Name _____ Class _____ Date _____

CHAPTER 13 Forces and Motion

SECTION 2

Gravity and Motion

BEFORE YOU READ

After you read this section, you should be able to answer these questions:

- How is acceleration related to gravity?
- When does acceleration stop?
- When does free fall occur?

California Science Standards

8.2.a, 8.2.b, 8.2.e, 8.2.f, 8.2.g

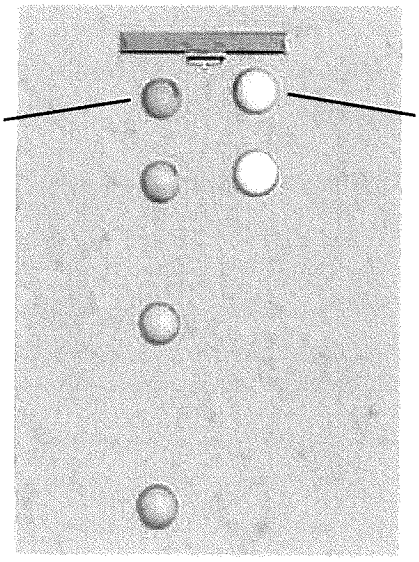
How Do Objects Fall?

Suppose you dropped a baseball and a marble at the same time. Which would land on the ground first?

If you thought that the baseball would land first, you were thinking along the same lines as Aristotle, a Greek philosopher, who lived around 400 BCE. He thought that the rate at which an object falls depends on its mass. Because the baseball has the larger mass, he would have predicted that it would land on the ground first.

If you thought that the baseball and marble would land at the same time, your thinking is like that of Galileo Galilei, an Italian scientist in the 16th century. Galileo thought that the mass of an object does not affect the time the object takes to fall to the ground. According to one story, Galileo proved his argument by dropping two cannon balls of different masses from a tower. ☑

This stop-action photo shows that a table-tennis ball and a golf ball fall at the same rate even though they have different masses.



STUDY TIP

Compare In your Science Notebook, make a Comparison Table that compares the motion of falling bodies without air resistance, with air resistance, and with a starting forward velocity.

READING CHECK

1. Contrast How does Aristotle's idea about how two objects would fall differ from Galileo's?

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TAKE A LOOK

2. Observe In the figure, the last two positions of the golf ball are not shown. Draw two circles to show where the golf ball would be found.

How Does Acceleration Affect Falling Objects?

Acceleration is how quickly velocity changes. An object accelerates when the forces on it are unbalanced. As you know, gravity exerts a downward, unbalanced force on falling objects. So, objects accelerate as they fall.

A table-tennis ball and a golf ball fall to the ground at the same rate. This is because acceleration due to gravity is the same for all objects. How can this be?

Acceleration depends on both force and mass. A heavier object is pulled by a greater gravitational force than a lighter object. But a heavier object is also harder to accelerate because of its larger mass. The extra mass of the heavy object exactly makes up for its larger gravitational force. ☑

Falling objects accelerate toward Earth at a rate of 9.8 meters per second per second. This is written as 9.8 m/s^2. For every second that an object falls, its downward velocity increases by 9.8 m/s.

READING CHECK

3. Examine Why do objects of the same size and shape fall to the ground at the same rate?

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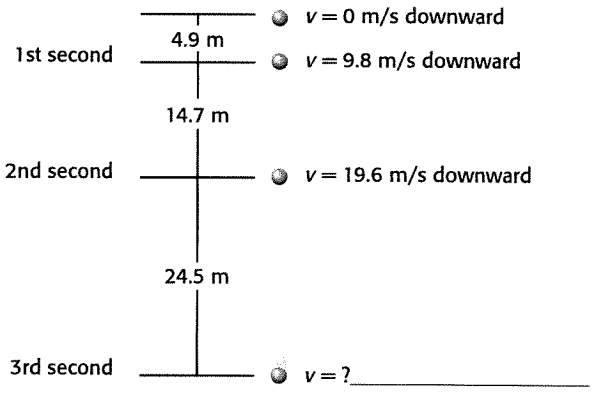

A falling object accelerates at a constant rate. The object falls faster and farther each second than it did the second before.

