4

# NEWTON'S LAWS OF MOTION

**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).

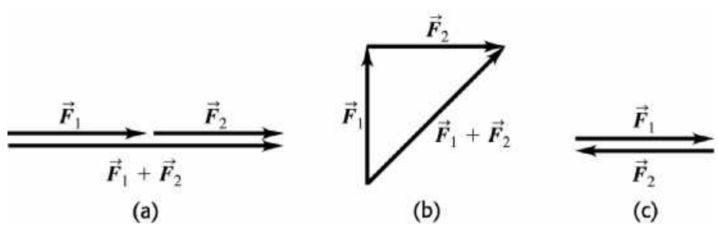



**Figure 4.1**

**4.2.** **IDENTIFY:** We know the magnitudes and directions of three vectors and want to use them to find their components, and then to use the components to find the magnitude and direction of the resultant vector.

**SET UP:** Let $F_1 = 985\text{ N}$, $F_2 = 788\text{ N}$, and $F_3 = 411\text{ N}$. The angles $\theta$ that each force makes with the $+x$ axis are $\theta_1 = 31°$, $\theta_2 = 122°$, and $\theta_3 = 233°$. The components of a force vector are $F_x = F\cos\theta$ and $F_y = F\sin\theta$, and $R = \sqrt{R_x^2 + R_y^2}$ and $\tan\theta = \dfrac{R_y}{R_x}$.

**EXECUTE:** **(a)** $F_{1x} = F_1\cos\theta_1 = 844\text{ N}$, $F_{1y} = F_1\sin\theta_1 = 507\text{ N}$, $F_{2x} = F_2\cos\theta_2 = -418\text{ N}$, $F_{2y} = F_2\sin\theta_2 = 668\text{ N}$, $F_{3x} = F_3\cos\theta_3 = -247\text{ N}$, and $F_{3y} = F_3\sin\theta_3 = -328\text{ N}$.

**(b)** $R_x = F_{1x} + F_{2x} + F_{3x} = 179\text{ N}$; $R_y = F_{1y} + F_{2y} + F_{3y} = 847\text{ N}$. $R = \sqrt{R_x^2 + R_y^2} = 886\text{ N}$; $\tan\theta = \dfrac{R_y}{R_x}$ so $\theta = 78.1°$. $\vec{R}$ and its components are shown in Figure 4.2.

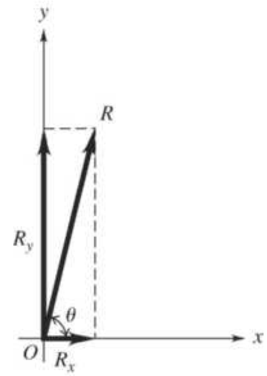



**Figure 4.2**

**EVALUATE:** A graphical sketch of the vector sum should agree with the results found in (b). Adding the forces as vectors gives a very different result from adding their magnitudes.

**4.3.** **IDENTIFY:** We know the resultant of two vectors of equal magnitude and want to find their magnitudes. They make the same angle with the vertical.

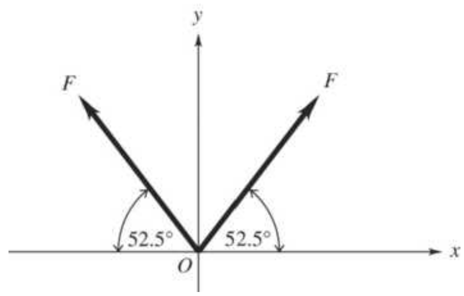



**Figure 4.3**

**SET UP:** Take $+y$ to be upward, so $\sum F_y = 5.00\text{ N}$. The strap on each side of the jaw exerts a force $F$ directed at an angle of 52.5° above the horizontal, as shown in Figure 4.3.

**EXECUTE:** $\sum F_y = 2F\sin 52.5° = 5.00\text{ N}$, so $F = 3.15\text{ N}$.

**EVALUATE:** The resultant force has magnitude 5.00 N which is *not* the same as the sum of the magnitudes of the two vectors, which would be 6.30 N.

