ANNOUNCEMENTS

- Homework #4, due today!

  Conceptual questions: Chapter 4, #6 and #10
  Problems: Chapter 4, #26, #42

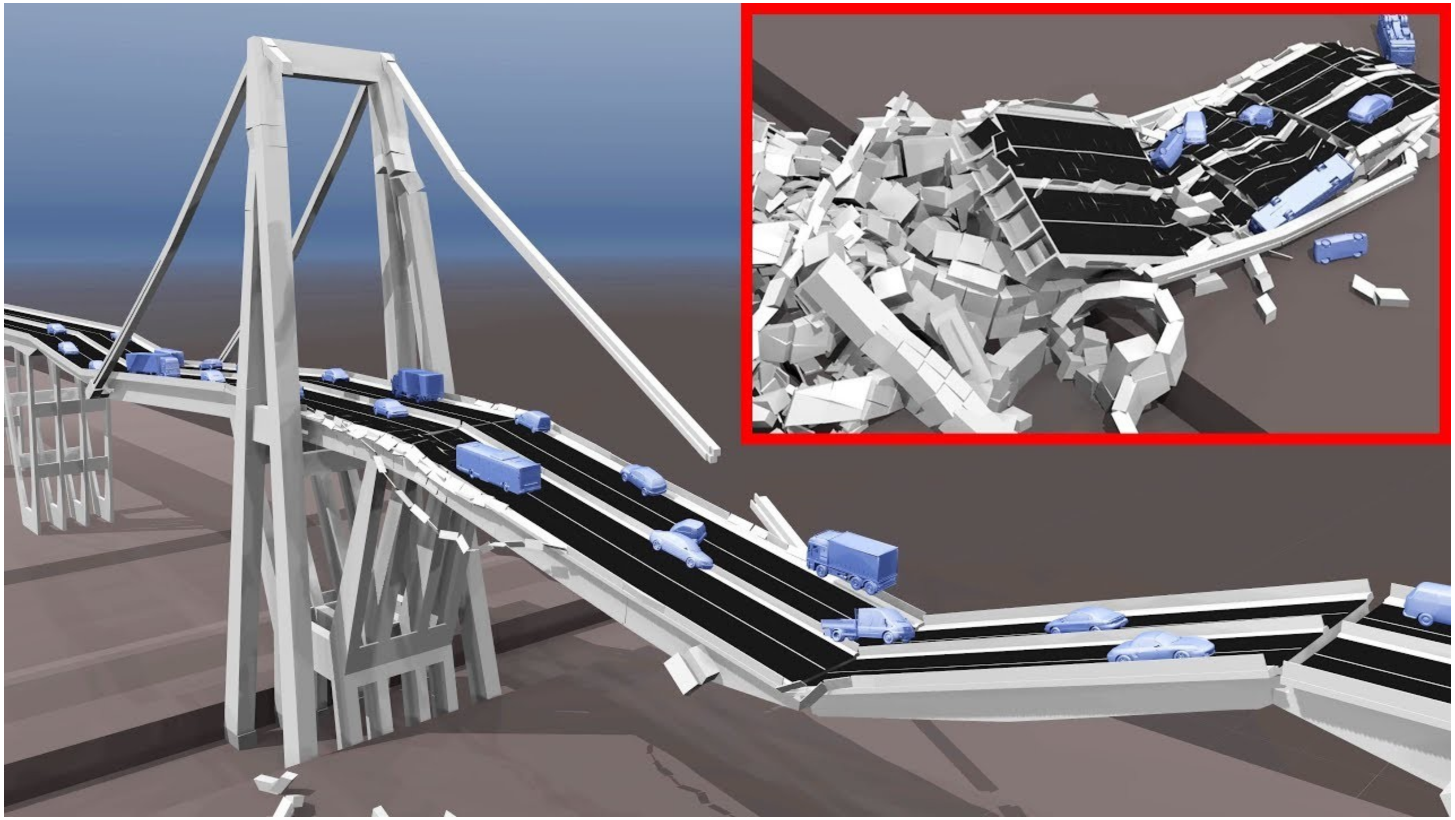
- 5-minute quiz on Chapter 4:
  Wednesday, September 19 at beginning of class

- First in-class test will be Friday, September 21

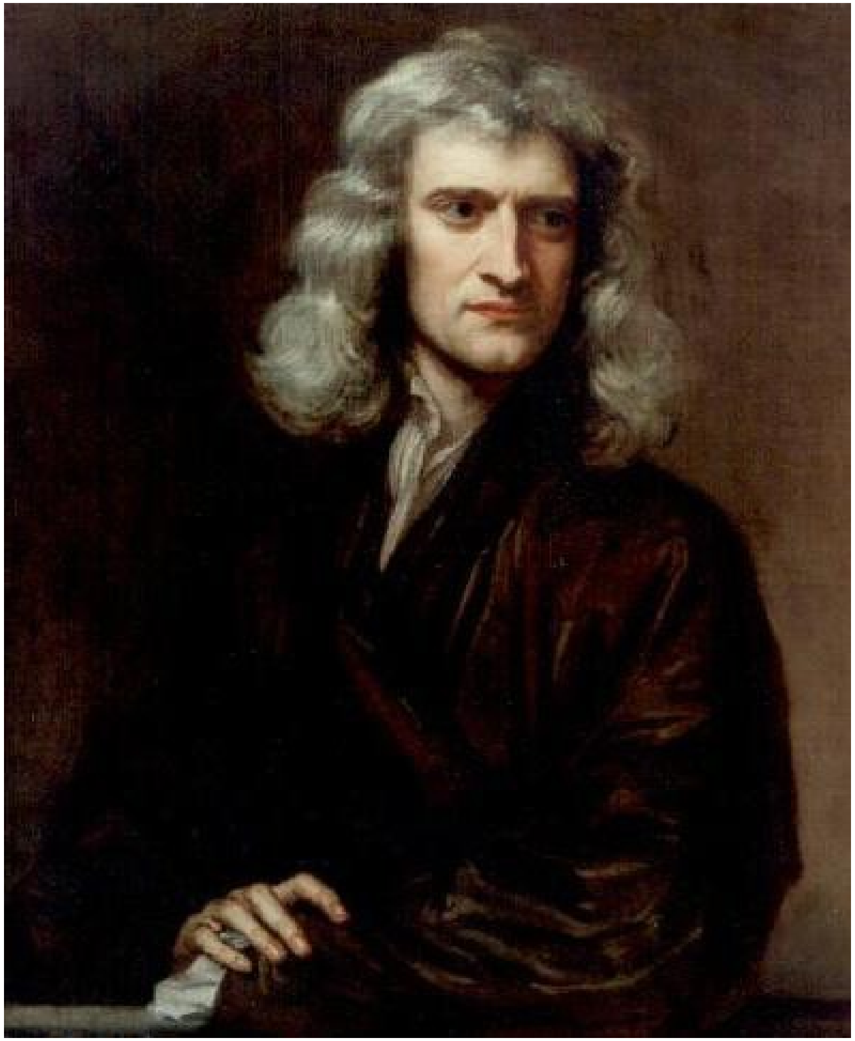
FORCES

The Golden Gate Bridge, one of the greatest works of modern engineering, was the longest suspension bridge in the world in the year it opened, 1937. It is still among the 10 longest suspension bridges as of this writing. In designing and building a bridge, what physics must we consider? What forces act on the bridge? What forces keep the bridge from falling? How do the towers, cables, and ground interact to maintain stability?


