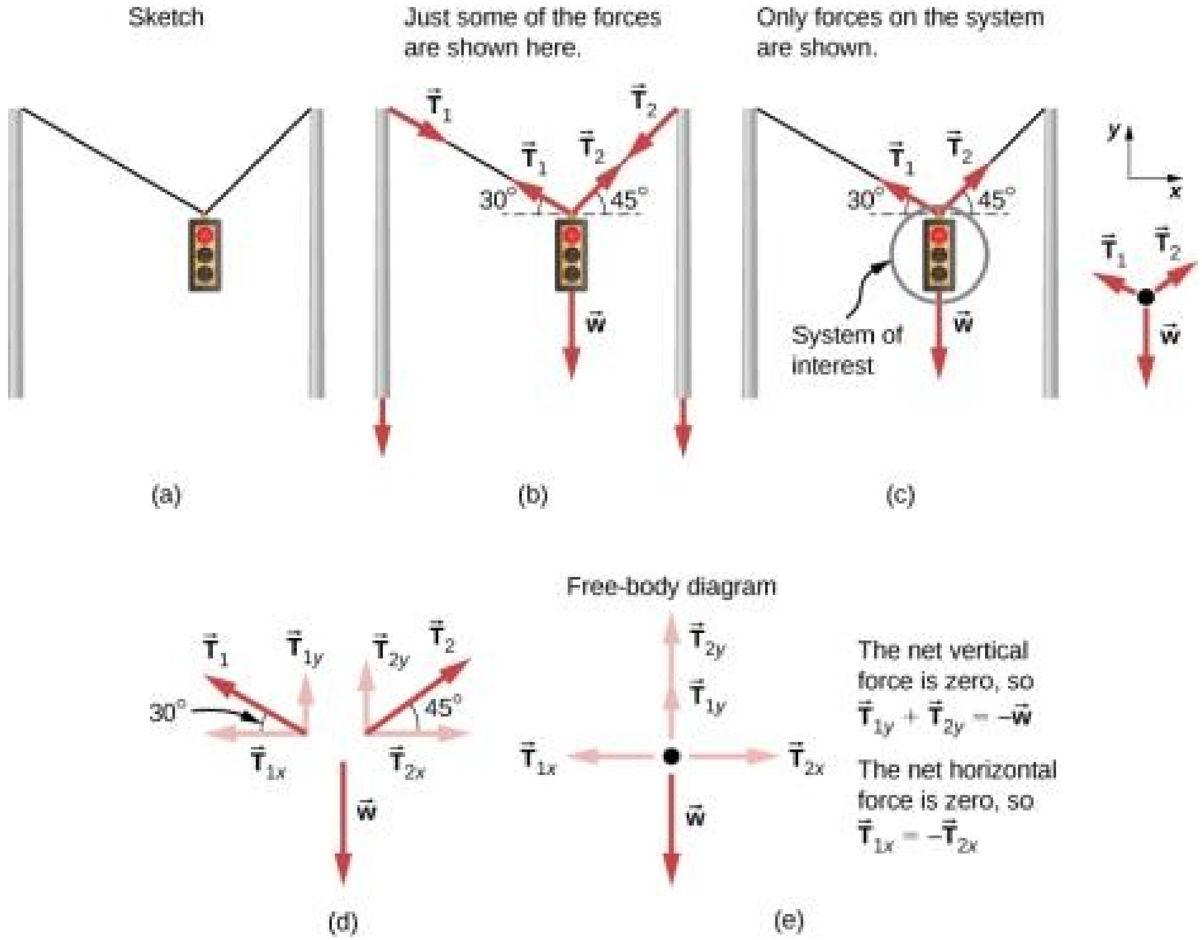
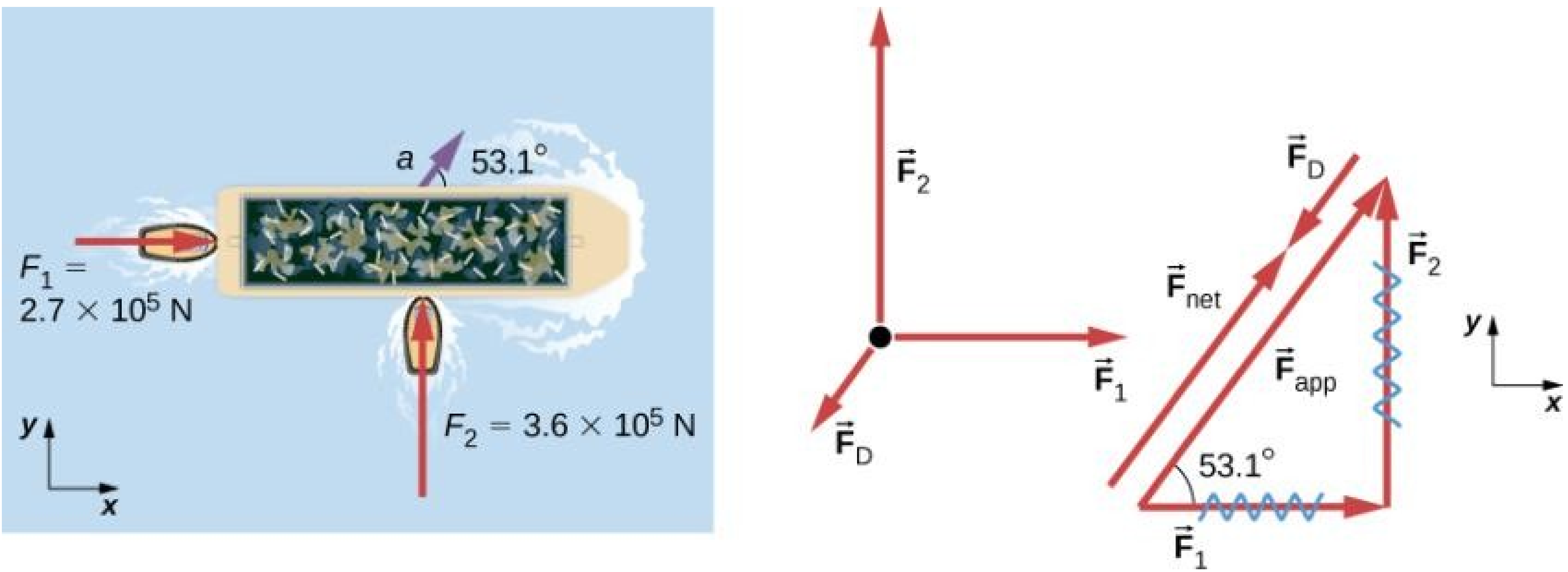
FIGURE 6.3



A traffic light is suspended from two wires. (b) Some of the forces involved. (c) Only forces acting on the system are shown here. The free-body diagram for the traffic light is also shown. (d) The forces projected onto vertical (y) and horizontal (x) axes. The horizontal components of the tensions must cancel, and the sum of the vertical components of the tensions must equal the weight of the traffic light. (e) The free-body diagram shows the vertical and horizontal forces acting on the traffic light.

FIGURE 6.4



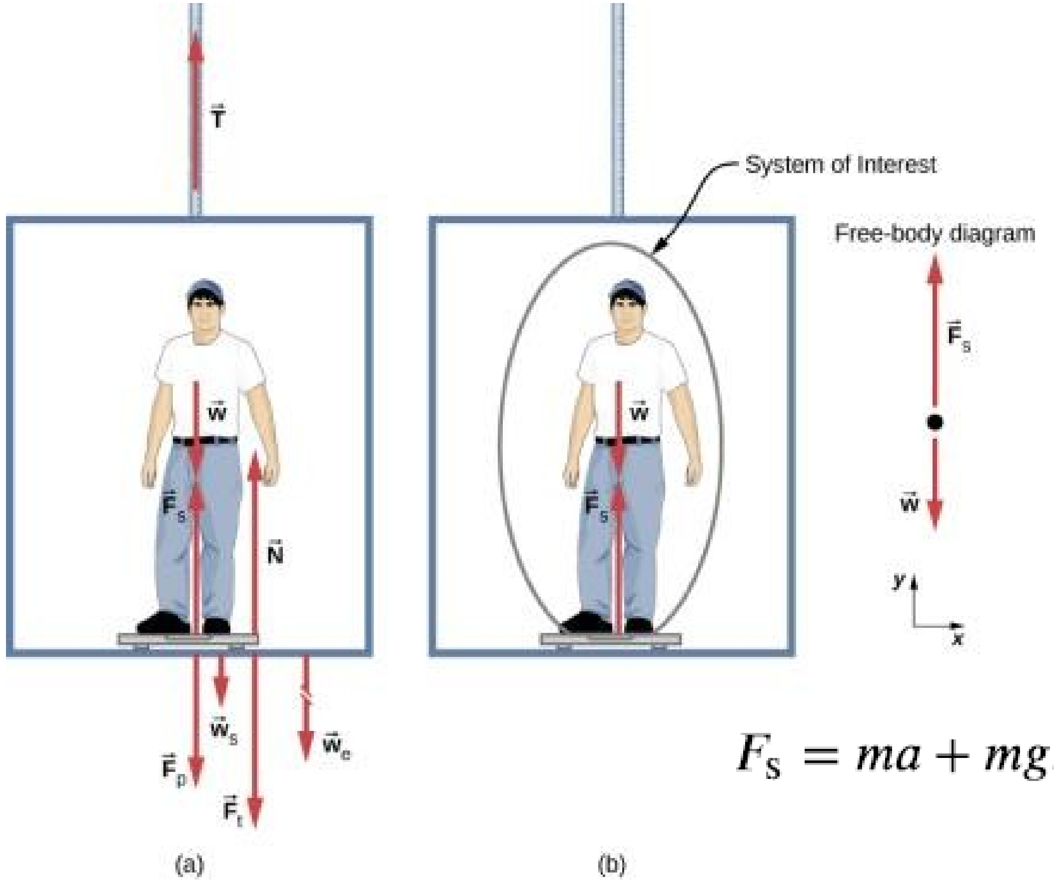
(a) (b)

(a) A view from above of two tugboats pushing on a barge.

(b) The free-body diagram for the ship contains only forces acting in the plane of the water. It omits the two vertical forces—the weight of the barge and the buoyant force of the water supporting it cancel and are not shown. Note that is the total applied force of the tugboats.

