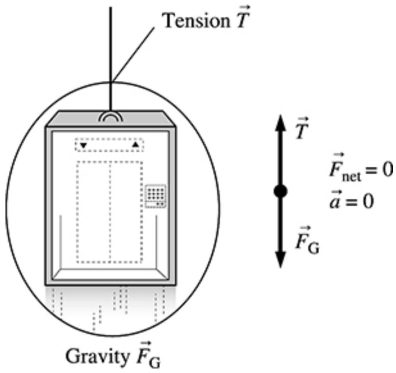
Chapter 6, Conceptual Questions

6.1. **(a)** Static equilibrium. The barbell is not accelerating and has a velocity of zero.
(b) Dynamic equilibrium. The girder is not accelerating but has a nonzero constant velocity.
(c) Not in equilibrium. Slowing down means the acceleration is not zero.
(d) Dynamic equilibrium. The plane is not accelerating but has a nonzero constant velocity.
(e) Not in equilibrium. The box slows down with the truck, so has a nonzero acceleration.

6.2. No. The ball is still changing its speed, and just momentarily has zero velocity.

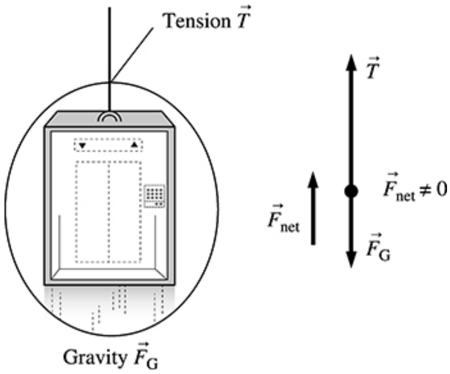
6.5. No, because the net force is not necessarily in the same direction as the motion. For example, a car using its brakes to slow its forward motion has a net force opposite its direction of motion.

6.6.



Equal. The tension in the cable is equal to the force of gravity, since the net force must be zero in order for the elevator to move with constant speed.

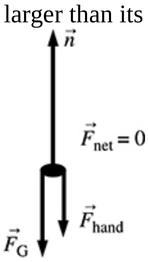
6.7.



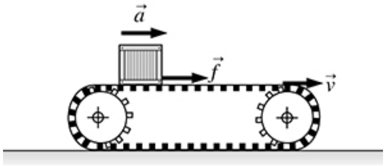
Greater. Since the elevator is slowing down as it moves downward, it has an upward net force, so the tension must be greater than the gravitational force.

6.15. The ball filled with lead is more massive. Since the balls are weightless, the astronaut must measure their inertia (mass) directly. One easy option is to move each ball side to side in turn. More force is required to change the more massive lead-filled ball's direction of motion.

6.16. Larger. A free-body diagram for the book is shown in the figure. The normal force of the table on the book is larger than its weight, since the net force is zero.



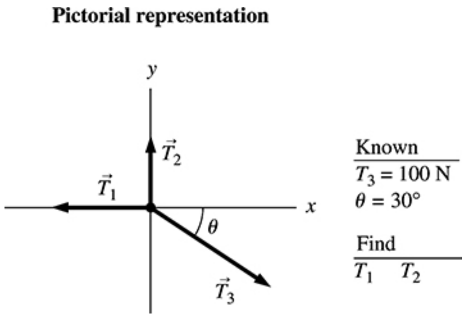
6.19. Yes, the friction force on a crate dropped on a conveyor belt speeds the crate up to the belt's speed.



6.20. North. The friction force on the crate is the only horizontal force and is responsible for speeding the crate up along with the truck. Therefore the friction force points in the same direction as the motion of the crate.

Chapter 6, Exercises and Problems

6.1. Model: We can assume that the ring is a single massless particle in static equilibrium.
Visualize:



Solve: Written in component form, Newton's first law is

$$(F_{\text{net}})_x = \Sigma F_x = T_{1x} + T_{2x} + T_{3x} = 0 \text{ N} \quad (F_{\text{net}})_y = \Sigma F_y = T_{1y} + T_{2y} + T_{3y} = 0 \text{ N}$$

Evaluating the components of the force vectors from the free-body diagram:

$$T_{1x} = -T_1 \quad T_{2x} = 0 \text{ N} \quad T_{3x} = T_3 \cos 30°$$

$$T_{1y} = 0 \text{ N} \quad T_{2y} = T_2 \quad T_{3y} = -T_3 \sin 30°$$

Using Newton's first law:

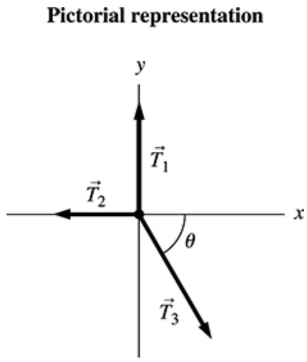
$$-T_1 + T_3 \cos 30° = 0 \text{ N} \quad T_2 - T_3 \sin 30° = 0 \text{ N}$$

Rearranging:

$$T_1 = T_3 \cos 30° = (100 \text{ N})(0.8666) = 86.7 \text{ N} \quad T_2 = T_3 \sin 30° = (100 \text{ N})(0.5) = 50.0 \text{ N}$$

Assess: Since $\vec{T}_3$ acts closer to the *x*-axis than to the *y*-axis, it makes sense that $T_1 > T_2$.