**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)** $F = \dfrac{F_x}{\cos\theta} = \dfrac{60.0\text{ N}}{\cos 30°} = 69.3\text{ N}.$

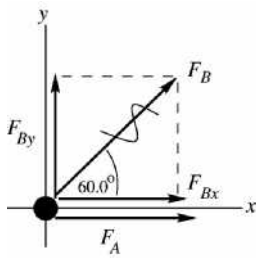
**(b)** $F_y = F\sin\theta = F_x \tan\theta = 34.6\text{ N}.$

**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.

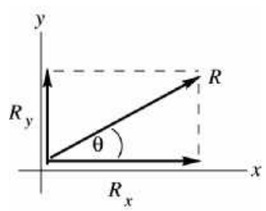
**EXECUTE:**




$$F_{Ax} = +270 \text{ N}, \quad F_{Ay} = 0$$
$$F_{Bx} = F_B \cos 60.0° = (300 \text{ N})\cos 60.0° = +150 \text{ N}$$
$$F_{By} = F_B \sin 60.0° = (300 \text{ N})\sin 60.0° = +260 \text{ N}$$

**Figure 4.5a**

$$\vec{R} = \vec{F}_A + \vec{F}_B$$
$$R_x = F_{Ax} + F_{Bx} = +270 \text{ N} + 150 \text{ N} = +420 \text{ N}$$
$$R_y = F_{Ay} + F_{By} = 0 + 260 \text{ N} = +260 \text{ N}$$




$$R = \sqrt{R_x^2 + R_y^2}$$
$$R = \sqrt{(420 \text{ N})^2 + (260 \text{ N})^2} = 494 \text{ N}$$
$$\tan\theta = \frac{R_y}{R_x} = 0.619$$
$$\theta = 31.8°$$

**Figure 4.5b**

**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 $\theta$ 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:** Friction is the only horizontal force acting on the skater, so it must be the one causing the acceleration. Newton's second law applies.

**SET UP:** Take $+x$ to be the direction in which the skater is moving initially. The final velocity is $v_x = 0$, since the skater comes to rest. First use the kinematics formula $v_x = v_{0x} + a_x t$ to find the acceleration, then apply $\sum F_x = 5.00 \text{ N}$ to the skater.

**EXECUTE:** $v_x = v_{0x} + a_x t$ so $a_x = \dfrac{v_x - v_{0x}}{t} = \dfrac{0 - 2.40 \text{ m/s}}{3.52 \text{ s}} = -0.682 \text{ m/s}^2$. The only horizontal force on the skater is the friction force, so $f_x = ma_x = (68.5 \text{ kg})(-0.682 \text{ m/s}^2) = -46.7 \text{ N}$. The force is 46.7 N, directed opposite to the motion of the skater.

**EVALUATE:** Although other forces are acting on the skater (gravity and the upward force of the ice), they are vertical and therefore do not affect the horizontal motion.

**4.8.** **IDENTIFY:** The elevator and everything in it are accelerating upward, so we apply Newton's second law in the vertical direction.
**SET UP:** Your mass is $m = w/g = 63.8$ kg. Both you and the package have the same acceleration as the elevator. Take $+y$ to be upward, in the direction of the acceleration of the elevator, and apply $\sum F_y = ma_y$.
**EXECUTE:** **(a)** Your free-body diagram is shown in Figure 4.8a, where $n$ is the scale reading. $\sum F_y = ma_y$ gives $n - w = ma$. Solving for $n$ gives $n = w + ma = 625\text{ N} + (63.8\text{ kg})(2.50\text{ m/s}^2) = 784\text{ N}$.
**(b)** The free-body diagram for the package is given in Figure 4.8b. $\sum F_y = ma_y$ gives $T - w = ma$, so $T = w + ma = (3.85\text{ kg})(9.80\text{ m/s}^2 + 2.50\text{ m/s}^2) = 47.4\text{ N}$.

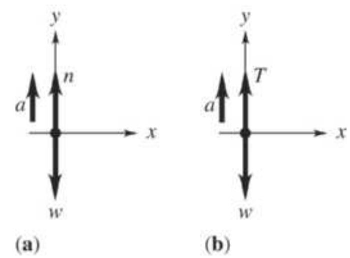



**Figure 4.8**

**EVALUATE:** The objects accelerate upward so for each of them the upward force is greater than the downward force.

**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. $\sum F_x = 48.0$ N.
**EXECUTE:** $\sum F_x = ma_x$ gives $m = \dfrac{\Sigma F_x}{a_x} = \dfrac{48.0\text{ N}}{3.00\text{ m/s}^2} = 16.0\text{ kg}$.
**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. $\sum F_x = 80.0$ N.
**EXECUTE:** **(a)** $x - x_0 = 11.0$ m, $t = 5.00$ s, $v_{0x} = 0$. $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ gives

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

**(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

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

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

**(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 $x = x_0 + 9.36 \text{ m} = 12.5 \text{ m} + 9.36 \text{ m} = 21.9 \text{ m}$.

