ANSWER KEY

CHAPTER 1

CHECK YOUR UNDERSTANDING

1.1. 4.79×10^2 Mg or 479 Mg

1.2. $3 \times 10^8\,\text{m/s}$

1.3. $10^8\ \text{km}^2$

1.4. The numbers were too small, by a factor of 4.45.

1.5. $4\pi r^3/3$

1.6. yes

1.7. $3 \times 10^4\,\text{m}$ or 30 km. It is probably an underestimate because the density of the atmosphere decreases with altitude. (In fact, 30 km does not even get us out of the stratosphere.)

1.8. No, the coach's new stopwatch will not be helpful. The uncertainty in the stopwatch is too great to differentiate between the sprint times effectively.

CONCEPTUAL QUESTIONS

1. Physics is the science concerned with describing the interactions of energy, matter, space, and time to uncover the fundamental mechanisms that underlie every phenomenon.

3. No, neither of these two theories is more valid than the other. Experimentation is the ultimate decider. If experimental evidence does not suggest one theory over the other, then both are equally valid. A given physicist might prefer one theory over another on the grounds that one seems more simple, more natural, or more beautiful than the other, but that physicist would quickly acknowledge that he or she cannot say the other theory is invalid. Rather, he or she would be honest about the fact that more experimental evidence is needed to determine which theory is a better description of nature.

5. Probably not. As the saying goes, "Extraordinary claims require extraordinary evidence."

7. Conversions between units require factors of 10 only, which simplifies calculations. Also, the same basic units can be scaled up or down using metric prefixes to sizes appropriate for the problem at hand.

9. a. Base units are defined by a particular process of measuring a base quantity whereas derived units are defined as algebraic combinations of base units. b. A base quantity is chosen by convention and practical considerations. Derived quantities are expressed as algebraic combinations of base quantities. c. A base unit is a standard for expressing the measurement of a base quantity within a particular system of units. So, a measurement of a base quantity could be expressed in terms of a base unit in any system of units using the same base quantities. For example, length is a base quantity in both SI and the English system, but the meter is a base unit in the SI system only.

11. a. Uncertainty is a quantitative measure of precision. b. Discrepancy is a quantitative measure of accuracy.

13. Check to make sure it makes sense and assess its significance.

PROBLEMS

15. a. 10^3; b. 10^5; c. 10^2; d. 10^{15}; e. 10^2; f. 10^{57}

17. 10^2 generations

19. 10^{11} atoms

21. 10^3 nerve impulses/s

23. 10^{26} floating-point operations per human lifetime

25. a. 957 ks; b. 4.5 cs or 45 ms; c. 550 ns; d. 31.6 Ms

27. a. 75.9 Mm; b. 7.4 mm; c. 88 pm; d. 16.3 Tm

29. a. 3.8 cg or 38 mg; b. 230 Eg; c. 24 ng; d. 8 Eg e. 4.2 g

31. a. 27.8 m/s; b. 62 mi/h

33. a. 3.6 km/h; b. 2.2 mi/h

35. $1.05 \times 10^5\ \text{ft}^2$

37. 8.847 km

39. a. $1.3 \times 10^{-9}\,\text{m};$ b. 40 km/My

41. $10^6\,\text{Mg}/\mu\text{L}$

43. 62.4 lbm/ft^3

45. 0.017 rad

47. 1 light-nanosecond

49. $3.6 \times 10^{-4}\,\text{m}^3$

51. a. Yes, both terms have dimension L^2T^{-2} b. No. c. Yes, both terms have dimension LT^{-1} d. Yes, both terms have dimension

LT^{-2}

53. a. $[v] = LT^{-1}$; b. $[a] = LT^{-2}$; c. $\left[\int v dt\right] = L$; d. $\left[\int a dt\right] = LT^{-1}$; e. $\left[\frac{da}{dt}\right] = LT^{-3}$

55. a. L; b. L; c. $L^0 = 1$ (that is, it is dimensionless)
57. 10^{28} atoms
59. 10^{51} molecules
61. 10^{16} solar systems
63. a. Volume = 10^{27} m^3, diameter is 10^9 m.; b. 10^{11} m
65. a. A reasonable estimate might be one operation per second for a total of 10^9 in a lifetime.; b. about $(10^9)(10^{-17}\text{ s}) = 10^{-8}$ s, or about 10 ns
67. 2 kg
69. 4%
71. 67 mL
73. a. The number 99 has 2 significant figures; 100. has 3 significant figures. b. 1.00%; c. percent uncertainties
75. a. 2%; b. 1 mm Hg
77. 7.557 cm^2
79. a. 37.2 lb; because the number of bags is an exact value, it is not considered in the significant figures; b. 1.4 N; because the value 55 kg has only two significant figures, the final value must also contain two significant figures

ADDITIONAL PROBLEMS

81. a. $[s_0] = L$ and units are meters (m); b. $[v_0] = LT^{-1}$ and units are meters per second (m/s); c. $[a_0] = LT^{-2}$ and units are meters per second squared (m/s^2); d. $[j_0] = LT^{-3}$ and units are meters per second cubed (m/s^3); e. $[S_0] = LT^{-4}$ and units are m/s^4; f. $[c] = LT^{-5}$ and units are m/s^5.

83. a. 0.059%; b. 0.01%; c. 4.681 m/s; d. 0.07%, 0.003 m/s
85. a. 0.02%; b. 1×10^4 lbm
87. a. 143.6 cm^3; b. 0.2 cm^3 or 0.14%

CHALLENGE PROBLEMS

89. Since each term in the power series involves the argument raised to a different power, the only way that every term in the power series can have the same dimension is if the argument is dimensionless. To see this explicitly, suppose $[x] = L^aM^bT^c$. Then, $[x^n] = [x]^n = L^{an}M^{bn}T^{cn}$. If we want $[x] = [x^n]$, then an = a, bn = b, and cn = c for all n. The only way this can happen is if a = b = c = 0.

CHAPTER 2

CHECK YOUR UNDERSTANDING

2.1. a. not equal because they are orthogonal; b. not equal because they have different magnitudes; c. not equal because they have different magnitudes and directions; d. not equal because they are antiparallel; e. equal.

2.2. 16 m; $\vec{\mathbf{D}} = -16\text{ m}\,\hat{\mathbf{u}}$

2.3. G = 28.2 cm, $\theta_G = 291°$

2.4. $\vec{\mathbf{D}} = (-5.0\,\hat{\mathbf{i}} - 3.0\,\hat{\mathbf{j}})\text{cm}$; the fly moved 5.0 cm to the left and 3.0 cm down from its landing site.

2.5. 5.83 cm, $211°$

2.6. $\vec{\mathbf{D}} = (-20\text{ m})\,\hat{\mathbf{j}}$

2.7. 35.1 m/s = 126.4 km/h

2.8. $\vec{\mathbf{G}} = (10.25\,\hat{\mathbf{i}} - 26.22\,\hat{\mathbf{j}})\text{cm}$

2.9. D = 55.7 N; direction $65.7°$ north of east

2.10. $\hat{\mathbf{v}} = 0.8\,\hat{\mathbf{i}} + 0.6\,\hat{\mathbf{j}}$, $36.87°$ north of east

2.11. $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}} = -57.3$, $\vec{\mathbf{F}} \cdot \vec{\mathbf{C}} = 27.8$

2.13. $131.9°$

2.14. $W_1 = 1.5\text{ J}$, $W_2 = 0.3\text{ J}$

2.15. $\vec{\mathbf{A}} \times \vec{\mathbf{B}} = -40.1\,\hat{\mathbf{k}}$ or, equivalently, $\left|\vec{\mathbf{A}} \times \vec{\mathbf{B}}\right| = 40.1$, and the direction is into the page;

$\vec{C} \times \vec{F} = +157.6\hat{k}$ or, equivalently, $\left|\vec{C} \times \vec{F}\right| = 157.6$, and the direction is out of the page.

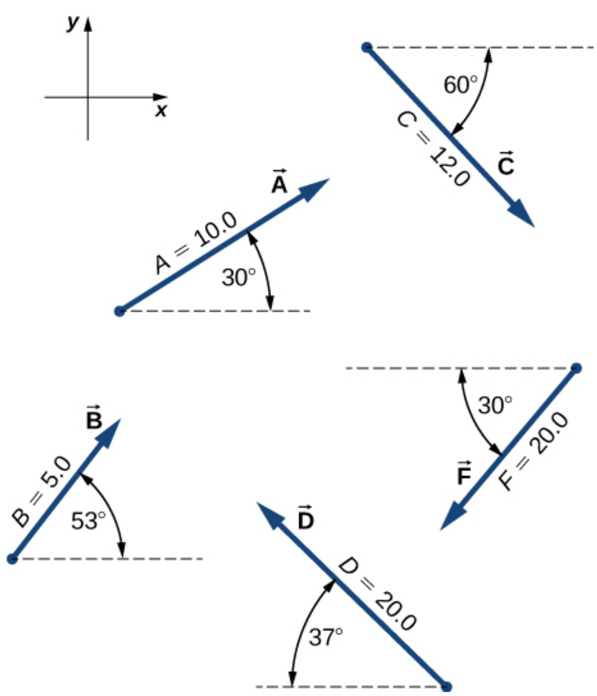
2.16. a. $-2\hat{k}$, b. 2, c. $153.4°$, d. $135°$

CONCEPTUAL QUESTIONS

1. scalar
3. answers may vary
5. parallel, sum of magnitudes, antiparallel, zero
7. no, yes
9. zero, yes
11. no
13. equal, equal, the same
15. a unit vector of the *x*-axis
17. They are equal.
19. yes
21. a. $C = \vec{A} \cdot \vec{B}$, b. $\vec{C} = \vec{A} \times \vec{B}$ or $\vec{C} = \vec{A} - \vec{B}$, c. $\vec{C} = \vec{A} \times \vec{B}$, d. $\vec{C} = A\vec{B}$, e. $\vec{C} + 2\vec{A} = \vec{B}$, f. $\vec{C} = \vec{A} \times \vec{B}$, g. left side is a scalar and right side is a vector, h. $\vec{C} = 2\vec{A} \times \vec{B}$, i. $\vec{C} = \vec{A}/B$, j. $\vec{C} = \vec{A}/B$
23. They are orthogonal.

PROBLEMS

25. $\vec{h} = -49\text{ m}\hat{u}$, 49 m
27. 30.8 m, $35.7°$ west of north
29. 134 km, $80°$
31. 7.34 km, $63.5°$ south of east
33. 3.8 km east, 3.2 km north, 7.0 km
35. 14.3 km, $65°$
37. a. $\vec{A} = +8.66\hat{i} + 5.00\hat{j}$, b. $\vec{B} = +30.09\hat{i} + 39.93\hat{j}$, c. $\vec{C} = +6.00\hat{i} - 10.39\hat{j}$, d. $\vec{D} = -15.97\hat{i} + 12.04\hat{j}$, f. $\vec{F} = -17.32\hat{i} - 10.00\hat{j}$



39. a. 1.94 km, 7.24 km; b. proof

41. 3.8 km east, 3.2 km north, 2.0 km, $\vec{\mathbf{D}} = (3.8\hat{\mathbf{i}} + 3.2\hat{\mathbf{j}})\text{km}$

43. $P_1(2.165\text{ m}, 1.250\text{ m})$, $P_2(-1.900\text{ m}, 3.290\text{ m})$, 5.27 m

45. 8.60 m, $A(2\sqrt{5}\text{ m}, 0.647\pi)$, $B(3\sqrt{2}\text{ m}, 0.75\pi)$

47. a. $\vec{\mathbf{A}} + \vec{\mathbf{B}} = -4\hat{\mathbf{i}} - 6\hat{\mathbf{j}}$, $\left|\vec{\mathbf{A}} + \vec{\mathbf{B}}\right| = 7.211, \theta = 213.7°$; b. $\vec{\mathbf{A}} - \vec{\mathbf{B}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}}$, $\left|\vec{\mathbf{A}} - \vec{\mathbf{B}}\right| = 2\sqrt{2}, \theta = -45°$

49. a. $\vec{\mathbf{C}} = (5.0\hat{\mathbf{i}} - 1.0\hat{\mathbf{j}} - 3.0\hat{\mathbf{k}})\text{m}, C = 5.92\text{ m}$;

b. $\vec{\mathbf{D}} = (4.0\hat{\mathbf{i}} - 11.0\hat{\mathbf{j}} + 15.0\hat{\mathbf{k}})\text{m}, D = 19.03\text{ m}$

51. $\vec{\mathbf{D}} = (3.3\hat{\mathbf{i}} - 6.6\hat{\mathbf{j}})\text{km}$, $\hat{\mathbf{i}}$ is to the east, 7.34 km, $-63.5°$

53. a. $\vec{\mathbf{R}} = -1.35\hat{\mathbf{i}} - 22.04\hat{\mathbf{j}}$, b. $\vec{\mathbf{R}} = -17.98\hat{\mathbf{i}} + 0.89\hat{\mathbf{j}}$

55. $\vec{\mathbf{D}} = (200\hat{\mathbf{i}} + 300\hat{\mathbf{j}})\text{yd}$, $D = 360.5$ yd, $56.3°$ north of east; The numerical answers would stay the same but the physical unit would be meters. The physical meaning and distances would be about the same because 1 yd is comparable with 1 m.

57. $\vec{\mathbf{R}} = -3\hat{\mathbf{i}} - 16\hat{\mathbf{j}}$

59. $\vec{\mathbf{E}} = E\hat{\mathbf{E}}$, $E_x = +178.9\text{V/m}$, $E_y = -357.8\text{V/m}$, $E_z = 0.0\text{V/m}$, $\theta_E = -\tan^{-1}(2)$

61. a. $\vec{\mathbf{R}}_B = (12.278\hat{\mathbf{i}} + 7.089\hat{\mathbf{j}} + 2.500\hat{\mathbf{k}})\text{km}$, $\vec{\mathbf{R}}_D = (-0.262\hat{\mathbf{i}} + 3.000\hat{\mathbf{k}})\text{km}$; b. $\left|\vec{\mathbf{R}}_B - \vec{\mathbf{R}}_D\right| = 14.414\text{ km}$

63. a. 8.66, b. 10.39, c. 0.866, d. 17.32

65. $\theta_i = 64.12°, \theta_j = 150.79°, \theta_k = 77.39°$

67. a. $-119.98\hat{\mathbf{k}}$, b. $-173.2\hat{\mathbf{k}}$, c. $+93.69\hat{\mathbf{k}}$, d. $-413.2\hat{\mathbf{k}}$, e. $+39.93\hat{\mathbf{k}}$, f. $-30.09\hat{\mathbf{k}}$, g. $+149.9\hat{\mathbf{k}}$, h. 0

69. a. 0, b. 173,194, c. $+199{,}993\hat{\mathbf{k}}$

ADDITIONAL PROBLEMS

71. a. 18.4 km and 26.2 km, b. 31.5 km and 5.56 km

73. a. $(r, \varphi + \pi/2)$, b. $(2r, \varphi + 2\pi)$, (c) $(3r, -\varphi)$

75. $d_{\text{PM}} = 33.12\text{ nmi} = 61.34\text{ km}$, $d_{\text{NP}} = 35.47\text{ nmi} = 65.69\text{ km}$

77. proof

79. a. 10.00 m, b. 5π m, c. 0

81. 22.2 km/h, $35.8°$ south of west

83. 240.2 m, $2.2°$ south of west

85. $\vec{\mathbf{B}} = -4.0\hat{\mathbf{i}} + 3.0\hat{\mathbf{j}}$ or $\vec{\mathbf{B}} = 4.0\hat{\mathbf{i}} - 3.0\hat{\mathbf{j}}$

87. proof

CHALLENGE PROBLEMS

89. $G_\perp = 2375\sqrt{17} \approx 9792$

91. proof

CHAPTER 3

CHECK YOUR UNDERSTANDING

3.1. (a) The rider's displacement is $\Delta x = x_f - x_0 = -1\text{ km}$. (The displacement is negative because we take east to be positive and west to be negative.) (b) The distance traveled is 3 km + 2 km = 5 km. (c) The magnitude of the displacement is 1 km.

3.2. (a) Taking the derivative of $x(t)$ gives $v(t) = -6t$ m/s. (b) No, because time can never be negative. (c) The velocity is $v(1.0\text{ s}) =$

-6 m/s and the speed is $|v(1.0\text{ s})| = 6\text{ m/s}$.

3.3. Inserting the knowns, we have

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{2.0 \times 10^7\text{ m/s} - 0}{10^{-4}\text{ s} - 0} = 2.0 \times 10^{11}\text{ m/s}^2.$$

3.4. If we take east to be positive, then the airplane has negative acceleration because it is accelerating toward the west. It is also decelerating; its acceleration is opposite in direction to its velocity.

3.5. To answer this, choose an equation that allows us to solve for time *t*, given only a, v_0, and *v*:

$$v = v_0 + at.$$

Rearrange to solve for *t*:

$$t = \frac{v - v_0}{a} = \frac{400\text{ m/s} - 0\text{ m/s}}{20\text{ m/s}^2} = 20\text{ s}.$$

3.6. $a = \frac{2}{3}\text{ m/s}^2$.

3.7. It takes 2.47 s to hit the water. The quantity distance traveled increases faster.

3.8.

a. The velocity function is the integral of the acceleration function plus a constant of integration. By **Equation 3.91**,

$$v(t) = \int a(t)dt + C_1 = \int (5 - 10t)dt + C_1 = 5t - 5t^2 + C_1.$$

Since $v(0) = 0$, we have $C_1 = 0$; so,

$$v(t) = 5t - 5t^2.$$

b. By **Equation 3.93**,

$$x(t) = \int v(t)dt + C_2 = \int (5t - 5t^2)dt + C_2 = \frac{5}{2}t^2 - \frac{5}{3}t^3 + C_2.$$

Since $x(0) = 0$, we have $C_2 = 0$, and

$$x(t) = \frac{5}{2}t^2 - \frac{5}{3}t^3.$$

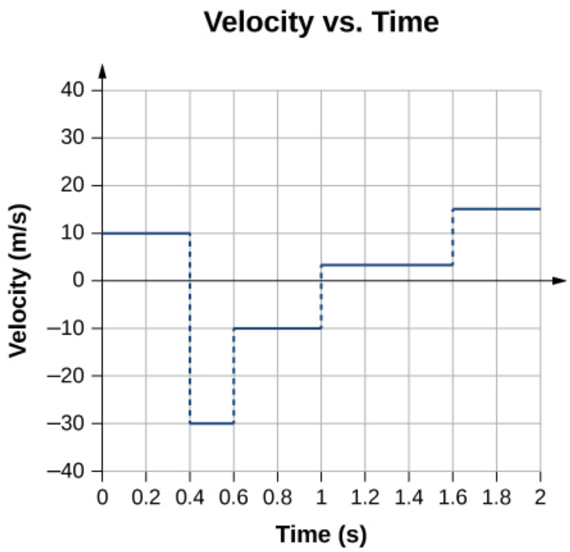
c. The velocity can be written as $v(t) = 5t(1 - t)$, which equals zero at $t = 0$, and $t = 1$ s.

CONCEPTUAL QUESTIONS

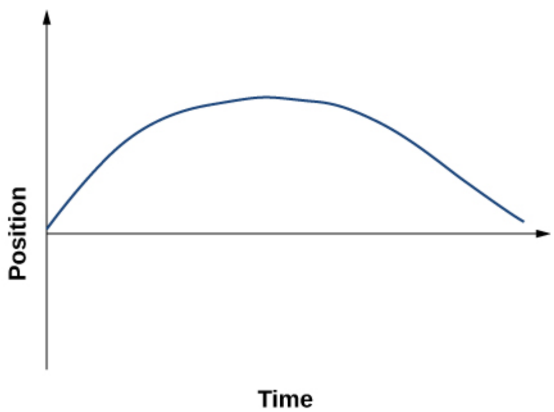
1. You drive your car into town and return to drive past your house to a friend's house.
3. If the bacteria are moving back and forth, then the displacements are canceling each other and the final displacement is small.
5. Distance traveled
7. Average speed is the total distance traveled divided by the elapsed time. If you go for a walk, leaving and returning to your home, your average speed is a positive number. Since Average velocity = Displacement/Elapsed time, your average velocity is zero.
9. Average speed. They are the same if the car doesn't reverse direction.
11. No, in one dimension constant speed requires zero acceleration.
13. A ball is thrown into the air and its velocity is zero at the apex of the throw, but acceleration is not zero.
15. Plus, minus
17. If the acceleration, time, and displacement are the knowns, and the initial and final velocities are the unknowns, then two kinematic equations must be solved simultaneously. Also if the final velocity, time, and displacement are the knowns then two kinematic equations must be solved for the initial velocity and acceleration.
19. a. at the top of its trajectory; b. yes, at the top of its trajectory; c. yes
21. Earth $v = v_0 - gt = -gt$; Moon $v' = \frac{g}{6}t'$ $v = v'$ $-gt = -\frac{g}{6}t'$ $t' = 6t$; Earth $y = -\frac{1}{2}gt^2$ Moon $y' = -\frac{1}{2}\frac{g}{6}(6t)^2 = -\frac{1}{2}g6t^2 = -6\left(\frac{1}{2}gt^2\right) = -6y$

PROBLEMS

25. a. $\vec{\mathbf{x}}_1 = (-2.0\text{ m})\hat{\mathbf{i}}$, $\vec{\mathbf{x}}_2 = (5.0\text{ m})\hat{\mathbf{i}}$; b. 7.0 m east
27. a. $t = 2.0$ s; b. $x(6.0) - x(3.0) = -8.0 - (-2.0) = -6.0\text{ m}$
29. a. 150.0 s, $\bar{v} = 156.7\text{ m/s}$; b. 45.7% the speed of sound at sea level



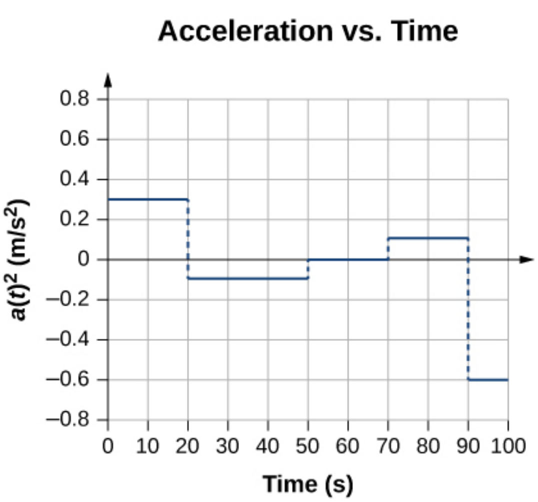
31.



33.

35. a. $v(t) = (10 - 4t)\text{m/s}$; $v(2\text{ s}) = 2\text{ m/s}$, $v(3\text{ s}) = -2\text{ m/s}$; b. $|v(2\text{ s})| = 2\text{ m/s}$, $|v(3\text{ s})| = 2\text{ m/s}$; (c) $\bar{v} = 0\text{ m/s}$

37. $a = 4.29\text{m/s}^2$



39.

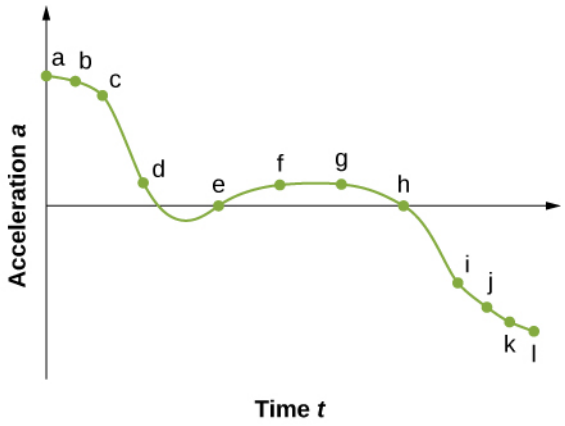
41. $a = 11.1g$

43. 150 m

45. a. 525 m;

b. $v = 180 \text{ m/s}$

47. a.



b. The acceleration has the greatest positive value at t_a

c. The acceleration is zero at t_e and t_h

d. The acceleration is negative at t_i, t_j, t_k, t_l

49. a. $a = -1.3 \text{ m/s}^2$;

b. $v_0 = 18 \text{ m/s}$;

c. $t = 13.8 \text{ s}$

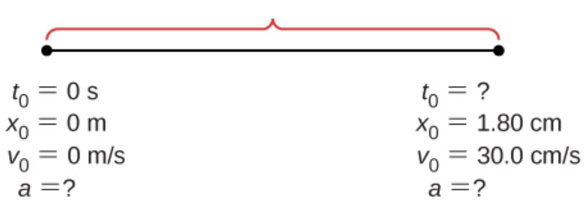
51. $v = 502.20 \text{ m/s}$

53. a.

b. Knowns: $a = 2.40 \text{ m/s}^2$, $t = 12.0 \text{ s}$, $v_0 = 0 \text{ m/s}$, and $x_0 = 0 \text{ m}$;

c. $x = x_0 + v_0 t + \frac{1}{2}at^2 = \frac{1}{2}at^2 = 2.40 \text{ m/s}^2 (12.0 \text{ s})^2 = 172.80 \text{ m}$, the answer seems reasonable at about 172.8 m; d. $v = 28.8 \text{ m/s}$

55. a.



b. Knowns: $v = 30.0 \text{ cm/s}$, $x = 1.80 \text{ cm}$;

c. $a = 250 \text{ cm/s}^2$, $t = 0.12 \text{ s}$;

d. yes

57. a. 6.87 s^2; b. $x = 52.26 \text{ m}$

59. a. $a = 8450 \text{ m/s}^2$;

b. $t = 0.0077 \text{ s}$

61. a. $a = 9.18\, g$;

b. $t = 6.67 \times 10^{-3}$ s;

c. $a = -40.0 \text{ m/s}^2$
$a = 4.08\,g$

63. Knowns: $x = 3$ m, $v = 0$ m/s, $v_0 = 54$ m/s. We want *a*, so we can use this equation: $a = -486 \text{ m/s}^2$.

65. a. $a = 32.58 \text{ m/s}^2$;
b. $v = 161.85$ m/s;
c. $v > v_{\text{max}}$, because the assumption of constant acceleration is not valid for a dragster. A dragster changes gears and would have a greater acceleration in first gear than second gear than third gear, and so on. The acceleration would be greatest at the beginning, so it would not be accelerating at 32.6 m/s^2 during the last few meters, but substantially less, and the final velocity would be less than 162 m/s.

67. a. $y = -8.23$ m
$v_1 = -18.9$ m/s;

b. $y = -18.9$ m
$v_2 = 23.8$ m/s;

c. $y = -32.0$ m
$v_3 = -28.7$ m/s;

d. $y = -47.6$ m
$v_4 = -33.6$ m/s;

e. $y = -65.6$ m
$v_5 = -38.5$ m/s

69. a. Knowns: $a = -9.8 \text{ m/s}^2$ $v_0 = -1.4$ m/s $t = 1.8$ s $y_0 = 0$ m;
b. $y = y_0 + v_0 t - \frac{1}{2}gt^2$ $y = v_0 t - \frac{1}{2}gt = -1.4 \text{ m/s}(1.8 \text{ sec}) - \frac{1}{2}(9.8)(1.8 \text{ s})^2 = -18.4$ m and the origin is at the rescuers, who are 18.4 m above the water.