6.2. Model: We can assume that the ring is a particle.
Visualize:



This is a static equilibrium problem. We will ignore the weight of the ring, because it is "very light," so the only three forces are the tension forces shown in the free-body diagram. Note that the diagram *defines* the angle θ.

Solve: Because the ring is in equilibrium it must obey $\vec{F}_{\text{net}} = 0$ N. This is a vector equation, so it has both *x*- and *y*-components:

$$(F_{\text{net}})_x = T_3 \cos\theta - T_2 = 0 \text{ N} \Rightarrow T_3 \cos\theta = T_2$$

$$(F_{\text{net}})_y = T_1 - T_3 \sin\theta = 0 \text{ N} \Rightarrow T_3 \sin\theta = T_1$$

We have two equations in the two unknowns T_3 and θ. Divide the *y*-equation by the *x*-equation:

$$\frac{T_3 \sin\theta}{T_3 \cos\theta} = \tan\theta = \frac{T_1}{T_2} = \frac{80 \text{ N}}{50 \text{ N}} = 1.6 \Rightarrow \theta = \tan^{-1}(1.6) = 58°$$

Now we can use the *x*-equation to find

$$T_3 = \frac{T_2}{\cos\theta} = \frac{50\text{ N}}{\cos 58°} = 94\text{ N}$$

The tension in the third rope is 94 N directed 58° below the horizontal.

6.5. Visualize: Please refer to the Figure EX6.5.
Solve: Applying Newton's second law to the diagram on the left,

$$a_x = \frac{(F_{\text{net}})_x}{m} = \frac{4\text{ N} - 2\text{ N}}{2\text{ kg}} = 1.0\text{ m/s}^2 \qquad a_y = \frac{(F_{\text{net}})_y}{m} = \frac{3\text{ N} - 3\text{ N}}{2\text{ kg}} = 0\text{ m/s}^2$$

For the diagram on the right:

$$a_x = \frac{(F_{\text{net}})_x}{m} = \frac{4\text{ N} - 2\text{ N}}{2\text{ kg}} = 1.0\text{ m/s}^2 \qquad a_y = \frac{(F_{\text{net}})_y}{m} = \frac{3\text{ N} - 1\text{ N} - 2\text{ N}}{2\text{ kg}} = 0\text{ m/s}^2$$

6.7. Visualize: Please refer to Figure EX6.7.
Solve: **(a)** Apply Newton's second law in both the x and y directions.

$$(F_{\text{net}})_x = (5.0\text{ N})\cos 37° - 2.0\text{ N} = (5.0\text{ kg})a_x$$

$$\Rightarrow a_x = 0.40\text{ m/s}^2$$

$$(F_{\text{net}})_y = 2.0\text{ N} + (5.0\text{ N})\sin 37° - 5.0\text{ N} = (5.0\text{ kg})a_y$$

$$\Rightarrow a_y = 0.0\text{ m/s}^2$$

(b) The angle that the 5.0 N force makes with the –y-axis is 37°. Apply Newton's second law for both the x and y direction.

$$(F_{\text{net}})_x = 3.0\text{ N} + (5.0\text{ N})\sin 37° - 2.0\text{ N} = (5.0\text{ kg})a_x$$

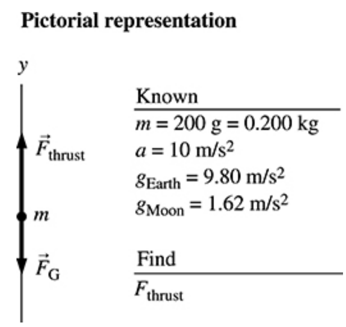
$$\Rightarrow a_x = 0.80\text{ m/s}^2$$

$$(F_{\text{net}})_y = 4.0\text{ N} - (5.0\text{ N})\cos 37° = (5.0\text{ kg})a_y$$

$$\Rightarrow a_y = 0.0\text{ m/s}^2$$

Assess: The orientation of the coordinate axes is chosen for convenience, and does not always need to conform to the horizontal and vertical.