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

**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 $(1.56 \text{ m/s})(4.0 \text{ s}) = 6.24$ 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 $v_{0x} = 0$, $x = \frac{1}{2}at^2 = 215$ m.

**(c)** $v_x = v_{0x} + a_x t$. With $v_{0x} = 0$, $v_x = a_x t = 2x/t = 43.0$ 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. $m = 4.50$ 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 $t = 0$, $F = A = 100.0$ N. At $t = 2.00$ s, $F = A + (4.00 \text{ s}^2)B = 150.0$ N and

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

**(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 $t = 3.00\text{ s}$, $F = A + B(3.00\text{ s})^2 = 212.5\text{ N}$.

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

**(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)** $v_{0x} = 0$, $(x - x_0) = 1.80\times10^{-2}\text{ m}$, $v_x = 3.00\times10^6\text{ m/s}$. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

$$a_x = \frac{v_x^2 - v_{0x}^2}{2(x - x_0)} = \frac{(3.00\times10^6\text{ m/s})^2 - 0}{2(1.80\times10^{-2}\text{ m})} = 2.50\times10^{14}\text{ m/s}^2$$

**(b)** $v_x = v_{0x} + a_x t$ gives $t = \dfrac{v_x - v_{0x}}{a_x} = \dfrac{3.00\times10^6\text{ m/s} - 0}{2.50\times10^{14}\text{ m/s}^2} = 1.2\times10^{-8}\text{ s}$

**(c)** $\sum F_x = ma_x = (9.11\times10^{-31}\text{ kg})(2.50\times10^{14}\text{ m/s}^2) = 2.28\times10^{-16}\text{ N}$.

**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:** Find weight from mass and vice versa.

**SET UP:** Equivalencies we'll need are: $1\,\mu\text{g} = 10^{-6}\text{ g} = 10^{-9}\text{ kg}$, $1\text{ mg} = 10^{-3}\text{ g} = 10^{-6}\text{ kg}$,

$1\text{ N} = 0.2248\text{ lb}$, and $g = 9.80\text{ m/s}^2 = 32.2\text{ ft/s}^2$.

**EXECUTE:** **(a)** $m = 210\,\mu\text{g} = 2.10\times10^{-7}\text{ kg}$. $w = mg = (2.10\times10^{-7}\text{ kg})(9.80\text{ m/s}^2) = 2.06\times10^{-6}\text{ N}$.

**(b)** $m = 12.3\text{ mg} = 1.23\times10^{-5}\text{ kg}$. $w = mg = (1.23\times10^{-5}\text{ kg})(9.80\text{ m/s}^2) = 1.21\times10^{-4}\text{ N}$.

**(c)** $(45\text{ N})\left(\dfrac{0.2248\text{ lb}}{1\text{ N}}\right) = 10.1\text{ lb}$. $m = \dfrac{w}{g} = \dfrac{45\text{ N}}{9.80\text{ m/s}^2} = 4.6\text{ kg}$.

**EVALUATE:** We are not converting mass to weight (or vice versa) since they are different types of quantities. We are finding what a given mass will weigh and how much mass a given weight contains.

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

**(b)** On Jupiter's moon, $m = 4.49\text{ kg}$, 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 her.

**4.22.** **IDENTIFY:** Newton's third law problem.

**SET UP:** The car exerts a force on the truck and the truck exerts a force on the car.

**EXECUTE:** The force and the reaction force are always exactly the same in magnitude, so the force that the truck exerts on the car is 1200 N, by Newton's third law.

**EVALUATE:** Even though the truck is much larger and more massive than the car, it cannot exert a larger force on the car than the car exerts on it.

**4.23.** **IDENTIFY:** The system is accelerating so we use Newton's second law.

**SET UP:** The acceleration of the entire system is due to the 100-N force, but the acceleration of box B is due to the force that box A exerts on it. $\sum F = ma$ applies to the two-box system and to each box individually.

**EXECUTE:** For the two-box system: $a_x = \dfrac{100\text{ N}}{25\text{ kg}} = 4.0\text{ m/s}^2$. Then for box *B*, where $F_A$ is the force exerted on *B* by *A*, $F_A = m_B a = (5.0\text{ kg})(4.0\text{ m/s}^2) = 20\text{ N}.$

**EVALUATE:** The force on B is less than the force on A.

**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 $a_y = \dfrac{650\text{ N} - 620\text{ N}}{(650\text{ N})/(9.80\text{ m/s}^2)} = 0.452\text{ m/s}^2$. The passenger's acceleration is $0.452\text{ m/s}^2$, 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 third 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:** $a = \dfrac{w}{m} = \dfrac{441\text{ N}}{6.0\times10^{24}\text{ kg}} = 7.4\times10^{-23}\text{ m/s}^2.$

**EVALUATE:** This is *much* smaller than her acceleration of $9.8 \text{ m/s}^2$. 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.

