NEWTON'S LAWS OF MOTION

4

4.1. IDENTIFY: Consider the vector sum in each case.

SET UP: Call the two forces $\vec{F}_1$ and $\vec{F}_2$. Let $\vec{F}_1$ be to the right. In each case select the direction of $\vec{F}_2$ such that $\vec{F} = \vec{F}_1 + \vec{F}_2$ has the desired magnitude.

EXECUTE: **(a)** For the magnitude of the sum to be the sum of the magnitudes, the forces must be parallel, and the angle between them is zero. The two vectors and their sum are sketched in Figure 4.1a.

(b) The forces form the sides of a right isosceles triangle, and the angle between them is $90°$. The two vectors and their sum are sketched in Figure 4.1b.

(c) For the sum to have zero magnitude, the forces must be antiparallel, and the angle between them is $180°$. The two vectors are sketched in Figure 4.1c.

EVALUATE: The maximum magnitude of the sum of the two vectors is $2F$, as in part (a).

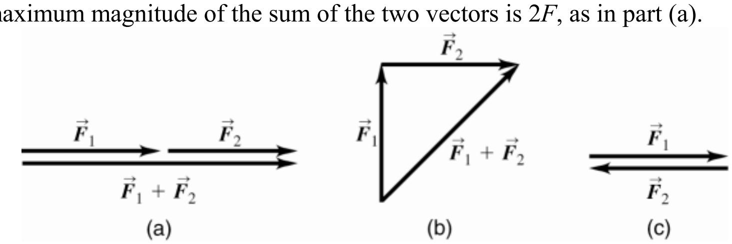


Figure 4.1

4.2. IDENTIFY: Add the three forces by adding their components.

SET UP: In the new coordinates, the 120-N force acts at an angle of $53°$ from the $-x$-axis, or $233°$ from the $+x$-axis, and the 50-N force acts at an angle of $323°$ from the $+x$-axis.

EXECUTE: **(a)** The components of the net force are

$$R_x = (120\text{ N})\cos 233° + (50\text{ N})\cos 323° = -32\text{ N}$$

$$R_y = (250\text{ N}) + (120\text{ N})\sin 233° + (50\text{ N})\sin 323° = 124\text{ N}.$$

(b) $R = \sqrt{R_x^2 + R_y^2} = 128\text{ N}$, $\arctan\left(\dfrac{124}{-32}\right) = 104°$. The results have the same magnitude as in Example 4.1, and the angle has been changed by the amount $(37°)$ that the coordinates have been rotated.

EVALUATE: We can use any set of coordinate axes that we wish to and can therefore select axes for which the analysis of the problem is the simplest.

4.3. IDENTIFY: Use right-triangle trigonometry to find the components of the force.

SET UP: Let $+x$ be to the right and let $+y$ be downward.

EXECUTE: The horizontal component of the force is $(10\text{ N})\cos 45° = 7.1\text{ N}$ to the right and the vertical component is $(10\text{ N})\sin 45° = 7.1\text{ N}$ down.

EVALUATE: In our coordinates each component is positive; the signs of the components indicate the directions of the component vectors.

4.4. IDENTIFY: $F_x = F\cos\theta$, $F_y = F\sin\theta$.

SET UP: Let $+x$ be parallel to the ramp and directed up the ramp. Let $+y$ be perpendicular to the ramp and directed away from it. Then $\theta = 30.0°$.

EXECUTE: **(a)** $F = \dfrac{F_x}{\cos\theta} = \dfrac{60.0\,\text{N}}{\cos 30°} = 69.3\text{ N}.$

(b) $F_y = F\sin\theta = F_x\tan\theta = 34.6\text{ N}.$

EVALUATE: We can verify that $F_x^2 + F_y^2 = F^2$. The signs of F_x and F_y show their direction.

4.5. **IDENTIFY:** Vector addition.

SET UP: Use a coordinate system where the $+x$-axis is in the direction of $\vec{F}_A$, the force applied by dog A. The forces are sketched in Figure 4.5.

EXECUTE:

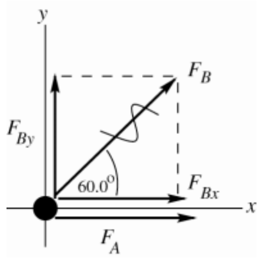


Figure 4.5a

$F_{Ax} = +270\text{ N},\ \ F_{Ay} = 0$

$F_{Bx} = F_B\cos 60.0° = (300\text{ N})\cos 60.0° = +150\text{ N}$

$F_{By} = F_B\sin 60.0° = (300\text{ N})\sin 60.0° = +260\text{ N}$

$\vec{R} = \vec{F}_A + \vec{F}_B$

$R_x = F_{Ax} + F_{Bx} = +270\text{ N} + 150\text{ N} = +420\text{ N}$

$R_y = F_{Ay} + F_{By} = 0 + 260\text{ N} = +260\text{ N}$

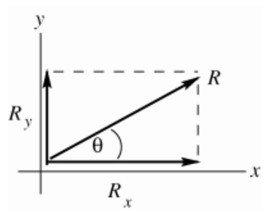


Figure 4.5b

$R = \sqrt{R_x^2 + R_y^2}$

$R = \sqrt{(420\text{ N})^2 + (260\text{ N})^2} = 494\text{ N}$

$\tan\theta = \dfrac{R_y}{R_x} = 0.619$

$\theta = 31.8°$

EVALUATE: The forces must be added as vectors. The magnitude of the resultant force is less than the sum of the magnitudes of the two forces and depends on the angle between the two forces.

4.6. **IDENTIFY:** Add the two forces using components.

SET UP: $F_x = F\cos\theta$, $F_y = F\sin\theta$, where θ is the angle $\vec{F}$ makes with the $+x$ axis.

EXECUTE: **(a)** $F_{1x} + F_{2x} = (9.00\text{ N})\cos 120° + (6.00\text{ N})\cos(233.1°) = -8.10\text{ N}$

$F_{1y} + F_{2y} = (9.00\text{ N})\sin 120° + (6.00\text{ N})\sin(233.1°) = +3.00\text{ N}.$

(b) $R = \sqrt{R_x^2 + R_y^2} = \sqrt{(8.10\text{ N})^2 + (3.00\text{ N})^2} = 8.64\text{ N}.$

EVALUATE: Since $F_x < 0$ and $F_y > 0$, $\vec{F}$ is in the second quadrant.

4.7. **IDENTIFY:** Apply $\sum\vec{F} = m\vec{a}$.

SET UP: Let $+x$ be in the direction of the force.

EXECUTE: $a_x = F_x/m = (132\text{ N})/(60\text{ kg}) = 2.2\text{ m/s}^2$.

EVALUATE: The acceleration is in the direction of the force.

4.8. **IDENTIFY:** Apply $\sum\vec{F} = m\vec{a}$.

SET UP: Let $+x$ be in the direction of the acceleration.

EXECUTE: $F_x = ma_x = (135\text{ kg})(1.40\text{ m/s}^2) = 189\text{ N}.$

EVALUATE: The net force must be in the direction of the acceleration.

4.9. **IDENTIFY:** Apply $\sum\vec{F} = m\vec{a}$ to the box.

SET UP: Let $+x$ be the direction of the force and acceleration. $\sum F_x = 48.0\text{ N}$.

EXECUTE: $\sum F_x = ma_x$ gives $m = \frac{\sum F_x}{a_x} = \frac{48.0\text{ N}}{3.00\text{ m/s}^2} = 16.0\text{ kg}$.

EVALUATE: The vertical forces sum to zero and there is no motion in that direction.

4.10. **IDENTIFY:** Use the information about the motion to find the acceleration and then use $\sum F_x = ma_x$ to calculate *m*.

SET UP: Let $+x$ be the direction of the force. $\sum F_x = 80.0\text{ N}$.

EXECUTE: **(a)** $x - x_0 = 11.0\text{ m}$, $t = 5.00\text{ s}$, $v_{0x} = 0$. $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ gives

$a_x = \frac{2(x - x_0)}{t^2} = \frac{2(11.0\text{ m})}{(5.00\text{ s})^2} = 0.880\text{ m/s}^2$. $m = \frac{\sum F_x}{a_x} = \frac{80.0\text{ N}}{0.880\text{ m/s}^2} = 90.9\text{ kg}$.

(b) $a_x = 0$ and v_x is constant. After the first 5.0 s, $v_x = v_{0x} + a_x t = (0.880\text{ m/s}^2)(5.00\text{ s}) = 4.40\text{ m/s}$.

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2 = (4.40\text{ m/s})(5.00\text{ s}) = 22.0\text{ m}$.

EVALUATE: The mass determines the amount of acceleration produced by a given force. The block moves farther in the second 5.00 s than in the first 5.00 s.

4.11. **IDENTIFY** and **SET UP:** Use Newton's second law in component form (Eq.4.8) to calculate the acceleration produced by the force. Use constant acceleration equations to calculate the effect of the acceleration on the motion.

EXECUTE: **(a)** During this time interval the acceleration is constant and equal to

$$a_x = \frac{F_x}{m} = \frac{0.250\text{ N}}{0.160\text{ kg}} = 1.562\text{ m/s}^2$$

We can use the constant acceleration kinematic equations from Chapter 2.

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2 = 0 + \frac{1}{2}(1.562\text{ m/s}^2)(2.00\text{ s})^2$,

so the puck is at $x = 3.12$ m.

$v_x = v_{0x} + a_x t = 0 + (1.562\text{ m/s}^2)(2.00\text{ s}) = 3.13\text{ m/s}$.

(b) In the time interval from $t = 2.00$ s to 5.00 s the force has been removed so the acceleration is zero. The speed stays constant at $v_x = 3.12$ m/s. The distance the puck travels is $x - x_0 = v_{0x}t = (3.12\text{ m/s})(5.00\text{ s} - 2.00\text{ s}) = 9.36\text{ m}$.