6.12. Model: We assume the rocket is a particle moving in a vertical straight line under the influence of only two forces: gravity and its own thrust.
Visualize:



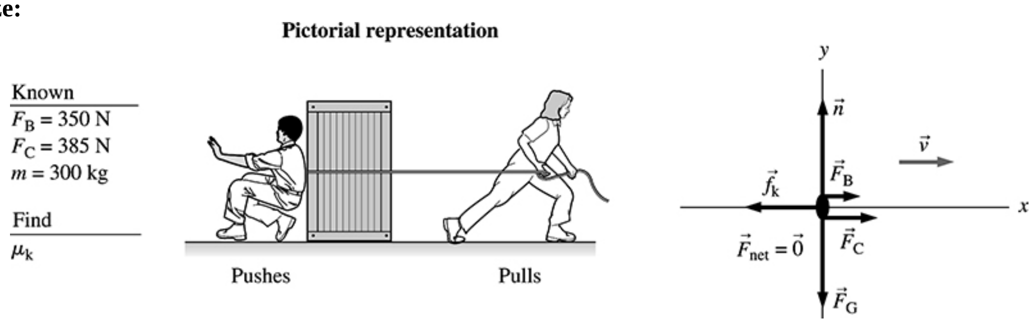
Solve: **(a)** Using Newton's second law and reading the forces from the free-body diagram,

$$F_{\text{thrust}} - F_G = ma \Rightarrow F_{\text{thrust}} = ma + mg_{\text{Earth}} = (0.200\text{ kg})(10\text{ m/s}^2 + 9.80\text{ m/s}^2) = 3.96\text{ N}$$

(b) Likewise, the thrust on the moon is $(0.200\text{ kg})(10\text{ m/s}^2 + 1.62\text{ m/s}^2) = 2.32\text{ N}$.
Assess: The thrust required is smaller on the moon, as it should be, given the moon's weaker gravitational pull. The magnitude of a few newtons seems reasonable for a small model rocket.

6.17. Model: We assume that the safe is a particle moving only in the x-direction. Since it is sliding during the entire problem, we can use the model of kinetic friction.

Visualize:



Solve: The safe is in equilibrium, since it's not accelerating. Thus we can apply Newton's first law in the vertical and horizontal directions:

$$(F_{net})_x = \Sigma F_x = F_B + F_C - f_k = 0 \text{ N} \Rightarrow f_k = F_B + F_C = 350 \text{ N} + 385 \text{ N} = 735 \text{ N}$$

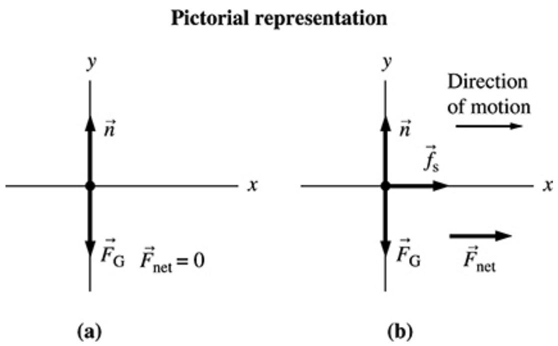
$$(F_{net})_y = \Sigma F_y = n - F_G = 0 \text{ N} \Rightarrow n = F_G = mg = (300 \text{ kg})(9.80 \text{ m/s}^2) = 2.94\times10^3 \text{ N}$$

Then, for kinetic friction:

$$f_k = \mu_k n \Rightarrow \mu_k = \frac{f_k}{n} = \frac{735 \text{ N}}{2.94\times10^3 \text{ N}} = 0.250$$

Assess: The value of $\mu_k = 0.250$ is hard to evaluate without knowing the material the floor is made of, but it seems reasonable.

6.19. Model: We will represent the crate as a particle.
Visualize:



Solve: **(a)** When the belt runs at constant speed, the crate has an acceleration $\vec{a} = \vec{0} \text{ m/s}^2$ and is in dynamic equilibrium. Thus $\vec{F}_{net} = \vec{0}$. It is tempting to think that the belt exerts a friction force on the crate. But if it did, there would be a *net* force because there are no other possible horizontal forces to balance a friction force. Because there is no net force, there cannot be a friction force. The only forces are the upward normal force and the gravitational force on the crate. (A friction force would have been needed to get the crate moving initially, but no horizontal force is needed to keep it moving once it is moving with the same constant speed as the belt.)

(b) If the belt accelerates gently, the crate speeds up without slipping on the belt. Because it is accelerating, the crate must have a net horizontal force. So *now* there is a friction force, and the force points in the direction of the crate's motion. Is it static friction or kinetic friction? Although the crate is moving, there is *no* motion of the crate relative to the belt. Thus, it is a *static* friction force that accelerates the crate so that it moves without slipping on the belt.