Rete7.it
THE Sun

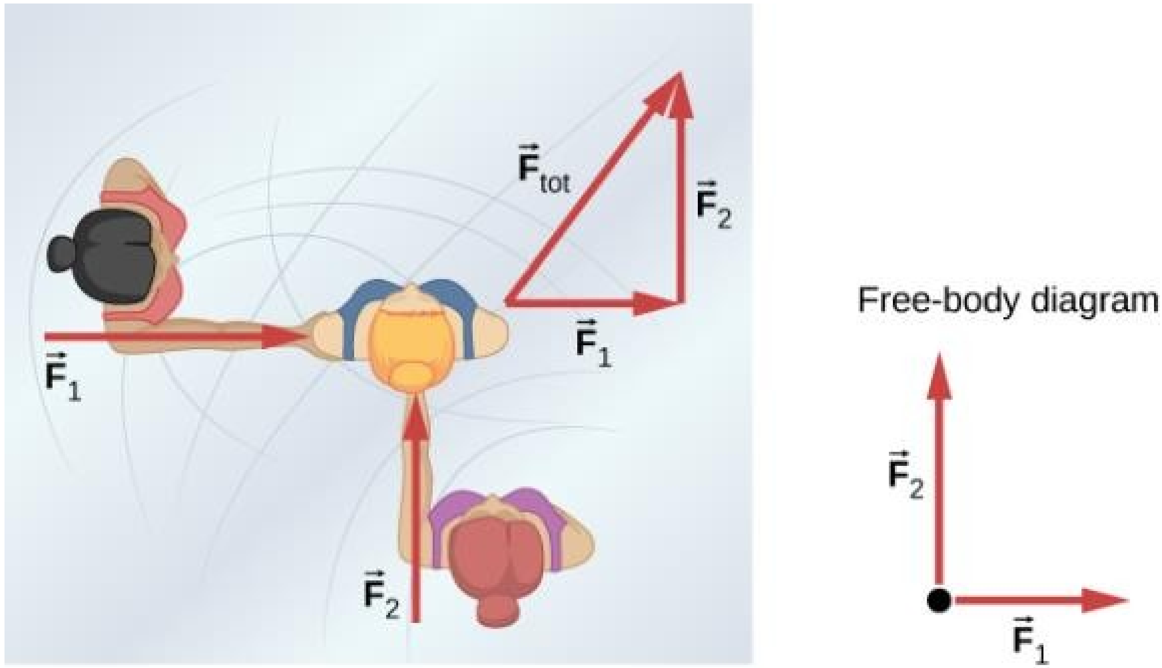


NEWTON’S LAWS



Isaac Newton (1642–1727) published his amazing work, *Philosophiae Naturalis Principia Mathematica*, in 1687. It proposed scientific laws that still apply today to describe the motion of objects (the laws of motion). Newton also discovered the law of gravity, invented calculus, and made great contributions to the theories of light and color.

FREE BODY DIAGRAM

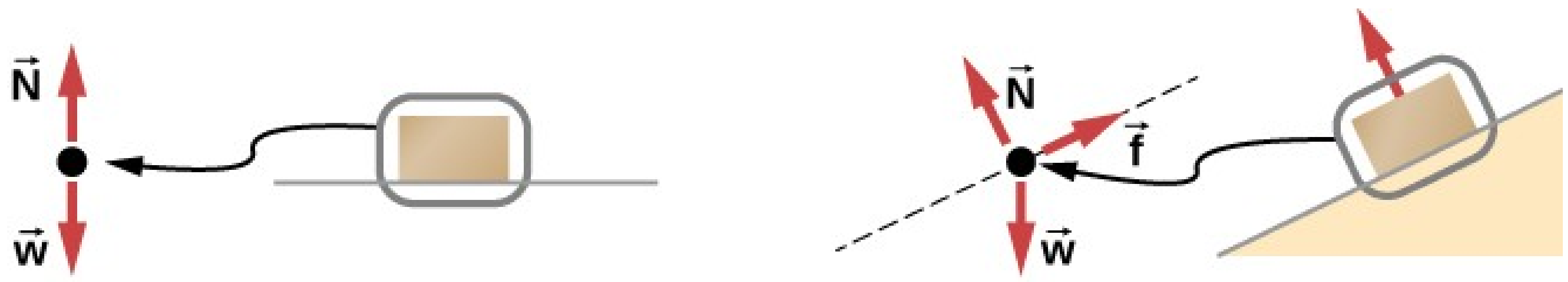


(a) (b)

(a) An overhead view of two ice skaters pushing on a third skater. Forces are vectors and add like other vectors, so the total force on the third skater is in the direction shown.

(b) A free-body diagram representing the forces acting on the third skater.

