6\ \text{kcal/g}$, which is consistent with our results to part (a), to one significant figure.

69. $0.139\ °\text{C}$

71. It should be lower. The beaker will not make much difference: $16.3\ °\text{C}$

73. a. $1.00 \times 10^5\ \text{J}$; b. $3.68 \times 10^5\ \text{J}$; c. The ice is much more effective in absorbing heat because it first must be melted, which requires a lot of energy, and then it gains the same amount of heat as the bag that started with water. The first $2.67 \times 10^5\ \text{J}$ of heat is used to melt the ice, then it absorbs the $1.00 \times 10^5\ \text{J}$ of heat as water.

75. 58.1 g

77. Let *M* be the mass of pool water and *m* be the mass of pool water that evaporates.

$$Mc\Delta T = mL_{\text{V}(37\ °\text{C})} \Rightarrow \frac{m}{M} = \frac{c\Delta T}{L_{\text{V}(37\ °\text{C})}} = \frac{(1.00\ \text{kcal/kg} \cdot °\text{C})(1.50\ °\text{C})}{580\ \text{kcal/kg}} = 2.59 \times 10^{-3};$$

(Note that L_V for water at $37\ °\text{C}$ is used here as a better approximation than L_V for $100\ °\text{C}$ water.)

79. a. $1.47 \times 10^{15}\ \text{kg}$; b. $4.90 \times 10^{20}\ \text{J}$; c. 48.5 y

81. a. 9.67 L; b. Crude oil is less dense than water, so it floats on top of the water, thereby exposing it to the oxygen in the air, which it uses to burn. Also, if the water is under the oil, it is less able to absorb the heat generated by the oil.

83. a. 319 kcal; b. $2.00\ °\text{C}$

85. First bring the ice up to $0\ °\text{C}$ and melt it with heat Q_1 : 4.74 kcal. This lowers the temperature of water by ΔT_2 : $23.15\ °\text{C}$. Now, the heat lost by the hot water equals that gained by the cold water (T_f is the final temperature): $20.6\ °\text{C}$

87. Let the subscripts r, e, v, and w represent rock, equilibrium, vapor, and water, respectively.

$$m_\text{r} c_\text{r} (T_1 - T_\text{e}) = m_\text{V} L_\text{V} + m_\text{W} c_\text{W} (T_\text{e} - T_2);$$

$$\begin{aligned} m_\text{r} &= \frac{m_\text{V} L_\text{V} + m_\text{W} c_\text{W} (T_\text{e} - T_2)}{c_\text{r}(T_1 - T_\text{e})} \\ &= \frac{(0.0250\ \text{kg})\left(2256 \times 10^3\ \text{J/kg}\right) + (3.975\ \text{kg})\left(4186 \times 10^3\ \text{J/kg} \cdot °\text{C}\right)(100\ °\text{C} - 15\ °\text{C})}{(840\ \text{J/kg} \cdot °\text{C})(500\ °\text{C} - 100\ °\text{C})} \\ &= 4.38\ \text{kg} \end{aligned}$$

89. a. $1.01 \times 10^3\ \text{W}$; b. One 1-kilowatt room heater is needed.

91. 84.0 W

93. 2.59 kg

95. a. 39.7 W; b. 820 kcal

97. $\dfrac{Q}{t} = \dfrac{kA(T_2 - T_1)}{d}$, so that

$$\frac{(Q/t)_\text{wall}}{(Q/t)_\text{window}} = \frac{k_\text{wall} A_\text{wall} d_\text{window}}{k_\text{window} A_\text{window} d_\text{wall}} = \frac{(2 \times 0.042\ \text{J/s} \cdot \text{m} \cdot °\text{C})\left(10.0\ \text{m}^2\right)\left(0.750 \times 10^{-2}\ \text{m}\right)}{(0.84\ \text{J/s} \cdot \text{m} \cdot °\text{C})\left(2.00\ \text{m}^2\right)\left(13.0 \times 10^{-2}\ \text{m}\right)}$$

This gives 0.0288 wall: window, or 35:1 window: wall

99. $\dfrac{Q}{t} = \dfrac{kA(T_2 - T_1)}{d} = \dfrac{kA\Delta T}{d} \Rightarrow$

$$\Delta T = \frac{d(Q/t)}{kA} = \frac{\left(6.00 \times 10^{-3}\ \text{m}\right)(2256\ \text{W})}{(0.84\ \text{J/s} \cdot \text{m} \cdot °\text{C})\left(1.54 \times 10^{-2}\ \text{m}^2\right)} = 1046\ °\text{C} = 1.05 \times 10^3\ \text{K}$$

101. We found in the preceding problem that $P = 126\Delta T\ \text{W} \cdot °\text{C}$ as baseline energy use. So the total heat loss during this period is $Q = (126\ \text{J/s} \cdot °\text{C})(15.0\ °\text{C})(120\ \text{days})\left(86.4 \times 10^3\ \text{s/day}\right) = 1960 \times 10^6\ \text{J}$. At the cost of \$1/MJ, the cost is \$1960. From an earlier problem, the savings is 12% or \$235/y. We need $150\ \text{m}^2$ of insulation in the attic. At $\$4/\text{m}^2$, this is a \$500 cost. So the payback period is $\$600/(\$235/\text{y}) = 2.6\ \text{years}$ (excluding labor costs).

ADDITIONAL PROBLEMS

103. 7.39%

105. $\dfrac{F}{A} = \left(210 \times 10^9\ \text{Pa}\right)\left(12 \times 10^{-6}/°\text{C}\right)(40\ °\text{C} - (-15\ °\text{C})) = 1.4 \times 10^8\ \text{N/m}^2$.

107. a. 1.06 cm; b. 1.11 cm

109. $1.7\ \text{kJ/(kg} \cdot \text{ºC)}$

111. a. $1.57 \times 10^4\ \text{kcal}$; b. $18.3\ \text{kW} \cdot \text{h}$; c. $1.29 \times 10^4\ \text{kcal}$

113. $6.3\ \text{°C}$. All of the ice melted.

115. $63.9\ \text{°C}$, all the ice melted

117. a. 83 W; b. $1.97 \times 10^3\ \text{W}$; The single-pane window has a rate of heat conduction equal to 1969/83, or 24 times that of a double-pane window.

119. The rate of heat transfer by conduction is 20.0 W. On a daily basis, this is 1,728 kJ/day. Daily food intake is $2400\ \text{kcal/d} \times 4186\ \text{J/kcal} = 10{,}050\ \text{kJ/day}$. So only 17.2% of energy intake goes as heat transfer by conduction to the environment at this ΔT.

121. 620 K

CHALLENGE PROBLEMS

123. Denoting the period by *P*, we know $P = 2\pi\sqrt{L/g}$. When the temperature increases by *dT*, the length increases by $\alpha L dT$. Then the new length is a. $P = 2\pi\sqrt{\frac{L + \alpha L dT}{g}} = 2\pi\sqrt{\frac{L}{g}(1 + \alpha dT)} = 2\pi\sqrt{\frac{L}{g}}\left(1 + \frac{1}{2}\alpha dT\right) = P\left(1 + \frac{1}{2}\alpha dT\right)$ by the binomial expansion. b. The clock runs slower, as its new period is 1.00019 s. It loses 16.4 s per day.

125. The amount of heat to melt the ice and raise it to $100\ \text{°C}$ is not enough to condense the steam, but it is more than enough to lower the steam's temperature by $50\ \text{°C}$, so the final state will consist of steam and liquid water in equilibrium, and the final temperature is $100\ \text{°C}$; 9.5 g of steam condenses, so the final state contains 49.5 g of steam and 40.5 g of liquid water.

127. a. $dL/dT = kT/\rho L$; b. $L = \sqrt{2kTt/\rho L_\text{f}}$; c. yes

129. a. $\sigma\left(\pi R^2\right)T_\text{s}{}^4$; b. $e\sigma\pi R^2 T_\text{s}{}^4$; c. $2e\sigma\pi R^2 T_\text{e}{}^4$; d. $T_s^4 = 2T_e^4$; e. $e\sigma T_\text{s}^4 + \frac{1}{4}(1 - A)S = \sigma T_\text{s}^4$; f. 288 K

CHAPTER 2

CHECK YOUR UNDERSTANDING

2.1. We first need to calculate the molar mass (the mass of one mole) of niacin. To do this, we must multiply the number of atoms of each element in the molecule by the element's molar mass.

$$(6\ \text{mol of carbon})(12.0\ \text{g/mol}) + (5\ \text{mol hydrogen})(1.0\ \text{g/mol})$$
$$+ (1\ \text{mol nitrogen})(14\ \text{g/mol}) + (2\ \text{mol oxygen})(16.0\ \text{g/mol}) = 123\ \text{g/mol}$$

Then we need to calculate the number of moles in 14 mg.

$$\left(\frac{14\ \text{mg}}{123\ \text{g/mol}}\right)\left(\frac{1\ \text{g}}{1000\ \text{mg}}\right) = 1.14 \times 10^{-4}\ \text{mol}.$$

Then, we use Avogadro's number to calculate the number of molecules:

$$N = nN_A = \left(1.14 \times 10^{-4}\ \text{mol}\right)\left(6.02 \times 10^{23}\ \text{molecules/mol}\right) = 6.85 \times 10^{19}\ \text{molecules}.$$

2.2. The density of a gas is equal to a constant, the average molecular mass, times the number density *N*/*V*. From the ideal gas law, $pV = Nk_\text{B}T,$ we see that $N/V = p/k_\text{B}T.$ Therefore, at constant temperature, if the density and, consequently, the number density are reduced by half, the pressure must also be reduced by half, and $p_\text{f} = 0.500\ \text{atm}.$

2.3. Density is mass per unit volume, and volume is proportional to the size of a body (such as the radius of a sphere) cubed. So if the distance between molecules increases by a factor of 10, then the volume occupied increases by a factor of 1000, and the density decreases by a factor of 1000. Since we assume molecules are in contact in liquids and solids, the distance between their centers is on the order of their typical size, so the distance in gases is on the order of 10 times as great.

2.4. Yes. Such fluctuations actually occur for a body of any size in a gas, but since the numbers of molecules are immense for macroscopic bodies, the fluctuations are a tiny percentage of the number of collisions, and the averages spoken of in this section vary imperceptibly. Roughly speaking, the fluctuations are inversely proportional to the square root of the number of collisions, so for small bodies, they can become significant. This was actually observed in the nineteenth century for pollen grains in water and is known as Brownian motion.

2.5. In a liquid, the molecules are very close together, constantly colliding with one another. For a gas to be nearly ideal, as air is under ordinary conditions, the molecules must be very far apart. Therefore the mean free path is much longer in the air.

2.6. As the number of moles is equal and we know the molar heat capacities of the two gases are equal, the temperature is halfway between the initial temperatures, 300 K.

CONCEPTUAL QUESTIONS

1. 2 moles, as that will contain twice as many molecules as the 1 mole of oxygen

3. pressure
5. The flame contains hot gas (heated by combustion). The pressure is still atmospheric pressure, in mechanical equilibrium with the air around it (or roughly so). The density of the hot gas is proportional to its number density *N*/*V* (neglecting the difference in composition between the gas in the flame and the surrounding air). At higher temperature than the surrounding air, the ideal gas law says that $N/V = p/k_B T$ is less than that of the surrounding air. Therefore the hot air has lower density than the surrounding air and is lifted by the buoyant force.
7. The mean free path is inversely proportional to the square of the radius, so it decreases by a factor of 4. The mean free time is proportional to the mean free path and inversely proportional to the rms speed, which in turn is inversely proportional to the square root of the mass. That gives a factor of $\sqrt{8}$ in the numerator, so the mean free time decreases by a factor of $\sqrt{2}$.
9. Since they're more massive, their gravity is stronger, so the escape velocity from them is higher. Since they're farther from the Sun, they're colder, so the speeds of atmospheric molecules including hydrogen and helium are lower. The combination of those facts means that relatively few hydrogen and helium molecules have escaped from the outer planets.
11. One where nitrogen is stored, as excess CO_2 will cause a feeling of suffocating, but excess nitrogen and insufficient oxygen will not.
13. Less, because at lower temperatures their heat capacity was only 3*RT*/2.
15. a. false; b. true; c. true; d. true
17. 1200 K

PROBLEMS

19. a. 0.137 atm; b. $p_g = (1\ \text{atm})\frac{T_2 V_1}{T_1 V_2} - 1\ \text{atm}.$ Because of the expansion of the glass, $V_2 = 0.99973$. Multiplying by that factor does not make any significant difference.
21. a. 1.79×10^{-3} mol; b. 0.227 mol; c. 1.08×10^{21} molecules for the nitrogen, 1.37×10^{23} molecules for the carbon dioxide
23. 7.84×10^{-2} mol
25. 1.87×10^{3}
27. 2.47×10^{7} molecules
29. 6.95×10^{5} Pa; 6.86 atm
31. a. 9.14×10^{6} Pa; b. 8.22×10^{6} Pa; c. 2.15 K; d. no
33. 40.7 km
35. a. 0.61 N; b. 0.20 Pa
37. a. 5.88 m/s; b. 5.89 m/s
39. 177 m/s
41. 4.54×10^{3}
43. a. 0.0352 mol; b. 5.65×10^{-21} J; c. 139 J
45. 21.1 kPa
47. 458 K
49. 3.22×10^{3} K
51. a. 1.004; b. 764 K; c. This temperature is equivalent to $915\ ^\circ\text{F}$, which is high but not impossible to achieve. Thus, this process is feasible. At this temperature, however, there may be other considerations that make the process difficult. (In general, uranium enrichment by gaseous diffusion is indeed difficult and requires many passes.)
53. 65 mol
55. a. 0.76 atm; b. 0.29 atm; c. The pressure there is barely above the quickly fatal level.
57. 4.92×10^{5} K; Yes, that's an impractically high temperature.
59. polyatomic
61. 3.08×10^{3} J
63. $29.2\ ^\circ\text{C}$
65. $-1.6\ ^\circ\text{C}$
67. 0.00157
69. About 0.072. Answers may vary slightly. A more accurate answer is 0.074.
71. a. 419 m/s; b. 472 m/s; c. 513 m/s
73. 541 K
75. 2400 K for all three parts

ADDITIONAL PROBLEMS

77. a. 1.20 kg/m^3 ; b. 65.9 kg/m^3

79. 7.9 m

81. a. supercritical fluid; b. $3.00\times10^7\text{ Pa}$

83. 40.18%

85. a. $2.21\times10^{27}\text{ molecules/m}^3$; b. $3.67\times10^3\text{ mol/m}^3$

87. 8.2 mm

89. a. 1080 J/kg °C ; b. 12%

91. $2\sqrt{e}/3$ or about 1.10

93. a. 411 m/s; b. According to **Table 2.3**, the C_V of H_2S is significantly different from the theoretical value, so the ideal gas model does not describe it very well at room temperature and pressure, and the Maxwell-Boltzmann speed distribution for ideal gases may not hold very well, even less well at a lower temperature.

CHALLENGE PROBLEMS

95. 29.5 N/m

97. Substituting $v=\sqrt{\frac{2k_BT}{m}}u$ and $dv=\sqrt{\frac{2k_BT}{m}}du$ gives

$$\int_0^\infty \frac{4}{\sqrt{\pi}}\left(\frac{m}{2k_BT}\right)^{3/2} v^2 e^{-mv^2/2k_BT}dv = \int_0^\infty \frac{4}{\sqrt{\pi}}\left(\frac{m}{2k_BT}\right)^{3/2}\left(\frac{2k_BT}{m}\right)u^2 e^{-u^2}\sqrt{\frac{2k_BT}{m}}du$$
$$= \int_0^\infty \frac{4}{\sqrt{\pi}}u^2e^{-u^2}du = \frac{4}{\sqrt{\pi}}\frac{\sqrt{\pi}}{4} = 1$$

99. Making the scaling transformation as in the previous problems, we find that

$$\overline{v^2} = \int_0^\infty \frac{4}{\sqrt{\pi}}\left(\frac{m}{2k_BT}\right)^{3/2} v^2 v^2 e^{-mv^2/2k_BT}dv = \int_0^\infty \frac{4}{\sqrt{\pi}}\frac{2k_BT}{m}u^4e^{-u^2}du.$$

As in the previous problem, we integrate by parts:

$$\int_0^\infty u^4e^{-u^2}du = \left[-\frac{1}{2}u^3e^{-u^2}\right]_0^\infty + \frac{3}{2}\int_0^\infty u^2e^{-u^2}du.$$

Again, the first term is 0, and we were given in an earlier problem that the integral in the second term equals $\frac{\sqrt{\pi}}{4}$. We now have

$$\overline{v^2} = \frac{4}{\sqrt{\pi}}\frac{2k_BT}{m}\frac{3}{2}\frac{\sqrt{\pi}}{4} = \frac{3k_BT}{m}.$$

Taking the square root of both sides gives the desired result: $v_{rms}=\sqrt{\frac{3k_BT}{m}}$.

CHAPTER 3

CHECK YOUR UNDERSTANDING

3.1. $p_2(V_2-V_1)$

3.2. Line 1, $\Delta E_{int}=40\text{ J}$; line 2, $W=50\text{ J}$ and $\Delta E_{int}=40\text{ J}$; line 3, $Q=80\text{ J}$ and $\Delta E_{int}=40\text{ J}$; and line 4, $Q=0$ and $\Delta E_{int}=40\text{ J}$

3.3. So that the process is represented by the curve $p=nRT/V$ on the pV plot for the evaluation of work.

3.4. $1.26\times10^3\text{ J}$.

CONCEPTUAL QUESTIONS

1. a. SE; b. ES; c. ES

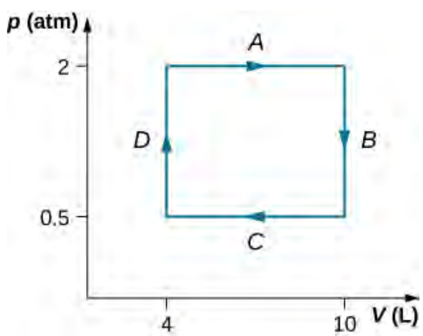
3. Some of the energy goes into changing the phase of the liquid to gas.

5. Yes, as long as the work done equals the heat added there will be no change in internal energy and thereby no change in temperature. When water freezes or when ice melts while removing or adding heat, respectively, the temperature remains constant.

7. If more work is done on the system than heat added, the internal energy of the system will actually decrease.
9. The system must be in contact with a heat source that allows heat to flow into the system.
11. Isothermal processes must be slow to make sure that as heat is transferred, the temperature does not change. Even for isobaric and isochoric processes, the system must be in thermal equilibrium with slow changes of thermodynamic variables.
13. Typically C_p is greater than C_V because when expansion occurs under constant pressure, it does work on the surroundings. Therefore, heat can go into internal energy and work. Under constant volume, all heat goes into internal energy. In this example, water contracts upon heating, so if we add heat at constant pressure, work is done on the water by surroundings and therefore, C_p is less than C_V.
15. No, it is always greater than 1.
17. An adiabatic process has a change in temperature but no heat flow. The isothermal process has no change in temperature but has heat flow.

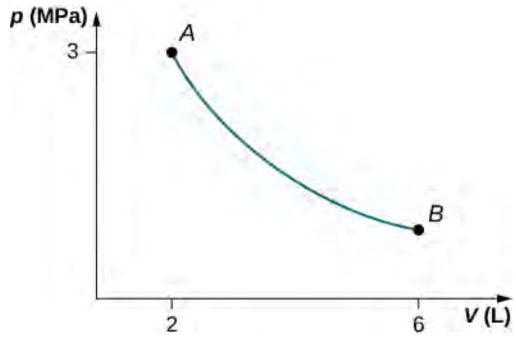
PROBLEMS

19. $p(V - b) = -c_T$ is the temperature scale desired and mirrors the ideal gas if under constant volume.
21. $V - bpT + cT^2 = 0$
23. 74 K
25. 1.4 times
27. pVln(4)
29. a. 160 J; b. –160 J
31.



$W = 900\text{ J}$

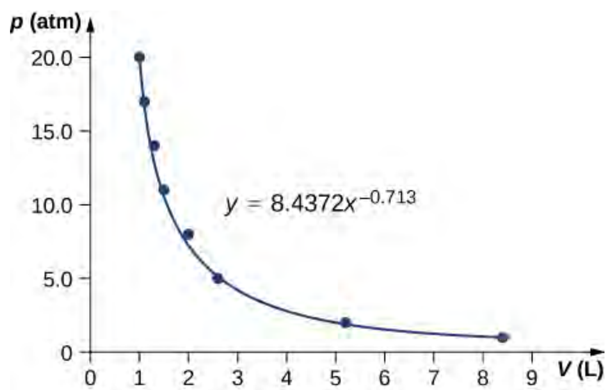
33. 3.53×10^4 J
35. a. 1:1; b. 10:1
37. a. 600 J; b. 0; c. 500 J; d. 200 J; e. 800 J; f. 500 J
39. 580 J
41. a. 600 J; b. 600 J; c. 800 J
43. a. 0; b. 160 J; c. –160 J
45. a. –150 J; b. –400 J
47. No work is done and they reach the same common temperature.
49. 54,500 J
51. a. $(p_1 + 3V_1^2)(V_2 - V_1) - 3V_1(V_2^2 - V_1^2) + (V_2^3 - V_1^3)$; b. $\frac{3}{2}(p_2 V_2 - p_1 V_1)$; c. the sum of parts (a) and (b); d. $T_1 = \frac{p_1 V_1}{nR}$ and $T_2 = \frac{p_2 V_2}{nR}$
53. a.



