Name _____ Class _____ Date _____

CHAPTER 6 Forces and Motion

SECTION 1

Gravity and Motion

BEFORE YOU READ

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

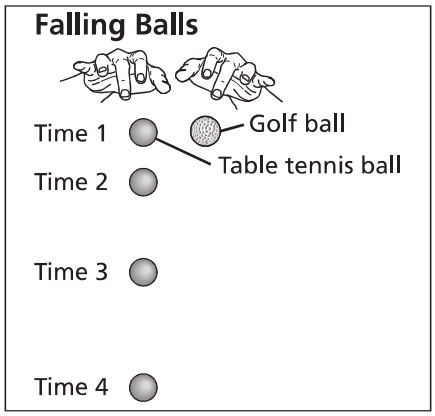
- How does gravity affect objects?
- How does air resistance affect falling objects?
- What is free fall?
- Why does an object that is thrown horizontally follow a curved path?

How Does Gravity Affect Falling Objects?

In ancient Greece, a great thinker named Aristotle said that heavy objects fall faster than light objects. For almost 2,000 years, people thought this was true. Then, in the late 1500s, an Italian scientist named Galileo Galilei proved that heavy and light objects actually fall at the same rate.

It has been said that Galileo proved this by dropping two cannonballs from the top of a tower at the same time. The cannonballs were the same size, but one was much heavier than the other. The people watching saw both cannonballs hit the ground at the same time. ☑

Why don't heavy objects fall faster than light objects? Gravity pulls on heavy objects more than it pulls on light objects. However, heavy objects are harder to move than light objects. So, the extra force from gravity on the heavy object is balanced by how much harder it is to move.



STUDY TIP

Practice After every page, stop reading and think about what you've read. Try to think of examples from everyday life. Don't go on to the next section until you think you understand.

READING CHECK

1. Describe What did the people watching the cannonballs see that told them the cannonballs fell at the same rate?

_____

_____

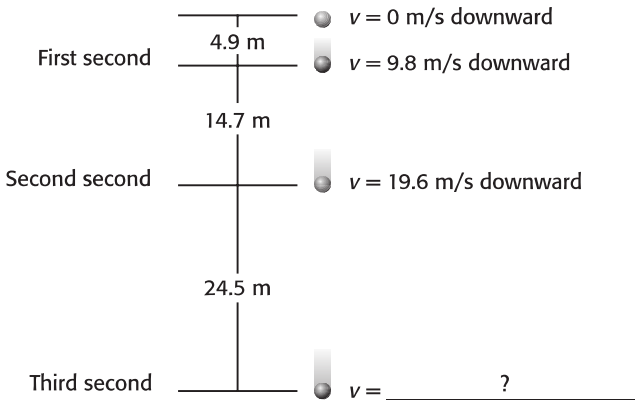
_____

TAKE A LOOK

2. Predict The golf ball is heavier than the table tennis ball. On the figure, draw three circles to show where the golf ball will be at times 2, 3, and 4.

How Much Acceleration Does Gravity Cause?

Because of gravity, all objects accelerate, or speed up, toward Earth at a rate of 9.8 meters per second per second. This is written as 9.8 m/s/s or 9.8 m/s^2. So, for every second an object falls, its velocity (speed) increases by 9.8 m/s. This is shown in the figure below.



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

Math Focus

3. Calculate How fast is the ball moving at the end of the third second? Explain your answer.

What Is the Velocity of a Falling Object?

Suppose you drop a rock from a cliff. How fast is it going when it reaches the bottom? If you have a stopwatch, you can calculate its final velocity.

If an object starts from rest and you know how long it falls, you can calculate its final velocity by using this equation:

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

In the equation, v_{final} stands for final velocity in meters per second, g stands for the acceleration due to gravity (9.8 m/s^2), and t stands for the time the object has been falling (in seconds).

If the rock took 4 s to hit the ground, how fast was it falling when it hit the ground?

Step 1: Write the equation.

