Everyday Forces

SECTION 4

SECTION OBJECTIVES

- **Explain the difference between mass and weight.**
- **Find the direction and magnitude of normal forces.**
- **Describe air resistance as a form of friction.**
- **Use coefficients of friction to calculate frictional force.**

WEIGHT

How do you know that a bowling ball weighs more than a tennis ball? If you imagine holding one ball in each hand, you can imagine the downward forces acting on your hands. Because the bowling ball has more mass than the tennis ball does, gravitational force pulls more strongly on the bowling ball. Thus, the bowling ball pushes your hand down with more force than the tennis ball does.

The gravitational force exerted on the ball by Earth, $\mathbf{F_g}$, is a vector quantity, directed toward the center of Earth. The magnitude of this force, F_g, is a scalar quantity called **weight.** The weight of an object can be calculated using the equation $F_g = ma_g$, where a_g is the magnitude of the acceleration due to gravity, or free-fall acceleration. On the surface of Earth, $a_g = g$, and $F_g = mg$. In this book, $g = 9.81\ m/s^2$ unless otherwise specified.

weight

a measure of the gravitational force exerted on an object; its value can change with the location of the object in the universe

Weight, unlike mass, is not an inherent property of an object. Because it is equal to the magnitude of the force due to gravity, weight depends on location. For example, if the astronaut in **Figure 10** weighs 800 N (180 lb) on Earth, he would weigh only about 130 N (30 lb) on the moon. As you will see in the chapter "Circular Motion and Gravitation," the value of a_g on the surface of a planet depends on the planet's mass and radius. On the moon, a_g is about $1.6\ m/s^2$—much smaller than $9.81\ m/s^2$.

Even on Earth, an object's weight may vary with location. Objects weigh less at higher altitudes than they do at sea level because the value of a_g decreases as distance from the surface of Earth increases. The value of a_g also varies slightly with changes in latitude.

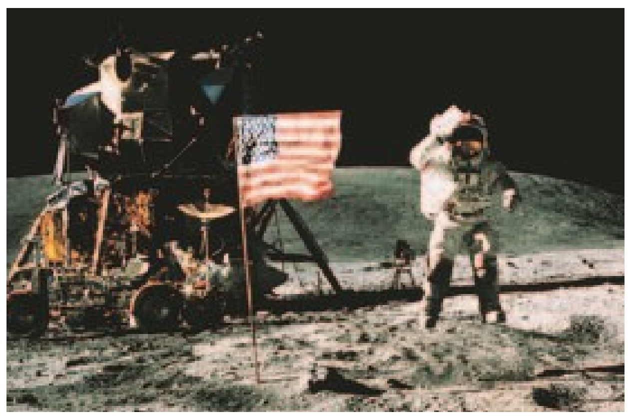

Figure 10
On the moon, astronauts weigh much less than they do on Earth.

THE NORMAL FORCE

Imagine a television set at rest on a table. We know that the gravitational force is acting on the television. How can we use Newton's laws to explain why the television does not continue to fall toward the center of Earth?

An analysis of the forces acting on the television will reveal the forces that are in equilibrium. First, we know that the gravitational force of Earth, $\mathbf{F_g}$, is acting downward. Because the television is in equilibrium, we know that another force, equal in magnitude to $\mathbf{F_g}$ but in the opposite direction, must be acting on it. This force is the force exerted on the television by the table. This force is called the **normal force,** $\mathbf{F_n}$.

normal force

a force that acts on a surface in a direction perpendicular to the surface

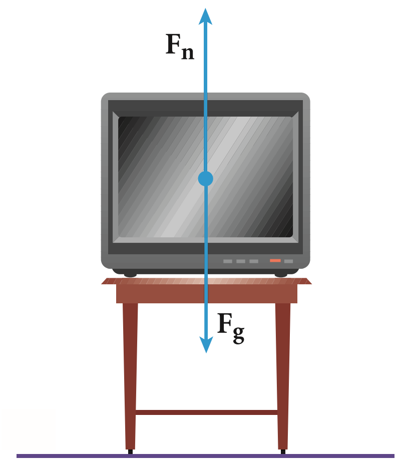

Figure 11
In this example, the normal force, $\mathbf{F_n}$, is equal and opposite to the force due to gravity, $\mathbf{F_g}$.