;

b. $W = 4.39\ \text{kJ}, \Delta E_{\text{int}} = -4.39\ \text{kJ}$

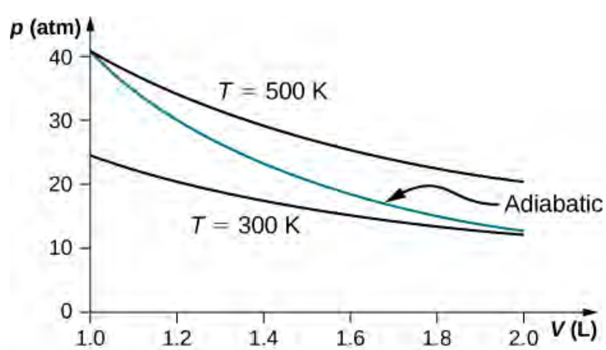
55. a. 1660 J; b. −2730 J; c. It does not depend on the process.
57. a. 700 J; b. 500 J
59. a. −3 400 J; b. 3400 J enters the gas
61. 100 J
63. a. 370 J; b. 100 J; c. 500 J
65. 850 J
67. pressure decreased by 0.31 times the original pressure
69.



;

$\gamma = 0.713$

71. 84 K
73. An adiabatic expansion has less work done and no heat flow, thereby a lower internal energy comparing to an isothermal expansion which has both heat flow and work done. Temperature decreases during adiabatic expansion.
75. Isothermal has a greater final pressure and does not depend on the type of gas.
77.



ADDITIONAL PROBLEMS

79. a. $W_{AB} = 0,\ W_{BC} = 2026\ \text{J},\ W_{AD} = 810.4\ \text{J},\ W_{DC} = 0;$ b. $\Delta E_{AB} = 3600\ \text{J},\ \Delta E_{BC} = 374\ \text{J};$ c. $\Delta E_{AC} = 3974\ \text{J};$

d. $Q_{ADC} = 4784\text{ J}$; e. No, because heat was added for both parts *AD* and *DC*. There is not enough information to figure out how much is from each segment of the path.
81. 300 J
83. a. 59.5 J; b. 170 N
85. $2.4 \times 10^3\text{ J}$
87. a. 15,000 J; b. 10,000 J; c. 25,000 J
89. 78 J
91. A cylinder containing three moles of nitrogen gas is heated at a constant pressure of 2 atm. a. −1220 J; b. +1220 J
93. a. 7.6 L, 61.6 K; b. 81.3 K; c. $3.63\text{ L} \cdot \text{atm} = 367\text{ J}$; d. −367 J

CHALLENGE PROBLEMS

95. a. 1700 J; b. 1200 J; c. 2400 J
97. a. 2.2 mol; b. $V_A = 6.7 \times 10^{-2}\text{m}^3$, $V_B = 3.3 \times 10^{-2}\text{m}^3$; c. $T_A = 2400\text{ K}$, $T_B = 397\text{ K}$; d. 26,000 J

CHAPTER 4

CHECK YOUR UNDERSTANDING

4.1. A perfect heat engine would have $Q_c = 0$, which would lead to $e = 1 - Q_c/Q_h = 1.$ A perfect refrigerator would need zero work, that is, $W = 0$, which leads to $K_R = Q_c/W \to \infty.$
4.2. From the engine on the right, we have $W = Q'_h - Q'_c.$ From the refrigerator on the right, we have $Q_h = Q_c + W.$ Thus, $W = Q'_h - Q'_c = Q_h - Q_c.$
4.3. a. $e = 1 - T_c/T_h = 0.55$; b. $Q_h = eW = 9.1\text{ J}$; c. $Q_c = Q_h - W = 4.1\text{ J}$; d. -273 °C and 400 °C
4.4. a. $K_R = T_c/(T_h - T_c) = 10.9$; b. $Q_c = K_R W = 2.18\text{ kJ}$; c. $Q_h = Q_c + W = 2.38\text{ kJ}$
4.5. When heat flows from the reservoir to the ice, the internal (mainly kinetic) energy of the ice goes up, resulting in a higher average speed and thus an average greater position variance of the molecules in the ice. The reservoir does become more ordered, but due to its much larger amount of molecules, it does not offset the change in entropy in the system.
4.6. $-Q/T_h$; Q/T_c; and $Q(T_h - T_c)/(T_h T_c)$
4.7. a. 4.71 J/K; b. −4.18 J/K; c. 0.53 J/K

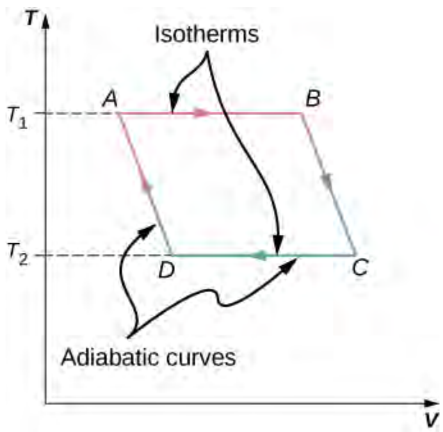
CONCEPTUAL QUESTIONS

1. Some possible solutions are frictionless movement; restrained compression or expansion; energy transfer as heat due to infinitesimal temperature nonuniformity; electric current flow through a zero resistance; restrained chemical reaction; and mixing of two samples of the same substance at the same state.
3. The temperature increases since the heat output behind the refrigerator is greater than the cooling from the inside of the refrigerator.
5. If we combine a perfect engine and a real refrigerator with the engine converting heat *Q* from the hot reservoir into work $W = Q$ to drive the refrigerator, then the heat dumped to the hot reservoir by the refrigerator will be $W + \Delta Q$, resulting in a perfect refrigerator transferring heat ΔQ from the cold reservoir to hot reservoir without any other effect.
7. Heat pumps can efficiently extract heat from the ground to heat on cooler days or pull heat out of the house on warmer days. The disadvantage of heat pumps are that they are more costly than alternatives, require maintenance, and will not work efficiently when temperature differences between the inside and outside are very large. Electric heating is much cheaper to purchase than a heat pump; however, it may be more costly to run depending on the electric rates and amount of usage.
9. A nuclear reactor needs to have a lower temperature to operate, so its efficiency will not be as great as a fossil-fuel plant. This argument does not take into consideration the amount of energy per reaction: Nuclear power has a far greater energy output than fossil fuels.
11. In order to increase the efficiency, the temperature of the hot reservoir should be raised, and the cold reservoir should be lowered as much as possible. This can be seen in **Equation 4.8**.
13. adiabatic and isothermal processes
15. Entropy will not change if it is a reversible transition but will change if the process is irreversible.
17. Entropy is a function of disorder, so all the answers apply here as well.

PROBLEMS

19. $4.53 \times 10^3\text{ J}$
21. $4.5\,pV_0$
23. 0.667

25. a. 0.556; b. 125.0 J
27. a. 0.50; b. 100 J; c. 50 J
29. a. 600 J; b. 800 J
31. a. 69 J; b. 11 J
33. 2.0
35. 50 J
37.



39. a. 900 J; b. 100 J
41. a. 546 K; b. 137 K
43. –1 J/K
45. –13 J(K mole)
47. $-\frac{Q}{T_{\mathrm{h}}}, \frac{Q}{T_{\mathrm{c}}}, Q\left(\frac{1}{T_{\mathrm{c}}} - \frac{1}{T_{\mathrm{h}}}\right)$
49. a. –540 J/K; b. 1600 J/K; c. 1100 J/K
51. a. $Q = nR\Delta T$; b. $S = nR\ln(T_2/T_1)$
53. 3.78×10^{-3} W/K
55. 430 J/K
57. $80\,°\mathrm{C}$, $80\,°\mathrm{C}$, 6.70×10^4 J, 215 J/K, –190 J/K, 25 J/K
59. $\Delta S_{\mathrm{H_2O}} = 215\ \mathrm{J/K}$, $\Delta S_{\mathrm{R}} = -208\ \mathrm{J/K}$, $\Delta S_{\mathrm{U}} = 7\ \mathrm{J/K}$
61. a. 1200 J; b. 600 J; c. 600 J; d. 0.50
63. $\Delta S = nC_V\ \ln\left(\frac{T_2}{T_1}\right) + nC_p\ \ln\left(\frac{T_3}{T_2}\right)$
65. a. 0.33, 0.39; b. 0.91

ADDITIONAL PROBLEMS

67. 1.45×10^7 J
69. a. $V_B = 0.042\ \mathrm{m}^3$, $V_D = 0.018\ \mathrm{m}^3$; b. 13,000 J; c. 13,000 J; d. –8,000 J; e. –8,000 J; f. 6200 J; g. –6200 J; h. 39%; with temperatures efficiency is 40%, which is off likely by rounding errors.
71. –670 J/K
73. a. –570 J/K; b. 570 J/K
75. 82 J/K
77. a. 2000 J; b. 40%
79. 60%
81. 64.4%

CHALLENGE PROBLEMS

83. derive
85. derive
87. 18 J/K

89. proof

91. $K_{\text{R}} = \frac{3(p_1 - p_2)V_1}{5p_2 V_3 - 3p_1 V_1 - p_2 V_1}$

93. $W = 110{,}000 \text{ J}$

CHAPTER 5

CHECK YOUR UNDERSTANDING

5.1. The force would point outward.
5.2. The net force would point $58°$ below the −*x*-axis.

5.3. $\vec{\mathbf{E}} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$

5.4. We will no longer be able to take advantage of symmetry. Instead, we will need to calculate each of the two components of the electric field with their own integral.
5.5. The point charge would be $Q = \sigma ab$ where *a* and *b* are the sides of the rectangle but otherwise identical.

5.6. The electric field would be zero in between, and have magnitude $\frac{\sigma}{\varepsilon_0}$ everywhere else.

CONCEPTUAL QUESTIONS

1. There are mostly equal numbers of positive and negative charges present, making the object electrically neutral.
3. a. yes; b. yes
5. Take an object with a known charge, either positive or negative, and bring it close to the rod. If the known charged object is positive and it is repelled from the rod, the rod is charged positive. If the positively charged object is attracted to the rod, the rod is negatively charged.
7. No, the dust is attracted to both because the dust particle molecules become polarized in the direction of the silk.
9. Yes, polarization charge is induced on the conductor so that the positive charge is nearest the charged rod, causing an attractive force.
11. Charging by conduction is charging by contact where charge is transferred to the object. Charging by induction first involves producing a polarization charge in the object and then connecting a wire to ground to allow some of the charge to leave the object, leaving the object charged.
13. This is so that any excess charge is transferred to the ground, keeping the gasoline receptacles neutral. If there is excess charge on the gasoline receptacle, a spark could ignite it.
15. The dryer charges the clothes. If they are damp, the presence of water molecules suppresses the charge.
17. There are only two types of charge, attractive and repulsive. If you bring a charged object near the quartz, only one of these two effects will happen, proving there is not a third kind of charge.
19. a. No, since a polarization charge is induced. b. Yes, since the polarization charge would produce only an attractive force.
21. The force holding the nucleus together must be greater than the electrostatic repulsive force on the protons.
23. Either sign of the test charge could be used, but the convention is to use a positive test charge.
25. The charges are of the same sign.
27. At infinity, we would expect the field to go to zero, but because the sheet is infinite in extent, this is not the case. Everywhere you are, you see an infinite plane in all directions.

29. The infinite charged plate would have $E = \frac{\sigma}{2\varepsilon_0}$ everywhere. The field would point toward the plate if it were negatively charged and point away from the plate if it were positively charged. The electric field of the parallel plates would be zero between them if they had the same charge, and *E* would be $E = \frac{\sigma}{\varepsilon_0}$ everywhere else. If the charges were opposite, the situation is reversed, zero outside the plates and $E = \frac{\sigma}{\varepsilon_0}$ between them.

31. yes; no
33. At the surface of Earth, the gravitational field is always directed in toward Earth’s center. An electric field could move a charged particle in a different direction than toward the center of Earth. This would indicate an electric field is present.
35. 10

PROBLEMS

37. a. $2.00 \times 10^{-9} \text{ C}\left(\frac{1}{1.602 \times 10^{-19}} \text{e/C}\right) = 1.248 \times 10^{10} \text{ electrons}$;

b. $0.500 \times 10^{-6} \text{ C}\left(\frac{1}{1.602 \times 10^{-19}} \text{e/C}\right) = 3.121 \times 10^{12} \text{ electrons}$

39. $\frac{3.750 \times 10^{21} \text{ e}}{6.242 \times 10^{18} \text{ e/C}} = 600.8 \text{ C}$

41. a. $2.0 \times 10^{-9} \text{ C} (6.242 \times 10^{18} \text{ e/C}) = 1.248 \times 10^{10} \text{ e}$;

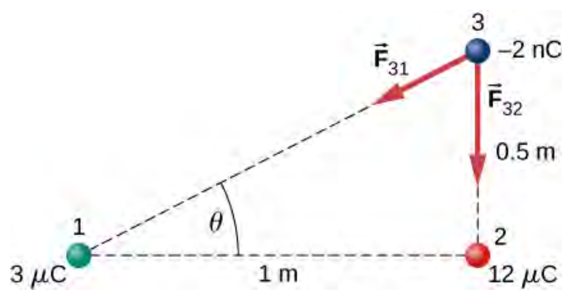
b. $9.109 \times 10^{-31} \text{ kg} (1.248 \times 10^{10} \text{ e}) = 1.137 \times 10^{-20} \text{ kg}$,
$\frac{1.137 \times 10^{-20} \text{ kg}}{2.5 \times 10^{-3} \text{ kg}} = 4.548 \times 10^{-18}$ or $4.545 \times 10^{-16} \%$

43. $5.00 \times 10^{-9} \text{ C} (6.242 \times 10^{18} \text{ e/C}) = 3.121 \times 10^{19} \text{ e}$;
$3.121 \times 10^{19} \text{ e} + 1.0000 \times 10^{12} \text{ e} = 3.1210001 \times 10^{19} \text{ e}$

45. atomic mass of copper atom times $1 \text{ u} = 1.055 \times 10^{-25} \text{ kg}$;
number of copper atoms $= 4.739 \times 10^{23}$ atoms;
number of electrons equals 29 times number of atoms or 1.374×10^{25} electrons;
$\frac{2.00 \times 10^{-6} \text{ C}(6.242 \times 10^{18} \text{ e/C})}{1.374 \times 10^{25} \text{ e}} = 9.083 \times 10^{-13}$ or $9.083 \times 10^{-11} \%$

47. $244.00 \text{ u}(1.66 \times 10^{-27} \text{ kg/u}) = 4.050 \times 10^{-25} \text{ kg}$;
$\frac{4.00 \text{ kg}}{4.050 \times 10^{-25} \text{ kg}} = 9.877 \times 10^{24}$ atoms $9.877 \times 10^{24}(94) = 9.284 \times 10^{26}$ protons;
$9.284 \times 10^{26}(1.602 \times 10^{-19} \text{ C/p}) = 1.487 \times 10^{8} \text{ C}$

49. a. charge 1 is $3 \,\mu\text{C}$; charge 2 is $12 \,\mu\text{C}$, $F_{31} = 2.16 \times 10^{-4} \text{ N}$ to the left,
$F_{32} = 8.63 \times 10^{-4} \text{ N}$ to the right,
$F_{net} = 6.47 \times 10^{-4} \text{ N}$ to the right;
b. $F_{31} = 2.16 \times 10^{-4} \text{ N}$ to the right,
$F_{32} = 9.59 \times 10^{-5} \text{ N}$ to the right,
$F_{net} = 3.12 \times 10^{-4} \text{ N}$ to the right,



;

c. $\vec{F}_{31x} = -2.76 \times 10^{-5} \text{ N } \hat{\mathbf{i}}$,
$\vec{F}_{31y} = -1.38 \times 10^{-5} \text{ N } \hat{\mathbf{j}}$,
$\vec{F}_{32y} = -8.63 \times 10^{-4} \text{ N } \hat{\mathbf{j}}$
$\vec{F}_{net} = -2.76 \times 10^{-5} \text{ N } \hat{\mathbf{i}} - 8.77 \times 10^{-4} \text{ N } \hat{\mathbf{j}}$

51. $F = 230.7 \text{ N}$

53. $F = 53.94 \text{ N}$

55. The tension is $T = 0.049 \text{ N}$. The horizontal component of the tension is 0.0043 N

$d = 0.088\text{ m}, \quad q = 6.1 \times 10^{-8}\text{ C}$.

The charges can be positive or negative, but both have to be the same sign.

57. Let the charge on one of the spheres be rQ, where r is a fraction between 0 and 1. In the numerator of Coulomb's law, the term involving the charges is $rQ(1 - r)Q$. This is equal to $(r - r^2)Q^2$. Finding the maximum of this term gives $1 - 2r = 0 \Rightarrow r = \frac{1}{2}$

59. Define right to be the positive direction and hence left is the negative direction, then $F = -0.05\text{ N}$

61. The particles form triangle of sides 13, 13, and 24 cm. The x-components cancel, whereas there is a contribution to the y-component from both charges 24 cm apart. The y-axis passing through the third charge bisects the 24-cm line, creating two right triangles of sides 5, 12, and 13 cm.

$F_y = 2.56\text{ N}$ in the negative y-direction since the force is attractive. The net force from both charges is $\vec{\mathbf{F}}_{\text{net}} = -5.12\text{ N}\,\hat{\mathbf{j}}$

.

63. The diagonal is $\sqrt{2}a$ and the components of the force due to the diagonal charge has a factor $\cos\theta = \frac{1}{\sqrt{2}}$;

$$\vec{\mathbf{F}}_{\text{net}} = \left[k\frac{q^2}{a^2} + k\frac{q^2}{2a^2}\frac{1}{\sqrt{2}}\right]\hat{\mathbf{i}} - \left[k\frac{q^2}{a^2} + k\frac{q^2}{2a^2}\frac{1}{\sqrt{2}}\right]\hat{\mathbf{j}}$$

65. a. $E = 2.0 \times 10^{-2}\,\frac{\text{N}}{\text{C}}$;

b. $F = 2.0 \times 10^{-19}\text{ N}$

67. a. $E = 2.88 \times 10^{11}\text{ N/C}$;

b. $E = 1.44 \times 10^{11}\text{ N/C}$;

c. $F = 4.61 \times 10^{-8}\text{ N}$ on alpha particle;

$F = 4.61 \times 10^{-8}\text{ N}$ on electron

69. $E = \left(-2.0\,\hat{\mathbf{i}} + 3.0\,\hat{\mathbf{j}}\right)\text{N}$

71. $F = 3.204 \times 10^{-14}\text{ N}$,

$a = 3.517 \times 10^{16}\text{ m/s}^2$

73. $q = 2.78 \times 10^{-9}\text{ C}$

75. a. $E = 1.15 \times 10^{12}\text{ N/C}$;

b. $F = 1.47 \times 10^{-6}\text{ N}$

77. If the q_2 is to the right of q_1, the electric field vector from both charges point to the right. a. $E = 2.70 \times 10^6\text{ N/C}$;

b. $F = 54.0\text{ N}$

79. There is $45°$ right triangle geometry. The x-components of the electric field at $y = 3\text{ m}$ cancel. The y-components give $E(y = 3\text{ m}) = 2.83 \times 10^3\text{ N/C}$.

At the origin we have a a negative charge of magnitide

$q = -2.83 \times 10^{-6}\text{ C}$.

81. $\vec{\mathbf{E}}(z) = 3.6 \times 10^4\text{ N/C}\,\hat{\mathbf{k}}$

83. $dE = \frac{1}{4\pi\varepsilon_0}\frac{\lambda dx}{(x + a)^2}, \quad E = \frac{\lambda}{4\pi\varepsilon_0}\left[\frac{1}{l + a} - \frac{1}{a}\right]$

85. $\sigma = 0.02\text{ C/m}^2$ $E = 2.26 \times 10^9\text{ N/C}$

87. At P_1: $\vec{\mathbf{E}}(y) = \frac{1}{4\pi\varepsilon_0}\frac{\lambda L}{y\sqrt{y^2 + \frac{L^2}{4}}}\hat{\mathbf{j}} \Rightarrow \frac{1}{4\pi\varepsilon_0}\frac{q}{\frac{a}{2}\sqrt{(\frac{a}{2})^2 + \frac{L^2}{4}}}\hat{\mathbf{j}} = \frac{1}{\pi\varepsilon_0}\frac{q}{a\sqrt{a^2 + L^2}}\hat{\mathbf{j}}$

At P_2: Put the origin at the end of L.