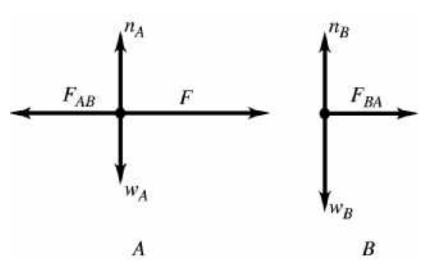



**Figure 4.27**

**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 $B$.

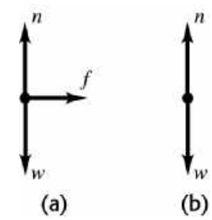



**Figure 4.28**

**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.

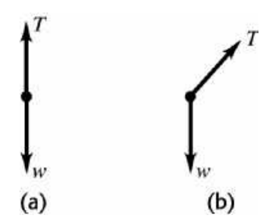



**Figure 4.29**

**4.30.** **IDENTIFY:** 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)** $v_{0x} = 350$ m/s, $v_x = 0$ and $(x - x_0) = 0.130$ m. $(x - x_0) = \left(\dfrac{v_{0x} + v_x}{2}\right)t$ 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 $a_x = \dfrac{v_x^2 - v_{0x}^2}{2(x - x_0)} = \dfrac{0 - (350\text{ m/s})^2}{2(0.130\text{ m})} = -4.71 \times 10^5\text{ m/s}^2$

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

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

**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 $n = 142$ N.

**EVALUATE:** $n$ is larger than the weight because $\vec{F}$ has a downward component.

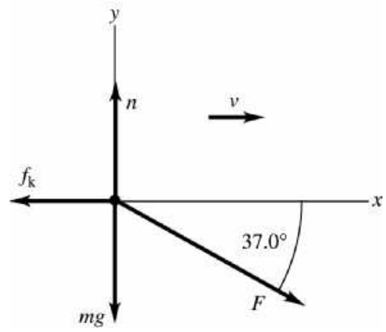



**Figure 4.31**

**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 $T = mg\sin\theta = (65.0\text{ kg})(9.80\text{ m/s}^2)\sin 26.0° = 279$ 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.

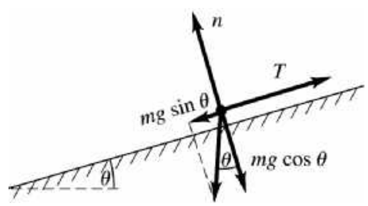



**Figure 4.32**

**4.33.** **IDENTIFY:** Apply Newton's second law to the bucket and constant-acceleration kinematics.
**SET UP:** The minimum time to raise the bucket will be when the tension in the cord is a maximum since this will produce the greatest acceleration of the bucket.
**EXECUTE:** Apply Newton's second law to the bucket: $T - mg = ma$. For the maximum acceleration, the tension is greatest, so $a = \dfrac{T - mg}{m} = \dfrac{75.0\text{ N} - (4.80\text{ kg})(9.8\text{ m/s}^2)}{4.80\text{ kg}} = 5.825\text{ m/s}^2$.

The kinematics equation for $y(t)$ gives $t = \sqrt{\dfrac{2(y - y_0)}{a_y}} = \sqrt{\dfrac{2(12.0\text{ m})}{5.825\text{ m/s}^2}} = 2.03$ s.

**EVALUATE:** A shorter time would require a greater acceleration and hence a stronger pull, which would break the cord.

**4.34.** **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 opposite to the relative motion between the surfaces.
**EXECUTE:** The free-body diagram for the box is given in Figure 4.34a. The free-body diagram for the truck is given in Figure 4.34b. 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.

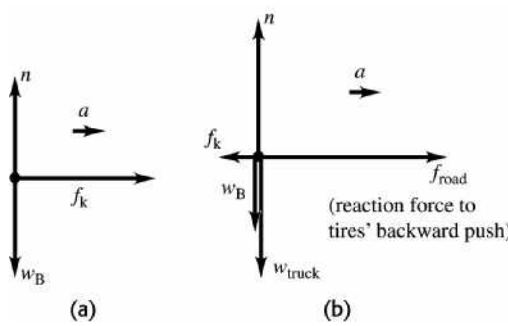
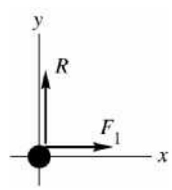



**Figure 4.34**

**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.




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

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

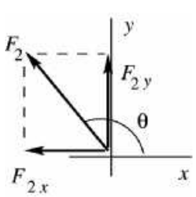
**Figure 4.35a**

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




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

$$F = 1840\text{ N}$$

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

$$\theta = 135°$$

**Figure 4.35b**

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 $w = mg$.