TAKE A LOOK

4. Compare How much faster does the ball fall each second? How did you get this answer?

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You can calculate the final velocity (v_{final}) of an object falling from rest by using the following equation:

$$v_{final} = g \times t$$

In this equation, g is the acceleration due to gravity, and t is the time the object falls. Let's use the equation to find the final speed of the ball after 4 s. ☑

$v_{final} = g \times t$

$v_{final} = 9.8 \text{ m/s}^2 \times 4 \text{ s} = 39.2 \text{ m/s downward}$

READING CHECK

5. Identify What does each variable stand for in the equation?

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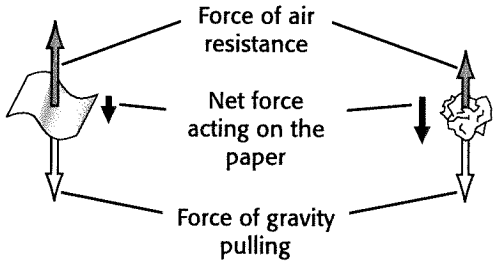
Would 39.2 m/s downward be the velocity after the 4th second in the figure above? The answer is yes because 29.4 + 9.8 = 39.2.

How Does Air Resistance Affect Falling Objects?

Suppose you were to drop two sheets of paper—one crumpled into a tight ball and the other kept flat. What would happen? You would find that the flat piece of paper would fall more slowly than the crumpled piece of paper.

Air resistance is the force that acts against the motion of objects through air. How much air resistance acts on an object depends on the size, shape, and speed of the object. The figure below shows how shape changes the way a sheet of paper will fall.

How Air Resistance Affects Velocity



The upward force of air resistance continues to increase as an object falls. It gets larger until it is equal to the downward force of gravity. At this point, the net force is 0 N, and the object stops accelerating. The object then falls at a constant velocity called the **terminal velocity**. If an object falls for a long enough time, it will reach a terminal velocity. ☑

Hailstones have a terminal velocity between 5 m/s and 40 m/s, depending on their mass. If there were no air resistance, hailstones would hit the ground at velocities near 350 m/s! Imagine the danger that hailstones would pose for people, houses, and cars.

TAKE A LOOK

6. Identify What two forces combine to determine the net force on a falling object?

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7. Explain Why does the crumpled paper fall faster than the flat paper?

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READING CHECK

8. Describe What is terminal velocity?

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What Is Free Fall?

Often you will hear about a sky diver who is in "free fall." This isn't the correct use of this term. An object is in **free fall** if the only force acting on the object is gravity. A sky diver has a large air resistance as she falls.

Because air resistance is a force, free fall can occur only where there is no air. There is no air, or any other matter, in a *vacuum*. Vacuum chambers are containers from which most of the air has been removed. ☑

READING CHECK

9. Describe What is a vacuum?

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The figure below shows two objects falling in a vacuum chamber. Because there is almost no air resistance, the two objects are in free fall.

TAKE A LOOK

10. Predict Which will hit the bottom of the chamber first? Explain your answer.

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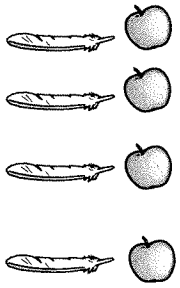

Air resistance usually causes a feather to fall more slowly than an apple falls. But in a vacuum, a feather and an apple fall with the same acceleration because both are in free fall.

What Is Projectile Motion?

Have you ever seen a bullfrog jump? Have you seen a swimmer dive into the water? Have you ever sprayed water from a hose? These are all examples of projectile motion. **Projectile motion** is the curved path an object follows when it is thrown or propelled near the surface of Earth. Horizontal and vertical movements combine to form a curved path. ☑