$dE = \frac{1}{4\pi\varepsilon_0}\frac{\lambda dx}{(x + a)^2}, \quad \vec{\mathbf{E}} = -\frac{q}{4\pi\varepsilon_0 l}\left[\frac{1}{l + a} - \frac{1}{a}\right]\hat{\mathbf{i}}$

89. a. $\vec{\mathbf{E}}(\vec{\mathbf{r}}) = \frac{1}{4\pi\varepsilon_0}\frac{2\lambda_x}{a}\hat{\mathbf{i}} + \frac{1}{4\pi\varepsilon_0}\frac{2\lambda_y}{b}\hat{\mathbf{j}}$; b. $\frac{1}{4\pi\varepsilon_0}\frac{2(\lambda_x + \lambda_y)}{c}\hat{\mathbf{k}}$

91. a. $\vec{\mathbf{F}} = 3.2 \times 10^{-17}\ \text{N}\,\hat{\mathbf{i}}$,

$\vec{\mathbf{a}} = 1.92 \times 10^{10}\ \text{m/s}^2\,\hat{\mathbf{i}}$;

b. $\vec{\mathbf{F}} = -3.2 \times 10^{-17}\ \text{N}\,\hat{\mathbf{i}}$,

$\vec{\mathbf{a}} = -3.51 \times 10^{13}\ \text{m/s}^2\,\hat{\mathbf{i}}$

93. $m = 6.5 \times 10^{-11}\ \text{kg}$,

$E = 1.6 \times 107\ \text{N/C}$

95. $E = 1.70 \times 10^6\ \text{N/C}$,

$F = 1.53 \times 10^{-3}\ \text{N}\ \ T\cos\theta = mg\ \ T\sin\theta = qE$,

$\tan\theta = 0.62 \Rightarrow \theta = 32.0°$,

This is independent of the length of the string.

97. circular arc $dE_x(-\hat{\mathbf{i}}) = \frac{1}{4\pi\varepsilon_0}\frac{\lambda ds}{r^2}\cos\theta(-\hat{\mathbf{i}})$,

$\vec{\mathbf{E}}_x = \frac{\lambda}{4\pi\varepsilon_0 r}(-\hat{\mathbf{i}})$,

$dE_y(-\hat{\mathbf{i}}) = \frac{1}{4\pi\varepsilon_0}\frac{\lambda ds}{r^2}\sin\theta(-\hat{\mathbf{j}})$,

$\vec{\mathbf{E}}_y = \frac{\lambda}{4\pi\varepsilon_0 r}(-\hat{\mathbf{j}})$;

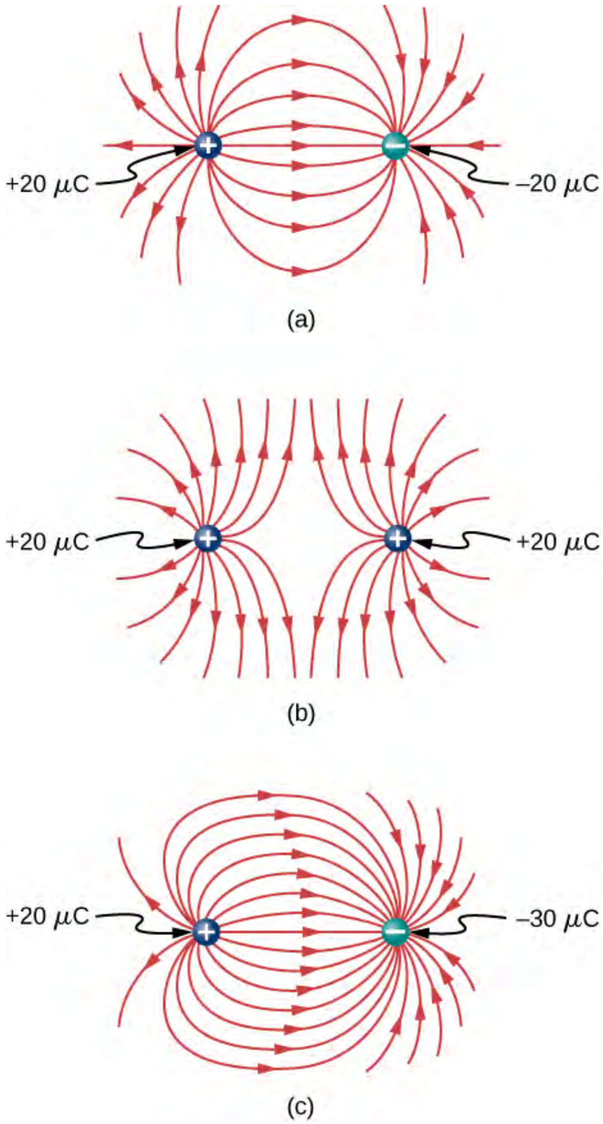
y-axis: $\vec{\mathbf{E}}_x = \frac{\lambda}{4\pi\varepsilon_0 r}(-\hat{\mathbf{i}})$;

x-axis: $\vec{\mathbf{E}}_y = \frac{\lambda}{4\pi\varepsilon_0 r}(-\hat{\mathbf{j}})$,

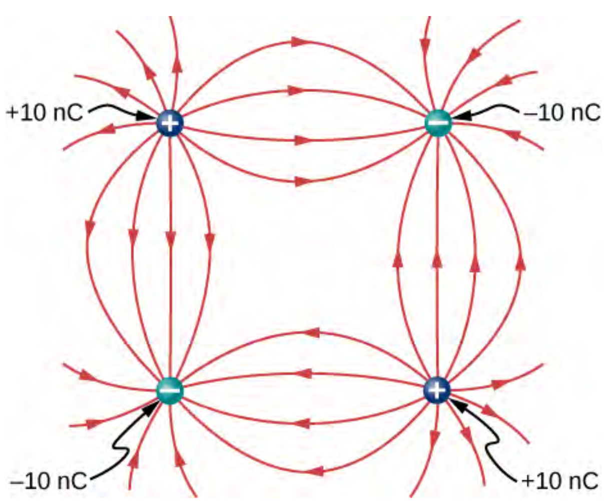
$\vec{\mathbf{E}} = \frac{\lambda}{2\pi\varepsilon_0 r}(-\hat{\mathbf{i}}) + \frac{\lambda}{2\pi\varepsilon_0 r}(-\hat{\mathbf{j}})$

99. a. $W = \frac{1}{2}m(v^2 - v_0^2)$, $\frac{Qq}{4\pi\varepsilon_0}\left(\frac{1}{r} - \frac{1}{r_0}\right) = \frac{1}{2}m(v^2 - v_0^2) \Rightarrow r_0 - r = \frac{4\pi\varepsilon_0}{Qq}\frac{1}{2}rr_0 m(v^2 - v_0^2)$; b. $r_0 - r$ is negative; therefore, $v_0 > v$, $r \to \infty$, and $v \to 0$: $\frac{Qq}{4\pi\varepsilon_0}\left(-\frac{1}{r_0}\right) = -\frac{1}{2}mv_0^2 \Rightarrow v_0 = \sqrt{\frac{Qq}{2\pi\varepsilon_0 m r_0}}$

101.



103.



105. $E_x = 0,$

$$E_y = \frac{1}{4\pi\varepsilon_0}\left[\frac{2q}{(x^2+a^2)}\frac{a}{\sqrt{(x^2+a^2)}}\right]$$

$$\Rightarrow x \gg a \Rightarrow \frac{1}{2\pi\varepsilon_0}\frac{qa}{x^3},$$

$$E_y = \frac{q}{4\pi\varepsilon_0}\left[\frac{2ya+2ya}{(y-a)^2(y+a)^2}\right]$$

$$\Rightarrow y \gg a \Rightarrow \frac{1}{\pi\varepsilon_0}\frac{qa}{y^3}$$

107. The net dipole moment of the molecule is the vector sum of the individual dipole moments between the two O-H. The separation O-H is 0.9578 angstroms:

$$\vec{\mathbf{p}} = 1.889 \times 10^{-29}\ \text{Cm}\ \hat{\mathbf{i}}$$

ADDITIONAL PROBLEMS

109. $\vec{\mathbf{F}}_{\text{net}} = [-8.99 \times 10^9 \frac{3.0 \times 10^{-6}(5.0 \times 10^{-6})}{(3.0\ \text{m})^2} - 8.99 \times 10^9 \frac{9.0 \times 10^{-6}(5.0 \times 10^{-6})}{(3.0\ \text{m})^2}]\hat{\mathbf{i}}$,

$$-8.99 \times 10^9 \frac{6.0 \times 10^{-6}(5.0 \times 10^{-6})}{(3.0\ \text{m})^2}\hat{\mathbf{j}} = -0.06\ \text{N}\ \hat{\mathbf{i}} - 0.03\ \text{N}\ \hat{\mathbf{j}}$$

111. Charges Q and q form a right triangle of sides 1 m and $3 + \sqrt{3}\ \text{m}$. Charges $2Q$ and q form a right triangle of sides 1 m and $\sqrt{3}\ \text{m}$.

$F_x = 0.036\ \text{N}$,

$F_y = 0.09\ \text{N}$,

$$\vec{\mathbf{F}}_{\text{net}} = 0.036\ \text{N}\ \hat{\mathbf{i}} + 0.09\ \text{N}\ \hat{\mathbf{j}}$$

113. $W = 0.054\ \text{J}$

115. a. $\vec{\mathbf{E}} = \frac{1}{4\pi\varepsilon_0}(\frac{q}{(2a)^2} - \frac{q}{a^2})\hat{\mathbf{i}}$; b. $\vec{\mathbf{E}} = \frac{\sqrt{3}}{4\pi\varepsilon_0}\frac{q}{a^2}(-\hat{\mathbf{j}})$; c. $\vec{\mathbf{E}} = \frac{2}{\pi\varepsilon_0}\frac{q}{a^2}\frac{1}{\sqrt{2}}(-\hat{\mathbf{j}})$

117. $\vec{\mathbf{E}} = 6.4 \times 10^6(\hat{\mathbf{i}}) + 1.5 \times 10^7(\hat{\mathbf{j}})\ \text{N/C}$

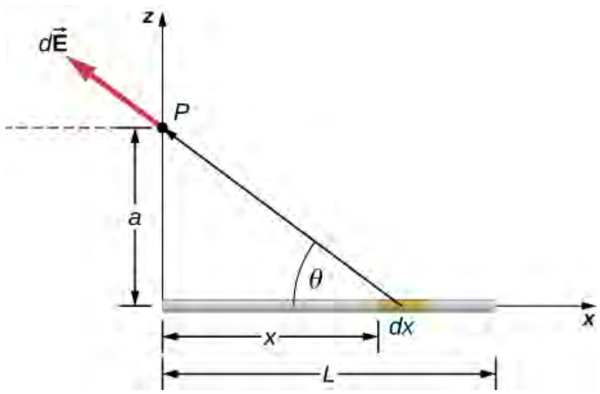
119. $F = qE_0(1 + x/a)$ $W = \frac{1}{2}m(v^2 - v_0^2)$,

$$\frac{1}{2}mv^2 = qE_0(\frac{15a}{2})\ \text{J}$$

121. Electric field of wire at x: $\vec{\mathbf{E}}(x) = \frac{1}{4\pi\varepsilon_0}\frac{2\lambda_y}{x}\hat{\mathbf{i}}$,

$$dF = \frac{\lambda_y \lambda_x}{2\pi\varepsilon_0}(\ln b - \ln a)$$

123.



$$dE_x = \frac{1}{4\pi\varepsilon_0}\frac{\lambda dx}{(x^2+a^2)}\frac{x}{\sqrt{x^2+a^2}},$$

$$\vec{\mathbf{E}}_x = \frac{\lambda}{4\pi\varepsilon_0}\left[\frac{1}{\sqrt{L^2+a^2}} - \frac{1}{a}\right]\hat{\mathbf{i}},$$

$$dE_z = \frac{1}{4\pi\varepsilon_0}\frac{\lambda dx}{(x^2+a^2)}\frac{a}{\sqrt{x^2+a^2}},$$

$$\vec{\mathbf{E}}_z = \frac{\lambda}{4\pi\varepsilon_0 a}\frac{L}{\sqrt{L^2+a^2}}\hat{\mathbf{k}},$$

Substituting z for a, we have:

$$\vec{\mathbf{E}}(z) = \frac{\lambda}{4\pi\varepsilon_0}\left[\frac{1}{\sqrt{L^2+z^2}} - \frac{1}{z}\right]\hat{\mathbf{i}} + \frac{\lambda}{4\pi\varepsilon_0 z}\frac{L}{\sqrt{L^2+z^2}}\hat{\mathbf{k}}$$

125. There is a net force only in the *y*-direction. Let θ be the angle the vector from *dx* to *q* makes with the *x*-axis. The components along the *x*-axis cancel due to symmetry, leaving the *y*-component of the force.

$$dF_y = \frac{1}{4\pi\varepsilon_0}\frac{aq\lambda dx}{(x^2+a^2)^{3/2}},$$

$$F_y = \frac{1}{2\pi\varepsilon_0}\frac{q\lambda}{a}\left[\frac{l/2}{((l/2)^2+a^2)^{1/2}}\right]$$

CHAPTER 6

CHECK YOUR UNDERSTANDING

6.1. Place it so that its unit normal is perpendicular to $\vec{\mathbf{E}}$.

6.2. $mab^2/2$

6.3. a. $3.4 \times 10^5\ \text{N}\cdot\text{m}^2/\text{C}$; b. $-3.4 \times 10^5\ \text{N}\cdot\text{m}^2/\text{C}$; c. $3.4 \times 10^5\ \text{N}\cdot\text{m}^2/\text{C}$; d. 0

6.4. In this case, there is only $\vec{\mathbf{E}}_{\text{out}}$. So, yes.

6.5. $\vec{\mathbf{E}} = \frac{\lambda_0}{2\pi\varepsilon_0}\frac{1}{d}\hat{\mathbf{r}}$; This agrees with the calculation of **Example 5.5** where we found the electric field by integrating over the charged wire. Notice how much simpler the calculation of this electric field is with Gauss's law.

6.6. If there are other charged objects around, then the charges on the surface of the sphere will not necessarily be spherically symmetrical; there will be more in certain direction than in other directions.

CONCEPTUAL QUESTIONS

1. a. If the planar surface is perpendicular to the electric field vector, the maximum flux would be obtained. b. If the planar surface were parallel to the electric field vector, the minimum flux would be obtained.

3. true

5. Since the electric field vector has a $\frac{1}{r^2}$ dependence, the fluxes are the same since $A = 4\pi r^2$.

7. a. no; b. zero

9. Both fields vary as $\frac{1}{r^2}$. Because the gravitational constant is so much smaller than $\frac{1}{4\pi\varepsilon_0}$, the gravitational field is orders of magnitude weaker than the electric field.

11. No, it is produced by all charges both inside and outside the Gaussian surface.

13. yes, using superposition

15. Any shape of the Gaussian surface can be used. The only restriction is that the Gaussian integral must be calculable; therefore, a box or a cylinder are the most convenient geometrical shapes for the Gaussian surface.

17. yes

19. Since the electric field is zero inside a conductor, a charge of $-2.0\,\mu\text{C}$ is induced on the inside surface of the cavity. This will put a charge of $+2.0\,\mu C$ on the outside surface leaving a net charge of $-3.0\,\mu\text{C}$ on the surface.

PROBLEMS

21. $\Phi = \vec{\mathbf{E}} \cdot \vec{\mathbf{A}} \rightarrow EA\cos\theta = 2.2 \times 10^4\,\text{N}\cdot\text{m}^2/\text{C}$ electric field in direction of unit normal; $\Phi = \vec{\mathbf{E}} \cdot \vec{\mathbf{A}} \rightarrow EA\cos\theta = -2.2 \times 10^4\,\text{N}\cdot\text{m}^2/\text{C}$ electric field opposite to unit normal

23. $\frac{3 \times 10^{-5}\ \text{N}\cdot\text{m}^2/\text{C}}{(0.05\ \text{m})^2} = E \Rightarrow \sigma = 2.12 \times 10^{-13}\ \text{C/m}^2$

25. a. $\Phi = 0.17\,\text{N}\cdot\text{m}^2/\text{C}$;

b. $\Phi = 0$; c. $\Phi = EA\cos 0° = 1.0 \times 10^3\ \text{N/C}(2.0 \times 10^{-4}\ \text{m})^2\ \cos 0° = 0.20\,\text{N}\cdot\text{m}^2/\text{C}$

27. $\Phi = 3.8 \times 10^4\ \text{N}\cdot\text{m}^2/\text{C}$

29. $\vec{\mathbf{E}}\,(z) = \frac{1}{4\pi\varepsilon_0}\frac{2\lambda}{z}\hat{\mathbf{k}},\ \int \vec{\mathbf{E}} \cdot \hat{\mathbf{n}}\,dA = \frac{\lambda}{\varepsilon_0}l$

31. a. $\Phi = 3.39 \times 10^3\ \text{N}\cdot\text{m}^2/\text{C}$; b. $\Phi = 0$;

c. $\Phi = -2.25 \times 10^5\ \text{N}\cdot\text{m}^2/\text{C}$;

d. $\Phi = 90.4\,\text{N}\cdot\text{m}^2/\text{C}$

33. $\Phi = 1.13 \times 10^6\ \text{N}\cdot\text{m}^2/\text{C}$

35. Make a cube with q at the center, using the cube of side a. This would take four cubes of side a to make one side of the large cube. The shaded side of the small cube would be 1/24th of the total area of the large cube; therefore, the flux through the shaded area would be

$\Phi = \frac{1}{24}\frac{q}{\varepsilon_0}$.

37. $q = 3.54 \times 10^{-7}\ \text{C}$

39. zero, also because flux in equals flux out

41. $r > R,\ E = \frac{Q}{4\pi\varepsilon_0 r^2};\ r < R,\ E = \frac{qr}{4\pi\varepsilon_0 R^3}$

43. $EA = \frac{\lambda l}{\varepsilon_0} \Rightarrow E = 4.50 \times 10^7\ \text{N/C}$

45. a. 0; b. 0; c. $\vec{\mathbf{E}} = 6.74 \times 10^6\ \text{N/C}(-\hat{\mathbf{r}})$

47. a. 0; b. $E = 2.70 \times 10^6\ \text{N/C}$

49. a. Yes, the length of the rod is much greater than the distance to the point in question. b. No, The length of the rod is of the same order of magnitude as the distance to the point in question. c. Yes, the length of the rod is much greater than the distance to the point in question. d. No. The length of the rod is of the same order of magnitude as the distance to the point in question.

51. a. $\vec{\mathbf{E}} = \frac{R\sigma_0}{\varepsilon_0}\frac{1}{r}\hat{\mathbf{r}} \Rightarrow \sigma_0 = 5.31 \times 10^{-11}\ \text{C/m}^2,$

$\lambda = 3.33 \times 10^{-12}\ \text{C/m}$;

b. $\Phi = \frac{q_{\text{enc}}}{\varepsilon_0} = \frac{3.33 \times 10^{-12}\ \text{C/m}(0.05\ \text{m})}{\varepsilon_0} = 0.019\,\text{N}\cdot\text{m}^2/\text{C}$

53. $E2\pi rl = \frac{\rho\pi r^2 l}{\varepsilon_0} \Rightarrow E = \frac{\rho r}{2\varepsilon_0}\,(r \le R)$;

$E2\pi rl = \frac{\rho\pi R^2 l}{\varepsilon_0} \Rightarrow E = \frac{\rho R^2}{2\varepsilon_0 r}(r \geq R)$

55. $\Phi = \frac{q_{\text{enc}}}{\varepsilon_0} \Rightarrow q_{\text{enc}} = -4.45 \times 10^{-10}\text{ C}$

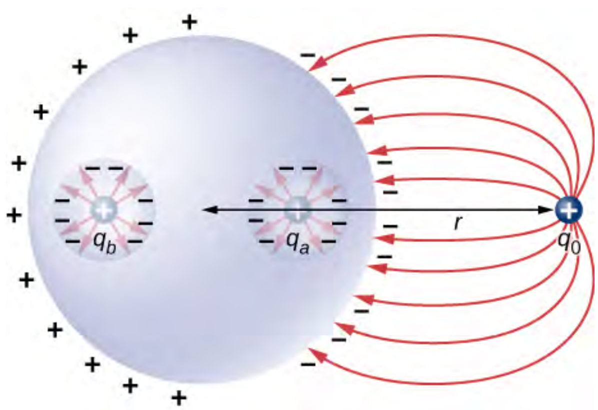
57. $q_{\text{enc}} = \frac{4}{5}\pi\alpha r^5,$

$E4\pi r^2 = \frac{4\pi\alpha r^5}{5\varepsilon_0} \Rightarrow E = \frac{\alpha r^3}{5\varepsilon_0}(r \leq R),$

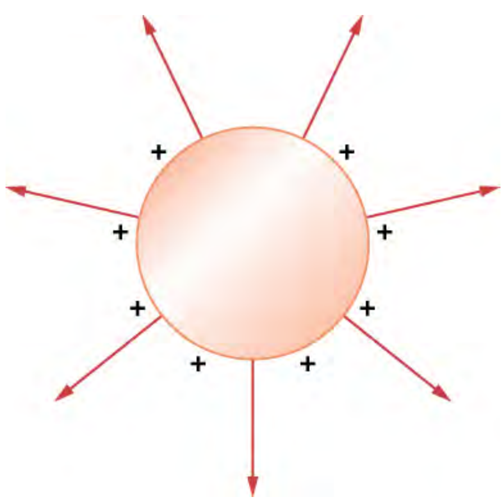
$q_{\text{enc}} = \frac{4}{5}\pi\alpha R^5,\ E4\pi r^2 = \frac{4\pi\alpha R^5}{5\varepsilon_0} \Rightarrow E = \frac{\alpha R^5}{5\varepsilon_0 r^2}(r \geq R)$

59. integrate by parts: $q_{\text{enc}} = 4\pi\rho_0\left[-e^{-\alpha r}(\frac{(r)^2}{\alpha} + \frac{2r}{\alpha^2} + \frac{2}{\alpha^3}) + \frac{2}{\alpha^3}\right] \Rightarrow E = \frac{\rho_0}{r^2\varepsilon_0}\left[-e^{-\alpha r}(\frac{(r)^2}{\alpha} + \frac{2r}{\alpha^2} + \frac{2}{\alpha^3}) + \frac{2}{\alpha^3}\right]$

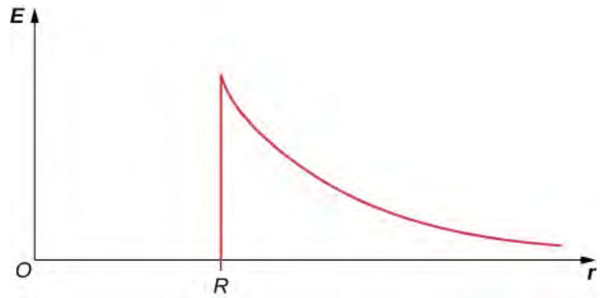
61.



