ANNOUNCEMENTS

- Homework #5, due Friday, September 28

  Conceptual questions: Chapter 5, #8 and #12
  Problems: Chapter 5, #64, #88

- Study Textbook Chapter 6 before Monday, October 1

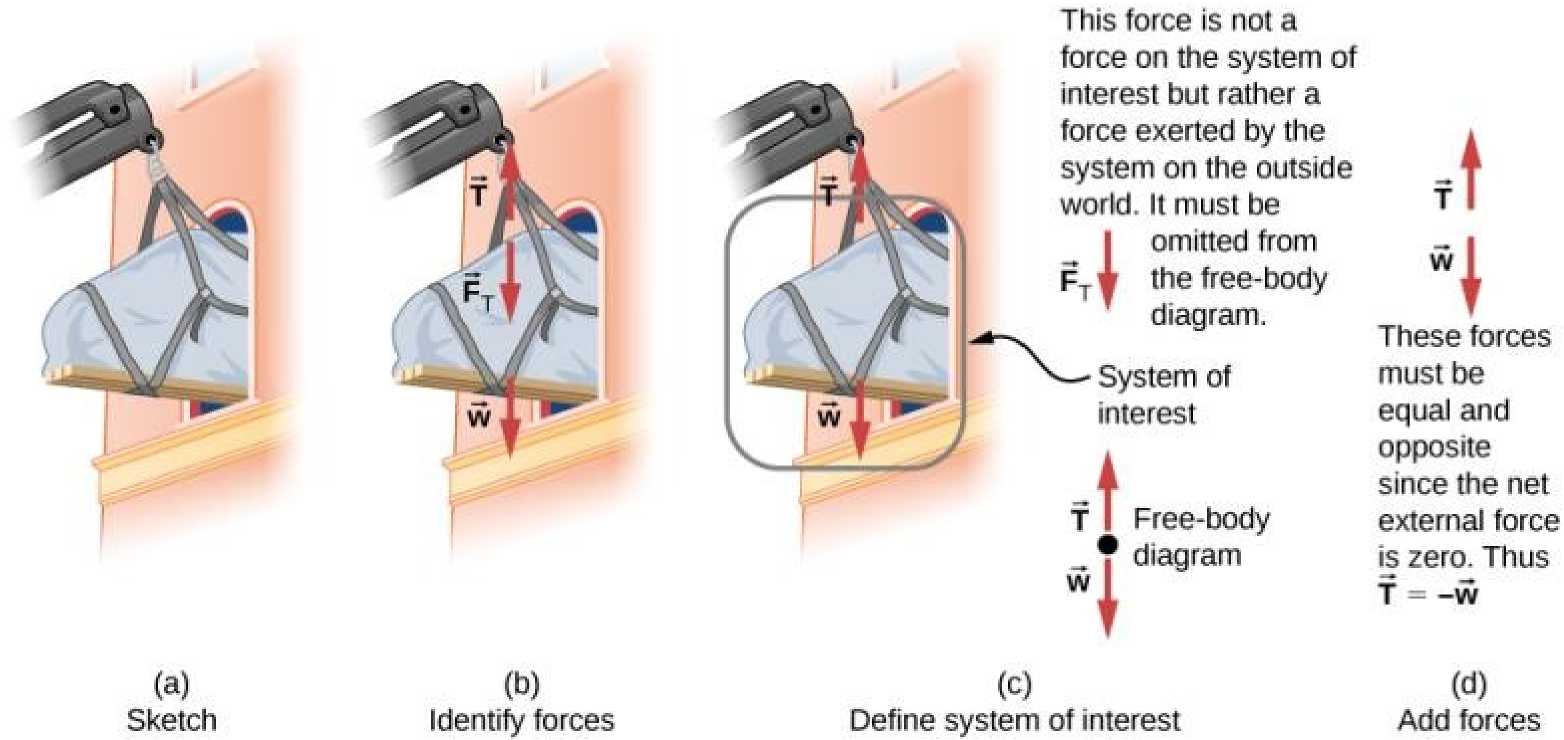
- 5-minute quiz on Chapter 6: Wednesday, October 3

Problem-Solving Strategy: Applying Newton's Laws of Motion

1. Identify the physical principles involved by listing the givens and the quantities to be calculated.
2. Sketch the situation, using arrows to represent all forces.
3. Determine the system of interest. The result is a free-body diagram that is essential to solving the problem.
4. Apply Newton's second law to solve the problem. If necessary, apply appropriate kinematic equations from the chapter on motion along a straight line.
5. Check the solution to see whether it is reasonable.

$$\sum F_x = ma_x, \quad \sum F_y = ma_y.$$

EXAMPLE



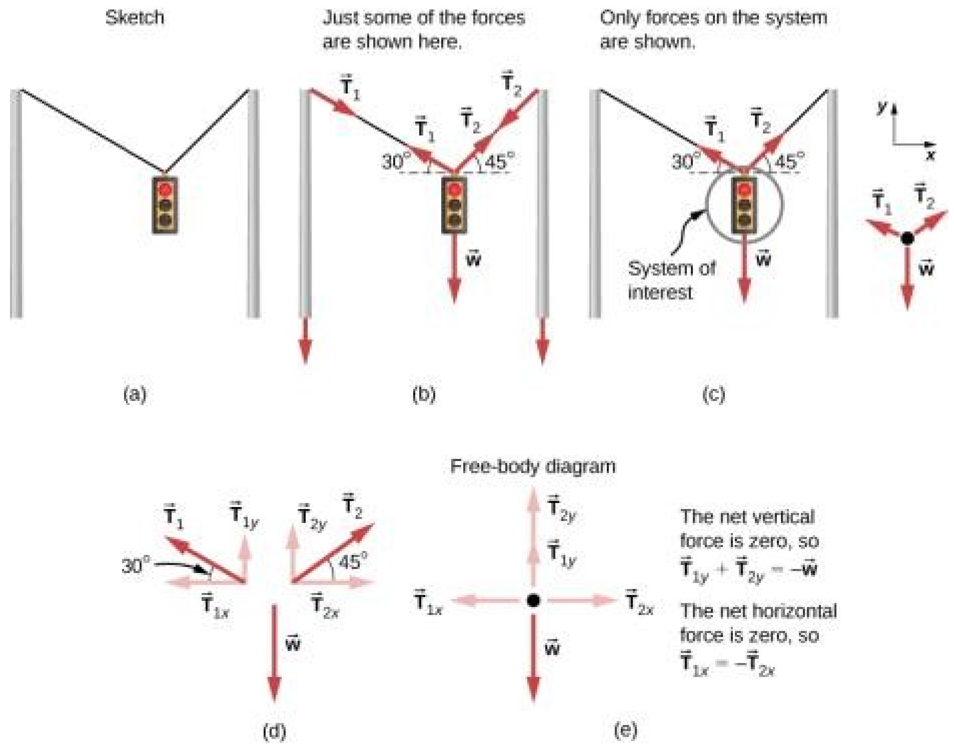
(a) A grand piano is being lifted to a second-story apartment.

(b) Arrows are used to represent all forces: $\vec{\mathbf{T}}$ is the tension in the rope above the piano, $\vec{\mathbf{F}}_{\mathrm{T}}$ is the force that the piano exerts on the rope, and $\vec{\mathbf{w}}$ is the weight of the piano. All other forces, such as the nudge of a breeze, are assumed to be negligible.

(c) Suppose we are given the piano's mass and asked to find the tension in the rope. We then define the system of interest as shown and draw a free-body diagram. Now $\vec{\mathbf{F}}_{\mathrm{T}}$ is no longer shown, because it is not a force acting on the system of interest; rather, $\vec{\mathbf{F}}_{\mathrm{T}}$ acts on the outside world.