(c) Part of the applied force is used to counter the drag force, the remainder is the net force

FIGURE 6.5

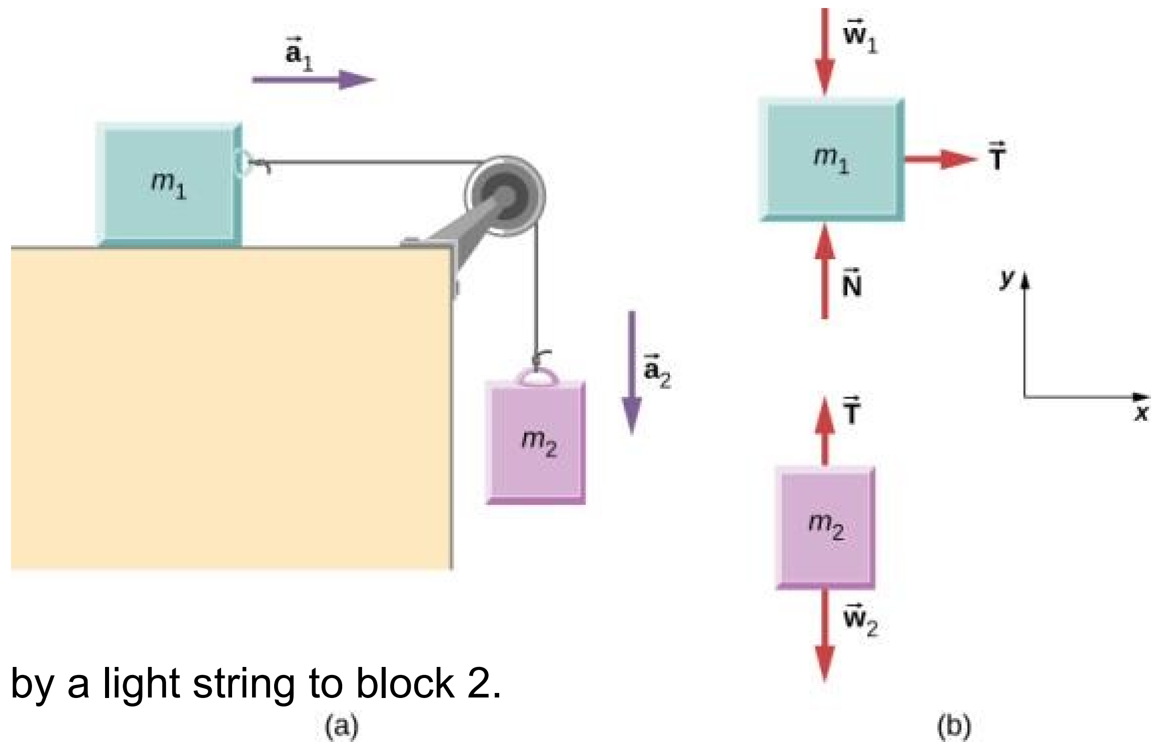


$$F_S = ma + mg.$$

(a)The various forces acting when a person stands on a bathroom scale in an elevator. The arrows are approximately correct for when the elevator is accelerating upward—broken arrows represent forces too large to be drawn to scale. is the tension in the supporting cable, is the weight of the person, is the weight of the scale, is the weight of the elevator, is the force of the scale on the person, is the force of the person on the scale, is the force of the scale on the floor of the elevator, and is the force of the floor upward on the scale. Ignore all this. Focus on the person

(b)The free-body diagram shows only the external forces acting on the designated system of interest—the person—and is the diagram we use for the solution of the problem.

FIGURE 6.6



(a) Block 1 is connected by a light string to block 2.

(b) The free-body diagrams of the blocks.

Find the acceleration of the blocks and the tension in the string in terms of m_1, m_2, g

Block 1

$$\sum F_x = ma_x$$

$$T_x = m_1 a_{1x}$$

Block 2

$$\sum F_y = ma_y$$

$$T_y - m_2 g = m_2 a_{2y}.$$

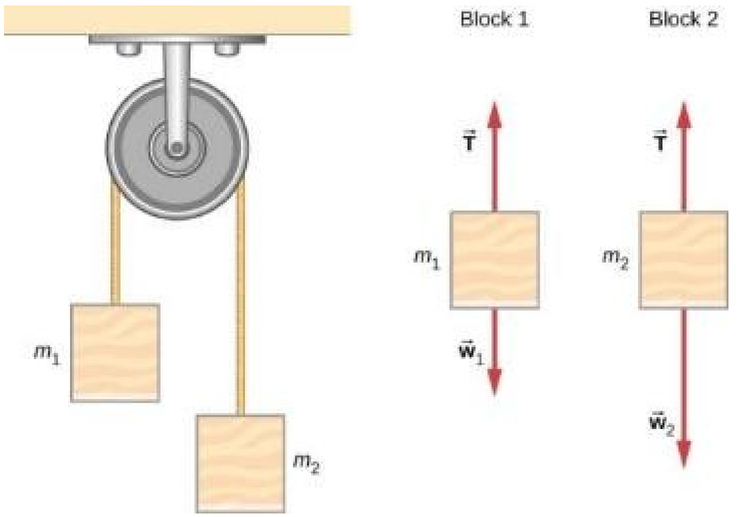
Rope is taut=> $a_{1x} = -a_{2y}.$ = a

Same tension

Get $$a = \frac{m_2}{m_1 + m_2} g$$

FIGURE 6.7 ATWOOD MACHINE

(a) If m_2 is released, what will its acceleration be? (b) What is the tension in the string?



For m_1, $\sum F_y = T - m_1 g = m_1 a.$

For m_2, $\sum F_y = T - m_2 g = -m_2 a.$

$(m_2 - m_1)g = (m_1 + m_2)a.$ We get

$$a = \frac{m_2 - m_1}{m_1 + m_2} g$$

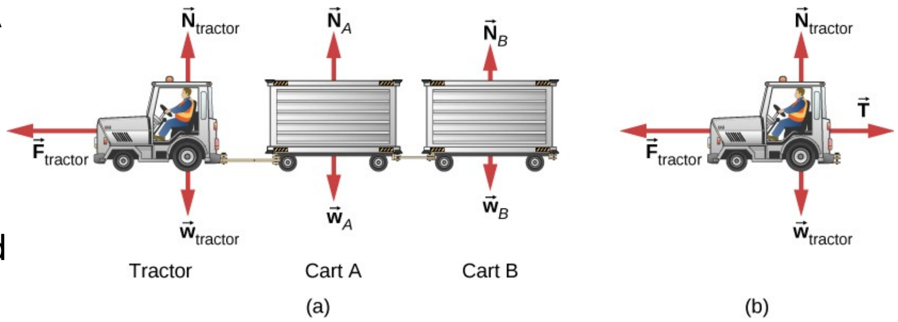
$$T - m_1 g = m_1 a$$

X6.8 The tractor has mass 650.0 kg, while cart A has mass 250.0 kg and cart B has mass 150.0 kg.

The driving force acting for a brief period of time accelerates the system from rest and acts for 3.00 s.

(a) If this driving force is given by F =820.0 t N find the speed after 3.00 seconds.

(b) (b) What is the horizontal force acting on the connecting cable between at this instant?



Figure

a)

$$\sum F_x = 820.0t, \text{ so}$$

$$\begin{aligned} 820.0t &= (650.0 + 250.0 + 150.0)a \\ a &= 0.7809t. \end{aligned}$$

$$dv = a dt, \quad \int_0^3 dv = \int_0^{3.00} a dt = \int_0^{3.00} 0.7809t dt, \quad v = 0.3905t^2\Big]_0^{3.00} = 3.51 \text{ m/s}.$$

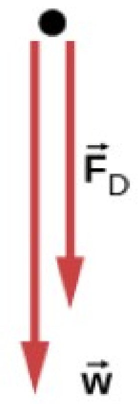
b)

$$\begin{aligned} \sum F_x &= m_{\text{tractor}} a_x \\ 820.0t - T &= m_{\text{tractor}}(0.7805)t \\ (820.0)(3.00) - T &= (650.0)(0.7805)(3.00) \\ T &= 938 \text{ N}. \end{aligned}$$

EXAMPLE 6.9

Motion of a Projectile Fired Vertically

A 10.0-kg mortar shell is fired vertically upward from the ground, with an initial velocity of 50.0 m/s (see Figure 6.9). Determine the maximum height it will travel if atmospheric resistance is measured as $F_D = (0.0100v^2)$ N, where v is the speed at any instant.



Initially, $y_0 = 0$ and $v_0 = 50.0$ m/s. At the maximum height $y = h, v = 0$. The free-body diagram shows F_D tc act downward, because it slows the upward motion of the mortar shell. Thus, we can write

$$\sum F_y = ma_y$$

$$\begin{aligned} -F_D - w &= ma_y \\ -0.0100v^2 - 98.0 &= 10.0a \\ a &= -0.00100v^2 - 9.80. \end{aligned}$$

The acceleration depends on v and is therefore variable. Since $a = f(v)$, we can relate a to v using the rearrangement described above,

$$ads = vdv.$$

We replace ds with dy because we are dealing with the vertical direction,

$$ady = vdv, \quad (-0.00100v^2 - 9.80)dy = vdv.$$

We now separate the variables (v's and dv's on one side; dy on the other):

$$\int_0^h dy = \int_{50.0}^0 \frac{vdv}{(-0.00100v^2 - 9.80)}$$

$$\int_0^h dy = -\int_{50.0}^0 \frac{vdv}{(0.00100v^2 + 9.80)} = (-5 \times 10^3)\ln(0.00100v^2 + 9.80)\Big|_{50.0}^0.$$

Thus, $h = 114$ m.

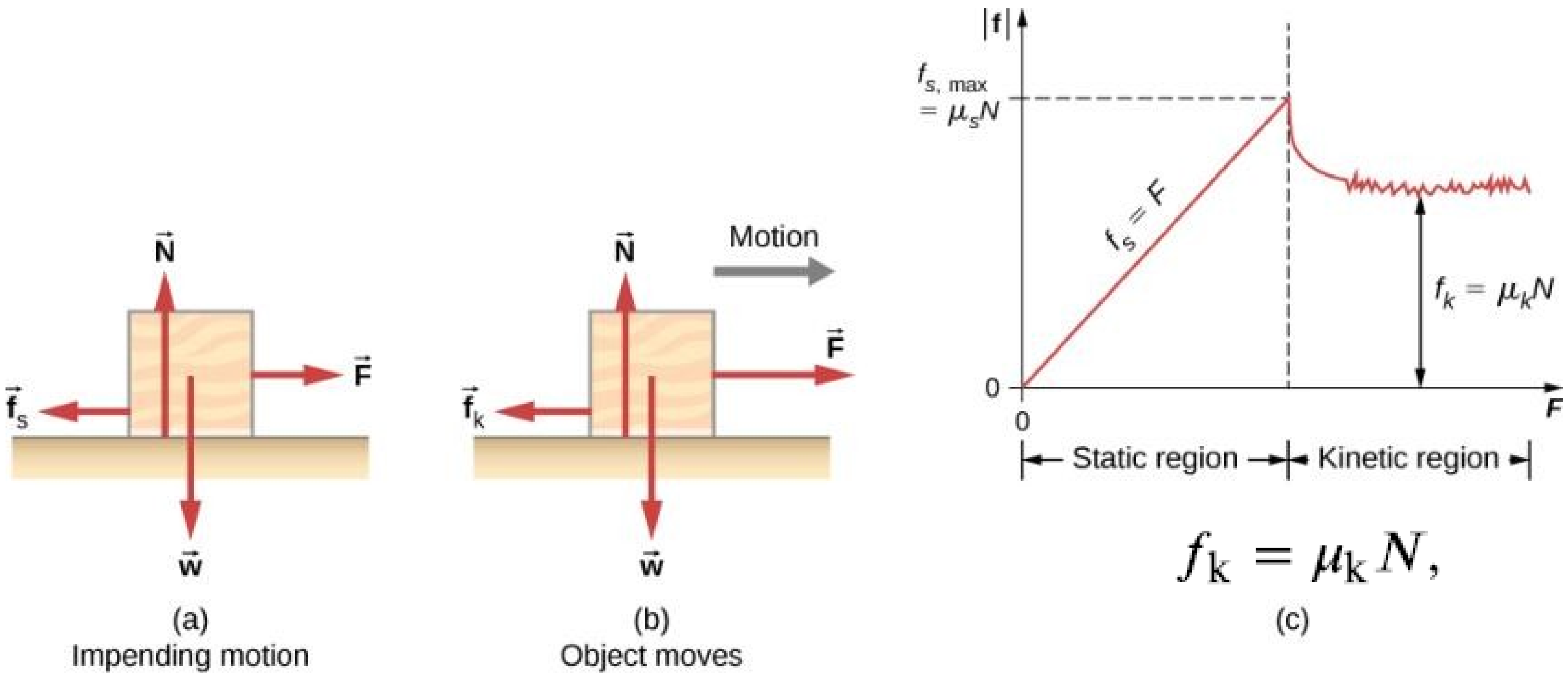
1) ds/dt= v

2) dv/dt =a

From 1) dt= ds/v

From 2) dt = dv//a

FIGURE 6.11 STATIC VS KINETIC FRICTION



$$f_k = \mu_k N,$$

(c)

(a) The force of friction between the block and the rough surface opposes the direction of the applied force . The magnitude of the static friction balances that of the applied force. This is shown in the left side of the graph in (c).