71. a. $v^2 = v_0^2 - 2g(y - y_0)$ $y_0 = 0$ $v = 0$ $y = \frac{v_0^2}{2g} = \frac{(4.0 \text{ m/s})^2}{2(9.80)} = 0.82$ m; b. to the apex $v = 0.41$ s times 2 to the board = 0.82 s from the board to the water $y = y_0 + v_0 t - \frac{1}{2}gt^2$ $y = -1.80$ m $y_0 = 0$ $v_0 = 4.0$ m/s $-1.8 = 4.0t - 4.9t^2$ $4.9t^2 - 4.0t - 1.80 = 0$, solution to quadratic equation gives 1.13 s; c.
$v^2 = v_0^2 - 2g(y - y_0)$ $y_0 = 0$ $v_0 = 4.0$ m/s $y = -1.80$ m
$v = 7.16$ m/s

73. Time to the apex: $t = 1.12$ s times 2 equals 2.24 s to a height of 2.20 m. To 1.80 m in height is an additional 0.40 m.
$y = y_0 + v_0 t - \frac{1}{2}gt^2$ $y = -0.40$ m $y_0 = 0$ $v_0 = -11.0$ m/s
$y = y_0 + v_0 t - \frac{1}{2}gt^2$ $y = -0.40$ m $y_0 = 0$ $v_0 = -11.0$ m/s.
$-0.40 = -11.0t - 4.9t^2$ or $4.9t^2 + 11.0t - 0.40 = 0$

Take the positive root, so the time to go the additional 0.4 m is 0.04 s. Total time is $2.24 \text{ s} + 0.04 \text{ s} = 2.28 \text{ s}$.

75. a. $v^2 = v_0^2 - 2g(y - y_0)$ $y_0 = 0$ $v = 0$ $y = 2.50$ m
$v_0^2 = 2gy \Rightarrow v_0 = \sqrt{2(9.80)(2.50)} = 7.0$ m/s; b. $t = 0.72$ s times 2 gives 1.44 s in the air

77. a. $v = 70.0$ m/s; b. time heard after rock begins to fall: 0.75 s, time to reach the ground: 6.09 s

79. a. $A = \text{m/s}^2 \quad B = \text{m/s}^{5/2}$;

b. $$v(t) = \int a(t)dt + C_1 = \int \left(A - Bt^{1/2}\right)dt + C_1 = At - \frac{2}{3}Bt^{3/2} + C_1$$ $$v(0) = 0 = C_1 \text{ so } v(t_0) = At_0 - \frac{2}{3}Bt_0^{3/2}$$;

c. $$x(t) = \int v(t)dt + C_2 = \int \left(At - \frac{2}{3}Bt^{3/2}\right)dt + C_2 = \frac{1}{2}At^2 - \frac{4}{15}Bt^{5/2} + C_2$$ $$x(0) = 0 = C_2 \text{ so } x(t_0) = \frac{1}{2}At_0^2 - \frac{4}{15}Bt_0^{5/2}$$

81. a. $$a(t) = 3.2\text{m/s}^2 \quad t \le 5.0 \text{ s}$$ $$a(t) = 1.5\text{m/s}^2 \quad 5.0 \text{ s} \le t \le 11.0 \text{ s};$$ $$a(t) = 0\text{m/s}^2 \quad t > 11.0 \text{ s}$$

b. $$x(t) = \int v(t)dt + C_2 = \int 3.2t dt + C_2 = 1.6t^2 + C_2$$ $$t \le 5.0 \text{ s}$$ $$x(0) = 0 \Rightarrow C_2 = 0 \text{ therefore, } x(2.0 \text{ s}) = 6.4 \text{ m}$$ $$x(t) = \int v(t)dt + C_2 = \int [16.0 - 1.5(t - 5.0)]dt + C_2 = 16t - 1.5\left(\frac{t^2}{2} - 5.0t\right) + C_2$$ $$5.0 \le t \le 11.0 \text{ s}$$ $$x(5 \text{ s}) = 1.6(5.0)^2 = 40 \text{ m} = 16(5.0 \text{ s}) - 1.5\left(\frac{5^2}{2} - 5.0(5.0)\right) + C_2$$ $$40 = 98.75 + C_2 \Rightarrow C_2 = -58.75$$ $$x(7.0 \text{ s}) = 16(7.0) - 1.5\left(\frac{7^2}{2} - 5.0(7)\right) - 58.75 = 69 \text{ m}$$ $$x(t) = \int 7.0 dt + C_2 = 7t + C_2$$ $$t \ge 11.0 \text{ s}$$ $$x(11.0 \text{ s}) = 16(11) - 1.5\left(\frac{11^2}{2} - 5.0(11)\right) - 58.75 = 109 = 7(11.0 \text{ s}) + C_2 \Rightarrow C_2 = 32 \text{ m}$$ $$x(t) = 7t + 32 \text{ m}$$ $$x \ge 11.0 \text{ s} \Rightarrow x(12.0 \text{ s}) = 7(12) + 32 = 116 \text{ m}$$

ADDITIONAL PROBLEMS

83. Take west to be the positive direction.
1st plane: $\bar{v} = 600$ km/h
2nd plane $\bar{v} = 667.0$ km/h

85. $a = \frac{v - v_0}{t - t_0}$, $t = 0$, $a = \frac{-3.4 \text{ cm/s} - v_0}{4 \text{ s}} = 1.2 \text{ cm/s}^2 \Rightarrow v_0 = -8.2 \text{ cm/s}$ $v = v_0 + at = -8.2 + 1.2t$; $v = -7.0 \text{ cm/s}$ $v = -1.0 \text{ cm/s}$

87. $a = -3 \text{ m/s}^2$

89. a. $v = 8.7 \times 10^5 \text{ m/s}$;
b. $t = 7.8 \times 10^{-8} \text{ s}$

91. $1 \text{ km} = v_0(80.0 \text{ s}) + \frac{1}{2}a(80.0)^2$; $2 \text{ km} = v_0(200.0) + \frac{1}{2}a(200.0)^2$ solve simultaneously to get $a = -\frac{0.1}{2400.0}\text{km/s}^2$ and $v_0 = 0.014167 \text{ km/s}$, which is 51.0 km/h. Velocity at the end of the trip is $v = 21.0 \text{ km/h}$.

93. $a = -0.9 \text{ m/s}^2$

95. Equation for the speeding car: This car has a constant velocity, which is the average velocity, and is not accelerating, so use the equation for displacement with $x_0 = 0$: $x = x_0 + \bar{v}t = \bar{v}t$; Equation for the police car: This car is accelerating, so use the equation for displacement with $x_0 = 0$ and $v_0 = 0$, since the police car starts from rest: $x = x_0 + v_0 t + \frac{1}{2}at^2 = \frac{1}{2}at^2$; Now we have an equation of motion for each car with a common parameter, which can be eliminated to find the solution. In this case, we solve for t. Step 1, eliminating x: $x = \bar{v}t = \frac{1}{2}at^2$; Step 2, solving for t: $t = \frac{2\bar{v}}{a}$. The speeding car has a constant velocity of 40 m/s, which is its average velocity. The acceleration of the police car is 4 m/s^2. Evaluating *t*, the time for the police car to reach the speeding car, we have $t = \frac{2\bar{v}}{a} = \frac{2(40)}{4} = 20\text{ s}$.

97. At this acceleration she comes to a full stop in $t = \frac{-v_0}{a} = \frac{8}{0.5} = 16\text{ s}$, but the distance covered is $x = 8\text{ m/s}(16\text{ s}) - \frac{1}{2}(0.5)(16\text{ s})^2 = 64\text{ m}$, which is less than the distance she is away from the finish line, so she never finishes the race.

99. $x_1 = \frac{3}{2}v_0 t$

$x_2 = \frac{5}{3}x_1$

101. $v_0 = 7.9\text{ m/s}$ velocity at the bottom of the window.

$v = 7.9\text{ m/s}$

$v_0 = 14.1\text{ m/s}$

103. a. $v = 5.42\text{ m/s}$;

b. $v = 4.64\text{ m/s}$;

c. $a = 2874.28\text{ m/s}^2$;

d. $(x - x_0) = 5.11 \times 10^{-3}\text{ m}$

105. Consider the players fall from rest at the height 1.0 m and 0.3 m.
0.9 s
0.5 s

107. a. $t = 6.37\text{ s}$ taking the positive root;

b. $v = 59.5\text{ m/s}$

109. a. $y = 4.9\text{ m}$;

b. $v = 38.3\text{ m/s}$;

c. -33.3 m

111. $h = \frac{1}{2}gt^2$, *h* = total height and time to drop to ground

$\frac{2}{3}h = \frac{1}{2}g(t-1)^2$ in *t* – 1 seconds it drops 2/3*h*

$\frac{2}{3}\left(\frac{1}{2}gt^2\right) = \frac{1}{2}g(t-1)^2$ or $\frac{t^2}{3} = \frac{1}{2}(t-1)^2$

$0 = t^2 - 6t + 3 \quad t = \frac{6 \pm \sqrt{6^2 - 4 \cdot 3}}{2} = 3 \pm \frac{\sqrt{24}}{2}$

t = 5.45 s and *h* = 145.5 m. Other root is less than 1 s. Check for *t* = 4.45 s $h = \frac{1}{2}gt^2 = 97.0\text{ m} = \frac{2}{3}(145.5)$

CHALLENGE PROBLEMS

113. a. $v(t) = 10t - 12t^2\text{ m/s}, a(t) = 10 - 24t\text{ m/s}^2$;

b. $v(2\text{ s}) = -28\text{ m/s}, a(2\text{ s}) = -38\text{m/s}^2$; c. The slope of the position function is zero or the velocity is zero. There are two possible solutions: *t* = 0, which gives *x* = 0, or *t* = 10.0/12.0 = 0.83 s, which gives *x* = 1.16 m. The second answer is the correct choice; d. 0.83 s (e) 1.16 m

115. $96\text{ km/h} = 26.67\text{ m/s}, a = \frac{26.67\text{ m/s}}{4.0\text{ s}} = 6.67\text{m/s}^2$, 295.38 km/h = 82.05 m/s, $t = 12.3\text{ s}$ time to accelerate to maximum speed

$x = 504.55\text{ m}$ distance covered during acceleration

7495.44 m at a constant speed

$\frac{7495.44 \text{ m}}{82.05 \text{ m/s}} = 91.35 \text{ s}$ so total time is $91.35 \text{ s} + 12.3 \text{ s} = 103.65 \text{ s}$.

CHAPTER 4

CHECK YOUR UNDERSTANDING

4.1. (a) Taking the derivative with respect to time of the position function, we have $\vec{\mathbf{v}}(t) = 9.0t^2\,\hat{\mathbf{i}}$ and $\vec{\mathbf{v}}(3.0\text{s}) = 81.0\,\hat{\mathbf{i}}\text{ m/s}.$ (b) Since the velocity function is nonlinear, we suspect the average velocity is not equal to the instantaneous velocity. We check this and find

$$\vec{\mathbf{v}}_{\text{avg}} = \frac{\vec{\mathbf{r}}(t_2) - \vec{\mathbf{r}}(t_1)}{t_2 - t_1} = \frac{\vec{\mathbf{r}}(4.0\text{ s}) - \vec{\mathbf{r}}(2.0\text{ s})}{4.0\text{ s} - 2.0\text{ s}} = \frac{(144.0\,\hat{\mathbf{i}} - 36.0\,\hat{\mathbf{i}})\text{ m}}{2.0\text{ s}} = 54.0\,\hat{\mathbf{i}}\text{ m/s},$$

which is different from $\vec{\mathbf{v}}(3.0\text{s}) = 81.0\,\hat{\mathbf{i}}\text{ m/s}.$

4.2. The acceleration vector is constant and doesn't change with time. If *a*, *b*, and *c* are not zero, then the velocity function must be linear in time. We have $\vec{\mathbf{v}}(t) = \int \vec{\mathbf{a}}\,dt = \int (a\,\hat{\mathbf{i}} + b\,\hat{\mathbf{j}} + c\,\hat{\mathbf{k}})dt = (a\,\hat{\mathbf{i}} + b\,\hat{\mathbf{j}} + c\,\hat{\mathbf{k}})t\text{ m/s},$ since taking the derivative of the velocity function produces $\vec{\mathbf{a}}(t)$. If any of the components of the acceleration are zero, then that component of the velocity would be a constant.

4.3. (a) Choose the top of the cliff where the rock is thrown from the origin of the coordinate system. Although it is arbitrary, we typically choose time $t = 0$ to correspond to the origin. (b) The equation that describes the horizontal motion is $x = x_0 + v_x t.$ With $x_0 = 0,$ this equation becomes $x = v_x t.$ (c) **Equation 4.27** through **Equation 4.29** and **Equation 4.46** describe the vertical motion, but since $y_0 = 0$ and $v_{0y} = 0,$ these equations simplify greatly to become $y = \frac{1}{2}(v_{0y} + v_y)t = \frac{1}{2}v_y t,$ $v_y = -gt,$ $y = -\frac{1}{2}gt^2,$ and $v_y^2 = -2gy.$ (d) We use the kinematic equations to find the *x* and *y* components of the velocity at the point of impact. Using $v_y^2 = -2gy$ and noting the point of impact is −100.0 m, we find the *y* component of the velocity at impact is $v_y = 44.3\text{ m/s}.$ We are given the *x* component, $v_x = 15.0\text{ m/s},$ so we can calculate the total velocity at impact: $v = 46.8$ m/s and $\theta = 71.3°$ below the horizontal.

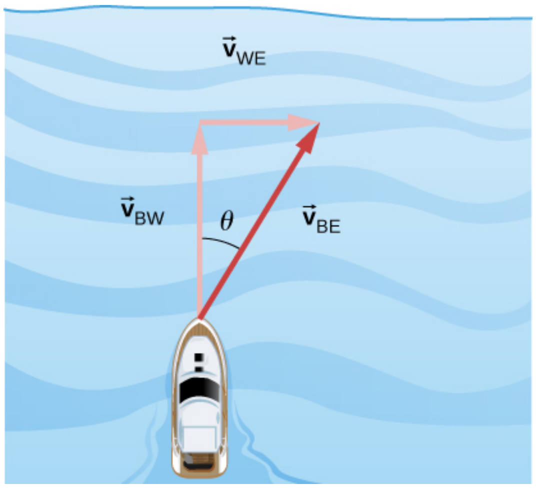
4.4. The golf shot at $30°$.

4.5. 134.0 cm/s

4.6. Labeling subscripts for the vector equation, we have B = boat, R = river, and E = Earth. The vector equation becomes $\vec{\mathbf{v}}_{\text{BE}} = \vec{\mathbf{v}}_{\text{BR}} + \vec{\mathbf{v}}_{\text{RE}}.$ We have right triangle geometry shown in Figure 04_05_BoatRiv_img. Solving for $\vec{\mathbf{v}}_{\text{BE}}$, we have

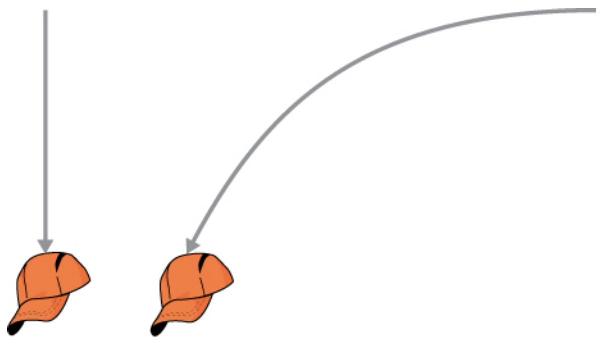
$$v_{\text{BE}} = \sqrt{v_{\text{BR}}^2 + v_{\text{RE}}^2} = \sqrt{4.5^2 + 3.0^2}$$

$$v_{\text{BE}} = 5.4\text{ m/s},\quad \theta = \tan^{-1}\left(\frac{3.0}{4.5}\right) = 33.7°.$$



CONCEPTUAL QUESTIONS

1. straight line
3. The slope must be zero because the velocity vector is tangent to the graph of the position function.
5. No, motions in perpendicular directions are independent.
7. a. no; b. minimum at apex of trajectory and maximum at launch and impact; c. no, velocity is a vector; d. yes, where it lands
9. They both hit the ground at the same time.
11. yes
13. If he is going to pass the ball to another player, he needs to keep his eyes on the reference frame in which the other players on the team are located.



15.

PROBLEMS

17. $\vec{r} = 1.0\hat{i} - 4.0\hat{j} + 6.0\hat{k}$

19. $\Delta\vec{r}_{Total} = 472.0\,m\,\hat{i} + 80.3\,m\,\hat{j}$

21. $\text{Sum of displacements} = -6.4\,km\,\hat{i} + 9.4\,km\,\hat{j}$

23. a. $\vec{v}(t) = 8.0t\,\hat{i} + 6.0t^2\,\hat{k}, \quad \vec{v}(0) = 0, \quad \vec{v}(1.0) = 8.0\,\hat{i} + 6.0\,\hat{k}\,m/s$,

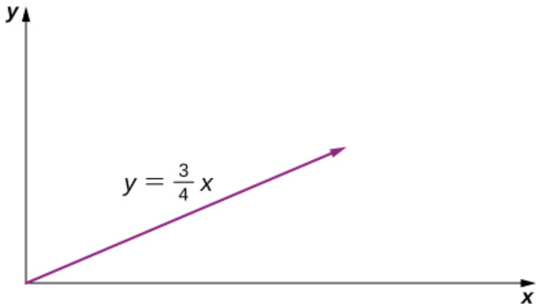
b. $\vec{v}_{avg} = 4.0\,\hat{i} + 2.0\,\hat{k}\,m/s$

25. $\Delta\vec{r}_1 = 20.00\,m\,\hat{j}, \Delta\vec{r}_2 = (2.000 \times 10^4\,m)(\cos 30°\,\hat{i} + \sin 30°\,\hat{j})$

$\Delta\vec{r} = 1.700 \times 10^4\,m\,\hat{i} + 1.002 \times 10^4\,m\,\hat{j}$

27. a. $\vec{\mathbf{v}}(t) = (4.0t\,\hat{\mathbf{i}} + 3.0t\,\hat{\mathbf{j}})\text{m/s}, \quad \vec{\mathbf{r}}(t) = (2.0t^2\,\hat{\mathbf{i}} + \frac{3}{2}t^2\,\hat{\mathbf{j}})\,\text{m}$,

b. $x(t) = 2.0t^2\,\text{m},\ y(t) = \frac{3}{2}t^2\,\text{m},\ t^2 = \frac{x}{2} \Rightarrow y = \frac{3}{4}x$



29. a. $\vec{\mathbf{v}}(t) = (6.0t\,\hat{\mathbf{i}} - 21.0t^2\,\hat{\mathbf{j}} + 10.0t^{-3}\,\hat{\mathbf{k}})\text{m/s}$,

b. $\vec{\mathbf{a}}(t) = (6.0\,\hat{\mathbf{i}} - 42.0t\,\hat{\mathbf{j}} - 30t^{-4}\,\hat{\mathbf{k}})\text{m/s}^2$,

c. $\vec{\mathbf{v}}(2.0s) = (12.0\,\hat{\mathbf{i}} - 84.0\,\hat{\mathbf{j}} + 1.25\,\hat{\mathbf{k}})\text{m/s}$,

d. $\vec{\mathbf{v}}(1.0\,\text{s}) = 6.0\,\hat{\mathbf{i}} - 21.0\,\hat{\mathbf{j}} + 10.0\,\hat{\mathbf{k}}\,\text{m/s},\ \left|\vec{\mathbf{v}}(1.0\,\text{s})\right| = 24.0\,\text{m/s}$

$\vec{\mathbf{v}}(3.0\,\text{s}) = 18.0\,\hat{\mathbf{i}} - 189.0\,\hat{\mathbf{j}} + 0.37\,\hat{\mathbf{k}}\,\text{m/s},\ \left|\vec{\mathbf{v}}(3.0\,\text{s})\right| = 199.0\,\text{m/s}$,

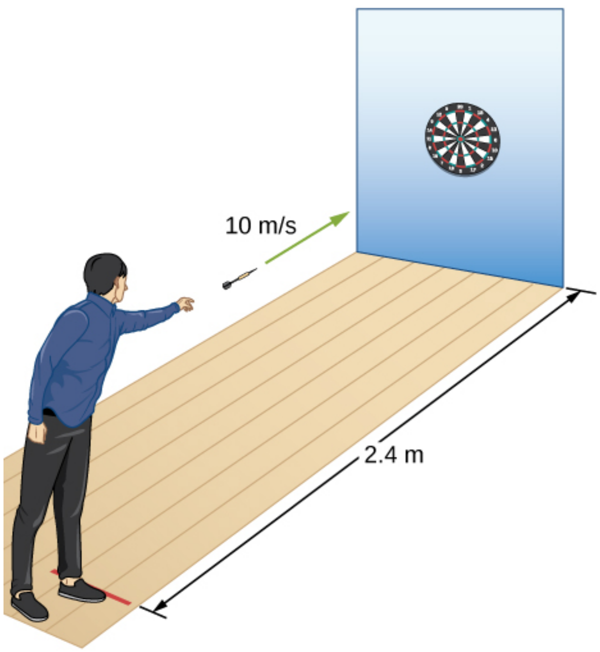
e. $\vec{\mathbf{r}}(t) = (3.0t^2\,\hat{\mathbf{i}} - 7.0t^3\,\hat{\mathbf{j}} - 5.0t^{-2}\,\hat{\mathbf{k}})\text{cm}$

$\vec{\mathbf{v}}_{\text{avg}} = 9.0\,\hat{\mathbf{i}} - 49.0\,\hat{\mathbf{j}} - 6.3\,\hat{\mathbf{k}}\,\text{m/s}$

31. a. $\vec{\mathbf{v}}(t) = -\sin(1.0t)\,\hat{\mathbf{i}} + \cos(1.0t)\,\hat{\mathbf{j}} + \hat{\mathbf{k}}$, b. $\vec{\mathbf{a}}(t) = -\cos(1.0t)\,\hat{\mathbf{i}} - \sin(1.0t)\,\hat{\mathbf{j}}$

33. a. $t = 0.55\,\text{s}$, b. $x = 110\,\text{m}$

35. a. $t = 0.24\text{s},\ d = 0.28\,\text{m}$, b. They aim high.



37. a., $t = 12.8\text{ s},\ x = 5619\text{ m}$ b. $v_y = 125.0\text{ m/s},\ v_x = 439.0\text{ m/s},\ \left|\vec{v}\right| = 456.0\text{ m/s}$

39. a. $v_y = v_{0y} - gt,\quad t = 10\text{s},\ v_y = 0,\quad v_{0y} = 98.0\text{ m/s},\quad v_0 = 196.0\text{ m/s}$, b. $h = 490.0\text{ m},$

c. $v_{0x} = 169.7\text{ m/s},\ x = 3394.0\text{ m},$

d. $$\begin{aligned} x &= 2545.5\text{ m} \\ y &= 465.5\text{ m} \\ \vec{\mathbf{s}} &= 2545.5\text{ m}\,\hat{\mathbf{i}} + 465.5\text{ m}\,\hat{\mathbf{j}} \end{aligned}$$

41. $-100\text{ m} = (-2.0\text{ m/s})t - (4.9\text{ m/s}^2)t^2,\quad t = 4.3\text{ s},\ x = 86.0\text{ m}$

43. $R_{Moon} = 48\text{ m}$

45. a. $v_{0y} = 24\text{ m/s}\ \ v_y^2 = v_{0y}^2 - 2gy \Rightarrow h = 23.4\text{ m}$,

b. $t = 3\text{ s}\ \ v_{0x} = 18\text{ m/s}\ \ x = 54\text{ m}$,

c. $y = -100\text{ m}\ \ y_0 = 0\ \ y - y_0 = v_{0y}t - \frac{1}{2}gt^2\quad -100 = 24t - 4.9t^2\quad \Rightarrow t = 7.58\text{ s}$,

d. $x = 136.44\text{ m}$,

e. $t = 2.0\text{ s}\ \ y = 28.4\text{ m}\ \ x = 36\text{ m}$

$t = 4.0\text{ s}\ \ y = 17.6\text{ m}\ \ x = 22.4\text{ m}$

$t = 6.0\text{ s}\ \ y = -32.4\text{ m}\ \ x = 108\text{ m}$

47. $v_{0y} = 12.9\text{ m/s}\ y - y_0 = v_{0y}t - \frac{1}{2}gt^2\quad -20.0 = 12.9t - 4.9t^2$

$t = 3.7\text{ s}\ \ v_{0x} = 15.3\text{ m/s} \Rightarrow x = 56.7\text{ m}$

So the golfer's shot lands 13.3 m short of the green.

49. a. $R = 60.8\text{ m}$,

b. $R = 137.8\text{ m}$

51. a. $v_y^2 = v_{0y}^2 - 2gy \Rightarrow y = 2.9\text{ m/s}$

$y = 3.3\text{ m/s}$

$y = \frac{v_{0y}^2}{2g} = \frac{(v_0\sin\theta)^2}{2g} \Rightarrow \sin\theta = 0.91 \Rightarrow \theta = 65.5°$

53. $R = 18.5\text{ m}$

55. $y = (\tan\theta_0)x - \left[\frac{g}{2(v_0\cos\theta_0)^2}\right]x^2 \Rightarrow v_0 = 16.4\text{ m/s}$

57. $R = \frac{v_0^2\sin 2\theta_0}{g} \Rightarrow \theta_0 = 15.0°$

59. It takes the wide receiver 1.1 s to cover the last 10 m of his run.

$T_{\text{tof}} = \frac{2(v_0\sin\theta)}{g} \Rightarrow \sin\theta = 0.27 \Rightarrow \theta = 15.6°$

61. $a_C = 40\text{ m/s}^2$

63. $a_C = \frac{v^2}{r} \Rightarrow v^2 = r\ \ a_C = 78.4,\quad v = 8.85\text{ m/s}$

$T = 5.68\text{ s},$ which is $0.176\text{ rev/s} = 10.6\text{ rev/min}$

65. Venus is 108.2 million km from the Sun and has an orbital period of 0.6152 y.

$r = 1.082 \times 10^{11}\text{ m}\ \ T = 1.94 \times 10^7\text{ s}$

$v = 3.5 \times 10^4\text{ m/s},\ \text{a}_C = 1.135 \times 10^{-2}\text{ m/s}^2$

67. $360\text{ rev/min} = 6\text{ rev/s}$

$v = 3.8\text{ m/s}\ \ a_C = 144.\text{ m/s}^2$

69. a. $O'(t) = (4.0\hat{\mathbf{i}} + 3.0\hat{\mathbf{j}} + 5.0\hat{\mathbf{k}})t\text{ m}$,

b. $\vec{\mathbf{r}}_{PS} = \vec{\mathbf{r}}_{PS'} + \vec{\mathbf{r}}_{S'S}$, $\quad \vec{\mathbf{r}}(t) = \vec{\mathbf{r}}'(t) + (4.0\hat{\mathbf{i}} + 3.0\hat{\mathbf{j}} + 5.0\hat{\mathbf{k}})t\text{ m}$,

c. $\vec{\mathbf{v}}(t) = \vec{\mathbf{v}}'(t) + (4.0\hat{\mathbf{i}} + 3.0\hat{\mathbf{j}} + 5.0\hat{\mathbf{k}})\text{ m/s}$, d. The accelerations are the same.