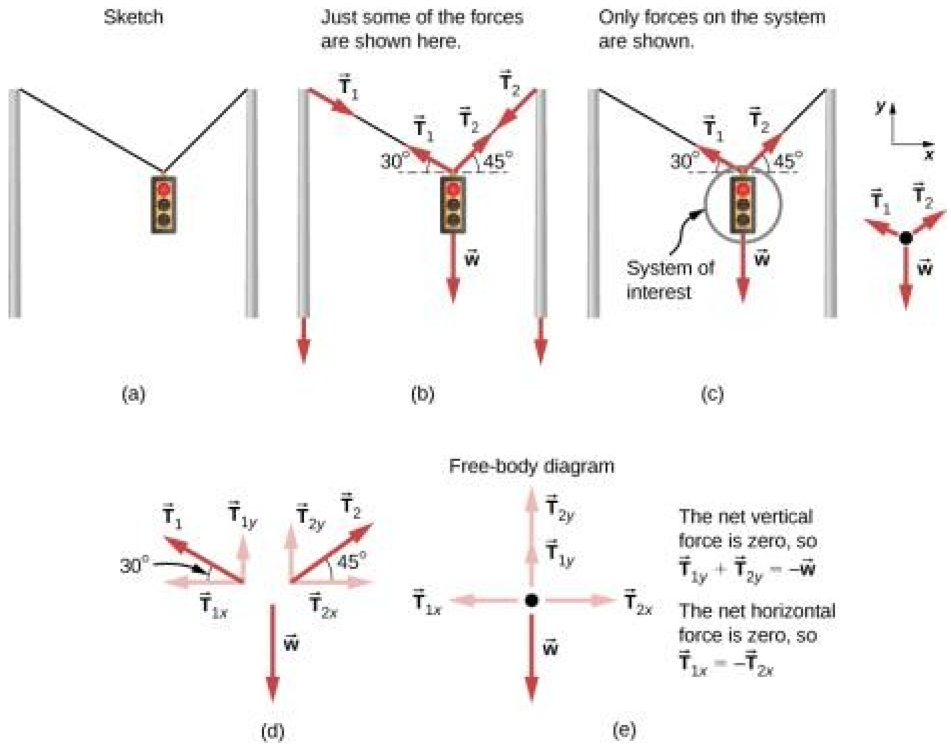
(d) Showing only the arrows, the head-to-tail method of addition is used. It is apparent that if the piano is stationary, $\vec{\mathbf{T}} = -\vec{\mathbf{w}}$.

EXAMPLE



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.

EXAMPLE



Solution

First consider the horizontal or *x*-axis:

$$F_{\text{net } x} = T_{2x} + T_{1x} = 0.$$

Thus, as you might expect,

$$|T_{1x}| = |T_{2x}|.$$

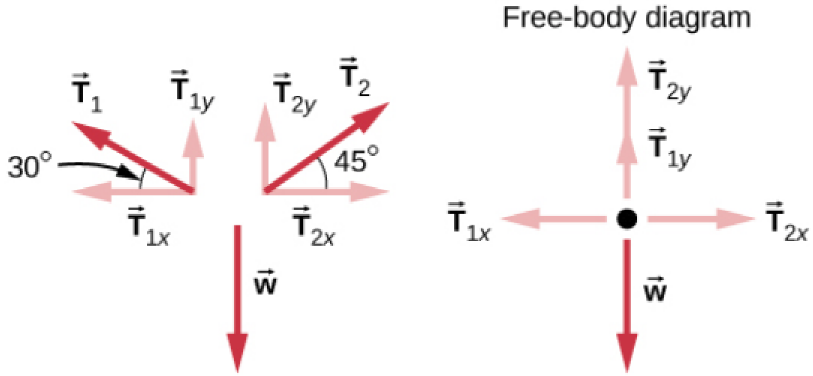
This gives us the following relationship:

$$T_1 \cos 30° = T_2 \cos 45°.$$

Thus,

$$T_2 = 1.225 T_1.$$

EXAMPLE



The net vertical force is zero, so $\vec{T}_{1y} + \vec{T}_{2y} = -\vec{w}$

The net horizontal force is zero, so $\vec{T}_{1x} = -\vec{T}_{2x}$

Now consider the force components along the vertical or *y*-axis:

$$F_{\text{net }y} = T_{1y} + T_{2y} - w = 0.$$

This implies

$$T_{1y} + T_{2y} = w.$$

Substituting the expressions for the vertical components gives

$$T_1 \sin 30° + T_2 \sin 45° = w.$$

There are two unknowns in this equation, but substituting the expression for T_2 in terms of T_1 reduces this to one equation with one unknown:

$$T_1(0.500) + (1.225T_1)(0.707) = w = mg,$$

which yields

$$1.366T_1 = (15.0 \text{ kg})(9.80 \text{ m/s}^2).$$

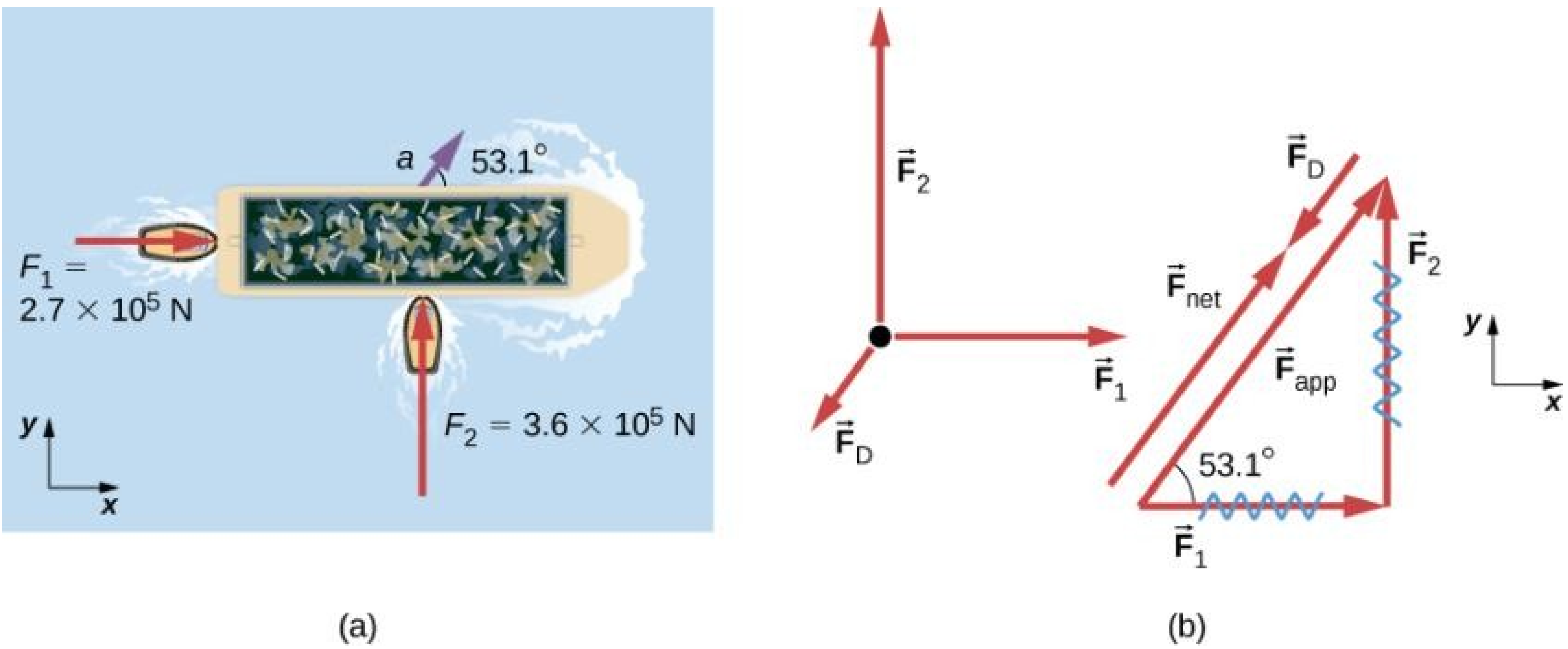
Solving this last equation gives the magnitude of T_1 to be

$$T_1 = 108 \text{ N}.$$

Finally, we find the magnitude of T_2 by using the relationship between them, $T_2 = 1.225T_1$, found above. Thus we obtain