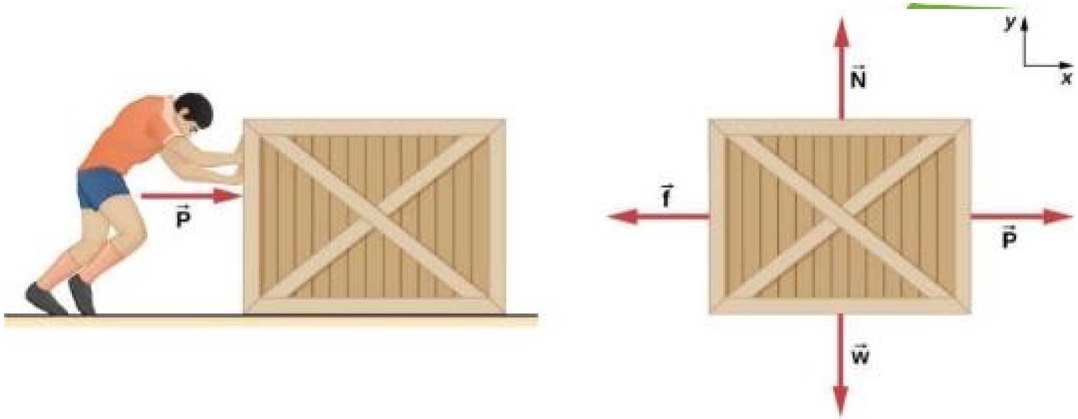
(b) At some point, the magnitude of the applied force is greater than the force of kinetic friction, and the block moves to the right. This is shown in the right side of the graph.

(c) The graph of the frictional force versus the applied force; note that . This means that .

FIGURE 6.13

(a) A crate on a horizontal surface is pushed with a force .

(b) The forces on the crate. Here, may represent either the static or the kinetic frictional force.



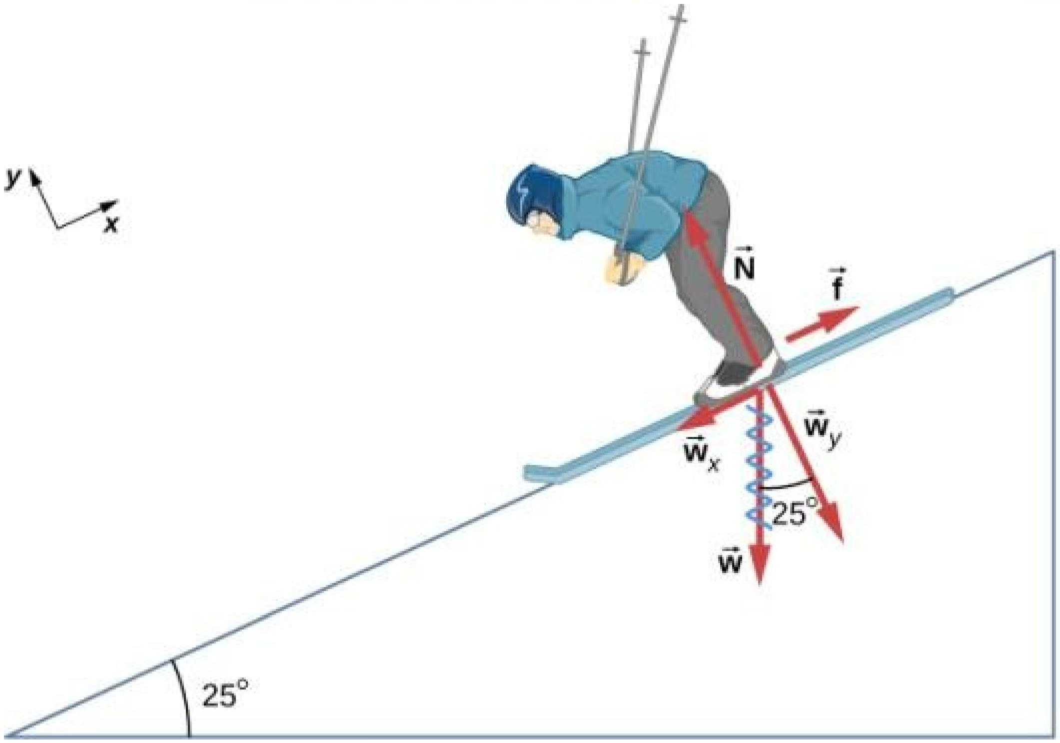
A 20.0-kg crate is at rest on a floor as shown in Figure 6.13. The coefficient of static friction between the crate and floor is 0.700 and the coefficient of kinetic friction is 0.600. A horizontal force $\vec{\mathbf{P}}$ is applied to the crate. Find the force of friction if (a) $\vec{\mathbf{P}} = 20.0\,\text{N}\hat{\mathbf{i}}$, (b) $\vec{\mathbf{P}} = 30.0\,\text{N}\hat{\mathbf{i}}$, (c) $\vec{\mathbf{P}} = 120.0\,\text{N}\hat{\mathbf{i}}$, and (d) $\vec{\mathbf{P}} = 180.0\,\text{N}\hat{\mathbf{i}}$.

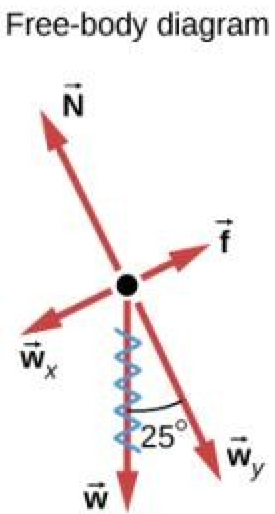
which is also equal to N. The maximum force of static friction is therefore $(0.700)\,(196\text{ N}) = 137\text{ N}$. As long as $\vec{\mathbf{P}}$ is less than 137 N, the force of static friction keeps the crate stationary and $f_s = \vec{\mathbf{P}}$. Thus, (a) $f_s = 20.0\text{ N}$, (b) $f_s = 30.0\text{ N}$, and (c) $f_s = 120.0\text{ N}$.

(d) If $\vec{\mathbf{P}} = 180.0\text{ N}$, the applied force is greater than the maximum force of static friction (137 N), so the crate can no longer remain at rest. Once the crate is in motion, kinetic friction acts. Then

$$f_k = \mu_k N = (0.600)(196\text{ N}) = 118\text{ N},$$

$$a_x = \frac{P - f_k}{m} = \frac{180.0\text{ N} - 118\text{ N}}{20.0\text{ kg}} = 3.10\text{ m/s}^2.$$





The motion of the skier and friction are parallel to the slope, so it is most convenient to project all forces onto a coordinate system where one axis is parallel to the slope and the other is perpendicular (axes shown to left of skier). The normal force is perpendicular to the slope, and friction is parallel to the slope, but the skier's weight has components along both axes, namely and . The normal force is equal in magnitude to , so there is no motion perpendicular to the slope. However, is less than in magnitude, so there is acceleration down the slope (along the *x*-axis).

An object slides down an inclined plane at a constant velocity if the net force on the object .

$$\mu_k = \frac{f_k}{N}$$

, $f_k = w_x$

$$\mu_k mg \cos\theta = mg \sin\theta.$$

$$\mu_k = \frac{mg \sin\theta}{mg \cos\theta} = \tan\theta.$$

(a) (b)

A snowboarder glides down a slope inclined at 13° to the horizontal. Given μ_k =0.20 What is the acceleration of the snowboarder?

$$\sum F_x = ma_x \qquad \sum F_y = ma_y$$

$$mg \sin\theta - \mu_k N = ma_x \qquad N - mg\cos\theta = m(0).$$

$$\begin{aligned} a_x &= g(\sin\theta - \mu_\mathrm{k}\cos\theta) \\ &= g(\sin 13° - 0.20\cos 13°) = 0.29\ \mathrm{m/s^2}. \end{aligned}$$

Notice from this equation that if θ is small enough or μ_k is large enough, a_x is negative, that is, the snowboarder slows down.

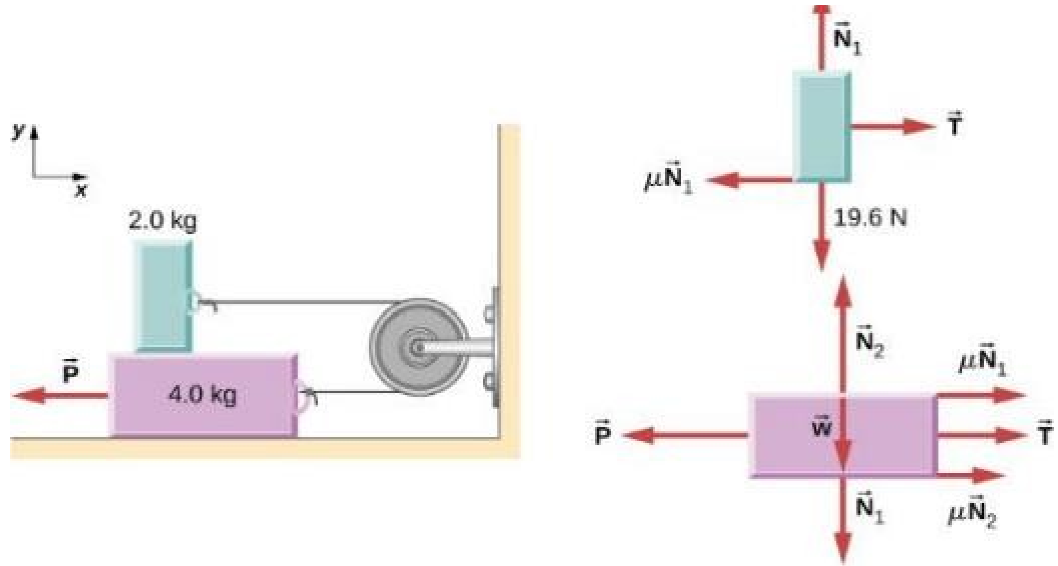
EXAMPLE 6.12

Sliding Blocks

The two blocks of Figure 6.17 are attached to each other by a massless string that is wrapped around a frictionless pulley. When the bottom 4.00-kg block is pulled to the left by the constant force $\vec{\mathbf{P}}$, the top 2.00-kg block slides across it to the right. Find the magnitude of the force necessary to move the blocks at constant speed. Assume that the coefficient of kinetic friction between all surfaces is 0.400.