FREE BODY DIAGRAM

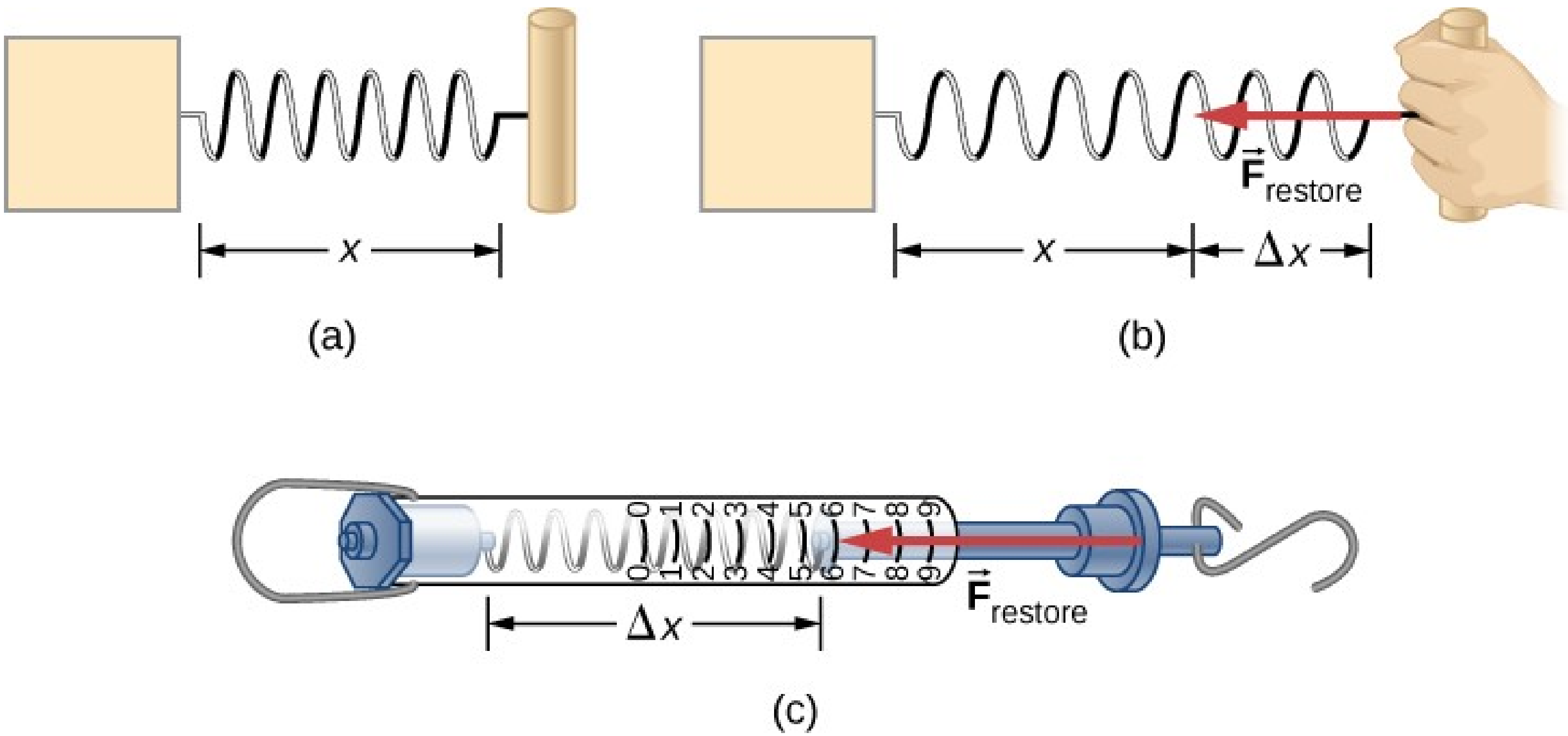


(a) Box at rest on a horizontal surface

(b) Box on an inclined plane

In these free-body diagrams, $\vec{N}$ is the normal force, $\vec{w}$ is the weight of the object, and $\vec{f}$ is the friction.

FORCE: EXAMPLE



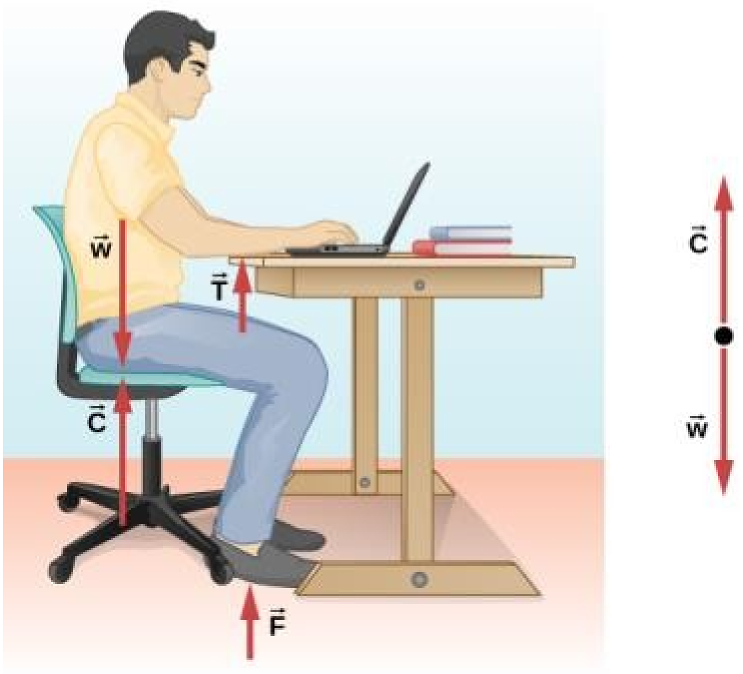
The force exerted by a stretched spring can be used as a standard unit of force.

(a) This spring has a length *x* when undistorted.

(b) When stretched a distance Δx, the spring exerts a restoring force $\vec{\mathbf{F}}_{\text{restore}}$, which is reproducible.

(c) A spring scale is one device that uses a spring to measure force. The force $\vec{\mathbf{F}}_{\text{restore}}$ is exerted on whatever is attached to the hook. Here, this force has a magnitude of six units of the force standard being employed.

EXAMPLE



(a) (b)

(a) The forces acting on the student are due to the chair, the table, the floor, and Earth's gravitational attraction.

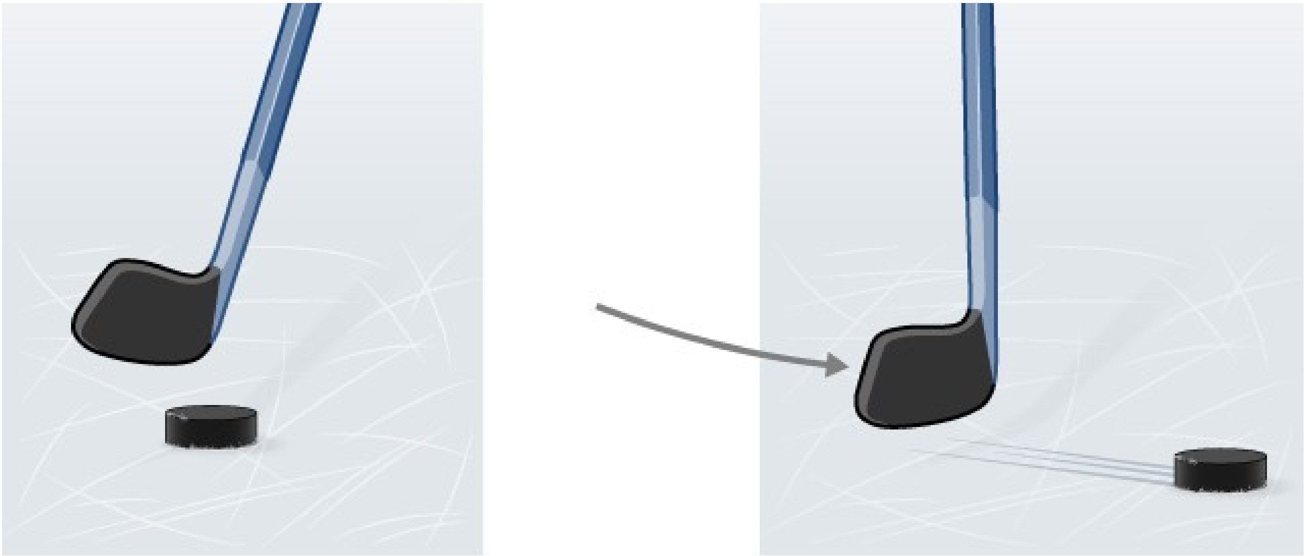
(b) In solving a problem involving the student, we may want to consider the forces acting along the line running through his torso. A free-body diagram for this situation is shown.

$$\vec{F}_{net} = \sum \vec{F} = \vec{F}_1 + \vec{F}_2 + \cdots \tag{5.1}$$

NEWTON'S FIRST LAW OF MOTION

NEWTON'S FIRST LAW OF MOTION

A body at rest remains at rest or, if in motion, remains in motion at constant velocity unless acted on by a net external force.