71. $\vec{\mathbf{v}}_{PC} = (2.0\hat{\mathbf{i}} + 5.0\hat{\mathbf{j}} + 4.0\hat{\mathbf{k}})\text{m/s}$

73. a. A = air, S = seagull, G = ground

$\vec{\mathbf{v}}_{\text{SA}} = 9.0\text{ m/s}$ velocity of seagull with respect to still air

$\vec{\mathbf{v}}_{\text{AG}} = ?\quad \vec{\mathbf{v}}_{\text{SG}} = 5\text{ m/s}\quad \vec{\mathbf{v}}_{\text{SG}} = \vec{\mathbf{v}}_{\text{SA}} + \vec{\mathbf{v}}_{\text{AG}} \Rightarrow \vec{\mathbf{v}}_{\text{AG}} = \vec{\mathbf{v}}_{\text{SG}} - \vec{\mathbf{v}}_{\text{SA}}$

$\vec{\mathbf{v}}_{\text{AG}} = -4.0\text{ m/s}$

b. $\vec{\mathbf{v}}_{\text{SG}} = \vec{\mathbf{v}}_{\text{SA}} + \vec{\mathbf{v}}_{\text{AG}} \Rightarrow \vec{\mathbf{v}}_{\text{SG}} = -13.0\text{ m/s}$

$\frac{-6000\text{ m}}{-13.0\text{ m/s}} = 7\text{ min }42\text{ s}$

75. Take the positive direction to be the same direction that the river is flowing, which is east. S = shore/Earth, W = water, and B = boat.

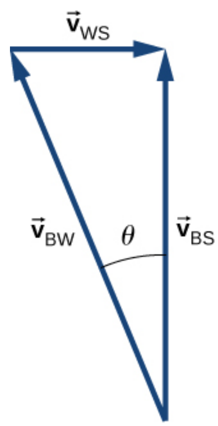
a. $\vec{\mathbf{v}}_{\text{BS}} = 11\text{ km/h}$

$t = 8.2\text{ min}$

b. $\vec{\mathbf{v}}_{\text{BS}} = -5\text{ km/h}$

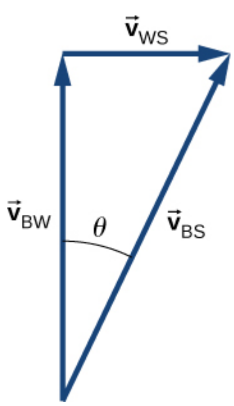
$t = 18\text{ min}$

c. $\vec{\mathbf{v}}_{\text{BS}} = \vec{\mathbf{v}}_{\text{BW}} + \vec{\mathbf{v}}_{\text{WS}}\quad \theta = 22°$ west of north



d. $|\vec{\mathbf{v}}_{\text{BS}}| = 7.4\text{ km/h}\quad t = 6.5\text{ min}$

e. $\vec{\mathbf{v}}_{\text{BS}} = 8.54\text{ km/h},$ but only the component of the velocity straight across the river is used to get the time



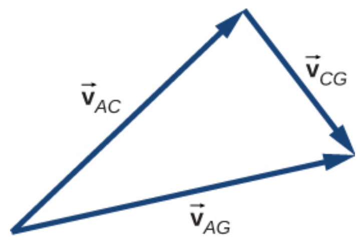
$t = 6.0\text{ min}$

Downstream = 0.3 km

77. $\vec{v}_{AG} = \vec{v}_{AC} + \vec{v}_{CG}$

$|\vec{v}_{AC}| = 25\text{ km/h}$ $|\vec{v}_{CG}| = 15\text{ km/h}$ $|\vec{v}_{AG}| = 29.15\text{ km/h}$ $\vec{v}_{AG} = \vec{v}_{AC} + \vec{v}_{CG}$

The angle between $\vec{v}_{AC}$ and $\vec{v}_{AG}$ is $31°$, so the direction of the wind is $14°$ north of east.



ADDITIONAL PROBLEMS

79. $a_{\text{C}} = 39.6\text{ m/s}^2$

81. $90.0\text{ km/h} = 25.0\text{ m/s},\ 9.0\text{ km/h} = 2.5\text{ m/s},\quad 60.0\text{ km/h} = 16.7\text{ m/s}$

$a_{\text{T}} = -2.5\text{ m/s}^2, a_{\text{C}} = 1.86\text{ m/s}^2, a = 3.1\text{ m/s}^2$

83. The radius of the circle of revolution at latitude λ is $R_E \cos\lambda.$ The velocity of the body is $\frac{2\pi r}{T}.\ a_C = \frac{4\pi^2 R_E \cos\lambda}{T^2}$ for $\lambda = 40°,\ a_{\text{C}} = 0.26\%\ g$

85. $a_{\text{T}} = 3.00\text{ m/s}^2$

$v(5\text{ s}) = 15.00\text{ m/s}$ $a_{\text{C}} = 150.00\text{ m/s}^2$ $\theta = 88.8°$ with respect to the tangent to the circle of revolution directed inward. $|\vec{a}| = 150.03\text{ m/s}^2$

87. $\vec{a}(t) = -A\omega^2 \cos\omega t\,\hat{i} - A\omega^2 \sin\omega t\,\hat{j}$

$a_C = 5.0\text{ m}\omega^2 \quad \omega = 0.89\text{ rad/s}$

$\vec{v}(t) = -2.24\text{ m/s}\,\hat{i} - 3.87\text{ m/s}\,\hat{j}$

89. $\vec{r}_1 = 1.5\hat{j} + 4.0\hat{k} \quad \vec{r}_2 = \Delta\vec{r} + \vec{r}_1 = 2.5\hat{i} + 4.7\hat{j} + 2.8\hat{k}$

91. $v_x(t) = 265.0\text{ m/s}$

$v_y(t) = 20.0\text{ m/s}$

$\vec{v}(5.0\text{ s}) = (265.0\hat{i} + 20.0\hat{j})\text{m/s}$

93. $R = 1.07\text{ m}$

95. $v_0 = 20.1\text{ m/s}$

97. $v = 3072.5\text{ m/s}$

$a_{\text{C}} = 0.223\text{ m/s}^2$

CHALLENGE PROBLEMS

99. a. $-400.0\text{ m} = v_{0y}t - 4.9t^2 \quad 359.0\text{ m} = v_{0x}t \quad t = \frac{359.0}{v_{0x}} \quad -400.0 = 359.0\frac{v_{0y}}{v_{0x}} - 4.9(\frac{359.0}{v_{0x}})^2$

$-400.0 = 359.0\tan 40 - \frac{631{,}516.9}{v_{0x}^2} \Rightarrow v_{0x}^2 = 900.6 \quad v_{0x} = 30.0\text{ m/s} \quad v_{0y} = v_{0x}\tan 40 = 25.2\text{ m/s}$

$v = 39.2\text{ m/s}$, b. $t = 12.0\text{ s}$

101. a. $\vec{r}_{TC} = (-32 + 80t)\hat{i} + 50t\hat{j},\ |\vec{r}_{TC}|^2 = (-32 + 80t)^2 + (50t)^2$

$2r\frac{dr}{dt} = 2(-32 + 80t) + 100t \quad \frac{dr}{dt} = \frac{2(-32 + 80t) + 100t}{2r} = 0$

$260t = 64 \Rightarrow t = 15 \text{ min}$,

b. $|\vec{\mathbf{r}}_{TC}| = 17 \text{ km}$

CHAPTER 5

CHECK YOUR UNDERSTANDING

5.1. 14 N, $56°$ measured from the positive x-axis

5.2. a. His weight acts downward, and the force of air resistance with the parachute acts upward. b. neither; the forces are equal in magnitude

5.3. 0.1 m/s^2

5.4. 40 m/s^2

5.5. a. $159.0\hat{\mathbf{i}} + 770.0\hat{\mathbf{j}}$ N; b. $0.1590\hat{\mathbf{i}} + 0.7700\hat{\mathbf{j}}$ N

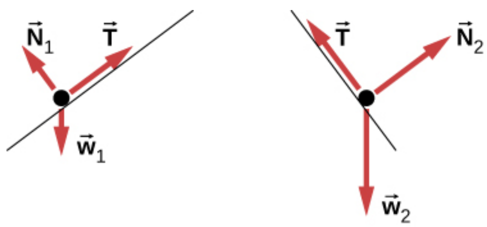
5.6. $a = 2.78 \text{ m/s}^2$

5.7. a. 3.0 m/s^2; b. 18 N

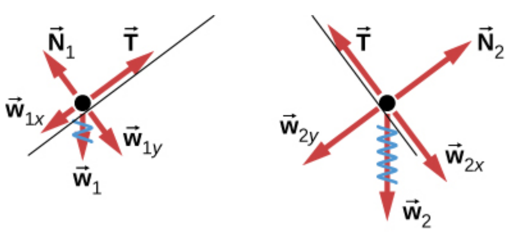
5.8. a. 1.7 m/s^2; b. 1.3 m/s^2

5.9. 6.0×10^2 N

5.10.



;



CONCEPTUAL QUESTIONS

1. Forces are directional and have magnitude.

3. The cupcake velocity before the braking action was the same as that of the car. Therefore, the cupcakes were unrestricted bodies in motion, and when the car suddenly stopped, the cupcakes kept moving forward according to Newton's first law.

5. No. If the force were zero at this point, then there would be nothing to change the object's momentary zero velocity. Since we do not observe the object hanging motionless in the air, the force could not be zero.

7. The astronaut is truly weightless in the location described, because there is no large body (planet or star) nearby to exert a gravitational force. Her mass is 70 kg regardless of where she is located.

9. The force you exert (a contact force equal in magnitude to your weight) is small. Earth is extremely massive by comparison. Thus, the acceleration of Earth would be incredibly small. To see this, use Newton's second law to calculate the acceleration you would cause if your weight is 600.0 N and the mass of Earth is 6.00×10^{24} kg.

11. a. action: Earth pulls on the Moon, reaction: Moon pulls on Earth; b. action: foot applies force to ball, reaction: ball applies force to foot; c. action: rocket pushes on gas, reaction: gas pushes back on rocket; d. action: car tires push backward on road, reaction: road pushes forward on tires; e. action: jumper pushes down on ground, reaction: ground pushes up on jumper; f. action: gun pushes forward on bullet, reaction: bullet pushes backward on gun.

13. a. The rifle (the shell supported by the rifle) exerts a force to expel the bullet; the reaction to this force is the force that the bullet exerts on the rifle (shell) in opposite direction. b. In a recoilless rifle, the shell is not secured in the rifle; hence, as the bullet is pushed to move forward, the shell is pushed to eject from the opposite end of the barrel. c. It is not safe to stand behind a recoilless

rifle.
15. a. Yes, the force can be acting to the left; the particle would experience deceleration and lose speed. B. Yes, the force can be acting downward because its weight acts downward even as it moves to the right.
17. two forces of different types: weight acting downward and normal force acting upward

PROBLEMS

19. a. $\vec{\mathbf{F}}_{\text{net}} = 5.0\,\hat{\mathbf{i}} + 10.0\,\hat{\mathbf{j}}\ \text{N}$; b. the magnitude is $F_{\text{net}} = 11\ \text{N}$, and the direction is $\theta = 63°$

21. a. $\vec{\mathbf{F}}_{\text{net}} = 660.0\,\hat{\mathbf{i}} + 150.0\,\hat{\mathbf{j}}\ \text{N}$; b. $F_{\text{net}} = 676.6\ \text{N}$ at $\theta = 12.8°$ from David's rope

23. a. $\vec{\mathbf{F}}_{\text{net}} = 95.0\,\hat{\mathbf{i}} + 283\,\hat{\mathbf{j}}\ \text{N}$; b. 299 N at $71°$ north of east; c. $\vec{\mathbf{F}}_{\text{DS}} = -\left(95.0\,\hat{\mathbf{i}} + 283\,\hat{\mathbf{j}}\right)\text{N}$

25. Running from rest, the sprinter attains a velocity of $v = 12.96\ \text{m/s}$, at end of acceleration. We find the time for acceleration using $x = 20.00\ \text{m} = 0 + 0.5at_1{}^2$, or $t_1 = 3.086\ \text{s}$. For maintained velocity, $x_2 = vt_2$, or $t_2 = x_2/v = 80.00\ \text{m}/12.96\ \text{m/s} = 6.173\ \text{s}$. Total time $= 9.259\ \text{s}$.

27. a. $m = 56.0\ \text{kg}$; b. $a_{\text{meas}} = a_{\text{astro}} + a_{\text{ship}}$, where $a_{\text{ship}} = \dfrac{m_{\text{astro}} a_{\text{astro}}}{m_{\text{ship}}}$; c. If the force could be exerted on the astronaut by another source (other than the spaceship), then the spaceship would not experience a recoil.

29. $F_{\text{net}} = 4.12 \times 10^5\ \text{N}$

31. $a = 253\ \text{m/s}^2$

33. $F_{\text{net}} = F - f = ma \Rightarrow F = 1.26 \times 10^3\ \text{N}$

35. $$\begin{aligned} v^2 &= v_0^2 + 2ax \Rightarrow a = -7.80\ \text{m/s}^2 \\ F_{\text{net}} &= -7.80 \times 10^3\ \text{N} \end{aligned}$$

37. a. $\vec{\mathbf{F}}_{\text{net}} = m\,\vec{\mathbf{a}} \Rightarrow \vec{\mathbf{a}} = 9.0\,\hat{\mathbf{i}}\ \text{m/s}^2$; b. The acceleration has magnitude $9.0\ \text{m/s}^2$, so $x = 110\ \text{m}$.

39. $1.6\,\hat{\mathbf{i}} - 0.8\,\hat{\mathbf{j}}\ \text{m/s}^2$

41. a. $$\begin{aligned} w_{\text{Moon}} &= mg_{\text{Moon}} \\ m &= 150\ \text{kg} \\ w_{\text{Earth}} &= 1.5 \times 10^3\ \text{N} \end{aligned}$$; b. Mass does not change, so the suited astronaut's mass on both Earth and the Moon is $150\ \text{kg}$.

43. a. $$\begin{aligned} F_{\text{h}} &= 3.68 \times 10^3\ \text{N and} \\ w &= 7.35 \times 10^2\ \text{N} \\ \frac{F_{\text{h}}}{w} &= 5.00\ \text{times greater than weight} \end{aligned}$$;
b. $$\begin{aligned} F_{\text{net}} &= 3750\ \text{N} \\ \theta &= 11.3°\ \text{from horizontal} \end{aligned}$$

45. $$\begin{aligned} w &= 19.6\ \text{N} \\ F_{\text{net}} &= 5.40\ \text{N} \\ F_{\text{net}} &= ma \Rightarrow a = 2.70\ \text{m/s}^2 \end{aligned}$$

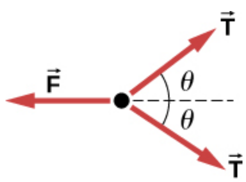
47. $0.60\,\hat{\mathbf{i}} - 8.4\,\hat{\mathbf{j}}\ \text{m/s}^2$

49. 497 N

51. a. $F_{\text{net}} = 2.64 \times 10^7\ \text{N}$; b. The force exerted on the ship is also $2.64 \times 10^7\ \text{N}$ because it is opposite the shell's direction of motion.

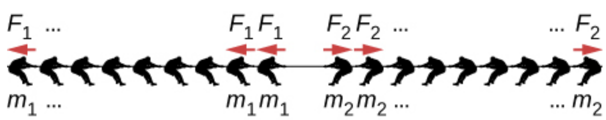
53. Because the weight of the history book is the force exerted by Earth on the history book, we represent it as $\vec{\mathbf{F}}_{\text{EH}} = -14\,\hat{\mathbf{j}}\ \text{N}$. Aside from this, the history book interacts only with the physics book. Because the acceleration of the history book is zero, the net force on it is zero by Newton's second law: $\vec{\mathbf{F}}_{\text{PH}} + \vec{\mathbf{F}}_{\text{EH}} = \vec{\mathbf{0}}$, where $\vec{\mathbf{F}}_{\text{PH}}$ is the force exerted by the physics book on the history book. Thus, $\vec{\mathbf{F}}_{\text{PH}} = -\vec{\mathbf{F}}_{\text{EH}} = -\left(-14\hat{\mathbf{j}}\right)\text{N} = 14\hat{\mathbf{j}}\ \text{N}.$ We find that the physics book exerts an upward force of magnitude 14 N on the history book. The physics book has three forces exerted on it: $\vec{\mathbf{F}}_{\text{EP}}$ due to Earth, $\vec{\mathbf{F}}_{\text{HP}}$ due to the history book, and $\vec{\mathbf{F}}_{\text{DP}}$ due to the desktop. Since the physics book weighs 18 N, $\vec{\mathbf{F}}_{\text{EP}} = -18\hat{\mathbf{j}}\ \text{N}.$ From Newton's third law, $\vec{\mathbf{F}}_{\text{HP}} = -\vec{\mathbf{F}}_{\text{PH}},$ so $\vec{\mathbf{F}}_{\text{HP}} = -14\hat{\mathbf{j}}\ \text{N}.$ Newton's second law applied to the physics book gives $\sum\vec{\mathbf{F}} = \vec{\mathbf{0}}$, or $\vec{\mathbf{F}}_{\text{DP}} + \vec{\mathbf{F}}_{\text{EP}} + \vec{\mathbf{F}}_{\text{HP}} = \vec{\mathbf{0}}$, so $\vec{\mathbf{F}}_{\text{DP}} = -\left(-18\hat{\mathbf{j}}\right) - \left(-14\hat{\mathbf{j}}\right) = 32\hat{\mathbf{j}}\ \text{N}.$ The desk exerts an upward force of 32 N on the physics book. To arrive at this solution, we apply Newton's second law twice and Newton's third law once.

55. a. The free-body diagram of the pulley closest to the foot:



b. $T = mg, \quad F = 2T\cos\theta = 2mg\cos\theta$

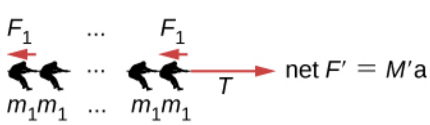
57. a.



$$\begin{aligned} F_{\text{net}} &= Ma\,; F_1 = 1350\ \text{N}; F_2 = 1365\ \text{N} \\ 9(F_2 - F_1) &= 9(m_1 + m_2)a;\ m_1 = 68\ \text{kg}; m_2 = 73\ \text{kg} \\ a &= 0.11\ \text{m/s}^2; \end{aligned}$$

Thus, the heavy team wins.

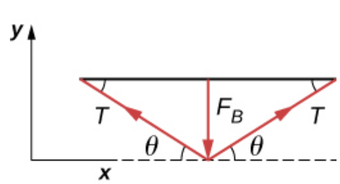
b.



$$\begin{aligned} T - 9F_1 &= 9m_1 a \Rightarrow T = 9m_1 a + 9F_1 \\ &= 1.2 \times 10^4\ \text{N} \end{aligned}$$

59. a. $T = 1.96 \times 10^{-4}$ N;

b. $T' = 4.71 \times 10^{-4}$ N
$\frac{T'}{T} = 2.40$ times the tension in the vertical strand



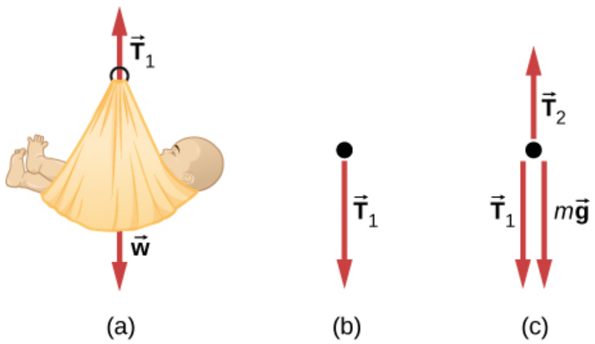
61.

$$F_{y\,\text{net}} = F_{\perp} - 2T\sin\theta = 0$$
$$F_{\perp} = 2T\sin\theta$$
$$T = \frac{F_{\perp}}{2\sin\theta}$$

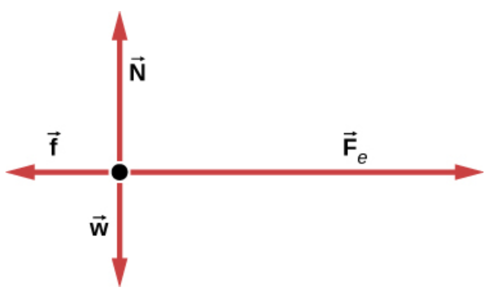
63. a. see **Example 5.13**; b. 1.5 N; c. 15 N

65. a. 5.6 kg; b. 55 N; c. $T_2 = 60\text{ N}$;

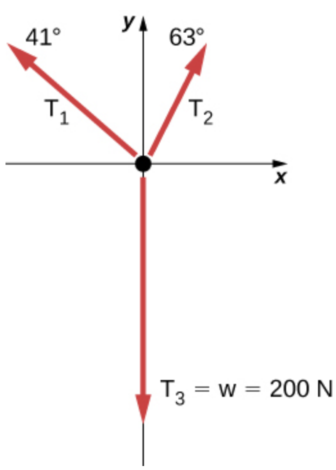
d.



67. a. 4.9 m/s^2, 17 N; b. 9.8 N



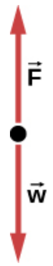
69.



71.

ADDITIONAL PROBLEMS

73. 5.90 kg



75.

77. a. $F_{\text{net}} = \dfrac{m(v^2 - v_0{}^2)}{2x}$; b. 2590 N

79. $\vec{\mathbf{F}}_{\text{net}} = 4.05\,\hat{\mathbf{i}} + 12.0\,\hat{\mathbf{j}}\,\text{N}$

$\vec{\mathbf{F}}_{\text{net}} = m\vec{\mathbf{a}} \Rightarrow \vec{\mathbf{a}} = 0.405\,\hat{\mathbf{i}} + 1.20\,\hat{\mathbf{j}}\ \text{m/s}^2$

81. $\vec{\mathbf{F}}_{\text{net}} = \vec{\mathbf{F}}_{\text{A}} + \vec{\mathbf{F}}_{\text{B}}$

$\vec{\mathbf{F}}_{\text{net}} = A\,\hat{\mathbf{i}} + \left(-1.41A\,\hat{\mathbf{i}} - 1.41A\,\hat{\mathbf{j}}\right)$

$\vec{\mathbf{F}}_{\text{net}} = A\left(-0.41\,\hat{\mathbf{i}} - 1.41\,\hat{\mathbf{j}}\right)$

$\theta = 254°$

(We add $180°$, because the angle is in quadrant IV.)

83. $F = 2kmx$; First, take the derivative of the velocity function to obtain $a = 2kx$. Then apply Newton's second law $F = ma = m(2kx) = 2kmx$.

85. a. For box A, $N_{\text{A}} = mg$ and $N_{\text{B}} = mg\cos\theta$; b. $N_{\text{A}} > N_{\text{B}}$ because for $\theta < 90°$, $\cos\theta < 1$; c. $N_{\text{A}} > N_{\text{B}}$ when $\theta = 10°$

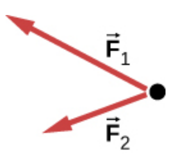
87. a. 8.66 N; b. 0.433 m

89. 0.40 or 40%

91. 16 N

CHALLENGE PROBLEMS

93. a.



; b. No; $\vec{\mathbf{F}}_{\text{R}}$ is not shown, because it would replace $\vec{\mathbf{F}}_1$ and $\vec{\mathbf{F}}_2$. (If we want to show it, we could draw it and then place squiggly lines on $\vec{\mathbf{F}}_1$ and $\vec{\mathbf{F}}_2$ to show that they are no longer considered.

95. a. 14.1 m/s; b. 601 N

97. $\frac{F}{m}t^2$

99. 936 N

101. $\vec{\mathbf{a}} = -248\,\hat{\mathbf{i}} - 433\,\hat{\mathbf{j}}\,\text{m/s}^2$

103. $0.548\ \text{m/s}^2$

105. a. $T_1 = \dfrac{2mg}{\sin\theta}$, $T_2 = \dfrac{mg}{\sin\left(\arctan\left(\frac{1}{2}\tan\theta\right)\right)}$, $T_3 = \dfrac{2mg}{\tan\theta}$; b. $\phi = \arctan\left(\frac{1}{2}\tan\theta\right)$; c. $2.56°$; (d) $x = d\left(2\cos\theta + 2\cos\left(\arctan\left(\frac{1}{2}\tan\theta\right)\right) + 1\right)$

107. a. $\vec{\mathbf{a}} = \left(\frac{5.00}{m}\hat{\mathbf{i}} + \frac{3.00}{m}\hat{\mathbf{j}}\right)\text{m/s}^2$; b. 1.38 kg; c. 21.2 m/s; d. $\vec{\mathbf{v}} = \left(18.1\hat{\mathbf{i}} + 10.9\hat{\mathbf{j}}\right)\text{m/s}^2$

109. a. $0.900\hat{\mathbf{i}} + 0.600\hat{\mathbf{j}}\ \text{N}$; b. 1.08 N

CHAPTER 6

CHECK YOUR UNDERSTANDING

6.1. $F_s = 645\ \text{N}$

6.2. $a = 3.68\ \text{m/s}^2,\quad T = 18.4\ \text{N}$

6.3. $T = \frac{2m_1 m_2}{m_1 + m_2}g$ (This is found by substituting the equation for acceleration in **Figure 6.7** (a), into the equation for tension in **Figure 6.7** (b).)

6.4. 1.49 s
6.5. 49.4 degrees
6.6. 128 m; no
6.7. a. 4.9 N; b. 0.98 m/s^2
6.8. $-0.23\ \text{m/s}^2$; the negative sign indicates that the snowboarder is slowing down.
6.9. 0.40
6.10. 34 m/s
6.11. 0.27 kg/m

CONCEPTUAL QUESTIONS

1. The scale is in free fall along with the astronauts, so the reading on the scale would be 0. There is no difference in the apparent weightlessness; in the aircraft and in orbit, free fall is occurring.
3. If you do not let up on the brake pedal, the car's wheels will lock so that they are not rolling; sliding friction is now involved and the sudden change (due to the larger force of static friction) causes the jerk.
5. 5.00 N
7. Centripetal force is defined as any net force causing uniform circular motion. The centripetal force is not a new kind of force. The label "centripetal" refers to *any* force that keeps something turning in a circle. That force could be tension, gravity, friction, electrical attraction, the normal force, or any other force. Any combination of these could be the source of centripetal force, for example, the centripetal force at the top of the path of a tetherball swung through a vertical circle is the result of both tension and gravity.
9. The driver who cuts the corner (on Path 2) has a more gradual curve, with a larger radius. That one will be the better racing line. If the driver goes too fast around a corner using a racing line, he will still slide off the track; the key is to stay at the maximum value of static friction. So, the driver wants maximum possible speed and maximum friction. Consider the equation for centripetal force: $F_c = m\frac{v^2}{r}$ where *v* is speed and *r* is the radius of curvature. So by decreasing the curvature (1/*r*) of the path that the car takes, we reduce the amount of force the tires have to exert on the road, meaning we can now increase the speed, *v*. Looking at this from the point of view of the driver on Path 1, we can reason this way: the sharper the turn, the smaller the turning circle; the smaller the turning circle, the larger is the required centripetal force. If this centripetal force is not exerted, the result is a skid.
11. The barrel of the dryer provides a centripetal force on the clothes (including the water droplets) to keep them moving in a circular path. As a water droplet comes to one of the holes in the barrel, it will move in a path tangent to the circle.
13. If there is no friction, then there is no centripetal force. This means that the lunch box will move along a path tangent to the circle, and thus follows path *B*. The dust trail will be straight. This is a result of Newton's first law of motion.
15. There must be a centripetal force to maintain the circular motion; this is provided by the nail at the center. Newton's third law explains the phenomenon. The action force is the force of the string on the mass; the reaction force is the force of the mass on the string. This reaction force causes the string to stretch.
17. Since the radial friction with the tires supplies the centripetal force, and friction is nearly 0 when the car encounters the ice, the car will obey Newton's first law and go off the road in a straight line path, tangent to the curve. A common misconception is that the car will follow a curved path off the road.
19. Anna is correct. The satellite is freely falling toward Earth due to gravity, even though gravity is weaker at the altitude of the satellite, and *g* is not $9.80\ \text{m/s}^2$. Free fall does not depend on the value of *g*; that is, you could experience free fall on Mars if you jumped off Olympus Mons (the tallest volcano in the solar system).
21. The pros of wearing body suits include: (1) the body suit reduces the drag force on the swimmer and the athlete can move more easily; (2) the tightness of the suit reduces the surface area of the athlete, and even though this is a small amount, it can make a difference in performance time. The cons of wearing body suits are: (1) The tightness of the suits can induce cramping and breathing problems. (2) Heat will be retained and thus the athlete could overheat during a long period of use.
23. The oil is less dense than the water and so rises to the top when a light rain falls and collects on the road. This creates a

dangerous situation in which friction is greatly lowered, and so a car can lose control. In a heavy rain, the oil is dispersed and does not affect the motion of cars as much.