At the end of the interval it is at $x = x_0 + 9.36\text{ m} = 12.5\text{ m}$.

In the time interval from $t = 5.00$ s to 7.00 s the acceleration is again $a_x = 1.562\text{ m/s}^2$. At the start of this interval $v_{0x} = 3.12$ m/s and $x_0 = 12.5$ m.

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2 = (3.12\text{ m/s})(2.00\text{ s}) + \frac{1}{2}(1.562\text{ m/s}^2)(2.00\text{ s})^2$.

$x - x_0 = 6.24\text{ m} + 3.12\text{ m} = 9.36\text{ m}$.

Therefore, at $t = 7.00$ s the puck is at $x = x_0 + 9.36\text{ m} = 12.5\text{ m} + 9.36\text{ m} = 21.9\text{ m}$.

$$v_x = v_{0x} + a_x t = 3.12\text{ m/s} + (1.562\text{ m/s}^2)(2.00\text{ s}) = 6.24\text{ m/s}$$

EVALUATE: The acceleration says the puck gains 1.56 m/s of velocity for every second the force acts. The force acts a total of 4.00 s so the final velocity is $(1.56\text{ m/s})(4.0\text{ s}) = 6.24\text{ m/s}$.

4.12. **IDENTIFY:** Apply $\sum \vec{F} = m\vec{a}$. Then use a constant acceleration equation to relate the kinematic quantities.

SET UP: Let $+x$ be in the direction of the force.

EXECUTE: **(a)** $a_x = F_x / m = (140\text{ N})/(32.5\text{ kg}) = 4.31\text{ m/s}^2$.

(b) $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$. With $v_{0x} = 0$, $x = \frac{1}{2}at^2 = 215\text{ m}$.

(c) $v_x = v_{0x} + a_x t$. With $v_{0x} = 0$, $v_x = a_x t = 2x/t = 43.0\text{ m/s}$.

EVALUATE: The acceleration connects the motion to the forces.

4.13. **IDENTIFY:** The force and acceleration are related by Newton's second law.

SET UP: $\sum F_x = ma_x$, where $\sum F_x$ is the net force. $m = 4.50\text{ kg}$.

EXECUTE: **(a)** The maximum net force occurs when the acceleration has its maximum value.

$\sum F_x = ma_x = (4.50\text{ kg})(10.0\text{ m/s}^2) = 45.0\text{ N}$. This maximum force occurs between 2.0 s and 4.0 s.

(b) The net force is constant when the acceleration is constant. This is between 2.0 s and 4.0 s.

(c) The net force is zero when the acceleration is zero. This is the case at $t = 0$ and $t = 6.0$ s.

EVALUATE: A graph of $\sum F_x$ versus *t* would have the same shape as the graph of a_x versus *t*.

4.14. **IDENTIFY:** The force and acceleration are related by Newton's second law. $a_x = \dfrac{dv_x}{dt}$, so a_x is the slope of the graph of v_x versus *t*.

SET UP: The graph of v_x versus *t* consists of straight-line segments. For $t = 0$ to $t = 2.00$ s, $a_x = 4.00\text{ m/s}^2$. For $t = 2.00$ s to 6.00 s, $a_x = 0$. For $t = 6.00$ s to 10.0 s, $a_x = 1.00\text{ m/s}^2$.

$\sum F_x = ma_x$, with $m = 2.75$ kg. $\sum F_x$ is the net force.

EXECUTE: **(a)** The maximum net force occurs when the acceleration has its maximum value.

$\sum F_x = ma_x = (2.75\text{ kg})(4.00\text{ m/s}^2) = 11.0\text{ N}$. This maximum occurs in the interval $t = 0$ to $t = 2.00$ s.

(b) The net force is zero when the acceleration is zero. This is between 2.00 s and 6.00 s.

(c) Between 6.00 s and 10.0 s, $a_x = 1.00\text{ m/s}^2$, so $\sum F_x = (2.75\text{ kg})(1.00\text{ m/s}^2) = 2.75\text{ N}$.

EVALUATE: The net force is largest when the velocity is changing most rapidly.

4.15. **IDENTIFY:** The net force and the acceleration are related by Newton's second law. When the rocket is near the surface of the earth the forces on it are the upward force $\vec{F}$ exerted on it because of the burning fuel and the downward force $\vec{F}_{\text{grav}}$ of gravity. $F_{\text{grav}} = mg$.

SET UP: Let $+y$ be upward. The weight of the rocket is $F_{\text{grav}} = (8.00\text{ kg})(9.80\text{ m/s}^2) = 78.4\text{ N}$.

EXECUTE: **(a)** At $t = 0$, $F = A = 100.0\text{ N}$. At $t = 2.00$ s, $F = A + (4.00\text{ s}^2)B = 150.0\text{ N}$ and

$$B = \frac{150.0\text{ N} - 100.0\text{ N}}{4.00\text{ s}^2} = 12.5\text{ N/s}^2.$$

(b) (i) At $t = 0$, $F = A = 100.0\text{ N}$. The net force is $\sum F_y = F - F_{\text{grav}} = 100.0\text{ N} - 78.4\text{ N} = 21.6\text{ N}$.

$a_y = \dfrac{\sum F_y}{m} = \dfrac{21.6\text{ N}}{8.00\text{ kg}} = 2.70\text{ m/s}^2$. (ii) At $t = 3.00$ s, $F = A + B(3.00\text{ s})^2 = 212.5\text{ N}$.

$\sum F_y = 212.5\text{ N} - 78.4\text{ N} = 134.1\text{ N}$. $a_y = \dfrac{\sum F_y}{m} = \dfrac{134.1\text{ N}}{8.00\text{ kg}} = 16.8\text{ m/s}^2$.

(c) Now $F_{\text{grav}} = 0$ and $\sum F_y = F = 212.5\text{ N}$. $a_y = \dfrac{212.5\text{ N}}{8.00\text{ kg}} = 26.6\text{ m/s}^2$.

EVALUATE: The acceleration increases as *F* increases.

4.16. **IDENTIFY:** Use constant acceleration equations to calculate a_x and *t*. Then use $\sum \vec{F} = m\vec{a}$ to calculate the net force.

SET UP: Let $+x$ be in the direction of motion of the electron.

EXECUTE: **(a)** $v_{0x} = 0$, $(x - x_0) = 1.80 \times 10^{-2}$ m, $v_x = 3.00 \times 10^6$ m/s. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

$$a_x = \frac{v_x^2 - v_{0x}^2}{2(x - x_0)} = \frac{(3.00 \times 10^6\text{ m/s})^2 - 0}{2(1.80 \times 10^{-2}\text{ m})} = 2.50 \times 10^{14}\text{ m/s}^2$$

(b) $v_x = v_{0x} + a_x t$ gives $t = \dfrac{v_x - v_{0x}}{a_x} = \dfrac{3.00 \times 10^6\text{ m/s} - 0}{2.50 \times 10^{14}\text{ m/s}^2} = 1.2 \times 10^{-8}\text{ s}$

(c) $\sum F_x = ma_x = (9.11 \times 10^{-31}\text{ kg})(2.50 \times 10^{14}\text{ m/s}^2) = 2.28 \times 10^{-16}\text{ N}$.

EVALUATE: The acceleration is in the direction of motion since the speed is increasing, and the net force is in the direction of the acceleration.

4.17. **IDENTIFY** and **SET UP:** $F = ma$. We must use $w = mg$ to find the mass of the boulder.

EXECUTE: $m = \dfrac{w}{g} = \dfrac{2400\text{ N}}{9.80\text{ m/s}^2} = 244.9\text{ kg}$

Then $F = ma = (244.9\text{ kg})(12.0\text{ m/s}^2) = 2940\text{ N}$.

EVALUATE: We must use mass in Newton's second law. Mass and weight are proportional.

4.18. **IDENTIFY:** Apply $\sum \vec{F} = m\vec{a}$.

SET UP: $m = w/g = (71.2\text{ N})/(9.80\text{ m/s}^2) = 7.27\text{ kg}$.

EXECUTE: $a_x = \dfrac{F_x}{m} = \dfrac{160\text{ N}}{7.27\text{ kg}} = 22.0\text{ m/s}^2$

EVALUATE: The weight of the ball is a vertical force and doesn't affect the horizontal acceleration. However, the weight is used to calculate the mass.

4.19. **IDENTIFY** and **SET UP:** $w = mg$. The mass of the watermelon is constant, independent of its location. Its weight differs on earth and Jupiter's moon. Use the information about the watermelon's weight on earth to calculate its mass:

EXECUTE: $w = mg$ gives that $m = \dfrac{w}{g} = \dfrac{44.0\text{ N}}{9.80\text{ m/s}^2} = 4.49\text{ kg}.$

On Jupiter's moon, $m = 4.49$ kg, the same as on earth. Thus the weight on Jupiter's moon is

$w = mg = (4.49\text{ kg})(1.81\text{ m/s}^2) = 8.13\text{ N}.$

EVALUATE: The weight of the watermelon is less on Io, since g is smaller there.

4.20. **IDENTIFY:** Weight and mass are related by $w = mg$. The mass is constant but g and w depend on location.

SET UP: On earth, $g = 9.80\text{ m/s}^2$.

EXECUTE: **(a)** $\dfrac{w}{g} = m$, which is constant, so $\dfrac{w_E}{g_E} = \dfrac{w_A}{g_A}$. $w_E = 17.5\text{ N}$, $g_E = 9.80\text{ m/s}^2$, and $w_A = 3.24\text{ N}$.

$$g_A = \left(\frac{w_A}{w_E}\right)g_E = \left(\frac{3.24\text{ N}}{17.5\text{ N}}\right)(9.80\text{ m/s}^2) = 1.81\text{ m/s}^2.$$

(b) $m = \dfrac{w_E}{g_E} = \dfrac{17.5\text{ N}}{9.80\text{ m/s}^2} = 1.79\text{ kg}$.

