6

Forces and Motion

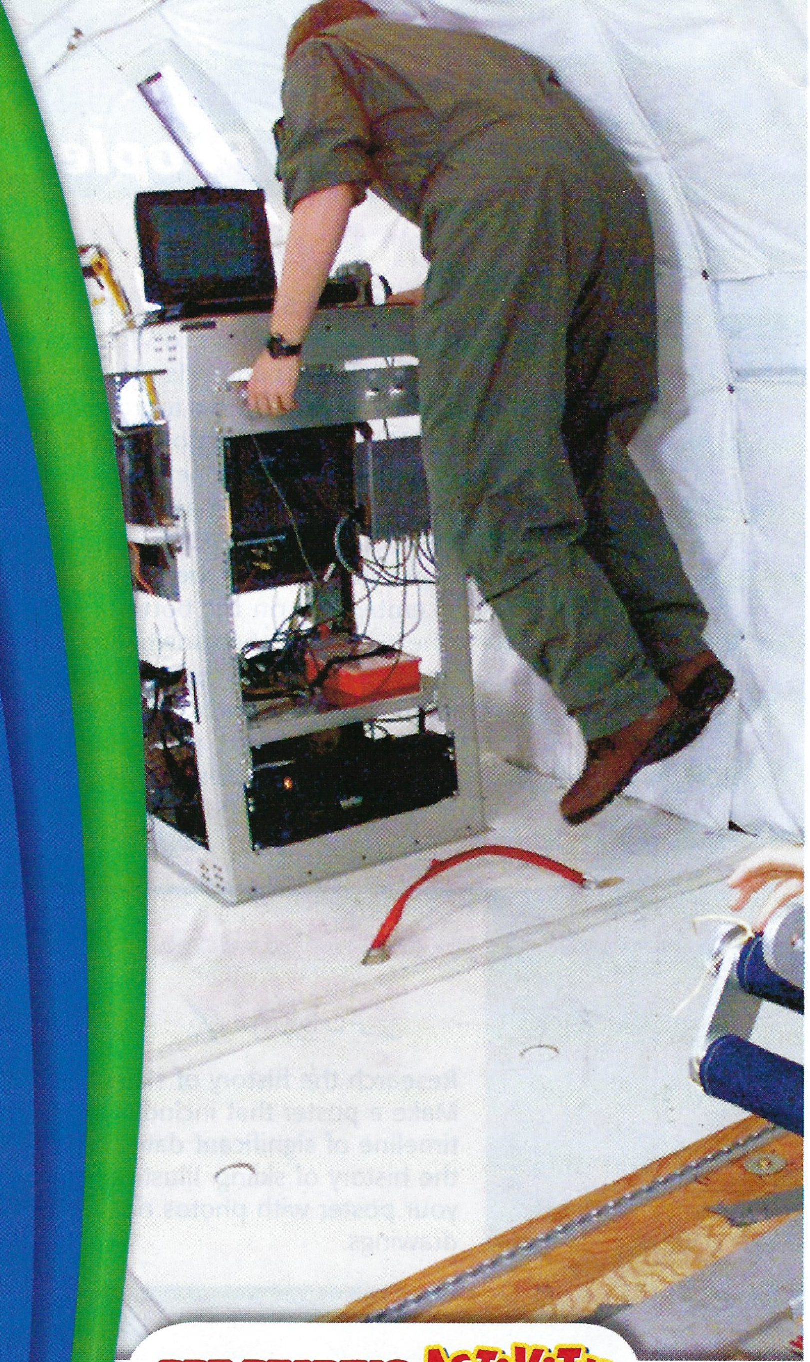
The Big Idea

Unbalanced forces cause changes in motion that can be predicted and described.