$$T_2 = 132 \text{ N}.$$

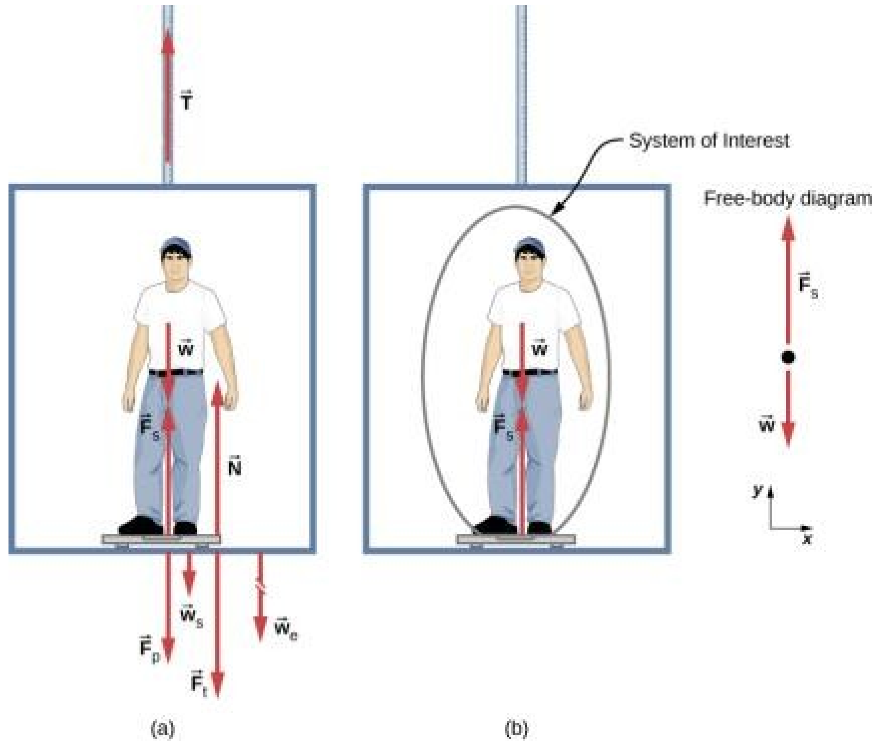
EXAMPLE



(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 $\vec{\mathbf{F}}_{\text{app}}$ is the total applied force of the tugboats.

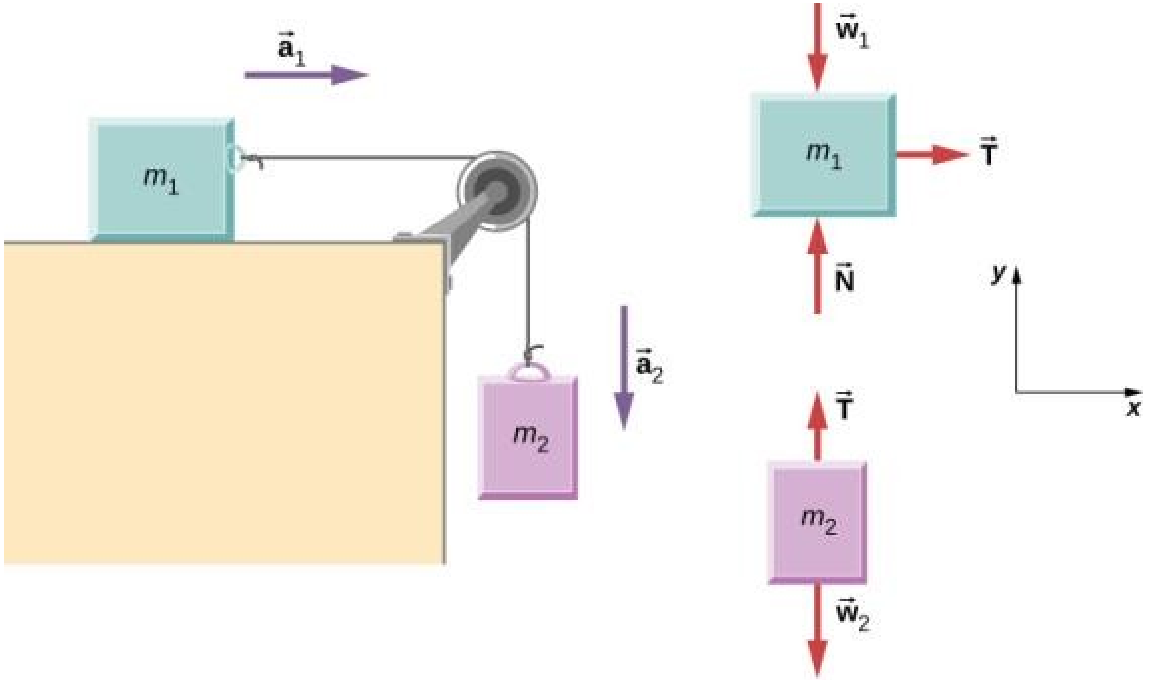
EXAMPLE



(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. $\vec{\mathbf{T}}$ is the tension in the supporting cable, $\vec{\mathbf{w}}$ is the weight of the person, $\vec{\mathbf{w}}_s$ is the weight of the scale, $\vec{\mathbf{w}}_e$ is the weight of the elevator, $\vec{\mathbf{F}}_s$ is the force of the scale on the person, $\vec{\mathbf{F}}_p$ is the force of the person on the scale, $\vec{\mathbf{F}}_t$ is the force of the scale on the floor of the elevator, and $\vec{\mathbf{N}}$ is the force of the floor upward on the scale.

(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.

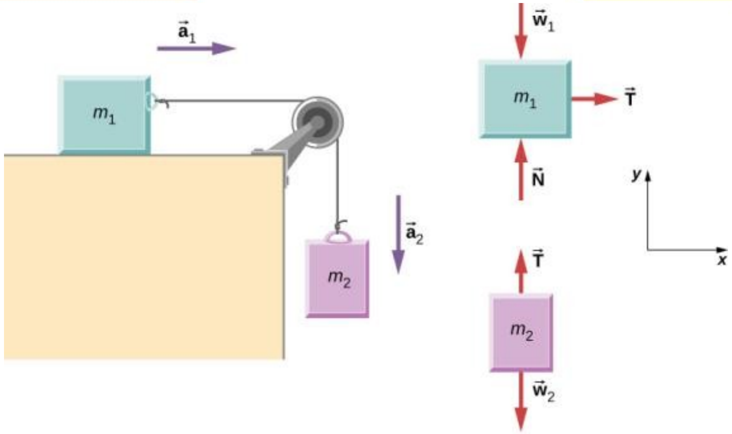
EXAMPLE



(a) (b)

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

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



Solution

The component equations follow from the vector equations above. We see that block 1 has the vertical forces balanced, so we ignore them and write an equation relating the *x*-components. There are no horizontal forces on block 2, so only the *y*-equation is written. We obtain these results:

$$\begin{array}{ll} \textbf{Block 1} & \textbf{Block 2} \\ \sum F_x = ma_x & \sum F_y = ma_y \\ T_x = m_1 a_{1x} & T_y - m_2 g = m_2 a_{2y}. \end{array}$$

When block 1 moves to the right, block 2 travels an equal distance downward; thus, $a_{1x} = -a_{2y}$. Writing the common acceleration of the blocks as $a = a_{1x} = -a_{2y}$, we now have

$$T = m_1 a$$

and

$$T - m_2 g = -m_2 a.$$

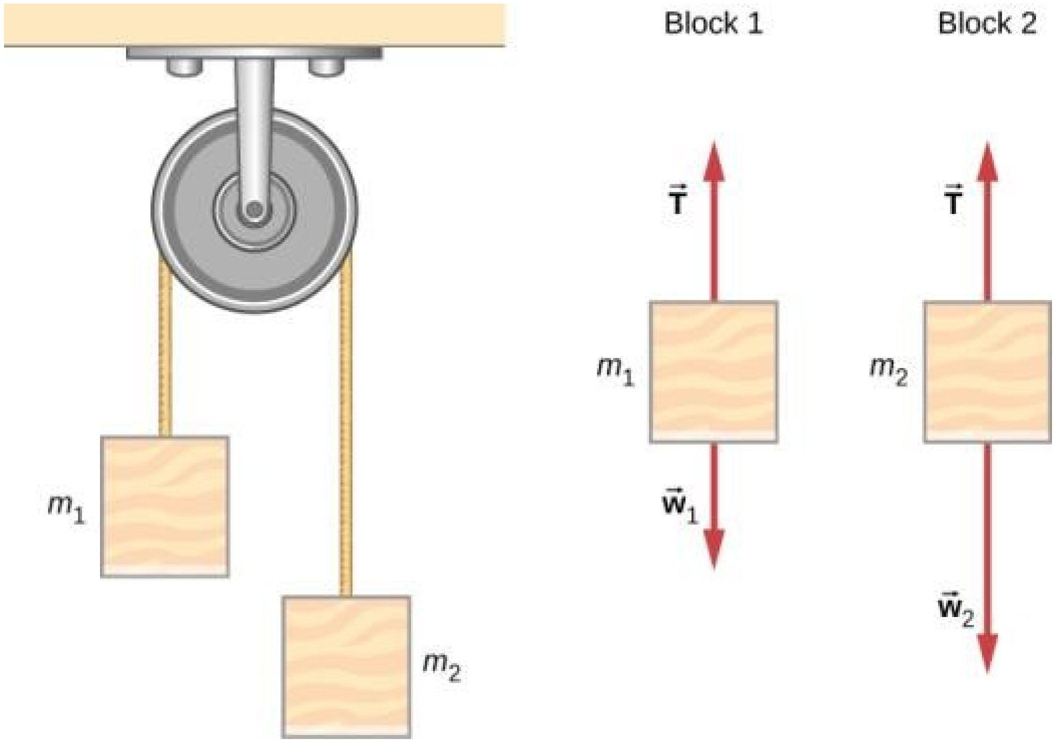
From these two equations, we can express *a* and *T* in terms of the masses m_1 and m_2, and g :

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

and

$$T = \frac{m_1 m_2}{m_1 + m_2} g.$$

DIY!

