CHAPTER 6 # Forces in Motion

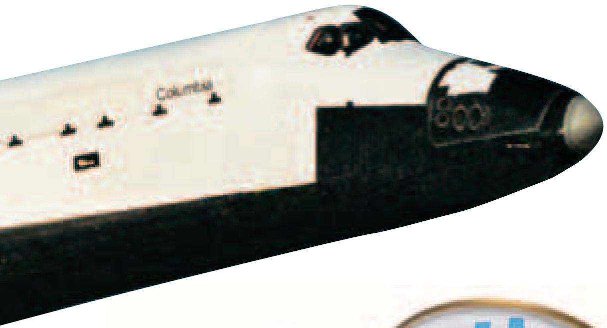
Imagine . . .

You have been selected to travel on the space shuttle as NASA's first student astronaut. You're going into space! Like all astronauts, you must go through a year of training to prepare for space travel. When you are in the space shuttle, many different forces will be acting on your body that might make you dizzy or disoriented. You must get used to these forces quickly before you go into space. NASA won't be able to shorten the mission just because you don't feel well!

There are many parts to your training. For instance, there is a machine that spins you around in all directions. There is also underwater training that lets you experience what reduced gravity feels like. But the most exciting part of your training is riding on the KC-135 airplane.

The KC-135 is a modified commercial airliner that is designed to simulate what it feels like to orbit Earth in the space shuttle. The KC-135 flies upward at a steep angle, then flies downward at a 45° angle. When the airplane flies downward, the effect of reduced gravity is produced inside. As the plane "falls" out from under the passengers, the astronaut trainees inside the plane can "float," as shown above. Because the floating often makes passengers queasy, the KC-135 has earned a nickname—the Vomit Comet.

NASA scientists used their knowledge of forces, gravity, and the laws of motion to develop these training procedures. In this chapter, you will learn how gravity affects the motion of objects and how the laws of motion apply to your life.



What Do You Think?

In your ScienceLog, try to answer the following questions based on what you already know:

1. How does the force of gravity affect falling objects?
2. What is projectile motion?
3. What are Newton’s laws of motion?
4. What is momentum?

Investigate!

Falling Water

Gravity is one of the most important forces you encounter in your daily life. Without it, objects that are thrown or dropped would never land on the ground—they would just float in space. In this activity, you will observe the effect of gravity on a falling object.

Procedure

1. Place a **wide plastic tub** on the floor.
2. Punch a small hole in the side of a **paper cup,** near the bottom.
3. Hold your finger over the hole, and fill the cup with **water colored with food coloring.**
4. Keeping your finger over the hole, hold the cup about waist high above the tub.
5. Uncover the hole. Describe your observations in your ScienceLog.
6. Cover the hole with your finger again, and refill the cup.
7. Predict what will happen to the water if you drop the cup at the same time you uncover the hole. Write your predictions in your ScienceLog.
8. Uncover the hole, and drop the cup at the same time. Record your observations.
9. Clean up any spilled water with **paper towels.**

Analysis

10. What differences did you observe in the behavior of the water during the two trials?
11. In the second trial, how fast did the cup fall compared with the water?
12. How is the water in the cup similar to passengers in the KC-135 jet?

Section 1

Gravity and Motion

NEW TERMS

terminal velocity
free fall
projectile motion

OBJECTIVES

- Explain how gravity and air resistance affect the acceleration of falling objects.
- Explain why objects in orbit appear to be weightless.
- Describe how an orbit is formed.
- Describe projectile motion.

Suppose you drop a basketball, a baseball, and a marble at the same time from the same height. In what order do you think they would land on the ground? In ancient Greece around 400 B.C., an important philosopher named Aristotle (ER is TAWT uhl) believed that the rate at which an object falls depends on the object's mass. Imagine that you could ask Aristotle which object would land first. Based on their masses, he would predict that the basketball would land first, then the baseball, and finally the marble.

All Objects Fall with the Same Acceleration

In the late 1500s, a young Italian scientist named Galileo questioned Aristotle's idea about falling objects. Galileo proposed that all objects will land at the same time when they are dropped at the same time from the same height.

Galileo proved that the mass of an object does not affect the rate at which it falls. According to one story, Galileo did this by dropping two cannonballs of different masses from the top of the Leaning Tower of Pisa. The crowd watching from the ground was amazed to see the two cannonballs land at the same time. Whether or not this story is true, Galileo's idea changed people's understanding of gravity and falling objects.

Objects fall to the ground at the same rate because the acceleration due to gravity is the same for all objects. Does that seem odd? The force of gravity is greater between Earth and an object with a large mass than between Earth and a less massive object, so you may think that the acceleration due to gravity should be greater too. But a greater force must be applied to a large mass than to a small mass to produce the same acceleration. Thus, the difference in force is canceled by the difference in mass. **Figure 1** shows objects with different masses falling with the same acceleration.

