### **KEY CONCEPT**



## BEFORE, you learned

- Every action force has an equal and opposite reaction force
- Newton's laws are used to describe the motions of objects
- Mass is the amount of matter an object contains

## NOW, you will learn

- How mass and distance affect gravity
- What keeps objects in orbit

## VOCABULARY

gravity p. 381 weight p. 383 orbit p. 384

VOCABULARY Create a four square

your notebook.

diagram for gravity in

## **EXPLORE** Downward Acceleration

# How do the accelerations of two falling objects compare?

## PROCEDURE

- Make a prediction: Which ball will fall faster?
- Drop both balls from the same height at the same time.
- **3** Observe the balls as they hit the ground.

### WHAT DO YOU THINK?

- Were the results what you had expected?
- How did the times it took the two balls to hit the ground compare?

## MATERIALS

- golf ball
- Ping-Pong ball

# Masses attract each other.

When you drop any object—such as a pen, a book, or a football—it falls to the ground. As the object falls, it moves faster and faster. The fact that the object accelerates means there must be a force acting on it. The downward pull on the object is due to gravity. **Gravity** is the force that objects exert on each other because of their masses. You are familiar with the force of gravity between Earth and objects on Earth.

Gravity is present not only between objects and Earth, however. Gravity is considered a universal force because it acts between any two masses anywhere in the universe. For example, there is a gravitational pull between the Sun and the Moon. Even small masses attract each other. The force of gravity between dust and gas particles in space helped form the solar system.



Why is gravity considered a universal force?







# The Force of Gravity

If there is a force between all masses, why are you not pulled toward your desk by the desk's gravity when you walk away from it? Remember that the net force on you determines how your motion changes. The force of gravity between you and the desk is extremely small compared with other forces constantly acting on you, such as friction, the force from your muscles, Earth's gravity, and the gravitational pull from many other objects. The strength of the gravitational force between two objects depends on two factors, mass and distance.

**The Mass of the Objects** The more mass two objects have, the greater the force of gravity the masses exert on each other. If one of the masses is doubled, the force of gravity between the objects is doubled.



**The Distance Between the Objects** As distance between the objects increases, the force of gravity decreases. If the distance is doubled, the force of gravity is one-fourth as strong as before.



**Gravity on Earth** 

The force of gravity acts on both masses equally, even though the effects on both masses may be very different. Earth's gravity exerts a downward pull on a dropped coin. Remember that every action force has an equal and opposite reaction force. The coin exerts an equal upward force on Earth. Because the coin has an extremely small mass compared with Earth, the coin can be easily accelerated. Earth's acceleration due to the force of the coin is far too small to notice because of Earth's large mass.

The acceleration due to Earth's gravity is called *g* and is equal to 9.8 m/s<sup>2</sup> at Earth's surface. You can calculate the force of gravity on an object using the object's mass and this acceleration. The formula that expresses Newton's second law is F = ma. If you use *g* as the acceleration, the formula for calculating the force due to gravity on a mass close to Earth's surface becomes F = mg.

# **Acceleration Due to Gravity**





If any two objects are dropped from the same height in a vacuum, they fall at the same rate even if they have different masses.

If an object has a velocity in the horizontal direction when it falls, the horizontal velocity does not change its downward acceleration.

In a vacuum—that is, where there is no air—all falling objects have the same acceleration.

- The quarter falls at the same rate as the penny when they are dropped together. Because the quarter has more mass, gravity exerts more force on it. But greater mass also means more inertia, so the greater force does not produce a larger acceleration. Objects with different masses fall with the same acceleration.
- 2 A coin that is dropped falls at the same rate as one that is thrown forward. Horizontal velocity does not affect acceleration due to gravity. Because gravity is directed downward, it changes only the downward velocity of the coin, not its forward velocity.

CHECK YOUR Compare the times it takes two objects with different masses to fall from the same height.

# **Weight and Mass**

While weight and mass are related, they are not the same properties. Mass is a measure of how much matter an object contains. **Weight** is the force of gravity on an object. Mass is a property that an object has no matter where it is located. Weight, on the other hand, depends on the force of gravity acting on that object.



Explore how objects fall at the same rate in a vacuum.



When you use a balance, you are measuring the mass of an object. A person with a mass of 50 kilograms will balance another mass of 50 kilograms whether she is on Earth or on the Moon. Traveling to the Moon would not change how much matter a person is made of. When you use a spring scale, such as a bathroom scale, to measure the weight of an object, however, you are measuring how hard gravity is pulling on an object. The Moon is less massive than Earth, and its gravitational pull is one-sixth that of Earth's. A spring scale would show that a person who has a weight of 490 newtons (110 lb) on Earth would have a weight of 82 newtons (18 lb) on the Moon.

# Gravity keeps objects in orbit.

Sir Isaac Newton hypothesized that the force that pulls objects to the ground—gravity—also pulls the Moon in its orbit around Earth. An **orbit** is the elliptical path one body, such as the Moon, follows around another body, such as Earth, due to the influence of gravity. The centripetal force keeping one object in orbit around another object is due to the gravitational pull between the two objects. In the case of the Moon's orbit, the centripetal force is the gravitational pull between the Sun by the gravitational force between Earth and the Sun.

You can think of an object orbiting Earth as an object that is falling around Earth rather than falling to the ground. Consider what happens to the ball in the illustration on page 385. A dropped ball will fall about five meters during the first second it falls. Throwing the ball straight ahead will not change that falling time. What happens as you throw faster and faster?