Construct the force diagrams for each block, carefully denoting all the forces exerting on each block, as explained below.

What simplifies this complex looking problem is the fact that each block moves at constant velocity.



We analyze the motions of the two blocks separately. The top block is subjected to a contact force exerted by the bottom block. The components of this force are the normal force N_1 and the frictional force $-0.400N_1$. Other forces on the top block are the tension $T\mathbf{i}$ in the string and the weight of the top block itself, 19.6 N. The bottom block is subjected to contact forces due to the top block and due to the floor. The first contact force has components $-N_1$ and $0.400N_1$, which are simply reaction forces to the contact forces that the bottom block exerts on the top block. The components of the contact force of the floor are N_2 and $0.400N_2$. Other forces on this block are $-P$, the tension $T\mathbf{i}$, and the weight -39.2 N.

Since the top block is moving horizontally to the right at constant velocity, its acceleration is zero in both the horizontal and the vertical directions. From Newton's second law,

$$\begin{aligned} \sum F_x &= m_1 a_x & \qquad \sum F_y &= m_1 a_y \\ T - 0.400 N_1 &= 0 & \qquad N_1 - 19.6\,\mathrm{N} &= 0. \end{aligned}$$

Solving for the two unknowns, we obtain $N_1 = 19.6\,\mathrm{N}$ and $T = 0.40 N_1 = 7.84\,\mathrm{N}$. The bottom block is also not accelerating, so the application of Newton's second law to this block gives

$$\begin{aligned} &\sum F_x = m_2 a_x & \qquad &\sum F_y = m_2 a_y \\ &T - P + 0.400\, N_1 + 0.400\, N_2 = 0 & \qquad &N_2 - 39.2\,\mathrm{N} - N_1 = 0. \end{aligned}$$

The values of N_1 and T were found with the first set of equations. When these values are substituted into the second set of equations, we can determine N_2 and P. They are

$$N_2 = 58.8\,\mathrm{N} \quad \text{and} \quad P = 39.2\,\mathrm{N}.$$

EXAMPLE 6.13

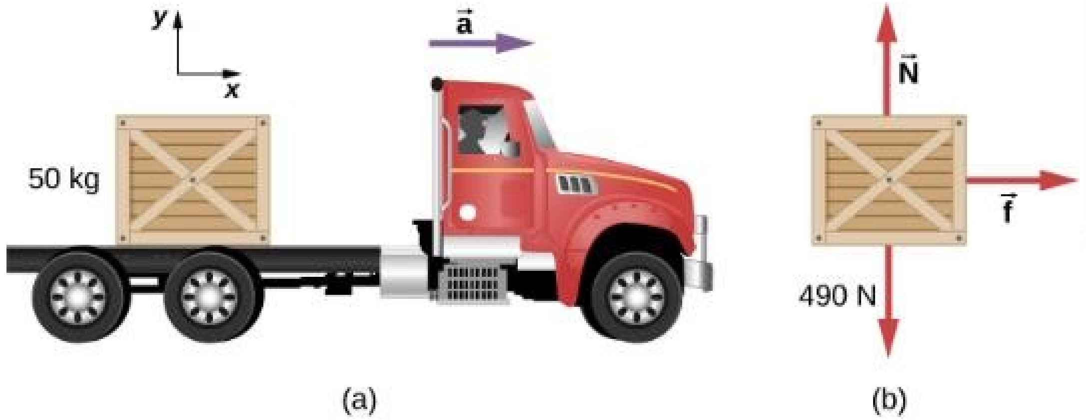
A Crate on an Accelerating Truck

A 50.0-kg crate rests on the bed of a truck as shown in Figure 6.18. The coefficients of friction between the surfaces are $\mu_k = 0.300$ and $\mu_s = 0.400$. Find the frictional force on the crate when the truck is accelerating forward relative to the ground at (a) $2.00\ \text{m/s}^2$, and (b) $5.00\ \text{m/s}^2$.

Need to distinguish between when to use static friction and when to use kinetic friction.

Part a) calculates the maximum value of the force of static friction

Part b) invokes kinetic friction



a. Application of Newton's second law to the crate, using the reference frame attached to the ground, yields

$$\begin{aligned} \sum F_x &= ma_x \\ f_s &= (50.0\,\text{kg})(2.00\,\text{m/s}^2) \\ &= 1.00 \times 10^2\ \text{N} \end{aligned} \qquad \begin{aligned} \sum F_y &= ma_y \\ N - 4.90 \times 10^2\ \text{N} &= (50.0\,\text{kg})(0) \\ N &= 4.90 \times 10^2\ \text{N}. \end{aligned}$$

We can now check the validity of our no-slip assumption. The maximum value of the force of static friction is

$$\mu_s N = (0.400)(4.90 \times 10^2\ \text{N}) = 196\ \text{N},$$

whereas the *actual* force of static friction that acts when the truck accelerates forward at $2.00\ \text{m/s}^2$ is only 1.00×10^2 N. Thus, the assumption of no slipping is valid.

b. If the crate is to move with the truck when it accelerates at $5.0\ \text{m/s}^2$, the force of static friction must be

$$f_s = ma_x = (50.0\ \text{kg})(5.00\ \text{m/s}^2) = 250\ \text{N}.$$

Since this exceeds the maximum of 196 N, the crate must slip. The frictional force is therefore kinetic and is

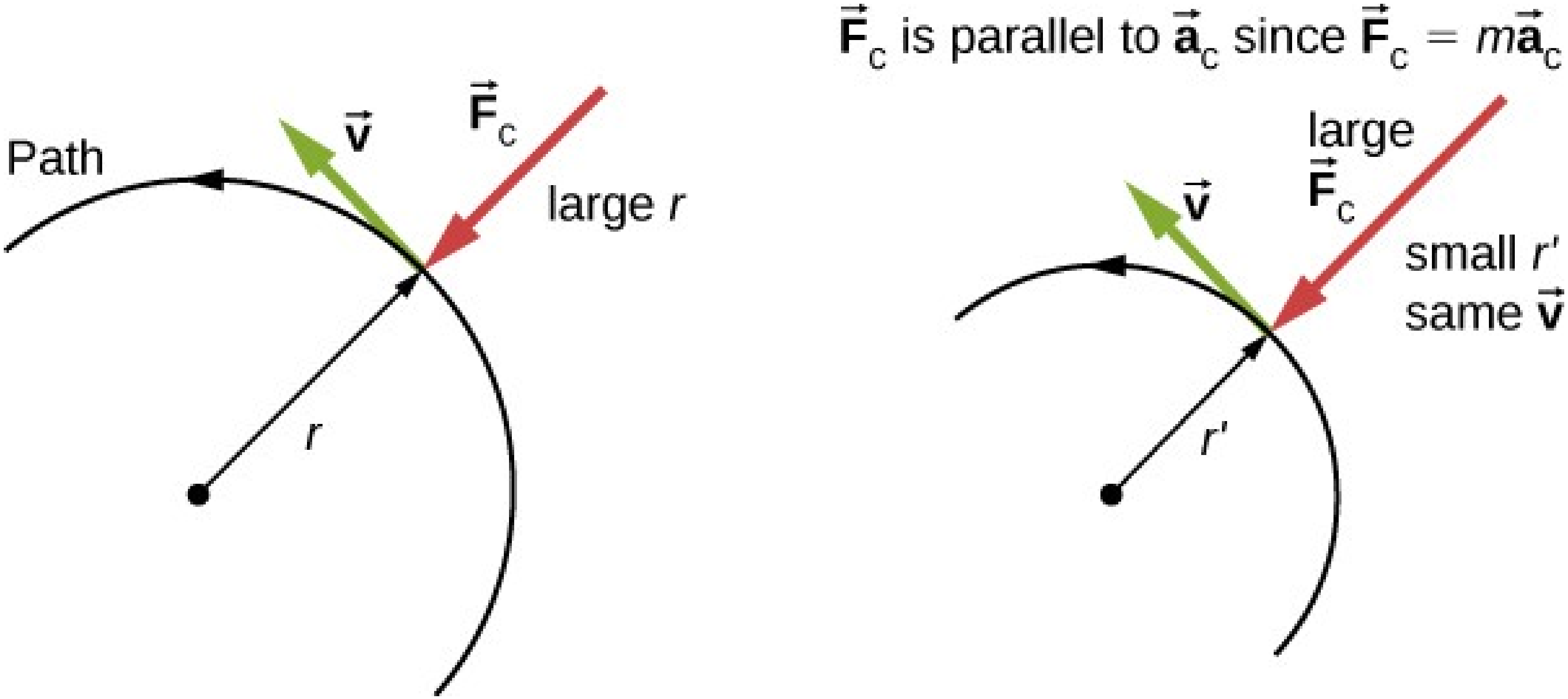
$$f_k = \mu_k N = (0.300)(4.90 \times 10^2\ \text{N}) = 147\ \text{N}.$$

The horizontal acceleration of the crate relative to the ground is now found from

$$\begin{aligned} \sum F_x &= ma_x \\ 147\ \text{N} &= (50.0\ \text{kg})a_x, \\ \text{so } a_x &= 2.94\ \text{m/s}^2. \end{aligned}$$

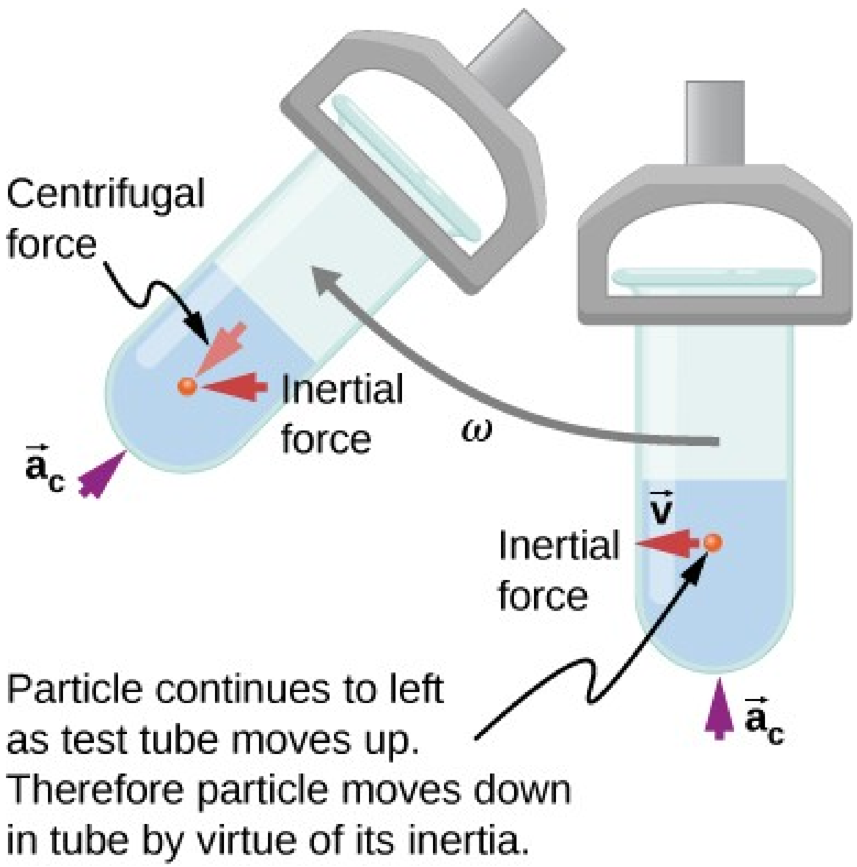
Relative to the ground, the truck is accelerating forward at $5.0\ \text{m/s}^2$, and the crate is accelerating forward at $2.94\ \text{m/s}^2$. Hence the crate is sliding backward relative to the be $2.94\ \text{m/s}^2 - 5.00\ \text{m/s}^2 = -2.06\ \text{m/s}^2$. tion

FIGURE 6.20



The frictional force supplies the centripetal force and is numerically equal to it. Centripetal force is perpendicular to velocity and causes uniform circular motion. The larger the F_c, the smaller the radius of curvature r and the sharper the curve. The second curve has the same v, but a larger F_c produces a smaller r'.