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

Step 2: Place values into the equation, and solve for the answer.

$$v_{\text{final}} = 9.8 \frac{\text{m/s}}{\cancel{\text{s}}} \times 4 \cancel{\text{s}} = 39.2 \text{ m/s}$$

The velocity of the rock was 39.2 m/s when it hit the ground.

Math Focus

4. Calculate A penny is dropped from the top of a tall stairwell. What is the velocity of the penny after it has fallen for 2 s? Show your work.

How Can You Calculate How Long an Object Was Falling?

Suppose some workers are building a bridge. One of them drops a metal bolt from the top of the bridge. When the bolt hits the ground, it is moving 49 m/s. How long does it take the bolt to fall to the ground?

Step 1: Write the equation.

$$t = \frac{v_{\text{final}}}{g}$$

Step 2: Place values into the equation, and solve for the answer.

$$t = \frac{49 \text{ m/s}}{9.8 \frac{\text{m/s}}{\text{s}}} = 5 \text{ s}$$

The bolt fell for 5 s before it hit the ground.

Math Focus

5. Calculate A rock falls from a cliff and hits the ground with a velocity of 98 m/s. How long does the rock fall? Show your work.

How Does Air Resistance Affect Falling Objects?

Try dropping a pencil and a piece of paper from the same height. What happens? Does this simple experiment show what you just learned about falling objects? Now crumple the paper into a tight ball. Drop the crumpled paper and the pencil from the same height.

What happens? The flat paper falls more slowly than the crumpled paper because of air resistance. *Air resistance* is the force that opposes the motion of falling objects. ☑

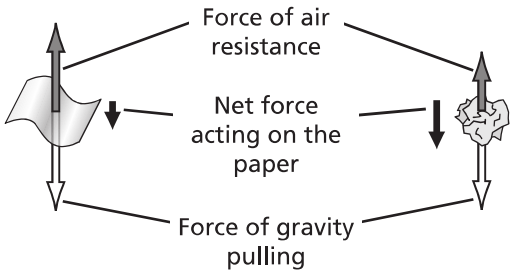
How much air resistance will affect an object depends on the size, shape, and speed of the object. The flat paper has more surface area than the crumpled sheet. This causes the flat paper to fall more slowly.

READING CHECK

6. Identify Which has more air resistance, the flat paper or the crumpled paper?

_____

How Air Resistance Affects Velocity



TAKE A LOOK

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

_____

_____

_____

What Is Terminal Velocity?

As the speed of a falling body increases, air resistance also increases. The upward force of air resistance keeps increasing until it is equal to the downward force of gravity. At this point, the total force on the object is zero, so the object stops accelerating.

When the object stops accelerating, it does not stop moving. It falls without speeding up or slowing down. It falls at a constant velocity called the terminal velocity. **Terminal velocity** is the speed of an object when the force of air resistance equals the force of gravity. ☑

READING CHECK

8. Describe When does an object reach its terminal velocity?

_____

_____

Air resistance causes the terminal velocity of hailstones to be between 5 m/s and 40 m/s. Without air resistance, they could reach the ground at a velocity of 350 m/s! Air resistance also slows sky divers to a safe landing velocity.

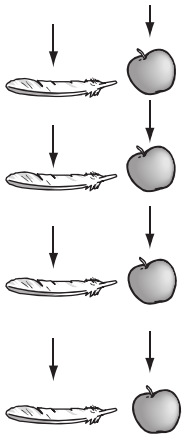
TAKE A LOOK

9. Identify A sky diver is falling at terminal velocity. Draw and label an arrow showing the direction and size of the force due to gravity on the sky diver. Draw and label a second arrow showing the direction and size of the force of air resistance on the sky diver.

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

What Is Free Fall?

Free fall is the motion of an object when gravity is the only force acting on the object. The figure below shows a feather and an apple falling in a vacuum, a place without any air. Without air resistance, they fall at the same rate.



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.