(c) The static friction force has a maximum possible value $(f_s)_{max} = \mu_s n$. The maximum possible acceleration of the crate is

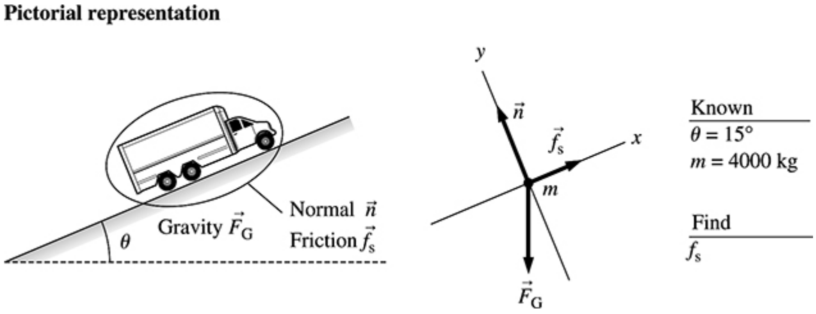
$$a_{max} = \frac{(f_s)_{max}}{m} = \frac{\mu_s n}{m}$$

If the belt accelerates more rapidly than this, the crate will not be able to keep up and will slip. It is clear from the free-body diagram that $n = F_G = mg$. Thus,

$$a_{max} = \mu_s g = (0.5)(9.80 \text{ m/s}^2) = 4.9 \text{ m/s}^2$$

6.20. Model: We assume that the truck is a particle in equilibrium, and use the model of static friction.

Visualize:

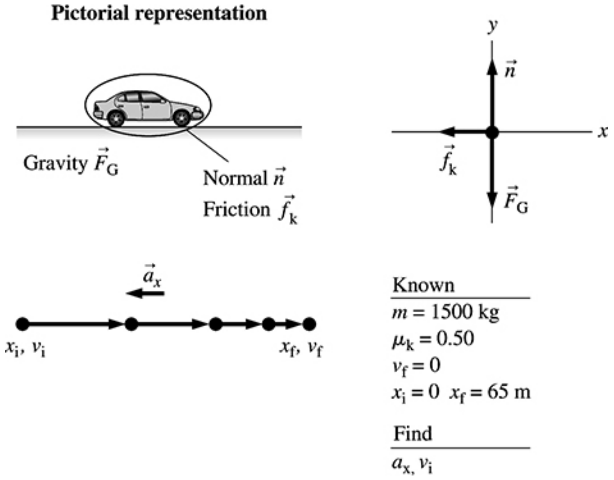


Solve: The truck is not accelerating, so it is in equilibrium, and we can apply Newton's first law. The normal force has no component in the *x*-direction, so we can ignore it here. For the other two forces:

$$(F_{net})_x = \Sigma F_x = f_s - (F_G)_x = 0 \text{ N} \Rightarrow f_s = (F_G)_x = mg\sin\theta = (4000 \text{ kg})(9.80 \text{ m/s}^2)(\sin 15°) = 10{,}145 \text{ N}$$

Assess: The truck's weight (*mg*) is roughly 40,000 N. A friction force that is $\approx 25\%$ of the truck's weight seems reasonable.

6.21. Model: The car is a particle subject to Newton's laws and kinematics.
Visualize:



Solve: Kinetic friction provides a horizontal acceleration which stops the car. From the figure, applying Newton's first and second laws gives

$$\sum F_x = -f_k = ma_x$$

$$\sum F_y = n - F_G = 0 \Rightarrow n = F_G = mg$$

Combining these two equations with $f_k = \mu_k n$ yields

$$a_x = -\mu_k g = -(0.50)(9.80 \text{ m/s}^2) = -4.9 \text{ m/s}$$

Kinematics can be used to determine the initial velocity.

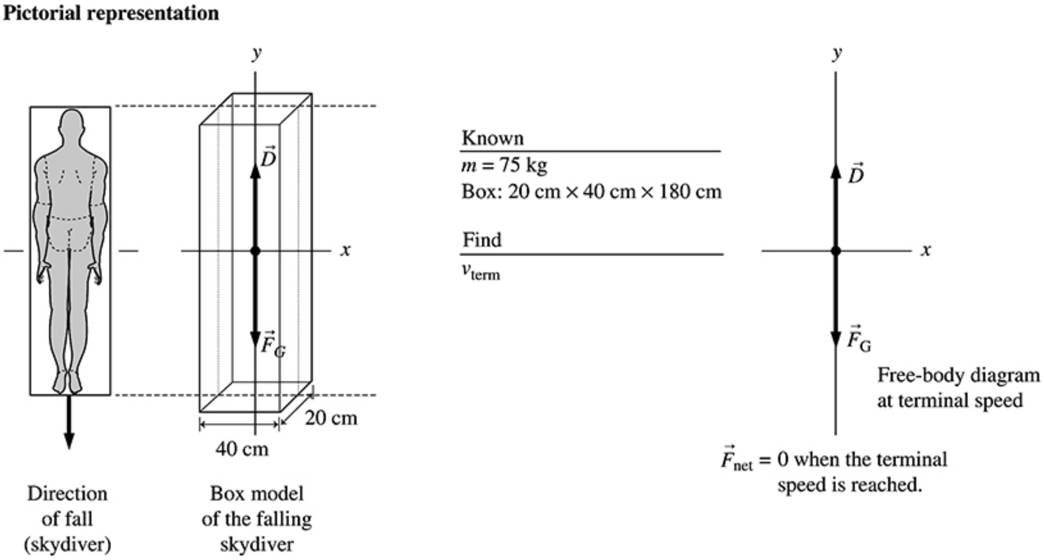
$$v_f^2 = v_i^2 + 2a\Delta x \Rightarrow v_i^2 = -2a_x\Delta x$$