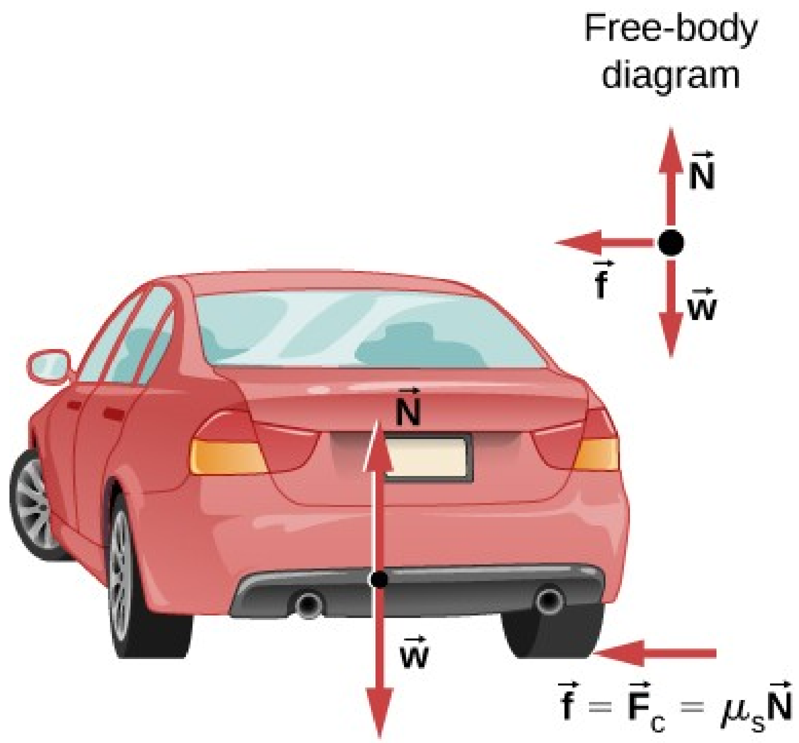
FIGURE 6.26



Centrifuges use inertia to perform their task. Particles in the fluid sediment settle out because their inertia carries them away from the center of rotation. The large angular velocity of the centrifuge quickens the sedimentation. Ultimately, the particles come into contact with the test tube walls, which then supply the centripetal force needed to make them move in a circle of constant radius.

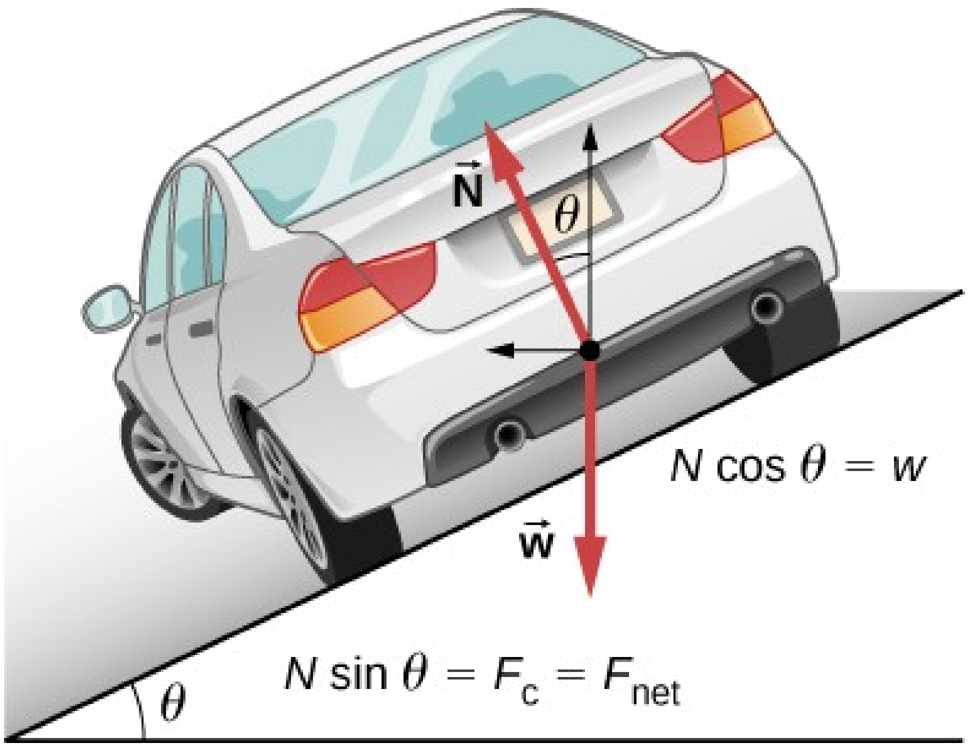
Estimate the speed of rotation.
BlackBoard

FIGURE 6.21



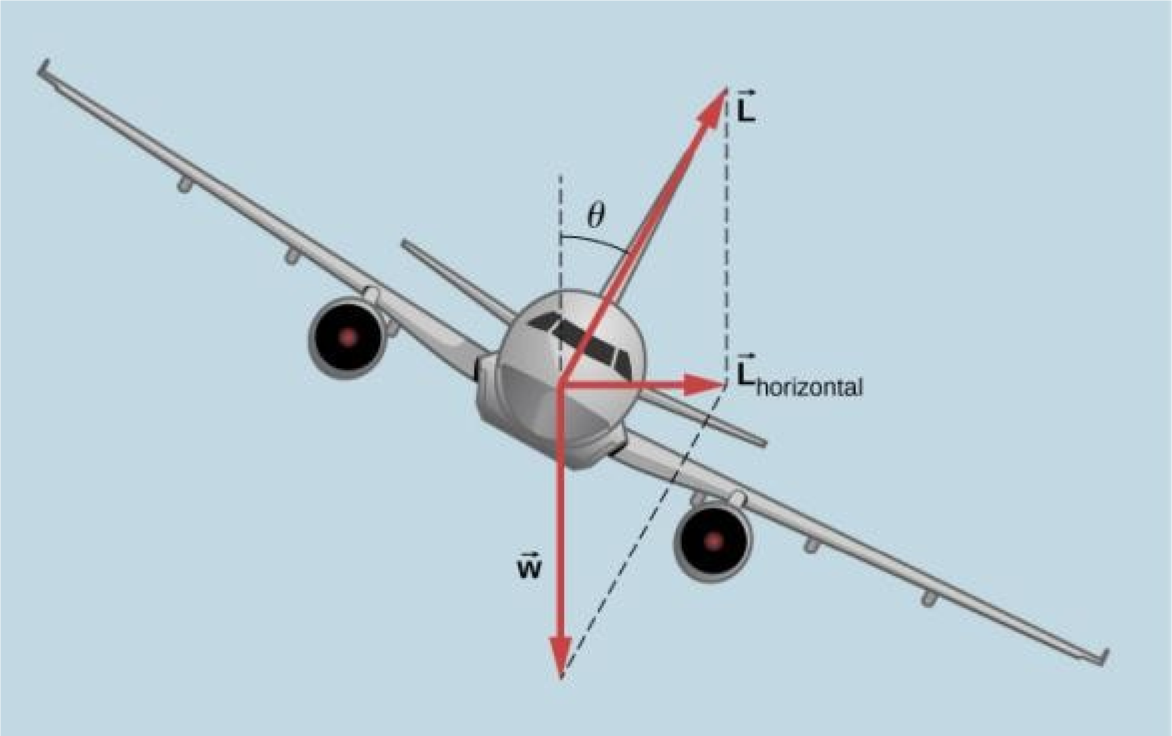
This car on level ground is moving away and turning to the left. The centripetal force causing the car to turn in a circular path is due to friction between the tires and the road. A minimum coefficient of friction is needed, or the car will move in a larger-radius curve and leave the roadway.

FIGURE 6.22



The car on this banked curve is moving away and turning to the left.

FIGURE 6.23



In a banked turn, the horizontal component of lift is unbalanced and accelerates the plane. The normal component of lift balances the plane’s weight. The banking angle is given by . Compare the vector diagram with that shown in **Figure 6.22**.

DRAG FORCE AND TERMINAL VELOCITY

$$F_D = \frac{1}{2} C \rho A v^2$$

Drag force experienced by an object when moving at high velocity in a fluid (through air or water), where C is the drag coefficient, A is the area of the object facing the fluid, and ρ is the density of the fluid.

At Terminal Velocity

$$F_{net} = mg - F_D = ma = 0.$$

Drag force balances the

Gravitational force and the obj

moves with constant velocity

$$mg = F_D.$$

$$mg = \frac{1}{2} C \rho A v_T^2.$$

$$v_T = \sqrt{\frac{2mg}{\rho C A}}.$$

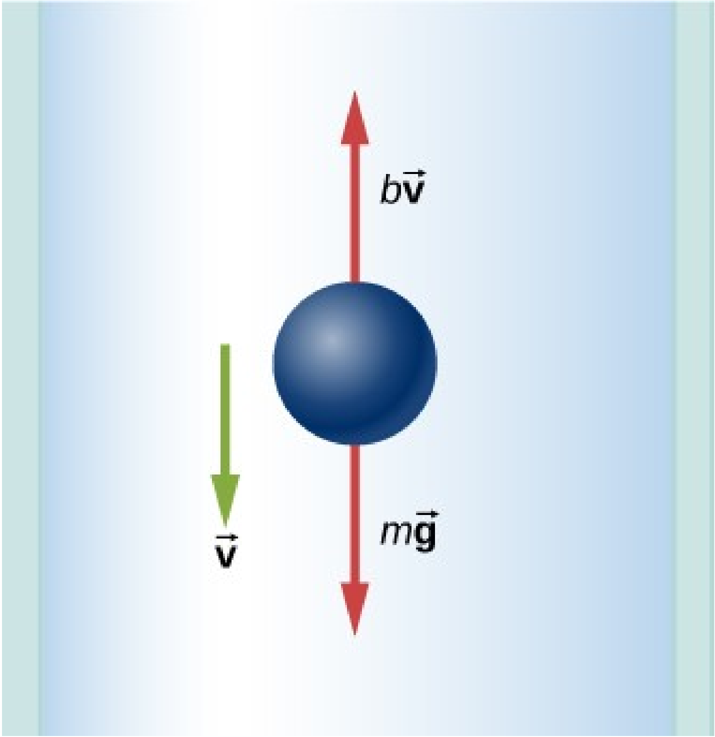
Stokes' Law

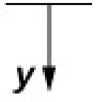
For a spherical object falling in a medium, the drag force is

$$F_s = 6\pi r \eta v,$$

where r is the radius of the object, η is the viscosity of the fluid, and v is the object's velocity

