Answer to Essential Question 3.3: Yes, but only for an instant. If an object experiences a net force, its motion changes. If the object is initially at rest, it will start to move. If the object is initially moving, the net force might bring it to rest for an instant and then reverse its direction.

3-4 Connecting Force and Motion

Why would someone think that an object with more mass falls faster than an object with less mass? One reason is that an object with more mass has a larger force of gravity acting on it. Consider the following statement, made by a student before taking a physics course: "The force of gravity is what makes an object fall to the floor when we let go of it, so an object with more mass should fall faster." That sounds logical, but it is incorrect. What directly determines how much time something takes to fall to the ground is the acceleration, not the force. Force and acceleration are directly related, but they are not the same.

The force of gravity acting on an object is proportional to its mass. If we are dropping objects relatively small distances when we are at, or near, the surface of the Earth, the force of gravity is constant and is given by:

$\vec{F}_G = m\vec{g}$, (Equation 3.2: **Force of gravity at the surface of the Earth**)

where $\vec{g}$ is commonly referred to as the acceleration due to gravity. As we discussed in chapter 2, at the surface of the Earth, the value of $\vec{g}$ is about 9.8 N/kg directed down. A better name for $\vec{g}$ is "the value of the local gravitational field," but we will address that in chapter 8 when we talk about gravity in detail, and when we show where the value of 9.8 N/kg comes from.

Figure 3.9 shows the free-body diagrams of two objects, one with a mass of *m* and the other with a mass of 3*m*, when they are in free fall. Because the objects move under the influence of gravity alone, only one force, the force of gravity, appears on each free-body diagram. The force of gravity is proportional to mass, so the force of gravity acting on the second object is three times larger than the force acting on the first object. Figure 3.9 is correct, but these free-body diagrams reinforce the incorrect idea that an object with more mass falls faster. Let's go beyond the free-body diagrams, and apply Equation 3.1.

For object 1: $\vec{a}_1 = \frac{\sum \vec{F}}{m} = \frac{m\vec{g}}{m} = \vec{g}$;

For object 2: $\vec{a}_2 = \frac{\sum \vec{F}}{3m} = \frac{3m\vec{g}}{3m} = \vec{g}$.

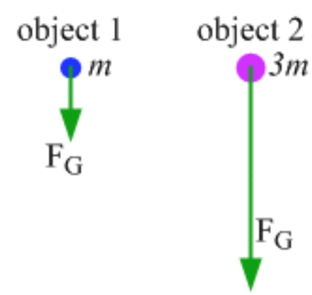

Figure 3.9: Free-body diagrams for two objects in free fall. Object 2 has three times the mass of object 1, so the force of gravity acting on it is three times as large as that on object 1. Despite this, the objects have equal accelerations.

Even though the forces have different magnitudes, the accelerations are the same. This is why both objects reach the ground at the same time.

It is easy to confuse force and acceleration, and we will consider more situations later where we must carefully distinguish the two. As a final thought, consider the following.

Question: Take two identical objects and apply a net force to the second one that is three times larger than the net force applied to the first one, as shown in Figure 3.10. If both objects start from rest at the same time, which object has a larger acceleration?

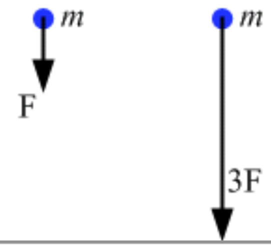

Figure 3.10: Free-body diagrams for two identical objects, one experiencing a force three times larger than that experienced by the other.

Answer: Now the obvious answer is the correct one – the second object has an acceleration three times larger than the first because its net force is three times larger. This is true only because the objects have the same mass! Compare this situation to that shown in Figure 3.9, in which we dropped objects of different mass.

Force and motion are connected by acceleration. Knowing about forces can give us an acceleration we can use in the constant-acceleration equations. Conversely, we can use the equations to find acceleration and then find the net force. Here is an example of that process.

EXAMPLE 3.4 – Combining forces with the constant-acceleration equations

Cindy kicks a soccer ball, with a mass of 0.40 kg. If the ball starts from rest on the ground and ends up with a velocity of 15 m/s directed horizontally, what is the average force exerted on the ball by Cindy's foot if her foot is in contact with the ball for 0.10 s?

SOLUTION

A diagram of the situation and a free-body diagram of the ball are shown in Figure 3.11. Table 3.1 summarizes what we know about the motion.

Initial position	$\vec{x}_0 = 0$
Initial velocity	$\vec{v}_0 = 0$
Final velocity	$\vec{v} = +15\text{ m/s}$
Time	$t = 0.10\text{ s}$

Table 3.1: A summary of the data for the ball.

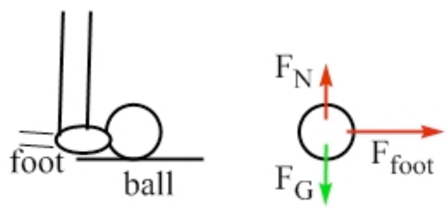

Figure 3.11: A diagram, and free-body diagram, for the ball.

There is enough information here to solve for the ball's acceleration using Equation 2.7, $\vec{v} = \vec{v}_0 + \vec{a}t$. Re-arranging this equation to solve for the acceleration gives:

$$\vec{a} = \frac{\vec{v} - \vec{v}_0}{t} = \frac{+15\text{ m/s} - 0}{0.10\text{ s}} = +150\text{ m/s}^2 .$$

We can apply a re-arranged version of Equation 3.1, $\sum \vec{F} = m\vec{a}$, to determine the force Cindy exerts on the ball. Assume that $\vec{F}_{foot}$, the force Cindy's foot exerts on the ball, is horizontal, so the normal force the ground exerts on the ball balances the force of gravity acting on the ball.

$$\vec{F}_{foot} = (0.40\text{ kg})(+150\text{ m/s}^2) = +60\text{ N} .$$

Related End-of-Chapter Exercises: 14, 26, 27, 52, 55.

Essential Question 3.4: Let's say that, in Example 3.4, the ball is rolling toward Cindy at a speed of 8.0 m/s at the instant she kicks it, and she exerts the same force on the ball for the same time period as in Example 3.4 above. What is the ball's final velocity in this new situation?