Earth is curved. This fact is noticeable only over very long distances. For every 8000 meters you travel, Earth curves downward about 5 meters. If you could throw a ball at 8000 meters per second, it would fall to Earth in such a way that its path would curve the same amount that Earth curves. Since the ball would fall along the curve of Earth, the ball would never actually land on the ground. The ball would be in orbit.

#### READING TIP

An ellipse is shaped as shown below. A circle is a special type of ellipse.

# Orbits

An object in orbit, like an object falling to the ground, is pulled toward Earth's center. If the object moves far enough forward as it falls, it orbits around Earth instead of hitting the ground.



If a ball is thrown straight ahead from a 5-meter height, it will drop 5 meters in the first second it falls. At low speeds, the ball will hit the ground after 1 second. If the ball is going fast enough, the curvature of Earth becomes important. While the ball still drops 5 meters in the first second, it must fall farther than 5 meters to hit the ground. If the ball is going fast enough to travel 8000 meters forward as it drops downward 5 meters, it follows the curvature of Earth. The ball will fall around Earth, not into it.

A ball thrown horizontally at 8000 m/s will not hit Earth during its fall. Gravity acts as a centripetal force, continually pulling the ball toward Earth's center. The ball circles Earth in an orbit.

#### **Real-World Application**

A satellite is launched upward until it is above Earth's atmosphere. The engine then gives the satellite a horizontal speed great enough to keep it in orbit.

**READING** Compare the direction of the velocity with the direction of the force **VisUALS** for an object in a circular orbit.

= force

= velocity

# **Spacecraft in Orbit**

The minimum speed needed to send an object into orbit is approximately 8000 meters per second. At this speed, the path of a falling object matches the curve of Earth's surface. If you launch a spacecraft or a satellite at a slower speed, it will eventually fall to the ground.

A spacecraft launched at a greater speed can reach a higher orbit than one launched at a lower speed. The higher the orbit, the weaker the force from Earth's gravity. The force of gravity is still very strong, however. If a craft is in a low orbit—about 300 kilometers (190 mi)— Earth's gravitational pull is about 91 percent of what it is at Earth's surface. The extra distance makes a difference in the force of only about 9 percent.

If a spacecraft is launched with a speed of 11,000 meters per second or more, it is moving too fast to go into an orbit. Instead, the spacecraft will ultimately escape the pull of Earth's gravity altogether. The speed that a spacecraft needs to escape the gravitational pull of an object such as a planet or a star is called the escape velocity. A spacecraft that escapes Earth's gravity will go into orbit around the Sun unless it is also going fast enough to escape the Sun's gravity.

CHECK YOUR Did any facts in the text above surprise you? If so, which surprised you and why?

# **INVESTIGATE** Gravity

# How does gravity affect falling objects? PROCEDURE

- Carefully use the pencil to punch a hole that is the width of the pencil in the side of the cup, about one-third of the way up from the bottom.
- (2) Holding your finger over the hole, fill the cup three-fourths full of water.
- Hold the cup above the dishpan. Predict what will happen if you remove your finger from the hole. Remove your finger and observe what happens.
- With your finger over the hole, refill the cup to the same level as in step 2. Predict how the water will move if you hold the cup 50 cm above the dishpan and drop the cup and its contents straight down into the pan.
- (5) Drop the cup and observe what happens to the water while the cup is falling.

### WHAT DO YOU THINK?

- What happened to the water in step 3? in step 5?
- How did gravity affect the water when you dropped the cup?

**CHALLENGE** Why did the water behave differently the second time?



# **People in Orbit**

When an elevator you are riding in accelerates downward, you may feel lighter for a short time. If you were standing on a scale during the downward acceleration, the scale would show that you weighed less than usual. Your mass would not have changed, nor would the pull of gravity. What would cause the apparent weight loss?

When the elevator is still, the entire force of your weight presses against the scale. When the elevator accelerates downward, you are not pressing as hard on the scale, because the scale is also moving downward. Since the scale measures how hard you are pushing on it, you appear to weigh less. If you and the scale were in free fall—a fall due entirely to gravity—the scale would fall as fast as you did. You would not press against the scale at all, so you would appear to be weightless.

A spacecraft in orbit is in free fall. Gravity is acting on the astronauts and on the ship—without gravity, there could be no orbit. However, the ship and the astronauts are falling around Earth at the same rate. While astronauts are in orbit, their weight does not press against the floor of the spacecraft. The result is an environment, called a microgravity environment, in which objects behave as if there were no gravity. People and objects simply float as if they were weightless.

**READING** Why do astronauts float when they are in orbit?



Astronaut Mae Jemison is shown here working in a microgravity environment.

# 12.1 Review

# **KEY CONCEPTS**

- 1. What effect would increasing the mass of two objects have on the gravitational attraction between them?
- 2. What effect would decreasing the distance between objects have on their gravitational attraction to each other?
- **3.** How does gravity keep the Moon in orbit around Earth?

# **CRITICAL THINKING**

- **4. Compare** How does the size of the force exerted by Earth's gravity on a car compare with the size of the force the car exerts on Earth?
- 5. Apply What would be the effect on the mass and the weight of an object if the object were taken to a planet with twice the gravity of Earth?

## CHALLENGE

6. Synthesize Precision measurements of the acceleration due to gravity show that the acceleration is slightly different in different locations on Earth. Explain why the force of gravity is not exactly the same everywhere on Earth's surface. Hint: Think about the details of Earth's surface.