TAKE A LOOK

10. Predict When air resistance acts on the apple and the feather, which falls faster?

_____

Orbiting Objects Are in Free Fall

Satellites and the space shuttle orbit Earth. You may have seen that astronauts inside the shuttle float unless they are belted to a seat. They seem weightless. In fact, they are not weightless, because they still have mass.

Weight is a measure of the pull of gravity on an object. Gravity acts between any two objects in the universe. Every object in the universe pulls on every other object. Every object with mass has weight. ☑

READING CHECK

11. Explain When will an object have no weight? Explain your answer.

_____

_____

The force of gravity between two objects depends on the masses of the objects and how far apart they are. The more massive the objects are, the greater the force is. The closer the objects, the greater the force.

Your weight is determined mostly by the mass of Earth because it is so big and so close to you. If you were to move away from Earth, you would weigh less. However, you would always be attracted to Earth and to other objects, so you would always have weight.

Astronauts float in the shuttle because the shuttle is in free fall. That's right—the shuttle is always falling. Because the astronauts are in the shuttle, they are also falling. The astronauts and the shuttle are falling at the same rate. That is why the astronauts seem to float inside the shuttle. ☑

READING CHECK

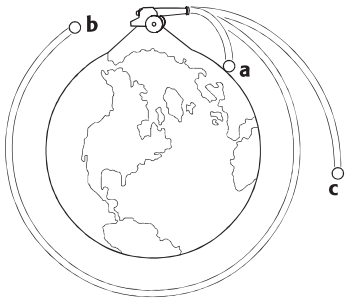
12. Explain Why don't the astronauts in the orbiting shuttle fall to the floor?

_____

_____

_____

Isaac Newton first predicted this kind of free fall in the late 17th century. He reasoned that if a cannon were placed on a mountain and fired, the cannon ball would fall to Earth. Yet, if the cannon ball were shot with enough force, it would fall at the same rate that Earth's surface curves away. The cannon ball would never hit the ground, so it would orbit Earth. The figure below shows this "thought experiment."



Newton's cannon is a "thought experiment." Newton reasoned that a cannon ball shot hard enough from a mountain top would orbit Earth.

Critical Thinking

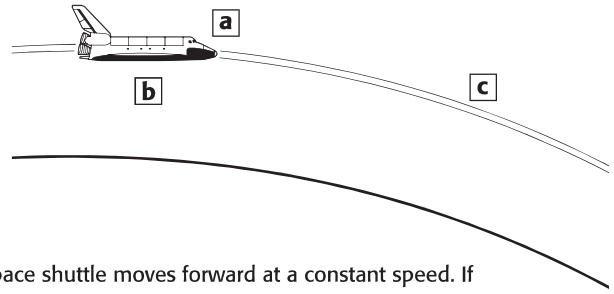
13. Infer Compared with cannon ball **b**, what do you think cannon ball **c** would do?

_____

_____

What Motions Combine to Make an Object Orbit?

An object is in orbit (is orbiting) when it is going around another object in space. When the space shuttle orbits Earth, it is moving forward. Yet, the shuttle is also in free fall. The figure below shows how these two motions combine to cause orbiting.



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.

TAKE A LOOK

14. Identify On the figure, draw a line showing the path that the space shuttle would take if gravity were not acting on it.

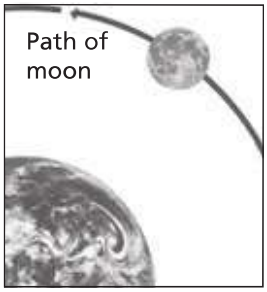
What Force Keeps an Object in Orbit?

Many objects in space are orbiting other objects. The moon orbits Earth, while Earth and the other planets orbit the sun. These objects all follow nearly circular paths. An object that travels in a circle is always changing direction.

If all the forces acting on an object balance each other out, the object will move in the same direction at the same speed forever. So, objects cannot orbit unless there is an unbalanced force acting on them. *Centripetal force* is the force that keeps an object moving in a circular path. Centripetal force pulls the object toward the center of the circle. The centripetal force of a body orbiting in space comes from gravity. ☑

READING CHECK

15. Identify What must be applied to an object to change its direction?



The moon stays in orbit around Earth because Earth's gravity provides a centripetal force on the moon.