PROBLEMS

25. a. 170 N; b. 170 N

27. $\vec{\mathbf{F}}_3 = (-7\hat{\mathbf{i}} + 2\hat{\mathbf{j}} + 4\hat{\mathbf{k}})\text{ N}$

29. 376 N pointing up (along the dashed line in the figure); the force is used to raise the heel of the foot.

31. −68.5 N

33. a. 7.70 m/s^2; b. 4.33 s

35. a. 46.4 m/s; b. $2.40 \times 10^3 \text{ m/s}^2$; c. 5.99×10^3 N; ratio of 245

37. a. 1.87×10^4 N; b. 1.67×10^4 N; c. 1.56×10^4 N; d. 19.4 m, 0 m/s

39. a. 10 kg; b. 90 N; c. 98 N; d. 0

41. a. 3.35 m/s^2; b. 4.2 s

43. a. 2.0 m/s^2; b. 7.8 N; c. 2.0 m/s

45. a. 0.933 m/s^2 (mass 1 accelerates up the ramp as mass 2 falls with the same acceleration); b. 21.5 N

47. a. 10.0 N; b. 97.0 N

49. a. 4.9 m/s^2; b. The cabinet will not slip. c. The cabinet will slip.

51. a. 32.3 N, $35.2°$; b. 0; c. 0.301 m/s^2 in the direction of $\vec{\mathbf{F}}_{\text{tot}}$

53.
$$\begin{aligned}\text{net } F_y &= 0 \Rightarrow N = mg\cos\theta \\ \text{net } F_x &= ma \\ a &= g(\sin\theta - \mu_\text{k}\cos\theta)\end{aligned}$$

55. a. 1.69 m/s^2; b. $5.71°$

57. a. 10.8 m/s^2; b. 7.85 m/s^2; c. 2.00 m/s^2

59. a. 9.09 m/s^2; b. 6.16 m/s^2; c. 0.294 m/s^2

61. a. 272 N, 512 N; b. 0.268

63. a. 46.5 N; b. 0.629 m/s^2

65. a. 483 N; b. 17.4 N; c. 2.24, 0.0807

67. $4.14°$

69. a. 24.6 m; b. 36.6 m/s^2; c. 3.73 times g

71. a. 16.2 m/s; b. 0.234

73. a. 179 N; b. 290 N; c. 8.3 m/s

75. 20.7 m/s

77. 21 m/s

79. 115 m/s or 414 km/h

81. $v_\text{T} = 25 \text{ m/s}; v_2 = 9.9 \text{ m/s}$

83. $\left(\frac{110}{65}\right)^2 = 2.86$ times

85. Stokes' law is $F_\text{s} = 6\pi r\eta v$. Solving for the viscosity, $\eta = \frac{F_\text{s}}{6\pi rv}$. Considering only the units, this becomes $[\eta] = \frac{\text{kg}}{\text{m}\cdot\text{s}}$.

87. $0.76 \text{ kg/m}\cdot\text{s}$

89. a. 0.049 kg/s; b. 0.57 m

91. a. 1860 N, 2.53; b. The value (1860 N) is more force than you expect to experience on an elevator. The force of 1860 N is 418 pounds, compared to the force on a typical elevator of 904 N (which is about 203 pounds); this is calculated for a speed from 0 to 10 miles per hour, which is about 4.5 m/s, in 2.00 s). c. The acceleration $a = 1.53 \times g$ is much higher than any standard elevator. The final speed is too large (30.0 m/s is VERY fast)! The time of 2.00 s is not unreasonable for an elevator.

93. 189 N

95. 15 N

97. 12 N

ADDITIONAL PROBLEMS

99. $a_x = 0.40 \text{ m/s}^2$ and $T = 11.2 \times 10^3 \text{ N}$

101. $m(6pt + 2q)$

103. $\vec{\mathbf{v}}(t) = \left(\frac{pt}{m} + \frac{nt^2}{2m}\right)\hat{\mathbf{i}} + \left(\frac{qt^2}{2}\right)\hat{\mathbf{j}}$ and $\vec{\mathbf{r}}(t) = \left(\frac{pt^2}{2m} + \frac{nt^3}{6m}\right)\hat{\mathbf{i}} + \left(\frac{qt^3}{60m}\right)\hat{\mathbf{j}}$

105. 9.2 m/s
107. 1.3 s
109. 5.4 m/s^2

111. a. 0.60; b. 1200 N; c. 1.2 m/s^2 and 1080 N; d. -1.2 m/s^2; e. 120 N

113. 0.789
115. a. 0.186 N; b. 774 N; c. 0.48 N
117. 13 m/s
119. 20.7 m/s
121. a. 28,300 N; b. 2540 m
123. 25 N
125. $a = \frac{F}{4} - \mu_k g$

127. 14 m

CHALLENGE PROBLEMS

129. $v = \sqrt{v_0{}^2 - 2gr_0\left(1 - \frac{r_0}{r}\right)}$

131. 78.7 m
133. a. 53.9 m/s; b. 328 m; c. 4.58 m/s; d. 257 s
135. a. $v = 20.0(1 - e^{-0.01t})$; b. $v_{\text{limiting}} = 20 \text{ m/s}$

CHAPTER 7

CHECK YOUR UNDERSTANDING

7.1. No, only its magnitude can be constant; its direction must change, to be always opposite the relative displacement along the surface.
7.2. No, it's only approximately constant near Earth's surface.
7.3. $W = 35 \text{ J}$

7.4. a. The spring force is the opposite direction to a compression (as it is for an extension), so the work it does is negative. b. The work done depends on the square of the displacement, which is the same for $x = \pm 6 \text{ cm}$, so the magnitude is 0.54 J.

7.5. a. the car; b. the truck
7.6. against
7.7. $\sqrt{3} \text{ m/s}$

7.8. 980 W

CONCEPTUAL QUESTIONS

1. When you push on the wall, this "feels" like work; however, there is no displacement so there is no physical work. Energy is consumed, but no energy is transferred.
3. If you continue to push on a wall without breaking through the wall, you continue to exert a force with no displacement, so no work is done.
5. The total displacement of the ball is zero, so no work is done.
7. Both require the same gravitational work, but the stairs allow Tarzan to take this work over a longer time interval and hence gradually exert his energy, rather than dramatically by climbing a vine.
9. The first particle has a kinetic energy of $4(\frac{1}{2}mv^2)$ whereas the second particle has a kinetic energy of $2(\frac{1}{2}mv^2)$, so the first particle has twice the kinetic energy of the second particle.
11. The mower would gain energy if $-90° < \theta < 90°$. It would lose energy if $90° < \theta < 270°$. The mower may also lose energy due to friction with the grass while pushing; however, we are not concerned with that energy loss for this problem.
13. The second marble has twice the kinetic energy of the first because kinetic energy is directly proportional to mass, like the work done by gravity.
15. Unless the environment is nearly frictionless, you are doing some positive work on the environment to cancel out the frictional

work against you, resulting in zero total work producing a constant velocity.
17. Appliances are rated in terms of the energy consumed in a relatively small time interval. It does not matter how long the appliance is on, only the rate of change of energy per unit time.
19. The spark occurs over a relatively short time span, thereby delivering a very low amount of energy to your body.
21. If the force is antiparallel or points in an opposite direction to the velocity, the power expended can be negative.

PROBLEMS

23. 3.00 J
25. a. 593 kJ; b. –589 kJ; c. 0
27. 3.14 kJ
29. a. –700 J; b. 0; c. 700 J; d. 38.6 N; e. 0
31. 100 J
33. a. 2.45 J; b. – 2.45 J; c. 0
35. a. 2.22 kJ; b. −2.22 kJ; c. 0
37. 18.6 kJ
39. a. 2.32 kN; b. 22.0 kJ
41. 835 N
43. 257 J
45. a. 1.47 m/s; b. answers may vary
47. a. 772 kJ; b. 4.0 kJ; c. 1.8×10^{-16} J
49. a. 2.6 kJ; b. 640 J
51. 2.72 kN
53. 102 N
55. 2.8 m/s
57. $W(\text{bullet}) = 20 \times W(\text{crate})$
59. 12.8 kN
61. 0.25
63. a. 24 m/s, −4.8 m/s^2; b. 29.4 m
65. 310 m/s
67. a. 40; b. 8 million
69. $149
71. a. 208 W; b. 141 s
73. a. 3.20 s; b. 4.04 s
75. a. 224 s; b. 24.8 MW; c. 49.7 kN
77. a. 1.57 kW; b. 6.28 kW
79. $6.83 \mu\text{W}$
81. a. 8.51 J; b. 8.51 W
83. 1.7 kW

ADDITIONAL PROBLEMS

85. $15 \text{ N} \cdot \text{m}$
87. $39 \text{ N} \cdot \text{m}$
89. a. $208 \text{ N} \cdot \text{m}$; b. $240 \text{ N} \cdot \text{m}$
91. a. $-0.9 \text{ N} \cdot \text{m}$; b. $-0.83 \text{ N} \cdot \text{m}$
93. a. 10. J; b. 10. J; c. 380 N/m
95. 160 J/s
97. a. 10 N; b. 20 W

CHALLENGE PROBLEMS

99. If crate goes up: a. 3.46 kJ; b. −1.89 kJ; c. −1.57 kJ; d. 0; If crate goes down: a. −0.39 kJ; b. −1.18 kJ; c. 1.57 kJ; d. 0
101. 8.0 J
103. 35.7 J
105. 24.3 J
107. a. 40 hp; b. 39.8 MJ, independent of speed; c. 80 hp, 79.6 MJ at 30 m/s; d. If air resistance is proportional to speed, the car gets about 22 mpg at 34 mph and half that at twice the speed, closer to actual driving experience.

CHAPTER 8

CHECK YOUR UNDERSTANDING

8.1. $(4.63\ \text{J}) - (-2.38\ \text{J}) = 7.00\ \text{J}$

8.2. 35.3 kJ, 143 kJ, 0

8.3. 22.8 cm. Using 0.02 m for the initial displacement of the spring (see above), we calculate the final displacement of the spring to be 0.028 m; therefore the length of the spring is the unstretched length plus the displacement, or 22.8 cm.

8.4. It increases because you had to exert a downward force, doing positive work, to pull the mass down, and that's equal to the change in the total potential energy.

8.5. 2.83 N

8.6. $F = 4.8\ \text{N},$ directed toward the origin

8.7. $0.033\ \text{m}$

8.8. b. At any given height, the gravitational potential energy is the same going up or down, but the kinetic energy is less going down than going up, since air resistance is dissipative and does negative work. Therefore, at any height, the speed going down is less than the speed going up, so it must take a longer time to go down than to go up.

8.9. constant $U(x) = -1\ \text{J}$

8.10. a. yes, motion confined to $-1.055\ \text{m} \le x \le 1.055\ \text{m}$; b. same equilibrium points and types as in example

8.11. $x(t) = \pm\sqrt{(2E/k)}\,\sin\left[\left(\sqrt{k/m}\right)t\right]$ and $v_0 = \pm\sqrt{(2E/m)}$

CONCEPTUAL QUESTIONS

1. The potential energy of a system can be negative because its value is relative to a defined point.

3. If the reference point of the ground is zero gravitational potential energy, the javelin first increases its gravitational potential energy, followed by a decrease in its gravitational potential energy as it is thrown until it hits the ground. The overall change in gravitational potential energy of the javelin is zero unless the center of mass of the javelin is lower than from where it is initially thrown, and therefore would have slightly less gravitational potential energy.

5. the vertical height from the ground to the object

7. A force that takes energy away from the system that can't be recovered if we were to reverse the action.

9. The change in kinetic energy is the net work. Since conservative forces are path independent, when you are back to the same point the kinetic and potential energies are exactly the same as the beginning. During the trip the total energy is conserved, but both the potential and kinetic energy change.

11. The car experiences a change in gravitational potential energy as it goes down the hills because the vertical distance is decreasing. Some of this change of gravitational potential energy will be taken away by work done by friction. The rest of the energy results in a kinetic energy increase, making the car go faster. Lastly, the car brakes and will lose its kinetic energy to the work done by braking to a stop.

13. It states that total energy of the system E is conserved as long as there are no non-conservative forces acting on the object.

15. He puts energy into the system through his legs compressing and expanding.

17. Four times the original height would double the impact speed.

PROBLEMS

19. 40,000

21. a. $-200\ \text{J}$; b. $-200\ \text{J}$; c. $-100\ \text{J}$; d. $-300\ \text{J}$

23. a. $0.068\ \text{J}$; b. $-0.068\ \text{J}$; c. $0.068\ \text{J}$; d. $0.068\ \text{J}$; e. $-0.068\ \text{J}$; f. $46\ \text{cm}$

25. a. $-120\ \text{J}$; b. $120\ \text{J}$

27. a. $\left(\frac{-2a}{b}\right)^{1/6}$; b. 0; c. $\sim x^6$

29. $14\ \text{m/s}$

31. $14\ \text{J}$

33. proof

35. $9.7\ \text{m/s}$

37. $39\ \text{m/s}$

39. 1900 J

41. 151 J

43. 3.5 cm

45. $10x$ with x-axis pointed away from the wall and origin at the wall

47. 4.6 m/s

49. a. 5.6 m/s; b. 5.2 m/s; c. 6.4 m/s; d. no; e. yes

51. a. where $k = 0.02,\ A = 1,\ \alpha = 1$; b. $F = kx - \alpha x A e^{-\alpha x^2}$; c. The potential energy at $x = 0$ must be less than the kinetic plus potential energy at $x = a$ or $A \le \frac{1}{2}mv^2 + \frac{1}{2}ka^2 + Ae^{-\alpha a^2}$. Solving this for A matches results in the problem.

53. 8700 N/m
55. a. 70.6 m/s; b. 69.9 m/s
57. a. 180 N/m; b. 11 m
59. a. 9.8×10^3 J ; b. 1.4×10^3 J ; c. 14 m/s
61. a. 47.6 m; b. 1.88×10^5 J ; c. 373 N
63. 33.9 cm
65. a. 0.0269 J; b. $U = 0$; c. 1.11 m/s; d. 4.96 cm
67. 42 cm

ADDITIONAL PROBLEMS

69. 0.44 J
71. 3.6 m/s
73. $bD^4/4$
75. proof
77. a. $\sqrt{\dfrac{2m^2gh}{k(m+M)}}$; b. $\dfrac{mMgh}{m+M}$
79. a. 2.24 m/s; b. 1.94 m/s; c. 1.94 m/s
81. 18 m/s
83. $v_A = 24$ m/s; $v_B = 14$ m/s; $v_C = 31$ m/s
85. a. Loss of energy is $240\ \text{N}\cdot\text{m}$; b. $F = 8$ N
87. 89.7 m/s
89. 32 J

CHAPTER 9

CHECK YOUR UNDERSTANDING

9.1. To reach a final speed of $v_\text{f} = \frac{1}{4}\left(3.0 \times 10^8\ \text{m/s}\right)$ at an acceleration of 10g, the time required is

$$\begin{aligned} 10g &= \frac{v_\text{f}}{\Delta t} \\ \Delta t &= \frac{v_\text{f}}{10g} \frac{\frac{1}{4}\left(3.0 \times 10^8\ \text{m/s}\right)}{10g} = 7.7 \times 10^5\ \text{s} = 8.9\ \text{d} \end{aligned}$$

9.2. If the phone bounces up with approximately the same initial speed as its impact speed, the change in momentum of the phone will be $\Delta \vec{\mathbf{p}} = m\Delta \vec{\mathbf{v}} - \left(-m\Delta \vec{\mathbf{v}}\right) = 2m\Delta \vec{\mathbf{v}}$. This is twice the momentum change than when the phone does not bounce, so the impulse-momentum theorem tells us that more force must be applied to the phone.
9.3. If the smaller cart were rolling at 1.33 m/s to the left, then conservation of momentum gives

$$\begin{aligned} (m_1 + m_2)\vec{\mathbf{v}}_\mathbf{f} &= m_1 v_1 \hat{\mathbf{i}} - m_2 v_2 \hat{\mathbf{i}} \\ \vec{\mathbf{v}}_\mathbf{f} &= \left(\frac{m_1 v_1 - m_2 v_2}{m_1 + m_2}\right)\hat{\mathbf{i}} \\ &= \left[\frac{(0.675\ \text{kg})(0.75\ \text{m/s}) - (0.500\ \text{kg})(1.33\ \text{m/s})}{1.175\ \text{kg}}\right]\hat{\mathbf{i}} \\ &= -(0.135\ \text{m/s})\,\hat{\mathbf{i}} \end{aligned}$$

Thus, the final velocity is 0.135 m/s to the left.
9.4. If the ball does not bounce, its final momentum $\vec{\mathbf{p}}_2$ is zero, so

$$\begin{aligned}\Delta \vec{\mathbf{p}} &= \vec{\mathbf{p}}_2 - \vec{\mathbf{p}}_1 \\ &= (0)\hat{\mathbf{j}} - (-1.4\ \text{kg}\cdot\text{m/s})\hat{\mathbf{j}} \\ &= +(1.4\ \text{kg}\cdot\text{m/s})\hat{\mathbf{j}}\end{aligned}$$

9.5. Consider the impulse momentum theory, which is $\vec{J} = \Delta\vec{p}$. If $\vec{J} = 0$, we have the situation described in the example. If a force acts on the system, then $\vec{J} = \vec{F}_{\text{ave}}\Delta t$. Thus, instead of $\vec{\mathbf{p}}_f = \vec{\mathbf{p}}_i$, we have

$$\vec{F}_{\text{ave}}\Delta t = \Delta\vec{p} = \vec{p}_{\text{f}} - \vec{p}_{\text{i}}$$

where $\vec{\mathbf{F}}_{\text{ave}}$ is the force due to friction.

9.6. The impulse is the change in momentum multiplied by the time required for the change to occur. By conservation of momentum, the changes in momentum of the probe and the comment are of the same magnitude, but in opposite directions, and the interaction time for each is also the same. Therefore, the impulse each receives is of the same magnitude, but in opposite directions. Because they act in opposite directions, the impulses are not the same. As for the impulse, the force on each body acts in opposite directions, so the forces on each are not equal. However, the change in kinetic energy differs for each, because the collision is not elastic.

9.7. This solution represents the case in which no interaction takes place: the first puck misses the second puck and continues on with a velocity of 2.5 m/s to the left. This case offers no meaningful physical insights.

9.8. If zero friction acts on the car, then it will continue to slide indefinitely ($d \to \infty$), so we cannot use the work-kinetic-energy theorem as is done in the example. Thus, we could not solve the problem from the information given.

9.9. Were the initial velocities not at right angles, then one or both of the velocities would have to be expressed in component form. The mathematical analysis of the problem would be slightly more involved, but the physical result would not change.

9.10. The volume of a scuba tank is about 11 L. Assuming air is an ideal gas, the number of gas molecules in the tank is

$$\begin{aligned}PV &= NRT \\ N &= \frac{PV}{RT} = \frac{(2500\ \text{psi})(0.011\ \text{m}^3)}{(8.31\ \text{J/mol}\cdot\text{K})(300\ \text{K})}\left(\frac{6894.8\ \text{Pa}}{1\ \text{psi}}\right) \\ &= 7.59\times 10^1\ \text{mol}\end{aligned}$$

The average molecular mass of air is 29 g/mol, so the mass of air contained in the tank is about 2.2 kg. This is about 10 times less than the mass of the tank, so it is safe to neglect it. Also, the initial force of the air pressure is roughly proportional to the surface area of each piece, which is in turn proportional to the mass of each piece (assuming uniform thickness). Thus, the initial acceleration of each piece would change very little if we explicitly consider the air.

9.11. The average radius of Earth's orbit around the Sun is 1.496×10^9 m. Taking the Sun to be the origin, and noting that the mass of the Sun is approximately the same as the masses of the Sun, Earth, and Moon combined, the center of mass of the Earth + Moon system and the Sun is

$$\begin{aligned}R_{\text{CM}} &= \frac{m_{\text{Sun}}R_{\text{Sun}} + m_{\text{em}}R_{\text{em}}}{m_{\text{Sun}}} \\ &= \frac{(1.989\times 10^{30}\ \text{kg})(0) + (5.97\times 10^{24}\ \text{kg} + 7.36\times 10^{22}\ \text{kg})(1.496\times 10^9\ \text{m})}{1.989\times 10^{30}\ \text{kg}} \\ &= 4.6\ \text{km}\end{aligned}$$

Thus, the center of mass of the Sun, Earth, Moon system is 4.6 km from the center of the Sun.

9.12. On a macroscopic scale, the size of a unit cell is negligible and the crystal mass may be considered to be distributed homogeneously throughout the crystal. Thus,

$$\vec{\mathbf{r}}_{\text{CM}} = \frac{1}{M}\sum_{j=1}^{N} m_j\vec{r}_j = \frac{1}{M}\sum_{j=1}^{N} m\vec{r}_j = \frac{m}{M}\sum_{j=1}^{N}\vec{r}_j = \frac{Nm}{M}\frac{\sum_{j=1}^{N}\vec{r}_j}{N}$$

where we sum over the number *N* of unit cells in the crystal and *m* is the mass of a unit cell. Because *Nm* = *M*, we can write

$$\vec{\mathbf{r}}_{\text{CM}} = \frac{m}{M}\sum_{j=1}^{N}\vec{r}_j = \frac{Nm}{M}\frac{\sum_{j=1}^{N}\vec{r}_j}{N} = \frac{1}{N}\sum_{j=1}^{N}\vec{r}_j.$$

This is the definition of the geometric center of the crystal, so the center of mass is at the same point as the geometric center.

9.13. The explosions would essentially be spherically symmetric, because gravity would not act to distort the trajectories of the expanding projectiles.

9.14. The notation m_g stands for the mass of the fuel and *m* stands for the mass of the rocket plus the initial mass of the fuel. Note that m_g changes with time, so we write it as $m_g(t)$. Using m_R as the mass of the rocket with no fuel, the total mass of the rocket plus fuel is $m = m_R + m_g(t)$. Differentiation with respect to time gives

$$\frac{dm}{dt} = \frac{dm_R}{dt} + \frac{dm_g(t)}{dt} = \frac{dm_g(t)}{dt}$$

where we used $\frac{dm_R}{dt} = 0$ because the mass of the rocket does not change. Thus, time rate of change of the mass of the rocket is the same as that of the fuel.

CONCEPTUAL QUESTIONS

1. Since $K = p^2/2m$, then if the momentum is fixed, the object with smaller mass has more kinetic energy.

3. Yes; impulse is the force applied multiplied by the time during which it is applied ($J = F\Delta t$), so if a small force acts for a long time, it may result in a larger impulse than a large force acting for a small time.

5. By friction, the road exerts a horizontal force on the tires of the car, which changes the momentum of the car.

7. Momentum is conserved when the mass of the system of interest remains constant during the interaction in question and when no *net* external force acts on the system during the interaction.

9. To accelerate air molecules in the direction of motion of the car, the car must exert a force on these molecules by Newton's second law $\vec{F} = d\vec{p}/dt$. By Newton's third law, the air molecules exert a force of equal magnitude but in the opposite direction on the car. This force acts in the direction opposite the motion of the car and constitutes the force due to air resistance.

11. No, he is not a closed system because a net nonzero external force acts on him in the form of the starting blocks pushing on his feet.

13. Yes, all the kinetic energy can be lost if the two masses come to rest due to the collision (i.e., they stick together).

15. The angle between the directions must be 90°. Any system that has zero net external force in one direction and nonzero net external force in a perpendicular direction will satisfy these conditions.

17. Yes, the rocket speed can exceed the exhaust speed of the gases it ejects. The thrust of the rocket does not depend on the relative speeds of the gases and rocket, it simply depends on conservation of momentum.

PROBLEMS

19. a. magnitude: $25\ \text{kg}\cdot\text{m/s}$; b. same as a.

21. $1.78 \times 10^{29}\ \text{kg}\cdot\text{m/s}$

23. $1.3 \times 10^{9}\ \text{kg}\cdot\text{m/s}$

25. a. $1.50 \times 10^{6}\ \text{N}$; b. $1.00 \times 10^{5}\ \text{N}$

27. $4.69 \times 10^{5}\ \text{N}$

29. $2.10 \times 10^{3}\ \text{N}$

31. $\vec{\mathbf{p}}(t) = \left(10\,\hat{\mathbf{i}} + 20t\,\hat{\mathbf{j}}\right)\text{kg}\cdot\text{m/s}$; $\vec{\mathbf{F}} = (20\ \text{N})\,\hat{\mathbf{j}}$

33. Let the positive *x*-axis be in the direction of the original momentum. Then $p_x = 1.5\ \text{kg}\cdot\text{m/s}$ and $p_y = 7.5\ \text{kg}\cdot\text{m/s}$

35. $(0.122\ \text{m/s})\,\hat{\mathbf{i}}$

37. a. 47 m/s in the bullet to block direction; b. $70.6\ \text{N}\cdot\text{s}$, toward the bullet; c. $70.6\ \text{N}\cdot\text{s}$, toward the block; d. magnitude is $2.35 \times 10^{4}\ \text{N}$

39. 3.1 m/s

41. 5.9 m/s

43. a. 6.80 m/s, 5.33°; b. yes (calculate the ratio of the initial and final kinetic energies)

45. 2.5 cm

47. the speed of the leading bumper car is 6.00 m/s and that of the trailing bumper car is 5.60 m/s

49. 6.6%

51. 1.9 m/s

53. 22.1 m/s at $32.2°$ below the horizontal

55. a. 33 m/s and 110 m/s; b. 57 m; c. 480 m

57. $(732\ \text{m/s})\,\hat{\mathbf{i}} + (-80.6\ \text{m/s})\,\hat{\mathbf{j}}$

59. $-(0.21\text{ m/s})\hat{\mathbf{i}} + (0.25\text{ m/s})\hat{\mathbf{j}}$

61. 341 m/s at 86.8° with respect to the $\hat{\mathbf{i}}$ axis.