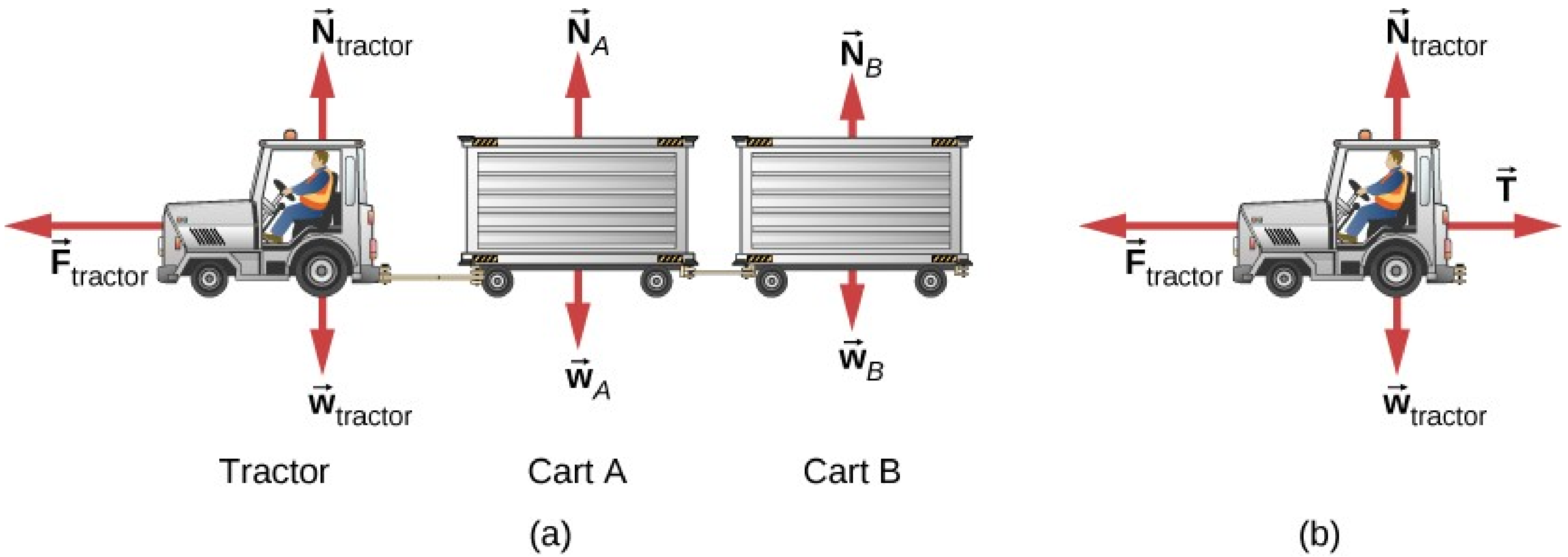


An Atwood machine and free-body diagrams for each of the two blocks.

EXAMPLE

Baggage Tractor

Figure 6.8(a) shows a baggage tractor pulling luggage carts from an airplane. 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 $F = (820.0t)\ \mathrm{N}$, find the speed after 3.00 seconds. (b) What is the horizontal force acting on the connecting cable between the tractor and cart A at this instant?



(a) A free-body diagram is shown, which indicates all the external forces on the system consisting of the tractor and baggage carts for carrying airline luggage.

(b) A free-body diagram of the tractor only is shown isolated in order to calculate the tension in the cable to the carts.

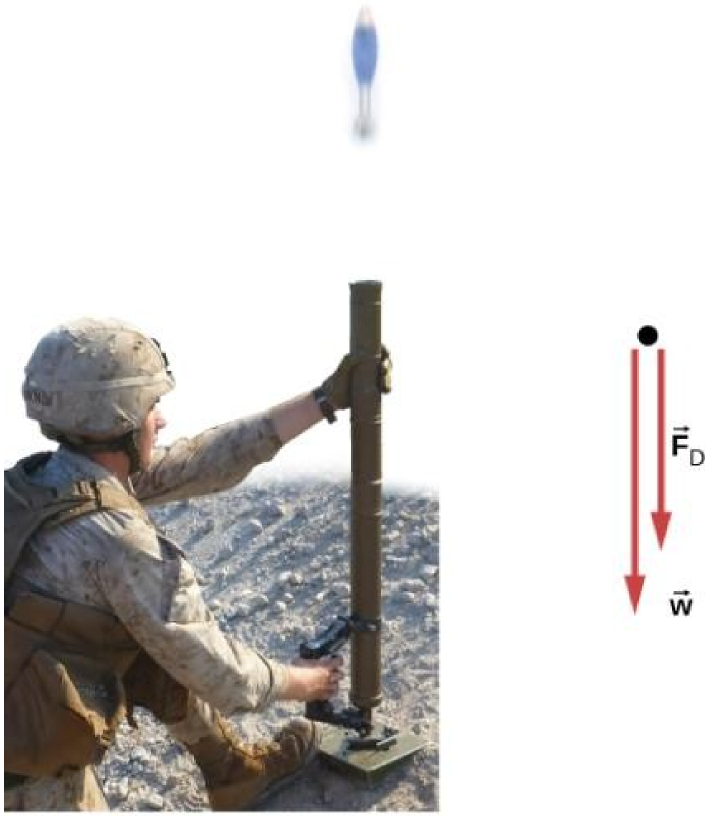
DIY

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.

(a) The mortar fires a shell straight up; we consider the friction force provided by the air.

(b) A free-body diagram is shown which indicates all the forces on the mortar shell.