Thus $$v_i = \sqrt{-2(-4.9 \text{ m/s}^2)(65 \text{ m} - 0 \text{ m})} = 25 \text{ m/s}^2$$

Assess: The initial speed of $25 \text{ m/s}^2 \approx 56$ mph is a reasonable speed to have initially for a vehicle to leave 65-meter-long skid marks.

6.25. Model: We assume that the skydiver is shaped like a box and is a particle.

Visualize:



The skydiver falls straight down toward the earth's surface, that is, the direction of fall is vertical. Since the skydiver falls feet first, the surface perpendicular to the drag has the cross-sectional area $A = 20\text{ cm}\times 40\text{ cm}.$ The physical conditions needed to use Equation 6.16 for the drag force are satisfied. The terminal speed corresponds to the situation when the net force acting on the skydiver becomes zero.

Solve: The expression for the magnitude of the drag with *v* in m/s is

$$D \approx \frac{1}{4}Av^2 = 0.25(0.20\times 0.40)v^2\text{ N} = 0.020v^2\text{ N}$$

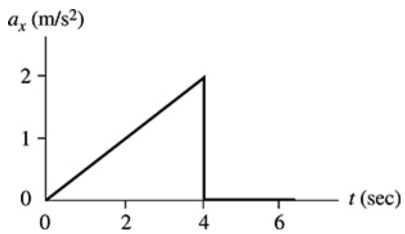
The gravitational force on the skydiver is $F_G = mg = (75\text{ kg})(9.8\text{ m/s}^2) = 735\text{ N}.$ The mathematical form of the condition defining dynamical equilibrium for the skydiver and the terminal speed is

$$\vec{F}_{net} = \vec{F}_G + \vec{D} = 0\text{ N}$$

$$\Rightarrow 0.02v_{term}^2\text{ N} - 735\text{ N} = 0\text{ N} \Rightarrow v_{term} = \sqrt{\frac{735}{0.02}} \approx 192\text{ m/s}$$

Assess: The result of the above simplified physical modeling approach and subsequent calculation, even if approximate, shows that the terminal velocity is very high. This result implies that the skydiver will be very badly hurt at landing if the parachute does not open in time.

6.27. Visualize:



We used the force-versus-time graph to draw the acceleration-versus-time graph. The peak acceleration was calculated as follows:

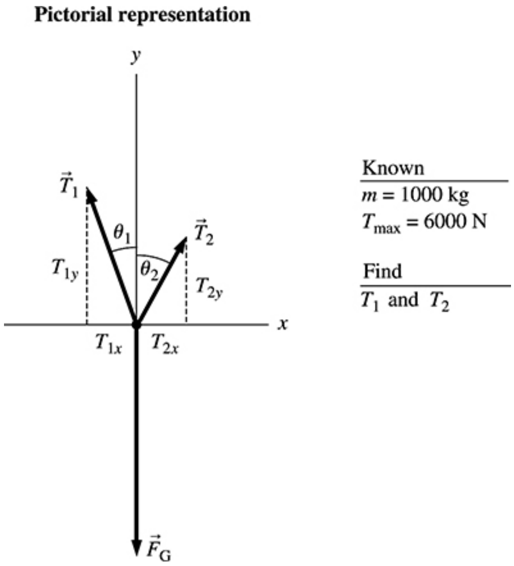
$$a_{max} = \frac{F_{max}}{m} = \frac{10\text{ N}}{5\text{ kg}} = 2\text{ m/s}^2$$

Solve: The acceleration is not constant, so we cannot use constant acceleration kinematics. Instead, we use the more general result that

$$v(t) = v_0 + \text{area under the acceleration curve from 0 s to } t$$

The object starts from rest, so $v_0 = 0$ m/s. The area under the acceleration curve between 0 s and 6 s is $\frac{1}{2}(4\text{ s})(2\text{ m/s}^2) = 4.0$ m/s. We've used the fact that the area between 4 s and 6 s is zero. Thus, at $t = 6$ s, $v_x = 4.0$ m/s.