FIGURE 6.33 VELOCITY-DEPENDENT FRICTIONAL FORCES

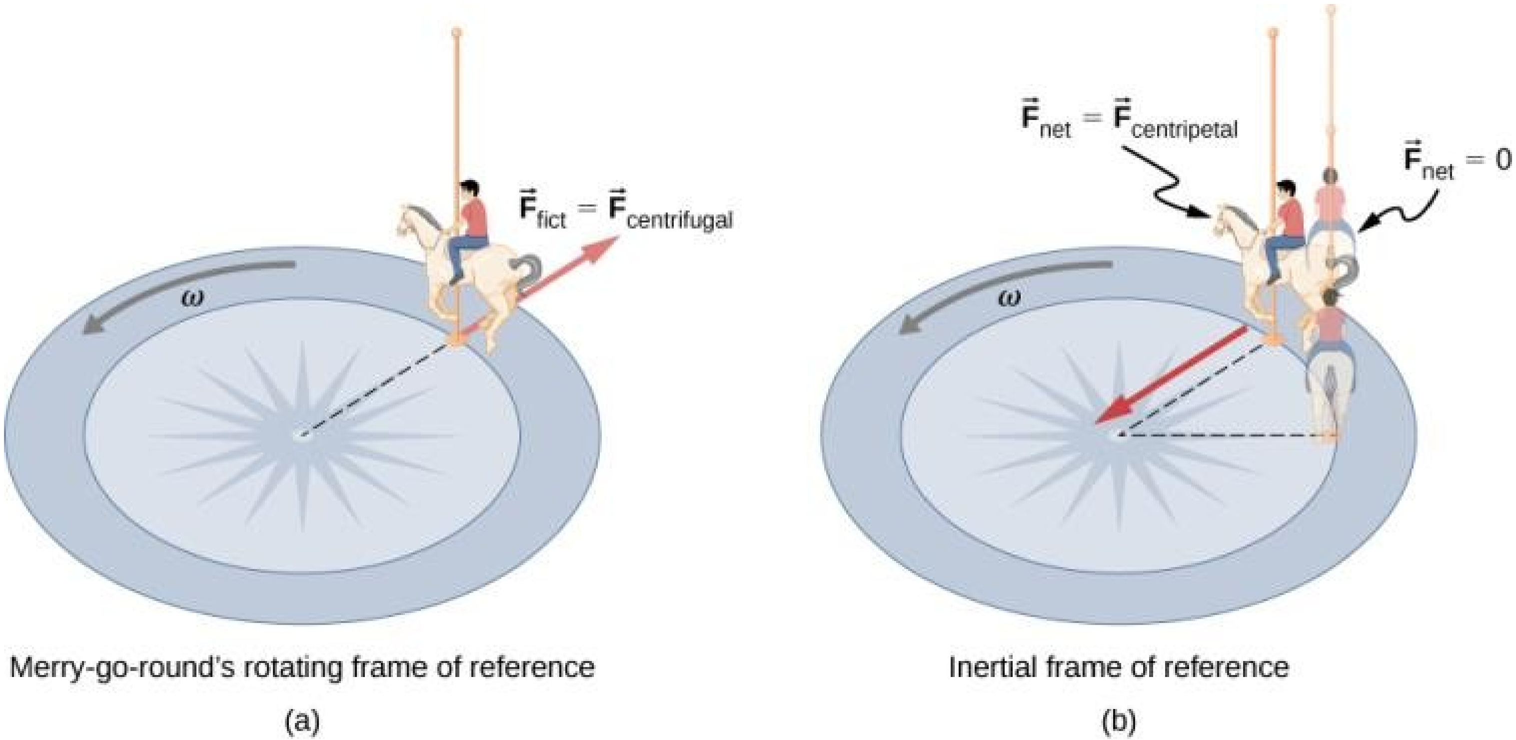




Free-body diagram of an object falling through a resistive medium.

Black board derivation

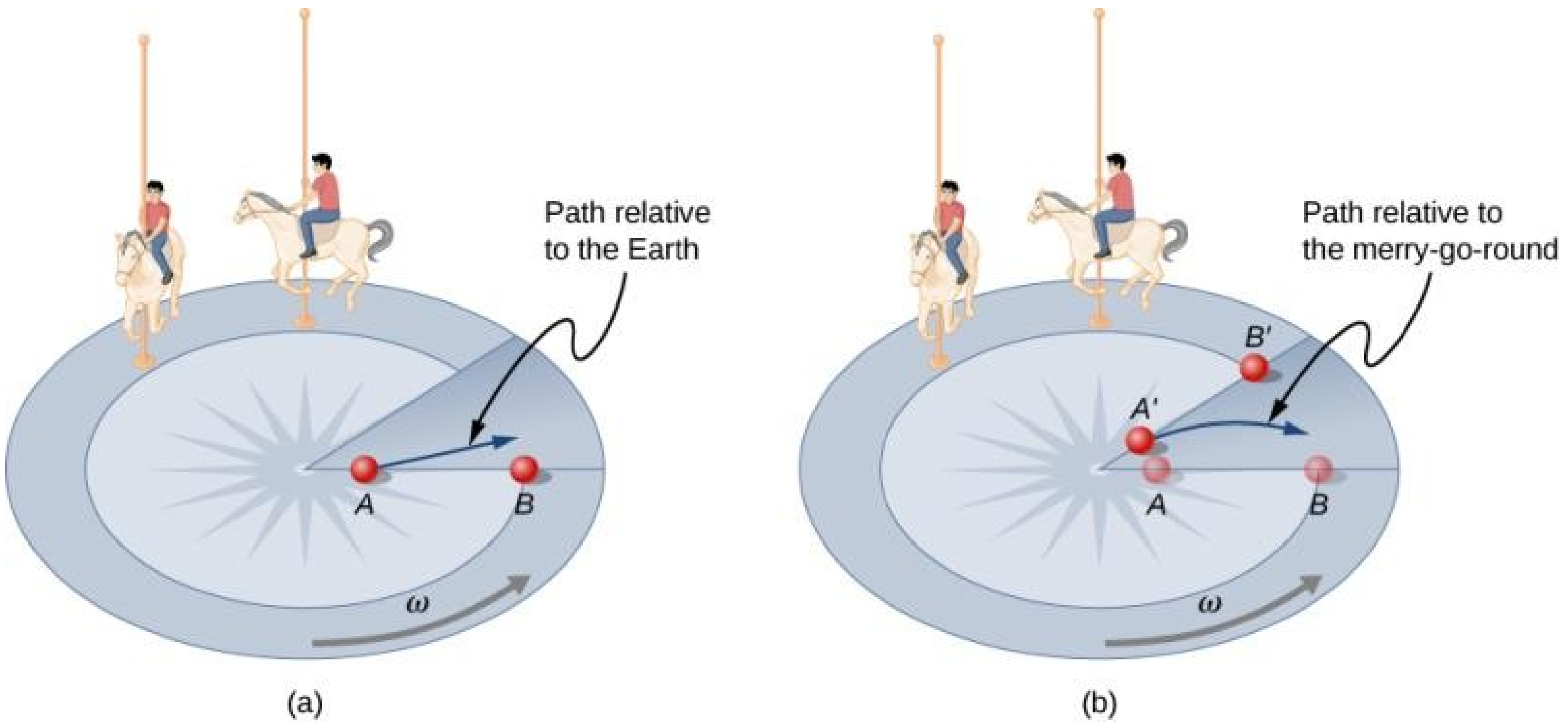
FIGURE 6.25 READ ABOUT CORIOLIS FORCE, EXCLUDED IN QUIZ OR EXAMS



(a) A rider on a merry-go-round feels as if he is being thrown off. This inertial force is sometimes mistakenly called the centrifugal force in an effort to explain the rider's motion in the rotating frame of reference.

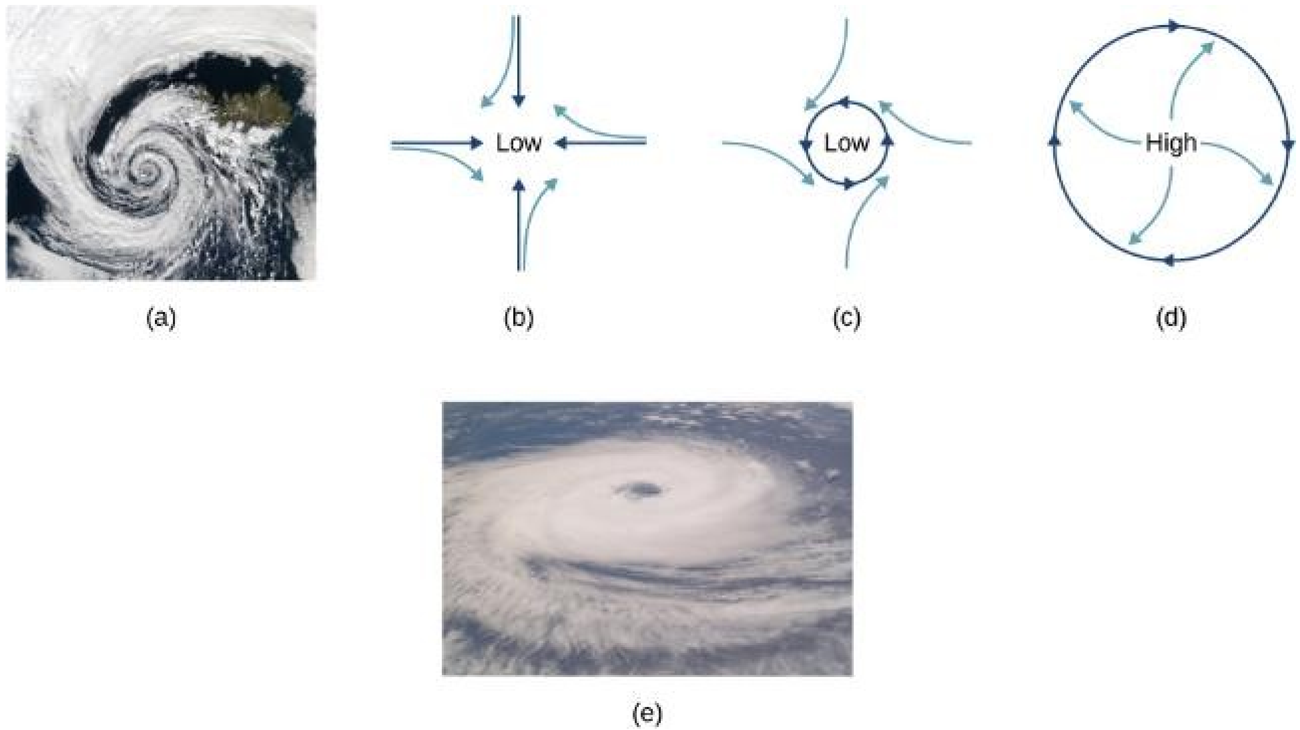
(b) In an inertial frame of reference and according to Newton's laws, it is his inertia that carries him off (the unshaded rider has and heads in a straight line). A force, , is needed to cause a circular path.