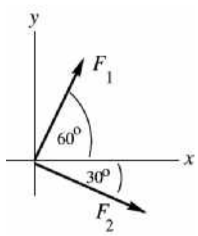
**SET UP:** Let $+y$ be downward and take $y_0 = 0$. $v_{0y} = 0$ since the ball is released from rest.

**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

$w_X = mg_X = (0.100\text{ kg})(4.13\text{ m/s}^2) = 0.41\text{ N}$.

**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 $\sum F_y = 0$.




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.

**Figure 4.37**

**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), $v_{0y} = ?$, $a_y = -9.80\ \text{m/s}^2$, $y - y_0 = +1.2\ \text{m}$

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

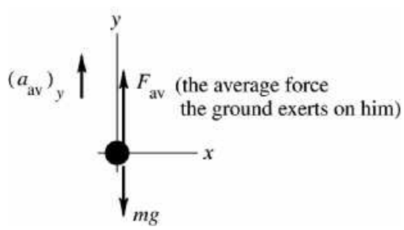
**EXECUTE:** $v_{0y} = \sqrt{-2a_y(y - y_0)} = \sqrt{-2(-9.80\ \text{m/s}^2)(1.2\ \text{m})} = 4.85\ \text{m/s}$

**(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:

$$(a_{\text{av}})_y = \frac{v_y - v_{0y}}{t} = \frac{4.85\ \text{m/s} - 0}{0.300\ \text{s}} = 16.2\ \text{m/s}^2$$

**(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.




**EXECUTE:**

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

$\sum F_y = ma_y$

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

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

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

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

**Figure 4.39**

This is the average force exerted on him by the ground. But by Newton's third law, the average force he exerts on the ground is equal and opposite, so is 2360 N, downward. The net force on him is equal to *ma*, so $F_{\text{net}} = ma = (90.8\ \text{kg})(16.2\ \text{m/s}^2) = 1470\ \text{N}$ upward.

**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

$$F = m\frac{v_{0x}^2}{2(x - x_0)} = (850\ \text{kg})\frac{(12.5\ \text{m/s})^2}{2(1.8\times10^{-2}\ \text{m})} = 3.7\times10^6\ \text{N}.$$

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

**4.41.** **IDENTIFY:** Using constant-acceleration kinematics, we can find the acceleration of the ball. Then we can apply Newton's second law to find the force causing that acceleration.

**SET UP:** Use coordinates where $+x$ is in the direction the ball is thrown. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ and $\sum F_x = ma_x$.

**EXECUTE:** **(a)** Solve for $a_x$: $x - x_0 = 1.0$ m, $v_{0x} = 0$, $v_x = 46$ m/s. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

$$a_x = \frac{v_x^2 - v_{0x}^2}{2(x - x)} = \frac{(46 \text{ m/s})^2 - 0}{2(1.0 \text{ m})} = 1058 \text{ m/s}^2.$$

The free-body diagram for the ball during the pitch is shown in Figure 4.41a. The force $\vec{F}$ is applied to the ball by the pitcher's hand. $\sum F_x = ma_x$ gives $F = (0.145 \text{ kg})(1058 \text{ m/s}^2) = 153$ N.

**(b)** The free-body diagram after the ball leaves the hand is given in Figure 4.41b. The only force on the ball is the downward force of gravity.

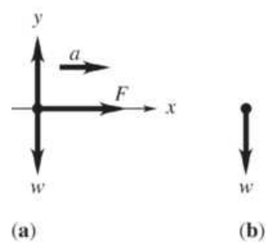



**Figure 4.41**

**EVALUATE:** The force is much greater than the weight of the ball because it gives it an acceleration much greater than $g$.

**4.42.** **IDENTIFY:** Kinematics will give us the ball's acceleration, and Newton's second law will give us the horizontal force acting on it.

**SET UP:** Use coordinates with $+x$ horizontal and in the direction of the motion of the ball and with $+y$ upward. $\sum F_x = ma_x$ and for constant acceleration, $v_x = v_{0x} + a_x t$.