EVALUATE: The weight at a location and the acceleration due to gravity at that location are directly proportional.

4.21. **IDENTIFY:** Apply $\sum F_x = ma_x$ to find the resultant horizontal force.

SET UP: Let the acceleration be in the $+x$ direction.

EXECUTE: $\sum F_x = ma_x = (55\text{ kg})(15\text{ m/s}^2) = 825\text{ N}$. The force is exerted by the blocks. The blocks push on the sprinter because the sprinter pushes on the blocks.

EVALUATE: The force the blocks exert on the sprinter has the same magnitude as the force the sprinter exerts on the blocks. The harder the sprinter pushes, the greater the force on him.

4.22. **IDENTIFY:** $\sum \vec{F} = m\vec{a}$ refers to forces that all act on one object. The third law refers to forces that a pair of objects exert on each other.

SET UP: An object is in equilibrium if the vector sum of all the forces on it is zero. A third law pair of forces have the same magnitude regardless of the motion of either object.

EXECUTE: **(a)** the earth (gravity)

(b) 4 N; the book

(c) no, these two forces are exerted on the same object

(d) 4 N; the earth; the book; upward

(e) 4 N, the hand; the book; downward

(f) second (The two forces are exerted on the same object and this object has zero acceleration.)

(g) third (The forces are between a pair of objects.)

(h) No. There is a net upward force on the book equal to 1 N.

(i) No. The force exerted on the book by your hand is 5 N, upward. The force exerted on the book by the earth is 4 N, downward.

(j) Yes. These forces form a third-law pair and are equal in magnitude and opposite in direction.

(k) Yes. These forces form a third-law pair and are equal in magnitude and opposite in direction.

(l) One, only the gravity force.

(m) No. There is a net downward force of 5 N exerted on the book.

EVALUATE: Newton's second and third laws give complementary information about the forces that act.

4.23. **IDENTIFY:** Identify the forces on the bottle.

SET UP: Classify forces as contact or noncontact forces. The noncontact force is gravity and the contact forces come from things that touch the object. Gravity is always directed downward toward the center of the earth. Air resistance is always directed opposite to the velocity of the object relative to the air.

EXECUTE: **(a)** The free-body diagram for the bottle is sketched in Figure 4.23a

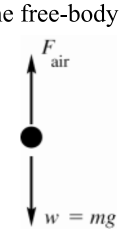


Figure 4.23a

The only forces on the bottle are gravity (downward) and air resistance (upward).

(b)

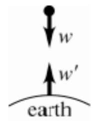


Figure 4.23b

w is the force of gravity that the earth exerts on the bottle. The reaction to this force is w', force that the bottle exerts on the earth

Note that these two equal and opposite forces produce very different accelerations because the bottle and the earth have very different masses.

F_{air} is the force that the air exerts on the bottle and is upward. The reaction to this force is a downward force F'_{air} that the bottle exerts on the air. These two forces have equal magnitudes and opposite directions.

EVALUATE: The only thing in contact with the bottle while it is falling is the air. Newton's third law always deals with forces on two different objects.

4.24. **IDENTIFY:** The reaction forces in Newton's third law are always between a pair of objects. In Newton's second law all the forces act on a single object.

SET UP: Let $+y$ be downward. $m = w/g$.

EXECUTE: The reaction to the upward normal force on the passenger is the downward normal force, also of magnitude 620 N, that the passenger exerts on the floor. The reaction to the passenger's weight is the gravitational force that the passenger exerts on the earth, upward and also of magnitude 650 N. $\dfrac{\sum F_y}{m} = a_y$ gives

$$a_y = \frac{650\text{ N} - 620\text{ N}}{(650\text{ N})/(9.80\text{ m/s}^2)} = 0.452\text{ m/s}^2$$. The passenger's acceleration is 0.452 m/s^2 , downward.

EVALUATE: There is a net downward force on the passenger and the passenger has a downward acceleration.

4.25. **IDENTIFY:** Apply Newton's second law to the earth.

SET UP: The force of gravity that the earth exerts on her is her weight, $w = mg = (45\text{ kg})(9.8\text{ m/s}^2) = 441\text{ N}$. By Newton's 3rd law, she exerts an equal and opposite force on the earth.

Apply $\sum \vec{F} = m\vec{a}$ to the earth, with $\left|\sum \vec{F}\right| = w = 441\text{ N}$, but must use the mass of the earth for m.

EXECUTE: $$a = \frac{w}{m} = \frac{441\text{ N}}{6.0\times10^{24}\text{ kg}} = 7.4\times10^{-23}\text{ m/s}^2.$$

EVALUATE: This is *much* smaller than her acceleration of 9.8 m/s^2. The force she exerts on the earth equals in magnitude the force the earth exerts on her, but the acceleration the force produces depends on the mass of the object and her mass is *much* less than the mass of the earth.

4.26. **IDENTIFY** and **SET UP:** The only force on the ball is the gravity force, $\vec{F}_{\text{grav}}$. This force is mg , downward and is independent of the motion of the object.

EXECUTE: The free-body diagram is sketched in Figure 4.26. The free-body diagram is the same in all cases.

EVALUATE: Some forces, such as friction, depend on the motion of the object but the gravity force does not.

Figure 4.26

4.27. **IDENTIFY:** Identify the forces on each object.

SET UP: In each case the forces are the noncontact force of gravity (the weight) and the forces applied by objects that are in contact with each crate. Each crate touches the floor and the other crate, and some object applies $\vec{F}$ to crate A.

EXECUTE: **(a)** The free-body diagrams for each crate are given in Figure 4.27.

F_{AB} (the force on m_A due to m_B) and F_{BA} (the force on m_B due to m_A) form an action-reaction pair.

(b) Since there is no horizontal force opposing F, any value of F, no matter how small, will cause the crates to accelerate to the right. The weight of the two crates acts at a right angle to the horizontal, and is in any case balanced by the upward force of the surface on them.

EVALUATE: Crate B is accelerated by F_{BA} and crate A is accelerated by the net force $F - F_{AB}$. The greater the total weight of the two crates, the greater their total mass and the smaller will be their acceleration.

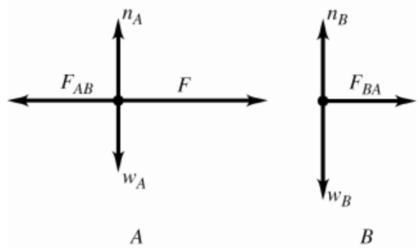


Figure 4.27

4.28. **IDENTIFY:** The surface of block B can exert both a friction force and a normal force on block A. The friction force is directed so as to oppose relative motion between blocks B and A. Gravity exerts a downward force w on block A.
SET UP: The pull is a force on B not on A.
EXECUTE: **(a)** If the table is frictionless there is a net horizontal force on the combined object of the two blocks, and block B accelerates in the direction of the pull. The friction force that B exerts on A is to the right, to try to prevent A from slipping relative to B as B accelerates to the right. The free-body diagram is sketched in Figure 4.28a. f is the friction force that B exerts on A and n is the normal force that B exerts on A.
(b) The pull and the friction force exerted on B by the table cancel and the net force on the system of two blocks is zero. The blocks move with the same constant speed and B exerts no friction force on A. The free-body diagram is sketched in Figure 4.28b.
EVALUATE: If in part (b) the pull force is decreased, block B will slow down, with an acceleration directed to the left. In this case the friction force on A would be to the left, to prevent relative motion between the two blocks by giving A an acceleration equal to that of B.

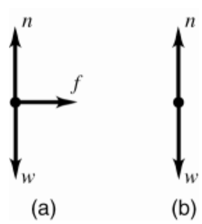


Figure 4.28

4.29. **IDENTIFY:** Since the observer in the train sees the ball hang motionless, the ball must have the same acceleration as the train car. By Newton's second law, there must be a net force on the ball in the same direction as its acceleration.
SET UP: The forces on the ball are gravity, which is w, downward, and the tension $\vec{T}$ in the string, which is directed along the string.
EXECUTE: **(a)** The acceleration of the train is zero, so the acceleration of the ball is zero. There is no net horizontal force on the ball and the string must hang vertically. The free-body diagram is sketched in Figure 4.29a.
(b) The train has a constant acceleration directed east so the ball must have a constant eastward acceleration. There must be a net horizontal force on the ball, directed to the east. This net force must come from an eastward component of $\vec{T}$ and the ball hangs with the string displaced west of vertical. The free-body diagram is sketched in Figure 4.29b.
EVALUATE: When the motion of an object is described in an inertial frame, there must be a net force in the direction of the acceleration.

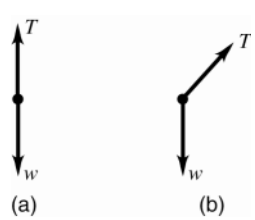


Figure 4.29

4.30. **IDENTIFY:** Identify the forces for each object. Action-reaction pairs of forces act between two objects.
SET UP: Friction is parallel to the surfaces and is directly to oppose relative motion between the surfaces.
EXECUTE: The free-body diagram for the box is given in Figure 4.30a. The free body diagram for the truck is given in Figure 4.30b. The box's friction force on the truck bed and the truck bed's friction force on the box form an action-reaction pair. There would also be some small air-resistance force action to the left, presumably negligible at this speed.

EVALUATE: The friction force on the box, exerted by the bed of the truck, is in the direction of the truck's acceleration. This friction force can't be large enough to give the box the same acceleration that the truck has and the truck acquires a greater speed than the box.