READING CHECK

11. Describe What are the two components or parts of projectile motion?

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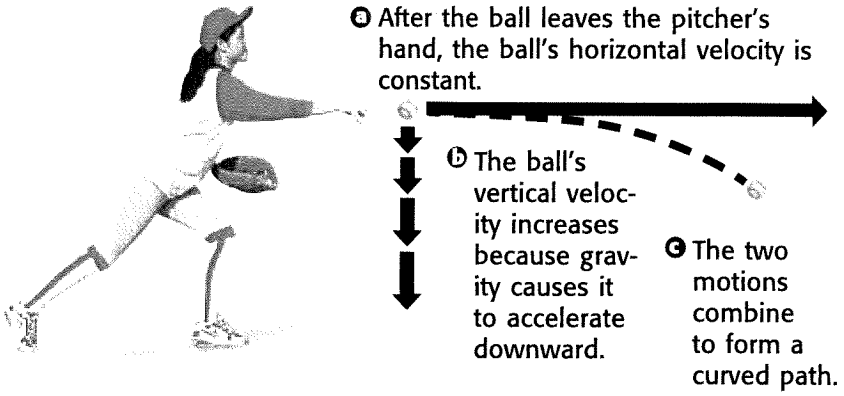
Although the horizontal and vertical movements combine, the two motions are separate from each other in a very important way. The horizontal motion does not influence the vertical motion.



Suppose you throw a ball to a friend. The horizontal and vertical motions of the ball form the curved path as shown in the figure above.

HORIZONTAL MOVEMENT

Your hand gives a force to the ball that makes the ball move forward. This is the horizontal movement, which is parallel to the ground. After the ball leaves your hand, no horizontal forces are acting on the ball (if you ignore air resistance). The horizontal velocity of the ball stays constant after the ball leaves your hand. ☑

VERTICAL MOVEMENT

Gravity pulls everything on Earth down toward the center of Earth. A ball in your hand doesn't fall because your hand is holding the ball. After you throw the ball, gravity pulls the ball down. Gravity gives the ball vertical movement, which is movement perpendicular to the ground. Gravity pulls the ball down at an acceleration of 9.8 m/s^2 (ignoring air resistance).

Objects in projectile motion accelerate down. You always have to aim above a target if you want to hit it with a thrown object. If you want to shoot an arrow at a round bull's-eye, you have to aim above the bull's-eye. If you aim at a bull's-eye on a target, the arrow will hit below it.

Arrow Shot at a Bull's-Eye

Critical Thinking

12. Apply the Concept What gives an arrow shot horizontally from a bow its vertical movement?

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READING CHECK

13. Identify After a thrown ball leaves your hand, what happens to its horizontal velocity?

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Critical Thinking

14. Apply Concepts Draw the path that the arrow took to the target.

How Does Gravity Affect Orbiting?

An object is orbiting when it is moving around another object in space. A spacecraft orbiting Earth is moving forward, but it is also in free fall toward Earth. In the figure below, you can see how these two movements come together to form an orbit. ☑

READING CHECK

15. Identify What two motions form an orbit?

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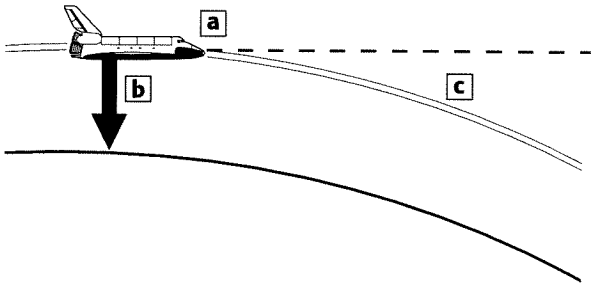

a. The space shuttle moves forward at a constant speed. If there were no gravity, the space shuttle would continue to move in a straight line.

b. The space shuttle is in free fall because gravity pulls it toward Earth. The space shuttle would move straight down if it were not traveling forward.

c. The path of the space shuttle follows the curve of Earth's surface. This path is known as an orbit.

Critical Thinking

16. Predict What would happen to the space shuttle if it lost its forward motion?

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Notice how the forward movement and the free fall movement of the space shuttle combine. Together they form the movement called *orbiting*. This is similar to how horizontal and vertical motions combine to form projectile motion. Of course, many other objects are in orbit in the universe. The moon orbits Earth. The planets orbit the sun. What forces act on objects in orbit?