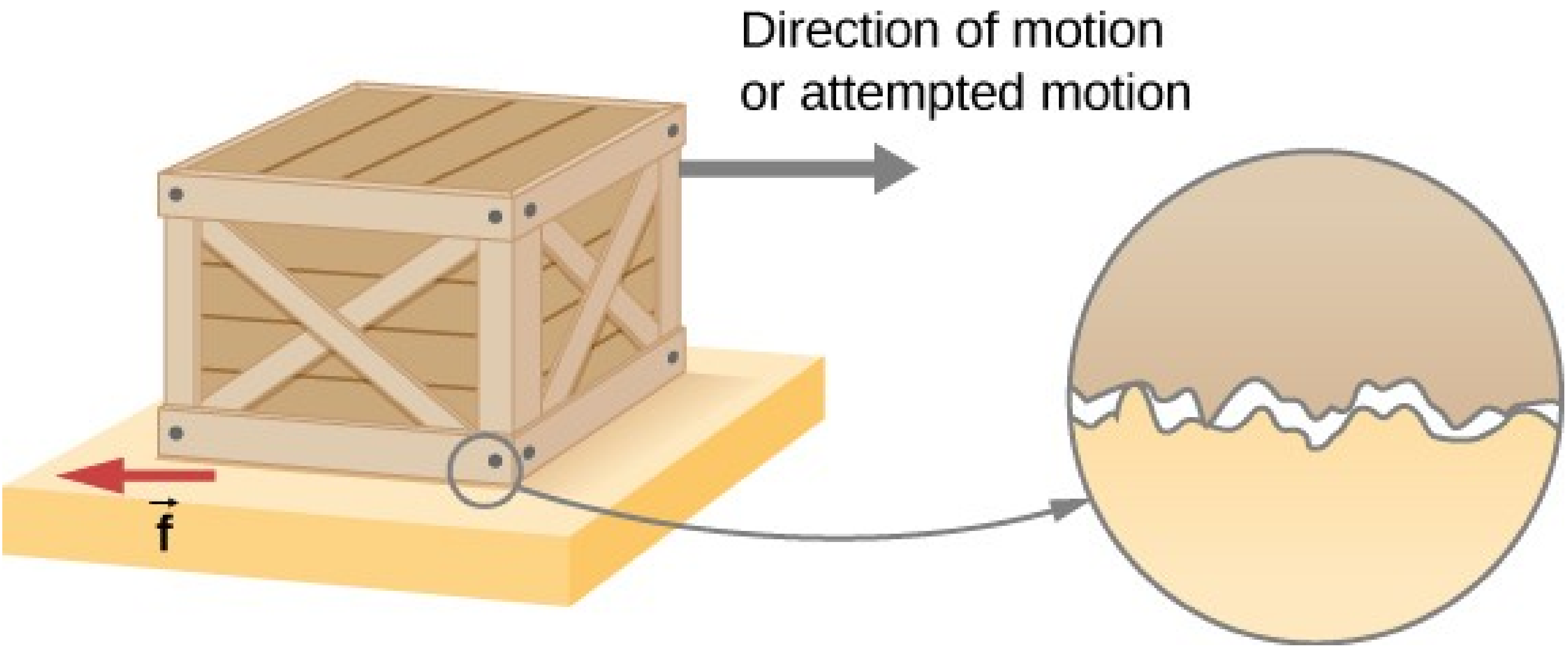


(a) (b)

FRICTION

FRICTION

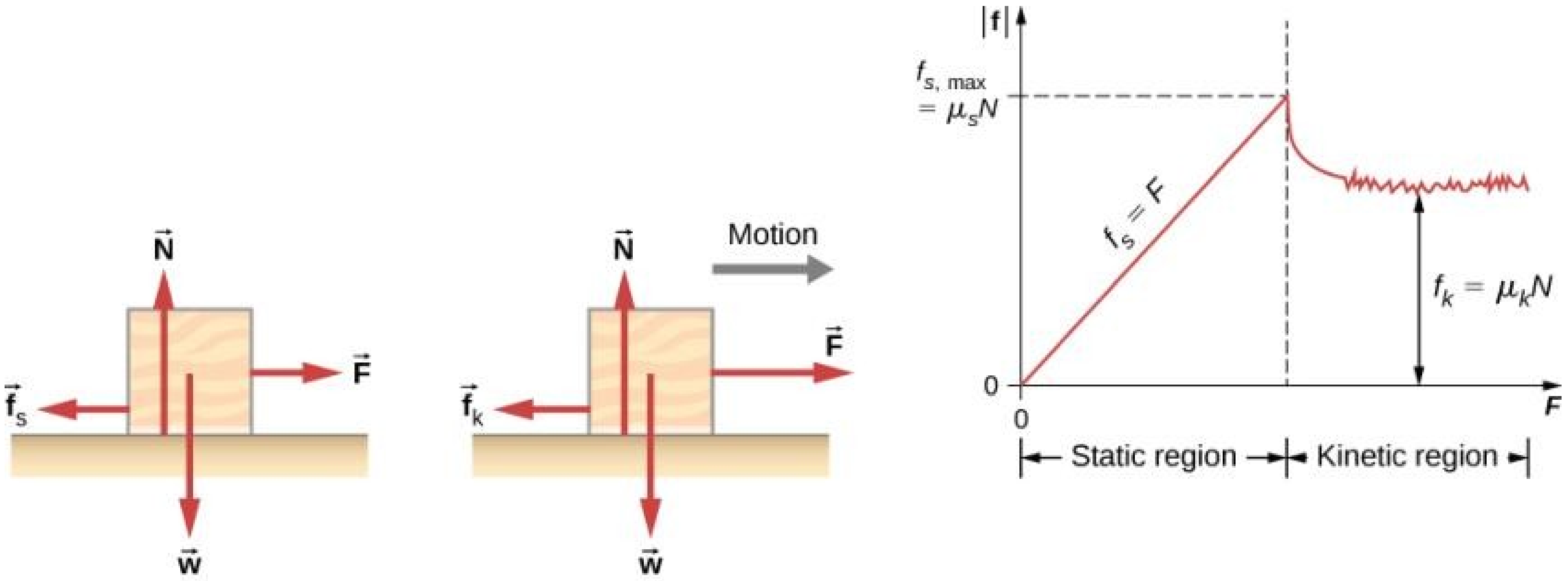
Friction is a force that opposes relative motion between systems in contact.



Frictional forces, such as $\vec{\mathbf{f}}$, always oppose motion or attempted motion between objects in contact. Friction arises in part because of the roughness of the surfaces in contact, as seen in the expanded view. For the object to move, it must rise to where the peaks of the top surface can skip along the bottom surface. Thus, a force is required just to set the object in motion. Some of the peaks will be broken off, also requiring a force to maintain motion. Much of the friction is actually due to attractive forces between molecules making up the two objects, so that even perfectly smooth surfaces are not friction-free. (In fact, perfectly smooth, clean surfaces of similar materials would adhere, forming a bond called a “cold weld.”)

STATIC AND KINETIC FRICTION

If two systems are in contact and stationary relative to one another, then the friction between them is called **static friction**. If two systems are in contact and moving relative to one another, then the friction between them is called **kinetic friction**.



(a) Impending motion

(b) Object moves

(c)

(a) The force of friction $\vec{\mathbf{f}}$ between the block and the rough surface opposes the direction of the applied force $\vec{\mathbf{F}}$. 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 $f_s(\max) > f_k$. This means that $\mu_s > \mu_k$.

MAGNITUDE OF STATIC FRICTION

The magnitude of static friction f_s is

$$f_s \leq \mu_s N, \tag{6.1}$$

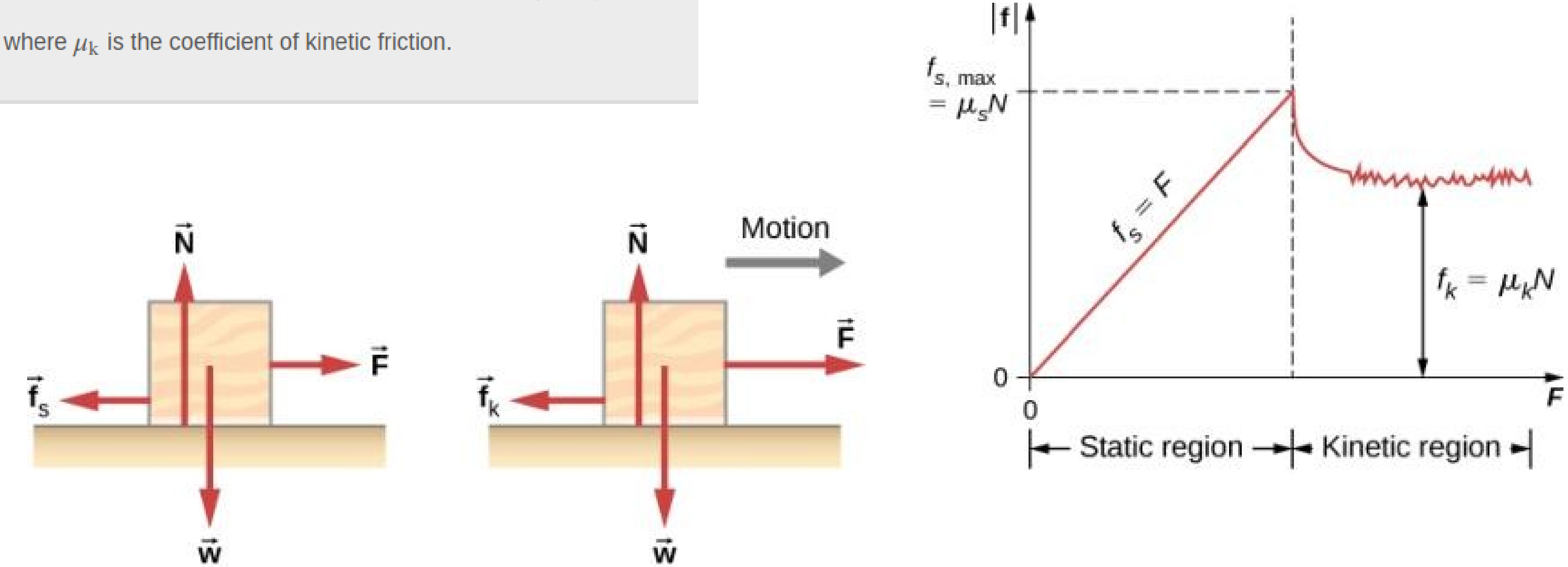
where μ_s is the coefficient of static friction and N is the magnitude of the normal force.