**SOLVE:** **(a)** $v_{0x} = 0$, $v_x = 73.14$ m/s, $t = 3.00 \times 10^{-2}$ s. $v_x = v_{0x} + a_x t$ gives

$$a_x = \frac{v_x - v_{0x}}{t} = \frac{73.14 \text{ m/s} - 0}{3.00 \times 10^{-2} \text{ s}} = 2.44 \times 10^3 \text{ m/s}^2.$$ $\sum F_x = ma_x$ gives

$$F = ma_x = (57 \times 10^{-3} \text{ kg})(2.44 \times 10^3 \text{ m/s}^2) = 140 \text{ N}.$$

**(b)** The free-body diagram while the ball is in contact with the racket is given in Figure 4.42a. $\vec{F}$ is the force exerted on the ball by the racket. After the ball leaves the racket, $\vec{F}$ ceases to act, as shown in Figure 4.42b.

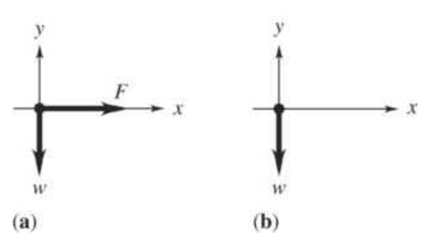


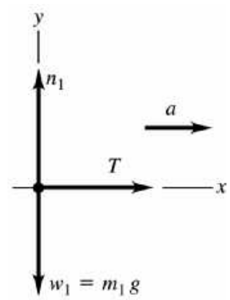

**Figure 4.42**

**EVALUATE:** The force is around 30 lb, which is quite large for a light-weight object like a tennis ball, but is reasonable because it acts for only 30 ms yet during that time gives the ball an acceleration of about 250*g*.

**4.43.** **IDENTIFY:** Use Newton's second 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, $2.50\ \text{m/s}^2$.

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



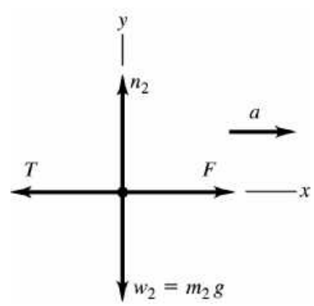

**EXECUTE:**

$\sum F_x = ma_x$

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

**Figure 4.43a**

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



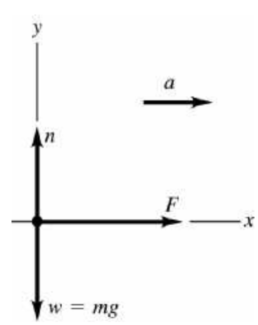

The crate accelerates to the right, so the net force is to the right. *F* must be larger than *T*.

**Figure 4.43b**

**(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.




$\sum F_x = ma_x$

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

This agrees with our answer in part (d).

**Figure 4.43c**

**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)** $a = \dfrac{F}{m} = \dfrac{80.0\text{ N}}{105.0\ kg} = 0.762\text{ m/s}^2.$
**(d)** There is no net force on the massless cable, so the force that the spacecraft 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 spacecraft 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, $x = (9.0\times 10^3\text{ m/s}^2)(0.025\text{ s})^2 - (8.0\times 10^4\text{ m/s}^3)(0.025\text{ s})^3 = 4.4\text{ m}.$
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 $\sum F_x = (1.50\text{ kg})(18.0\times 10^3\text{ m/s}^2) = 2.7\times 10^4\text{ N}.$
(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
$\sum F_x = (1.50\text{ kg})(6.0\times 10^3\text{ m/s}^2) = 9.0\times 10^3\text{ N}.$
**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 $a_1$. $a_1 = +1.20\text{ m/s}^2$ 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
$w = \dfrac{a_1F_2 - a_2F_1}{a_1 - a_2}.$ Substituting the given numbers, with $+y$ upward, gives

$$w = \frac{(1.20\text{ m/s}^2)(10.0\times10^3\text{ N}) - (-0.80\text{ m/s}^2)(25.0\times10^3\text{ N})}{1.20\text{ m/s}^2 - (-0.80\text{ m/s}^2)} = 16.0\times10^3\text{ N}.$$

**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 $T > w$.

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

$\sum F_y = ma_y$ 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.

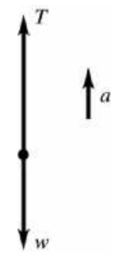



**Figure 4.47**

**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:** Using kinematics we can find the acceleration of the froghopper and then apply Newton's second law to find the force on it from the ground.