63. With the origin defined to be at the position of the 150-g mass, $x_{\text{CM}} = -1.23\text{cm}$ and $y_{\text{CM}} = 0.69\text{cm}$

65. $y_{\text{CM}} = \begin{cases} \frac{h}{2} - \frac{1}{4}gt^2, & t < T \\ h - \frac{1}{2}gt^2 - \frac{1}{4}gT^2 + \frac{1}{2}gtT, & t \geq T \end{cases}$

67. a. $R_1 = 4\text{ m}$, $R_2 = 2\text{ m}$; b. $X_{\text{CM}} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$, $Y_{\text{CM}} = \frac{m_1 y_1 + m_2 y_2}{m_1 + m_2}$; c. yes, with $R = \frac{1}{m_1 + m_2}\sqrt{16m_1^2 + 4m_2^2}$

69. $x_{cm} = \frac{3}{4}L\left(\frac{\rho_1 + \rho_0}{\rho_1 + 2\rho_0}\right)$

71. $\left(\frac{2a}{3}, \frac{2b}{3}\right)$

73. $(x_{\text{CM}}, y_{\text{CM}}, z_{\text{CM}}) = (0, 0, h/4)$

75. $(x_{\text{CM}}, y_{\text{CM}}, z_{\text{CM}}) = (0, 4R/(3\pi), 0)$

77. (a) 0.413 m/s, (b) about 0.2 J
79. 1551 kg
81. 4.9 km/s

ADDITIONAL PROBLEMS

84. the elephant has a higher momentum
86. Answers may vary. The first clause is true, but the second clause is not true in general because the velocity of an object with small mass may be large enough so that the momentum of the object is greater than that of a larger-mass object with a smaller velocity.
88. $4.5 \times 10^3\text{ N}$

90. $\vec{\mathbf{J}} = \int_0^\tau \left[m\vec{g} - m\vec{g}\left(1 - e^{-bt/m}\right)\right]dt = \frac{m^2}{b}\vec{g}\left(e^{-b\tau/m} - 1\right)$

92. a. $-\left(2.1 \times 10^3\text{ kg}\cdot\text{m/s}\right)\hat{\mathbf{i}}$, b. $-\left(24 \times 10^3\text{ N}\right)\hat{\mathbf{i}}$

94. a. $\left(1.1 \times 10^3\text{ kg}\cdot\text{m/s}\right)\hat{\mathbf{i}}$, b. $(0.010\text{ kg}\cdot\text{m/s})\hat{\mathbf{i}}$, c. $-(0.00093\text{ m/s})\hat{\mathbf{i}}$, d. $-(0.0012\text{ m/s})\hat{\mathbf{i}}$

96. 0.10 kg, $-(130\text{ m/s})\hat{\mathbf{i}}$

98. $v_{1,\text{f}} = v_{1,\text{i}}\frac{m_1 - m_2}{m_1 + m_2}$, $v_{2,\text{f}} = v_{1,\text{i}}\frac{2m_1}{m_1 + m_2}$

100. 2.8 m/s
102. 0.094 m/s

104. final velocity of cue ball is $-(0.76\text{ m/s})\hat{\mathbf{i}}$, final velocities of the other two balls are 2.6 m/s at ±30° with respect to the initial velocity of the cue ball

106. ball 1: $-(1.4\text{ m/s})\hat{\mathbf{i}} - (0.4\text{ m/s})\hat{\mathbf{j}}$, ball 2: $(2.2\text{ m/s})\hat{\mathbf{i}} + (2.4\text{ m/s})\hat{\mathbf{j}}$

108. ball 1: $(1.4\text{ m/s})\hat{\mathbf{i}} - (1.7\text{ m/s})\hat{\mathbf{j}}$, ball 2: $-(2.8\text{ m/s})\hat{\mathbf{i}} + (0.012\text{ m/s})\hat{\mathbf{j}}$

110. $(r, \theta) = (2R/3, \pi/8)$

112. Answers may vary. The rocket is propelled forward not by the gasses pushing against the surface of Earth, but by conservation of momentum. The momentum of the gas being expelled out the back of the rocket must be compensated by an increase in the forward momentum of the rocket.

CHALLENGE PROBLEMS

114. a. $617\text{ N}\cdot\text{s}$, 108°; b. $F_x = 2.91 \times 10^4\text{ N}$, $F_y = 2.6 \times 10^5\text{ N}$; c. $F_x = 5265\text{ N}$, $F_y = 5850\text{ N}$

116. Conservation of momentum demands $m_1 v_{1,i} + m_2 v_{2,i} = m_1 v_{1,f} + m_2 v_{2,f}$. We are given that $m_1 = m_2$, $v_{1,i} = v_{2,f}$, and $v_{2,i} = v_{1,f} = 0$. Combining these equations with the equation given by conservation of momentum gives $v_{1,i} = v_{1,i}$, which is true, so conservation of momentum is satisfied. Conservation of energy demands $\frac{1}{2}m_1 v_{1,i}^2 + \frac{1}{2}m_2 v_{2,i}^2 = \frac{1}{2}m_1 v_{1,f}^2 + \frac{1}{2}m_2 v_{2,f}^2$. Again combining this equation with the conditions given above give $v_{1,i} = v_{1,i}$, so conservation of energy is satisfied.

118. Assume origin on centerline and at floor, then $(x_{CM}, y_{CM}) = (0{,}86\ \text{cm})$

CHAPTER 10

CHECK YOUR UNDERSTANDING

10.1. a. $40.0\ \text{rev/s} = 2\pi(40.0)\ \text{rad/s}$, $\bar{\alpha} = \frac{\Delta\omega}{\Delta t} = \frac{2\pi(40.0) - 0\ \text{rad/s}}{20.0\ \text{s}} = 2\pi(2.0) = 4.0\pi\ \text{rad/s}^2$; b. Since the angular velocity increases linearly, there has to be a constant acceleration throughout the indicated time. Therefore, the instantaneous angular acceleration at any time is the solution to $4.0\pi\ \text{rad/s}^2$.

10.2. a. Using **Equation 10.25**, we have $7000\ \text{rpm} = \frac{7000.0(2\pi\ \text{rad})}{60.0\ \text{s}} = 733.0\ \text{rad/s},$

$$\alpha = \frac{\omega - \omega_0}{t} = \frac{733.0\ \text{rad/s}}{10.0\ \text{s}} = 73.3\ \text{rad/s}^2;$$

b. Using **Equation 10.29**, we have

$$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta \Rightarrow \Delta\theta = \frac{\omega^2 - \omega_0^2}{2\alpha} = \frac{0 - (733.0\ \text{rad/s})^2}{2(73.3\ \text{rad/s}^2)} = 3665.2\ \text{rad}$$

10.3. The angular acceleration is $\alpha = \frac{(5.0 - 0)\text{rad/s}}{20.0\ \text{s}} = 0.25\ \text{rad/s}^2$. Therefore, the total angle that the boy passes through is

$$\Delta\theta = \frac{\omega^2 - \omega_0^2}{2\alpha} = \frac{(5.0)^2 - 0}{2(0.25)} = 50\ \text{rad}.$$

Thus, we calculate

$$s = r\theta = 5.0\ \text{m}(50.0\ \text{rad}) = 250.0\ \text{m}.$$

10.4. The initial rotational kinetic energy of the propeller is

$$K_0 = \frac{1}{2}I\omega^2 = \frac{1}{2}(800.0\ \text{kg-m}^2)(4.0 \times 2\pi\ \text{rad/s})^2 = 2.53 \times 10^5\ \text{J}.$$

At 5.0 s the new rotational kinetic energy of the propeller is

$$K_f = 2.03 \times 10^5\ \text{J}.$$

and the new angular velocity is

$$\omega = \sqrt{\frac{2(2.03 \times 10^5\ \text{J})}{800.0\ \text{kg-m}^2}} = 22.53\ \text{rad/s}$$

which is 3.58 rev/s.

10.5. $I_{\text{parallel-axis}} = I_{\text{center of mass}} + md^2 = mR^2 + mR^2 = 2mR^2$

10.6. The angle between the lever arm and the force vector is $80°$; therefore, $r_\perp = 100\text{m}(\sin 80°) = 98.5\ \text{m}$. The cross product $\vec{\boldsymbol{\tau}} = \vec{\mathbf{r}} \times \vec{\mathbf{F}}$ gives a negative or clockwise torque. The torque is then $\tau = -r_\perp F = -98.5\ \text{m}(5.0 \times 10^5\text{N}) = -4.9 \times 10^7\ \text{N}\cdot\text{m}$.

10.7. a. The angular acceleration is $\alpha = \frac{20.0(2\pi)\text{rad/s} - 0}{10.0\ \text{s}} = 12.56\ \text{rad/s}^2$. Solving for the torque, we have $\sum_i \tau_i = I\alpha = (30.0\ \text{kg}\cdot\text{m}^2)(12.56\ \text{rad/s}^2) = 376.80\ \text{N}\cdot\text{m}$; b. The angular acceleration is $\alpha = \frac{0 - 20.0(2\pi)\text{rad/s}}{20.0\ \text{s}} = -6.28\ \text{rad/s}^2$. Solving for the torque, we have $\sum_i \tau_i = I\alpha = (30.0\ \text{kg-m}^2)(-6.28\ \text{rad/s}^2) = -188.50\ \text{N}\cdot\text{m}$

10.8. 3 MW

CONCEPTUAL QUESTIONS

1. The second hand rotates clockwise, so by the right-hand rule, the angular velocity vector is into the wall.
3. They have the same angular velocity. Points further out on the bat have greater tangential speeds.
5. straight line, linear in time variable
7. constant
9. The centripetal acceleration vector is perpendicular to the velocity vector.
11. a. both; b. nonzero centripetal acceleration; c. both
13. The hollow sphere, since the mass is distributed further away from the rotation axis.
15. a. It decreases. b. The arms could be approximated with rods and the discus with a disk. The torso is near the axis of rotation so it doesn't contribute much to the moment of inertia.
17. Because the moment of inertia varies as the square of the distance to the axis of rotation. The mass of the rod located at distances greater than $L/2$ would provide the larger contribution to make its moment of inertia greater than the point mass at $L/2$.
19. magnitude of the force, length of the lever arm, and angle of the lever arm and force vector
21. The moment of inertia of the wheels is reduced, so a smaller torque is needed to accelerate them.
23. yes
25. $\left|\vec{\mathbf{r}}\right|$ can be equal to the lever arm but never less than the lever arm
27. If the forces are along the axis of rotation, or if they have the same lever arm and are applied at a point on the rod.

PROBLEMS

29. $\omega = \dfrac{2\pi \text{ rad}}{45.0 \text{ s}} = 0.14 \text{ rad/s}$

31. a. $\theta = \frac{s}{r} = \dfrac{3.0 \text{ m}}{1.5 \text{ m}} = 2.0 \text{ rad}$; b. $\omega = \dfrac{2.0 \text{ rad}}{1.0 \text{ s}} = 2.0 \text{ rad/s}$; c. $\dfrac{v^2}{r} = \dfrac{(3.0 \text{ m/s})^2}{1.5 \text{ m}} = 6.0 \text{ m/s}^2$.

33. The propeller takes only $\Delta t = \dfrac{\Delta\omega}{\alpha} = \dfrac{0 \text{ rad/s} - 10.0(2\pi) \text{ rad/s}}{-2.0 \text{ rad/s}^2} = 31.4 \text{ s}$ to come to rest, when the propeller is at 0 rad/s, it would start rotating in the opposite direction. This would be impossible due to the magnitude of forces involved in getting the propeller to stop and start rotating in the opposite direction.

35. a. $\omega = 25.0(2.0 \text{ s}) = 50.0 \text{ rad/s}$; b. $\alpha = \dfrac{d\omega}{dt} = 25.0 \text{ rad/s}^2$

37. a. $\omega = 54.8 \text{ rad/s}$;
b. $t = 11.0 \text{ s}$

39. a. 0.87 rad/s^2;
b. $\theta = 66{,}264 \text{ rad}$

41. a. $\omega = 42.0 \text{ rad/s}$;

b. $\theta = 200 \text{ rad}$; c. $\begin{array}{l} v_t = 42 \text{ m/s} \\ a_t = 4.0 \text{ m/s}^2 \end{array}$

43. a. $\omega = 7.0 \text{ rad/s}$;
b. $\theta = 22.5 \text{ rad}$; c. $a_\text{t} = 0.1 \text{ m/s}$

45. $\alpha = 28.6 \text{ rad/s}^2$.

47. $r = 0.78 \text{ m}$

49. a. $\alpha = -0.314 \text{ rad/s}^2$,
b. $a_\text{c} = 197.4 \text{ m/s}^2$; c. $a = \sqrt{a_\text{c}^2 + a_\text{t}^2} = \sqrt{197.4^2 + (-6.28)^2} = 197.5 \text{ m/s}^2$

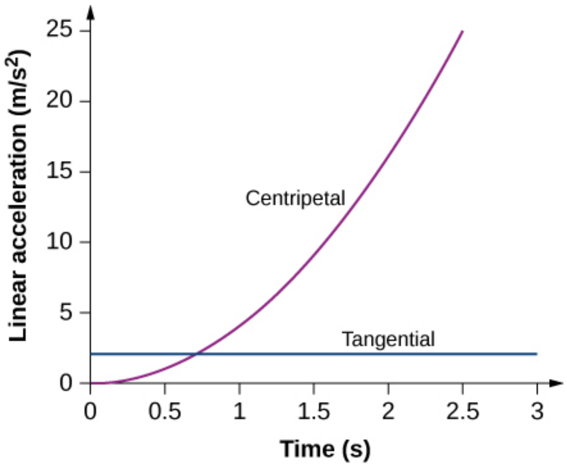
$\theta = \tan^{-1}\dfrac{-6.28}{197.4} = -1.8°$ in the clockwise direction from the centripetal acceleration vector

51. $ma = 40.0 \text{ kg}(5.1 \text{ m/s}^2) = 204.0 \text{ N}$

The maximum friction force is $\mu_\text{S} N = 0.6(40.0 \text{ kg})(9.8 \text{ m/s}^2) = 235.2 \text{ N}$ so the child does not fall off yet.

53.
$$\begin{aligned} v_\text{t} &= r\omega = 1.0(2.0t) \text{ m/s} \\ a_\text{c} &= \frac{v_t^2}{r} = \frac{(2.0t)^2}{1.0 \text{ m}} = 4.0t^2 \text{ m/s}^2 \\ a_\text{t}(t) &= r\alpha(t) = r\frac{d\omega}{dt} = 1.0 \text{ m}(2.0) = 2.0 \text{ m/s}^2. \end{aligned}$$

Plotting both accelerations gives



The tangential acceleration is constant, while the centripetal acceleration is time dependent, and increases with time to values much greater than the tangential acceleration after t = 1s. For times less than 0.7 s and approaching zero the centripetal acceleration is much less than the tangential acceleration.

55. a. $K = 2.56 \times 10^{29}$ J;

b. $K = 2.68 \times 10^{33}$ J

57. $K = 434.0\,\text{J}$

59. a. $v_{\text{f}} = 86.5\,\text{m/s}$;

b. The rotational rate of the propeller stays the same at 20 rev/s.

61. $K = 3.95 \times 10^{42}$ J

63. a. $I = 0.315\,\text{kg} \cdot \text{m}^2$;

b. $K = 621.8\,\text{J}$

65. $I = \frac{7}{36}mL^2$

67. $v = 7.14\,\text{m/s}.$

69. $\theta = 10.2°$

71. $F = 30\,\text{N}$

73. a. $0.85\,\text{m}(55.0\,\text{N}) = 46.75\,\text{N} \cdot \text{m}$; b. It does not matter at what height you push.

75. $m_2 = \frac{4.9\,\text{N} \cdot \text{m}}{9.8(0.3\,\text{m})} = 1.67\,\text{kg}$

77. $\tau_{net} = -9.0\,\text{N} \cdot \text{m} + 3.46\,\text{N} \cdot \text{m} + 0 - 3.28\,\text{N} \cdot \text{m} = -8.82\,\text{N} \cdot \text{m}$

79. $\tau = 5.66\,\text{N} \cdot \text{m}$

81. $\sum \tau = 57.82\,\text{N} \cdot \text{m}$

83. $\vec{\mathbf{r}} \times \vec{\mathbf{F}} = 4.0\,\hat{\mathbf{i}} + 2.0\,\hat{\mathbf{j}} - 16.0\,\hat{\mathbf{k}}\,\text{N} \cdot \text{m}$

85. a. $\tau = (0.280\,\text{m})(180.0\,\text{N}) = 50.4\,\text{N} \cdot \text{m}$; b. $\alpha = 17.14\,\text{rad/s}^2$;

c. $\alpha = 17.04\,\text{rad/s}^2$

87. $\tau = 8.0\,\text{N} \cdot \text{m}$

89. $\tau = -43.6\,\text{N} \cdot \text{m}$

91. a. $\alpha = 1.4 \times 10^{-10}$ rad/s^2;

b. $\tau = 1.36 \times 10^{28}$ N-m; c. $F = 2.1 \times 10^{21}$ N

93. $a = 3.6\,\text{m/s}^2$

95. a. $a = r\alpha = 14.7\,\text{m/s}^2$; b. $a = \frac{L}{2}\alpha = \frac{3}{4}g$

97. $\tau = \frac{P}{\omega} = \frac{2.0 \times 10^6 \text{ W}}{2.1 \text{ rad/s}} = 9.5 \times 10^5 \text{ N} \cdot \text{m}$

99. a. $K = 888.50 \text{ J}$;
b. $\Delta\theta = 294.6 \text{ rev}$

101. a. $I = 114.6 \text{ kg} \cdot \text{m}^2$;
b. $P = 104{,}700 \text{ W}$

103. $v = L\omega = \sqrt{3Lg}$

105. a. $a = 5.0 \text{ m/s}^2$; b. $W = 1.25 \text{ N} \cdot \text{m}$

ADDITIONAL PROBLEMS

107. $\Delta t = 10.0 \text{ s}$

109. a. 0.06 rad/s^2; b. $\theta = 105.0 \text{ rad}$

111. $s = 405.26 \text{ m}$

113. a. $I = 0.363 \text{ kg} \cdot \text{m}^2$;

b. $I = 2.34 \text{ kg} \cdot \text{m}^2$

115. $\omega = \sqrt{\frac{5.36 \text{ J}}{4.4 \text{ kgm}^2}} = 1.10 \text{ rad/s}$

117. $F = 23.3 \text{ N}$

119. $\alpha = \frac{190.0 \text{ N-m}}{2.94 \text{ kg-m}^2} = 64.4 \text{ rad/s}^2$

CHALLENGE PROBLEMS

121. a. $\omega = 2.0t - 1.5t^2$; b. $\theta = t^2 - 0.5t^3$; c. $\theta = -400.0 \text{ rad}$; d. the vector is at $-0.66(360°) = -237.6°$

123. $I = \frac{2}{5}mR^2$

125. a. $\omega = 8.2 \text{ rad/s}$; b. $\omega = 8.0 \text{ rad/s}$

CHAPTER 11

CHECK YOUR UNDERSTANDING

11.1. a. $\mu_S \geq \frac{\tan\theta}{1 + (mr^2/I_{CM})}$; inserting the angle and noting that for a hollow cylinder $I_{CM} = mr^2$, we have $\mu_S \geq \frac{\tan 60°}{1 + (mr^2/mr^2)} = \frac{1}{2}\tan 60° = 0.87;$ we are given a value of 0.6 for the coefficient of static friction, which is less than 0.87, so the condition isn't satisfied and the hollow cylinder will slip; b. The solid cylinder obeys the condition $\mu_S \geq \frac{1}{3}\tan\theta = \frac{1}{3}\tan 60° = 0.58.$ The value of 0.6 for μ_S satisfies this condition, so the solid cylinder will not slip.

11.2. From the figure, we see that the cross product of the radius vector with the momentum vector gives a vector directed out of the page. Inserting the radius and momentum into the expression for the angular momentum, we have

$$\vec{\mathbf{l}} = \vec{\mathbf{r}} \times \vec{\mathbf{p}} = (0.4 \text{ m } \hat{\mathbf{i}}) \times (1.67 \times 10^{-27} \text{ kg}(4.0 \times 10^6 \text{ m/s})\hat{\mathbf{j}}) = 2.7 \times 10^{-21} \text{ kg} \cdot \text{m}^2/\text{s}\,\hat{\mathbf{k}}$$

11.3. $I_{\text{sphere}} = \frac{2}{5}mr^2, \quad I_{\text{cylinder}} = \frac{1}{2}mr^2$; Taking the ratio of the angular momenta, we have:

$\frac{L_{\text{cylinder}}}{L_{\text{sphere}}} = \frac{I_{\text{cylinder}}\omega_0}{I_{\text{sphere}}\omega_0} = \frac{\frac{1}{2}mr^2}{\frac{2}{5}mr^2} = \frac{5}{4}$. Thus, the cylinder has 25% more angular momentum. This is because the cylinder has more mass distributed farther from the axis of rotation.

11.4. Using conservation of angular momentum, we have

$$I(4.0 \text{ rev/min}) = 1.25I\omega_f, \quad \omega_f = \frac{1.0}{1.25}(4.0 \text{ rev/min}) = 3.2 \text{ rev/min}$$

11.5. The Moon's gravity is 1/6 that of Earth's. By examining **Equation 11.83**, we see that the top's precession frequency is linearly proportional to the acceleration of gravity. All other quantities, mass, moment of inertia, and spin rate are the same on the

Moon. Thus, the precession frequency on the Moon is

$$\omega_P(\text{Moon}) = \frac{1}{6}\omega_P(\text{Earth}) = \frac{1}{6}(5.0\text{ rad/s}) = 0.83\text{ rad/s}.$$

CONCEPTUAL QUESTIONS

1. No, the static friction force is zero.
3. The wheel is more likely to slip on a steep incline since the coefficient of static friction must increase with the angle to keep rolling motion without slipping.
5. The cylinder reaches a greater height. By **Equation 11.20**, its acceleration in the direction down the incline would be less.
7. All points on the straight line will give zero angular momentum, because a vector crossed into a parallel vector is zero.
9. The particle must be moving on a straight line that passes through the chosen origin.
11. Without the small propeller, the body of the helicopter would rotate in the opposite sense to the large propeller in order to conserve angular momentum. The small propeller exerts a thrust at a distance *R* from the center of mass of the aircraft to prevent this from happening.
13. The angular velocity increases because the moment of inertia is decreasing.
15. More mass is concentrated near the rotational axis, which decreases the moment of inertia causing the star to increase its angular velocity.
17. A torque is needed in the direction perpendicular to the angular momentum vector in order to change its direction. These forces on the space vehicle are external to the container in which the gyroscope is mounted and do not impart torques to the gyroscope's rotating disk.

PROBLEMS

19. $v_{\text{CM}} = R\omega \;\Rightarrow\; \omega = 66.7\text{ rad/s}$

21. $\alpha = 3.3\text{ rad/s}^2$

23. $I_{\text{CM}} = \frac{2}{5}mr^2,\;\; a_{\text{CM}} = 3.5\text{ m/s}^2;\;\; x = 15.75\text{ m}$

25. positive is down the incline plane;

$$a_{\text{CM}} = \frac{mg\sin\theta}{m + (I_{\text{CM}}/r^2)} \Rightarrow I_{\text{CM}} = r^2\left[\frac{mg\sin 30}{a_{\text{CM}}} - m\right],$$

$$x - x_0 = v_0 t - \frac{1}{2}a_{\text{CM}}t^2 \Rightarrow a_{\text{CM}} = 2.96\text{ m/s}^2,$$

$$I_{\text{CM}} = 0.66\,mr^2$$

27. $\alpha = 67.9\text{ rad/s}^2$,

$(a_{\text{CM}})_x = 1.5\text{ m/s}^2$

29. $W = -1080.0\text{ J}$

31. Mechanical energy at the bottom equals mechanical energy at the top;

$$\frac{1}{2}mv_0^2 + \frac{1}{2}\left(\frac{1}{2}mr^2\right)\left(\frac{v_0}{r}\right)^2 = mgh \Rightarrow h = \frac{1}{g}\left(\frac{1}{2} + \frac{1}{4}\right)v_0^2,$$

$h = 7.7\text{ m},$ so the distance up the incline is 22.5 m.

33. Use energy conservation

$$\frac{1}{2}mv_0^2 + \frac{1}{2}I_{\text{Cyl}}\omega_0^2 = mgh_{\text{Cyl}},$$

$$\frac{1}{2}mv_0^2 + \frac{1}{2}I_{\text{Sph}}\omega_0^2 = mgh_{\text{Sph}}.$$

Subtracting the two equations, eliminating the initial translational energy, we have

$$\frac{1}{2}I_{\text{Cyl}}\omega_0^2 - \frac{1}{2}I_{\text{Sph}}\omega_0^2 = mg(h_{\text{Cyl}} - h_{\text{Sph}}),$$

$$\frac{1}{2}mr^2\left(\frac{v_0}{r}\right)^2 - \frac{1}{2}\frac{2}{3}mr^2\left(\frac{v_0}{r}\right)^2 = mg(h_{\text{Cyl}} - h_{\text{Sph}}),$$

$$\frac{1}{2}v_0^2 - \frac{1}{2}\frac{2}{3}v_0^2 = g(h_{\text{Cyl}} - h_{\text{Sph}}),$$

$$h_{\text{Cyl}} - h_{\text{Sph}} = \frac{1}{g}\left(\frac{1}{2} - \frac{1}{3}\right)v_0^2 = \frac{1}{9.8\text{ m/s}^2}\left(\frac{1}{6}\right)(5.0\text{ m/s})^2 = 0.43\text{ m}.$$

Thus, the hollow sphere, with the smaller moment of inertia, rolls up to a lower height of $1.0 - 0.43 = 0.57\text{ m}.$

35. The magnitude of the cross product of the radius to the bird and its momentum vector yields $rp\sin\theta$, which gives $r\sin\theta$

as the altitude of the bird h. The direction of the angular momentum is perpendicular to the radius and momentum vectors, which we choose arbitrarily as $\hat{\mathbf{k}}$, which is in the plane of the ground:

$$\vec{\mathbf{L}} = \vec{\mathbf{r}} \times \vec{\mathbf{p}} = hmv\hat{\mathbf{k}} = (300.0\,\text{m})(2.0\,\text{kg})(20.0\,\text{m/s})\hat{\mathbf{k}} = 12{,}000.0\,\text{kg}\cdot\text{m}^2/\text{s}\hat{\mathbf{k}}$$

37. a. $\vec{\mathbf{l}} = 45.0\,\text{kg}\cdot\text{m}^2/\text{s}\hat{\mathbf{k}}$;

b. $\vec{\boldsymbol{\tau}} = 10.0\,\text{N}\cdot\text{m}\hat{\mathbf{k}}$

39. a. $\vec{\mathbf{l}}_1 = -0.4\,\text{kg}\cdot\text{m}^2/\text{s}\hat{\mathbf{k}}$, $\vec{\mathbf{l}}_2 = \vec{\mathbf{l}}_4 = 0$,

$\vec{\mathbf{l}}_3 = 1.35\,\text{kg}\cdot\text{m}^2/\text{s}\hat{\mathbf{k}}$; b. $\vec{\mathbf{L}} = 0.95\,\text{kg}\cdot\text{m}^2/\text{s}\hat{\mathbf{k}}$

41. a. $L = 1.0 \times 10^{11}\,\text{kg}\cdot\text{m}^2/\text{s}$; b. No, the angular momentum stays the same since the cross-product involves only the perpendicular distance from the plane to the ground no matter where it is along its path.