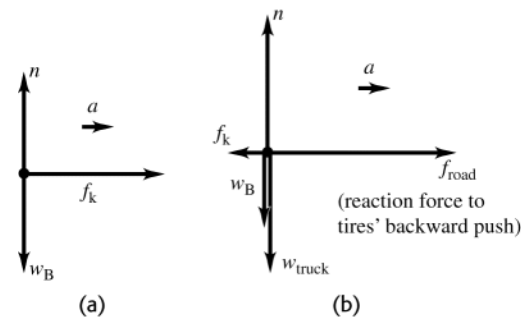


Figure 4.30

4.31. **IDENTIFY:** Identify the forces on the chair. The floor exerts a normal force and a friction force.
SET UP: Let $+y$ be upward and let $+x$ be in the direction of the motion of the chair.
EXECUTE: **(a)** The free-body diagram for the chair is given in Figure 4.31.
(b) For the chair, $a_y = 0$ so $\sum F_y = ma_y$ gives $n - mg - F\sin 37° = 0$ and $n = 142\text{ N}$.
EVALUATE: n is larger than the weight because $\vec{F}$ has a downward component.

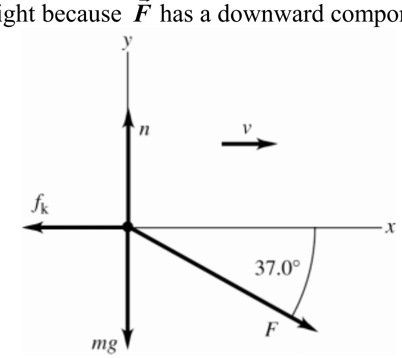


Figure 4.31

4.32. **IDENTIFY:** Identify the forces on the skier and apply $\sum \vec{F} = m\vec{a}$. Constant speed means $a = 0$.
SET UP: Use coordinates that are parallel and perpendicular to the slope.
EXECUTE: **(a)** The free-body diagram for the skier is given in Figure 4.32.
(b) $\sum F_x = ma_x$ with $a_x = 0$ gives $T = mg\sin\theta = (65.0\text{ kg})(9.80\text{ m/s}^2)\sin 26.0° = 279\text{ N}$.
EVALUATE: T is less than the weight of the skier. It is equal to the component of the weight that is parallel to the incline.

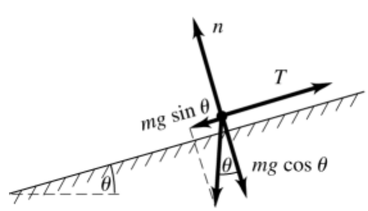


Figure 4.32

4.33. **IDENTIFY:** $\sum \vec{F} = m\vec{a}$ must be satisfied for each object. Newton's third law says that the force $\vec{F}_{\text{C on T}}$ that the car exerts on the truck is equal in magnitude and opposite in direction to the force $\vec{F}_{\text{T on C}}$ that the truck exerts on the car.
SET UP: The only horizontal force on the car is the force $\vec{F}_{\text{T on C}}$ exerted by the truck. The car exerts a force $\vec{F}_{\text{C on T}}$ on the truck. There is also a horizontal friction force $\vec{f}$ that the highway surface exerts on the truck. Assume the system is accelerating to the right in the free-body diagrams.
EXECUTE: **(a)** The free-body diagram for the car is sketched in Figure 4.33a
(b) The free-body diagram for the truck is sketched in Figure 4.33b.

(c) The friction force $\vec{f}$ accelerates the system forward. The tires of the truck push backwards on the highway surface as they rotate, so by Newton's third law the roadway pushes forward on the tires.

EVALUATE: $F_{\text{T on C}}$ and $F_{\text{C on T}}$ each equal the tension T in the rope. Both objects have the same acceleration $\vec{a}$. $T = m_C a$ and $f - T = m_T a$, so $f = (m_C + m_T)a$. The acceleration of the two objects is proportional to f.

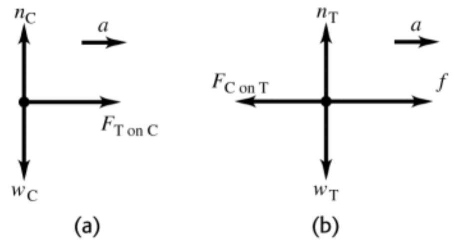


Figure 4.33

4.34. **IDENTIFY:** Use a constant acceleration equation to find the stopping time and acceleration. Then use $\sum \vec{F} = m\vec{a}$ to calculate the force.

SET UP: Let $+x$ be in the direction the bullet is traveling. $\vec{F}$ is the force the wood exerts on the bullet.

EXECUTE: **(a)** $v_{0x} = 350 \text{ m/s}$, $v_x = 0$ and $(x - x_0) = 0.130 \text{ m}$. $(x - x_0) = \left(\frac{v_{0x} + v_x}{2}\right)t$

gives $t = \frac{2(x - x_0)}{v_{0x} + v_x} = \frac{2(0.130 \text{ m})}{350 \text{ m/s}} = 7.43 \times 10^{-4} \text{ s}$.

(b) $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives $a_x = \frac{v_x^2 - v_{0x}^2}{2(x - x_0)} = \frac{0 - (350 \text{ m/s})^2}{2(0.130 \text{ m})} = -4.71 \times 10^5 \text{ m/s}^2$

$\sum F_x = ma_x$ gives $-F = ma_x$ and $F = -ma_x = -(1.80 \times 10^{-3} \text{ kg})(-4.71 \times 10^5 \text{ m/s}^2) = 848 \text{ N}$.

EVALUATE: The acceleration and net force are opposite to the direction of motion of the bullet.

4.35. **IDENTIFY:** Vector addition problem. Write the vector addition equation in component form. We know one vector and its resultant and are asked to solve for the other vector.

SET UP: Use coordinates with the $+x$-axis along $\vec{F}_1$ and the $+y$-axis along $\vec{R}$; as shown in Figure 4.35a.

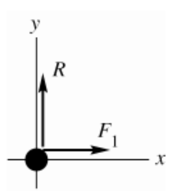


Figure 4.35a

$F_{1x} = +1300 \text{ N}$, $F_{1y} = 0$

$R_x = 0$, $R_y = +1300 \text{ N}$

$\vec{F}_1 + \vec{F}_2 = \vec{R}$, so $\vec{F}_2 = \vec{R} - \vec{F}_1$

EXECUTE: $F_{2x} = R_x - F_{1x} = 0 - 1300 \text{ N} = -1300 \text{ N}$

$F_{2y} = R_y - F_{1y} = +1300 \text{ N} - 0 = +1300 \text{ N}$

The components of $\vec{F}_2$ are sketched in Figure 4.35b.

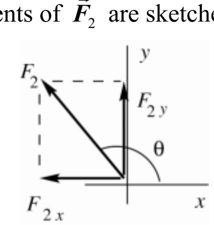


Figure 4.35b

$F_2 = \sqrt{F_{2x}^2 + F_{2y}^2} = \sqrt{(-1300 \text{ N})^2 + (1300 \text{ N})^2}$

$F = 1840 \text{ N}$

$\tan\theta = \frac{F_{2y}}{F_{2x}} = \frac{+1300 \text{ N}}{-1300 \text{ N}} = -1.00$

$\theta = 135°$

The magnitude of $\vec{F}_2$ is 1840 N and its direction is $135°$ counterclockwise from the direction of $\vec{F}_1$.

EVALUATE: $\vec{F}_2$ has a negative x-component to cancel $\vec{F}_1$ and a y-component to equal $\vec{R}$.

4.36. **IDENTIFY:** Use the motion of the ball to calculate g, the acceleration of gravity on the planet. Then $w = mg$.

SET UP: Let $+y$ be downward and take $y_0 = 0$. $v_{0y} = 0$ since the ball is released from rest.

EXECUTE: Get g on X: $y=\frac{1}{2}gt^2$ gives $10.0\text{ m}=\frac{1}{2}g(2.2\text{ s})^2$. $g=4.13\text{ m/s}^2$ and then

$w_X = mg_X = (0.100\text{ kg})(4.03\text{ m/s}^2) = 0.41\text{ N}$.

EVALUATE: g on Planet X is smaller than on earth and the object weighs less than it would on earth.

4.37. **IDENTIFY:** If the box moves in the $+x$-direction it must have $a_y = 0$, so $\sum F_y = 0$.

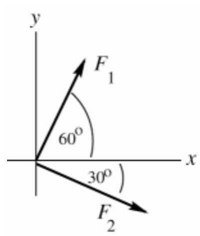


Figure 4.37

The smallest force the child can exert and still produce such motion is a force that makes the y-components of all three forces sum to zero, but that doesn't have any x-component.

SET UP: $\vec{F}_1$ and $\vec{F}_2$ are sketched in Figure 4.37. Let $\vec{F}_3$ be the force exerted by the child.

$\sum F_y = ma_y$ implies $F_{1y}+F_{2y}+F_{3y}=0$, so $F_{3y}=-(F_{1y}+F_{2y})$.

EXECUTE: $F_{1y}=+F_1\sin 60° = (100\text{ N})\sin 60° = 86.6\text{ N}$

$F_{2y}=+F_2\sin(-30°) = -F_2\sin 30° = -(140\text{ N})\sin 30° = -70.0\text{ N}$

Then $F_{3y}=-(F_{1y}+F_{2y}) = -(86.6\text{ N}-70.0\text{ N}) = -16.6\text{ N}$; $F_{3x}=0$

The smallest force the child can exert has magnitude 17 N and is directed at $90°$ clockwise from the $+x$-axis shown in the figure.