63. a. Outside: $E2\pi rl = \frac{\lambda l}{\varepsilon_0} \Rightarrow E = \frac{3.0\text{ C/m}}{2\pi\varepsilon_0 r}$; Inside $E_{\text{in}} = 0$; b.



65. a. $E2\pi rl = \frac{\lambda l}{\varepsilon_0} \Rightarrow E = \frac{\lambda}{2\pi\varepsilon_0 r}\ r \geq R$ E inside equals 0; b.



67. $E = 5.65 \times 10^4$ N/C

69. $\lambda = \frac{\lambda l}{\varepsilon_0} \Rightarrow E = \frac{a\sigma}{\varepsilon_0 r}\, r \geq a$, $E = 0$ inside since q enclosed $= 0$

71. a. $E = 0$; b. $E 2\pi r L = \frac{Q}{\varepsilon_0} \Rightarrow E = \frac{Q}{2\pi\varepsilon_0 r L}$; c. $E = 0$ since r would be either inside the second shell or if outside then q enclosed equals 0.

ADDITIONAL PROBLEMS

73. $\int \vec{\mathbf{E}} \cdot \hat{\mathbf{n}}\, dA = a^4$

75. a. $\int \vec{\mathbf{E}} \cdot \hat{\mathbf{n}}\, dA = E_0 r^2 \pi$; b. zero, since the flux through the upper half cancels the flux through the lower half of the sphere

77. $\Phi = \frac{q_{\text{enc}}}{\varepsilon_0}$; There are two contributions to the surface integral: one at the side of the rectangle at $x = 0$ and the other at the side at $x = 2.0$ m;

$-E(0)[1.5\ \text{m}^2] + E(2.0\ \text{m})[1.5\ \text{m}^2] = \frac{q_{\text{enc}}}{\varepsilon_0} = -100\ \text{Nm}^2/\text{C}$

where the minus sign indicates that at $x = 0$, the electric field is along positive x and the unit normal is along negative x. At $x = 2$, the unit normal and the electric field vector are in the same direction: $q_{\text{enc}} = \varepsilon_0\, \Phi = -8.85 \times 10^{-10}$ C.

79. didn't keep consistent directions for the area vectors, or the electric fields

81. a. $\sigma = 3.0 \times 10^{-3}\ \text{C/m}^2$, $+3 \times 10^{-3}\ \text{C/m}^2$ on one and $-3 \times 10^{-3}\ \text{C/m}^2$ on the other; b. $E = 3.39 \times 10^8$ N/C

83. Construct a Gaussian cylinder along the z-axis with cross-sectional area A.

$|z| \geq \frac{a}{2}\, q_{\text{enc}} = \rho A a,\ \Phi = \frac{\rho A a}{\varepsilon_0} \Rightarrow E = \frac{\rho a}{2\varepsilon_0}$,

$|z| \leq \frac{a}{2}\, q_{\text{enc}} = \rho A 2z,\ E(2A) = \frac{\rho A 2z}{\varepsilon_0} \Rightarrow E = \frac{\rho z}{\varepsilon_0}$

85. a. $r > b_2\ E 4\pi r^2 = \frac{\frac{4}{3}\pi[\rho_1(b_1^3 - a_1^3) + \rho_2(b_2^3 - a_2^3)}{\varepsilon_0} \Rightarrow E = \frac{\rho_1(b_1^3 - a_1^3) + \rho_2(b_2^3 - a_2^3)}{3\varepsilon_0 r^2}$;

b. $a_2 < r < b_2 \quad E 4\pi r^2 = \frac{\frac{4}{3}\pi[\rho_1(b_1^3 - a_1^3) + \rho_2(r^3 - a_2^3)]}{\varepsilon_0} \Rightarrow E = \frac{\rho_1(b_1^3 - a_1^3) + \rho_2(r^3 - a_2^3)}{3\varepsilon_0 r^2}$;

c. $b_1 < r < a_2 \quad E 4\pi r^2 = \frac{\frac{4}{3}\pi\rho_1(b_1^3 - a_1^3)}{\varepsilon_0} \Rightarrow E = \frac{\rho_1(b_1^3 - a_1^3)}{3\varepsilon_0 r^2}$;

d. $a_1 < r < b_1 \quad E 4\pi r^2 = \frac{\frac{4}{3}\pi\rho_1(r^3 - a_1^3)}{\varepsilon_0} \Rightarrow E = \frac{\rho_1(r^3 - a_1^3)}{3\varepsilon_0 r^2}$; e. 0

87. Electric field due to plate without hole: $E = \frac{\sigma}{2\varepsilon_0}$.

Electric field of just hole filled with $-\sigma\ E = \frac{-\sigma}{2\varepsilon_0}\left(1 - \frac{z}{\sqrt{R^2 + z^2}}\right)$.

Thus, $E_{\textbf{net}} = \frac{\sigma}{2\varepsilon_0} \frac{h}{\sqrt{R^2 + h^2}}$.

89. a. $E = 0$; b. $E = \frac{q_1}{4\pi\varepsilon_0 r^2}$; c. $E = \frac{q_1 + q_2}{4\pi\varepsilon_0 r^2}$; d. $0\, q_1 - q_1,\ q_1 + q_2$

CHALLENGE PROBLEMS

91. Given the referenced link, using a distance to Vega of 237×10^{15} m[1] and a diameter of 2.4 m for the primary mirror,[2] we find that at a wavelength of 555.6 nm, Vega is emitting 1.1×10^{25} J/s at that wavelength. Note that the flux through the mirror is essentially constant.

93. The symmetry of the system forces $\vec{\mathbf{E}}$ to be perpendicular to the sheet and constant over any plane parallel to the sheet. To calculate the electric field, we choose the cylindrical Gaussian surface shown. The cross-section area and the height of the cylinder are *A* and 2*x*, respectively, and the cylinder is positioned so that it is bisected by the plane sheet. Since *E* is perpendicular to each end and parallel to the side of the cylinder, we have *EA* as the flux through each end and there is no flux through the side. The charge enclosed by the cylinder is σA, so from Gauss's law, $2EA = \frac{\sigma A}{\varepsilon_0}$, and the electric field of an infinite sheet of charge is $E = \frac{\sigma}{2\varepsilon_0}$, in agreement with the calculation of in the text.

95. There is *Q*/2 on each side of the plate since the net charge is *Q*: $\sigma = \frac{Q}{2A}$,

$$\oint_S \vec{\mathbf{E}} \cdot \hat{\mathbf{n}}\, dA = \frac{2\sigma\Delta A}{\varepsilon_0} \Rightarrow E_P = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 2A}$$

CHAPTER 7

CHECK YOUR UNDERSTANDING

7.1. $K = \frac{1}{2}mv^2,\ v = \sqrt{2\frac{K}{m}} = \sqrt{2\frac{4.5 \times 10^{-7}\text{ J}}{4.00 \times 10^{-9}\text{ kg}}} = 15\text{ m/s}$

7.2. It has kinetic energy of 4.5×10^{-7} J at point r_2 and potential energy of 9.0×10^{-7} J, which means that as *Q* approaches infinity, its kinetic energy totals three times the kinetic energy at r_2, since all of the potential energy gets converted to kinetic.

7.3. positive, negative, and these quantities are the same as the work you would need to do to bring the charges in from infinity

7.4. $\Delta U = q\Delta V = (100\text{ C})(1.5\text{ V}) = 150\text{ J}$

7.5. –2.00 C, $n_e = 1.25 \times 10^{19}$ electrons

7.6. It would be going in the opposite direction, with no effect on the calculations as presented.

7.7. Given a fixed maximum electric field strength, the potential at which a strike occurs increases with increasing height above the ground. Hence, each electron will carry more energy. Determining if there is an effect on the total number of electrons lies in the future.

7.8. $V = k\frac{q}{r} = \left(8.99 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2\right)\left(\frac{-3.00 \times 10^{-9}\text{ C}}{5.00 \times 10^{-3}\text{ m}}\right) = -5390\text{ V}$; recall that the electric field inside a conductor is zero. Hence, any path from a point on the surface to any point in the interior will have an integrand of zero when calculating the change in potential, and thus the potential in the interior of the sphere is identical to that on the surface.

7.9. The *x*-axis the potential is zero, due to the equal and opposite charges the same distance from it. On the *z*-axis, we may superimpose the two potentials; we will find that for $z >> d$, again the potential goes to zero due to cancellation.

7.10. It will be zero, as at all points on the axis, there are equal and opposite charges equidistant from the point of interest. Note that this distribution will, in fact, have a dipole moment.

7.11. Any, but cylindrical is closest to the symmetry of a dipole.

7.12. infinite cylinders of constant radius, with the line charge as the axis

CONCEPTUAL QUESTIONS

1. No. We can only define potential energies for conservative fields.

3. No, though certain orderings may be simpler to compute.

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1. http://webviz.u-strasbg.fr/viz-bin/VizieR-5?-source=I/311&HIP=91262
2. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19910003124.pdf

5. The electric field strength is zero because electric potential differences are directly related to the field strength. If the potential difference is zero, then the field strength must also be zero.
7. Potential difference is more descriptive because it indicates that it is the difference between the electric potential of two points.
9. They are very similar, but potential difference is a feature of the system; when a charge is introduced to the system, it will have a potential energy which may be calculated by multiplying the magnitude of the charge by the potential difference.
11. An electron-volt is a volt multiplied by the charge of an electron. Volts measure potential difference, electron-volts are a unit of energy.
13. The second has 1/4 the dipole moment of the first.
15. The region outside of the sphere will have a potential indistinguishable from a point charge; the interior of the sphere will have a different potential.
17. No. It will be constant, but not necessarily zero.
19. no
21. No; it might not be at electrostatic equilibrium.
23. Yes. It depends on where the zero reference for potential is. (Though this might be unusual.)
25. So that lightning striking them goes into the ground instead of the television equipment.
27. They both make use of static electricity to stick small particles to another surface. However, the precipitator has to charge a wide variety of particles, and is not designed to make sure they land in a particular place.

PROBLEMS

29. a. $U = 3.4\text{ J}$;

b. $\frac{1}{2}mv^2 = kQ_1Q_2\left(\frac{1}{r_i} - \frac{1}{r_f}\right) \rightarrow v = 750\text{ m/s}$

31. $U = 4.36 \times 10^{-18}\text{ J}$

33. $$\begin{aligned}\frac{1}{2}m_e v_e^2 &= qV, \ \frac{1}{2}m_\text{H} v_\text{H}^2 = qV, \text{ so that} \\ \frac{m_e v_e^2}{m_\text{H} v_\text{H}^2} &= 1 \text{ or } \frac{v_e}{v_\text{H}} = 42.8\end{aligned}$$

35. $1\text{ V} = 1\text{ J/C}; 1\text{ J} = 1\text{ N}\cdot\text{m} \rightarrow 1\text{ V/m} = 1\text{ N/C}$

37. a. $V_{AB} = 3.00\text{ kV}$; b. $V_{AB} = 7.50\text{ kV}$

39. a. $V_{AB} = Ed \rightarrow E = 5.63\text{ kV/m}$;

b. $V_{AB} = 563\text{ V}$

41. a. $$\begin{aligned}\Delta K &= q\Delta V \text{ and } V_{AB} = Ed, \text{ so that} \\ \Delta K &= 800\text{ keV};\end{aligned}$$

b. $d = 25.0\text{ km}$

43. One possibility is to stay at constant radius and go along the arc from P_1 to P_2, which will have zero potential due to the path being perpendicular to the electric field. Then integrate from *a* to *b*: $V_{ab} = \alpha \ln\left(\frac{b}{a}\right)$

45. $V = 144\text{ V}$

47. $V = \frac{kQ}{r} \rightarrow Q = 8.33 \times 10^{-7}\text{ C}$;

The charge is positive because the potential is positive.
49. a. $V = 45.0\text{ MV}$;

b. $V = \frac{kQ}{r} \rightarrow r = 45.0\text{ m}$;

c. $\Delta U = 132\text{ MeV}$

51. $V = kQ/\,r$; a. Relative to origin, find the potential at each point and then calculate the difference.

$\Delta V = 135 \times 10^3\text{ V}$;

b. To double the potential difference, move the point from 20 cm to infinity; the potential at 20 cm is halfway between zero and that at 10 cm.
53. a. $V_{P1} = 7.4 \times 10^5\text{ V}$

and $V_{P2} = 6.9 \times 10^3\text{ V}$;

b. $V_{P1} = 6.9 \times 10^5\text{ V}$ and $V_{P2} = 6.9 \times 10^3\text{ V}$

55. The problem is describing a uniform field, so $E = 200\ \text{V/m}$ in the –*z*-direction.

57. Apply $\vec{\mathbf{E}} = -\vec{\nabla} V$ with $\vec{\nabla} = \hat{\mathbf{r}}\frac{\partial}{\partial r} + \hat{\varphi}\frac{1}{r}\frac{\partial}{\partial \varphi} + \hat{\mathbf{z}}\frac{\partial}{\partial z}$ to the potential calculated earlier, $V = -2k\lambda \ln s$: $\vec{\mathbf{E}} = 2k\lambda\frac{1}{r}\hat{\mathbf{r}}$ as expected.

59. a. decreases; the constant (negative) electric field has this effect, the reference point only matters for magnitude; b. they are planes parallel to the sheet; c. 0.59 m

61. a. from the previous chapter, the electric field has magnitude $\frac{\sigma}{\varepsilon_0}$ in the region between the plates and zero outside; defining the negatively charged plate to be at the origin and zero potential, with the positively charged plate located at $+5\ \text{mm}$ in the *z*-direction, $V = 1.7 \times 10^4\ \text{V}$ so the potential is 0 for $z < 0$, $1.7 \times 10^4\ \text{V}\left(\frac{z}{5\ \text{mm}}\right)$ for $0 \le z \le 5\ \text{mm}, 1.7 \times 10^4\ \text{V}$ for $z > 5\ \text{mm}$;

b. $qV = \frac{1}{2}mv^2 \rightarrow v = 7.7 \times 10^7\ \text{m/s}$

63. $V = 85\ \text{V}$

65. In the region $a \le r \le b$, $\vec{\mathbf{E}} = \frac{kQ}{r^2}\hat{\mathbf{r}}$, and *E* is zero elsewhere; hence, the potential difference is $V = kQ\left(\frac{1}{a} - \frac{1}{b}\right)$.

67. From previous results $V_P - V_R = -2k\lambda \ln\frac{s_P}{s_R}$., note that *b* is a very convenient location to define the zero level of potential: $\Delta V = -2k\frac{Q}{L}\ln\frac{a}{b}$.

69. a. $F = 5.58 \times 10^{-11}\ \text{N/C}$; The electric field is towards the surface of Earth. b. The coulomb force is much stronger than gravity.

71. We know from the Gauss's law chapter that the electric field for an infinite line charge is $\vec{\mathbf{E}}_P = 2k\lambda\frac{1}{s}\hat{\mathbf{s}}$, and from earlier in this chapter that the potential of a wire-cylinder system of this sort is $V_P = -2k\lambda \ln\frac{s_P}{R}$ by integration. We are not given λ, but we are given a fixed V_0; thus, we know that $V_0 = -2k\lambda \ln\frac{a}{R}$ and hence $\lambda = -\frac{V_0}{2k \ln\left(\frac{a}{R}\right)}$. We may substitute this back in to find a. $\vec{\mathbf{E}}_P = -\frac{V_0}{\ln\left(\frac{a}{R}\right)}\frac{1}{s}\hat{\mathbf{s}}$; b. $V_P = V_0\frac{\ln\left(\frac{s_P}{R}\right)}{\ln\left(\frac{a}{R}\right)}$; c. $4.74 \times 10^4\ \text{N/C}$

73. a. $\begin{aligned} U_1 &= -7.68 \times 10^{-18}\ \text{J} \\ U_2 &= -5.76 \times 10^{-18}\ \text{J} \end{aligned}$;

b. $U_1 + U_2 = -1.34 \times 10^{-17}\ \text{J}$

75. a. $U = 2.30 \times 10^{-16}\ \text{J}$;

b. $\bar{K} = \frac{3}{2}kT \rightarrow T = 1.11 \times 10^7\ \text{K}$

77. a. $1.9 \times 10^6\ \text{m/s}$; b. $4.2 \times 10^6\ \text{m/s}$; c. $5.9 \times 10^6\ \text{m/s}$; d. $7.3 \times 10^6\ \text{m/s}$; e. $8.4 \times 10^6\ \text{m/s}$

79. a. $\begin{array}{l} E = 2.5 \times 10^6\ \text{V/m} < 3 \times 10^6\ \text{V/m} \\ \text{No, the field trength is smaller than the breakdown strength for air.} \end{array}$;

b. $d = 1.7\ \text{mm}$

81. $\begin{aligned} K_\text{f} &= qV_\text{AB} = qEd \rightarrow \\ E &= 8.00 \times 10^5\ \text{V/m} \end{aligned}$

83. a. $\text{Energy} = 2.00 \times 10^9\ \text{J}$;

b. $\begin{aligned} Q &= m(c\Delta T + L_\nabla) \\ m &= 766\ \text{kg} \end{aligned}$;

c. The expansion of the steam upon boiling can literally blow the tree apart.

85. a. $V = \frac{kQ}{r} \rightarrow r = 1.80\text{ km}$; b. A 1-C charge is a very large amount of charge; a sphere of 1.80 km is impractical.

87. The alpha particle approaches the gold nucleus until its original energy is converted to potential energy. $5.00\text{ MeV} = 8.00 \times 10^{-13}\text{ J}$, so

$$E_0 = \frac{qkQ}{r} \rightarrow$$
$$r = 4.54 \times 10^{-14}\text{ m}$$

(Size of gold nucleus is about $7 \times 10^{-15}\text{ m}$).

ADDITIONAL PROBLEMS

89.
$$E_{\text{tot}} = 4.67 \times 10^{7}\text{ J}$$
$$E_{\text{tot}} = qV \rightarrow q = \frac{E_{\text{tot}}}{V} = 3.89 \times 10^{6}\text{ C}$$

91. $V_P = k\frac{q_{\text{tot}}}{\sqrt{z^2 + R^2}} \rightarrow q_{\text{tot}} = -3.5 \times 10^{-11}\text{ C}$

93. $V_P = -2.2\text{ GV}$

95. Recall from the previous chapter that the electric field $E_P = \frac{\sigma_0}{2\varepsilon_0}$ is uniform throughout space, and that for uniform fields we have $E = -\frac{\Delta V}{\Delta z}$ for the relation. Thus, we get $\frac{\sigma}{2\varepsilon_0} = \frac{\Delta V}{\Delta z} \rightarrow \Delta z = 0.22\text{ m}$ for the distance between 25-V equipotentials.