43. a. $\vec{\mathbf{v}} = -gt\hat{\mathbf{j}}$, $\vec{\mathbf{r}}_\perp = -d\hat{\mathbf{i}}$, $\vec{\mathbf{l}} = mdgt\hat{\mathbf{k}}$;

b. $\vec{\mathbf{F}} = -mg\hat{\mathbf{j}}$, $\sum \vec{\boldsymbol{\tau}} = dmg\hat{\mathbf{k}}$; c. yes

45. a. $mgh = \frac{1}{2}m(r\omega)^2 + \frac{1}{2}\frac{2}{5}mr^2\omega^2$;

$\omega = 51.2\,\text{rad/s}$;

$L = 16.4\,\text{kg}\cdot\text{m}^2/\text{s}$;

b. $\omega = 72.5\,\text{rad/s}$;

$L = 23.2\,\text{kg}\cdot\text{m}^2/\text{s}$

47. a. $I = 720.0\,\text{kg}\cdot\text{m}^2$; $\alpha = 4.20\,\text{rad/s}^2$;

$\omega(10\,\text{s}) = 42.0\,\text{rad/s}$; $L = 3.02 \times 10^4\,\text{kg}\cdot\text{m}^2/\text{s}$;

$\omega(20\,\text{s}) = 84.0\,\text{rad/s}$;

b. $\tau = 3.03 \times 10^3\,\text{N}\cdot\text{m}$

49. a. $L = 1.131 \times 10^7\,\text{kg}\cdot\text{m}^2/\text{s}$;

b. $\tau = 3.77 \times 10^4\,\text{N}\cdot\text{m}$

51. $\omega = 28.6\,\text{rad/s} \Rightarrow L = 2.6\,\text{kg}\cdot\text{m}^2/\text{s}$

53. $L_f = \frac{2}{5}M_S(3.5 \times 10^3\,\text{km})^2\frac{2\pi}{T_f}$,

$$(7.0 \times 10^5\,\text{km})^2\frac{2\pi}{28\,\text{days}} = (3.5 \times 10^3\,\text{km})^2\frac{2\pi}{T_f} \qquad T_f$$

$$= 28\,\text{days}\frac{(3.5 \times 10^3\,\text{km})^2}{(7.0 \times 10^5\,\text{km})^2} = 7.0 \times 10^{-4}\,\text{day} = 60.5\,\text{s}$$

55. $f_\text{f} = 2.1\,\text{rev/s} \Rightarrow f_0 = 0.5\,\text{rev/s}$

57. $r_P mv_P = r_A mv_A \Rightarrow v_P = 18.3\,\text{km/s}$

59. a. $I_\text{disk} = 5.0 \times 10^{-4}\,\text{kg}\cdot\text{m}^2$,

$I_\text{bug} = 2.0 \times 10^{-4}\,\text{kg}\cdot\text{m}^2$,

$(I_\text{disk} + I_\text{bug})\omega_1 = I_\text{disk}\omega_2$,

$\omega_2 = 14.0\,\text{rad/s}$

b. $\Delta K = 0.014\,\text{J}$;

c. $\omega_3 = 10.0\,\text{rad/s}$ back to the original value;

d. $\frac{1}{2}(I_{\text{disk}} + I_{\text{bug}})\omega_3^2 = 0.035\text{ J}$ back to the original value;

e. work of the bug crawling on the disk

61. $L_{\text{i}} = 400.0\text{ kg}\cdot\text{m}^2\text{/s}$,

$L_{\text{f}} = 500.0\text{ kg}\cdot\text{m}^2\omega$,

$\omega = 0.80\text{ rad/s}$

63. $I_0 = 340.48\text{ kg}\cdot\text{m}^2$,

$I_{\text{f}} = 268.8\text{ kg}\cdot\text{m}^2$,

$\omega_{\text{f}} = 25.33\text{ rpm}$

65. a. $L = 280\text{ kg}\cdot\text{m}^2\text{/s}$,

$I_{\text{f}} = 89.6\text{ kg}\cdot\text{m}^2$,

$\omega_{\text{f}} = 3.125\text{ rad/s}$; b. $K_{\text{i}} = 437.5\text{ J}$,

$K_{\text{f}} = 437.5\text{ J}$

67. Moment of inertia in the record spin: $I_0 = 0.5\text{ kg}\cdot\text{m}^2$,

$I_{\text{f}} = 1.1\text{ kg}\cdot\text{m}^2$,

$\omega_{\text{f}} = \frac{I_0}{I_{\text{f}}}\omega_0 \Rightarrow f_{\text{f}} = 155.5\text{ rev/min}$

69. Her spin rate in the air is: $f_{\text{f}} = 2.0\text{ rev/s}$;

She can do four flips in the air.

71. Moment of inertia with all children aboard:

$I_0 = 2.4 \times 10^5\text{ kg}\cdot\text{m}^2$;

$I_{\text{f}} = 1.5 \times 10^5\text{ kg}\cdot\text{m}^2$;

$f_{\text{f}} = 0.3\text{rev/s}$

73. $I_0 = 1.00 \times 10^{10}\text{ kg}\cdot\text{m}^2$,

$I_{\text{f}} = 9.94 \times 10^9\text{ kg}\cdot\text{m}^2$,

$f_{\text{f}} = 3.32\text{ rev/min}$

75. $I = 2.5 \times 10^{-3}\text{ kg}\cdot\text{m}^2$,

$\omega_P = 0.78\text{ rad/s}$

77. a. $L_{\text{Earth}} = 7.06 \times 10^{33}\text{ kg}\cdot\text{m}^2\text{/s}$,

$\Delta L = 5.63 \times 10^{33}\text{ kg}\cdot\text{m}^2\text{/s}$;

b. $\tau = 1.7 \times 10^{22}\text{ N}\cdot\text{m}$;

c. The two forces at the equator would have the same magnitude but different directions, one in the north direction and the other in the south direction on the opposite side of Earth. The angle between the forces and the lever arms to the center of Earth is $90°$, so a given torque would have magnitude $\tau = FR_{\text{E}}\sin 90° = FR_{\text{E}}$. Both would provide a torque in the same direction:

$\tau = 2FR_{\text{E}} \Rightarrow F = 1.3 \times 10^{15}\text{ N}$

ADDITIONAL PROBLEMS

79. $a_{\text{CM}} = -\frac{3}{10}g$,

$v^2 = v_0^2 + 2a_{\text{CM}}x \Rightarrow v^2 = (7.0\text{ m/s})^2 - 2\left(\frac{3}{10}g\right)x, \quad v^2 = 0 \Rightarrow x = 8.34\text{ m};$

b. $t = \frac{v - v_0}{a_{\text{CM}}}, \quad v = v_0 + a_{\text{CM}}t \Rightarrow t = 2.38\text{ s}$;

The hollow sphere has a larger moment of inertia, and therefore is harder to bring to a rest than the marble, or solid sphere. The distance travelled is larger and the time elapsed is longer.

81. a. $W = -500.0\,\text{J}$;

b. $K + U_{\text{grav}} = \text{constant}$,

$500\,\text{J} + 0 = 0 + (6.0\,\text{kg})(9.8\,\text{m/s}^2)h$,

$h = 8.5\,\text{m},\ d = 17.0\,\text{m}$;

The moment of inertia is less for the hollow sphere, therefore less work is required to stop it. Likewise it rolls up the incline a shorter distance than the hoop.

83. a. $\tau = 34.0\,\text{N} \cdot \text{m}$;

b. $l = mr^2\omega \Rightarrow \omega = 3.6\,\text{rad/s}$

85. a. $d_{\text{M}} = 3.85 \times 10^8\ \text{m}$ average distance to the Moon; orbital period $27.32\text{d} = 2.36 \times 10^6\,\text{s}$; speed of the Moon $\dfrac{2\pi 3.85 \times 10^8\ \text{m}}{2.36 \times 10^6\,\text{s}} = 1.0 \times 10^3\ \text{m/s}$; mass of the Moon $7.35 \times 10^{22}\ \text{kg}$,

$L = 2.90 \times 10^{34}\ \text{kgm}^2/\text{s}$;

b. radius of the Moon $1.74 \times 10^6\ \text{m}$; the orbital period is the same as (a): $\omega = 2.66 \times 10^{-6}\ \text{rad/s}$,

$L = 2.37 \times 10^{29}\ \text{kg} \cdot \text{m}^2/\text{s}$;

The orbital angular momentum is 1.22×10^5 times larger than the rotational angular momentum for the Moon.

87. $I = 0.135\,\text{kg} \cdot \text{m}^2$,

$\alpha = 4.19\,\text{rad/s}^2, \quad \omega = \omega_0 + \alpha t$,

$\omega(5\,\text{s}) = 21.0\,\text{rad/s}, \quad L = 2.84\,\text{kg} \cdot \text{m}^2/\text{s}$,

$\omega(10\,\text{s}) = 41.9\,\text{rad/s}, \quad L = 5.66\,\text{kg} \cdot \text{m/s}^2$

89. In the conservation of angular momentum equation, the rotation rate appears on both sides so we keep the (rev/min) notation as the angular velocity can be multiplied by a constant to get (rev/min):

$$\begin{aligned} L_{\text{i}} &= -0.04\,\text{kg} \cdot \text{m}^2(300.0\,\text{rev/min}), \\ L_{\text{f}} &= 0.08\,\text{kg} \cdot \text{m}^2 f_{\text{f}} \Rightarrow f_{\text{f}} = -150.0\,\text{rev/min clockwise} \end{aligned}$$

91. $I_0\omega_0 = I_{\text{f}}\omega_{\text{f}}$,

$I_0 = 6120.0\,\text{kg} \cdot \text{m}^2$,

$I_{\text{f}} = 1180.0\,\text{kg} \cdot \text{m}^2$,

$\omega_{\text{f}} = 31.1\,\text{rev/min}$

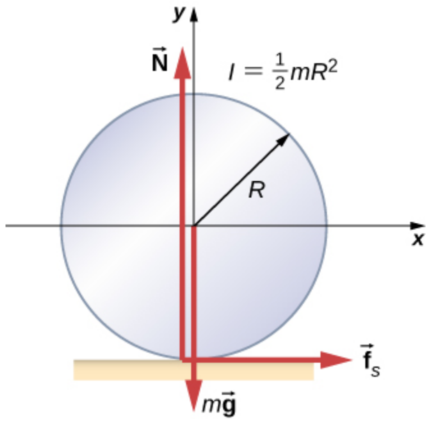
93. $L_{\text{i}} = 1.00 \times 10^7\ \text{kg} \cdot \text{m}^2/\text{s}$,

$I_{\text{f}} = 2.025 \times 10^5\ \text{kg} \cdot \text{m}^2$,

$\omega_{\text{f}} = 7.86\,\text{rev/s}$

CHALLENGE PROBLEMS

95. Assume the roll accelerates forward with respect to the ground with an acceleration a'. Then it accelerates backwards relative to the truck with an acceleration $(a - a')$.



Also, $R\alpha = a - a'$ $I = \frac{1}{2}mR^2$ $\sum F_x = f_s = ma'$,

$\sum \tau = f_s R = I\alpha = I\frac{a - a'}{R}$ $f_s = \frac{I}{R^2}(a - a') = \frac{1}{2}m(a - a')$,

Solving for a': $f_s = \frac{1}{2}m(a - a')$; $a' = \frac{a}{3}$,

$x - x_0 = v_0 t + \frac{1}{2}at^2$; $d = \frac{1}{3}at^2$; $t = \sqrt{\frac{3d}{a}}$;

therefore, $s = 1.5d$

97. a. The tension in the string provides the centripetal force such that $T\sin\theta = mr_\perp \ \omega^2$. The component of the tension that is vertical opposes the gravitational force such that $T\cos\theta = mg$. This gives $T = 5.7\text{ N}$. We solve for $r_\perp \ = 0.16\text{ m}$. This gives the length of the string as $r = 0.32\text{ m}$.
At $\omega = 10.0\text{ rad/s}$, there is a new angle, tension, and perpendicular radius to the rod. Dividing the two equations involving the tension to eliminate it, we have $\frac{\sin\theta}{\cos\theta} = \frac{(0.32\text{ m}\sin\theta)\omega^2}{g} \Rightarrow \frac{1}{\cos\theta} = \frac{0.32\text{ m}\omega^2}{g}$;
$\cos\theta = 0.31 \Rightarrow \theta = 72.2°$; b. $l_{\text{initial}} = 0.08\text{ kg}\cdot\text{m}^2\text{/s}$,
$l_{\text{fina}} \ = 0.46\text{ kg}\cdot\text{m}^2\text{/s}$; c. No, the cosine of the angle is inversely proportional to the square of the angular velocity, therefore in order for $\theta \to 90°, \quad \omega \to \infty$. The rod would have to spin infinitely fast.

CHAPTER 12

CHECK YOUR UNDERSTANDING

12.1. $x = 1.3\text{ m}$

12.2. (b), (c)

12.3. 316.7 g; 5.8 N

12.4. $T = 1963\text{ N};\ \text{F} = 1732\text{ N}$

12.5. $\mu_s < 0.5\cot\beta$

12.6. $\vec{\mathbf{F}}_{\text{door on }A} = 100.0\text{ N}\,\hat{\mathbf{i}} - 200.0\text{ N}\,\hat{\mathbf{j}}$; $\vec{\mathbf{F}}_{\text{door on }B} = -100.0\text{ N}\,\hat{\mathbf{i}} - 200.0\text{ N}\,\hat{\mathbf{j}}$

12.7. 711.0 N; 466.0 N

12.8. 1167 N; 980 N directed upward at $18°$ above the horizontal

12.9. $206.8\text{ kPa};\ 4.6\times10^{-5}$

12.10. 5.0×10^{-4}

12.11. 63 mL

12.12. Fluids have different mechanical properties than those of solids; fluids flow.

CONCEPTUAL QUESTIONS

1. constant

3. magnitude and direction of the force, and its lever arm
5. True, as the sum of forces cannot be zero in this case unless the force itself is zero.
7. False, provided forces add to zero as vectors then equilibrium can be achieved.
9. It helps a wire-walker to maintain equilibrium.
11. (Proof)
13. In contact with the ground, stress in squirrel's limbs is smaller than stress in human's limbs.
15. tightly
17. compressive; tensile
19. no
23. It acts as "reinforcement," increasing a range of strain values before the structure reaches its breaking point.

PROBLEMS

25. $46.8\ \text{N} \cdot \text{m}$
27. 153.4°
29. 23.3 N
31. 80.0 kg
33. 40 kg
35. right cable, 444.3 N; left cable, 888.5 N; weight of equipment 156.8 N; 16.0 kg
37. 784 N, 376 N
39. a. 539 N; b. 461 N; c. do not depend on the angle
41. tension 778 N; at hinge 778 N at $45°$ above the horizontal; no
43. 1500 N; 1620 N at $30°$
45. 0.3 mm
47. 9.0 cm
49. $4.0 \times 10^2\ \text{N/cm}^2$
51. $0.149\ \mu\text{m}$
53. 0.57 mm
55. 8.59 mm
57. $1.35 \times 10^9\ \text{Pa}$
59. 259.0 N
61. 0.01%
63. 1.44 cm
65. 0.63 cm

ADDITIONAL PROBLEMS

69. $\tan^{-1}(1/\mu_s) = 51.3°$
71. a. at corner 66.7 N at $30°$ with the horizontal; at floor 192.4 N at $60°$ with the horizontal; b. $\mu_\text{s} = 0.577$
73. a. $1.10 \times 10^9\ \text{N/m}^2$; b. 5.5×10^{-3}; c. 11.0 mm, 31.4 mm

CHALLENGE PROBLEMS

75. $F = Mg \tan\theta$; $f = 0$
77. with the horizontal, $\theta = 42.2°$; $\alpha = 17.8°$ with the steeper side of the wedge
79. $W(l_1/l_2 - 1)$; $Wl_1/l_2 + mg$
81. a. 1.1 mm; b. 6.6 mm to the right; c. $1.11 \times 10^5\ \text{N}$

CHAPTER 13

CHECK YOUR UNDERSTANDING

13.1. The force of gravity on each object increases with the square of the inverse distance as they fall together, and hence so does the acceleration. For example, if the distance is halved, the force and acceleration are quadrupled. Our average is accurate only for a linearly increasing acceleration, whereas the acceleration actually increases at a greater rate. So our calculated speed is too small. From Newton's third law (action-reaction forces), the force of gravity between any two objects must be the same. But the accelerations will not be if they have different masses.
13.2. The tallest buildings in the world are all less than 1 km. Since g is proportional to the distance squared from Earth's center, a simple ratio shows that the change in g at 1 km above Earth's surface is less than 0.0001%. There would be no need to consider this in structural design.

13.3. The value of g drops by about 10% over this change in height. So $\Delta U = mg(y_2 - y_1)$ will give too large a value. If we use $g = 9.80 \text{ m/s}$, then we get $\Delta U = mg(y_2 - y_1) = 3.53 \times 10^{10} \text{ J}$ which is about 6% greater than that found with the correct method.
13.4. The probe must overcome both the gravitational pull of Earth and the Sun. In the second calculation of our example, we found the speed necessary to escape the Sun from a distance of Earth's orbit, not from Earth itself. The proper way to find this value is to start with the energy equation, **Equation 13.26**, in which you would include a potential energy term for both Earth and the Sun.
13.5. You change the direction of your velocity with a force that is perpendicular to the velocity at all points. In effect, you must constantly adjust the thrusters, creating a centripetal force until your momentum changes from tangential to radial. A simple momentum vector diagram shows that the net *change* in momentum is $\sqrt{2}$ times the magnitude of momentum itself. This turns out to be a very inefficient way to reach Mars. We discuss the most efficient way in **Kepler's Laws of Planetary Motion**.
13.6. In **Equation 13.32**, the radius appears in the denominator inside the square root. So the radius must increase by a factor of 4, to decrease the orbital velocity by a factor of 2. The circumference of the orbit has also increased by this factor of 4, and so with half the orbital velocity, the period must be 8 times longer. That can also be seen directly from **Equation 13.33**.
13.7. The assumption is that orbiting object is much less massive than the body it is orbiting. This is not really justified in the case of the Moon and Earth. Both Earth and the Moon orbit about their common center of mass. We tackle this issue in the next example.
13.8. The stars on the "inside" of each galaxy will be closer to the other galaxy and hence will feel a greater gravitational force than those on the outside. Consequently, they will have a greater acceleration. Even without this force difference, the inside stars would be orbiting at a smaller radius, and, hence, there would develop an elongation or stretching of each galaxy. The force difference only increases this effect.
13.9. The semi-major axis for the highly elliptical orbit of Halley's comet is 17.8 AU and is the average of the perihelion and aphelion. This lies between the 9.5 AU and 19 AU orbital radii for Saturn and Uranus, respectively. The radius for a circular orbit is the same as the semi-major axis, and since the period increases with an increase of the semi-major axis, the fact that Halley's period is between the periods of Saturn and Uranus is expected.
13.10. Consider the last equation above. The values of r_1 and r_2 remain nearly the same, but the diameter of the Moon, $(r_2 - r_1)$, is one-fourth that of Earth. So the tidal forces on the Moon are about one-fourth as great as on Earth.

13.11. Given the incredible density required to force an Earth-sized body to become a black hole, we do not expect to see such small black holes. Even a body with the mass of our Sun would have to be compressed by a factor of 80 beyond that of a neutron star. It is believed that stars of this size cannot become black holes. However, for stars with a few solar masses, it is believed that gravitational collapse at the end of a star's life could form a black hole. As we will discuss later, it is now believed that black holes are common at the center of galaxies. These galactic black holes typically contain the mass of many millions of stars.

CONCEPTUAL QUESTIONS

1. The ultimate truth is experimental verification. Field theory was developed to help explain how force is exerted without objects being in contact for both gravity and electromagnetic forces that act at the speed of light. It has only been since the twentieth century that we have been able to measure that the force is not conveyed immediately.
3. The centripetal acceleration is not directed along the gravitational force and therefore the correct line of the building (i.e., the plumb bob line) is not directed towards the center of Earth. But engineers use either a plumb bob or a transit, both of which respond to both the direction of gravity and acceleration. No special consideration for their location on Earth need be made.
5. As we move to larger orbits, the change in potential energy increases, whereas the orbital velocity decreases. Hence, the ratio is highest near Earth's surface (technically infinite if we orbit at Earth's surface with no elevation change), moving to zero as we reach infinitely far away.
7. The period of the orbit must be 24 hours. But in addition, the satellite must be located in an equatorial orbit and orbiting in the same direction as Earth's rotation. All three criteria must be met for the satellite to remain in one position relative to Earth's surface. At least three satellites are needed, as two on opposite sides of Earth cannot communicate with each other. (This is not technically true, as a wavelength could be chosen that provides sufficient diffraction. But it would be totally impractical.)
9. The speed is greatest where the satellite is closest to the large mass and least where farther away—at the periapsis and apoapsis, respectively. It is conservation of angular momentum that governs this relationship. But it can also be gleaned from conservation of energy, the kinetic energy must be greatest where the gravitational potential energy is the least (most negative). The force, and hence acceleration, is always directed towards M in the diagram, and the velocity is always tangent to the path at all points. The acceleration vector has a tangential component along the direction of the velocity at the upper location on the y-axis; hence, the satellite is speeding up. Just the opposite is true at the lower position.
11. The laser beam will hit the far wall at a lower elevation than it left, as the floor is accelerating upward. Relative to the lab, the laser beam "falls." So we would expect this to happen in a gravitational field. The mass of light, or even an object with mass, is not relevant.

PROBLEMS

13. $7.4 \times 10^{-8} \text{ N}$

15. a. 7.01×10^{-7} N ; b. The mass of Jupiter is

$$m_\text{J} = 1.90 \times 10^{27} \text{ kg}$$

$$F_\text{J} = 1.35 \times 10^{-6} \text{ N}$$

$$\frac{F_\text{f}}{F_\text{J}} = 0.521$$

17. a. 9.25×10^{-6} N ; b. Not very, as the ISS is not even symmetrical, much less spherically symmetrical.
19. a. $1.41 \times 10^{-15}\,\text{m/s}^2$; b. $1.69 \times 10^{-4}\ \text{m/s}^2$
21. a. $1.62\,\text{m/s}^2$; b. $3.75\,\text{m/s}^2$
23. a. 147 N; b. 25.5 N; c. 15 kg; d. 0; e. 15 kg
25. $12\,\text{m/s}^2$
27. $(3/2)R_\text{E}$
29. 5000 m/s
31. 1440 m/s
33. 11 km/s
35. a. 5.85×10^{10} J ; b. -5.85×10^{10} J ; No. It assumes the kinetic energy is recoverable. This would not even be reasonable if we had an elevator between Earth and the Moon.
37. a. 0.25; b. 0.125
39. a. 5.08×10^{3} km ; b. This less than the radius of Earth.
41. 1.89×10^{27} kg
43. a. 4.01×10^{13} kg ; b. The satellite must be outside the radius of the asteroid, so it can't be larger than this. If it were this size, then its density would be about $1200\,\text{kg/m}^3$. This is just above that of water, so this seems quite reasonable.
45. a. $1.66 \times 10^{-10}\ \text{m/s}^2$; Yes, the centripetal acceleration is so small it supports the contention that a nearly inertial frame of reference can be located at the Sun. b. $2.17 \times 10^{5}\,\text{m/s}$
47. 1.98×10^{30} kg ; The values are the same within 0.05%.
49. Compare **Equation 13.33** and **Equation 13.53** to see that they differ only in that the circular radius, *r*, is replaced by the semi-major axis, *a*. Therefore, the mean radius is one-half the sum of the aphelion and perihelion, the same as the semi-major axis.
51. The semi-major axis, 3.78 AU is found from the equation for the period. This is one-half the sum of the aphelion and perihelion, giving an aphelion distance of 4.95 AU.
53. 1.75 years
55. 19,800 N; this is clearly not survivable
57. $1.19 \times 10^{7}\,\text{km}$

ADDITIONAL PROBLEMS

59. a. 1.85×10^{14} N ; b. Don't do it!
61. $1.49 \times 10^{8}\,\text{km}$
63. The value of g for this planet is 2.4 m/s^2, which is about one-fourth that of Earth. So they are weak high jumpers.
65. At the North Pole, 983 N; at the equator, 980 N
67. a. The escape velocity is still 43.6 km/s. By launching from Earth in the direction of Earth's tangential velocity, you need $43.4 - 29.8 = 13.8\,\text{km/s}$ relative to Earth. b. The total energy is zero and the trajectory is a parabola.
69. 44.9 km/s
71. a. 1.3×10^{7} m ; b. 1.56×10^{10} J ; -3.12×10^{10} J ; -1.56×10^{10} J
73. a. 6.24×10^{3} s or about 1.7 hours. This was using the 520 km average diameter. b. Vesta is clearly not very spherical, so you would need to be above the largest dimension, nearly 580 km. More importantly, the nonspherical nature would disturb the orbit very quickly, so this calculation would not be very accurate even for one orbit.
75. a. 323 km/s; b. No, you need only the difference between the solar system's orbital speed and escape speed, so about $323 - 228 = 95\,\text{km/s}$.
77. Setting $e = 1$, we have $\frac{\alpha}{r} = 1 + \cos\theta \rightarrow \alpha = r + r\cos\theta = r + x$; hence, $r^2 = x^2 + y^2 = (\alpha - x)^2$. Expand and collect

to show $x = \frac{1}{-2\alpha} y^2 + \frac{\alpha}{2}$.

79. Substitute directly into the energy equation using $pv_p = qv_q$ from conservation of angular momentum, and solve for v_p.

CHALLENGE PROBLEMS

81. $g = \frac{4}{3} G\rho\pi r \rightarrow F = mg = \left[\frac{4}{3} Gm\rho\pi\right] r$, and from $F = m\frac{d^2 r}{dt^2}$, we get $\frac{d^2 r}{dt^2} = \left[\frac{4}{3} G\rho\pi\right] r$ where the first term is ω^2.

Then $T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{3}{4G\rho\pi}}$ and if we substitute $\rho = \frac{M}{4/3\pi R^3}$, we get the same expression as for the period of orbit *R*.

83. Using the mass of the Sun and Earth's orbital radius, the equation gives $2.24 \times 10^{15}\ \text{m}^2/\text{s}$. The value of $\pi R_{\text{ES}}^2/(1\ \text{year})$ gives the same value.

85. $\Delta U = U_f - U_i = -\frac{GM_\text{E} m}{r_f} + \frac{GM_\text{E} m}{r_i} = GM_\text{E} m\left(\frac{r_f - r_i}{r_f r_i}\right)$ where $h = r_f - r_i$. If $h << \text{R}_\text{E}$, then $r_f r_i \approx R_\text{E}^2$, and upon substitution, we have $\Delta U = GM_\text{E} m\left(\frac{h}{R_\text{E}^2}\right) = m\left(\frac{GM_\text{E}}{R_\text{E}^2}\right) h$ where we recognize the expression with the parenthesis as the definition of *g*.

87. a. Find the difference in force,

$F_\text{tidal} = = \frac{2GMm}{R^3}\Delta r$;

b. For the case given, using the Schwarzschild radius from a previous problem, we have a tidal force of $9.5 \times 10^{-3}\ \text{N}$. This won't even be noticed!

CHAPTER 14

CHECK YOUR UNDERSTANDING

14.1. The pressure found in part (a) of the example is completely independent of the width and length of the lake; it depends only on its average depth at the dam. Thus, the force depends only on the water's average depth and the dimensions of the dam, not on the horizontal extent of the reservoir. In the diagram, note that the thickness of the dam increases with depth to balance the increasing force due to the increasing pressure.
14.2. The density of mercury is 13.6 times greater than the density of water. It takes approximately 76 cm (29.9 in.) of mercury to measure the pressure of the atmosphere, whereas it would take approximately 10 m (34 ft.) of water.
14.3. Yes, it would still work, but since a gas is compressible, it would not operate as efficiently. When the force is applied, the gas would first compress and warm. Hence, the air in the brake lines must be bled out in order for the brakes to work properly.