SECTION

About the PHOTO

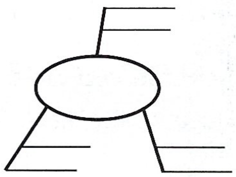
To train for space flight, astronauts fly in a modified KC-135 cargo airplane. The airplane first flies upward at a steep angle. Then, it flies downward at a 45° angle, which causes the feeling of reduced gravity inside. Under these conditions, the astronauts in the plane can float and can practice carrying out tasks that they will need to perform when they are in orbit. Because the floating makes people queasy, this KC-135 is nicknamed the "Vomit Comet."



PRE-READING ACTIVITY

Graphic Organizer

Spider Map Before you read the chapter, create the graphic organizer entitled "Spider Map" described in the **Study Skills** section of the Appendix. Label the circle "Motion." Create a leg for each law of motion, a leg for gravity, and a leg for momentum. As you read the chapter, fill in the map with details about how motion is related to the laws of motion, gravity, and momentum.



SECTION 1

Gravity and Motion

Suppose you dropped a baseball and a marble at the same time from the top of a tall building. Which do you think would land on the ground first?

What You Will Learn

- Explain the effect of gravity and air resistance on falling objects.
- Explain why objects in orbit are in free fall and appear to be weightless.
- Describe how projectile motion is affected by gravity.

Vocabulary

terminal velocity
free fall
projectile motion

READING STRATEGY

Reading Organizer As you read this section, create an outline of the section. Use the headings from the section in your outline.

In ancient Greece around 400 BCE, a philosopher named Aristotle (AR is TAWT uhl) thought that the rate at which an object falls depended on the object's mass. If you asked Aristotle whether the baseball or the marble would land first, he would have said the baseball. But Aristotle never tried dropping objects with different masses to test his idea about falling objects.

Gravity and Falling Objects

In the late 1500s, a young Italian scientist named Galileo Galilei (GAL uh LAY oh GAL uh LAY) questioned Aristotle's idea about falling objects. Galileo argued 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 cannonballs of different masses from the top of the Leaning Tower of Pisa in Italy. The people watching from the ground below were amazed to see the two cannonballs land at the same time. Whether or not this story is true, Galileo's work changed people's understanding of gravity and falling objects.

Gravity and Acceleration

Objects fall to the ground at the same rate because the acceleration due to gravity is the same for all objects. Why is this true? Acceleration depends on both force and mass. A heavier object experiences a greater gravitational force than a lighter object does. But a heavier object is also harder to accelerate because it has more mass. The extra mass of the heavy object exactly balances the additional gravitational force. **Figure 1** shows objects that have different masses falling with the same acceleration.

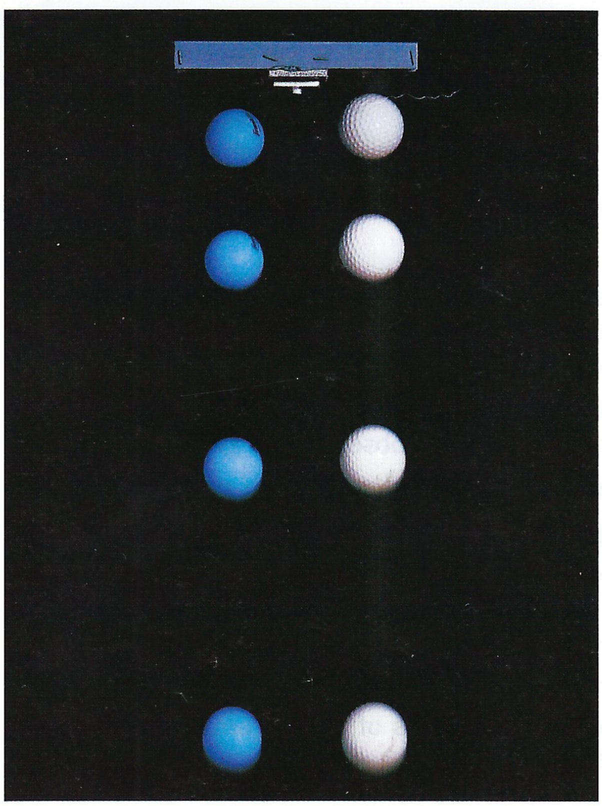


Figure 1 *This stop-action photo shows that a table-tennis ball and a golf ball fall at the same rate even though they have different masses.*