(b) IDENTIFY and **SET UP:** Apply $\sum F_x = ma_x$. We know the forces and a_x so can solve for m. The force exerted by the child is in the $-y$-direction and has no x-component.

EXECUTE: $F_{1x}=F_1\cos 60° = 50\text{ N}$

$F_{2x}=F_2\cos 30° = 121.2\text{ N}$

$\sum F_x = F_{1x}+F_{2x} = 50\text{ N}+121.2\text{ N} = 171.2\text{ N}$

$$m=\frac{\sum F_x}{a_x}=\frac{171.2\text{ N}}{2.00\text{ m/s}^2}=85.6\text{ kg}$$

Then $w = mg = 840\text{ N}$.

EVALUATE: In part (b) we don't need to consider the y-component of Newton's second law. $a_y = 0$ so the mass doesn't appear in the $\sum F_y = ma_y$ equation.

4.38. **IDENTIFY:** Use $\sum \vec{F} = m\vec{a}$ to calculate the acceleration of the tanker and then use constant acceleration kinematic equations.

SET UP: Let $+x$ be the direction the tanker is moving initially. Then $a_x = -F/m$.

EXECUTE: $v_x^2 = v_{0x}^2 + 2a_x(x-x_0)$ says that if the reef weren't there the ship would stop in a distance of

$$x-x_0=-\frac{v_{0x}^2}{2a_x}=\frac{v_0^2}{2(F/m)}=\frac{mv_0^2}{2F}=\frac{(3.6\times10^7\text{ kg})(1.5\text{ m/s})^2}{2(8.0\times10^4\text{ N})}=506\text{ m},$$

so the ship would hit the reef. The speed when the tanker hits the reef is found from $v_x^2 = v_{0x}^2 + 2a_x(x-x_0)$, so it is

$$v=\sqrt{v_0^2-(2Fx/m)}=\sqrt{(1.5\text{ m/s})^2-\frac{2(8.0\times10^4\text{ N})(500\text{ m})}{(3.6\times10^7\text{ kg})}}=0.17\text{ m/s},$$

and the oil should be safe.

EVALUATE: The force and acceleration are directed opposite to the initial motion of the tanker and the speed decreases.

4.39. **IDENTIFY:** We can apply constant acceleration equations to relate the kinematic variables and we can use Newton's second law to relate the forces and acceleration.

(a) SET UP: First use the information given about the height of the jump to calculate the speed he has at the instant his feet leave the ground. Use a coordinate system with the $+y$-axis upward and the origin at the position when his feet leave the ground.

$v_y = 0$ (at the maximum height), $v_{0y} = ?$, $a_y = -9.80\text{ m/s}^2$, $y - y_0 = +1.2\text{ m}$

$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$

EXECUTE: $v_{0y} = \sqrt{-2a_y(y - y_0)} = \sqrt{-2(-9.80\text{ m/s}^2)(1.2\text{ m})} = 4.85\text{ m/s}$

(b) SET UP: Now consider the acceleration phase, from when he starts to jump until when his feet leave the ground. Use a coordinate system where the $+y$-axis is upward and the origin is at his position when he starts his jump.

EXECUTE: Calculate the average acceleration:

$$(a_{\text{av}})_y = \frac{v_y - v_{0y}}{t} = \frac{4.89\text{ m/s} - 0}{0.300\text{ s}} = 16.2\text{ m/s}^2$$

(c) SET UP: Finally, find the average upward force that the ground must exert on him to produce this average upward acceleration. (Don't forget about the downward force of gravity.) The forces are sketched in Figure 4.39.

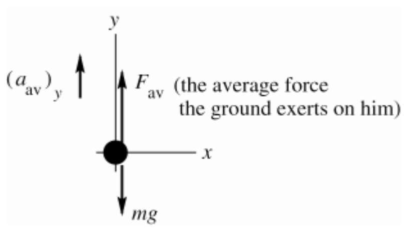


Figure 4.39

EXECUTE:

$m = w/g = \dfrac{890\text{ N}}{9.80\text{ m/s}^2} = 90.8\text{ kg}$

$\sum F_y = ma_y$

$F_{\text{av}} - mg = m(a_{\text{av}})_y$

$F_{\text{av}} = m(g + (a_{\text{av}})_y)$

$F_{\text{av}} = 90.8\text{ kg}(9.80\text{ m/s}^2 + 16.2\text{ m/s}^2)$

$F_{\text{av}} = 2360\text{ N}$

This is the average force exerted on him by the ground. But by Newton's 3rd law, the average force he exerts on the ground is equal and opposite, so is 2360 N, downward.

EVALUATE: In order for him to accelerate upward, the ground must exert an upward force greater than his weight.

4.40. IDENTIFY: Use constant acceleration equations to calculate the acceleration a_x that would be required. Then use $\sum F_x = ma_x$ to find the necessary force.

SET UP: Let $+x$ be the direction of the initial motion of the auto.

EXECUTE: $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ with $v_x = 0$ gives $a_x = -\dfrac{v_{0x}^2}{2(x - x_0)}$. The force F is directed opposite to the motion and $a_x = -\dfrac{F}{m}$. Equating these two expressions for a_x gives

$$F = m\frac{v_{0x}^2}{2(x - x_0)} = (850\text{ kg})\frac{(12.5\text{ m/s})^2}{2(1.8\times 10^{-2}\text{ m})} = 3.7\times 10^6\text{ N}.$$

EVALUATE: A very large force is required to stop such a massive object in such a short distance.

4.41. IDENTIFY: Apply Newton's second law to calculate a.

(a) SET UP: The free-body diagram for the bucket is sketched in Figure 4.41.

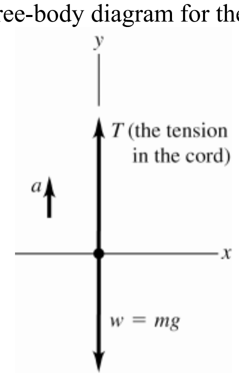


Figure 4.41

The net force on the bucket is $T - mg$, upward.

(b) EXECUTE: $\sum F_y = ma_y$ gives $T - mg = ma$

$$a = \frac{T - mg}{m} = \frac{75.0\text{ N} - (4.80\text{ kg})(9.80\text{ m/s}^2)}{4.80\text{ kg}} = \frac{75.0\text{ N} - 47.04\text{ N}}{4.80\text{ kg}} = 5.82\text{ m/s}^2.$$

EVALUATE: The weight of the bucket is 47.0 N. The upward force exerted by the cord is larger than this, so the bucket accelerates upward.

4.42. IDENTIFY: Apply $\sum \vec{F} = m\vec{a}$ to the parachutist.

SET UP: Let $+y$ be upward. $\vec{F}_{\text{air}}$ is the force of air resistance.

EXECUTE: **(a)** $w = mg = (55.0\text{ kg})(9.80\text{ m/s}^2) = 539\text{ N}$

(b) The free-body diagram is given in Fig. 4.42. $\sum F_y = F_{\text{air}} - w = 620\text{ N} - 539\text{ N} = 81\text{ N}$. The net force is upward.

(c) $a_y = \frac{\sum F_y}{m} = \frac{81\text{ N}}{55.0\text{ kg}} = 1.5\text{ m/s}^2$, upward.

EVALUATE: Both the net force and the acceleration are upward. Since her velocity is downward and her acceleration is upward, her speed decreases.

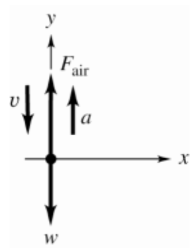


Figure 4.42

4.43. IDENTIFY: Use Newton's 2nd law to relate the acceleration and forces for each crate.

(a) SET UP: Since the crates are connected by a rope, they both have the same acceleration, 2.50 m/s^2.

(b) The forces on the 4.00 kg crate are shown in Figure 4.43a.

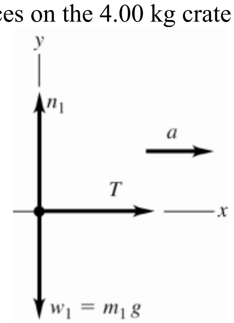


Figure 4.43a

EXECUTE:

$\sum F_x = ma_x$

$T = m_1 a = (4.00\text{ kg})(2.50\text{ m/s}^2) = 10.0\text{ N}.$

(c) SET UP: Forces on the 6.00 kg crate are shown in Figure 4.43b

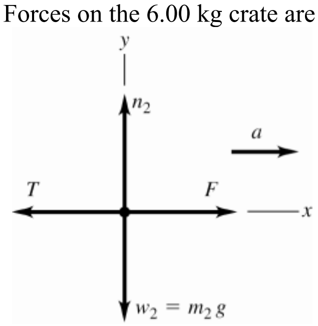


Figure 4.43b

The crate accelerates to the right, so the net force is to the right. *F* must be larger than *T*.

(d) EXECUTE: $\sum F_x = ma_x$ gives $F - T = m_2 a$

$$F = T + m_2 a = 10.0\text{ N} + (6.00\text{ kg})(2.50\text{ m/s}^2) = 10.0\text{ N} + 15.0\text{ N} = 25.0\text{ N}$$

EVALUATE: We can also consider the two crates and the rope connecting them as a single object of mass $m = m_1 + m_2 = 10.0$ kg. The free-body diagram is sketched in Figure 4.43c.

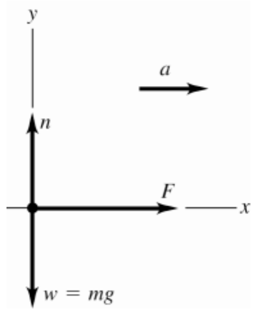


Figure 4.43c

$\sum F_x = ma_x$

$F = ma = (10.0 \text{ kg})(2.50 \text{ m/s}^2) = 25.0 \text{ N}$

This agrees with our answer in part (d).