97. a. Take the result from **Example 7.13**, divide both the numerator and the denominator by x, take the limit of that, and then apply a Taylor expansion to the resulting log to get: $V_P \approx k\lambda\frac{L}{x}$; b. which is the result we expect, because at great distances, this should look like a point charge of $q = \lambda L$

99. a. $V = 9.0 \times 10^{3}\text{ V}$; b. $-9.0 \times 10^{3}\text{ V}\left(\frac{1.25\text{ cm}}{2.0\text{ cm}}\right) = -5.7 \times 10^{3}\text{ V}$

101. a. $E = \frac{KQ}{r^2} \rightarrow Q = -6.76 \times 10^{5}\text{ C}$;

b.
$$F = ma = qE \rightarrow$$
$$a = \frac{qE}{m} = 2.63 \times 10^{13}\text{ m/s}^2\text{ (upwards)};$$

c. $F = -mg = qE \rightarrow m = \frac{-qE}{g} = 2.45 \times 10^{-18}\text{ kg}$

103. If the electric field is zero ¼ from the way of q_1 and q_2, then we know from

$E = k\frac{Q}{r^2}$ that $|E_1| = |E_2| \rightarrow \frac{Kq_1}{x^2} = \frac{Kq_2}{(3x)^2}$ so that $\frac{q_2}{q_1} = \frac{(3x)^2}{x^2} = 9$; the charge q_2 is 9 times larger than q_1.

105. a. The field is in the direction of the electron's initial velocity.

b.
$$v^2 = v_0^2 + 2ax \rightarrow x = -\frac{v_0^2}{2a}(v = 0). \text{ Also, } F = ma = qE \rightarrow a = \frac{qE}{m},$$
$$x = 3.56 \times 10^{-4}\text{ m};$$

c.
$$v_2 = v_0 + at \rightarrow t = -\frac{v_0 m}{qE}(v = 0),$$
$$\therefore t = 1.42 \times 10^{-10}\text{ s};$$

d. $v = -\left(\frac{2qEx}{m}\right)^{1/2} -5.00 \times 10^{6}\text{ m/s}$ (opposite its initial velocity)

CHALLENGE PROBLEMS

107. Answers will vary. This appears to be proprietary information, and ridiculously difficult to find. Speeds will be 20 m/s or less, and there are claims of $\sim 10^{-7}$ grams for the mass of a drop.

109. Apply $\vec{\mathbf{E}} = -\vec{\nabla} V$ with $\vec{\nabla} = \hat{\mathbf{r}}\frac{\partial}{\partial r} + \hat{\theta}\frac{1}{r}\frac{\partial}{\partial \theta} + \hat{\varphi}\frac{1}{r\sin\theta}\frac{\partial}{\partial \varphi}$ to the potential calculated earlier, $V_P = k\frac{\vec{\mathbf{p}} \cdot \hat{\mathbf{r}}}{r^2}$

with $\vec{\mathbf{p}} = q\vec{\mathbf{d}}$, and assume that the axis of the dipole is aligned with the *z*-axis of the coordinate system. Thus, the potential is $V_P = k\frac{q\vec{\mathbf{d}} \cdot \hat{\mathbf{r}}}{r^2} = k\frac{qd\cos\theta}{r^2}$.

$$\vec{\mathbf{E}} = 2kqd\left(\frac{\cos\theta}{r^3}\right)\hat{\mathbf{r}} + kqd\left(\frac{\sin\theta}{r^3}\right)\hat{\theta}$$

CHAPTER 8

CHECK YOUR UNDERSTANDING

8.1. 1.1×10^{-3} m
8.3. 3.59 cm, 17.98 cm
8.4. a. 25.0 pF; b. 9.2
8.5. a. $C = 0.86\text{ pF}, Q_1 = 10\text{ pC}, Q_2 = 3.4\text{ pC}, Q_3 = 6.8\text{ pC}$;
b. $C = 2.3\text{ pF}, Q_1 = 12\text{ pC}, Q_2 = Q_3 = 16\text{ pC}$;
c. $C = 2.3\text{ pF}, Q_1 = 9.0\text{ pC}, Q_2 = 18\text{ pC}, Q_3 = 12\text{ pC}, Q_4 = 15\text{ pC}$
8.6. a. 4.0×10^{-13} J; b. 9 times
8.7. a. 3.0; b. $C = 3.0\,C_0$
8.9. a. $C_0 = 20\text{ pF}$, $C = 42\text{ pF}$; b. $Q_0 = 0.8\text{ nC}$, $Q = 1.7\text{ nC}$; c. $V_0 = V = 40\text{ V}$; d. $U_0 = 16\text{ nJ}$, $U = 34\text{ nJ}$

CONCEPTUAL QUESTIONS

1. no; yes
3. false
5. no
7. $3.0\ \mu\text{F}, 0.33\ \mu\text{F}$
9. answers may vary
11. Dielectric strength is a critical value of an electrical field above which an insulator starts to conduct; a dielectric constant is the ratio of the electrical field in vacuum to the net electrical field in a material.
13. Water is a good solvent.
15. When energy of thermal motion is large (high temperature), an electrical field must be large too in order to keep electric dipoles aligned with it.
17. answers may vary

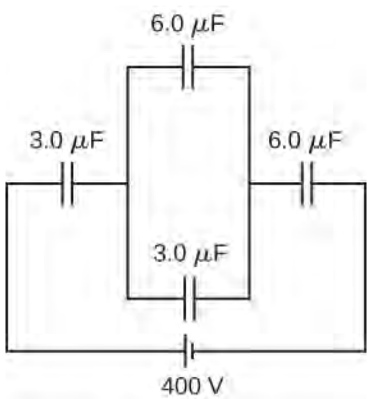
PROBLEMS

19. 21.6 mC
21. 1.55 V
23. 25.0 nF
25. $1.1 \times 10^{-3}\,\text{m}^2$
27. 500 μC
29. 1:16
31. a. 1.07 nC; b. 267 V, 133 V
33. $0.29\ \mu\text{F}$
34. 500 capacitors; connected in parallel
35. $3.08\ \mu\text{F}$ (series) and $13.0\ \mu\text{F}$ (parallel)
37. $11.4\ \mu\text{F}$
39. 0.89 mC; 1.78 mC; 444 V
41. $7.5\ \mu\text{J}$
43. a. 405 J; b. 90.0 mC
45. 1.15 J
47. a. 4.43×10^{-12} F; b. 452 V; c. 4.52×10^{-7} J; d. no
49. 0.7 mJ
51. a. 7.1 pF; b. 42 pF
53. a. before 3.00 V; after 0.600 V; b. before 1500 V/m; after 300 V/m
55. a. 3.91; b. 22.8 V

57. a. 37 nC; b. 0.4 MV/m; c. 19 nC
59. a. $4.4\,\mu\text{F}$; b. 4.0×10^{-5} C
61. $0.0135\ \text{m}^2$
63. $0.185\ \mu\text{J}$

ADDITIONAL PROBLEMS

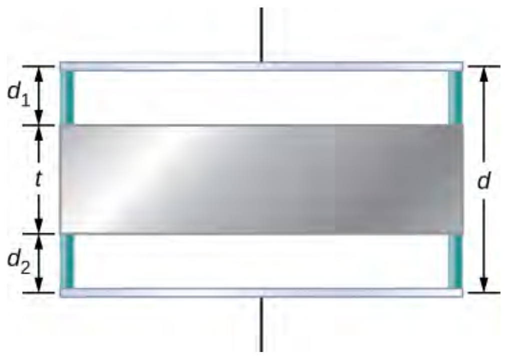
65. a. 0.277 nF; b. 27.7 nC; c. 50 kV/m
67. a. 0.065 F; b. 23,000 C; c. 4.0 GJ
69. a. $75.6\,\mu\text{C}$; b. 10.8 V
71. a. 0.13 J; b. no, because of resistive heating in connecting wires that is always present, but the circuit schematic does not indicate resistors



73. a. $-3.00\,\mu\text{F}$; b. You cannot have a negative C_2 capacitance. c. The assumption that they were hooked up in parallel, rather than in series, is incorrect. A parallel connection always produces a greater capacitance, while here a smaller capacitance was assumed. This could only happen if the capacitors are connected in series.
75. a. 14.2 kV; b. The voltage is unreasonably large, more than 100 times the breakdown voltage of nylon. c. The assumed charge is unreasonably large and cannot be stored in a capacitor of these dimensions.

CHALLENGE PROBLEMS

77. a. 89.6 pF; b. 6.09 kV/m; c. 4.47 kV/m; d. no
79. a. 421 J; b. 53.9 mF
81. $C = \varepsilon_0 A/(d_1 + d_2)$



83. proof

CHAPTER 9

CHECK YOUR UNDERSTANDING

9.1. The time for 1.00 C of charge to flow would be $\Delta t = \frac{\Delta Q}{I} = \frac{1.00\ \text{C}}{0.300 \times 10^{-3}\ \text{C/s}} = 3.33 \times 10^3\ \text{s}$, slightly less than an hour. This is quite different from the 5.55 ms for the truck battery. The calculator takes a very small amount of energy to operate, unlike the truck's starter motor. There are several reasons that vehicles use batteries and not solar cells. Aside from the obvious fact that a light source to run the solar cells for a car or truck is not always available, the large amount of current needed to start the engine cannot easily be supplied by present-day solar cells. Solar cells can possibly be used to charge the batteries. Charging the battery requires a small amount of energy when compared to the energy required to run the engine and the other accessories such as the heater and air conditioner. Present day solar-powered cars are powered by solar panels, which may power an electric motor, instead of an internal combustion engine.

9.2. The total current needed by all the appliances in the living room (a few lamps, a television, and your laptop) draw less current and require less power than the refrigerator.

9.3. The diameter of the 14-gauge wire is smaller than the diameter of the 12-gauge wire. Since the drift velocity is inversely proportional to the cross-sectional area, the drift velocity in the 14-gauge wire is larger than the drift velocity in the 12-gauge wire carrying the same current. The number of electrons per cubic meter will remain constant.

9.4. The current density in a conducting wire increases due to an increase in current. The drift velocity is inversely proportional to the current $\left(v_d = \frac{nqA}{I}\right)$, so the drift velocity would decrease.

9.5. Silver, gold, and aluminum are all used for making wires. All four materials have a high conductivity, silver having the highest. All four can easily be drawn into wires and have a high tensile strength, though not as high as copper. The obvious disadvantage of gold and silver is the cost, but silver and gold wires are used for special applications, such as speaker wires. Gold does not oxidize, making better connections between components. Aluminum wires do have their drawbacks. Aluminum has a higher resistivity than copper, so a larger diameter is needed to match the resistance per length of copper wires, but aluminum is cheaper than copper, so this is not a major drawback. Aluminum wires do not have as high of a ductility and tensile strength as copper, but the ductility and tensile strength is within acceptable levels. There are a few concerns that must be addressed in using aluminum and care must be used when making connections. Aluminum has a higher rate of thermal expansion than copper, which can lead to loose connections and a possible fire hazard. The oxidation of aluminum does not conduct and can cause problems. Special techniques must be used when using aluminum wires and components, such as electrical outlets, must be designed to accept aluminum wires.

9.6. The foil pattern stretches as the backing stretches, and the foil tracks become longer and thinner. Since the resistance is calculated as $R = \rho \frac{L}{A}$, the resistance increases as the foil tracks are stretched. When the temperature changes, so does the resistivity of the foil tracks, changing the resistance. One way to combat this is to use two strain gauges, one used as a reference and the other used to measure the strain. The two strain gauges are kept at a constant temperature

9.7. The longer the length, the smaller the resistance. The greater the resistivity, the higher the resistance. The larger the difference between the outer radius and the inner radius, that is, the greater the ratio between the two, the greater the resistance. If you are attempting to maximize the resistance, the choice of the values for these variables will depend on the application. For example, if the cable must be flexible, the choice of materials may be limited.

9.8. Yes, Ohm's law is still valid. At every point in time the current is equal to $I(t) = V(t)/R$, so the current is also a function of time, $I(t) = \frac{V_{\text{max}}}{R} \sin(2\pi f t)$.

9.9. Even though electric motors are highly efficient 10–20% of the power consumed is wasted, not being used for doing useful work. Most of the 10–20% of the power lost is transferred into heat dissipated by the copper wires used to make the coils of the motor. This heat adds to the heat of the environment and adds to the demand on power plants providing the power. The demand on the power plant can lead to increased greenhouse gases, particularly if the power plant uses coal or gas as fuel.

9.10. No, the efficiency is a very important consideration of the light bulbs, but there are many other considerations. As mentioned above, the cost of the bulbs and the life span of the bulbs are important considerations. For example, CFL bulbs contain mercury, a neurotoxin, and must be disposed of as hazardous waste. When replacing incandescent bulbs that are being controlled by a dimmer switch with LED, the dimmer switch may need to be replaced. The dimmer switches for LED lights are comparably priced to the incandescent light switches, but this is an initial cost which should be considered. The spectrum of light should also be considered, but there is a broad range of color temperatures available, so you should be able to find one that fits your needs. None of these considerations mentioned are meant to discourage the use of LED or CFL light bulbs, but they are considerations.

CONCEPTUAL QUESTIONS

1. If a wire is carrying a current, charges enter the wire from the voltage source's positive terminal and leave at the negative terminal, so the total charge remains zero while the current flows through it.

3. Using one hand will reduce the possibility of "completing the circuit" and having current run through your body, especially current running through your heart.

5. Even though the electrons collide with atoms and other electrons in the wire, they travel from the negative terminal to the positive terminal, so they drift in one direction. Gas molecules travel in completely random directions.

7. In the early years of light bulbs, the bulbs are partially evacuated to reduce the amount of heat conducted through the air to the glass envelope. Dissipating the heat would cool the filament, increasing the amount of energy needed to produce light from the filament. It also protects the glass from the heat produced from the hot filament. If the glass heats, it expands, and as it cools, it contacts. This expansion and contraction could cause the glass to become brittle and crack, reducing the life of the bulbs. Many bulbs are now partially filled with an inert gas. It is also useful to remove the oxygen to reduce the possibility of the filament actually burning. When the original filaments were replaced with more efficient tungsten filaments, atoms from the tungsten would evaporate off the filament at such high temperatures. The atoms collide with the atoms of the inert gas and land back on the filament.

9. In carbon, resistivity increases with the amount of impurities, meaning fewer free charges. In silicon and germanium, impurities decrease resistivity, meaning more free electrons.

11. Copper has a lower resistivity than aluminum, so if length is the same, copper must have the smaller diameter.

13. Device *B* shows a linear relationship and the device is ohmic.

15. Although the conductors have a low resistance, the lines from the power company can be kilometers long. Using a high voltage reduces the current that is required to supply the power demand and that reduces line losses.

17. The resistor would overheat, possibly to the point of causing the resistor to burn. Fuses are commonly added to circuits to prevent such accidents.

19. Very low temperatures necessitate refrigeration. Some materials require liquid nitrogen to cool them below their critical temperatures. Other materials may need liquid helium, which is even more costly.

PROBLEMS

21. a. $v = 4.38 \times 10^5 \frac{\text{m}}{\text{s}}$;

b. $\Delta q = 5.00 \times 10^{-3}\,\text{C}, \quad \text{no. of protons} = 3.13 \times 10^{16}$

23. $I = \frac{\Delta Q}{\Delta t}, \quad \Delta Q = 12.00\,\text{C}$

$\text{no. of electrons} = 7.46 \times 10^{15}$

25.

$$I(t) = 0.016\frac{\text{C}}{\text{s}^4}t^3 - 0.001\frac{\text{C}}{\text{s}}$$

$$I(3.00\,\text{s}) = 0.431\,\text{A}$$

27. $I(t) = -I_{\text{max}}\sin(\omega t + \phi)$

29. $|J| = 15.92\,\text{A/m}^2$

31. $I \;\; = 40\,\text{mA}$

33. a. $|J| = 7.60 \times 10^5 \frac{\text{A}}{\text{m}^2}$; b. $v_\text{d} = 5.60 \times 10^{-5} \frac{\text{m}}{\text{s}}$

35. $R = 6.750\,\text{k}\,\Omega$

37. $R = 0.10\,\Omega$

39.

$$R = \rho\frac{L}{A}$$

$$L = 3\,\text{mm}$$

41.

$$\frac{\frac{R_\text{Al}}{L_\text{Al}}}{\frac{R_\text{Cu}}{L_\text{Cu}}} = \frac{\rho_\text{Al}\frac{1}{\pi\left(\frac{D_\text{Al}}{2}\right)^2}}{\rho_\text{Cu}\frac{1}{\pi\left(\frac{D_\text{Cu}}{2}\right)^2}} = \frac{\rho_\text{Al}}{\rho_\text{Cu}}\left(\frac{D_\text{Cu}}{D_\text{Al}}\right)^2 = 1, \quad \frac{D_\text{Al}}{D_\text{Cu}} = \sqrt{\frac{\rho_\text{Al}}{\rho_{Cu}}}$$

43. a. $R = R_0(1 + \alpha\Delta T), \quad 2 = 1 + \alpha\Delta T, \quad \Delta T = 256.4\,°\text{C}, \quad T = 276.4\,°\text{C}$;

b. Under normal conditions, no it should not occur.

45.

$$R \;=\; R_0(1 + \alpha\Delta T)$$

$$\alpha \;= 0.006\,°\text{C}^{-1}$$, iron

47. a. $R = \rho\frac{L}{A}, \quad \rho = 2.44 \times 10^{-8}\,\Omega \cdot \text{m}$, gold;

b.

$$R = \rho\frac{L}{A}(1 + \alpha\Delta T)$$

$$R = 2.44 \times 10^{-8}\,\Omega \cdot \text{m}\left(\frac{25\,\text{m}}{\pi\left(\frac{0.100 \times 10^{-3}\,\text{m}}{2}\right)^2}\right)\left(1 + 0.0034\,°\text{C}^{-1}(150\,°\text{C} - 20\,°\text{C})\right)$$

$$R = 112\,\Omega$$

49.
$$R_{\text{Fe}} = 0.525\,\Omega\,, \quad R_{\text{Cu}} = 0.500\,\Omega\,, \quad \alpha_{\text{Fe}} = 0.0065\,°\text{C}^{-1} \quad \alpha_{\text{Cu}} = 0.0039\,°\text{C}^{-1}$$
$$R_{\text{Fe}} = R_{\text{Cu}}$$
$$R_{0\,\text{Fe}}\left(1 + \alpha_{\text{Fe}}(T - T_0)\right) = R_{0\,\text{Cu}}\left(1 + \alpha_{\text{Cu}}(T - T_0)\right)$$
$$\frac{R_{0\,\text{Fe}}}{R_{0\,\text{Cu}}}\left(1 + \alpha_{\text{Fe}}(T - T_0)\right) = 1 + \alpha_{\text{Cu}}(T - T_0)$$
$$T = 2.91\,°\text{C}$$

51.
$$R_{\text{min}} = 2.375 \times 10^5\ \Omega\,, \quad I_{\text{min}} = 12.63\,\mu\,\text{A}$$
$$R_{\text{max}} = 2.625 \times 10^5\ \Omega\,, \quad I_{\text{max}} = 11.43\,\mu\,\text{A}$$

53. $R = 100\,\Omega$

55. a. $I = 0.30\,\text{mA}$; b. $P = 0.90\,\text{mW}$; c. $P = 0.90\,\text{mW}$; d. It is converted into heat.

57.
$$P = \frac{V^2}{R}, \quad R = 40\,\Omega$$
$$A = 2.08\text{mm}^2, \quad \rho = 100 \times 10^{-8}\ \Omega \cdot \text{m}, \quad R = \rho\frac{L}{A}, \quad L = 83\ \text{m}$$

59. $I = 0.1\ \text{A}, \quad V = 14\ \text{V}$

$$I \approx 3.00\ \text{A} + \frac{100\ \text{W}}{110\ \text{V}} + \frac{60\ \text{W}}{110\ \text{V}} + \frac{3.00\ \text{W}}{110\ \text{V}} = 4.48\ \text{A}$$

61. a.
$$P = 493\ \text{W}$$
$$R = 9.91\,\Omega\,,$$
$$P_{\text{loss}} = 200.\ \text{W}$$
$$\%\text{loss} = 40\%$$

b.
$$P = 493\ \text{W}$$
$$I = 0.0045\ \text{A}$$
$$R = 9.91\,\Omega$$
$$P_{\text{loss}} = 201\mu\,\text{W}$$
$$\%\text{loss} = 0.00004\%$$

63. $R_{\text{copper}} = 0.24\,\Omega$

$$P = 2.377 \times 10^3\,\text{W}$$

65.
$$R = R_0\left(1 + \alpha(T - T_0)\right)$$
$$0.82R_0 = R_0\left(1 + \alpha(T - T_0)\right), \quad 0.82 = 1 - 0.06(T - 37\,°\text{C}), \quad T = 40\,°\text{C}$$

67. a. $R_{\text{Au}} = R_{\text{Ag}}, \quad \rho_{\text{Au}}\dfrac{L_{\text{Au}}}{A_{\text{Au}}} = \rho_{\text{Ag}}\dfrac{L_{\text{Ag}}}{A_{\text{Ag}}}, \quad L_{\text{Ag}} = 1.53\ \text{m}$;

b. $R_{\text{Au,20 °C}} = 0.0074\,\Omega\,, \quad R_{\text{Au,100 °C}} = 0.0094\,\Omega\,, \quad R_{\text{Ag, 100 °C}} = 0.0096\,\Omega$

ADDITIONAL PROBLEMS

69.
$$dR = \frac{\rho}{2\pi rL}dr$$
$$R = \frac{\rho}{2\pi L}\ln\frac{r_{\text{o}}}{r_{\text{i}}}$$
$$R = 2.21 \times 10^{11}\ \Omega$$

71. a.