FIGURE 6.27 READ ABOUT CORIOLIS FORCE, EXCLUDED IN QUIZ OR EXAMS



Looking down on the counterclockwise rotation of a merry-go-round, we see that a ball slid straight toward the edge follows a path curved to the right. The person slides the ball toward point *B*, starting at point *A*. Both points rotate to the shaded positions (*A*' and *B*') shown in the time that the ball follows the curved path in the rotating frame and a straight path in Earth's frame.

FIGURE 6.28 : READ ABOUT CORIOLIS FORCE, EXCLUDED IN QUIZ OR EXAMS



(a) The counterclockwise rotation of this Northern Hemisphere hurricane is a major consequence of the Coriolis force.

(b) Without the Coriolis force, air would flow straight into a low-pressure zone, such as that found in tropical cyclones.

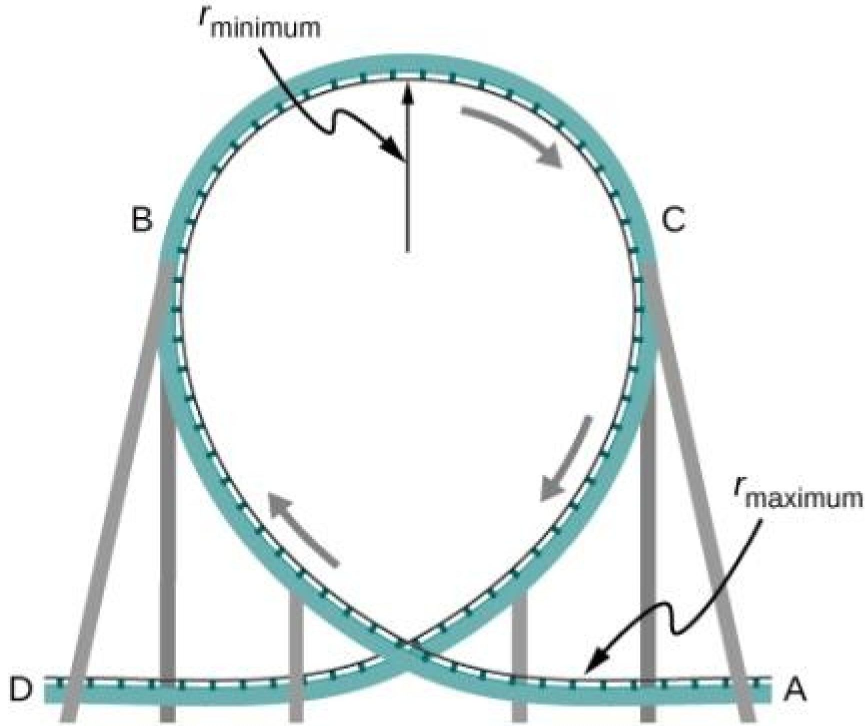
(c) The Coriolis force deflects the winds to the right, producing a counterclockwise rotation.

(d) Wind flowing away from a high-pressure zone is also deflected to the right, producing a clockwise rotation.

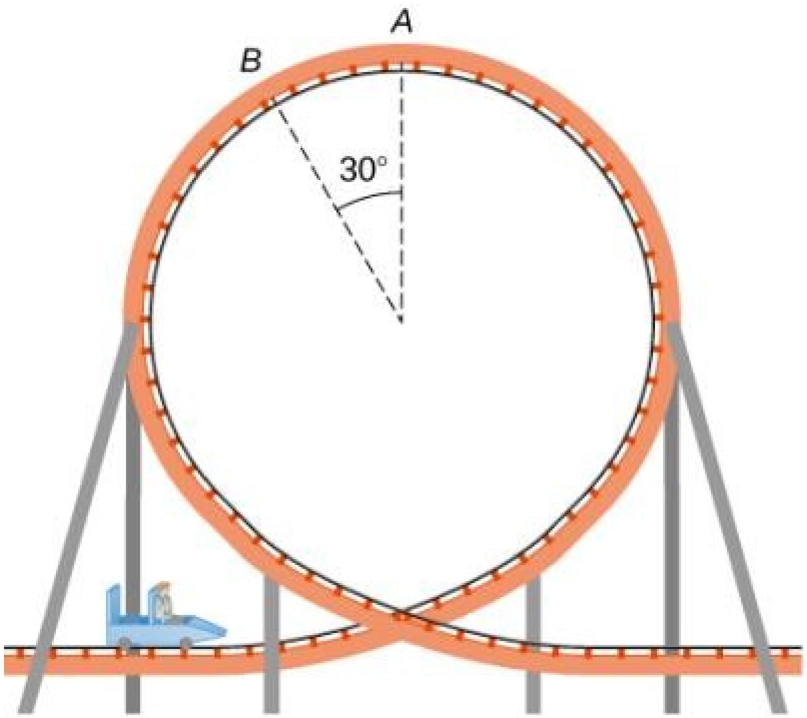
(e) The opposite direction of rotation is produced by the Coriolis force in the Southern Hemisphere, leading to tropical cyclones. (credit a and credit e: modifications of work by NASA)