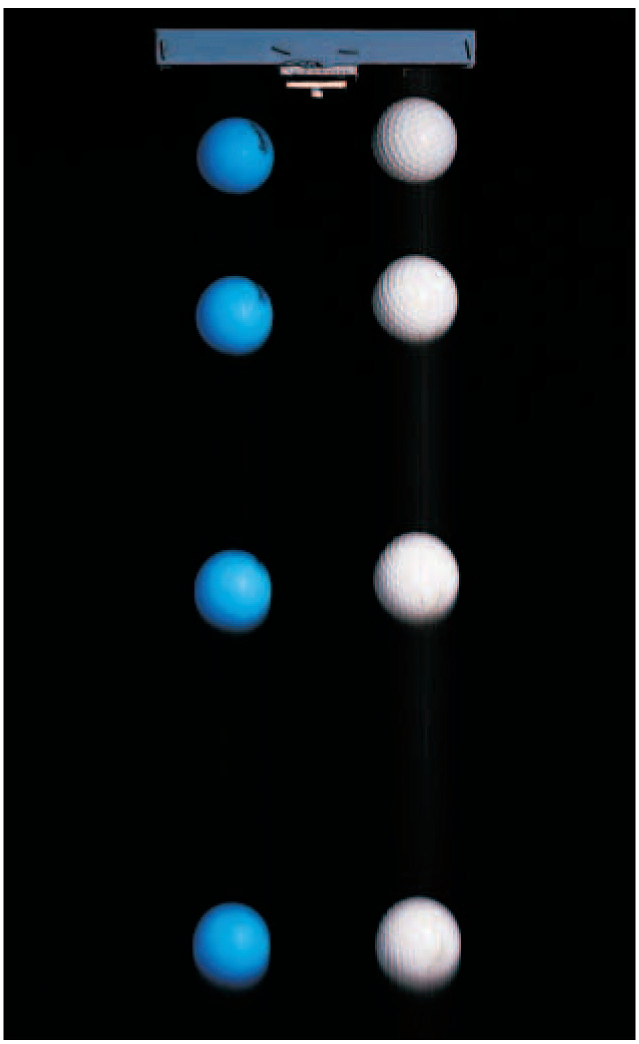


Figure 1 *A table tennis ball and a golf ball fall with the same acceleration even though they have different masses.*

All objects accelerate toward Earth at a rate of 9.8 meters per second per second, which is expressed as 9.8 m/s/s. This means that for every second that an object falls, the object's downward velocity increases by 9.8 m/s, as shown in **Figure 2.** Remember, this acceleration is the same for all objects regardless of their mass. Therefore, a basketball, baseball, and marble would land at the same time when dropped at the same time from the same height. Do the MathBreak at right to learn how to calculate the velocity of a falling object.

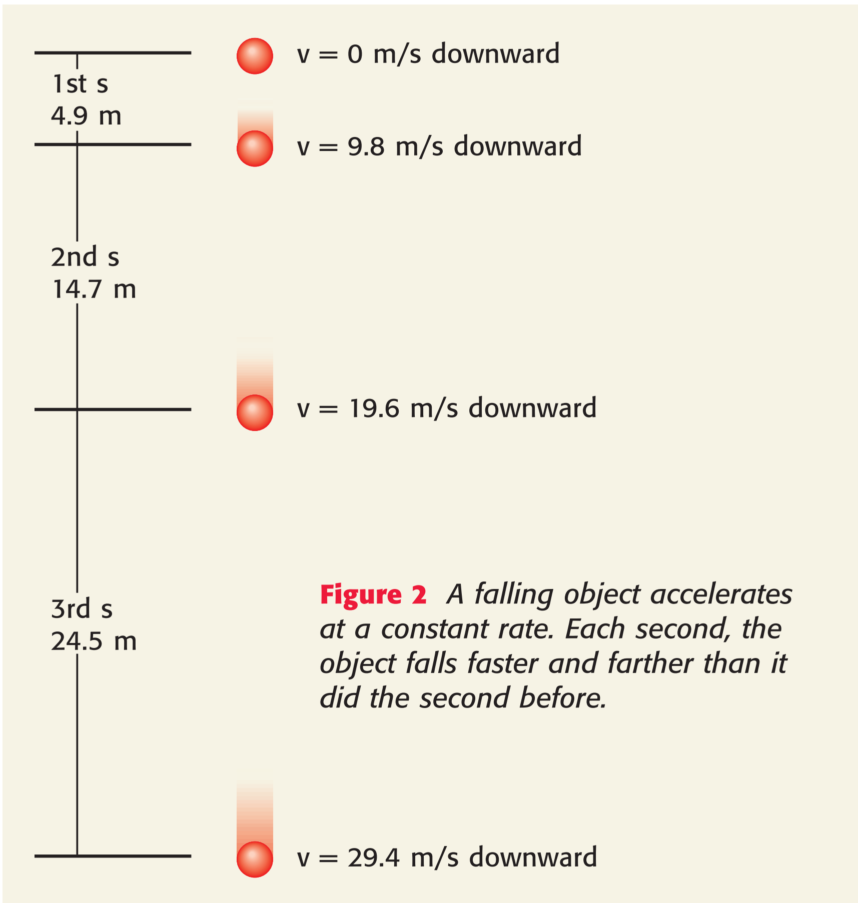


Figure 2 *A falling object accelerates at a constant rate. Each second, the object falls faster and farther than it did the second before.*