6.29. Model: You can model the beam as a particle in static equilibrium.
Visualize:



Solve: Using Newton's first law, the equilibrium equations in vector and component form are:

$$\vec{F}_{net} = \vec{T}_1 + \vec{T}_2 + \vec{F}_G = \vec{0}\text{ N}$$
$$(F_{net})_x = T_{1x} + T_{2x} + F_{Gx} = 0\text{ N}$$
$$(F_{net})_y = T_{1y} + T_{2y} + F_{Gy} = 0\text{ N}$$

Using the free-body diagram yields:

$$-T_1 \sin\theta_1 + T_2 \sin\theta_2 = 0\text{ N} \qquad T_1 \cos\theta_1 + T_2 \cos\theta_2 - F_G = 0\text{ N}$$

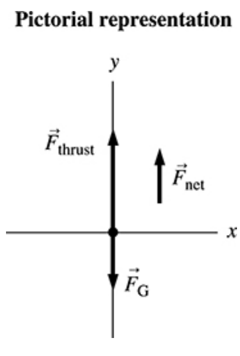
The mathematical model is reduced to a simple algebraic system of two equations with two unknowns, T_1 and T_2. Substituting $\theta_1 = 20°$, $\theta_2 = 30°$, and $F_G = mg = 9800$ N, the simultaneous equations become

$$-T_1 \sin 20° + T_2 \sin 30° = 0\text{ N} \qquad T_1 \cos 20° + T_2 \cos 30° = 9800\text{ N}$$

You can solve this system of equations by simple substitution. The result is $T_1 = 6397$ N and $T_2 = 4376$ N.

Assess: The above approach and result seem reasonable. Intuition indicates there is more tension in the left rope than in the right rope.

6.39. Model: Represent the rocket as a particle that follows Newton's second law.
Visualize:



Solve: **(a)** The *y*-component of Newton's second law is

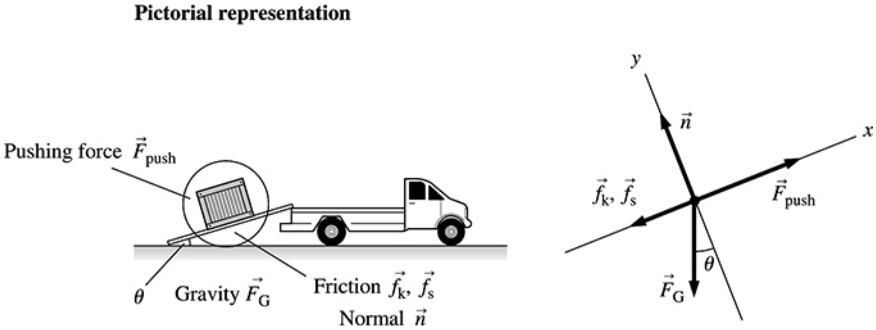
$$a_y = a = \frac{(F_{net})_y}{m} = \frac{F_{thrust} - mg}{m} = \frac{3.0\times10^5\text{ N}}{20{,}000\text{ kg}} - 9.80\text{ m/s}^2 = 5.2\text{ m/s}^2$$

(b) At 5000 m the acceleration has increased because the rocket mass has decreased. Solving the equation of part (a) for *m* gives

$$m_{5000\text{ m}} = \frac{F_{thrust}}{a_{5000\text{ m}} + g} = \frac{3.0\times10^5\text{ N}}{6.0\text{ m/s}^2 + 9.80\text{ m/s}^2} = 1.9\times10^4\text{ kg}$$

The mass of fuel burned is $m_{\text{fuel}} = m_{\text{initial}} - m_{5000\text{ m}} = 1.0 \times 10^3$ kg.

6.45. Model: We will model the box as a particle, and use the models of kinetic and static friction.
Visualize:



The pushing force is along the +*x*-axis, but the force of friction acts along the –*x*-axis. A component of the gravitational force on the box acts along the –*x*-axis as well. The box will move up if the pushing force is at least equal to the sum of the friction force and the component of the gravitational force in the *x*-direction.
Solve: Let's determine how much pushing force you would need to keep the box moving up the ramp at steady speed. Newton's second law for the box in dynamic equilibrium is

$$(F_{\text{net}})_x = \Sigma F_x = n_x + (F_G)_x + (f_k)_x + (F_{\text{push}})_x = 0 \text{ N} - mg \sin\theta - f_k + F_{\text{push}} = 0 \text{ N}$$

$$(F_{\text{net}})_y = \Sigma F_y = n_y + (F_G)_y + (f_k)_y + (F_{\text{push}})_y = n - mg \cos\theta + 0 \text{ N} + 0 \text{ N} = 0 \text{ N}$$