4.44. **IDENTIFY:** Apply Newton's second and third laws.

SET UP: Action-reaction forces act between a pair of objects. In the second law all the forces act on the same object.

EXECUTE: **(a)** The force the astronaut exerts on the cable and the force that the cable exerts on the astronaut are an action-reaction pair, so the cable exerts a force of 80.0 N on the astronaut.

(b) The cable is under tension.

(c) $a = \dfrac{F}{m} = \dfrac{80.0 \text{ N}}{105.0 \text{ kg}} = 0.762 \text{ m/s}^2$.

(d) There is no net force on the massless cable, so the force that the shuttle exerts on the cable must be 80.0 N (this is *not* an action-reaction pair). Thus, the force that the cable exerts on the shuttle must be 80.0 N.

(e) $a = \dfrac{F}{m} = \dfrac{80.0 \text{ N}}{9.05\times 10^4 \text{ kg}} = 8.84\times 10^{-4} \text{ m/s}^2$.

EVALUATE: Since the cable is massless the net force on it is zero and the tension is the same at each end.

4.45. **IDENTIFY** and **SET UP:** Take derivatives of $x(t)$ to find v_x and a_x. Use Newton's second law to relate the acceleration to the net force on the object.

EXECUTE:

(a) $x = (9.0\times 10^3 \text{ m/s}^2)t^2 - (8.0\times 10^4 \text{m/s}^3)t^3$

$x = 0$ at $t = 0$

When $t = 0.025$ s, $x = (9.0\times 10^3 \text{ m/s}^2)(0.025 \text{ s})^2 - (8.0\times 10^4 \text{ m/s}^3)(0.025 \text{ s})^3 = 4.4$ m.

The length of the barrel must be 4.4 m.

(b) $v_x = \dfrac{dx}{dt} = (18.0\times 10^3 \text{ m/s}^2)t - (24.0\times 10^4 \text{ m/s}^3)t^2$

At $t = 0$, $v_x = 0$ (object starts from rest).

At $t = 0.025$ s, when the object reaches the end of the barrel,

$v_x = (18.0\times 10^3 \text{ m/s}^2)(0.025 \text{ s}) - (24.0\times 10^4 \text{ m/s}^3)(0.025 \text{ s})^2 = 300 \text{ m/s}$

(c) $\sum F_x = ma_x$, so must find a_x.

$a_x = \dfrac{dv_x}{dt} = 18.0\times 10^3 \text{ m/s}^2 - (48.0\times 10^4 \text{ m/s}^3)t$

(i) At $t = 0$, $a_x = 18.0\times 10^3 \text{ m/s}^2$ and $\sum F_x = (1.50 \text{ kg})(18.0\times 10^3 \text{ m/s}^2) = 2.7\times 10^4$ N.

(ii) At $t = 0.025$ s, $a_x = 18\times 10^3 \text{ m/s}^2 - (48.0\times 10^4 \text{ m/s}^3)(0.025 \text{ s}) = 6.0\times 10^3 \text{ m/s}^2$ and $\sum F_x = (1.50 \text{ kg})(6.0\times 10^3 \text{ m/s}^2) = 9.0\times 10^3$ N.

EVALUATE: The acceleration and net force decrease as the object moves along the barrel.

4.46. **IDENTIFY:** Apply $\sum \vec{F} = m\vec{a}$ and solve for the mass m of the spacecraft.

SET UP: $w = mg$. Let $+y$ be upward.

EXECUTE: **(a)** The velocity of the spacecraft is downward. When it is slowing down, the acceleration is upward. When it is speeding up, the acceleration is downward.

(b) In each case the net force is in the direction of the acceleration. Speeding up: $w > F$ and the net force is downward. Slowing down: $w < F$ and the net force is upward.

(c) Denote the y-component of the acceleration when the thrust is F_1 by a_1 and the y-component of the acceleration when the thrust is F_2 by a_1. $a_y = +1.20\ \text{m/s}^2$ and $a_2 = -0.80\ \text{m/s}^2$. The forces and accelerations are then related by $F_1 - w = ma_1$, $F_2 - w = ma_2$. Dividing the first of these by the second to eliminate the mass gives $\dfrac{F_1 - w}{F_2 - w} = \dfrac{a_1}{a_2}$, and solving for the weight w gives

$w = \dfrac{a_1 F_2 - a_2 F_1}{a_1 - a_2}$. Substituting the given numbers, with $+y$ upward, gives

$$w = \frac{(1.20\ \text{m/s}^2)(10.0\times 10^3\ \text{N}) - (-0.80\ \text{m/s}^2)(25.0\times 10^3\ \text{N})}{1.20\ \text{m/s}^2 - (-0.80\ \text{m/s}^2)} = 16.0\times 10^3\ \text{N}.$$

EVALUATE: The acceleration due to gravity at the surface of Mercury did not need to be found.

4.47. **IDENTIFY:** The ship and instrument have the same acceleration. The forces and acceleration are related by Newton's second law. We can use a constant acceleration equation to calculate the acceleration from the information given about the motion.

SET UP: Let $+y$ be upward. The forces on the instrument are the upward tension $\vec{T}$ exerted by the wire and the downward force $\vec{w}$ of gravity. $w = mg = (6.50\ \text{kg})(9.80\ \text{m/s}^2) = 63.7\ \text{N}$

EXECUTE: **(a)** The free-body diagram is sketched in Figure 4.47. The acceleration is upward, so $T > w$.

$y - y_0 = 276\ \text{m}$, $t = 15.0\ \text{s}$, $v_{0y} = 0$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives $a_y = \dfrac{2(y - y_0)}{t^2} = \dfrac{2(276\ \text{m})}{(15.0\ \text{s})^2} = 2.45\ \text{m/s}^2$.

$\sum F_y = ma_y$ gives $T - w = ma$ and $T = w + ma = 63.7\ \text{N} + (6.50\ \text{kg})(2.45\ \text{m/s}^2) = 79.6\ \text{N}$.

EVALUATE: There must be a net force in the direction of the acceleration.

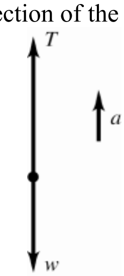


Figure 4.47

4.48. If the rocket is moving downward and its speed is decreasing, its acceleration is upward, just as in Problem 4.47. The solution is identical to that of Problem 4.47.

4.49. **IDENTIFY:** Apply $\sum \vec{F} = m\vec{a}$ to the gymnast.

SET UP: The upward force on the gymnast gives the tension in the rope. The free-body diagram for the gymnast is given in Figure 4.49.

EXECUTE: **(a)** If the gymnast climbs at a constant rate, there is no net force on the gymnast, so the tension must equal the weight; $T = mg$.

(b) No motion is no acceleration, so the tension is again the gymnast's weight.

(c) $T - w = T - mg = ma = m|\vec{\mathbf{a}}|$ (the acceleration is upward, the same direction as the tension), so $T = m(g + |\vec{\mathbf{a}}|)$.

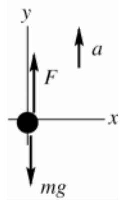
(d) $T - w = T - mg = ma = -m|\vec{\mathbf{a}}|$ (the acceleration is downward, the opposite direction to the tension), so $T = m\left(g - |\vec{\mathbf{a}}|\right)$.

EVALUATE: When she accelerates upward the tension is greater than her weight and when she accelerates downward the tension is less than her weight.

Figure 4.49

4.50. **IDENTIFY:** Apply $\sum \vec{F} = m\vec{a}$ to the elevator to relate the forces on it to the acceleration.

(a) SET UP: The free-body diagram for the elevator is sketched in Figure 4.50.



The net force is $T - mg$ (upward).

Figure 4.50

Take the $+y$-direction to be upward since that is the direction of the acceleration. The maximum upward acceleration is obtained from the maximum possible tension in the cables.

EXECUTE: $\sum F_y = ma_y$ gives $T - mg = ma$

$$a = \frac{T - mg}{m} = \frac{28{,}000\text{ N} - (2200\text{ kg})(9.80\text{ m/s}^2)}{2200\text{ kg}} = 2.93\text{ m/s}^2.$$

(b) What changes is the weight *mg* of the elevator.

$$a = \frac{T - mg}{m} = \frac{28{,}000\text{ N} - (2200\text{ kg})(1.62\text{ m/s}^2)}{2200\text{ kg}} = 11.1\text{ m/s}^2.$$

EVALUATE: The cables can give the elevator a greater acceleration on the moon since the downward force of gravity is less there and the same *T* then gives a greater net force.

4.51. **IDENTIFY:** He is in free-fall until he contacts the ground. Use the constant acceleration equations and apply $\sum \vec{F} = m\vec{a}$.

SET UP: Take $+y$ downward. While he is in the air, before he touches the ground, his acceleration is $a_y = 9.80\text{ m/s}^2$.

EXECUTE: **(a)** $v_{0y} = 0$, $y - y_0 = 3.10\text{ m}$, and $a_y = 9.80\text{ m/s}^2$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$$v_y = \sqrt{2a_y(y - y_0)} = \sqrt{2(9.80\text{ m/s}^2)(3.10\text{ m})} = 7.79\text{ m/s}$$

(b) $v_{0y} = 7.79\text{ m/s}$, $v_y = 0$, $y - y_0 = 0.60\text{ m}$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$$a_y = \frac{v_y^2 - v_{0y}^2}{2(y - y_0)} = \frac{0 - (7.79\text{ m/s})^2}{2(0.60\text{ m})} = -50.6\text{ m/s}^2.$$ The acceleration is upward.

(c) The free-body diagram is given in Fig. 4.51. $\vec{F}$ is the force the ground exerts on him.