MAGNITUDE OF KINETIC FRICTION

The magnitude of kinetic friction f_k is given by

$$f_k = \mu_k N,$$

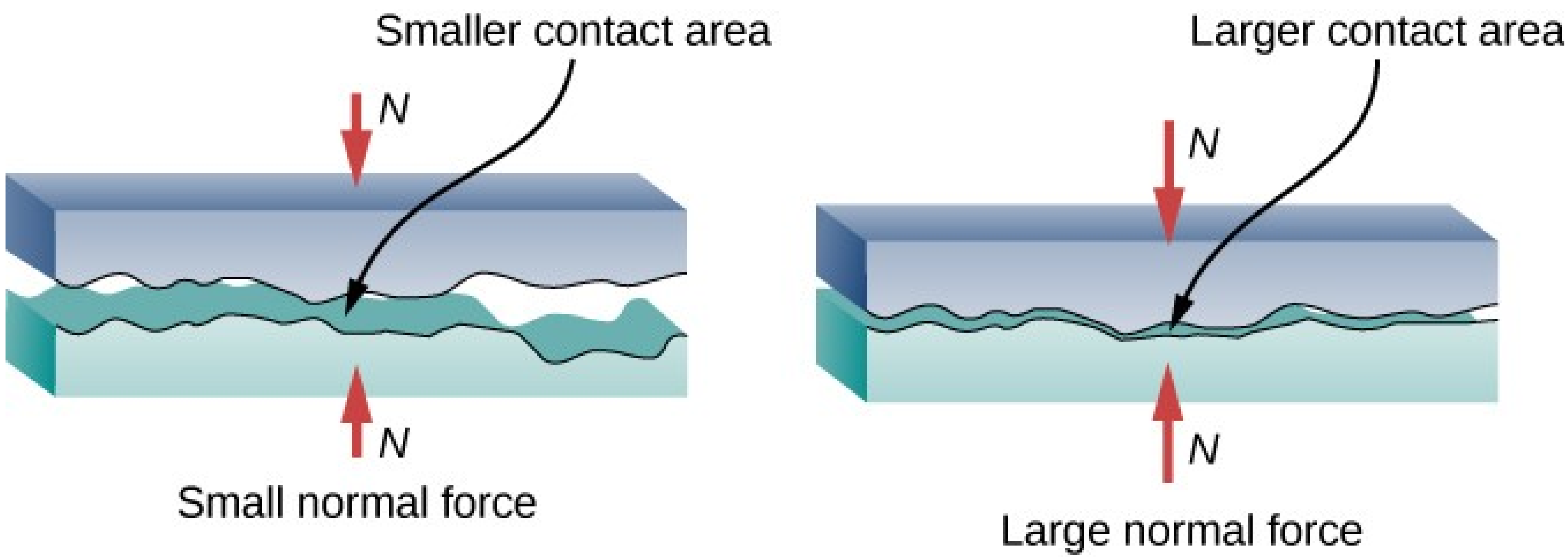
where μ_k is the coefficient of kinetic friction.



(a)
Impending motion

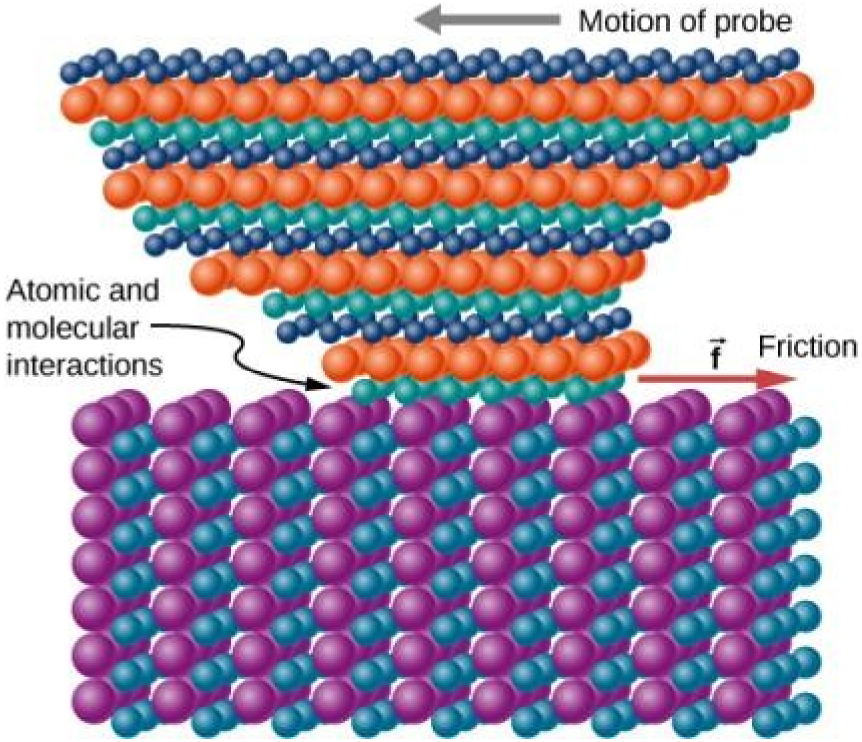
(b)
Object moves

(c)



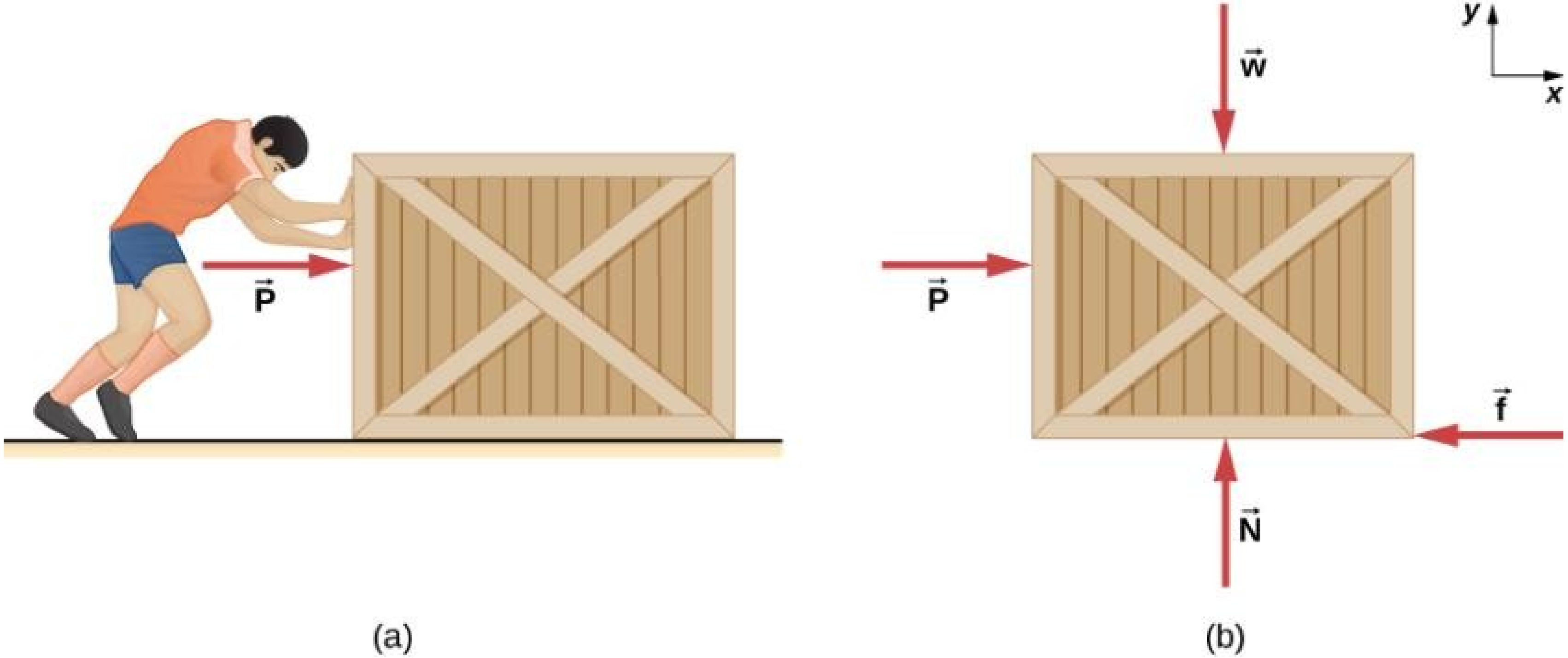
Two rough surfaces in contact have a much smaller area of actual contact than their total area. When the normal force is larger as a result of a larger applied force, the area of actual contact increases, as does friction.