$R_0 = 3.00 \times 10^6\ \Omega$; b.

$$T_{\text{c}} = 37.0\,°\text{C}$$
$$R = 3.02 \times 10^{-6}\ \Omega$$

73. $\rho = 5.00 \times 10^{-8}\ \Omega \cdot \text{m}$

75. $\rho = 1.71 \times 10^{-8}\ \Omega \cdot \text{m}$

77. a. $V = 6000\ \text{V}$; b. $V = 60\ \text{V}$

79. $P = \frac{W}{t}, \quad W = 8.64\ \text{J}$

CHALLENGE PROBLEMS

81. $V = 7.09\ \text{cm}^3$
$n = 8.49 \times 10^{28} \frac{\text{electrons}}{\text{m}^2}$
$v_\text{d} = 7.00 \times 10^{-5} \frac{\text{m}}{\text{s}}$

83. a. $v = 5.83 \times 10^{13}\ \frac{\text{protons}}{\text{m}^3}$

85. $E = 75\ \text{kJ}$

87. a. $P = 52\ \text{W}$; b. $V = 43.54\ \text{V}$
$R = 36\ \Omega$

89. a. $R = \frac{\rho}{2\pi L}\ln\left(\frac{R_0}{R_i}\right)$; b. $R = 2.5\ \text{m}\,\Omega$

91. a. $I = 8.69\ \text{A}$; b. $\#\ \text{electrons} = 2.61 \times 10^{25}$; c. $R = 13.23\ \Omega$; d. $q = 4.68 \times 10^6\ \text{J}$

93. $P = 1045\ \text{W}, \quad P = \frac{V^2}{R}, \quad R = 12.27\ \Omega$

CHAPTER 10

CHECK YOUR UNDERSTANDING

10.1. If a wire is connected across the terminals, the load resistance is close to zero, or at least considerably less than the internal resistance of the battery. Since the internal resistance is small, the current through the circuit will be large, $I = \frac{\varepsilon}{R + r} = \frac{\varepsilon}{0 + r} = \frac{\varepsilon}{r}.$ The large current causes a high power to be dissipated by the internal resistance $\left(P = I^2 r\right)$. The power is dissipated as heat.

10.2. The equivalent resistance of nine bulbs connected in series is 9*R*. The current is $I = V/9\,R.$ If one bulb burns out, the equivalent resistance is 8*R*, and the voltage does not change, but the current increases $(I = V/8\,R).$ As more bulbs burn out, the current becomes even higher. Eventually, the current becomes too high, burning out the shunt.

10.3. The equivalent of the series circuit would be $R_\text{eq} = 1.00\,\Omega + 2.00\,\Omega + 2.00\,\Omega = 5.00\,\Omega,$ which is higher than the equivalent resistance of the parallel circuit $R_\text{eq} = 0.50\,\Omega.$ The equivalent resistor of any number of resistors is always higher than the equivalent resistance of the same resistors connected in parallel. The current through for the series circuit would be $I = \frac{3.00\ \text{V}}{5.00\ \Omega} = 0.60\ \text{A},$ which is lower than the sum of the currents through each resistor in the parallel circuit, $I = 6.00\ \text{A}.$
This is not surprising since the equivalent resistance of the series circuit is higher. The current through a series connection of any number of resistors will always be lower than the current into a parallel connection of the same resistors, since the equivalent resistance of the series circuit will be higher than the parallel circuit. The power dissipated by the resistors in series would be $P = 1.80\ \text{W},$ which is lower than the power dissipated in the parallel circuit $P = 18.00\ \text{W}.$

10.4. A river, flowing horizontally at a constant rate, splits in two and flows over two waterfalls. The water molecules are analogous to the electrons in the parallel circuits. The number of water molecules that flow in the river and falls must be equal to the number of molecules that flow over each waterfall, just like sum of the current through each resistor must be equal to the current flowing into the parallel circuit. The water molecules in the river have energy due to their motion and height. The potential energy of the water molecules in the river is constant due to their equal heights. This is analogous to the constant change in voltage across a parallel circuit. Voltage is the potential energy across each resistor.
The analogy quickly breaks down when considering the energy. In the waterfall, the potential energy is converted into kinetic energy of the water molecules. In the case of electrons flowing through a resistor, the potential drop is converted into heat and light, not into the kinetic energy of the electrons.

10.5. 1. All the overhead lighting circuits are in parallel and connected to the main supply line, so when one bulb burns out, all the overhead lighting does not go dark. Each overhead light will have at least one switch in series with the light, so you can turn it on and off. 2. A refrigerator has a compressor and a light that goes on when the door opens. There is usually only one cord for the refrigerator to plug into the wall. The circuit containing the compressor and the circuit containing the lighting circuit are in parallel, but there is a switch in series with the light. A thermostat controls a switch that is in series with the compressor to control the temperature of the refrigerator.

10.6. The circuit can be analyzed using Kirchhoff's loop rule. The first voltage source supplies power: $P_{\text{in}} = IV_1 = 7.20\,\text{mW}.$ The second voltage source consumes power: $P_{\text{out}} = IV_2 + I^2R_1 + I^2R_2 = 7.2\,\text{mW}.$

10.7. The current calculated would be equal to $I = -0.20\text{ A}$ instead of $I = 0.20\text{ A}.$ The sum of the power dissipated and the power consumed would still equal the power supplied.

10.8. Since digital meters require less current than analog meters, they alter the circuit less than analog meters. Their resistance as a voltmeter can be far greater than an analog meter, and their resistance as an ammeter can be far less than an analog meter. Consult **Figure 10.36** and **Figure 10.35** and their discussion in the text.

CONCEPTUAL QUESTIONS

1. Some of the energy being used to recharge the battery will be dissipated as heat by the internal resistance.

3.

$$P = I^2R = \left(\frac{\varepsilon}{r+R}\right)^2 R = \varepsilon^2 R(r+R)^{-2}, \quad \frac{dP}{dR} = \varepsilon^2\left[(r+R)^{-2} - 2R(r+R)^{-3}\right] = 0,$$

$$\left[\frac{(r+R) - 2R}{(r+R)^3}\right] = 0, \quad r = R$$

5. It would probably be better to be in series because the current will be less than if it were in parallel.

7. two filaments, a low resistance and a high resistance, connected in parallel

9. It can be redrawn.

$$R_{\text{eq}} = \left[\frac{1}{R_6} + \frac{1}{R_1} + \frac{1}{R_2 + \left(\frac{1}{R_4} + \frac{1}{R_3 + R_5}\right)^{-1}}\right]^{-1}$$

11. In series the voltages add, but so do the internal resistances, because the internal resistances are in series. In parallel, the terminal voltage is the same, but the equivalent internal resistance is smaller than the smallest individual internal resistance and a higher current can be provided.

13. The voltmeter would put a large resistance in series with the circuit, significantly changing the circuit. It would probably give a reading, but it would be meaningless.

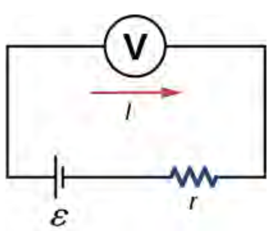
15. The ammeter has a small resistance; therefore, a large current will be produced and could damage the meter and/or overheat the battery.

17. The time constant can be shortened by using a smaller resistor and/or a smaller capacitor. Care should be taken when reducing the resistance because the initial current will increase as the resistance decreases.

19. Not only might water drip into the switch and cause a shock, but also the resistance of your body is lower when you are wet.

PROBLEMS

21. a.



b. 0.476W; c. 0.691 W; d. As R_L is lowered, the power difference decreases; therefore, at higher volumes, there is no significant difference.

23. a. $0.400\,\Omega$; b. No, there is only one independent equation, so only *r* can be found.

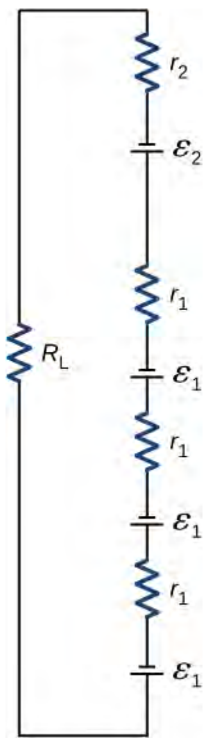
25. a. $0.400\,\Omega$; b. 40.0 W; c. $0.0956\,°\text{C/min}$

27. largest, $786\,\Omega$, smallest, $20.32\,\Omega$

29. 29.6 W

31. a. 0.74 A; b. 0.742 A

33. a. 60.8 W; b. 3.18 kW
35. a. $R_s = 9.00\,\Omega$; b. $I_1 = I_2 = I_3 = 2.00\text{ A}$;
c. $V_1 = 8.00\text{ V},\ V_2 = 2.00\text{ V},\ V_3 = 8.00\text{ V}$; d. $P_1 = 16.00\text{ W},\ P_2 = 4.00\text{ W},\ P_3 = 16.00\text{ W}$; e. $P = 36.00\text{ W}$
37. a. $I_1 = 0.6\text{ mA},\quad I_2 = 0.4\text{ mA},\quad I_3 = 0.2\text{ mA}$;
b. $I_1 = 0.04\text{ mA},\quad I_2 = 1.52\text{ mA},\quad I_3 = -1.48\text{ mA}$; c. $P_{\text{out}} = 0.92\text{ mW},\quad P_{\text{out}} = 4.50\text{ mW}$;
d. $P_{\text{in}} = 0.92\text{ mW},\quad P_{\text{in}} = 4.50\text{ mW}$
39. $V_1 = 42\text{ V},\ V_2 = 6\text{ V},\ R_4 = 6\,\Omega$
41. a. $I_1 = 1.5\text{ A},\ I_2 = 2\text{ A},\ I_3 = 0.5\text{ A},\ I_4 = 2.5\text{ A},\ I_5 = 2\text{ A}$; b. $P_{\text{in}} = I_2V_1 + I_5V_5 = 34\text{ W}$;
c. $P_{\text{out}} = I_1^2R_1 + I_2^2R_2 + I_3^2R_3 + I_4^2R_4 = 34\text{ W}$
43. $I_1 = \frac{3}{5}\frac{V}{R},\ I_2 = \frac{2}{5}\frac{V}{R},\ I_3 = \frac{1}{5}\frac{V}{R}$
45. a.



;
b. 0.617 A; c. 3.81 W; d. $18.0\,\Omega$
47. $I_1r_1 - \varepsilon_1 + I_1R_4 + \varepsilon_4 + I_2r_4 + I_4r_3 - \varepsilon_3 + I_2R_3 + I_1R_1 = 0$
49. $4.00\text{ to }30.0\text{ M}\Omega$
51. a. $2.50\,\mu\text{F}$; b. 2.00 s
53. a. 12.3 mA; b. $7.50 \times 10^{-4}\text{ s}$; c. 4.53 mA; d. 3.89 V
55. a. $1.00 \times 10^{-7}\text{ F}$; b. No, in practice it would not be difficult to limit the capacitance to less than 100 nF, since typical capacitors range from fractions of a picofarad (pF) to milifarad (mF).
57. $3.33 \times 10^{-3}\ \Omega$
59. 12.0 V
61. 400 V
63. a. 6.00 mV; b. It would not be necessary to take extra precautions regarding the power coming from the wall. However, it is possible to generate voltages of approximately this value from static charge built up on gloves, for instance, so some precautions are necessary.
65. a. $5.00 \times 10^{-2}\text{ C}$; b. 10.0 kV; c. $1.00\text{ k}\Omega$; d. $1.79 \times 10^{-2}\ ^\circ\text{C}$

ADDITIONAL PROBLEMS

67. a. $C_{eq} = 4.00\ \text{mF}$; b. $\tau = 80\ \text{ms}$; c. 55.45 ms

69. a. $R_{eq} = 20.00\ \Omega$;

b. $I_r = 1.50\ \text{A},\ I_1 = 1.00\ \text{A},\ I_2 = 0.50\ \text{A},\ I_3 = 0.75\ \text{A},\ I_4 = 0.75\ \text{A},\ I_5 = 1.50\ \text{A}$;

c. $V_r = 1.50\ \text{V},\ V_1 = 9.00\ \text{V},\ V_2 = 9.00\ \text{V},\ V_3 = 7.50\ \text{V},\ V_4 = 7.50\ \text{V},\ V_5 = 12.00\ \text{V}$;

d. $P_r = 2.25\ \text{W},\ P_1 = 9.00\ \text{W},\ P_2 = 4.50\ \text{W},\ P_3 = 5.625\ \text{W},\ P_4 = 5.625\ \text{W},\ P_5 = 18.00\ \text{W}$;

e. $P = 45.00\ \text{W}$

71. a. $\tau = \left(\left(1.38 \times 10^{-5}\,\frac{\Omega}{\text{m}}\left(\frac{5.00 \times 10^{-2}\ \text{m}}{3.14\left(\frac{0.05 \times 10^{-3}}{2}\right)^2}\right)\right)10 \times 10^{-3}\ \text{F} = 3.52\ \text{s}\right)$; b. $V = 0.017\ \text{A}\left(e^{-\frac{1.00\ \text{s}}{3.52\ \text{s}}}\right)351.59\ \Omega = 4.55\ \text{V}$

73. a. $t = \frac{3\ \text{A}\cdot\text{h}}{\frac{1.5\ \text{V}}{900\ \Omega}} = 1800\ \text{h}$; b. $t = \frac{3\ \text{A}\cdot\text{h}}{\frac{1.5\ \text{V}}{100\ \Omega}} = 200\ \text{h}$

75. $U_1 = C_1 V_1^2 = 0.16\text{J},\quad U_2 = C_2 V_2^2 = 0.075\ \text{J}$

77. a. $R_{eq} = 24.00\ \Omega$; b. $I_1 = 1.00\ \text{A},\ I_2 = 0.67\ \text{A},\ I_3 = 0.33\ \text{A},\ I_4 = 1.00\ \text{A}$;

c. $V_1 = 14.00\ \text{V},\ V_2 = 6.00\ \text{V},\ V_3 = 6.00\ \text{V},\ V_4 = 4.00\ \text{V}$;

d. $P_1 = 14.00\ \text{W},\ P_2 = 4.04\ \text{W},\ P_3 = 1.96\ \text{W},\ P_4 = 4.00\ \text{W}$; e. $P = 24.00\ \text{W}$

79. a. $R_{eq} = 12.00\ \Omega,\ I = 1.00\ \text{A}$; b. $R_{eq} = 12.00\ \Omega,\ I = 1.00\ \text{A}$

81. a. $-400\ \text{k}\Omega$; b. You cannot have negative resistance. c. The assumption that $R_{eq} < R_1$ is unreasonable. Series resistance is always greater than any of the individual resistances.

83. $E_2 - I_2 r_2 - I_2 R_2 + I_1 R_5 + I_1 r_1 - E_1 + I_1 R_1 = 0$

85. a. $I = 1.17\ \text{A},\ I_1 = 0.50\ \text{A},\ I_2 = 0.67\ \text{A},\ I_3 = 0.67\ \text{A},\ I_4 = 0.50\ \text{A},\ I_5 = 0.17\ \text{A}$;

b. $P_{output} = 23.4\ \text{W},\ P_{input} = 23.4\ \text{W}$

87. a. 4.99 s; b. $3.87\ °\text{C}$; c. $3.11 \times 10^4\ \Omega$; d. No, this change does not seem significant. It probably would not be noticed.

CHALLENGE PROBLEMS

89. a. 0.273 A; b. $V_T = 1.36\ \text{V}$

91. a. $V_s = V - I_M R_M = 9.99875\ \text{V}$; b. $R_S = \frac{V_P}{I_M} = 199.975\ \text{k}\Omega$

93. a. $\tau = 3800\ \text{s}$; b. 1.26 A; c. $t = 2633.96\ \text{s}$

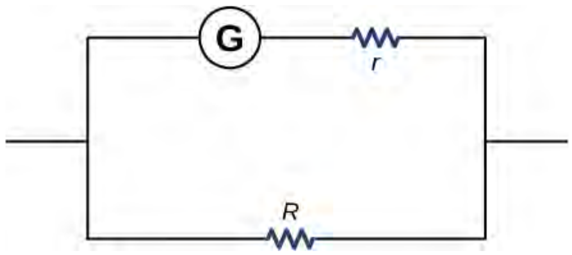
95. $R_{eq} = \left(1 + \sqrt{3}\right)R$

97. a. $P_{imheater} = \frac{1\text{cup}\left(\frac{0.000237\ \text{m}^3}{\text{cup}}\right)\left(\frac{1000\ \text{kg}}{\text{m}^3}\right)\left(4186\frac{\text{J}}{\text{kg}\ °\text{C}}\right)(100\ °\text{C} - 20\ °\text{C})}{180.00\ \text{s}} \approx 441\ \text{W}$;

b. $I = \frac{441\ \text{W}}{120\ \text{V}} + 4\left(\frac{100\ \text{W}}{120\ \text{V}}\right) + \frac{1500\ \text{W}}{120\ \text{V}} = 19.51\ \text{A}$; Yes, the breaker will trip.

c. $I = \frac{441\ \text{W}}{120\ \text{V}} + 4\left(\frac{18\ \text{W}}{120\ \text{V}}\right) + \frac{1500\ \text{W}}{120\ \text{V}} = 13.47\ \text{A}$; No, the breaker will not trip.

99.



,

$2.40 \times 10^{-3}\ \Omega$

CHAPTER 11

CHECK YOUR UNDERSTANDING

11.1. a. 0 N; b. $2.4 \times 10^{-14}\ \hat{\mathbf{k}}\text{N};$ c. $2.4 \times 10^{-14}\ \hat{\mathbf{j}}\ \text{N};$ d. $(7.2\hat{\mathbf{j}} + 2.2\hat{\mathbf{k}}) \times 10^{-15}\,\text{N}$

11.2. a. $9.6 \times 10^{-12}\,\text{N}$ toward the south; b. $\frac{w}{F_\text{m}} = 1.7 \times 10^{-15}$

11.3. a. bends upward; b. bends downward
11.4. a. aligned or anti-aligned; b. perpendicular
11.5. a. 1.1 T; b. 1.6 T
11.6. 0.32 m

CONCEPTUAL QUESTIONS

1. Both are field dependent. Electrical force is dependent on charge, whereas magnetic force is dependent on current or rate of charge flow.
3. The magnitude of the proton and electron magnetic forces are the same since they have the same amount of charge. The direction of these forces however are opposite of each other. The accelerations are opposite in direction and the electron has a larger acceleration than the proton due to its smaller mass.
5. The magnetic field must point parallel or anti-parallel to the velocity.
7. A compass points toward the north pole of an electromagnet.
9. Velocity and magnetic field can be set together in any direction. If there is a force, the velocity is perpendicular to it. The magnetic field is also perpendicular to the force if it exists.
11. A force on a wire is exerted by an external magnetic field created by a wire or another magnet.
13. Poor conductors have a lower charge carrier density, *n*, which, based on the Hall effect formula, relates to a higher Hall potential. Good conductors have a higher charge carrier density, thereby a lower Hall potential.

PROBLEMS

15. a. left; b. into the page; c. up the page; d. no force; e. right; f. down
17. a. right; b. into the page; c. down
19. a. into the page; b. left; c. out of the page
21. a. $2.64 \times 10^{-8}\ \text{N};$ b. The force is very small, so this implies that the effect of static charges on airplanes is negligible.
23. $10.1°;\ 169.9°$
25. 4.27 m
27. a. $4.80 \times 10^{-19}\ \text{C};$ b. 3; c. This ratio must be an integer because charges must be integer numbers of the basic charge of an electron. There are no free charges with values less than this basic charge, and all charges are integer multiples of this basic charge.
29. a. $4.09 \times 10^{3}\ \text{m/s};$ b. $7.83 \times 10^{3}\ \text{m};$ c. $1.75 \times 10^{5}\ \text{m/s},$ then, $1.83 \times 10^{2}\ \text{m};$ d. $4.27\,\text{m}$
31. a. $1.8 \times 10^{7}\,\text{m/s};$ b. $6.8 \times 10^{6}\,\text{eV};$ c. $6.8 \times 10^{6}\,\text{V}$
33. a. left; b. into the page; c. up; d. no force; e. right; f. down
35. a. into the page; b. left; c. out of the page
37. a. 2.50 N; b. This means that the light-rail power lines must be attached in order not to be moved by the force caused by Earth's magnetic field.
39. a. $\tau = NIAB,$ so τ decreases by 5.00% if *B* decreases by 5.00%; b. 5.26% increase
41. 10.0 A

43. $\text{A} \cdot \text{m}^2 \cdot \text{T} = \text{A} \cdot \text{m}^2 . \frac{\text{N}}{\text{A} \cdot \text{m}} = \text{N} \cdot \text{m}$

45. 3.48×10^{-26} N · m

47. 0.666 N · m

49. 5.8×10^{-7} V

51. 4.8×10^{7} C/kg

53. a. 4.4×10^{-8} s; b. 0.21 m

55. a. 1.8×10^{-12} J; b. 11.5 MeV; c. 11.5 MV; d. 5.2×10^{-8} s; e. 0.45×10^{-12} J, 2.88 MeV, 2.88 V, 10.4×10^{-8} s

57. a. 2.50×10^{-2} m; b. Yes, this distance between their paths is clearly big enough to separate the U-235 from the U-238, since it is a distance of 2.5 cm.