$\sum F_y = ma_y$ gives $mg - F = -ma$. $F = m(g + a) = (75.0\text{ kg})(9.80\text{ m/s}^2 + 50.6\text{ m/s}^2) = 4.53 \times 10^3\text{ N}$, upward.

$$\frac{F}{w} = \frac{4.53 \times 10^3\text{ N}}{(75.0\text{ kg})(9.80\text{ m/s}^2)} = 6.16,\text{ so } F = 6.16w.$$

By Newton's third law, the force his feet exert on the ground is $-\vec{F}$.

EVALUATE: The force the ground exerts on him is about six times his weight.

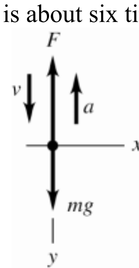


Figure 4.51

4.52. **IDENTIFY:** Apply $\sum \vec{F} = m\vec{a}$ to the hammer head. Use a constant acceleration equation to relate the motion to the acceleration.

SET UP: Let $+y$ be upward.

EXECUTE: **(a)** The free-body diagram for the hammer head is sketched in Figure 4.52.

(b) The acceleration of the hammer head is given by $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ with $v_y = 0$, $v_{0y} = -3.2\text{ m/s}^2$ and $y - y_0 = -0.0045\text{ m}$. $a_y = v_{0y}^2 / 2(y - y_0) = (3.2\text{ m/s})^2 / 2(0.0045\text{ cm}) = 1.138 \times 10^3\text{ m/s}^2$. The mass of the hammer head is its weight divided by g, $(4.9\text{ N})/(9.80\text{ m/s}^2) = 0.50\text{ kg}$, and so the net force on the hammer head is $(0.50\text{ kg})(1.138\times10^3\text{ m/s}^2) = 570\text{ N}$. This is the sum of the forces on the hammer head: the upward force that the nail exerts, the downward weight and the downward 15-N force. The force that the nail exerts is then 590 N, and this must be the magnitude of the force that the hammer head exerts on the nail.

(c) The distance the nail moves is 0.12 m, so the acceleration will be 4267 m/s^2, and the net force on the hammer head will be 2133 N. The magnitude of the force that the nail exerts on the hammer head, and hence the magnitude of the force that the hammer head exerts on the nail, is 2153 N, or about 2200 N.

EVALUATE: For the shorter stopping distance the acceleration has a larger magnitude and the force between the nail and hammer head is larger.

Figure 4.52

4.53. **IDENTIFY:** Apply $\sum\vec{F} = m\vec{a}$ to some portion of the cable.

SET UP: The free-body diagrams for the whole cable, the top half of the cable and the bottom half are sketched in Figure 4.53. The cable is at rest, so in each diagram the net force is zero.

EXECUTE: **(a)** The net force on a point of the cable at the top is zero; the tension in the cable must be equal to the weight *w*.

(b) The net force on the cable must be zero; the difference between the tensions at the top and bottom must be equal to the weight *w*, and with the result of part (a), there is no tension at the bottom.

(c) The net force on the bottom half of the cable must be zero, and so the tension in the cable at the middle must be half the weight, $w/2$. Equivalently, the net force on the upper half of the cable must be zero. From part (a) the tension at the top is *w*, the weight of the top half is $w/2$ and so the tension in the cable at the middle must be $w - w/2 = w/2$.

(d) A graph of *T* vs. distance will be a negatively sloped line.

EVALUATE: The tension decreases linearly from a value of *w* at the top to zero at the bottom of the cable.

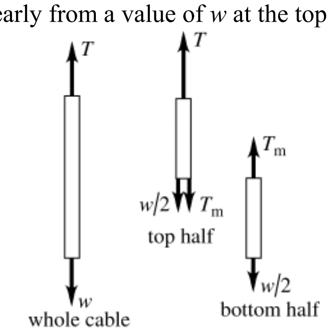


Figure 4.53

4.54. **IDENTIFY:** Note that in this problem the mass of the rope is given, and that it is not negligible compared to the other masses. Apply $\sum\vec{F} = m\vec{a}$ to each object to relate the forces to the acceleration.

(a) SET UP: The free-body diagrams for each block and for the rope are given in Figure 4.54a.

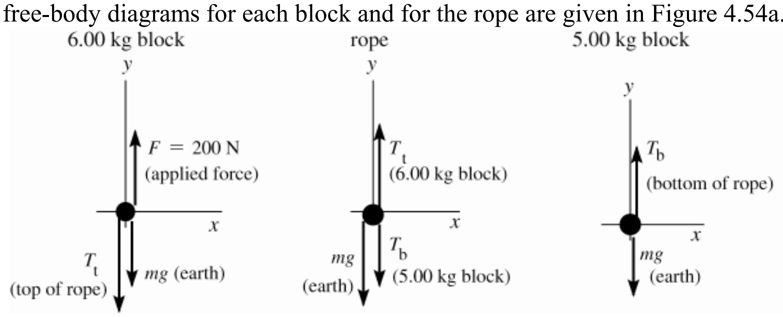


Figure 4.54a

T_t is the tension at the top of the rope and T_b is the tension at the bottom of the rope.

EXECUTE: **(b)** Treat the rope and the two blocks together as a single object, with mass $m = 6.00\text{ kg} + 4.00\text{ kg} + 5.00\text{ kg} = 15.0\text{ kg}$. Take $+y$ upward, since the acceleration is upward. The free-body diagram is given in Figure 4.54b.

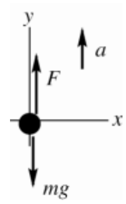


Figure 4.54b

$$\sum F_y = ma_y$$
$$F - mg = ma$$
$$a = \frac{F - mg}{m}$$
$$a = \frac{200\text{ N} - (15.0\text{ kg})(9.80\text{ m/s}^2)}{15.0\text{ kg}} = 3.53\text{ m/s}^2$$

(c) Consider the forces on the top block $(m = 6.00\text{ kg})$, since the tension at the top of the rope (T_t) will be one of these forces.

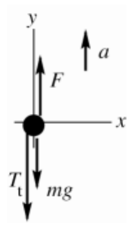


Figure 4.54c

$$\sum F_y = ma_y$$
$$F - mg - T_t = ma$$
$$T_t = F - m(g + a)$$
$$T = 200\text{ N} - (6.00\text{ kg})(9.80\text{ m/s}^2 + 3.53\text{ m/s}^2) = 120\text{ N}$$

Alternatively, can consider the forces on the combined object rope plus bottom block $(m = 9.00\text{ kg})$:

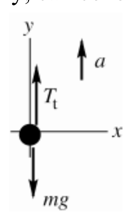


Figure 4.54d

$$\sum F_y = ma_y$$
$$T_t - mg = ma$$
$$T_t = m(g + a) = 9.00\text{ kg}(9.80\text{ m/s}^2 + 3.53\text{ m/s}^2) = 120\text{ N},$$

which checks

(d) One way to do this is to consider the forces on the top half of the rope $(m = 2.00\text{ kg})$. Let T_m be the tension at the midpoint of the rope.

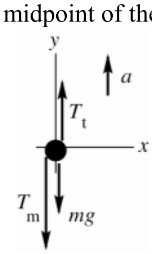


Figure 4.54e

$$\sum F_y = ma_y$$
$$T_t - T_m - mg = ma$$
$$T_m = T_t - m(g + a) = 120\text{ N} - 2.00\text{ kg}(9.80\text{ m/s}^2 + 3.53\text{ m/s}^2) = 93.3\text{ N}$$

To check this answer we can alternatively consider the forces on the bottom half of the rope plus the lower block taken together as a combined object $(m = 2.00\text{ kg} + 5.00\text{ kg} = 7.00\text{ kg})$:

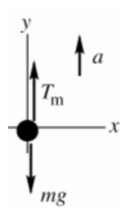


Figure 4.54f

$$\sum F_y = ma_y$$
$$T_m - mg = ma$$
$$T_m = m(g + a) = 7.00\text{ kg}(9.80\text{ m/s}^2 + 3.53\text{ m/s}^2) = 93.3\text{ N},$$

which checks

EVALUATE: The tension in the rope is not constant but increases from the bottom of the rope to the top. The tension at the top of the rope must accelerate the rope as well the 5.00-kg block. The tension at the top of the rope is less than F; there must be a net upward force on the 6.00-kg block.

4.55. **IDENTIFY:** Apply $\sum \vec{F} = m\vec{a}$ to the barbell and to the athlete. Use the motion of the barbell to calculate its acceleration.

SET UP: Let $+y$ be upward.

EXECUTE: **(a)** The free-body diagrams for the baseball and for the athlete are sketched in Figure 4.55.

(b) The athlete's weight is $mg = (90.0\text{ kg})(9.80\text{ m/s}^2) = 882\text{ N}$. The upward acceleration of the barbell is found from $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$. $a_y = \dfrac{2(y-y_0)}{t^2} = \dfrac{2(0.600\text{ m})}{(1.6\text{ s})^2} = 0.469\text{ m/s}^2$. The force needed to lift the barbell is given by $F_{\text{lift}} - w_{\text{barbell}} = ma_y$. The barbell's mass is $(490\text{ N})/(9.80\text{ m/s}^2) = 50.0\text{ kg}$, so

$F_{\text{lift}} = w_{\text{barbell}} + ma = 490\text{ N} + (50.0\text{ kg})(0.469\text{ m/s}^2) = 490\text{ N} + 23\text{ N} = 513\text{ N}$.

The athlete is not accelerating, so $F_{\text{floor}} - F_{\text{lift}} - w_{\text{athlete}} = 0$. $F_{\text{floor}} = F_{\text{lift}} + w_{\text{athlete}} = 513\text{ N} + 882\text{ N} = 1395\text{ N}$.