Centripetal force is the unbalanced force that makes things move in a circular path. The word centripetal means "toward the center." Gravity provides the centripetal force that keeps things in orbit. ☑

READING CHECK

17. Explain What does a centripetal force do?

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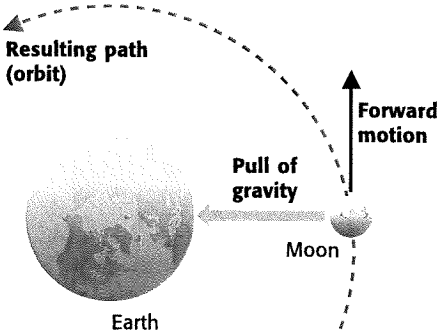


Gravity changes the straight-line path of the moon into a curved orbit. **What kind of force provided by gravity keeps the moon in orbit around Earth?**

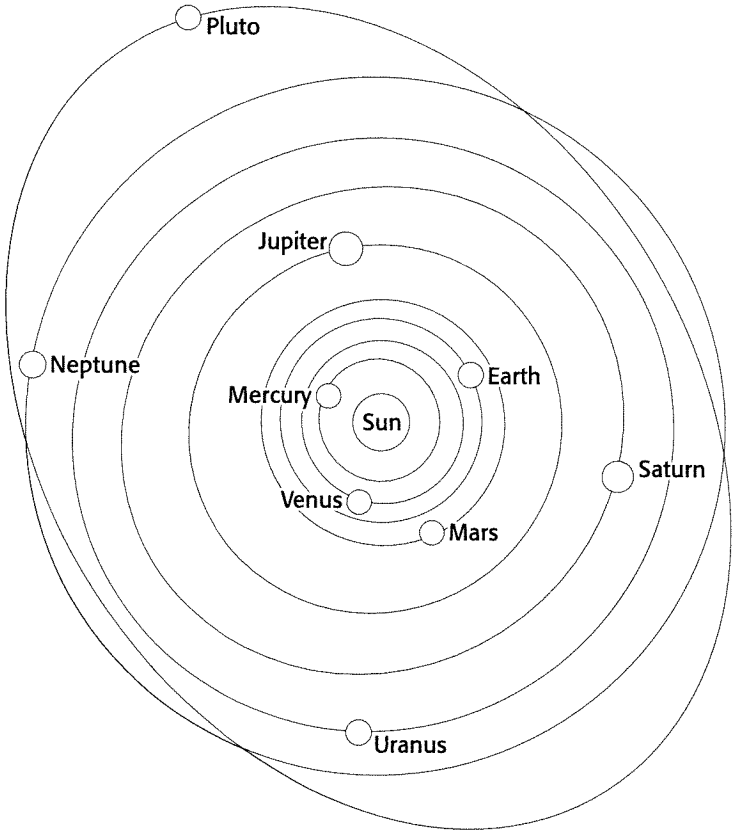
How Does Gravity Affect Objects in the Solar System?

Gravity maintains the shape of the solar system. Gravity between the sun and the planets keeps the planets in orbit around the sun. Gravity provides a centripetal force on the planets. Gravity also keeps the moons in orbit around their planets. The rings of Saturn, which are made of tiny pieces of ice and dust, are kept in place because of gravity.

Gravity makes the paths that planets follow nearly circular. This kind of shape is called an *ellipse*. An ellipse is sometimes called an oval. Examples of everyday objects that are shaped like ellipses include watermelons and footballs.

In the figure below, you can see that the paths of the planets look circular. But they are really ellipses. This type of path is called *elliptical*.

The Solar System



CALIFORNIA STANDARDS CHECK

8.2.g Students know the role of gravity in forming and maintaining the shapes of planets, stars, and the solar system.

Word Help: maintain
to keep the same

18. Compare How does gravity maintain the orbits in the solar system?

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TAKE A LOOK

19. Identify Which planet has the most elliptical orbit?

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Name _____ Class _____ Date _____

Section 2 Review

8.2.a, 8.2.b, 8.2.3, 8.2.f, 8.2.g

SECTION VOCABULARY

free fall the motion of a body when only gravity is acting on the body **projectile motion** the curved path an object follows when it is thrown or propelled near the surface of Earth	**terminal velocity** the constant velocity of a falling object when the force of air resistance is equal to the magnitude and opposite in direction to the force of gravity

1. **Justify** A brick has a greater mass than a sponge has. Why is the acceleration due to gravity the same for both objects?

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2. **Complete** Identify the forces that cause motion.

Motion	Forces
Object in free fall	_____ _____
Object falling at terminal velocity	_____ _____
Arrow traveling at a target	_____ _____
Satellite orbiting Earth	_____ _____

3. **Analyze** How does air resistance affect the acceleration of falling objects?

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4. **Explain** What force is needed to keep objects in circular motion? What supplies this force to keep planets in the solar system in orbit?

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