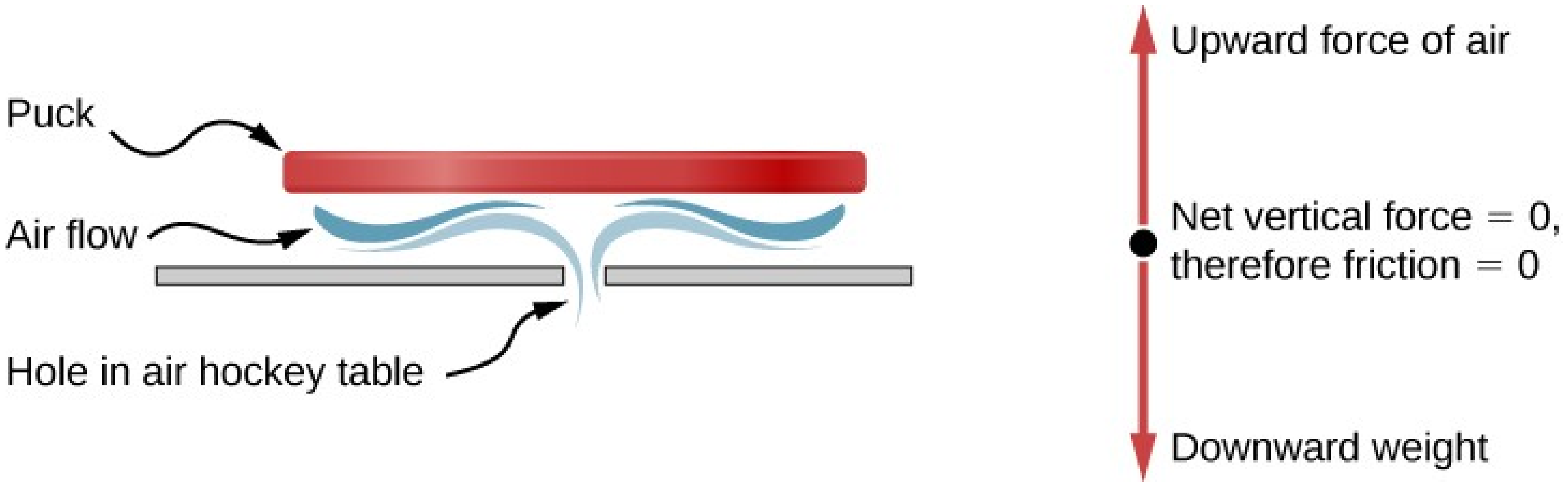


(a) (b)

(a) A hockey puck is shown at rest; it remains at rest until an outside force such as a hockey stick changes its state of rest;

(b) a hockey puck is shown in motion; it continues in motion in a straight line until an outside force causes it to change its state of motion. Although it is slick, an ice surface provides some friction that slows the puck.

EXAMPLE

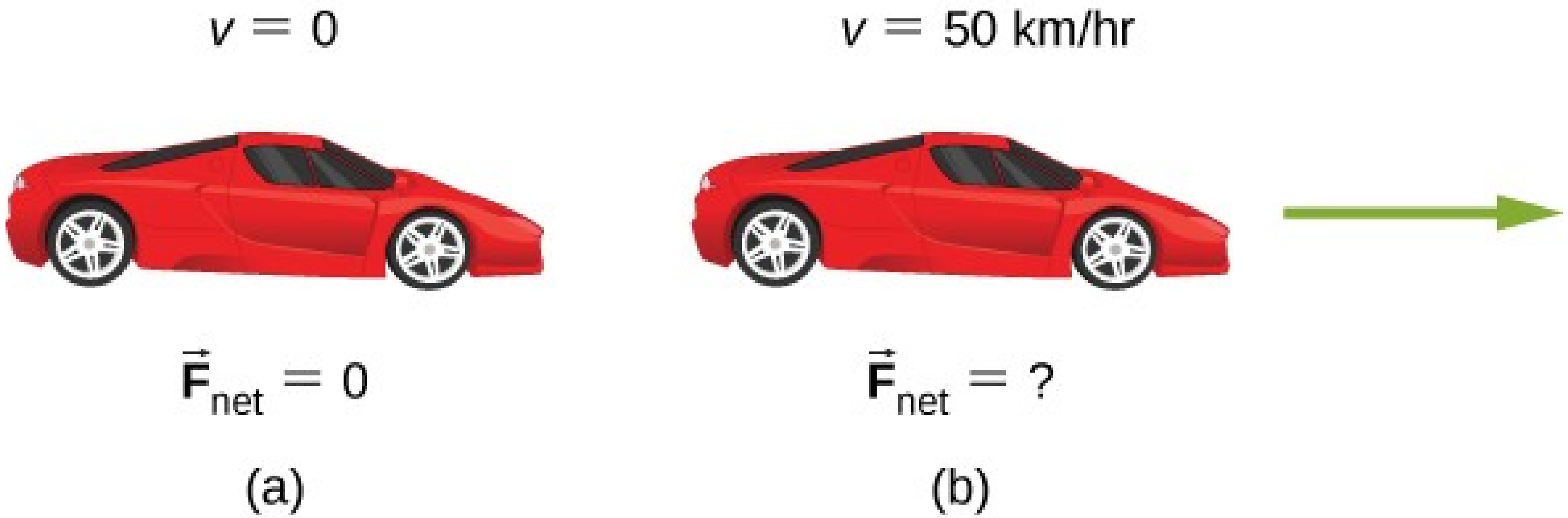


An air hockey table is useful in illustrating Newton's laws. When the air is off, friction quickly slows the puck; but when the air is on, it minimizes contact between the puck and the hockey table, and the puck glides far down the table.

INERTIAL REFERENCE FRAME

A reference frame moving at constant velocity relative to an inertial frame is also inertial. A reference frame accelerating relative to an inertial frame is not inertial.