**SET UP:** Take $+y$ to be upward. $\sum F_y = ma_y$ and for constant acceleration, $v_y = v_{0y} + a_y t$.

**EXECUTE:** **(a)** The free-body diagram for the froghopper while it is still pushing against the ground is given in Figure 4.49.

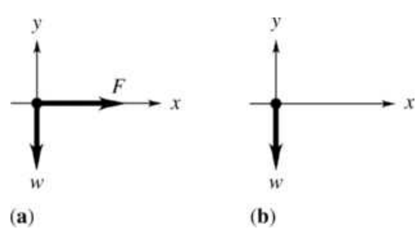



**Figure 4.49**

**(b)** $v_{0y} = 0$, $v_y = 4.0\text{ m/s}$, $t = 1.0\times10^{-3}\text{ s}$. $v_y = v_{0y} + a_y t$ gives

$a_y = \frac{v_y - v_{0y}}{t} = \frac{4.0\text{ m/s} - 0}{1.0\times10^{-3}\text{ s}} = 4.0\times10^3\text{ m/s}^2$. $\sum F_y = ma_y$ gives $n - w = ma$, so

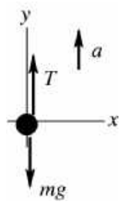
$n = w + ma = m(g + a) = (12.3\times10^{-6}\text{ kg})(9.8\text{ m/s}^2 + 4.0\times10^3\text{ m/s}^2) = 0.049\text{ N}$.

**(c)** $\frac{F}{w} = \frac{0.049\text{ N}}{(12.3\times10^{-6}\text{ kg})(9.8\text{ m/s}^2)} = 410$; $F = 410w$.

**EVALUATE:** Because the force from the ground is huge compared to the weight of the froghopper, it produces an acceleration of around 400*g*!

**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)** $v_{0y} = 0$, $y - y_0 = 3.10$ 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)** $v_{0y} = 7.79$ m/s, $v_y = 0$, $y - y_0 = 0.60$ 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 $mg - F = -ma$. $F = m(g + a) = (75.0\text{ kg})(9.80\text{ m/s}^2 + 50.6\text{ m/s}^2) = 4.53\times10^3$ N, upward.

$$\frac{F}{w} = \frac{4.53\times10^3\text{ N}}{(75.0\text{ kg})(9.80\text{ m/s}^2)}\ \text{ so, } F = 6.16w = 6.16mg.$$

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.

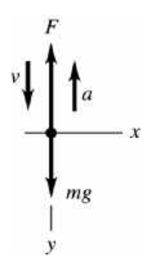



**Figure 4.51**

**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 $y - y_0 = -0.0045\text{ m}$. $a_y = v_{0y}^2/2(y - y_0) = (3.2\text{ m/s})^2/2(0.0045\text{ cm}) = 1.138\times10^3\text{ m/s}^2$. 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 $4267\text{ m/s}^2$, 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.

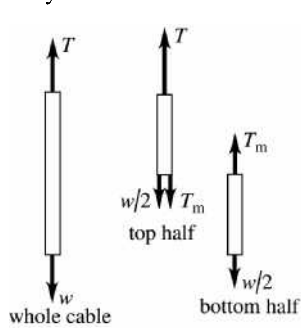



**Figure 4.53**

**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.

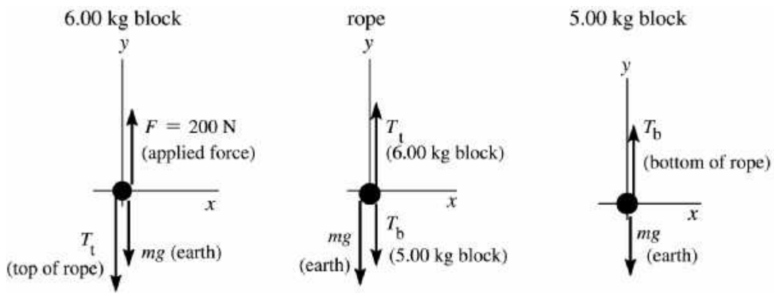
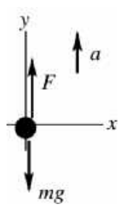



**Figure 4.54a**

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

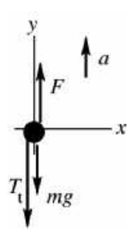
**EXECUTE:** **(b)** Treat the rope and the two blocks together as a single object, with mass $m = 6.00\ \text{kg} + 4.00\ \text{kg} + 5.00\ \text{kg} = 15.0\ \text{kg}$. Take $+y$ upward, since the acceleration is upward. The free-body diagram is given in Figure 4.54b.