Acceleration Due to Gravity

Acceleration is the rate at which velocity changes over time. So, the acceleration of an object is the object's change in velocity divided by the amount of time during which the change occurs. All objects accelerate toward Earth at a rate of 9.8 meters per second per second. This rate is written as 9.8 m/s/s, or 9.8 m/s^2. So, for every second that an object falls, the object's downward velocity increases by 9.8 m/s, as shown in **Figure 2.**

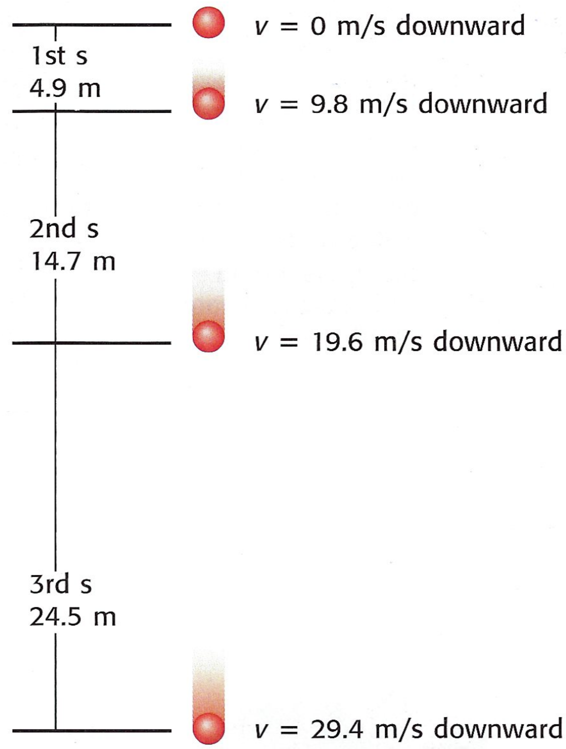


Figure 2 *A falling object accelerates at a constant rate. The object falls faster and farther each second than it did the second before.*

✓ Reading Check **What is the acceleration due to gravity?** (*See the Appendix for answers to Reading Checks.*)

Velocity of Falling Objects

You can calculate the change in velocity (Δv) of a falling object by using the following equation:

$$\Delta v = g \times t$$

In this equation, g is the acceleration due to gravity on Earth (9.8 m/s^2), and t is the time the object takes to fall (in seconds). The change in velocity is the difference between the final velocity and the starting velocity. If the object starts at rest, this equation yields the velocity of the object after a certain time period.

MATH FOCUS

Calculating the Velocity of Falling Objects A stone at rest is dropped from a cliff, and the stone hits the ground after a time of 3 s. What is the stone's velocity when it hits the ground?

Step 1: Write the equation for change in velocity.

$$\Delta v = g \times t$$

Step 2: Replace g with its value and t with the time given in the problem, and solve.

$$\Delta v = 9.8 \frac{m/s}{\cancel{s}} \times 3\,\cancel{s}$$
$$= 29.4 \text{ m/s}$$