EXAMPLE



A car is shown (a) parked and (b) moving at constant velocity. How do Newton's laws apply to the parked car? What does the knowledge that the car is moving at constant velocity tell us about the net horizontal force on the car?

$$\vec{\mathbf{v}} = \text{constant when } \vec{\mathbf{F}}_{\text{net}} = \vec{\mathbf{0}}\text{ N.} \tag{5.2}$$

NEWTON'S SECOND LAW OF MOTION

The acceleration of a system is directly proportional to and in the same direction as the net external force acting on the system and is inversely proportion to its mass. In equation form, Newton's second law is

$$\vec{\mathbf{a}} = \frac{\vec{\mathbf{F}}_{\text{net}}}{m},$$

where $\vec{\mathbf{a}}$ is the acceleration, $\vec{\mathbf{F}}_{\text{net}}$ is the net force, and m is the mass. This is often written in the more familiar form

$$\vec{\mathbf{F}}_{\text{net}} = \sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}, \tag{5.3}$$

but the first equation gives more insight into what Newton's second law means. When only the magnitude of force and acceleration are considered, this equation can be written in the simpler scalar form:

$$F_{\text{net}} = ma. \tag{5.4}$$

$$\sum \vec{\mathbf{F}}_x = m\vec{\mathbf{a}}_x, \sum \vec{\mathbf{F}}_y = m\vec{\mathbf{a}}_y, \text{ and } \sum \vec{\mathbf{F}}_z = m\vec{\mathbf{a}}_z. \tag{5.5}$$

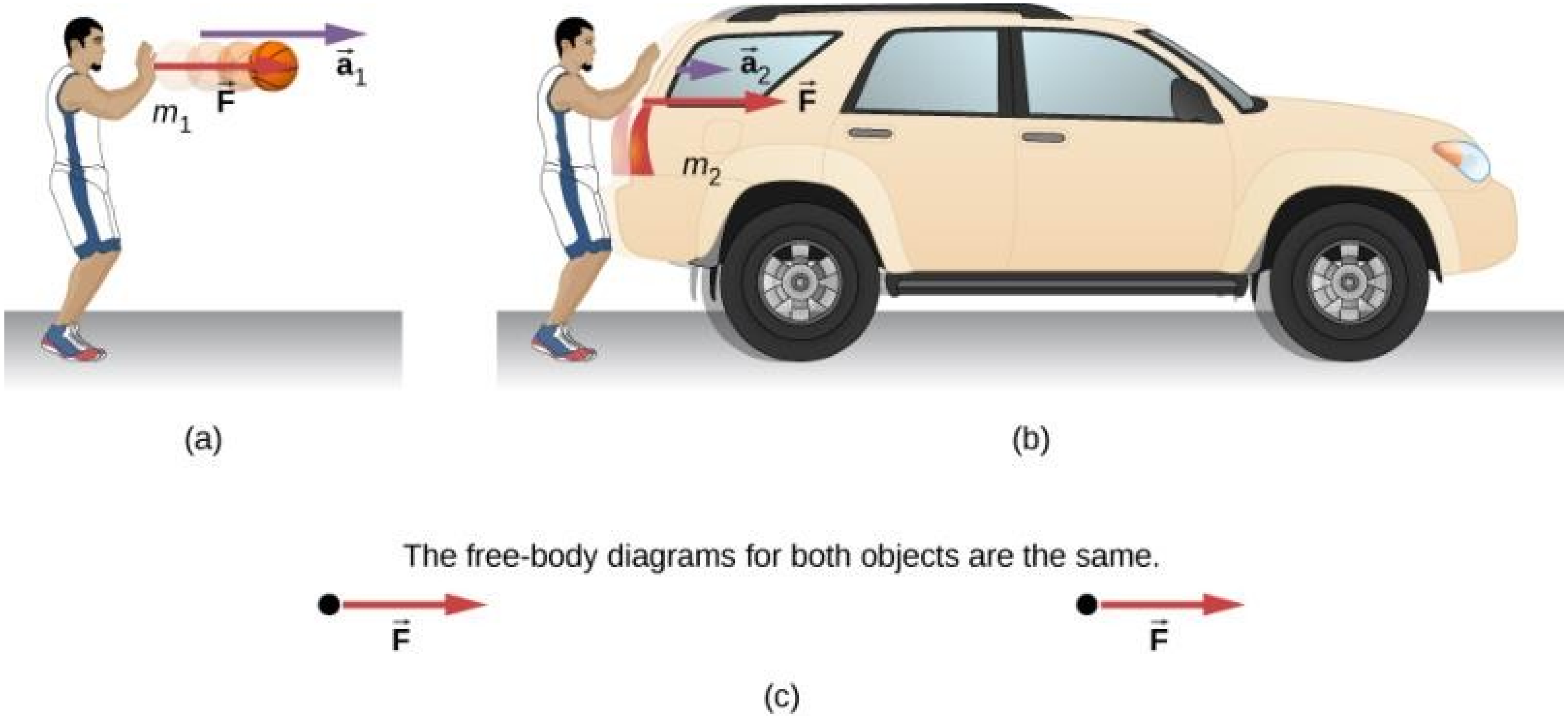
Units of Force

The equation $F_{\text{net}} = ma$ is used to define net force in terms of mass, length, and time. As explained earlier, the SI unit of force is the newton. Since $F_{\text{net}} = ma$,

$$1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2.$$

Although almost the entire world uses the newton for the unit of force, in the United States, the most familiar unit of force is the pound (lb), where 1 N = 0.225 lb. Thus, a 225-lb person weighs 1000 N.

FIGURE 5.11



The same force exerted on systems of different masses produces different accelerations.

(a) A basketball player pushes on a basketball to make a pass. (Ignore the effect of gravity on the ball.)

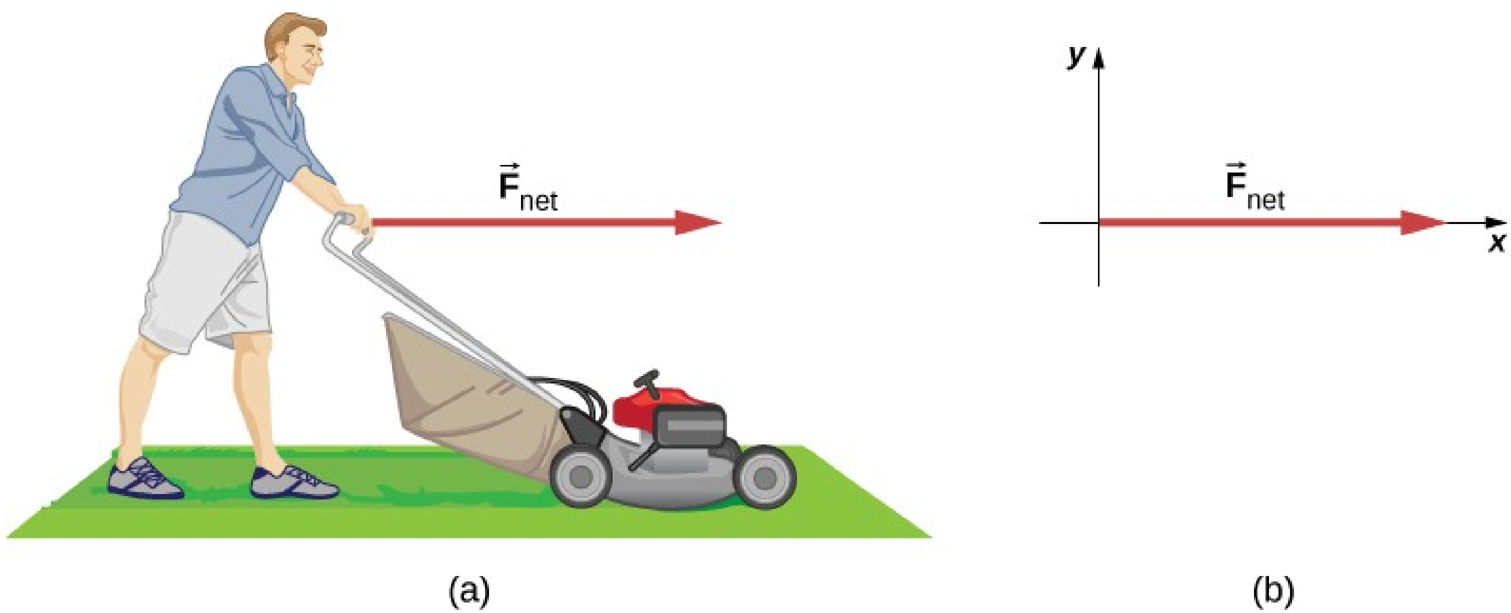
(b) The same player exerts an identical force on a stalled SUV and produces far less acceleration.