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

**Figure 4.54b**

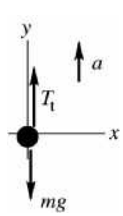
**(c)** Consider the forces on the top block $(m = 6.00\ \text{kg})$, since the tension at the top of the rope $(T_t)$ will be one of these forces.




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

**Figure 4.54c**

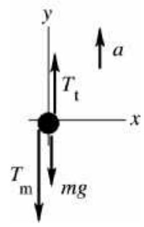
Alternatively, can consider the forces on the combined object rope plus bottom block $(m = 9.00\ \text{kg})$:




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

**Figure 4.54d**

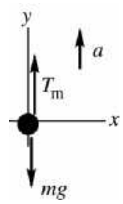
**(d)** One way to do this is to consider the forces on the top half of the rope $(m = 2.00\ \text{kg})$. Let $T_m$ be the tension at the midpoint of the rope.




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

**Figure 4.54e**

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 $(m = 2.00\text{ kg} + 5.00\text{ kg} = 7.00\text{ kg})$:




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

**Figure 4.54f**

**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, 1372 N, of the athlete plus barbell.

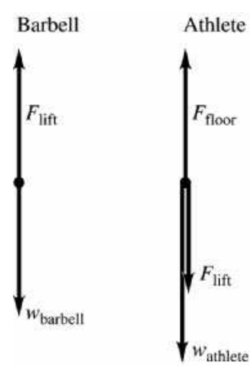



**Figure 4.55**

**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.

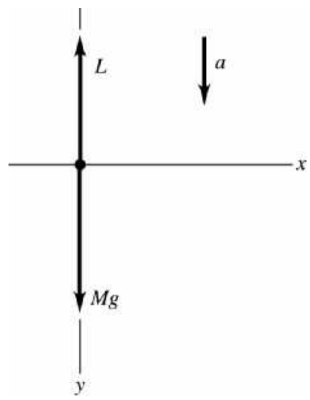



**Figure 4.56**

**4.57.** **IDENTIFY:** The system is accelerating, so we apply Newton's second law to each box and can use the constant acceleration kinematics for formulas to find the acceleration.

**SET UP:** First use the constant acceleration kinematics for formulas to find the acceleration of the system. Then apply $\sum F = ma$ to each box.

**EXECUTE:** **(a)** The kinematics formula for $y(t)$ gives

$a_y = \dfrac{2(y - y_0)}{t^2} = \dfrac{2(12.0\text{ m})}{(4.0\text{ s})^2} = 1.5\text{ m/s}^2$. For box $B$, $mg - T = ma$ and

$m = \dfrac{T}{g - a} = \dfrac{36.0\text{ N}}{9.8\text{ m/s}^2 - 1.5\text{ m/s}^2} = 4.34\text{ kg}$.

**(b)** For box $A$, $T + mg - F = ma$ and $m = \dfrac{F - T}{g - a} = \dfrac{80.0\text{ N} - 36.0\text{ N}}{9.8\text{ m/s}^2 - 1.5\text{ m/s}^2} = 5.30\text{ kg}$.

**EVALUATE:** The boxes have the same acceleration but experience different forces because they have different masses.

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

**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:** The rocket accelerates due to a variable force, so we apply Newton's second law. But the acceleration will not be constant because the force is not constant.

**SET UP:** We can use $a_x = F_x/m$ to find the acceleration, but must integrate to find the velocity and then the distance the rocket travels.

**EXECUTE:** Using $a_x = F_x/m$ gives $a_x(t) = \dfrac{(16.8 \text{ N/s})t}{45.0 \text{ kg}} = (0.3733 \text{ m/s}^3)t$. Now integrate the acceleration to get the velocity, and then integrate the velocity to get the distance moved.

$v_x(t) = v_0 + \int_0^t a_x(t')dt' = (0.1867 \text{ m/s}^3)t^2$ and $x - x_0 = \int_0^t v(t')dt' = (0.06222 \text{ m/s}^3)t^3$. At $t = 5.00$ s, $x - x_0 = 7.78$ m.

**EVALUATE:** The distance moved during the next 5.0 s would be considerably greater because the acceleration is increase with time.

**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:

$a_x = \dfrac{k_1}{m} + \dfrac{k_2k_3}{6m^2}t^3$, $v_x = \dfrac{k_1}{m}t + \dfrac{k_2k_3}{24m^2}t^4$ and $x = \dfrac{k_1}{2m}t^2 + \dfrac{k_2k_3}{120m^2}t^5$.

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

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