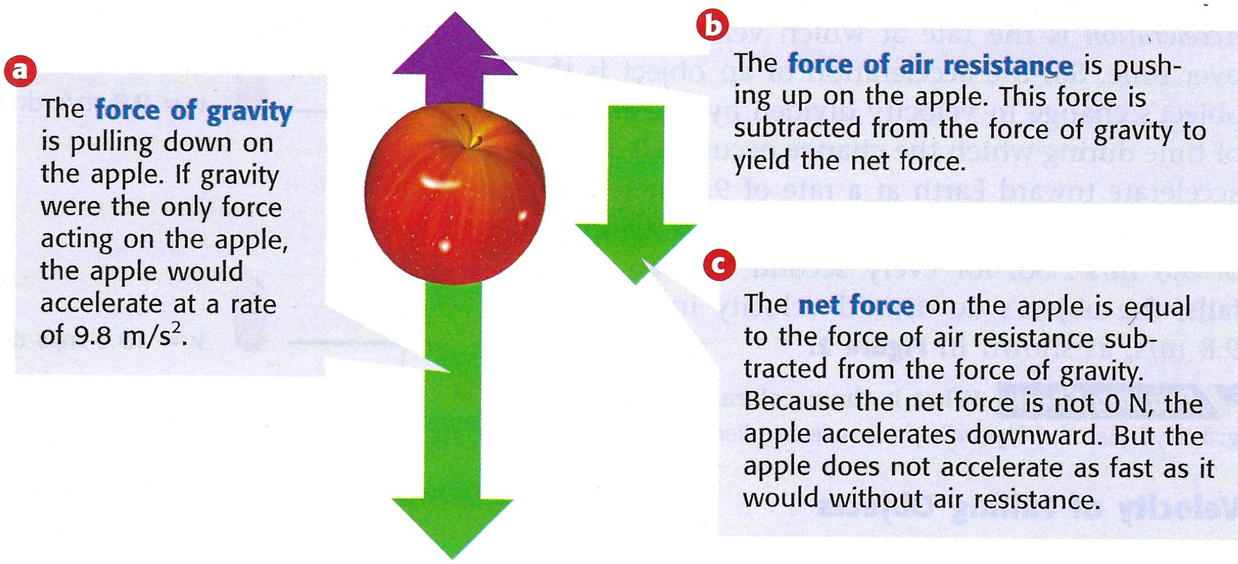
To rearrange the equation to find time, divide by the acceleration due to gravity:

$$t = \frac{\Delta v}{g}$$

Now It's Your Turn

1. A penny at rest is dropped from the top of a tall stairwell. What is the penny's velocity after it has fallen for 2 s?
2. The same penny hits the ground in 4.5 s. What is the penny's velocity as it hits the ground?
3. A marble at rest is dropped from a tall building. The marble hits the ground with a velocity of 98 m/s. How long was the marble in the air?
4. An acorn at rest falls from an oak tree. The acorn hits the ground with a velocity of 14.7 m/s. How long did it take the acorn to land?

Figure 3 Effect of Air Resistance on a Falling Object



Air Resistance and Falling Objects

Try dropping two sheets of paper—one crumpled in a tight ball and the other kept flat. What happened? Does this simple experiment seem to contradict what you just learned about falling objects? The flat paper falls more slowly than the crumpled paper because of *air resistance.* Air resistance is the force that opposes the motion of objects through air.

The amount of air resistance acting on an object depends on the size, shape, and speed of the object. Air resistance affects the flat sheet of paper more than the crumpled one. The larger surface area of the flat sheet causes the flat sheet to fall slower than the crumpled one. **Figure 3** shows the effect of air resistance on the downward acceleration of a falling object.

Reading Check **Will air resistance have more effect on the acceleration of a falling leaf or the acceleration of a falling acorn?**

Figure 4 *The parachute increases the air resistance of this sky diver and slows him to a safe terminal velocity.*

Acceleration Stops at the Terminal Velocity

As the speed of a falling object increases, air resistance increases. The upward force of air resistance continues to increase 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.**

terminal velocity the constant velocity of a falling object when the force of air resistance is equal in magnitude and opposite in direction to the force of gravity

Terminal velocity can be a good thing. Every year, cars, buildings, and vegetation are severely damaged in hailstorms. The terminal velocity of hailstones is between 5 and 40 m/s, depending on their size. If there were no air resistance, hailstones would hit the ground at velocities near 350 m/s! **Figure 4** shows another situation in which terminal velocity is helpful.

Free Fall Occurs When There Is No Air Resistance

Sky divers are often described as being in free fall before they open their parachutes. However, that is an incorrect description, because air resistance is always acting on the sky diver.