(c) The free-body diagrams are identical, permitting direct comparison of the two situations. A series of patterns for free-body diagrams will emerge as you do more problems and learn how to draw them in **Drawing Free-Body Diagrams**.

EXAMPLE 5.2

What Acceleration Can a Person Produce When Pushing a Lawn Mower?

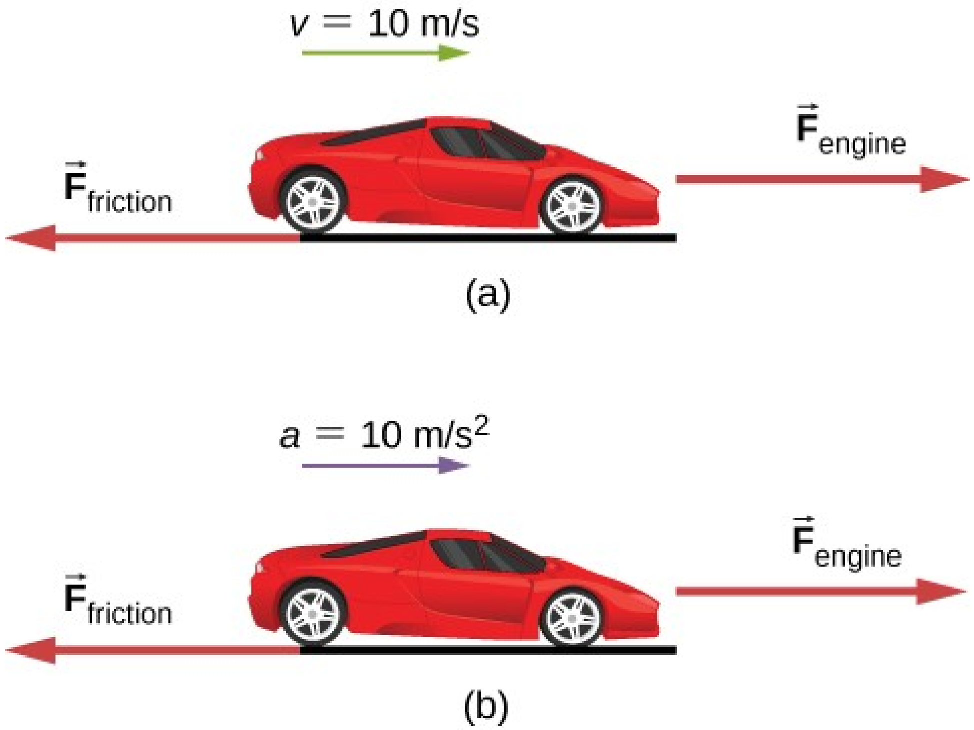
Suppose that the net external force (push minus friction) exerted on a lawn mower is 51 N (about 11 lb.) parallel to the ground (Figure 5.12). The mass of the mower is 24 kg. What is its acceleration?



(a) The net force on a lawn mower is 51 N to the right. At what rate does the lawn mower accelerate to the right?

(b) The free-body diagram for this problem is shown.

FIGURE 5.13



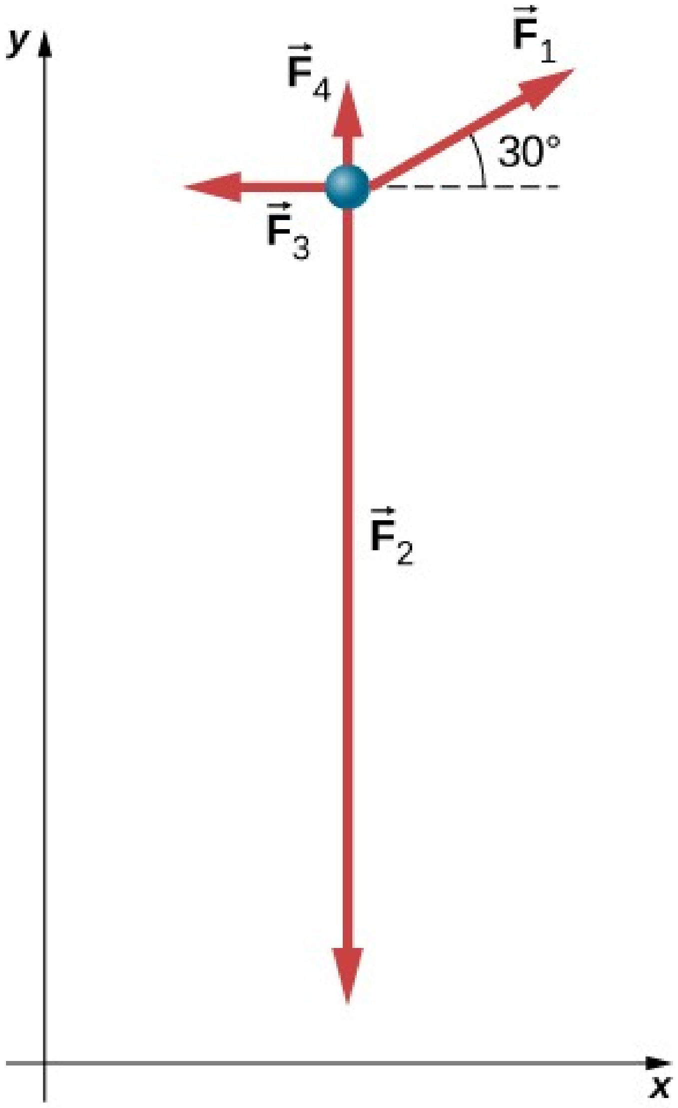
A car is shown (a) moving at constant speed and (b) accelerating. How do the forces acting on the car compare in each case?