TAKE A LOOK

16. Identify Draw an arrow on the figure to show the direction that centripetal force acts on the moon.

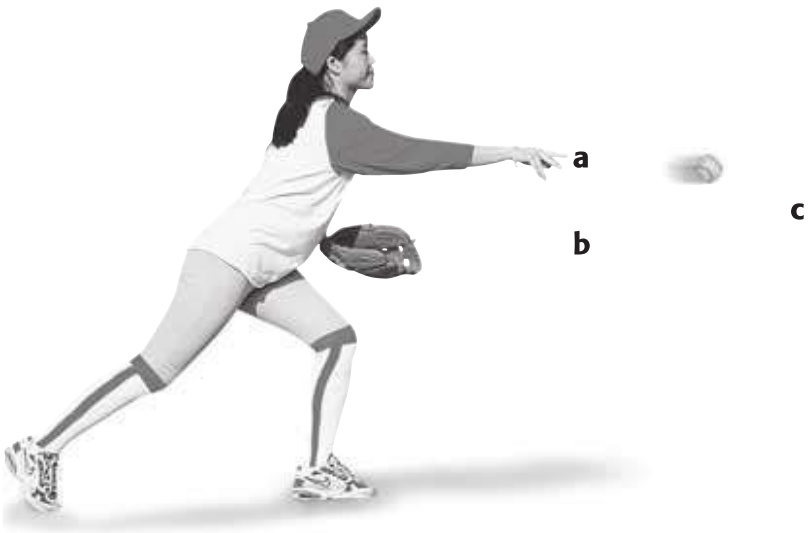
What Is Projectile Motion?

Projectile motion is the curved path an object follows when it is thrown near the Earth's surface. The motion of a ball that has been thrown forward is an example of projectile motion.

Projectile motion is made up of two parts: horizontal motion and vertical motion. Horizontal motion is motion that is parallel to the ground. Vertical motion is motion that is perpendicular to the ground. The two motions do not affect each other. Instead, they combine to form the curved path we call projectile motion. ☑

When you throw a ball forward, your hand pushes the ball to make it move forward. This force gives the ball its horizontal motion. After the ball leaves your hand, no horizontal forces act on the ball (if we forget air resistance for now). So the ball's horizontal velocity does not change after it leaves your hand.

However, gravity affects the vertical part of projectile motion. Gravity pulls the ball straight down. All objects that are thrown accelerate downward because of gravity.



a After the ball leaves the pitcher's hand, the ball's _____ velocity is constant.

b The ball's vertical velocity increases because _____ causes it to accelerate downward.

c The two motions combine to form a _____ path.

READING CHECK

17. List What two motions combine to make projectile motion?

_____

_____

Critical Thinking

18. Infer If you are playing darts and you want to hit the bulls-eye, where should you aim?

_____

_____

TAKE A LOOK

19. List On the figure, fill in the three blanks with the correct words.

20. Apply Concepts If there were no air resistance, how fast would the ball's downward velocity be changing? Explain your answer.

_____

_____

_____

_____

Name _____ Class _____ Date _____

Section 1 Review

SECTION VOCABULARY

free fall the motion of a body when only the force of gravity is acting on the body **projectile motion** the curved path that an object follows when thrown, launched, or otherwise projected near the surface of Earth	**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

1. **Explain** Is a parachutist in free fall? Why or why not?

2. **Identify Cause and Effect** Complete the table below to show how forces affect objects.

Cause	Effect
Gravity acts on a falling object.	
	The falling object reaches terminal velocity.

3. **Calculate** A rock at rest falls off a cliff and hits the ground after 3.5 s. What is the rock's velocity just before it hits the ground? Show your work.

4. **Identify** What force must be applied to an object to keep it moving in a circular path?

5. **Explain** Which part of projectile motion is affected by gravity? Explain how it is affected.