An object is in **free fall** only if gravity is pulling it down and no other forces are acting on it. Because air resistance is a force, free fall can occur only where there is no air. Two places that have no air are in space and in a vacuum. A vacuum is a place in which there is no matter. **Figure 5** shows objects falling in a vacuum. Because there is no air resistance in a vacuum, the two objects are in free fall.

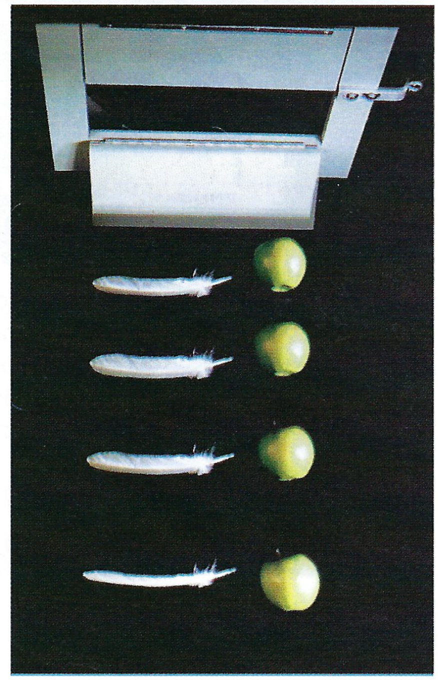


Figure 5 *Air resistance usually causes a feather to fall more slowly than an apple falls. But in a vacuum, a feather and an apple fall with the same acceleration because both are in free fall.*

free fall the motion of a body when only the force of gravity is acting on the body

Orbiting Objects Are in Free Fall

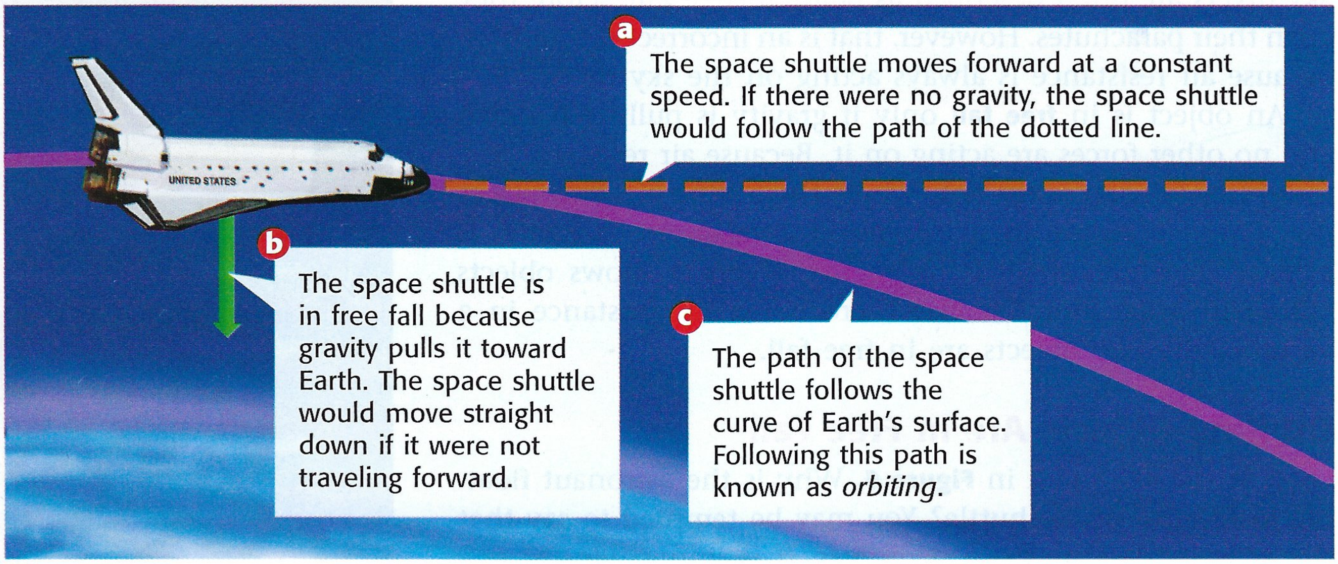
Look at the astronaut in **Figure 6.** Why is the astronaut floating inside the space shuttle? You may be tempted to say that she is weightless in space. However, it is impossible for any object to be weightless anywhere in the universe.