(a) What does the knowledge that the car is moving at constant velocity tell us about the net horizontal force on the car compared to the friction force?

(b) What does the knowledge that the car is accelerating tell us about the horizontal force on the car compared to the friction force?

FIGURE 5.15

Four forces in the *xy*-plane are applied to a 4.0-kg particle.



FORCE AND MOMENTUM

$$\vec{\mathbf{F}}_{\text{net}} = \frac{d\vec{\mathbf{p}}}{dt}. \quad \boxed{(5.6)}$$

This means that Newton's second law addresses the central question of motion: What causes a change in motion of an object? Momentum was described by Newton as "quantity of motion," a way of combining both the velocity of an object and its mass. We devote Linear Momentum and Collisions to the study of momentum.

For now, it is sufficient to define *momentum* $\vec{\mathbf{p}}$ as the product of the mass of the object *m* and its velocity $\vec{\mathbf{v}}$:

$$\vec{\mathbf{p}} = m\vec{\mathbf{v}}. \quad \boxed{(5.7)}$$

Since velocity is a vector, so is momentum.

It is easy to visualize momentum. A train moving at 10 m/s has more momentum than one that moves at 2 m/s. In everyday life, we speak of one sports team as "having momentum" when they score points against the opposing team.

If we substitute Equation 5.7 into Equation 5.6, we obtain

$$\vec{\mathbf{F}}_{\text{net}} = \frac{d\vec{\mathbf{p}}}{dt} = \frac{d\left(m\vec{\mathbf{v}}\right)}{dt}.$$

When *m* is constant, we have

$$\vec{\mathbf{F}}_{\text{net}} = m\frac{d\left(\vec{\mathbf{v}}\right)}{dt} = m\vec{\mathbf{a}}.$$

WEIGHT

The gravitational force on a mass is its weight. We can write this in vector form, where $\vec{\mathbf{w}}$ is weight and *m* is mass, as

$$\vec{\mathbf{w}} = m\vec{\mathbf{g}}. \tag{5.8}$$

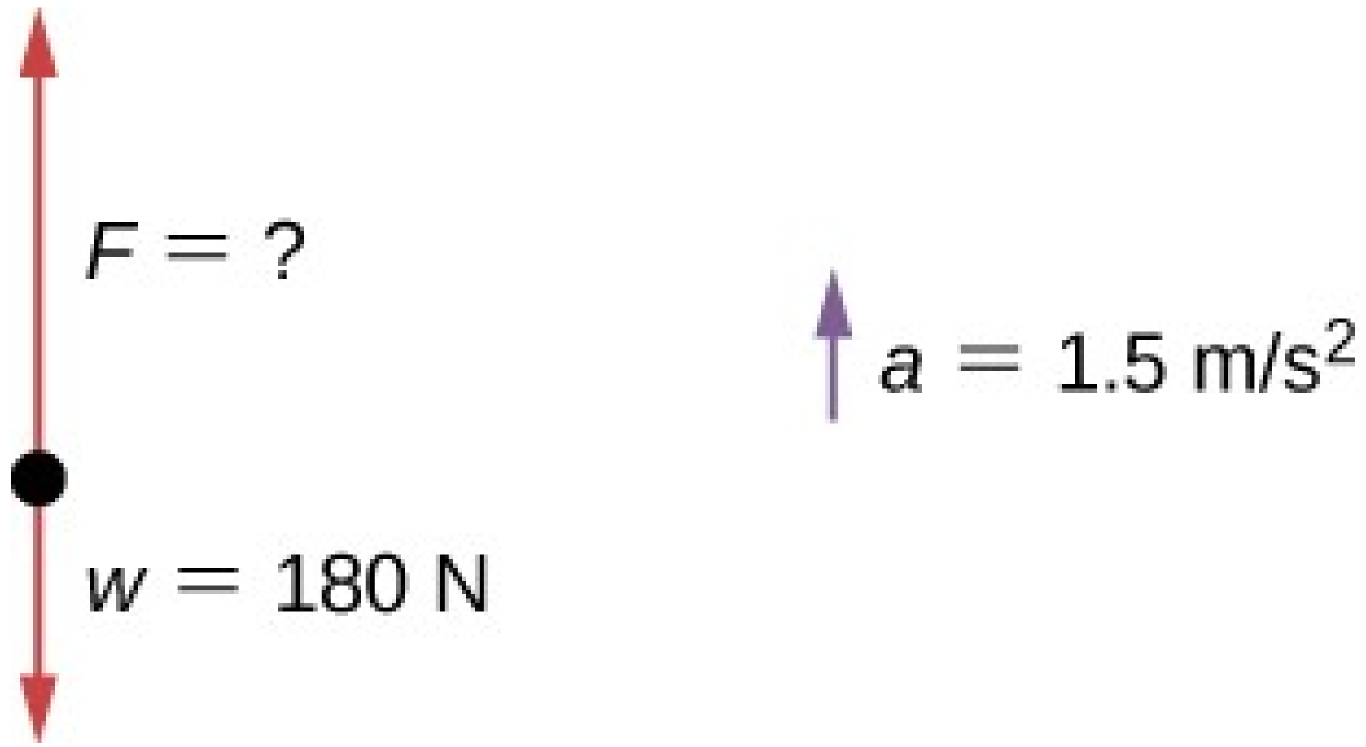
In scalar form, we can write

$$w = mg. \tag{5.9}$$

Since $g = 9.80 \text{ m/s}^2$ on Earth, the weight of a 1.00-kg object on Earth is 9.80 N:

$$w = mg = (1.00 \text{ kg})(9.80 \text{ m/s}^2) = 9.80 \text{ N}.$$

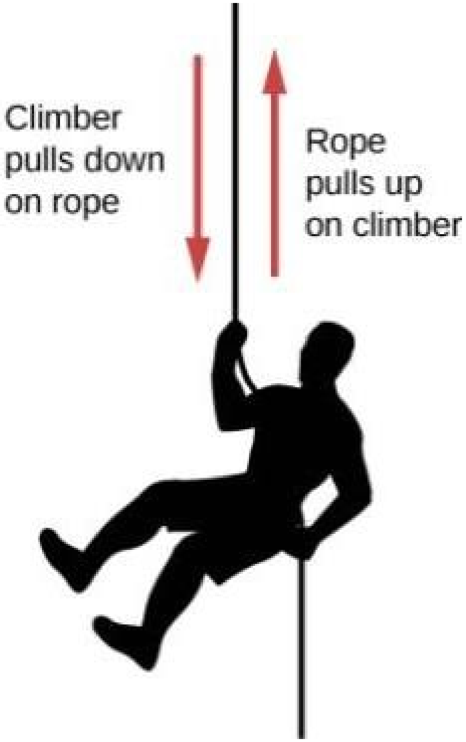
EXAMPLE



NEWTON'S THIRD LAW OF MOTION

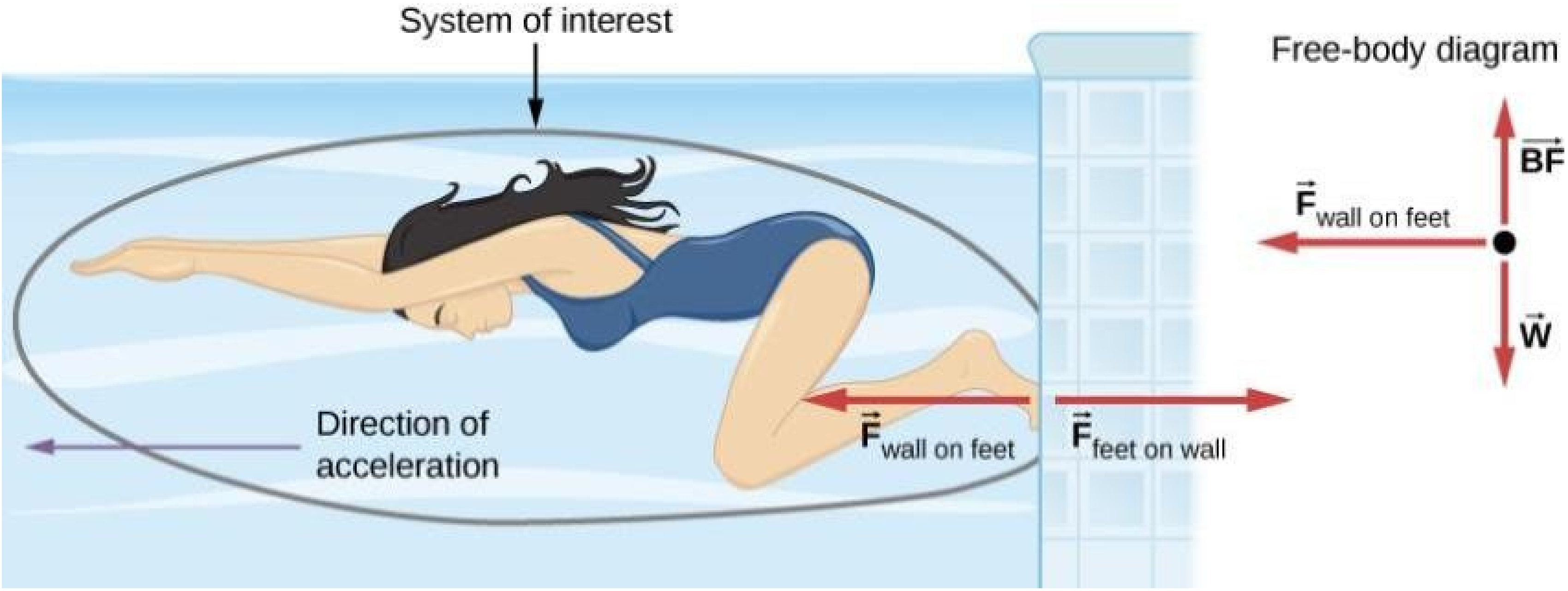
Whenever one body exerts a force on a second body, the first body experiences a force that is equal in magnitude and opposite in direction to the force that it exerts. Mathematically, if a body *A* exerts a force $\vec{\mathbf{F}}$ on body *B*, then *B* simultaneously exerts a force $-\vec{\mathbf{F}}$ on *A*, or in vector equation form,

$$\vec{\mathbf{F}}_{\mathrm{AB}} = -\vec{\mathbf{F}}_{\mathrm{BA}}. \tag{5.10}$$



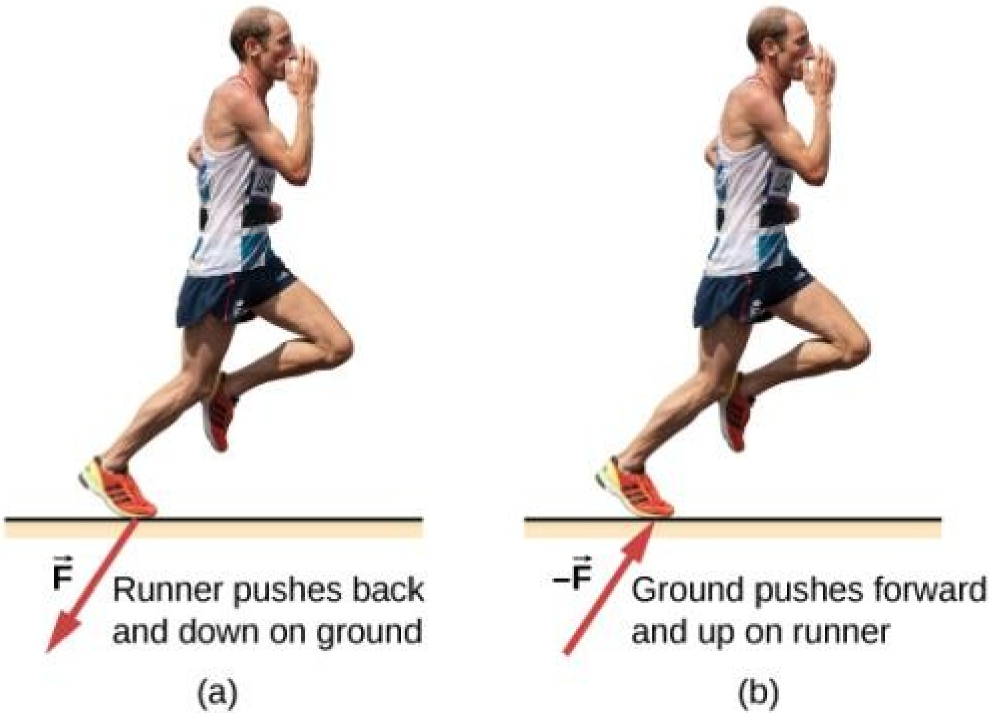
When the mountain climber pulls down on the rope, the rope pulls up on the mountain climber.

FIGURE 5.16



When the swimmer exerts a force on the wall, she accelerates in the opposite direction; in other words, the net external force on her is in the direction opposite of $\boldsymbol{F}_{\text{feet on wall}}$. This opposition occurs because, in accordance with Newton's third law, the wall exerts a force $\boldsymbol{F}_{\text{wall on feet}}$ on the swimmer that is equal in magnitude but in the direction opposite to the one she exerts on it. The line around the swimmer indicates the system of interest. Thus, the free-body diagram shows only $\boldsymbol{F}_{\text{wall on feet}}$, w (the gravitational force), and BF, which is the buoyant force of the water supporting the swimmer's weight. The vertical forces w and BF cancel because there is no vertical acceleration.

EXAMPLE



The runner experiences Newton's third law.

(a) A force is exerted by the runner on the ground.

(b) The reaction force of the ground on the runner pushes him forward.