The *x*-component equation and the model of kinetic friction yield:

$$F_{\text{push}} = mg \sin\theta + f_k = mg \sin\theta + \mu_k n$$

Let us obtain *n* from the *y*-component equation as $n = mg\cos\theta,$ and substitute it in the above equation to get

$$F_{\text{push}} = mg \sin\theta + \mu_k \, mg \cos\theta = mg(\sin\theta + \mu_k \cos\theta)$$

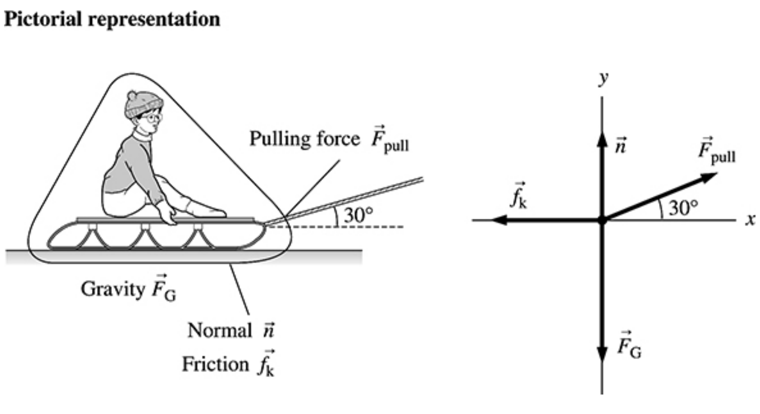
$$= (100 \text{ kg})(9.80 \text{ m/s}^2)(\sin 20° + 0.60 \cos 20°) = 888 \text{ N}$$

The force is less than your maximum pushing force of 1000 N. That is, once in motion, the box could be kept moving up the ramp. However, if you stop on the ramp and want to start the box from rest, the model of static friction applies. The analysis is the same except that the coefficient of static friction is used and we use the maximum value of the force of static friction. Therefore, we have

$$F_{\text{push}} = mg(\sin\theta + \mu_s \cos\theta) = (100 \text{ kg})(9.80 \text{ m/s}^2)(\sin 20° + 0.90 \cos 20°) = 1160 \text{ N}$$

Since you can push with a force of only 1000 N, you can't get the box started. The big static friction force and the weight are too much to overcome.

6.47. Model: We will model the sled and friend as a particle, and use the model of kinetic friction because the sled is in motion.
Visualize:



The net force on the sled is zero (note the constant speed of the sled). That means the component of the pulling force along the +*x*-direction is equal to the magnitude of the kinetic force of friction in the –*x*-direction. Also note that $(F_{\text{net}})_y = 0$ N, since the sled is not moving along the *y*-axis.

Solve: Newton's second law is

$$(F_{\text{net}})_x = \Sigma F_x = n_x + (F_G)_x + (f_k)_x + (F_{\text{pull}})_x = 0\text{ N} + 0\text{ N} - f_k + F_{\text{pull}}\cos\theta = 0\text{ N}$$

$$(F_{\text{net}})_y = \Sigma F_y = n_y + (F_G)_y + (f_k)_y + (F_{\text{pull}})_y = n - mg + 0\text{ N} + F_{\text{pull}}\sin\theta = 0\text{ N}$$

The *x*-component equation using the kinetic friction model $f_k = \mu_k n$ reduces to

$$\mu_k n = F_{\text{pull}}\cos\theta$$

The *y*-component equation gives

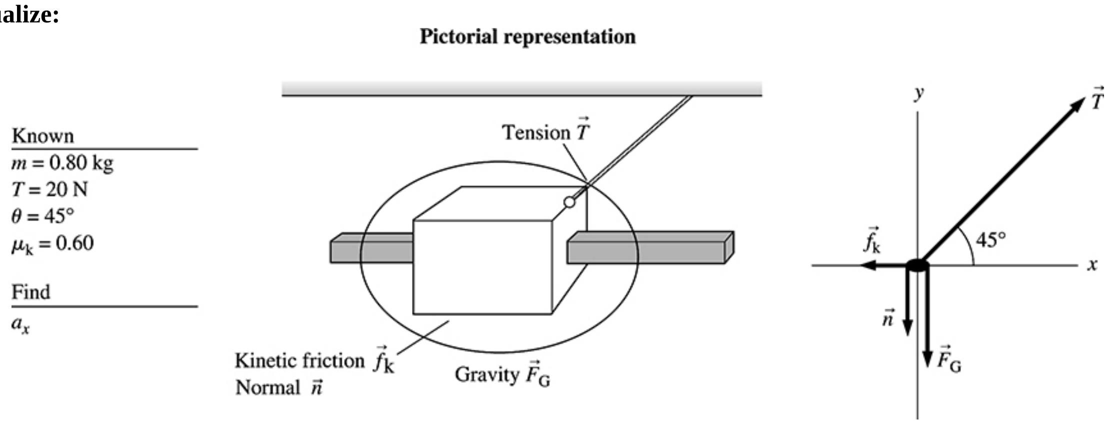
$$n = mg - F_{\text{pull}}\sin\theta$$

We see that the normal force is smaller than the gravitational force because F_{pull} has a component in a direction opposite to the direction of the gravitational force. In other words, F_{pull} is partly lifting the sled. From the *x*-component equation, μ_k can now be obtained as