Weight is a measure of gravitational force. The size of the force depends on the masses of objects and the distances between them. Suppose you traveled in space far away from all the stars and planets. The gravitational force acting on you would be very small because the distance between you and other objects would be very large. But you and all the other objects in the universe would still have mass. Therefore, gravity would attract you to other objects—even if just slightly—so you would still have weight.

Astronauts float in orbiting spacecrafts because of free fall. To better understand why astronauts float, you need to know what *orbiting* means.

Figure 6 *Astronauts appear to be weightless while they are floating inside the space shuttle—but they are not weightless!*

Figure 7 How an Orbit Is Formed



Two Motions Combine to Cause Orbiting

An object is orbiting when it is traveling around another object in space. When a spacecraft orbits Earth, it is moving forward. But the spacecraft is also in free fall toward Earth. **Figure 7** shows how these two motions combine to cause orbiting.

As you can see in **Figure 7,** the space shuttle is always falling while it is in orbit. So why don't astronauts hit their heads on the ceiling of the falling shuttle? Because they are also in free fall—they are always falling, too. Because astronauts are in free fall, they float.

Orbiting and Centripetal Force

Besides spacecrafts and satellites, many other objects in the universe are in orbit. The moon orbits the Earth. Earth and the other planets orbit the sun. In addition, many stars orbit large masses in the center of galaxies. Many of these objects are traveling in a circular or nearly circular path. Any object in circular motion is constantly changing direction. Because an unbalanced force is necessary to change the motion of any object, there must be an unbalanced force working on any object in circular motion.

The unbalanced force that causes objects to move in a circular path is called a *centripetal force* (sen TRIP uht uhl FOHRS). Gravity provides the centripetal force that keeps objects in orbit. The word *centripetal* means "toward the center." As you can see in **Figure 8,** the centripetal force on the moon points toward the center of the moon's circular orbit.

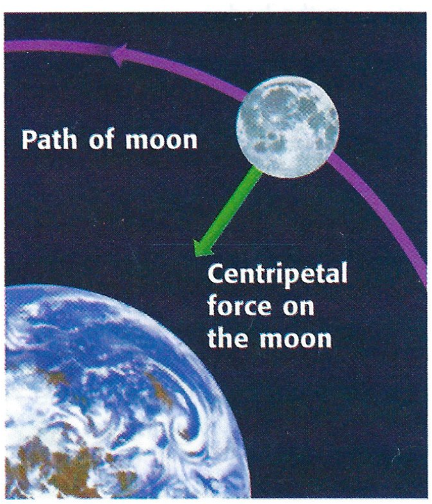


Figure 8 *The moon stays in orbit around Earth because Earth's gravitational force provides a centripetal force on the moon.*

Reading Check What does the word *centripetal* mean?

Projectile Motion and Gravity

The motion of a hopping grasshopper is an example of projectile motion (proh JEK tuhl MOH shuhn). **Projectile motion** is the curved path an object follows when it is thrown or propelled near the surface of the Earth. Projectile motion has two components—horizontal motion and vertical motion. The two components are independent, so they have no effect on each other. When the two motions are combined, they form a curved path, as shown in **Figure 9.** Some examples of projectile motion include the following:

- a frog leaping
- water sprayed by a sprinkler
- a swimmer diving into water
- balls being juggled
- an arrow shot by an archer