ADDITIONAL PROBLEMS

59. $-7.2 \times 10^{-15}\,\text{N}\,\hat{\mathbf{j}}$

61. $9.8 \times 10^{-5}\,\hat{\mathbf{j}}\,\text{T}$; the magnetic and gravitational forces must balance to maintain dynamic equilibrium

63. 1.13×10^{-3} T

65. $(1.6\,\hat{\mathbf{i}} - 1.4\,\hat{\mathbf{j}} - 1.1\,\hat{\mathbf{k}}) \times 10^{5}$ V/m

67. a. circular motion in a north, down plane; b. $(1.61\,\hat{\mathbf{j}} - 0.58\,\hat{\mathbf{k}}) \times 10^{-14}$ N

69. The proton has more mass than the electron; therefore, its radius and period will be larger.

71. 1.3×10^{-25} kg

73. 1:0.707:1

75. 1/4

77. a. 2.3×10^{-4} m; b. 1.37×10^{-4} T

79. a. $30.0°$; b. 4.80 N

81. a. 0.283 N; b. 0.4 N; c. 0 N; d. 0 N

83. 0 N and 0.010 Nm

85. a. $0.31\ \text{Am}^2$; b. 0.16 Nm

87. $0.024\ \text{Am}^2$

89. a. $0.16\ \text{Am}^2$; b. 0.016 Nm; c. 0.028 J

91. (Proof)

93. 4.65×10^{-7} V

95. Since $E = Blv$, where the width is twice the radius, $I = 2r$, $I = nqAv_d$,

$$v_{\text{d}} = \frac{I}{nqA} = \frac{I}{nq\pi r^2} \text{ so } E = B \times 2r \times \frac{\text{I}}{nq\pi r^2} = \frac{2IB}{nq\pi r} \propto \frac{1}{r} \propto \frac{1}{d}.$$

The Hall voltage is inversely proportional to the diameter of the wire.

97. 6.92×10^{7} m/s; 0.602 m

99. a. 2.4×10^{-19} C; b. not an integer multiple of e; c. need to assume all charges have multiples of e, could be other forces not accounted for

101. a. B = 5 T; b. very large magnet; c. applying such a large voltage

CHALLENGE PROBLEMS

103. $R = (mv\sin\theta)/qB$; $p = \left(\frac{2\pi m}{eB}\right)v\cos\theta$

105. $IaL^2/2$

107. $m = \frac{qB_0{}^2}{8V_{\text{acc}}}x^2$

109. 0.01 N

CHAPTER 12

CHECK YOUR UNDERSTANDING

12.1. 1.41 meters

12.2. $\frac{\mu_0 I}{2R}$

12.3. 4 amps flowing out of the page

12.4. Both have a force per unit length of 9.23×10^{-12} N/m

12.5. 0.608 meters

12.6. In these cases the integrals around the Ampèrian loop are very difficult because there is no symmetry, so this method would not be useful.

12.7. a. 1.00382; b. 1.00015

12.8. a. 1.0×10^{-4} T; b. 0.60 T; c. 6.0×10^{3}

CONCEPTUAL QUESTIONS

1. Biot-Savart law's advantage is that it works with any magnetic field produced by a current loop. The disadvantage is that it can take a long time.

3. If you were to go to the start of a line segment and calculate the angle θ to be approximately $0°$, the wire can be considered infinite. This judgment is based also on the precision you need in the result.

5. You would make sure the currents flow perpendicular to one another.

7. A magnetic field line gives the direction of the magnetic field at any point in space. The density of magnetic field lines indicates the strength of the magnetic field.

9. The spring reduces in length since each coil with have a north pole-produced magnetic field next to a south pole of the next coil.

11. Ampère's law is valid for all closed paths, but it is not useful for calculating fields when the magnetic field produced lacks symmetry that can be exploited by a suitable choice of path.

13. If there is no current inside the loop, there is no magnetic field (see Ampère's law). Outside the pipe, there may be an enclosed current through the copper pipe, so the magnetic field may not be zero outside the pipe.

15. The bar magnet will then become two magnets, each with their own north and south poles. There are no magnetic monopoles or single pole magnets.

PROBLEMS

17. 1×10^{-8} T

19. $B = \frac{\mu_o I}{8}\left(\frac{1}{a} - \frac{1}{b}\right)$ out of the page

21. $a = \frac{2R}{\pi}$; the current in the wire to the right must flow up the page.

23. 20 A

25. Both answers have the magnitude of magnetic field of 4.5×10^{-5} T.

27. At P1, the net magnetic field is zero. At P2, $B = \frac{3\mu_o I}{8\pi a}$ into the page.

29. The magnetic field is at a minimum at distance *a* from the top wire, or half-way between the wires.

31. a. $F/l = 2 \times 10^{-5}$ N/m away from the other wire; b. $F/l = 2 \times 10^{-5}$ N/m toward the other wire

33. $B = \frac{\mu_o I a}{2\pi b^2}$ into the page

35. 0.019 m

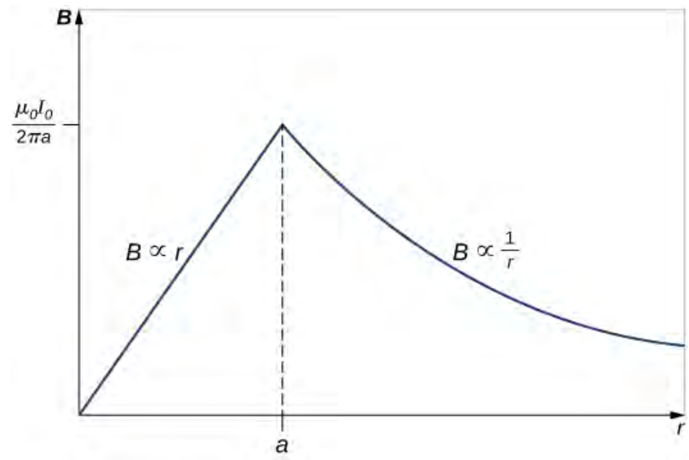
37. 6.28×10^{-5} T

39. $$B = \frac{\mu_o I R^2}{\left(\left(\frac{d}{2}\right)^2 + R^2\right)^{3/2}}$$

41. a. $\mu_0 I$; b. 0; c. $\mu_0 I$; d. 0

43. a. $3\mu_0 I$; b. 0; c. $7\mu_0 I$; d. $-2\mu_0 I$

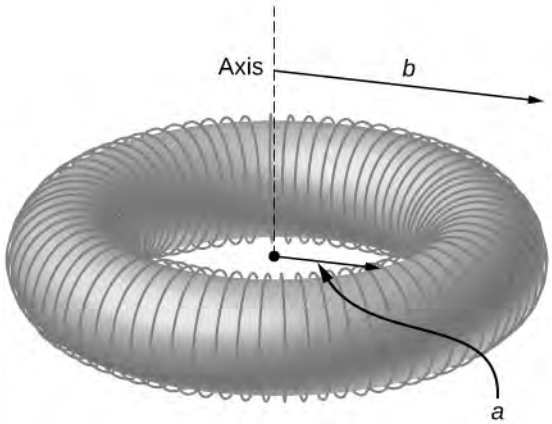
45. at the radius *R*



47.
49. $B = 1.3 \times 10^{-2}\,\text{T}$
51. roughly eight turns per cm
53. $B = \frac{1}{2}\mu_0 nI$
55. 0.0181 A
57. 0.0008 T
59. 317.31
61. $2.1 \times 10^{-4}\,\text{A} \cdot \text{m}^2$
2.7 A
63. 0.18 T

ADDITIONAL PROBLEMS

65. $B = 6.93 \times 10^{-5}\,\text{T}$
67. $3.2 \times 10^{-19}\,N$ in an arc away from the wire
69. a. above and below $B = \mu_0 j,$ in the middle $B = 0;$ b. above and below $B = 0,$ in the middle $B = \mu_0 j$
71. $\frac{dB}{B} = -\frac{dr}{r}$
73. a. 52778 turns; b. 0.10 T
75. $B_1(x) = \frac{\mu_0 IR^2}{2\left(R^2 + z^2\right)^{3/2}}$
77. $B = \frac{\mu_0 \sigma\omega}{2}R$
79. derivation
81. derivation
83. As the radial distance goes to infinity, the magnetic fields of each of these formulae go to zero.
85. a. $B = \frac{\mu_0 I}{2\pi r}$; b. $B = \frac{\mu_0 J_0 r^2}{3R}$
87. $B(r) = \mu_0 NI/2\pi r$



CHALLENGE PROBLEMS

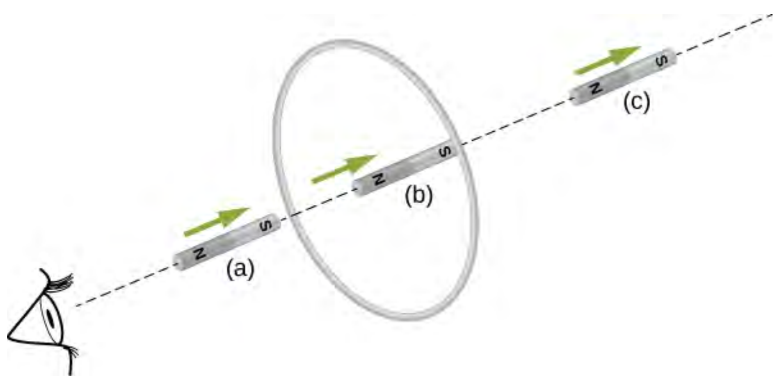
89. $B = \frac{\mu_0 I}{2\pi x}$.

91. a. $B = \frac{\mu_0 \sigma\omega}{2}\left[\frac{2h^2 + R^2}{\sqrt{R^2 + h^2}} - 2h\right]$; b. $B = 4.09 \times 10^{-5}\,\text{T}$, 82% of Earth's magnetic field

CHAPTER 13

CHECK YOUR UNDERSTANDING

13.1. 1.1 T/s
13.2. To the observer shown, the current flows clockwise as the magnet approaches, decreases to zero when the magnet is centered in the plane of the coil, and then flows counterclockwise as the magnet leaves the coil.



13.4. $\varepsilon = Bl^2\omega/2$, with O at a higher potential than S

13.5. 1.5 V

13.6. a. yes; b. Yes; however there is a lack of symmetry between the electric field and coil, making $\oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{l}}$ a more complicated relationship that can't be simplified as shown in the example.
13.7. 3.4×10^{-3} V/m

13.8. P_1, P_2, P_4

13.9. a. $3.1 \times 10^{-6}\,\text{V}$; b. 2.0×10^{-7} V/m

CONCEPTUAL QUESTIONS

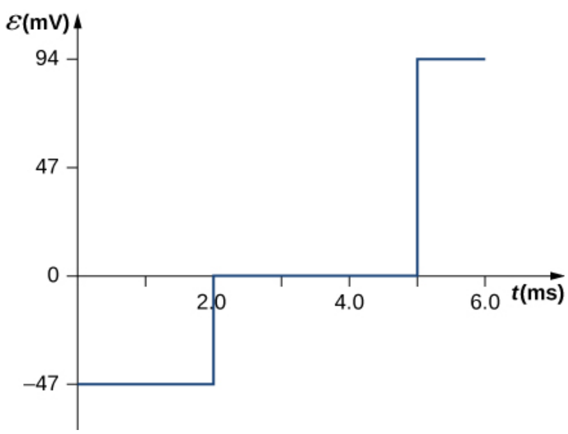
1. The emf depends on the rate of change of the magnetic field.
3. Both have the same induced electric fields; however, the copper ring has a much higher induced emf because it conducts electricity better than the wooden ring.

5. a. no; b. yes
7. As long as the magnetic flux is changing from positive to negative or negative to positive, there could be an induced emf.
9. Position the loop so that the field lines run perpendicular to the area vector or parallel to the surface.
11. a. CW as viewed from the circuit; b. CCW as viewed from the circuit
13. As the loop enters, the induced emf creates a CCW current while as the loop leaves the induced emf creates a CW current. While the loop is fully inside the magnetic field, there is no flux change and therefore no induced current.
15. a. CCW viewed from the magnet; b. CW viewed from the magnet; c. CW viewed from the magnet; d. CCW viewed from the magnet; e. CW viewed from the magnet; f. no current
17. Positive charges on the wings would be to the west, or to the left of the pilot while negative charges would be pulled east or to the right of the pilot. Thus, the left hand tips of the wings would be positive and the right hand tips would be negative.
19. The work is greater than the kinetic energy because it takes energy to counteract the induced emf.
21. The conducting sheet is shielded from the changing magnetic fields by creating an induced emf. This induced emf creates an induced magnetic field that opposes any changes in magnetic fields from the field underneath. Therefore, there is no net magnetic field in the region above this sheet. If the field were due to a static magnetic field, no induced emf will be created since you need a changing magnetic flux to induce an emf. Therefore, this static magnetic field will not be shielded.
23. a. zero induced current, zero force; b. clockwise induced current, force is to the left; c. zero induced current, zero force; d. counterclockwise induced current, force is to the left; e. zero induced current, zero force.

PROBLEMS

25. a. 3.8 V; b. 2.2 V; c. 0 V

27.
$$\begin{aligned} B &= 1.5t,\ 0 \le t < 2.0\,\text{ms},\ B = 3.0\,\text{mT},\ 2.0\,\text{ms} \le t \le 5.0\,\text{ms}, \\ B &= -3.0t + 18\,\text{mT},\ 5.0\,\text{ms} < t \le 6.0\,\text{ms}, \\ \varepsilon &= -\frac{d\Phi_\text{m}}{dt} = -\frac{d(BA)}{dt} = -A\frac{dB}{dt}, \\ \varepsilon &= -\pi(0.100\,\text{m})^2(1.5\,\text{T/s}) \\ &= -47\,\text{mV}(0 \le t < 2.0\,\text{ms}), \\ \varepsilon &= \pi(0.100\,\text{m})^2(0) = 0(2.0\,\text{ms} \le t \le 5.0\,\text{ms}), \\ \varepsilon &= -\pi(0.100\,\text{m})^2(-3.0\,\text{T/s}) = 94\,\text{mV}\ (5.0\,\text{ms} < t < 6.0\,\text{ms}). \end{aligned}$$



29. Each answer is 20 times the previously given answers.

31.
$$\begin{aligned} \hat{\mathbf{n}} &= \hat{k},\ d\Phi_\text{m} = Cy\sin(\omega t)dxdy, \\ \Phi_\text{m} &= \frac{Cab^2\sin(\omega t)}{2}, \\ \varepsilon &= -\frac{Cab^2\omega\cos(\omega t)}{2}. \end{aligned}$$

33. a. $7.8 \times 10^{-3}\,\text{V}$; b. CCW from the same view as the magnetic field
35. a. 150 A downward through the resistor; b. 232 A upward through the resistor; c. 0.093 A downward through the resistor
37. 0.0015 V
39. $\varepsilon = -B_0 ld\omega\cos\omega t$

41. $\varepsilon = Blv\cos\theta$

43. a. $2\times10^{-19}T$; b. 1.25 V/m; c. 0.3125 V; d. 16 m/s

45. 0.018 A, CW as seen in the diagram

47. 4.67 V/m

49. Inside, $B=\mu_0 nI$, $\oint \vec{\mathbf{E}}\cdot d\vec{\mathbf{l}} = (\pi r^2)\mu_0 n\frac{dI}{dt}$, so, $E=\frac{\mu_0 nr}{2}\cdot\frac{dI}{dt}$ (inside). Outside, $E(2\pi r)=\pi R^2\mu_0 n\frac{dI}{dt}$, so, $E=\frac{\mu_0 nR^2}{2r}\cdot\frac{dI}{dt}$ (outside)

51. a. $E_{\text{inside}}=\frac{r}{2}\frac{dB}{dt}$, $E_{\text{outside}}=\frac{r^2}{2R}\frac{dB}{dt}$; b. $W=4.19\times10^{-23}$ J; c. 0 J; d. $F_{\text{mag}}=4\times10^{-13}$ N, $F_{\text{elec}}=2.7\times10^{-22}$ N

53. $7.1\ \mu$A

55. three turns with an area of 1 m^2

57. a. $\omega = 120\pi$ rad/s,
$\varepsilon = 850\sin 120\pi t$ V;

b. $P=720\sin^2 120\pi t$ W;

c. $P=360\sin^2 120\pi t$ W

59. a. B is proportional to Q; b. If the coin turns easily, the magnetic field is perpendicular. If the coin is at an equilibrium position, it is parallel.

61. a. 1.33 A; b. 0.50 A; c. 60 W; d. 22.5 W; e. 2.5W

ADDITIONAL PROBLEMS

63. 3.0 A/s

65. 2.83×10^{-4} A, the direction as follows for increasing magnetic field:

67. 0.375 V

69. a. 0.94 V; b. 0.70 N; c. 3.52 J/s; d. 3.52 W

71. $\left(\frac{dB}{dt}\right)\frac{A}{2\pi r}$

73. a. $R_f+R_a=\frac{120\text{ V}}{2.0\text{ A}}=60\ \Omega$, so $R_f=50\ \Omega$;

b. $I=\frac{\varepsilon_s-\varepsilon_i}{R_f+R_a}$, $\Rightarrow \varepsilon_i=90$ V;

c. $\varepsilon_i=60$ V

CHALLENGE PROBLEMS

75. N is a maximum number of turns allowed.

77. 5.3 V

79.
$$\Phi = \frac{\mu_0 I_0 a}{2\pi}\ln\left(1+\frac{b}{x}\right),\quad \varepsilon=\frac{\mu_0 I_0 abv}{2\pi x(x+b)},$$
$$\text{so } I = \frac{\mu_0 I_0 abv}{2\pi Rx(x+b)}$$

81. a. 1.26×10^{-7} V; b. 1.71×10^{-8} V; c. 0 V

83. a. $v=\frac{mgR\sin\theta}{B^2l^2\cos^2\theta}$; b. $mgv\sin\theta$; c. $mc\Delta T$; d. current would reverse direction but bar would still slide at the same speed

85. a.

$B = \mu_0 nI, \ \Phi_m = BA = \mu_0 nIA,$

$\varepsilon = 9.9 \times 10^{-4}$ V;

b. 9.9×10^{-4} V;

c. $\oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{l}} = \varepsilon, \quad \Rightarrow \quad E = 1.6 \times 10^{-3}\,\text{V/m}$; d. 9.9×10^{-4} V;

e. no, because there is no cylindrical symmetry

87. a. 1.92×10^6 rad/s $= 1.83 \times 10^7$ rpm; b. This angular velocity is unreasonably high, higher than can be obtained for any mechanical system. c. The assumption that a voltage as great as 12.0 kV could be obtained is unreasonable.

89. $\frac{2\mu_0 \pi a^2 I_0 n\omega}{R}$

91. $\frac{mRv_o}{B^2 D^2}$

CHAPTER 14

CHECK YOUR UNDERSTANDING

14.1. 4.77×10^{-2} V

14.2. a. decreasing; b. increasing; Since the current flows in the opposite direction of the diagram, in order to get a positive emf on the left-hand side of diagram (a), we need to decrease the current to the left, which creates a reinforced emf where the positive end is on the left-hand side. To get a positive emf on the right-hand side of diagram (b), we need to increase the current to the left, which creates a reinforced emf where the positive end is on the right-hand side.

14.3. 40 A/s

14.4. a. 4.5×10^{-5} H; b. 4.5×10^{-3} V

14.5. a. 2.4×10^{-7} Wb; b. $6.4 \times 10^{-5}\ \text{m}^2$

14.6. 0.50 J

14.8. a. 2.2 s; b. 43 H; c. 1.0 s

14.10. a. $2.5\mu\text{F}$; b. $\pi/2$ rad or $3\pi/2$ rad; c. 1.4×10^3 rad/s

14.11. a. overdamped; b. 0.75 J

CONCEPTUAL QUESTIONS

1. $\frac{\text{Wb}}{\text{A}} = \frac{\text{T} \cdot \text{m}^2}{\text{A}} = \frac{\text{V} \cdot \text{s}}{\text{A}} = \frac{\text{V}}{\text{A/s}}$

3. The induced current from the 12-V battery goes through an inductor, generating a large voltage.

5. Self-inductance is proportional to the magnetic flux and inversely proportional to the current. However, since the magnetic flux depends on the current *I*, these effects cancel out. This means that the self-inductance does not depend on the current. If the emf is induced across an element, it does depend on how the current changes with time.