CONCEPTUAL QUESTIONS

1. Mercury and water are liquid at room temperature and atmospheric pressure. Air is a gas at room temperature and atmospheric pressure. Glass is an amorphous solid (non-crystalline) material at room temperature and atmospheric pressure. At one time, it was thought that glass flowed, but flowed very slowly. This theory came from the observation that old glass planes were thicker at the bottom. It is now thought unlikely that this theory is accurate.
3. The density of air decreases with altitude. For a column of air of a constant temperature, the density decreases exponentially with altitude. This is a fair approximation, but since the temperature does change with altitude, it is only an approximation.
5. Pressure is force divided by area. If a knife is sharp, the force applied to the cutting surface is divided over a smaller area than the same force applied with a dull knife. This means that the pressure would be greater for the sharper knife, increasing its ability to cut.
7. If the two chunks of ice had the same volume, they would produce the same volume of water. The glacier would cause the greatest rise in the lake, however, because part of the floating chunk of ice is already submerged in the lake, and is thus already contributing to the lake's level.
9. The pressure is acting all around your body, assuming you are not in a vacuum.
11. Because the river level is very high, it has started to leak under the levee. Sandbags are placed around the leak, and the water held by them rises until it is the same level as the river, at which point the water there stops rising. The sandbags will absorb water until the water reaches the height of the water in the levee.
13. Atmospheric pressure does not affect the gas pressure in a rigid tank, but it does affect the pressure inside a balloon. In general, atmospheric pressure affects fluid pressure unless the fluid is enclosed in a rigid container.
15. The pressure of the atmosphere is due to the weight of the air above. The pressure, force per area, on the manometer will be the same at the same depth of the atmosphere.
17. Not at all. Pascal's principle says that the change in the pressure is exerted through the fluid. The reason that the full tub requires more force to pull the plug is because of the weight of the water above the plug.

19. The buoyant force is equal to the weight of the fluid displaced. The greater the density of the fluid, the less fluid that is needed to be displaced to have the weight of the object be supported and to float. Since the density of salt water is higher than that of fresh water, less salt water will be displaced, and the ship will float higher.
21. Consider two different pipes connected to a single pipe of a smaller diameter, with fluid flowing from the two pipes into the smaller pipe. Since the fluid is forced through a smaller cross-sectional area, it must move faster as the flow lines become closer together. Likewise, if a pipe with a large radius feeds into a pipe with a small radius, the stream lines will become closer together and the fluid will move faster.
23. The mass of water that enters a cross-sectional area must equal the amount that leaves. From the continuity equation, we know that the density times the area times the velocity must remain constant. Since the density of the water does not change, the velocity times the cross-sectional area entering a region must equal the cross-sectional area times the velocity leaving the region. Since the velocity of the fountain stream decreases as it rises due to gravity, the area must increase. Since the velocity of the faucet stream speeds up as it falls, the area must decrease.
25. When the tube narrows, the fluid is forced to speed up, thanks to the continuity equation and the work done on the fluid. Where the tube is narrow, the pressure decreases. This means that the entrained fluid will be pushed into the narrow area.
27. The work done by pressure can be used to increase the kinetic energy and to gain potential energy. As the height becomes larger, there is less energy left to give to kinetic energy. Eventually, there will be a maximum height that cannot be overcome.
29. Because of the speed of the air outside the building, the pressure outside the house decreases. The greater pressure inside the building can essentially blow off the roof or cause the building to explode.
31. The air inside the hose has kinetic energy due to its motion. The kinetic energy can be used to do work against the pressure difference.
33. Potential energy due to position, kinetic energy due to velocity, and the work done by a pressure difference.
35. The water has kinetic energy due to its motion. This energy can be converted into work against the difference in pressure.
37. The water in the center of the stream is moving faster than the water near the shore due to resistance between the water and the shore and between the layers of fluid. There is also probably more turbulence near the shore, which will also slow the water down. When paddling up stream, the water pushes against the canoe, so it is better to stay near the shore to minimize the force pushing against the canoe. When moving downstream, the water pushes the canoe, increasing its velocity, so it is better to stay in the middle of the stream to maximize this effect.
39. You would expect the speed to be slower after the obstruction. Resistance is increased due to the reduction in size of the opening, and turbulence will be created because of the obstruction, both of which will clause the fluid to slow down.

PROBLEMS

41. 1.610 cm^3
43. The mass is 2.58 g. The volume of your body increases by the volume of air you inhale. The average density of your body decreases when you take a deep breath because the density of air is substantially smaller than the average density of the body.
45. 3.99 cm
47. 2.86 times denser
49. $15.6\ \text{g/cm}^3$
51. $0.760\ \text{m} = 76.0\ \text{cm} = 760\ \text{mm}$
53. proof
55. a. Pressure at $h = 7.06 \times 10^6\ \text{N}$;
b. The pressure increases as the depth increases, so the dam must be built thicker toward the bottom to withstand the greater pressure.
57. 4.08 m
59. 251 atm
61. $5.76 \times 10^3\ \text{N}$ extra force
63. If the system is not moving, the friction would not play a role. With friction, we know there are losses, so that $W_\text{o} = W_\text{i} - W_\text{f}$; therefore, the work output is less than the work input. In other words, to account for friction, you would need to push harder on the input piston than was calculated.
65. a. 99.5% submerged; b. 96.9% submerged
67. a. 39.5 g; b. $50\ \text{cm}^3$; c. $0.79\ \text{g/cm}^3$; ethyl alcohol
69. a. $960\ \text{kg/m}^3$; b. 6.34%; She floats higher in seawater.
71. a. 0.24; b. 0.68; c. Yes, the cork will float in ethyl alcohol.
73.
$$\begin{aligned}\text{net } F &= F_2 - F_1 = p_2 A - p_1 A = (p_2 - p_1)A = (h_2 \rho_\text{fl} g - h_1 \rho_\text{fl} g)A \\ &= (h_2 - h_1)\rho_\text{fl} gA, \text{ where } \rho_\text{fl} = \text{density of flui} . \\ \text{net } F &= (h_2 - h_1)A\rho_\text{fl} g = V_\text{fl} \rho_\text{fl} g = m_\text{fl} g = w_\text{fl}\end{aligned}$$
75. 2.77 cm^3/s

77. a. 0.75 m/s; b. 0.13 m/s
79. a. 12.6 m/s; b. $0.0800\ \text{m}^3/\text{s}$; c. No, the flow rate and the velocity are independent of the density of the fluid.
81. If the fluid is incompressible, the flow rate through both sides will be equal: $Q = A_1\bar{v}_1 = A_2\bar{v}_2$, or

$$\pi\frac{d_1^2}{4}\bar{v}_1 = \pi\frac{d_2^2}{4}\bar{v}_2 \Rightarrow \bar{v}_2 = \bar{v}_1(d_1^2/d_2^2) = \bar{v}_1(d_1/d_2)^2$$

83.
$$\begin{aligned} F &= pA \Rightarrow p = \frac{F}{A}, \\ [p] &= \text{N/m}^2 = \text{N}\cdot\text{m/m}^3 = \text{J/m}^3 = \text{energy/volume} \end{aligned}$$

85. −135 mm Hg
87. a. $1.58\times10^6\ \text{N/m}^2$; b. 163 m
89. a. $v_2 = 3.28\frac{\text{m}}{\text{s}}$;

b. $t = 0.55\ \text{s}$

$x = vt = 1.81\ \text{m}$

91. a. $3.02\times10^{-3}\ \text{N}$; b. 1.03×10^{-3}
93. proof
95. 40 m/s
97. $0.537r$; The radius is reduced to 53.7% of its normal value.
99. a. $2.40\times10^9\ \text{N}\cdot\text{s/m}^5$; b. $48.3\ (\text{N/m}^2)\cdot\text{s}$; c. $2.67\times10^4\ \text{W}$
101. a. Nozzle: $v = 25.5\frac{\text{m}}{\text{s}}$

$N_\text{R} = 1.27\times10^5 > 2000 \Rightarrow$

Flow is not laminar.
b. Hose: $v = 1.96\frac{\text{m}}{\text{s}}$

$N_\text{R} = 35{,}100 > 2000 \Rightarrow$

Flow is not laminar.
103. $3.16\times10^{-4}\ \text{m}^3/\text{s}$

ADDITIONAL PROBLEMS

105. 30.6 m

107. a. $\begin{aligned} p_{120} &= 1.60\times10^4\ \text{N/m}^2 \\ p_{80} &= 1.07\times10^4\ \text{N/m}^2 \end{aligned}$;

b. Since an infant is only approximately 20 inches tall, while an adult is approximately 70 inches tall, the blood pressure for an infant would be expected to be smaller than that of an adult. The blood only feels a pressure of 20 inches rather than 70 inches, so the pressure should be smaller.
109. a. 41.4 g; b. 41.4 cm^3; c. 1.09 g/cm^3. This is clearly not the density of the bone everywhere. The air pockets will have a density of approximately $1.29\times10^{-3}\ \text{g/cm}^3$, while the bone will be substantially denser.
111. 8.21 N
113. a. $3.02\times10^{-2}\ \text{cm/s}$. (This small speed allows time for diffusion of materials to and from the blood.) b. 2.37×10^{10} capillaries. (This large number is an overestimate, but it is still reasonable.)
115. a. $2.76\times10^5\ \text{N/m}^2$; b. $P_2 = 2.81\times10^5\ \text{N/m}^2$
117. $8.7\times10^{-2}\ \text{mm}^3/\text{s}$
119. a. 1.52; b. Turbulence would decrease the flow rate of the blood, which would require an even larger increase in the pressure difference, leading to higher blood pressure.

CHALLENGE PROBLEMS

121. $p = 0.99\times10^5\ \text{Pa}$

123. $800\ \text{kg/m}^3$

125. 11.2 m/s

127. a. 71.8 m/s; b. 257 m/s

129. a. $150\,\text{cm}^3/\text{s}$; b. $33.3\,\text{cm}^3/\text{s}$; c. $25.0\,\text{cm}^3/\text{s}$; d. $0.0100\,\text{cm}^3/\text{s}$; e. $0.0300\,\text{cm}^3/\text{s}$

131. a. $1.20 \times 10^5\ \text{N/m}^2$; b. The flow rate in the main increases by 90%. c. There are approximately 38 more users in the afternoon.

CHAPTER 15

CHECK YOUR UNDERSTANDING

15.1. The ruler is a stiffer system, which carries greater force for the same amount of displacement. The ruler snaps your hand with greater force, which hurts more.
15.2. You could increase the mass of the object that is oscillating. Other options would be to reduce the amplitude, or use a less stiff spring.
15.3. A ketchup bottle sits on a lazy Susan in the center of the dinner table. You set it rotating in uniform circular motion. A set of lights shine on the bottle, producing a shadow on the wall.
15.4. The movement of the pendulums will not differ at all because the mass of the bob has no effect on the motion of a simple pendulum. The pendulums are only affected by the period (which is related to the pendulum's length) and by the acceleration due to gravity.
15.5. Friction often comes into play whenever an object is moving. Friction causes damping in a harmonic oscillator.
15.6. The performer must be singing a note that corresponds to the natural frequency of the glass. As the sound wave is directed at the glass, the glass responds by resonating at the same frequency as the sound wave. With enough energy introduced into the system, the glass begins to vibrate and eventually shatters.

CONCEPTUAL QUESTIONS

1. The restoring force must be proportional to the displacement and act opposite to the direction of motion with no drag forces or friction. The frequency of oscillation does not depend on the amplitude.
3. Examples: Mass attached to a spring on a frictionless table, a mass hanging from a string, a simple pendulum with a small amplitude of motion. All of these examples have frequencies of oscillation that are independent of amplitude.
5. Since the frequency is proportional to the square root of the force constant and inversely proportional to the square root of the mass, it is likely that the truck is heavily loaded, since the force constant would be the same whether the truck is empty or heavily loaded.
7. In a car, elastic potential energy is stored when the shock is extended or compressed. In some running shoes elastic potential energy is stored in the compression of the material of the soles of the running shoes. In pole vaulting, elastic potential energy is stored in the bending of the pole.
9. The overall system is stable. There may be times when the stability is interrupted by a storm, but the driving force provided by the sun bring the atmosphere back into a stable pattern.
11. The maximum speed is equal to $v_{\text{max}} = A\omega$ and the angular frequency is independent of the amplitude, so the amplitude would be affected. The radius of the circle represents the amplitude of the circle, so make the amplitude larger.
13. The period of the pendulum is $T = 2\pi\sqrt{L/g}$. In summer, the length increases, and the period increases. If the period should be one second, but period is longer than one second in the summer, it will oscillate fewer than 60 times a minute and clock will run slow. In the winter it will run fast.
15. A car shock absorber.
17. The second law of thermodynamics states that perpetual motion machines are impossible. Eventually the ordered motion of the system decreases and returns to equilibrium.
19. All harmonic motion is damped harmonic motion, but the damping may be negligible. This is due to friction and drag forces. It is easy to come up with five examples of damped motion: (1) A mass oscillating on a hanging on a spring (it eventually comes to rest). (2) Shock absorbers in a car (thankfully they also come to rest). (3) A pendulum is a grandfather clock (weights are added to add energy to the oscillations). (4) A child on a swing (eventually comes to rest unless energy is added by pushing the child). (5) A marble rolling in a bowl (eventually comes to rest). As for the undamped motion, even a mass on a spring in a vacuum will eventually come to rest due to internal forces in the spring. Damping may be negligible, but cannot be eliminated.

PROBLEMS

21. Proof
23. 0.400 s/beat
25. 12,500 Hz
27. a. 340 km/hr; b. 11.3×10^3 rev/min
29. $f = \frac{1}{3}f_0$
31. 0.009 kg; 2%
33. a. 1.57×10^5 N/m; b. 77 kg, yes, he is eligible to play

35. a. 6.53×10^3 N/m ; b. yes, when the man is at his lowest point in his hopping the spring will be compressed the most
37. a. 1.99 Hz; b. 50.2 cm; c. 0.710 m
39. a. 0.335 m/s; b. 5.61×10^{-4} J
41. a. $x(t) = 2\text{ m}\cos\left(0.52\text{s}^{-1}\,t\right)$; b. $v(t) = (-1.05\text{ m/s})\sin\left(0.52\text{s}^{-1}\,t\right)$
43. 24.8 cm
45. 4.01 s
47. 1.58 s
49. 9.82002 m/s^2
51. 9%
53. 141 J
55. a. 4.90×10^{-3} m ; b. 1.15×10^{-2} m

ADDITIONAL PROBLEMS

57. 94.7 kg
59. a. 314 N/m; b. 1.00 s; c. 1.25 m/s
61. ratio of 2.45
63. The length must increase by 0.0116%.
65. $\theta = (0.31\text{ rad})\sin\left(3.13\text{ s}^{-1}\,t\right)$
67. a. 0.99 s; b. 0.11 m

CHALLENGE PROBLEMS

69. a. 3.95×10^6 N/m ; b. 7.90×10^6 J
71. $F \approx -\text{constant } r'$
73. a. 7.54 cm; b. 3.25×10^4 N/m

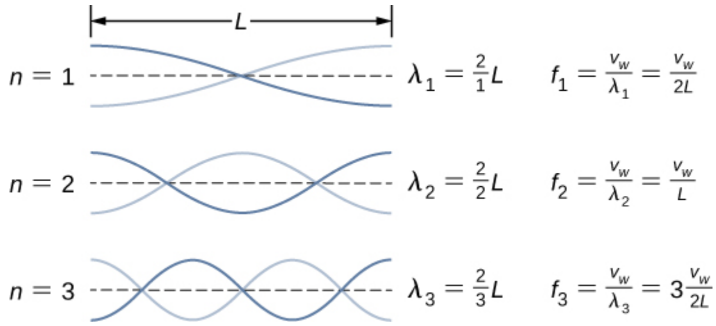
CHAPTER 16

CHECK YOUR UNDERSTANDING

16.1. The wavelength of the waves depends on the frequency and the velocity of the wave. The frequency of the sound wave is equal to the frequency of the wave on the string. The wavelengths of the sound waves and the waves on the string are equal only if the velocities of the waves are the same, which is not always the case. If the speed of the sound wave is different from the speed of the wave on the string, the wavelengths are different. This velocity of sound waves will be discussed in **Sound**.
16.2. In a transverse wave, the wave may move at a constant propagation velocity through the medium, but the medium oscillates perpendicular to the motion of the wave. If the wave moves in the positive *x*-direction, the medium oscillates up and down in the *y*-direction. The velocity of the medium is therefore not constant, but the medium's velocity and acceleration are similar to that of the simple harmonic motion of a mass on a spring.
16.3. Yes, a cosine function is equal to a sine function with a phase shift, and either function can be used in a wave function. Which function is more convenient to use depends on the initial conditions. In **Figure 16.11**, the wave has an initial height of $\text{y}(0.00,\ 0.00) = 0$ and then the wave height increases to the maximum height at the crest. If the initial height at the initial time was equal to the amplitude of the wave $\text{y}(0.00,\ 0.00) = +A,$ then it might be more convenient to model the wave with a cosine function.
16.4. This wave, with amplitude $A = 0.5\text{ m},$ wavelength $\lambda = 10.00\text{ m},$ period $T = 0.50\text{ s},$ is a solution to the wave equation with a wave velocity $v = 20.00\text{ m/s}.$
16.5. Since the speed of a wave on a taunt string is proportional to the square root of the tension divided by the linear density, the wave speed would increase by $\sqrt{2}.$
16.6. At first glance, the time-averaged power of a sinusoidal wave on a string may look proportional to the linear density of the string because $P = \frac{1}{2}\mu A^2\omega^2 v;$ however, the speed of the wave depends on the linear density. Replacing the wave speed with $\sqrt{\frac{F_T}{\mu}}$ shows that the power is proportional to the square root of tension and proportional to the square root of the linear mass density:

$$P = \frac{1}{2}\mu A^2\omega^2 v = \frac{1}{2}\mu A^2\omega^2\sqrt{\frac{F_T}{\mu}} = \frac{1}{2}A^2\omega^2\sqrt{\mu F_T}.$$

16.7. Yes, the equations would work equally well for symmetric boundary conditions of a medium free to oscillate on each end where there was an antinode on each end. The normal modes of the first three modes are shown below. The dotted line shows the equilibrium position of the medium.



Note that the first mode is two quarters, or one half, of a wavelength. The second mode is one quarter of a wavelength, followed by one half of a wavelength, followed by one quarter of a wavelength, or one full wavelength. The third mode is one and a half wavelengths. These are the same result as the string with a node on each end. The equations for symmetrical boundary conditions work equally well for fixed boundary conditions and free boundary conditions. These results will be revisited in the next chapter when discussing sound wave in an open tube.

CONCEPTUAL QUESTIONS

1. A wave on a guitar string is an example of a transverse wave. The disturbance of the string moves perpendicular to the propagation of the wave. The sound produced by the string is a longitudinal wave where the disturbance of the air moves parallel to the propagation of the wave.

3. Propagation speed is the speed of the wave propagating through the medium. If the wave speed is constant, the speed can be found by $v = \frac{\lambda}{T} = \lambda f.$ The frequency is the number of wave that pass a point per unit time. The wavelength is directly proportional to the wave speed and inversely proportional to the frequency.

5. No, the distance you move your hand up and down will determine the amplitude of the wave. The wavelength will depend on the frequency you move your hand up and down, and the speed of the wave through the spring.

7. Light from the Sun and stars reach Earth through empty space where there is no medium present.

9. The wavelength is equal to the velocity of the wave times the frequency and the wave number is equal to $k = \frac{2\pi}{\lambda},$ so yes, the wave number will depend on the frequency and also depend on the velocity of the wave propagating through the spring.

11. The medium moves in simple harmonic motion as the wave propagates through the medium, continuously changing speed, therefore it accelerates. The acceleration of the medium is due to the restoring force of the medium, which acts in the opposite direction of the displacement.

13. The wave speed is proportional to the square root of the tension, so the speed is doubled.

15. Since the speed of a wave on a string is inversely proportional to the square root of the linear mass density, the speed would be higher in the low linear mass density of the string.

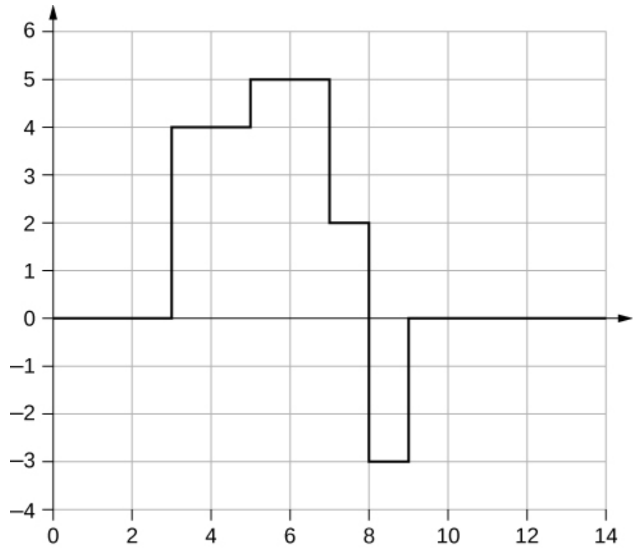
17. The tension in the wire is due to the weight of the electrical power cable.

19. The time averaged power is $P = \frac{E_\lambda}{T} = \frac{1}{2}\mu A^2 \omega^2 \frac{\lambda}{T} = \frac{1}{2}\mu A^2 \omega^2 v.$ If the frequency or amplitude is halved, the power decreases by a factor of 4.

21. As a portion on the string moves vertically, it exerts a force on the neighboring portion of the string, doing work on the portion and transferring the energy.

23. The intensity of a spherical wave is $I = \frac{P}{4\pi r^2},$ if no energy is dissipated the intensity will decrease by a factor of nine at three meters.

25. At the interface, the incident pulse produces a reflected pulse and a transmitted pulse. The reflected pulse would be out of phase with respect to the incident pulse, and would move at the same propagation speed as the incident pulse, but would move in the opposite direction. The transmitted pulse would travel in the same direction as the incident pulse, but at half the speed. The transmitted pulse would be in phase with the incident pulse. Both the reflected pulse and the transmitted pulse would have amplitudes less than the amplitude of the incident pulse.



27.

29. It may be as easy as changing the length and/or the density a small amount so that the parts do not resonate at the frequency of the motor.

31. Energy is supplied to the glass by the work done by the force of your finger on the glass. When supplied at the right frequency, standing waves form. The glass resonates and the vibrations produce sound.

33. For the equation $y(x,\ t) = 4.00\text{ cm}\sin\left(3\text{ m}^{-1}x\right)\cos\left(4\text{ s}^{-1}t\right)$, there is a node because when $x = 0.00\text{ m}$, $\sin\left(3\text{ m}^{-1}(0.00\text{ m})\right) = 0.00$, so $y(0.00\text{ m},\ t) = 0.00\text{ m}$ for all time. For the equation $y(x,\ t) = 4.00\text{ cm}\sin\left(3\text{ m}^{-1}x + \frac{\pi}{2}\right)\cos\left(4\text{ s}^{-1}t\right)$, there is an antinode because when $x = 0.00\text{ m}$, $\sin\left(3\text{ m}^{-1}(0.00\text{ m}) + \frac{\pi}{2}\right) = +1.00$, so $y(0.00\text{ m},\ t)$ oscillates between $+A$ and $-A$ as the cosine term oscillates between +1 and -1.

PROBLEMS

35. $2d = vt \Rightarrow d = 11.25\text{ m}$

37.
$$\begin{aligned} v &= f\lambda,\ \text{so that } f = 0.125\text{ Hz, so that} \\ N &= 7.50\text{ times} \end{aligned}$$

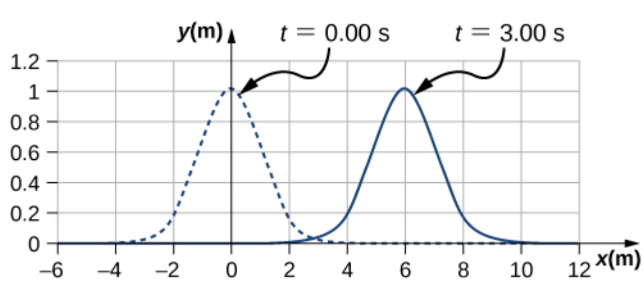
39. $v = f\lambda \Rightarrow \lambda = 0.400\text{ m}$

41. $v = f\lambda \Rightarrow f = 2.50 \times 10^9\text{ Hz}$

43. a. The P-waves outrun the S-waves by a speed of $v = 3.20\text{ km/s}$; therefore, $\Delta d = 0.320\text{ km}$. b. Since the uncertainty in the distance is less than a kilometer, our answer to part (a) does not seem to limit the detection of nuclear bomb detonations. However, if the velocities are uncertain, then the uncertainty in the distance would increase and could then make it difficult to identify the source of the seismic waves.

45.
$$\begin{aligned} v &= 1900\text{ m/s} \\ \Delta t &= 1.05\ \mu\text{s} \end{aligned}$$

47. $y(x,\ t) = -0.037\text{ cm}$



49.

The pulse will move $\Delta x = 6.00 \text{ m}$.

51. a. $A = 0.25 \text{ m}$; b. $k = 0.30 \text{ m}^{-1}$; c. $\omega = 0.90 \text{ s}^{-1}$; d. $v = 3.0 \text{ m/s}$; e. $\phi = \pi/3 \text{ rad}$; f. $\lambda = 20.93 \text{ m}$; g. $T = 6.98 \text{ s}$

53. $A = 0.30 \text{ m}, \ \lambda = 4.50 \text{ m}, \ v = 18.00 \text{ m/s}, \ f = 4.00 \text{ Hz}, \ T = 0.25 \text{ s}$

55. $y(x, \ t) = 0.23 \text{ m} \sin\left(3.49 \text{ m}^{-1} x - 0.63 \text{ s}^{-1} t\right)$

57. They have the same angular frequency, frequency, and period. They are traveling in opposite directions and $y_2(x, \ t)$ has twice the wavelength as $y_1(x, \ t)$ and is moving at half the wave speed.

59. Each particle of the medium moves a distance of 4*A* each period. The period can be found by dividing the velocity by the wavelength: $t = 10.42 \text{ s}$

61. a. $\mu = 0.040 \text{ kg/m}$; b. $v = 15.75 \text{ m/s}$

63. $v = 180 \text{ m/s}$

65. $v = 547.723 \text{ m/s}, \ \Delta t = 5.48 \text{ ms}$

67. $v_\text{s} = 347.56 \text{ m/s}$

69. $v_1 t + v_2 t = 2.00 \text{ m}, \ t = 1.69 \text{ ms}$

71. $v = 288.68 \text{ m/s}, \ \lambda = 0.73 \text{ m}$

73. a. $A = 0.0125 \text{ cm}$; b. $F_T = 0.96 \text{ N}$

75. $v = 74.54 \text{ m/s}, \ P_\lambda = 91.85 \text{ W}$

77. a. $I = 20.0 \text{ W/m}^2$; b.
$$\begin{aligned} I &= \frac{P}{A}, \ A = 10.0 \text{ m}^2 \\ A &= 4\pi r^2, \ r = 0.892 \text{ m} \end{aligned}$$

79. $I = 650 \text{ W/m}^2$

81.
$$\begin{aligned} &P \propto E \propto I \propto X^2 \Rightarrow \frac{P_2}{P_1} = \left(\frac{X_2}{X_1}\right)^2 \\ &P_2 = 2.50 \text{ kW} \end{aligned}$$

83.
$$\begin{aligned} &I \propto X^2 \Rightarrow \frac{I_1}{I_2} = \left(\frac{X_1}{X_2}\right)^2 \Rightarrow \\ &I_2 = 3.38 \times 10^{-5} \text{ W/m}^2 \end{aligned}$$

85. $f = 100.00 \text{ Hz}, \ A = 1.10 \text{ cm}$

87. a. $I_2 = 0.063 I_1$; b.
$$\begin{aligned} I_1 4\pi r_1^2 &= I_2 4\pi r_2^2 \\ r_2 &= 3.16 \text{ m} \end{aligned}$$

89. $2\pi r_1 A_1^2 = 2\pi r_2 A_2^2, \ A_1 = \left(\frac{r_2}{r_1}\right)^{1/2} A_1 = 0.17 \text{ m}$

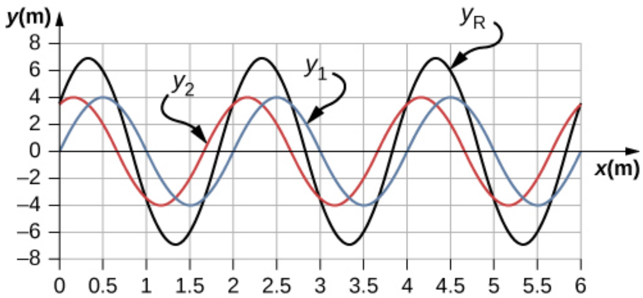
91. $y(x, \ t) = 0.76 \text{ m}$

93. $A_R = 2A\cos\left(\frac{\phi}{2}\right), \ \phi = 1.17 \text{ rad}$

95. $y_R = 1.90 \text{ cm}$

97.
$$\begin{aligned} \omega &= 6.28 \text{ s}^{-1}, \ k = 3.00 \text{ m}^{-1}, \ \phi = \frac{\pi}{8} \text{ rad}, \\ A_R &= 2A\cos\left(\frac{\phi}{2}\right), \ A = 0.37 \text{ m} \end{aligned}$$

99. a.