The word *normal* is used because the direction of the contact force is perpendicular to the table surface and one meaning of the word *normal* is "perpendicular." **Figure 11** shows the forces acting on the television.

The normal force is always perpendicular to the contact surface but is not always opposite in direction to the force due to gravity. **Figure 12** shows a free-body diagram of a refrigerator on a loading ramp. The normal force is perpendicular to the ramp, not directly opposite the force due to gravity. In the absence of other forces, the normal force, $\mathbf{F_n}$, is equal and opposite to the component of $\mathbf{F_g}$ that is perpendicular to the contact surface. The magnitude of the normal force can be calculated as $F_n = mg \cos \theta$. The angle θ is the angle between the normal force and a vertical line and is also the angle between the contact surface and a horizontal line.

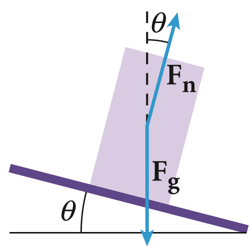

Figure 12
The normal force is not always opposite the force due to gravity, as shown by this example of a refrigerator on a loading ramp.

THE FORCE OF FRICTION

Consider a jug of juice at rest (in equilibrium) on a table, as in **Figure 13(a).** We know from Newton's first law that the net force acting on the jug is zero. Newton's second law tells us that any additional unbalanced force applied to the jug will cause the jug to accelerate and to remain in motion unless acted on by another force. But experience tells us that the jug will not move at all if we apply a very small horizontal force. Even when we apply a force large enough to move the jug, the jug will stop moving almost as soon as we remove this applied force.

Friction opposes the applied force

When the jug is at rest, the only forces acting on it are the force due to gravity and the normal force exerted by the table. These forces are equal and opposite, so the jug is in equilibrium. When you push the jug with a small horizontal force **F**, as shown in **Figure 13(b),** the table exerts an equal force in the opposite direction. As a result, the jug remains in equilibrium and therefore also remains at rest. The resistive force that keeps the jug from moving is called the force of **static friction,** abbreviated as $\mathbf{F_s}$.

static friction

the force that resists the initiation of sliding motion between two surfaces that are in contact and at rest

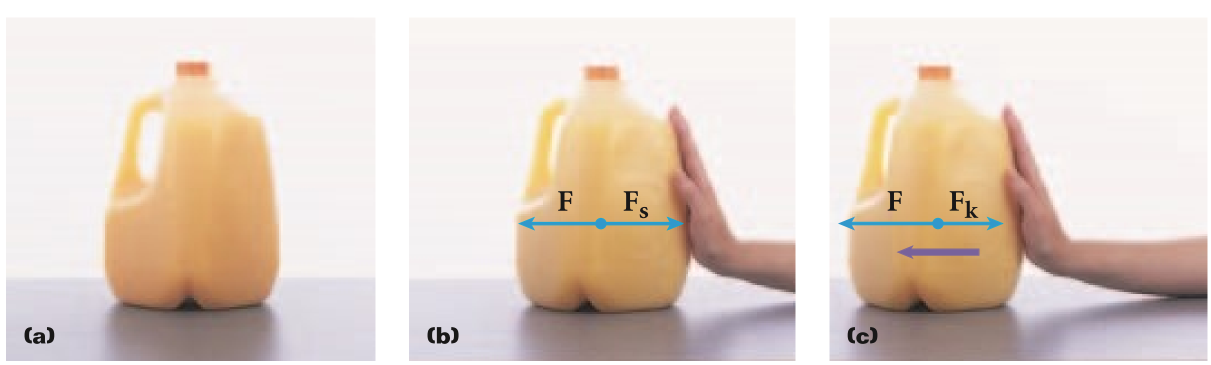

Figure 13
(a) Because this jug of juice is in equilibrium, any unbalanced horizontal force applied to it will cause the jug to accelerate.
(b) When a small force is applied, the jug remains in equilibrium because the static-friction force is equal but opposite to the applied force.
(c) The jug begins to accelerate as soon as the applied force exceeds the opposing static-friction force.