7. Consider the ends of a wire a part of an *RL* circuit and determine the self-inductance from this circuit.

9. The magnetic field will flare out at the end of the solenoid so there is less flux through the last turn than through the middle of the solenoid.

11. As current flows through the inductor, there is a back current by Lenz's law that is created to keep the net current at zero amps, the initial current.

13. no

15. At $t = 0$, or when the switch is first thrown.

17. 1/4

19. Initially, $I_{R1} = \frac{\varepsilon}{R_1}$ and $I_{R2} = 0$, and after a long time has passed, $I_{R1} = \frac{\varepsilon}{R_1}$ and $I_{R2} = \frac{\varepsilon}{R_2}$.

21. yes

23. The amplitude of energy oscillations depend on the initial energy of the system. The frequency in a *LC* circuit depends on the values of inductance and capacitance.

25. This creates an *RLC* circuit that dissipates energy, causing oscillations to decrease in amplitude slowly or quickly depending on the value of resistance.

27. You would have to pick out a resistance that is small enough so that only one station at a time is picked up, but big enough so that the tuner doesn't have to be set at exactly the correct frequency. The inductance or capacitance would have to be varied to tune into the station however practically speaking, variable capacitors are a lot easier to build in a circuit.

PROBLEMS

29. $M = 3.6 \times 10^{-3}$ H

31. a. 3.8×10^{-4} H; b. 3.8×10^{-4} H

33. $M_{21} = 2.3 \times 10^{-5}$ H

35. 0.24 H

37. 0.4 A/s

39. $\varepsilon = 480\pi \sin(120\pi t - \pi/2)$ V

41. 0.15 V. This is the same polarity as the emf driving the current.

43. a. 0.089 H/m; b. 0.44 V/m

45. $\frac{L}{l} = 4.16 \times 10^{-7}$ H/m

47. 0.01 A

49. 6.0 g

51. $U_{\text{m}} = 7.0 \times 10^{-7}$ J

53. a. 4.0 A; b. 2.4 A; c. on *R*: $V = 12$ V; on *L*: $V = 7.9$ V

55. 0.69τ

57. a. 2.52 ms; b. $99.2\,\Omega$

59. a. $I_1 = I_2 = 1.7\,A$; b. $I_1 = 2.73\,A,\ I_2 = 1.36\,A$; c. $I_1 = 0,\ I_2 = 0.54\,A$; d. $I_1 = I_2 = 0$

61. proof

63. $\omega = 3.2 \times 10^{-7}$ rad/s

65. a. 7.9×10^{-4} s; b. 4.0×10^{-4} s

67. $q = \frac{q_m}{\sqrt{2}},\ I = \frac{q_m}{\sqrt{2LC}}$

69.
$$\begin{aligned} C &= \frac{1}{4\pi^2 f^2 L} \\ f_1 &= 540\,\text{Hz}; \quad C_1 = 3.5 \times 10^{-11}\ \text{F} \\ f_2 &= 1600\,\text{Hz}; \quad C_2 = 4.0 \times 10^{-12}\ \text{F} \end{aligned}$$

71. 6.9 ms

ADDITIONAL PROBLEMS

73. proof
$$\begin{aligned} \text{Outside,}\quad B &= \frac{\mu_0 I}{2\pi r} \quad \text{Inside,} \quad B = \frac{\mu_0 I r}{2\pi a^2} \\ U &= \frac{\mu_0 I^2 l}{4\pi}\left(\frac{1}{4} + \ln\frac{R}{a}\right) \\ \text{So,}\quad \frac{2U}{I^2} &= \frac{\mu_0 l}{2\pi}\left(\frac{1}{4} + \ln\frac{R}{a}\right) \quad \text{and} \quad L = \infty \end{aligned}$$

75. $M = \frac{\mu_0 l}{\pi} \ln \frac{d + a}{d}$

77. a. 100 T; b. 2 A; c. 0.50 H

79. a. 0 A; b. 2.4 A

81. a. 2.50×10^{6} V; (b) The voltage is so extremely high that arcing would occur and the current would not be reduced so rapidly. (c) It is not reasonable to shut off such a large current in such a large inductor in such an extremely short time.

CHALLENGE PROBLEMS

83. proof

85. a. $\frac{dB}{dt} = 6 \times 10^{-6}$ T/s; b. $\Phi = \frac{\mu_0 a I}{2\pi} \ln\left(\frac{a + b}{b}\right)$; c. 4.0 nA

CHAPTER 15

CHECK YOUR UNDERSTANDING

15.1. 10 ms
15.2. a. $(20\text{ V})\sin 200\pi t, (0.20\text{ A})\sin 200\pi t$; b. $(20\text{ V})\sin 200\pi t, (0.13\text{ A})\sin(200\pi t + \pi/2)$; c. $(20\text{ V})\sin 200\pi t, (2.1\text{ A})\sin(200\pi t - \pi/2)$

15.3. $v_R = (V_0 R/Z)\sin(\omega t - \phi)$; $v_C = (V_0 X_C/Z)\sin(\omega t - \phi + \pi/2) = -(V_0 X_C/Z)\cos(\omega t - \phi)$; $v_L = (V_0 X_L/Z)\sin(\omega t - \phi + \pi/2) = (V_0 X_L/Z)\cos(\omega t - \phi)$

15.4. $v(t) = (10.0\text{ V})\sin 90\pi t$

15.5. 2.00 V; 10.01 V; 8.01 V

15.6. a. 160 Hz; b. $40\,\Omega$; c. $(0.25\text{ A})\sin 10^3 t$; d. 0.023 rad

15.7. a. halved; b. halved; c. same

15.8. $v(t) = (0.14\text{ V})\ \sin(4.0 \times 10^2 t)$

15.9. a. 12:1; b. 0.042 A; c. $2.6 \times 10^3\ \Omega$

CONCEPTUAL QUESTIONS

1. Angular frequency is 2π times frequency.

3. yes for both

5. The instantaneous power is the power at a given instant. The average power is the power averaged over a cycle or number of cycles.

7. The instantaneous power can be negative, but the power output can't be negative.

9. There is less thermal loss if the transmission lines operate at low currents and high voltages.

11. The adapter has a step-down transformer to have a lower voltage and possibly higher current at which the device can operate.

13. so each loop can experience the same changing magnetic flux

PROBLEMS

15. a. $530\,\Omega$; b. $53\,\Omega$; c. $5.3\,\Omega$

17. a. $1.9\,\Omega$; b. $19\,\Omega$; c. $190\,\Omega$

19. 360 Hz

21. $i(t) = (3.2\text{ A})\sin(120\pi t)$

23. a. $38\,\Omega$; b. $i(t) = (4.24\text{A})\sin(120\pi t - \pi/2)$

25. a. $770\,\Omega$; b. 0.16 A; c. $I = (0.16\text{ A})\cos(120\pi t)$; d. $v_R = 120\cos(120\pi t)$; $v_C = 120\cos(120\pi t - \pi/2)$

27. a. $690\,\Omega$; b. 0.15 A; c. $I = (0.15\text{A})\sin(1000\pi t - 0.753)$; d. $1100\,\Omega$, 0.092 A, $I = (0.092\text{A})\sin(1000\pi t + 1.09)$

29. a. $5.7\,\Omega$; b. $29°$; c. $I = (30.\text{ A})\cos(120\pi t)$

31. a. 0.89 A; b. 5.6A; c. 1.4 A

33. a. 7.3 W; b. 6.3 W

35. a. inductor; b. $X_L = 52\,\Omega$

37. 1.3×10^{-7} F

39. a. 820 Hz; b. 7.8

41. a. 50 Hz; b. 50 W; c. 13; d. 25 rad/s

43. The reactance of the capacitor is larger than the reactance of the inductor because the current leads the voltage. The power usage is 30 W.

45. a. 45:1; b. 0.68 A, 0.015 A; c. $160\,\Omega$

47. a. 41 turns; b. 40.9 mA

ADDITIONAL PROBLEMS

49. a. $i(t) = (1.26\text{A})\sin(200\pi t + \pi/2)$; b. $i(t) = (12.6\text{A})\sin(200\pi t - \pi/2)$; c. $i(t) = (2\text{A})\sin(200\pi t)$

51. a. $2.5 \times 10^3\,\Omega,\ 3.6 \times 10^{-3}$ A; b. $7.5\,\Omega,\ 1.2\text{A}$

53. a. 19 A; b. inductor leads by $90°$

55. $11.7\,\Omega$

57. 36 W

59. a. 5.9×10^4 W ; b. 1.64×10^{11} W

CHALLENGE PROBLEMS

61. a. 335 MV; b. the result is way too high, well beyond the breakdown voltage of air over reasonable distances; c. the input voltage is too high
63. a. $20\ \Omega$; b. 0.5 A; c. $5.4°$, lagging;
d. $V_R = (9.96\text{ V})\cos(250\pi t + 5.4°)$, $V_C = (12.7\text{ V})\cos(250\pi t + 5.4° - 90°)$, $V_L = (11.8\text{ V})\cos(250\pi t + 5.4° + 90°)$, $V_{\text{source}} = (10.0\text{ V})\cos(250\pi t)$; e. 0.995; f. 6.25 J
65. a. $0.75\ \Omega$; b. $7.5\ \Omega$; c. $0.75\ \Omega$; d. $7.5\ \Omega$; e. $1.3\ \Omega$; f. $0.13\ \Omega$
67. The units as written for inductive reactance **Equation 15.16** are $\frac{\text{rad}}{\text{s}}\text{H}$. Radians can be ignored in unit analysis. The Henry can be defined as $\text{H} = \frac{\text{V} \cdot \text{s}}{\text{A}} = \Omega \cdot \text{s}$. Combining these together results in a unit of Ω for reactance.
69. a. 156 V; b. 42 V; c. 154 V
71. a. $\frac{v_{\text{out}}}{v_{\text{in}}} = \frac{1}{\sqrt{1 + 1/\omega^2 R^2 C^2}}$ and $\frac{v_{\text{out}}}{v_{\text{in}}} = \frac{\omega L}{\sqrt{R^2 + \omega^2 L^2}}$; b. $v_{\text{out}} \approx v_{\text{in}}$ and $v_{\text{out}} \approx 0$

CHAPTER 16

CHECK YOUR UNDERSTANDING

16.1. It is greatest immediately after the current is switched on. The displacement current and the magnetic field from it are proportional to the rate of change of electric field between the plates, which is greatest when the plates first begin to charge.
16.2. No. The changing electric field according to the modified version of Ampère's law would necessarily induce a changing magnetic field.
16.3. (1) Faraday's law, (2) the Ampère-Maxwell law
16.4. a. The directions of wave propagation, of the E field, and of B field are all mutually perpendicular. b. The speed of the electromagnetic wave is the speed of light $c = 1/\sqrt{\varepsilon_0 \mu_0}$ independent of frequency. c. The ratio of electric and magnetic field amplitudes is $E/B = c$.
16.5. Its acceleration would decrease because the radiation force is proportional to the intensity of light from the Sun, which decreases with distance. Its speed, however, would not change except for the effects of gravity from the Sun and planets.
16.6. They fall into different ranges of wavelength, and therefore also different corresponding ranges of frequency.

CONCEPTUAL QUESTIONS

1. The current into the capacitor to change the electric field between the plates is equal to the displacement current between the plates.
3. The first demonstration requires simply observing the current produced in a wire that experiences a changing magnetic field. The second demonstration requires moving electric charge from one location to another, and therefore involves electric currents that generate a changing electric field. The magnetic fields from these currents are not easily separated from the magnetic field that the displacement current produces.
5. in (a), because the electric field is parallel to the wire, accelerating the electrons
7. A steady current in a dc circuit will not produce electromagnetic waves. If the magnitude of the current varies while remaining in the same direction, the wires will emit electromagnetic waves, for example, if the current is turned on or off.
9. The amount of energy (about 100 W/m^2) is can quickly produce a considerable change in temperature, but the light pressure (about $3.00 \times 10^{-7}\text{ N/m}^2$) is much too small to notice.
11. It has the magnitude of the energy flux and points in the direction of wave propagation. It gives the direction of energy flow and the amount of energy per area transported per second.
13. The force on a surface acting over time Δt is the momentum that the force would impart to the object. The momentum change of the light is doubled if the light is reflected back compared with when it is absorbed, so the force acting on the object is twice as great.
15. a. According to the right hand rule, the direction of energy propagation would reverse. b. This would leave the vector $\vec{\mathbf{S}}$, and therefore the propagation direction, the same.
17. a. Radio waves are generally produced by alternating current in a wire or an oscillating electric field between two plates; b. Infrared radiation is commonly produced by heated bodies whose atoms and the charges in them vibrate at about the right frequency.
19. a. blue; b. Light of longer wavelengths than blue passes through the air with less scattering, whereas more of the blue light is scattered in different directions in the sky to give it is blue color.
21. A typical antenna has a stronger response when the wires forming it are orientated parallel to the electric field of the radio

wave.
23. No, it is very narrow and just a small portion of the overall electromagnetic spectrum.
25. Visible light is typically produced by changes of energies of electrons in randomly oriented atoms and molecules. Radio waves are typically emitted by an ac current flowing along a wire, that has fixed orientation and produces electric fields pointed in particular directions.
27. Radar can observe objects the size of an airplane and uses radio waves of about 0.5 cm in wavelength. Visible light can be used to view single biological cells and has wavelengths of about 10^{-7} m.
29. ELF radio waves
31. The frequency of 2.45 GHz of a microwave oven is close to the specific frequencies in the 2.4 GHz band used for WiFi.

PROBLEMS

33.
$$\begin{aligned} B_{\text{ind}} &= \frac{\mu_0}{2\pi r} I_{\text{ind}} = \frac{\mu_0}{2\pi r}\varepsilon_0 \frac{\partial \Phi_E}{\partial t} = \frac{\mu_0}{2\pi r}\varepsilon_0 \left(A\frac{\partial E}{\partial t}\right) = \frac{\mu_0}{2\pi r}\varepsilon_0 A\left(\frac{1}{d}\frac{dV(t)}{dt}\right) \\ &= \frac{\mu_0}{2\pi r}\left[\frac{\varepsilon_0 A}{d}\right]\left[\frac{1}{C}\frac{dQ(t)}{dt}\right] = \frac{\mu_0}{2\pi r}\frac{dQ(t)}{dt} \qquad \text{because } C = \frac{\varepsilon_0 A}{d} \end{aligned}$$

35. a. $I_{\text{res}} = \dfrac{V_0 \sin \omega t}{R}$; b. $I_{\text{d}} = CV_0 \omega \cos \omega t$;

c. $I_{\text{real}} = I_{\text{res}} + \dfrac{dQ}{dt} = \dfrac{V_0 \sin \omega t}{R} + CV_0 \dfrac{d}{dt}\sin \omega t = \dfrac{V_0 \sin \omega t}{R} + CV_0 \omega \cos \omega t$; which is the sum of I_{res} and I_{real}, consistent with how the displacement current maintaining the continuity of current.
37. 1.77×10^{-3} A
39. $I_{\text{d}} = \left(7.97 \times 10^{-10} \text{ A}\right)\sin(150\, t)$
41. 499 s
43. 25 m
45. a. 5.00 V/m; b. 9.55×10^{8} Hz; c. 31.4 cm; d. toward the +*x*-axis;
e. $B = \left(1.67 \times 10^{-8} \text{ T}\right)\cos\left[kx - \left(6 \times 10^{9} \text{ s}^{-1}\right)t + 0.40\right]\hat{\mathbf{k}}$
47. $I_{\text{d}} = \pi \varepsilon_0 \omega R^2 E_0 \sin(kx - \omega t)$
49. The magnetic field is downward, and it has magnitude 2.00×10^{-8} T.
51. a. 6.45×10^{-3} V/m; b. 394 m
53. 11.5 m
55. 5.97×10^{-3} W/m^2
57. a. $E_0 = 1027$ V/m, $B_0 = 3.42 \times 10^{-6}$ T; b. 3.96×10^{26} W
59. 20.8 W/m^2
61. a. 4.42×10^{-6} W/m^2; b. 5.77×10^{-2} V/m
63. a. 7.47×10^{-14} W/m^2; b. 3.66×10^{-13} W; c. 1.12 W
65. 1.99×10^{-11} N/m^2

67.
$$\begin{aligned} F &= ma = (p)\left(\pi r^2\right),\ p = \frac{ma}{\pi r^2} = \frac{\varepsilon_0}{2}E_0^2 \\ E_0 &= \sqrt{\frac{2ma}{\varepsilon_0 \pi r^2}} = \sqrt{\frac{2\left(10^{-8} \text{ kg}\right)\left(0.30 \text{ m/s}^2\right)}{\left(8.854 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2\right)(\pi)\left(2 \times 10^{-6} \text{ m}\right)^2}} \\ E_0 &= 7.34 \times 10^{6} \text{ V/m} \end{aligned}$$

69. a. 4.50×10^{-6} N; b. it is reduced to half the pressure, 2.25×10^{-6} N
71. a. $W = \dfrac{1}{2}\dfrac{\pi^2 r^4}{mc^2} I^2 t^2$; b. $E = \pi r^2 It$
73. a. 1.5×10^{18} Hz; b. X-rays
75. a. The wavelength range is 187 m to 556 m. b. The wavelength range is 2.78 m to 3.41 m.

77. $P' = \left(\frac{12\text{ m}}{30\text{ m}}\right)^2(100\text{ mW}) = 16\text{ mW}$

79. time for $1\text{ bit} = 1.27 \times 10^{-8}\text{ s},$ difference in travel time is $2.67 \times 10^{-8}\text{ s}$

81. a. $1.5 \times 10^{-9}\text{ m};$ b. $5.9 \times 10^{-7}\text{ m};$ c. $3.0 \times 10^{-15}\text{ m}$

83. $5.17 \times 10^{-12}\text{ T},$ the non-oscillating geomagnetic field of 25–65 μT is much larger

85. a. $1.33 \times 10^{-2}\text{ V/m}$; b. $4.34 \times 10^{-11}\text{ T}$; c. $3.00 \times 10^{8}\text{ m}$

87. a. $5.00 \times 10^{6}\text{ m}$; b. radio wave; c. $4.33 \times 10^{-5}\text{ T}$

ADDITIONAL PROBLEMS

89. $I_\text{d} = (10\text{ N/C})\left(8.845 \times 10^{-12}\text{ C}^2/\text{N} \cdot \text{m}^2\right)\pi(0.03\text{ m})^2(5000) = 1.25 \times 10^{-5}\text{ mA}$

91. $6.0 \times 10^{5}\text{ km}$, which is much greater than Earth's circumference

93. a. 564 W; b. $1.80 \times 10^{4}\text{ W/m}^2$; c. $3.68 \times 10^{3}\text{ V/m}$; d. $1.23 \times 10^{-5}\text{ T}$

95. a. $5.00 \times 10^{3}\text{ W/m}^2$; b. $3.88 \times 10^{-6}\text{ N}$; c. $5.18 \times 10^{-12}\text{ N}$

97. a. $I = \frac{P}{A} = \frac{P}{4\pi r^2} \propto \frac{1}{r^2}$; b. $I \propto E_0^2,\ B_0^2 \Rightarrow E_0^2,\ B_0^2 \propto \frac{1}{r^2} \Rightarrow E_0,\ B_0 \propto \frac{1}{r}$

99.
$$\begin{aligned}\text{Power into the wire} &= \int \vec{\mathbf{S}} \cdot d\vec{\mathbf{A}} = \left(\frac{1}{\mu_0}EB\right)(2\pi rL) \\ &= \frac{1}{\mu_0}\left(\frac{V}{L}\right)\left(\frac{\mu_0 i}{2\pi r}\right)(2\pi rL) = iV = i^2R\end{aligned}$$

101. 0.431

103. a. $1.5 \times 10^{11}\text{ m}$; b. $5.0 \times 10^{-7}\text{ s}$; c. 33 ns

105.
$$\begin{aligned}\text{sound: } \lambda_\text{sound} &= \frac{v_s}{f} = \frac{343\text{ m/s}}{20.0\text{ Hz}} = 17.2\text{ m} \\ \text{radio: } \lambda_\text{radio} &= \frac{c}{f} = \frac{3.00 \times 10^8\text{ m/s}}{1030 \times 10^3\text{ Hz}} = 291\text{ m; or } 17.1\ \lambda_\text{sound}\end{aligned}$$

CHALLENGE PROBLEMS

107. a. $0.29\ \mu\text{m}$; b. The radiation pressure is greater than the Sun's gravity if the particle size is smaller, because the gravitational force varies as the radius cubed while the radiation pressure varies as the radius squared. c. The radiation force outward implies that particles smaller than this are less likely to be near the Sun than outside the range of the Sun's radiation pressure.