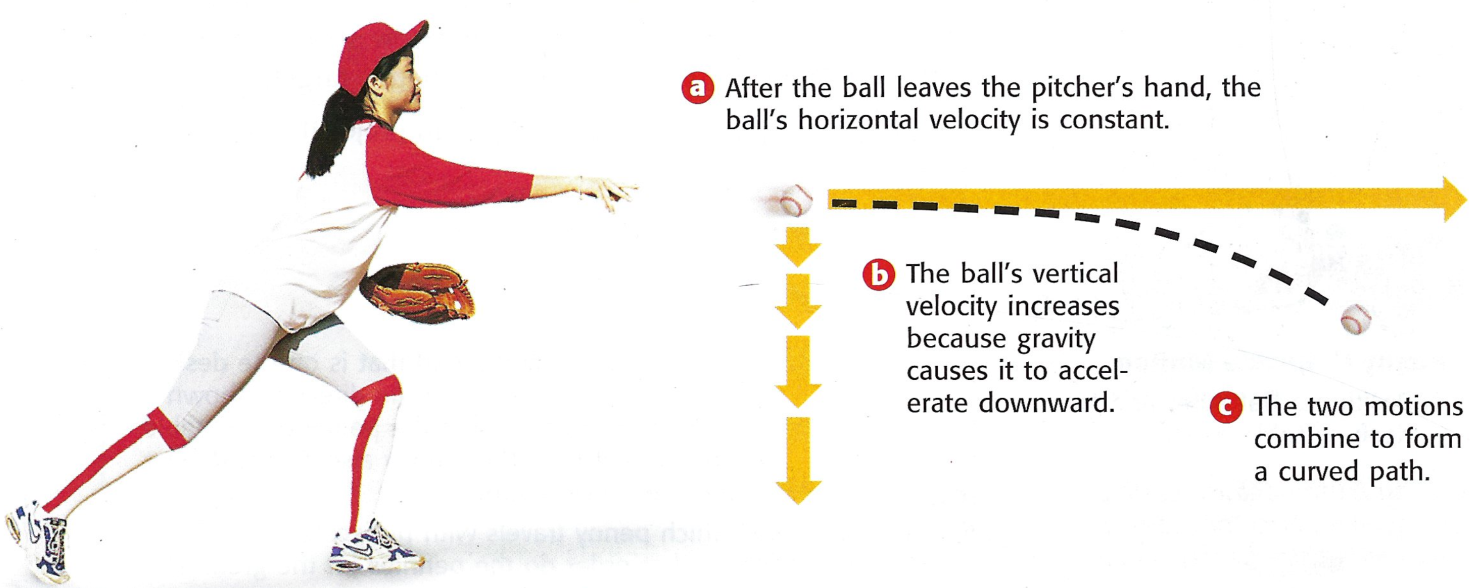
projectile motion the curved path that an object follows when thrown, launched, or otherwise projected near the surface of Earth

Horizontal Motion

When you throw a ball, your hand exerts a force on the ball that makes the ball move forward. This force gives the ball its horizontal motion, which is motion parallel to the ground.

After you release the ball, no horizontal forces are acting on the ball (if you ignore air resistance). Even gravity does not affect the horizontal component of projectile motion. So, there are no forces to change the ball's horizontal motion. Thus, the horizontal velocity of the ball is constant after the ball leaves your hand, as shown in **Figure 9.**

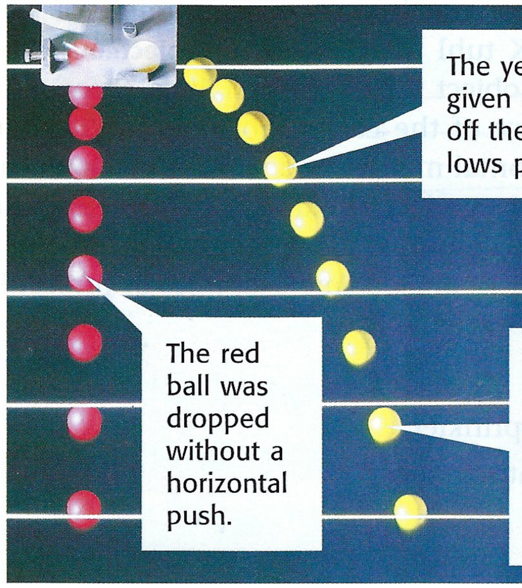
Figure 9 **Projectile Motion**



INTERNET ACTIVITY

For another activity related to this chapter, go to **go.hrw.com** and type in the keyword **HP5FORW.**