;

b. $\lambda = 2.0\text{ m},\ A = 4\text{ m}$; c. $\lambda_R = 2.0\text{ m},\ A_R = 6.93\text{ m}$

101. $y_R(x,\ t) = 2A\cos\left(\frac{\phi}{2}\right)\cos\left(kx - \omega t + \frac{\phi}{2}\right)$; The result is not surprising because $\cos(\theta) = \sin\left(\theta + \frac{\pi}{2}\right)$.

$$\lambda_n = \frac{2.00}{n}L, \quad f_n = \frac{v}{\lambda_n}$$

103. $\lambda_1 = 4.00\text{ m}, \quad f_1 = 12.5\text{ Hz}$
$\lambda_2 = 2.00\text{ m}, \quad f_2 = 25.00\text{ Hz}$
$\lambda_3 = 1.33\text{ m}, \quad f_3 = 37.59\text{ Hz}$

105. $v = 158.11\text{ m/s}, \quad \lambda = 4.44\text{ m}, \quad f = 35.61\text{ Hz}$
$\lambda_s = 9.63\text{ m}$

107. $y(x,\ t) = \left[0.60\text{ cm}\sin\left(3\text{ m}^{-1}x\right)\right]\cos\left(4\text{ s}^{-1}t\right)$

109. $\lambda_{100} = 0.06\text{ m}$
$v = 56.8\text{ m/s}, \quad f_n = nf_1, \quad n = 1,\ 2,\ 3,\ 4,\ 5...$
$f_{100} = 947\text{ Hz}$

111. $T = 2\Delta t, \quad v = \frac{\lambda}{T}, \quad \lambda = 2.12\text{ m}$

113. $\lambda_1 = 6.00\text{ m}, \quad \lambda_2 = 3.00\text{ m}, \quad \lambda_3 = 2.00\text{ m}, \quad \lambda_4 = 1.50\text{ m}$
$v = 258.20\text{ m/s} = \lambda f$
$f_1 = 43.03\text{ Hz}, \quad f_2 = 86.07\text{ Hz}, \quad f_3 = 129.10\text{ Hz}, \quad f_4 = 172.13\text{ Hz}$

115. $v = 134.16\text{ ms},\ \lambda = 1.4\text{ m},\ f = 95.83\text{ Hz},\ T = 0.0104\text{ s}$

ADDITIONAL PROBLEMS

117. $\lambda = 0.10\text{ m}$

119. a. $f = 4.74 \times 10^{14}\text{ Hz}$; b. $\lambda = 422\text{ nm}$

121. $\lambda = 16.00\text{ m}, \quad f = 0.10\text{ Hz}, \quad T = 10.00\text{ s}, \quad v = 1.6\text{ m/s}$

123. $\lambda = (v_b + v)t_b, \quad v = 3.75\text{ m/s}, \quad \lambda = 3.00\text{ m}$

$$\frac{\partial^2(y_1+y_2)}{\partial t^2} = -A\omega^2\ \sin(kx-\omega t) - A\omega^2\ \sin(kx-\omega t+\phi)$$
$$\frac{\partial^2(y_1+y_2)}{\partial x^2} = -Ak^2\ \sin(kx-\omega t) - Ak^2\ \sin(kx-\omega t+\phi)$$

125. $\frac{\partial^2 y(x,\ t)}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y(x,\ t)}{\partial t^2}$
$$-A\omega^2\ \sin(kx-\omega t) - A\omega^2\ \sin(kx-\omega t+\phi) = \left(\frac{1}{v^2}\right)\left(-Ak^2\ \sin(kx-\omega t) - Ak^2\ \sin(kx-\omega t+\phi)\right)$$
$$v = \frac{\omega}{k}$$

127. $y(x,\ t) = 0.40\ \text{m}\ \sin\left(0.015\ \text{m}^{-1}\,x + 1.5\ \text{s}^{-1}\,t\right)$

129. $v = 223.61\ \text{m/s},\ \ k = 1.57\ \text{m}^{-1},\ \ \omega = 142.43\ \text{s}^{-1}$

131. $P = \frac{1}{2}A^2(2\pi f)^2\sqrt{\mu F_T}$
$\mu = 2.00\times10^{-4}\ \text{kg/m}$

133. $P = \frac{1}{2}\mu A^2\omega^2\frac{\lambda}{T},\ \ \mu = 0.0018\ \text{kg/m}$

135. a. $A_R = 2A\cos\left(\frac{\phi}{2}\right),\ \ \cos\left(\frac{\phi}{2}\right) = 1,\ \ \phi = 0,\ 2\pi,\ 4\pi,...$; b. $A_R = 2A\cos\left(\frac{\phi}{2}\right),\ \ \cos\left(\frac{\phi}{2}\right) = 0,\ \ \phi = 0,\ \pi,\ 3\pi,\ 5\pi...$

137. $y_R(x,\ t) = 0.6\ \text{m}\ \sin\left(4\ \text{m}^{-1}\,x\right)\cos\left(3\ \text{s}^{-1}\,t\right)$

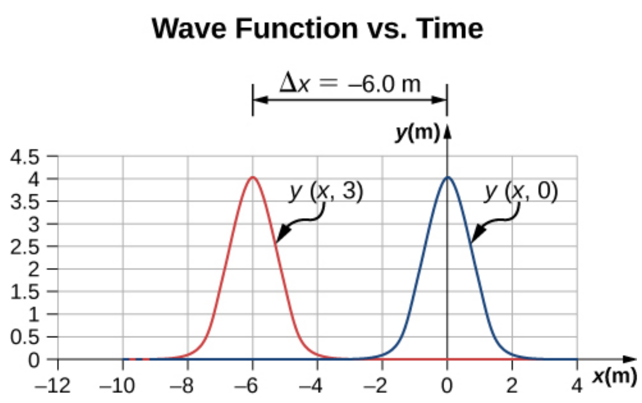
139. a.
$(1)F_T - 20.00\ \text{kg}\left(9.80\ \text{m/s}^2\right)\cos 45° = 0$
$(2)m\left(9.80\ \text{m/s}^2\right) - F_T = 0$
$m = 14.14\ \text{kg}$
; b. $\begin{aligned} F_T &= 138.57\ \text{N} \\ v &= 67.96\ \text{m/s} \end{aligned}$

141. $F_T = 12\ \text{N},\ v = 16.49\ \text{m/s}$

143. a.
$f_n = \frac{nv}{2L},\ \ v = \frac{2Lf_{n+1}}{n+1},\ \ \frac{n+1}{n} = \frac{2Lf_{n+1}}{2Lf_n},\ \ 1+\frac{1}{n} = 1.2,\ \ n = 5$
$\lambda_n = \frac{2}{n}L,\ \ \lambda_5 = 1.6\ \text{m},\ \ \lambda_6 = 1.33\ \text{m}$
; b. $F_T = 245.76\ \text{N}$

CHALLENGE PROBLEMS

145. a. Moves in the negative *x* direction at a propagation speed of $v = 2.00\ \text{m/s}$. b. $\Delta x = -6.00\ \text{m}$; c.

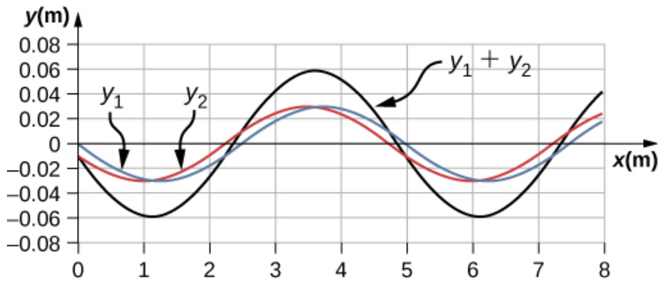


147.

$$\sin(kx-\omega t)=\sin\left(kx+\frac{\phi}{2}\right)\cos\left(\omega t+\frac{\phi}{2}\right)-\cos\left(kx+\frac{\phi}{2}\right)\sin\left(\omega t+\frac{\phi}{2}\right)$$
$$\sin(kx-\omega t+\phi)=\sin\left(kx+\frac{\phi}{2}\right)\cos\left(\omega t+\frac{\phi}{2}\right)+\cos\left(kx+\frac{\phi}{2}\right)\sin\left(\omega t+\frac{\phi}{2}\right)$$
$$\sin(kx-\omega t)+\sin(kx+\omega t+\phi)=2\sin\left(kx+\frac{\phi}{2}\right)\cos\left(\omega t+\frac{\phi}{2}\right)$$
$$y_R=2A\sin\left(kx+\frac{\phi}{2}\right)\cos\left(\omega t+\frac{\phi}{2}\right)$$

149. $\sin\left(kx+\frac{\phi}{2}\right)=0,\ kx+\frac{\phi}{2}=0,\ \pi,\ 2\pi,\ 1.26\,\text{m}^{-1}x+\frac{\pi}{20}=\pi,\ 2\pi,\ 3\pi$;

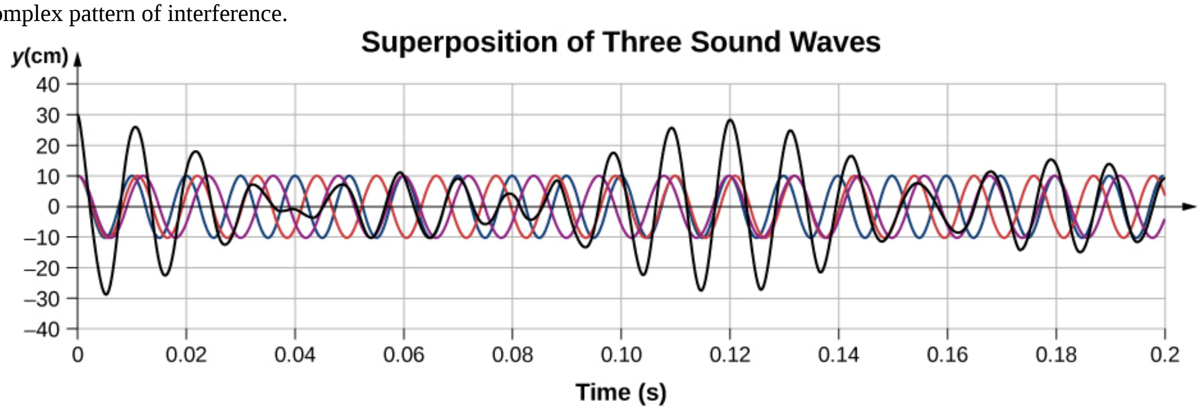
$x=2.37\text{ m},\ 4.86\text{ m},\ 7.35\text{ m}$



CHAPTER 17

CHECK YOUR UNDERSTANDING

17.1. Sound and light both travel at definite speeds, and the speed of sound is slower than the speed of light. The first shell is probably very close by, so the speed difference is not noticeable. The second shell is farther away, so the light arrives at your eyes noticeably sooner than the sound wave arrives at your ears.
17.2. 10 dB: rustle of leaves; 50 dB: average office; 100 dB: noisy factory
17.3. Amplitude is directly proportional to the experience of loudness. As amplitude increases, loudness increases.
17.4. In the example, the two speakers were producing sound at a single frequency. Music has various frequencies and wavelengths.
17.5. Regular headphones only block sound waves with a physical barrier. Noise-canceling headphones use destructive interference to reduce the loudness of outside sounds.
17.6. When the tube resonates at its natural frequency, the wave's node is located at the closed end of the tube, and the antinode is located at the open end. The length of the tube is equal to one-fourth of the wavelength of this wave. Thus, if we know the wavelength of the wave, we can determine the length of the tube.
17.7. Compare their sizes. High-pitch instruments are generally smaller than low-pitch instruments because they generate a smaller wavelength.
17.8. An easy way to understand this event is to use a graph, as shown below. It appears that beats are produced, but with a more complex pattern of interference.



17.9. If I am driving and I hear Doppler shift in an ambulance siren, I would be able to tell when it was getting closer and also if it has passed by. This would help me to know whether I needed to pull over and let the ambulance through.

CONCEPTUAL QUESTIONS

1. Sound is a disturbance of matter (a pressure wave) that is transmitted from its source outward. Hearing is the human perception of sound.
3. Consider a sound wave moving through air. The pressure of the air is the equilibrium condition, it is the change in pressure that produces the sound wave.
5. The frequency does not change as the sound wave moves from one medium to another. Since the speed changes and the frequency does not, the wavelength must change. This is similar to the driving force of a harmonic oscillator or a wave on the string.
7. The transducer sends out a sound wave, which reflects off the object in question and measures the time it takes for the sound wave to return. Since the speed of sound is constant, the distance to the object can found by multiplying the velocity of sound by half the time interval measured.
9. The ear plugs reduce the intensity of the sound both in water and on land, but Navy researchers have found that sound under water is heard through vibrations mastoid, which is the bone behind the ear.
11. The fundamental wavelength of a tube open at each end is $2L$, where the wavelength of a tube open at one end and closed at one end is $4L$. The tube open at one end has the lower fundamental frequency, assuming the speed of sound is the same in both tubes.
13. The wavelength in each is twice the length of the tube. The frequency depends on the wavelength and the speed of the sound waves. The frequency in room B is higher because the speed of sound is higher where the temperature is higher.
15. When resonating at the fundamental frequency, the wavelength for pipe C is $4L$, and for pipes A and B is $2L$. The frequency is equal to $f = v/\lambda.$ Pipe C has the lowest frequency and pipes A and B have equal frequencies, higher than the one in pipe C.
17. Since the boundary conditions are both symmetric, the frequencies are $f_n = \frac{nv}{2L}.$ Since the speed is the same in each, the frequencies are the same. If the wave speed were doubled in the string, the frequencies in the string would be twice the frequencies in the tube.
19. The frequency of the unknown fork is 255 Hz. No, if only the 250 Hz fork is used, listening to the beat frequency could only limit the possible frequencies to 245 Hz or 255 Hz.
21. The beat frequency is 0.7 Hz.
23. Observer 1 will observe the highest frequency. Observer 2 will observe the lowest frequency. Observer 3 will hear a higher frequency than the source frequency, but lower than the frequency observed by observer 1, as the source approaches and a lower frequency than the source frequency, but higher than the frequency observed by observer 1, as the source moves away from observer 3.
25. Doppler radar can not only detect the distance to a storm, but also the speed and direction at which the storm is traveling.
27. The speed of sound decreases as the temperature decreases. The Mach number is equal to $M = \frac{v_s}{v},$ so the plane should slow down.

PROBLEMS

29. $s_{max} = 4.00\,\text{nm}, \quad \lambda = 1.72\,\text{m}, \quad f = 200\,\text{Hz}, \quad v = 343.17\,\text{m/s}$

31. a. $\lambda = 68.60\,\mu\text{m}$; b. $\lambda = 360.00\,\mu\text{m}$

33. a. $k = 183.09\text{m}^{-1}$;
b. $\Delta P = -1.11\,\text{Pa}$

35.
$$\begin{gathered} s_1 = 7.00\,\text{nm},\ s_2 = 3.00\,\text{nm},\ kx_1 + \phi = 0\,\text{rad} \\ kx_2 + \phi = 1.128\,\text{rad} \\ k(x_2 - x_1) = 1.128\,\text{rad},\ k = 5.64\,\text{m}^{-1} \\ \lambda = 1.11\,\text{m},\ f = 306.31\,\text{Hz} \end{gathered}$$

37.
$$\begin{gathered} k = 5.28 \times 10^3\,\text{m} \\ s(x,\ t) = 4.50\,\text{nm}\cos\left(5.28 \times 10^3\ \text{m}^{-1}\,x - 2\pi(5.00\,\text{MHz})t\right) \end{gathered}$$

39. $\lambda = 3.43\,\text{mm}$

41. $\lambda = 6.00\text{ m}$
$s_{\max} = 2.00\text{ mm}$
$v = 600\text{ m/s}$
$T = 0.01\text{ s}$

43. (a) $f = 100\text{ Hz},$ (b) $\lambda = 3.43\text{ m}$

45. $f = 3400\text{ Hz}$

47. a. $v = 5.96 \times 10^3\text{ m/s}$; b. steel (from value in **Table 17.1**)

49. $v = 363\,\frac{\text{m}}{\text{s}}$

51. $\Delta x = 924\text{ m}$

53. $V = 0.05\text{ m}^3$
$m = 392.5\text{ kg}$
$\rho = 7850\text{ kg/m}^3$
$v = 5047.54\text{ m/s}$

55. $T_{\text{C}} = 35°\text{C},\ v = 351.58\text{ m/s}$
$\Delta x_1 = 35.16\text{ m},\ \Delta x_2 = 52.74\text{ m}$
$\Delta x = 63.39\text{ m}$

57. a. $t_{5.00°\text{C}} = 0.0180\text{ s},\quad t_{35.0°\text{C}} = 0.0171\text{ s}$; b. $\%\text{ uncertainty} = 5.00\%$; c. This uncertainty could definitely cause difficulties for the bat, if it didn't continue to use sound as it closed in on its prey. A 5% uncertainty could be the difference between catching the prey around the neck or around the chest, which means that it could miss grabbing its prey.

59. $1.26 \times 10^{-3}\text{ W/m}^2$

61. 85 dB

63. a. 93 dB; b. 83 dB

65. $1.58 \times 10^{-13}\text{ W/m}^2$

67. A decrease of a factor of 10 in intensity corresponds to a reduction of 10 dB in sound level: $120\text{ dB} - 10\text{ dB} = 110\text{ dB}.$

69. We know that 60 dB corresponds to a factor of 10^6 increase in intensity. Therefore,

$$I \propto X^2 \Rightarrow \frac{I_2}{I_1} = \left(\frac{X_2}{X_1}\right)^2,\ \text{so that } X_2 = 10^{-6}\text{ atm.}$$

120 dB corresponds to a factor of 10^{12} increase $\Rightarrow 10^{-9}\text{ atm}(10^{12})^{1/2} = 10^{-3}\text{ atm.}$

71. 28.2 dB

73. $1 \times 10^6\text{ km}$

75. $73\text{ dB} - 70\text{ dB} = 3\text{ dB};$ Such a change in sound level is easily noticed.

77. 2.5; The 100-Hz tone must be 2.5 times more intense than the 4000-Hz sound to be audible by this person.

79. 0.974 m

81. 11.0 kHz; The ear is not particularly sensitive to this frequency, so we don't hear overtones due to the ear canal.

83. a. $v = 344.08\text{ m/s},\ \lambda_1 = 16.00\text{ m},\ f_1 = 21.51\text{ Hz};$
b. $\lambda_3 = 5.33\text{ m},\ f_3 = 64.56\text{ Hz}$

85. $v_{\text{string}} = 149.07\text{ m/s},\ \lambda_3 = 1.33\text{ m},\ f_3 = 112.08\text{ Hz}$
$\lambda_1 = \frac{v}{f_1},\quad L = 1.53\text{ m}$

87. a. $22.0°\text{C}$; b. 1.01 m

89. $\text{fir t overtone} = 180\text{ Hz};$
$\text{second overtone} = 270\text{ Hz};$
$\text{third overtone} = 360\text{ Hz}$

91. 1.56 m
93. The pipe has symmetrical boundary conditions;

$$\lambda_n = \frac{2}{n}L, \quad f_n = \frac{nv}{2L}, \quad n = 1, 2, 3$$

$$\lambda_1 = 6.00\text{ m}, \quad \lambda_2 = 3.00\text{ m}, \quad \lambda_3 = 2.00\text{ m}$$
$$f_1 = 57.17\text{ Hz}, \quad f_2 = 114.33\text{ Hz}, \quad f_3 = 171.50\text{ Hz}$$

95. $\lambda_6 = 0.5\text{ m}$
$v = 1000\text{ m/s}$
$F_T = 6500\text{ N}$

97. $f = 6.40\text{ kHz}$

99. 1.03 or 3%

101.
$$\begin{aligned} f_B &= |f_1 - f_2| \\ |128.3\text{ Hz} - 128.1\text{ Hz}| &= 0.2\text{ Hz}; \\ |128.3\text{ Hz} - 127.8\text{ Hz}| &= 0.5\text{ Hz}; \\ |128.1\text{ Hz} - 127.8\text{ Hz}| &= 0.3\text{ Hz} \end{aligned}$$

103. $v_A = 135.87\text{ m/s}, \ v_B = 141.42\text{ m/s},$
$\lambda_A = \lambda_B = 0.40\text{ m}$
$\Delta f = 15.00\text{ Hz}$

105. $v = 155.54\text{ m/s},$
$f_{\text{string}} = 971.17\text{ Hz}, \ n = 16.23$
$f_{\text{string}} = 1076.83\text{ Hz}, \ n = 18.00$

The frequency is 1076.83 Hz and the wavelength is 0.14 m.

107. $f_2 = f_1 \pm f_B = 260.00\text{ Hz} \pm 1.50\text{ Hz},$
so that $f_2 = 261.50\text{ Hz}$ or $f_2 = 258.50\text{ Hz}$

109.
$$f_{\text{ace}} = \frac{f_1 + f_2}{2}; \ f_B = f_1 - f_2 (\text{assume} f_1 > f_2)$$
$$f_{\text{ace}} = \frac{(f_B + f_2) + f_2}{2} \Rightarrow$$

$$f_2 = 4099.750\text{ Hz}$$
$$f_1 = 4100.250\text{ Hz}$$

111. a. 878 Hz; b. 735 Hz
113. $3.79 \times 10^3\text{ Hz}$
115. a. 12.9 m/s; b. 193 Hz
117. The first eagle hears $4.23 \times 10^3\text{ Hz.}$ The second eagle hears $3.56 \times 10^3\text{ Hz.}$

119. $v_s = 31.29\text{ m/s}$
$f_o = 1.12\text{ kHz}$

121. An audible shift occurs when $\frac{f_{\text{obs}}}{f_s} \geq 1.003$; $f_{\text{obs}} = f_s \frac{v}{v - v_s} \Rightarrow \frac{f_{\text{obs}}}{f_s} = \frac{v}{v - v_s} \Rightarrow$
$v_s = 0.990\text{ m/s}$

123. $\theta = 30.02°$
$v_s = 680.00\ \text{m/s}$
$\tan\theta = \frac{y}{v_s t}, \quad t = 21.65\ \text{s}$

125. $\sin\theta = \frac{1}{M}, \quad \theta = 56.47°$
$y = 9.31\ \text{km}$

127. $s_1 = 6.34\ \text{nm}$
$s_2 = 2.30\ \text{nm}$
$kx_1 + \phi = 0\ \text{rad}$
$kx_2 + \phi = 1.20\ \text{rad}$
$k(x_2 - x_1) = 1.20\ \text{rad}$
$k = 3.00\ \text{m}^{-1}$
$\omega = 1019.62\ \text{s}^{-1}$
$s_1 = s_{\max}\cos(kx_1 - \phi)$
$\phi = 5.66\ \text{rad}$
$s(x,\ t) = 6.30\ \text{nm}\cos\left(3.00\ \text{m}^{-1}x - 1019.62\ \text{s}^{-1}t + 5.66\right)$

ADDITIONAL PROBLEMS

129. $v_s = 346.40\ \text{m/s}$;

$\lambda_n = \frac{2}{n}L \qquad f_n = \frac{v_s}{\lambda_n}$

$\lambda_1 = 1.60\ \text{m} \quad f_1 = 216.50\ \text{Hz}$
$\lambda_2 = 0.80\ \text{m} \quad f_1 = 433.00\ \text{Hz}$

131. a. $\lambda_6 = 0.40\ \text{m}$
$v = 57.15\frac{\text{m}}{\text{s}}$
$f_6 = 142.89\ \text{Hz}$
; b. $\lambda_s = 2.40\ \text{m}$

133. $v = 344.08\frac{\text{m}}{\text{s}}$
$v_A = 29.05\frac{\text{m}}{\text{s}}, \quad v_B = 33.52\ \text{m/s}$
$f_A = 961.18\ \text{Hz},$
$f_B = 958.89\ \text{Hz}$
$f_{A,\ \text{beat}} = 161.18\ \text{Hz}, \ f_{B,\ \text{beat}} = 158.89\ \text{Hz}$

135. $v = 345.24\frac{\text{m}}{\text{s}}$; a. $I = 31.62\frac{\mu\text{W}}{\text{m}^2}$; b. $I = 0.16\frac{\mu\text{W}}{\text{m}^2}$; c. $s_{\max} = 104.39\ \mu\text{m}$; d. $s_{\max} = 7.43\ \mu\text{m}$

137. $\frac{f_A}{f_D} = \frac{v + v_s}{v - v_s}, \quad (v - v_s)\frac{f_A}{f_D} = v + v_s, \quad v = 347.39\frac{\text{m}}{\text{s}}$
$T_C = 27.70°$

CHALLENGE PROBLEMS

139.
$$\sqrt{x^2 + d^2} - x = \lambda, \quad x^2 + d^2 = (\lambda + x)^2$$
$$x^2 + d^2 = \lambda^2 + 2x\lambda + x^2, \quad d^2 = \lambda^2 + 2x\lambda$$
$$x = \frac{d^2 - \left(\frac{v}{f}\right)^2}{2\frac{v}{f}}$$

141. a. For maxima
$$\Delta r = d\sin\theta$$
$$d\sin\theta = n\lambda \ \ n = 0, \ \pm 1, \ \pm 2...., \quad \theta = \sin^{-1}\left(n\frac{\lambda}{d}\right) \ n = 0, \ \pm 1, \ \pm 2....$$

b. For minima,
$$\Delta r = d\sin\theta$$
$$d\sin\theta = \left(n + \frac{1}{2}\right)\lambda \ \ n = 0, \ \pm 1, \ \pm 2....$$
$$\theta = \sin^{-1}\left(\left(n + \frac{1}{2}\right)\frac{\lambda}{d}\right) \ n = 0, \ \pm 1, \ \pm 2....$$

143. a. $v_{\text{string}} = 160.73\frac{\text{m}}{\text{s}}, \quad f_{\text{string}} = 535.77\text{ Hz}$; b. $f_{\text{fork}} = 512\text{ Hz}$; c. $f_{\text{fork}} = \frac{n\sqrt{\frac{F_T}{\mu}}}{2L}, \quad F_T = 141.56\text{ N}$

145. a. $f = 268.62\text{ Hz}$; b. $\Delta f \approx \frac{1}{2}\frac{\Delta F_T}{F_T}f = 1.34\text{ Hz}$

147. a. $v = 466.07\frac{\text{m}}{\text{s}}$; b. $\lambda_9 = 51.11\text{ mm}$; c. $f_9 = 9.12\text{ kHz}$;
d. $f_{\text{sound}} = 9.12\text{ kHz}$; e. $\lambda_{\text{air}} = 37.86\text{ mm}$