EXERCISE 11

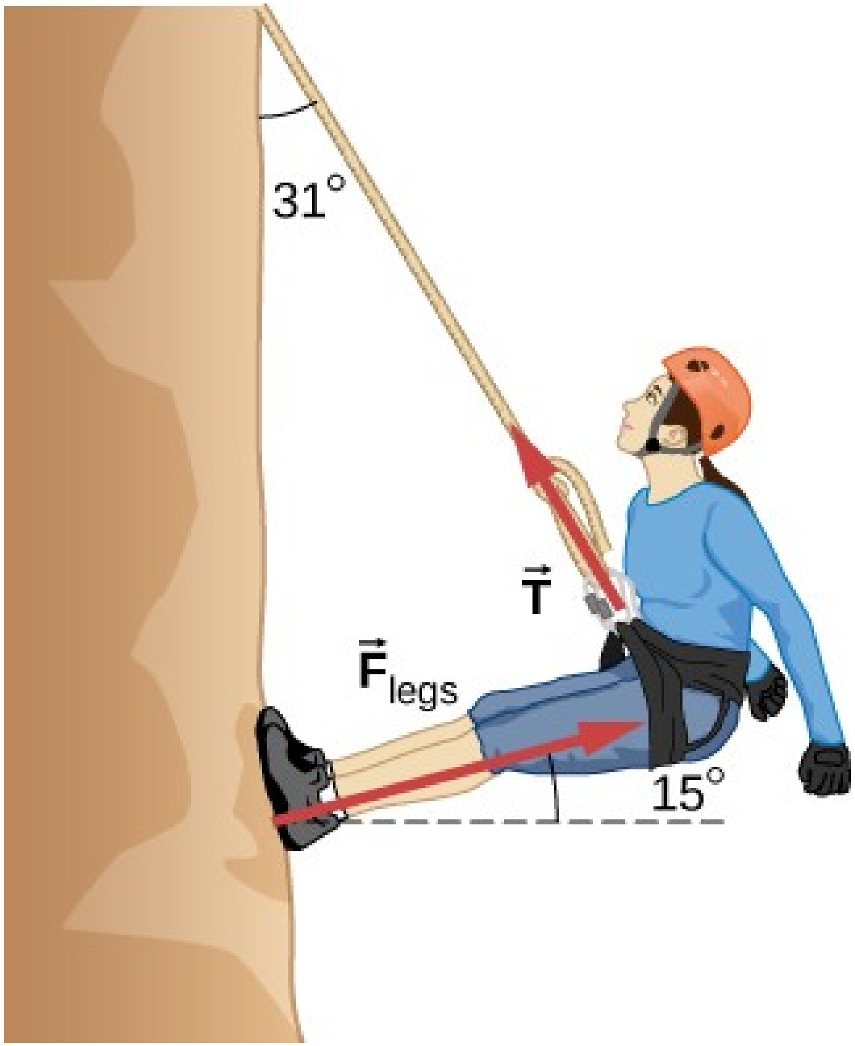
EXERCISE 72



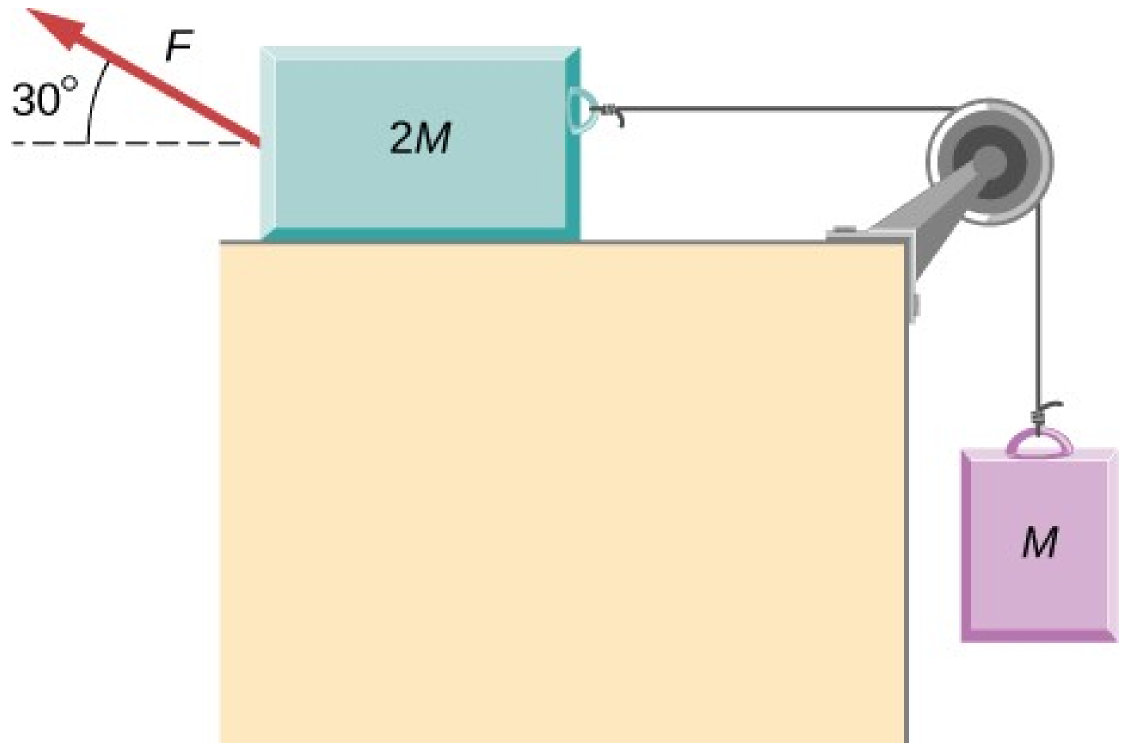
EXERCISE 73



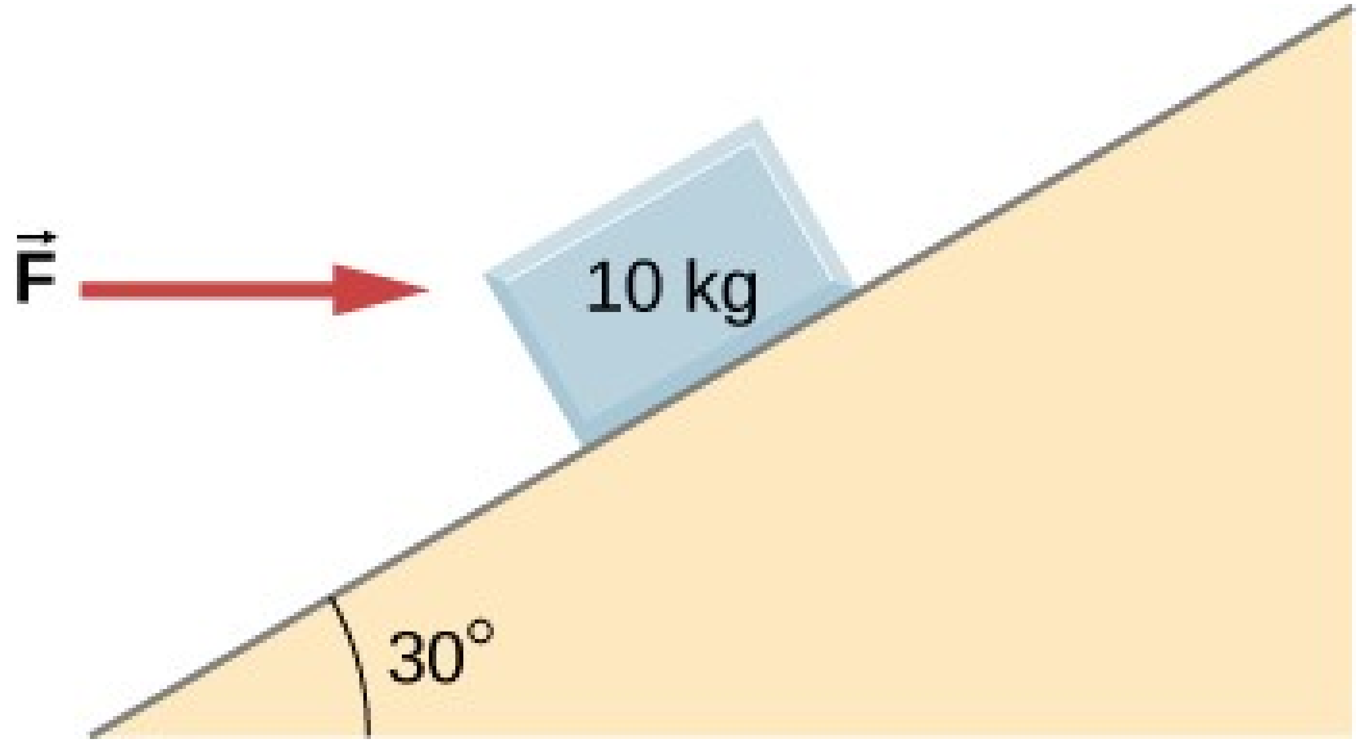
EXERCISE 61



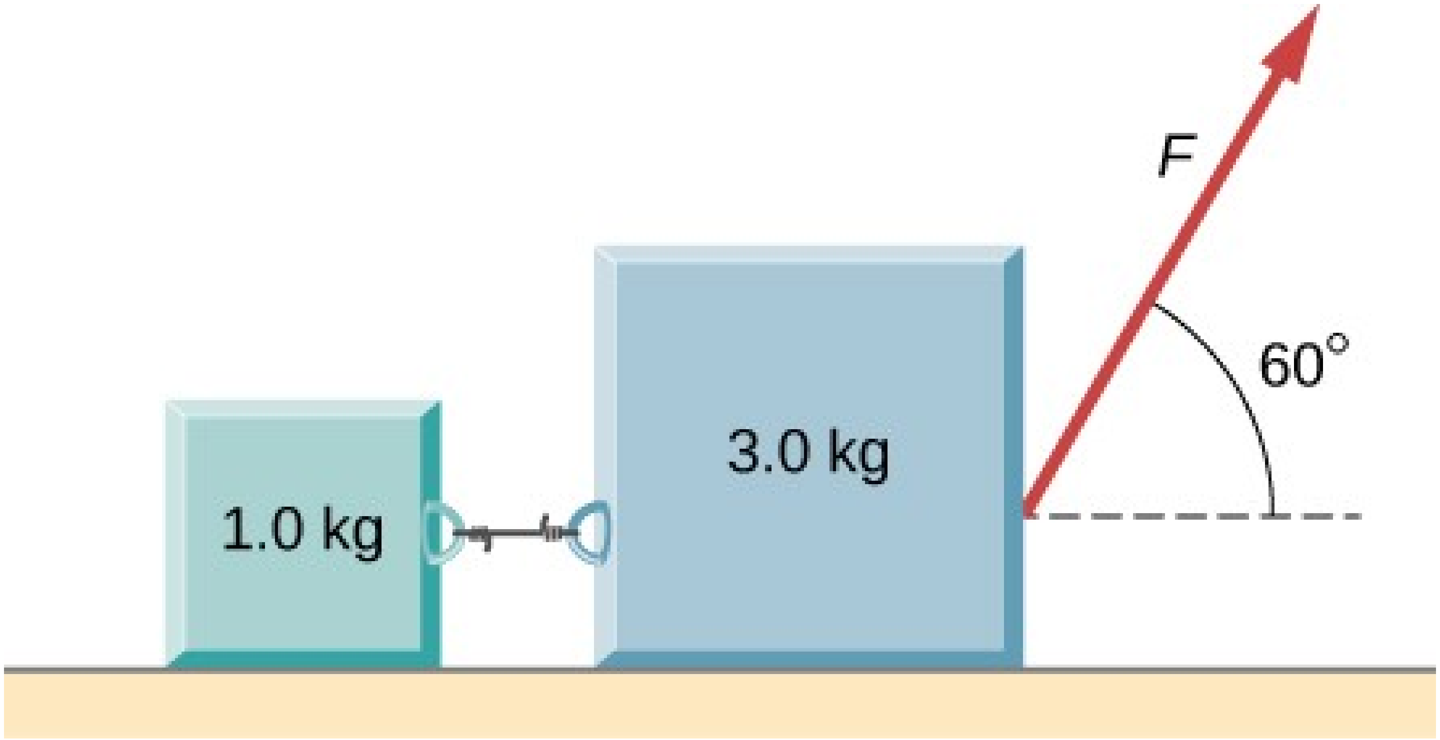
EXERCISE 94



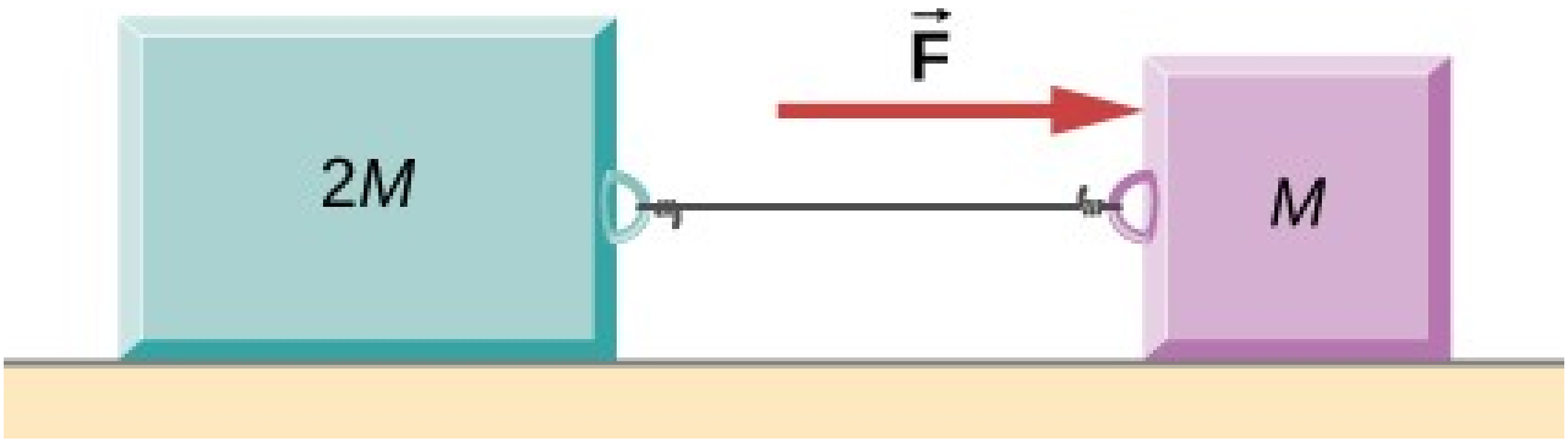
EXERCISE 108



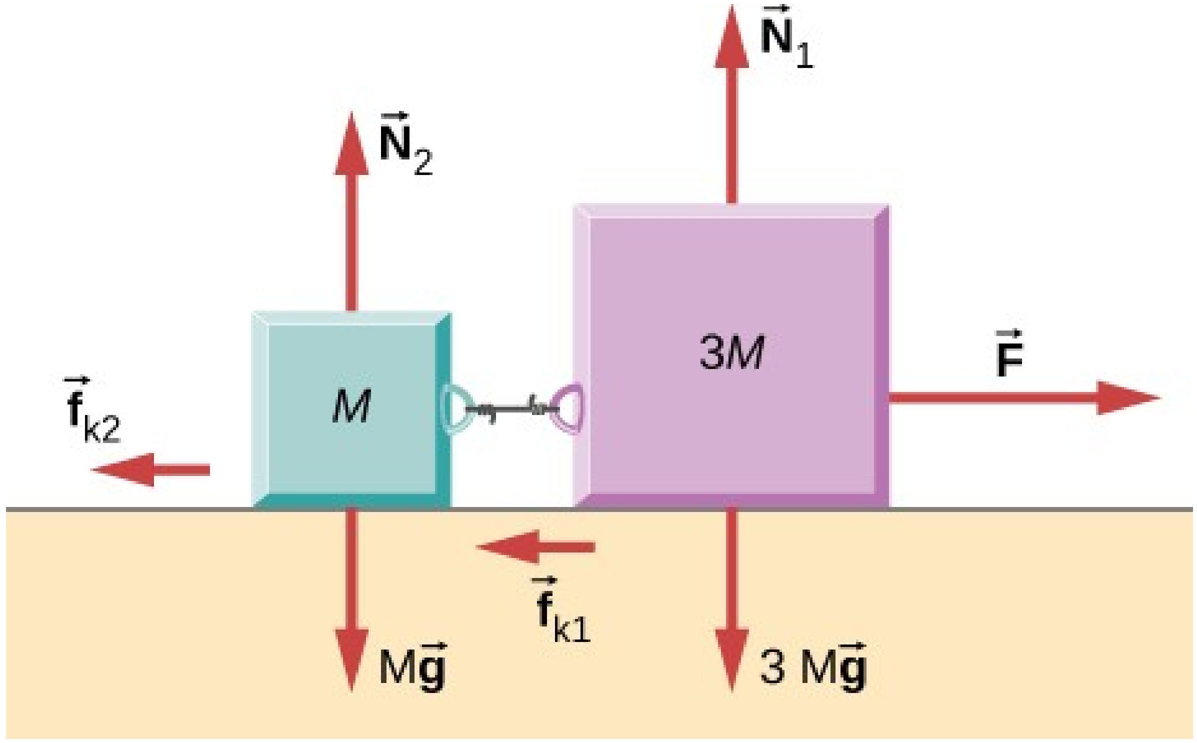
EXERCISE 123



EXERCISE 124



EXERCISE 125



EXERCISE 126