FIGURE 6.16



The tip of a probe is deformed sideways by frictional force as the probe is dragged across a surface. Measurements of how the force varies for different materials are yielding fundamental insights into the atomic nature of friction.

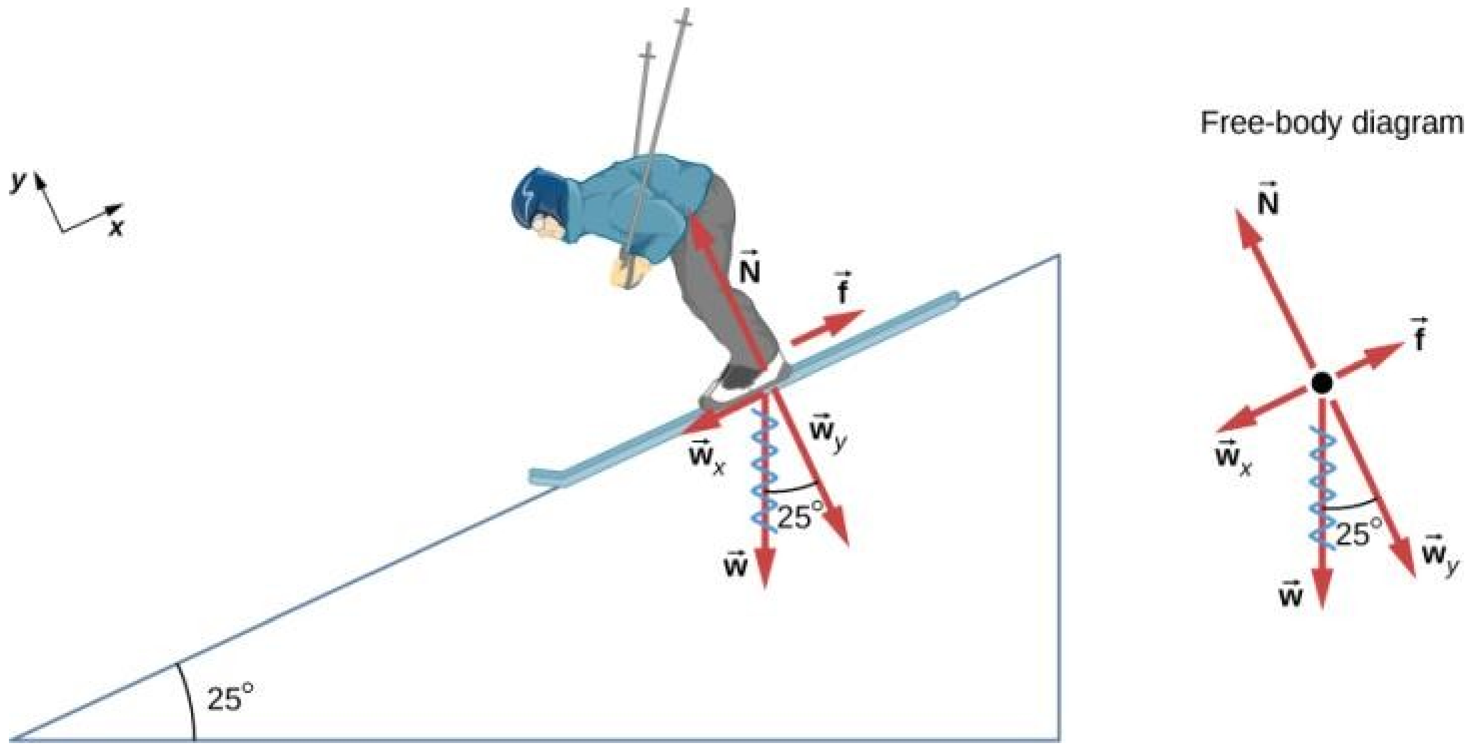
EXAMPLE



(a) A crate on a horizontal surface is pushed with a force $\vec{\mathbf{P}}$.

(b) The forces on the crate. Here, $\vec{\mathbf{f}}$ may represent either the static or the kinetic frictional force.

DIY!

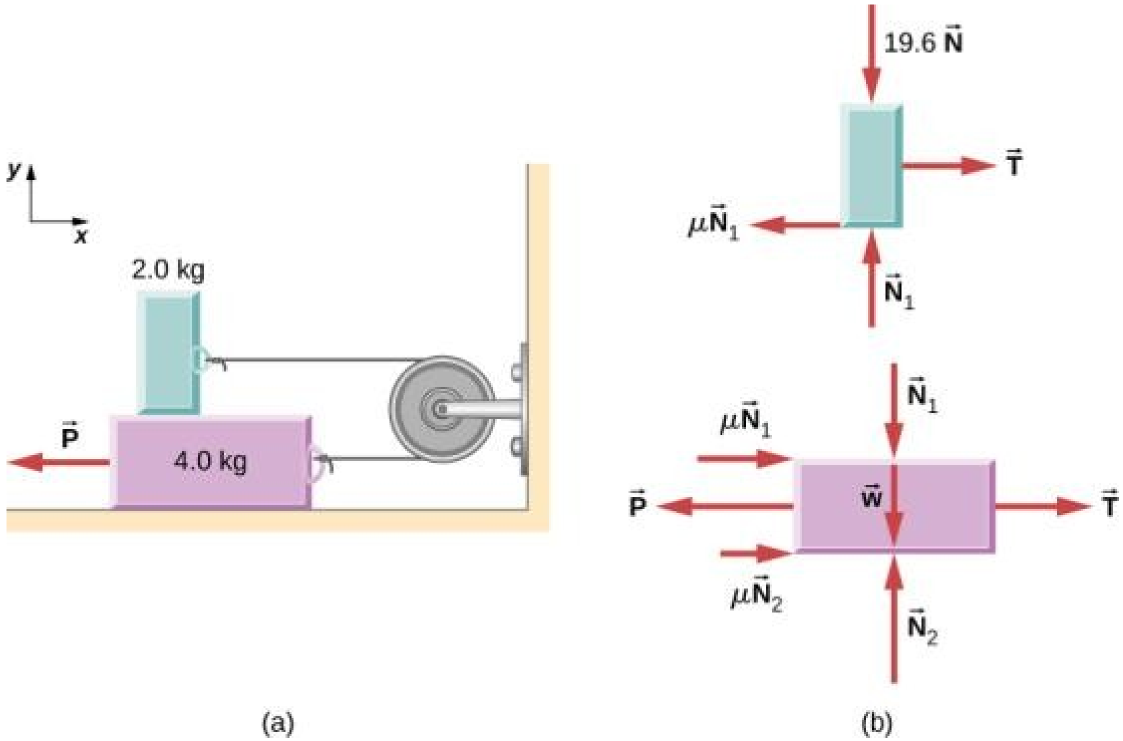


The motion of the skier and friction are parallel to the slope, so it is most convenient to project all forces onto a coordinate system where one axis is parallel to the slope and the other is perpendicular (axes shown to left of skier). The normal force $\vec{\mathbf{N}}$ is perpendicular to the slope,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

EXAMPLE

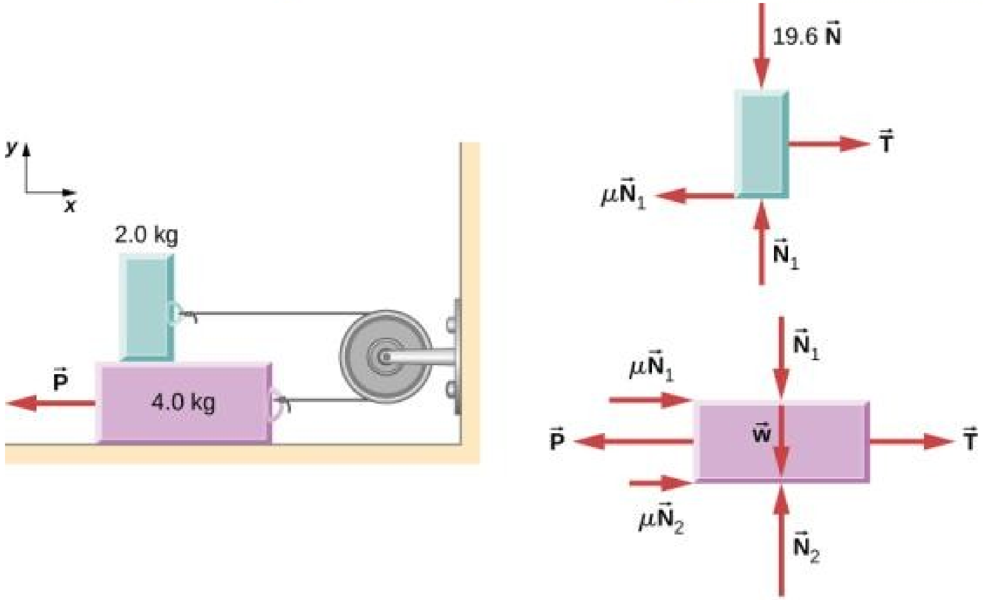
Sliding Blocks

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.