EVALUATE: Since the athlete pushes upward on the barbell with a force greater than its weight the barbell pushes down on him and the normal force on the athlete is greater than the total weight, 1362 N, of the athlete plus barbell.

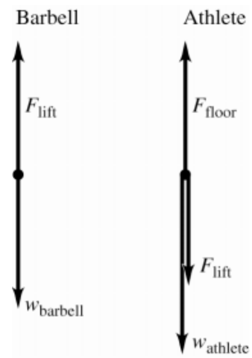


Figure 4.55

4.56. **IDENTIFY:** Apply $\sum \vec{F} = m\vec{a}$ to the balloon and its passengers and cargo, both before and after objects are dropped overboard.

SET UP: When the acceleration is downward take $+y$ to be downward and when the acceleration is upward take $+y$ to be upward.

EXECUTE: **(a)** The free-body diagram for the descending balloon is given in Figure 4.56. L is the lift force.

(b) $\sum F_y = ma_y$ gives $Mg - L = M(g/3)$ and $L = 2Mg/3$.

(c) Now $+y$ is upward, so $L - mg = m(g/2)$, where m is the mass remaining.

$L = 2Mg/3$, so $m = 4M/9$. Mass $5M/9$ must be dropped overboard.

EVALUATE: In part (b) the lift force is greater than the total weight and in part (c) the lift force is less than the total weight.

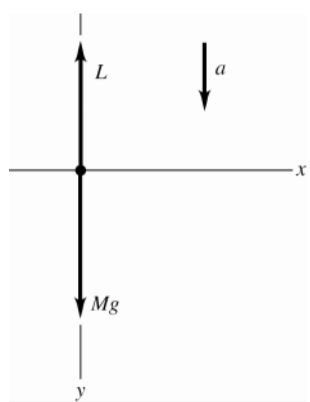


Figure 4.56

4.57. **IDENTIFY:** Apply $\sum \vec{F} = m\vec{a}$ to the entire chain and to each link.

SET UP: $m =$ mass of one link. Let $+y$ be upward.

EXECUTE: **(a)** The free-body diagrams are sketched in Figure 4.57. F_{top} is the force the top and middle links exert on each other. F_{middle} is the force the middle and bottom links exert on each other.

(b) (i) The weight of each link is $mg = (0.300 \text{ kg})(9.80 \text{ m/s}^2) = 2.94 \text{ N}$. Using the free-body diagram for the whole chain:

$$a = \frac{F_{student} - 3mg}{3m} = \frac{12 \text{ N} - 3(2.94 \text{ N})}{0.900 \text{ kg}} = \frac{3.18 \text{ N}}{0.900 \text{ kg}} = 3.53 \text{ m/s}^2$$

(ii) The top link also accelerates at 3.53 m/s^2, so $F_{student} - F_{top} - mg = ma$.

$F_{top} = F_{student} - m(g + a) = 12 \text{ N} - (0.300 \text{ kg})(9.80 \text{ m/s}^2 + 3.53 \text{ m/s}^2) = 8.0 \text{ N}$.

EVALUATE: The force exerted by the middle link on the bottom link is given by $F_{middle} - mg = ma$ and $F_{middle} = m(g + a) = 4.0 \text{ N}$. We can verify that with our results $\sum F_y = ma_y$ is satisfied for the middle link.

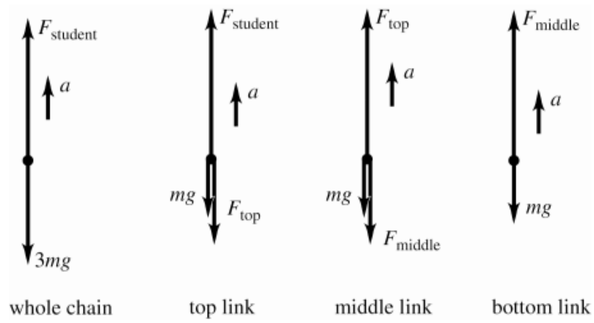


Figure 4.57

4.58. **IDENTIFY:** Calculate $\vec{a}$ from $\vec{a} = d^2\vec{r}/dt^2$. Then $\vec{F}_{net} = m\vec{a}$.

SET UP: $w = mg$

EXECUTE: Differentiating twice, the acceleration of the helicopter as a function of time is $\vec{a} = (0.120 \text{ m/s}^3)t\hat{i} - (0.12 \text{ m/s}^2)\hat{k}$ and at $t = 5.0 \text{s}$, the acceleration is $\vec{a} = (0.60 \text{ m/s}^2)\hat{i} - (0.12 \text{ m/s}^2)\hat{k}$. The force is then

$$\vec{F} = m\vec{a} = \frac{w}{g}\vec{a} = \frac{(2.75\times10^5 \text{ N})}{(9.80 \text{ m/s}^2)}\left[(0.60 \text{ m/s}^2)\hat{i} - (0.12 \text{ m/s}^2)\hat{k}\right] = (1.7\times10^4 \text{ N})\hat{i} - (3.4\times10^3 \text{ N})\hat{k}$$

EVALUATE: The force and acceleration are in the same direction. They are both time dependent.

4.59. **IDENTIFY:** $F_x = ma_x$ and $a_x = \dfrac{d^2x}{dt^2}$.

SET UP: $\dfrac{d}{dt}(t^n) = nt^{n-1}$

EXECUTE: The velocity as a function of time is $v_x(t) = A - 3Bt^2$ and the acceleration as a function of time is $a_x(t) = -6Bt$, and so the force as a function of time is $F_x(t) = ma(t) = -6mBt$.

EVALUATE: Since the acceleration is along the *x*-axis, the force is along the *x*-axis.

4.60. **IDENTIFY:** $\vec{a} = \vec{F}/m$. $\vec{v} = \vec{v}_0 + \int_0^t \vec{a}\, dt$.

SET UP: $v_0 = 0$ since the object is initially at rest.

EXECUTE: $\vec{v}(t) = \dfrac{1}{m}\int_0^t \vec{F}\, dt = \dfrac{1}{m}\left(k_1 t\hat{i} + \dfrac{k_2}{4}t^4\hat{j}\right)$.

EVALUATE: $\vec{F}$ has both *x* and *y* components, so $\vec{v}$ develops *x* and *y* components.

4.61. **IDENTIFY:** Follow the steps specified in the problem.

SET UP: The chain rule for differentiating says $\dfrac{dv}{dt} = \dfrac{dv}{dx}\dfrac{dv}{dt} = \dfrac{dv}{dx}v$.

EXECUTE: **(a)** The equation of motion, $-Cv^2 = m\frac{dv}{dt}$ cannot be integrated with respect to time, as the unknown function $v(t)$ is part of the integrand. The equation must be *separated* before integration; that is, $-\frac{C}{m}dt = \frac{dv}{v^2}$ and

$$-\frac{Ct}{m} = -\frac{1}{v} + \frac{1}{v_0},$$

where v_0 is the constant of integration that gives $v = v_0$ at $t = 0$. Note that this form shows that if $v_0 = 0$, there is no motion. This expression may be rewritten as $v = \frac{dx}{dt} = \left(\frac{1}{v_0} + \frac{Ct}{m}\right)^{-1}$,

which may be integrated to obtain $x - x_0 = \frac{m}{C}\ln\left[1 + \frac{Ctv_0}{m}\right]$.

To obtain *x* as a function of *v*, the time *t* must be eliminated in favor of *v*; from the expression obtained after the first integration, $\frac{Ctv_0}{m} = \frac{v_0}{v} - 1$, so $x - x_0 = \frac{m}{C}\ln\left(\frac{v_0}{v}\right)$.

(b) Applying the chain rule, $\sum F = m\frac{dv}{dt} = mv\frac{dv}{dx}$. Using the given expression for the net force, $-Cv^2 = \left(v\frac{dv}{dx}\right)m$. $-\frac{C}{m}dx = \frac{dv}{v}$. Integrating gives $-\frac{C}{m}(x - x_0) = \ln\left(\frac{v}{v_0}\right)$ and $x - x_0 = \frac{m}{C}\ln\left(\frac{v_0}{v}\right)$.

EVALUATE: If *C* is positive, our expression for $v(t)$ shows it decreases from its value of v_0. As *v* decreases, so does the acceleration and therefore the rate of decrease of *v*.

4.62. **IDENTIFY:** $x = \int_0^t v_x dt$ and $v_x = \int_0^t a_x dt$, and similar equations apply to the *y*-component.

SET UP: In this situation, the *x*-component of force depends explicitly on the *y*-component of position. As the *y*-component of force is given as an explicit function of time, v_y and *y* can be found as functions of time and used in the expression for $a_x(t)$.

EXECUTE: $a_y = (k_3/m)t$, so $v_y = (k_3/2m)t^2$ and $y = (k_3/6m)t^3$, where the initial conditions $v_{0y} = 0, y_0 = 0$ have been used. Then, the expressions for a_x, v_x and *x* are obtained as functions of time: $a_x = \frac{k_1}{m} + \frac{k_2k_3}{6m^2}t^3$,

$v_x = \frac{k_1}{m}t + \frac{k_2k_3}{24m^2}t^4$ and $x = \frac{k_1}{2m}t^2 + \frac{k_2k_3}{120m^2}t^5$.

In vector form, $\vec{r} = \left(\frac{k_1}{2m}t^2 + \frac{k_2k_3}{120m^2}t^5\right)\hat{i} + \left(\frac{k_3}{6m}t^3\right)\hat{j}$ and $\vec{v} = \left(\frac{k_1}{m}t + \frac{k_2k_3}{24m^2}t^4\right)\hat{i} + \left(\frac{k_3}{2m}t^2\right)\hat{j}$.

EVALUATE: a_x depends on time because it depends on *y*, and *y* is a function of time.