Figure 10 **Projectile Motion and Acceleration Due to Gravity**



Vertical Motion

Gravity pulls everything on Earth downward toward the center of Earth. A ball in your hand is prevented from falling by your hand. After you throw the ball, gravity pulls it downward and gives the ball vertical motion. Vertical motion is motion that is perpendicular to the ground. Gravity pulls objects in projectile motion down at an acceleration of 9.8 m/s^2 (if air resistance is ignored). This rate is the same for all falling objects. **Figure 10** shows that the downward acceleration of a thrown object and a falling object are the same.

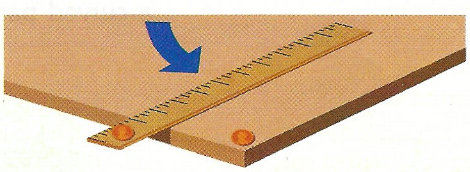
Because objects in projectile motion accelerate downward, you always have to aim above a target if you want to hit it with a thrown or propelled object. That's why when you aim an arrow directly at a bull's-eye, your arrow strikes the bottom of the target rather than the middle of the target.

✓ Reading Check **What gives an object in projectile motion its vertical motion?**

QUICK LAB

Penny Projectile Motion

1. Position a **flat ruler** and **two pennies** on a **desk or table** as shown below.



2. Hold the ruler by the end that is on the desk. Move the ruler quickly in the direction shown so that the ruler knocks the penny off the table and so that the other penny also drops. Repeat this step several times.
3. Which penny travels with projectile motion? In what order do the pennies hit the ground? Record and explain your answers.

SECTION Review

Summary

- Gravity causes all objects to accelerate toward Earth at a rate of 9.8 m/s^2.
- Air resistance slows the acceleration of falling objects. An object falls at its terminal velocity when the upward force of air resistance equals the downward force of gravity.
- An object is in free fall if gravity is the only force acting on it.
- Objects in orbit appear to be weightless because they are in free fall.
- A centripetal force is needed to keep objects in circular motion. Gravity acts as a centripetal force to keep objects in orbit.
- Projectile motion is the curved path an object follows when thrown or propelled near the surface of Earth.
- Projectile motion has two components—horizontal motion and vertical motion. Gravity affects only the vertical motion of projectile motion.

Using Key Terms

1. Use each of the following terms in a separate sentence: *terminal velocity* and *free fall.*

Understanding Key Ideas

2. Which of the following is in projectile motion?
   a. a feather falling in a vacuum
   b. a cat leaping on a toy
   c. a car driving up a hill
   d. a book laying on a desk
3. How does air resistance affect the acceleration of falling objects?
4. How does gravity affect the two components of projectile motion?
5. How is the acceleration of falling objects affected by gravity?
6. Why is the acceleration due to gravity the same for all objects?

Math Skills

7. A rock at rest falls off a tall cliff and hits the valley below after 3.5 s. What is the rock's velocity as it hits the ground?

Critical Thinking

8. **Applying Concepts** Think about a sport that uses a ball. Identify four examples from that sport in which an object is in projectile motion.
9. **Making Inferences** The moon has no atmosphere. Predict what would happen if an astronaut on the moon dropped a hammer and a feather at the same time from the same height.

Interpreting Graphics

10. Whenever Jon delivers a newspaper to the Zapanta house, the newspaper lands in the bushes, as shown below. What should Jon do to make sure the newspaper lands on the porch?