(a) Free-body diagrams for the blocks.

(b) Each block moves at constant velocity.



Solution

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,

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

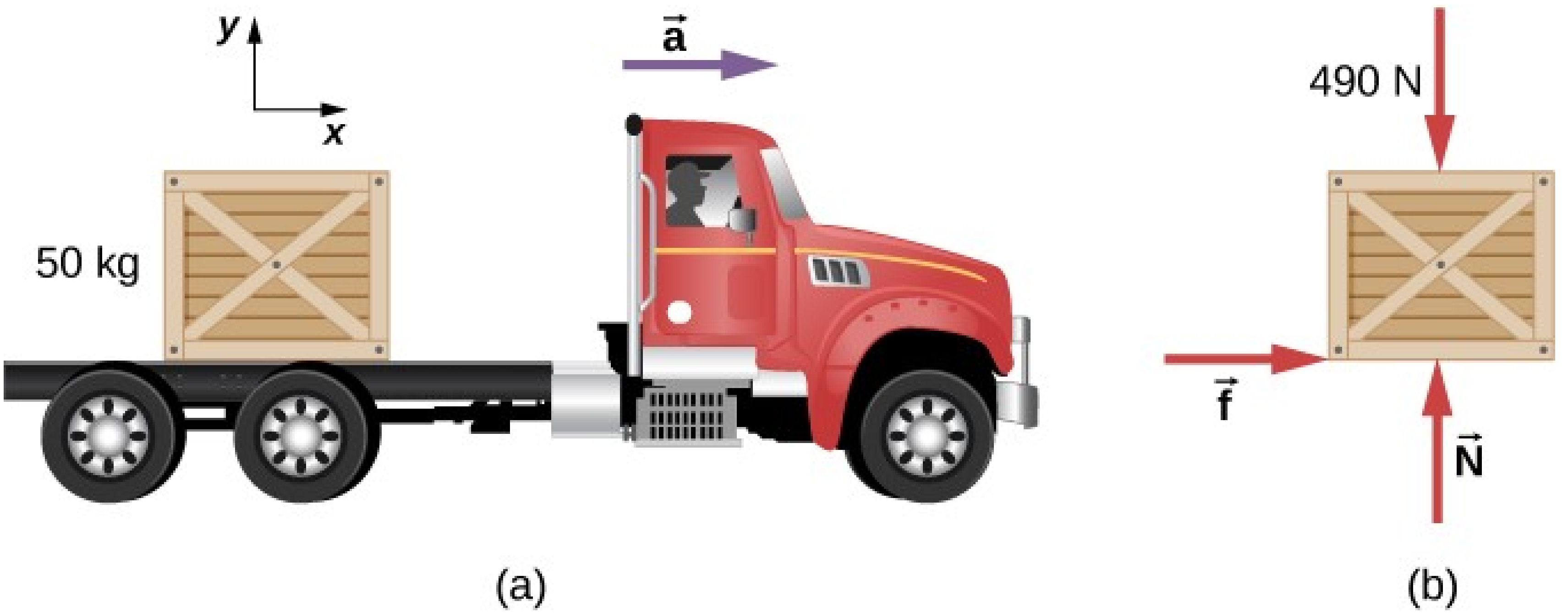
Solving for the two unknowns, we obtain $N_1 = 19.6\text{ N}$ and $T = 0.40 N_1 = 7.84\text{ N}$. The bottom block is also not accelerating, so the application of Newton's second law to this block gives

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

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

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

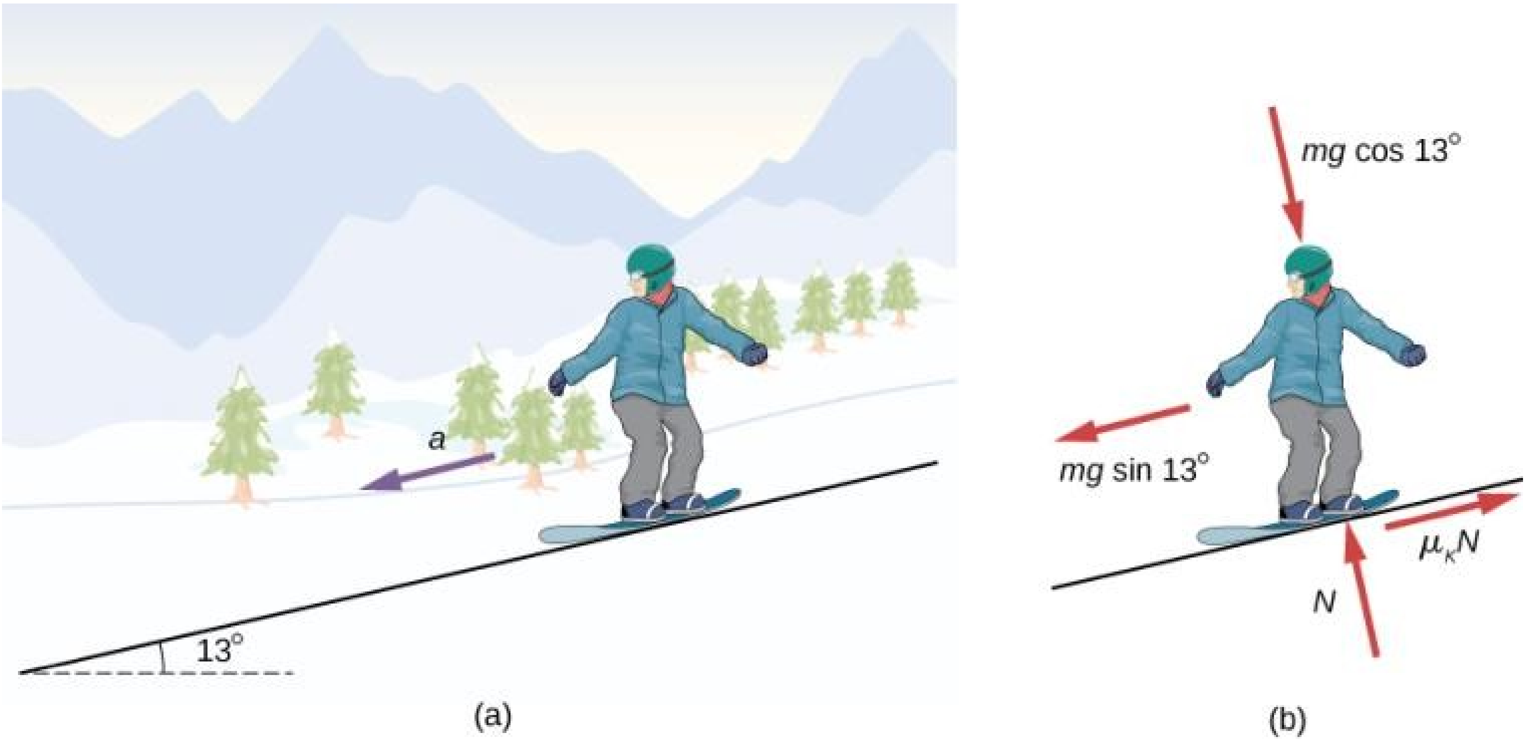
DIY!



(a) A crate rests on the bed of the truck that is accelerating forward.

(b) The free-body diagram of the crate.

DIY!



(a) A snowboarder glides down a slope inclined at 13° to the horizontal.

(b) The free-body diagram of the snowboarder.