$$\mu_k = \frac{F_{\text{pull}}\cos\theta}{mg - F_{\text{pull}}\sin\theta} = \frac{(75\text{ N})(\cos 30°)}{(60\text{ kg})(9.80\text{ m/s}^2) - (75\text{ N})(\sin 30°)} = 0.12$$

Assess: A quick glance at the various μ_k values in Table 6.1 suggests that a value of 0.12 for μ_k is reasonable.

6.70. Model: We will model the shuttle as a particle and assume the elastic cord to be massless. We will also use the model of kinetic friction for the motion of the shuttle along the square steel rail.
Visualize:



Solve: The upward tension component $T_y = T\sin 45° = 14.1\text{ N}$ is larger than the gravitational force on the shuttle. Consequently, the elastic cord pulls the shuttle up against the rail and the rail's normal force pushes downward. Newton's second law in component form is

$$(F_{\text{net}})_x = \Sigma F_x = T_x + (f_k)_x + (n)_x + (F_G)_x = T\cos 45° - f_k + 0\text{ N} + 0\text{ N} = ma_x = ma_x$$

$$(F_{\text{net}})_y = \Sigma F_y = T_y + (f_k)_y + (n)_y + (F_G)_y = T\sin 45° + 0\text{ N} - n - mg = ma_y = 0\text{ N}$$

The model of kinetic friction is $f_k = \mu_k n.$ We use the *y*-component equation to get an expression for *n* and hence f_k. Substituting into the *x*-component equation and using the value of μ_k in Table 6.1 gives us

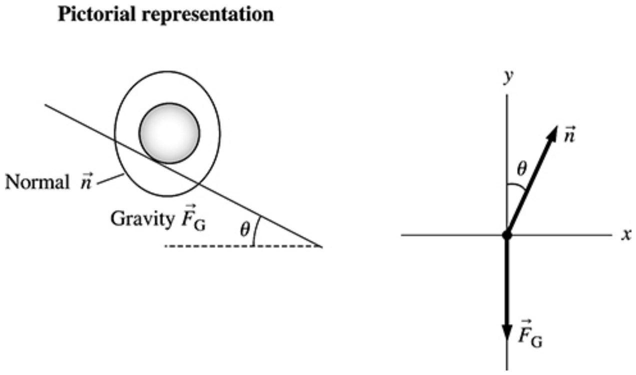
$$a_x = \frac{T\cos 45° - \mu_k(T\sin 45° - mg)}{m}$$

$$= \frac{(20\text{ N})\cos 45° - (0.60)\left[+(20\text{ N})\sin 45° - (0.800\text{ kg})(9.80\text{ m/s}^2)\right]}{0.800\text{ kg}} = 13.0\text{ m/s}^2$$

Assess: The *x*-component of the tension force is 14.1 N. On the other hand, the net force on the shuttle in the *x*-direction is $ma_x = (0.800\text{ kg})(13.0\text{ m/s}^2) = 10.4\text{ N}.$ This value for *ma* is reasonable since a part of the 14.1 N tension force is used up to overcome the force of kinetic friction.

6.71. Model: Assume the ball is a particle on a slope, and that the slope increases as the *x*-displacement increases. Assume that there is no friction and that the ball is being accelerated to the right so that it remains at rest on the slope.

Visualize: Although the ball is on a slope, it is accelerating to the right. Thus we'll use a coordinate system with horizontal and vertical axes.



Solve: Newton's second law is

$$\Sigma F_x = n\sin\theta = ma_x \qquad \Sigma F_y = n\cos\theta - F_G = ma_y = 0 \text{ N}$$

Combining the two equations, we get

$$ma_x = \frac{F_G}{\cos\theta}\sin\theta = mg\tan\theta \Rightarrow a_x = g\tan\theta$$

The curve is described by $y = x^2$. Its slope a position x is $\tan\theta$, which is also the derivative of the curve. Hence,

$$\frac{dy}{dx} = \tan\theta = 2x \Rightarrow a_x = (2x)g$$

(b) The acceleration at $x = 0.20$ m is $a_x = (2)(0.20)(9.8 \text{ m/s}^2) = 3.9 \text{ m/s}^2$.