Air Resistance Slows Down Acceleration

Try this simple experiment. Drop two sheets of paper—one crumpled in a tight ball and the other kept flat. Did your results contradict what you just learned about falling objects? The flat paper fell more slowly because of fluid friction that opposes the motion of objects through air. This fluid friction is also known as *air resistance*. Air resistance occurs between the surface of the falling object and the air that surrounds it.

MATH BREAK

Velocity of Falling Objects

To find the change in velocity (Δv) of a falling object, multiply the acceleration due to gravity (g) by the time it takes for the object to fall in seconds (t). The equation for finding a change in velocity is as follows:

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

For example, a stone at rest is dropped from a cliff, and it takes 3 seconds to hit the ground. Its downward velocity when it hits the ground is as follows:

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

Now It's Your Turn

A penny at rest is dropped from the top of a tall stairwell.

1. What is the penny's velocity after it has fallen for 2 seconds?
2. The penny hits the ground in 4.5 seconds. What is its final velocity?

Gravity helps make roller coasters thrilling to ride. Read about roller coaster design on page 159.

Self-Check

Which is more affected by air resistance—a leaf or an acorn? *(See page 596 to check your answer.)*

Air resistance affects some objects more than others. The amount of air resistance acting on an object depends on the size and shape of the object. Air resistance affects the flat sheet of paper more than the crumpled one, causing the flat sheet to fall more slowly than the crumpled one. Because air is all around you, any falling object you see is affected by air resistance. **Figure 3** shows the effect of air resistance on the downward acceleration of a falling object.

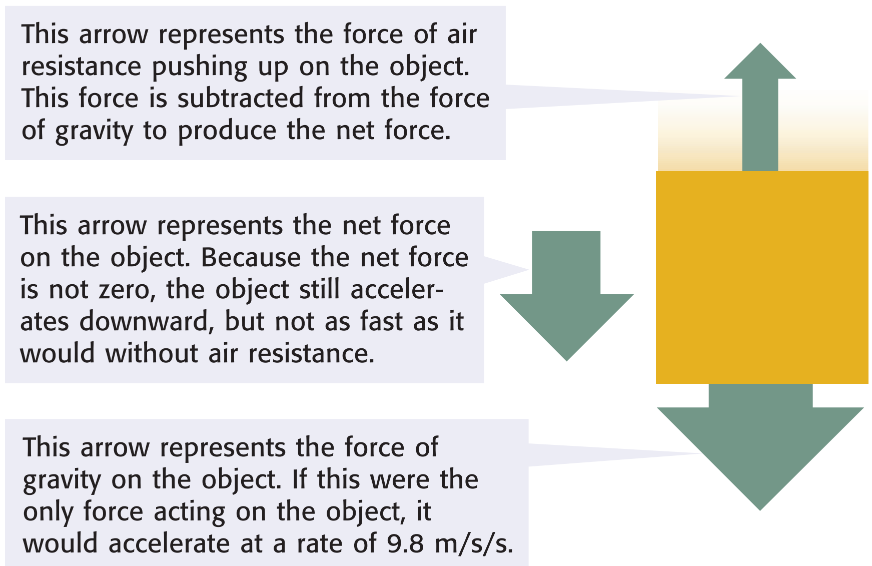


Figure 3 *The force of gravity pulls the object downward as the force of air resistance pushes it upward.*

Acceleration Stops at the Terminal Velocity

As long as the net force on a falling object is not zero, the object accelerates downward. But the amount of air resistance on an object increases as the speed of the object increases. As an object falls, the upward force of air resistance continues to increase until it exactly matches the downward force of gravity. When this happens, the net force is zero, and the object stops accelerating. The object then falls at a constant velocity, which is called the **terminal velocity.**

Sometimes the fact that falling objects have a terminal velocity is a good thing. The terminal velocity of hailstones is between 5 and 40 m/s, depending on the size of the stones. Every year cars, buildings, and vegetation are all severely damaged in hail storms. Imagine how much more destructive hail would be if there were no air resistance—hailstones would hit the Earth at velocities near 350 m/s! **Figure 4** shows another situation in which terminal velocity is helpful.

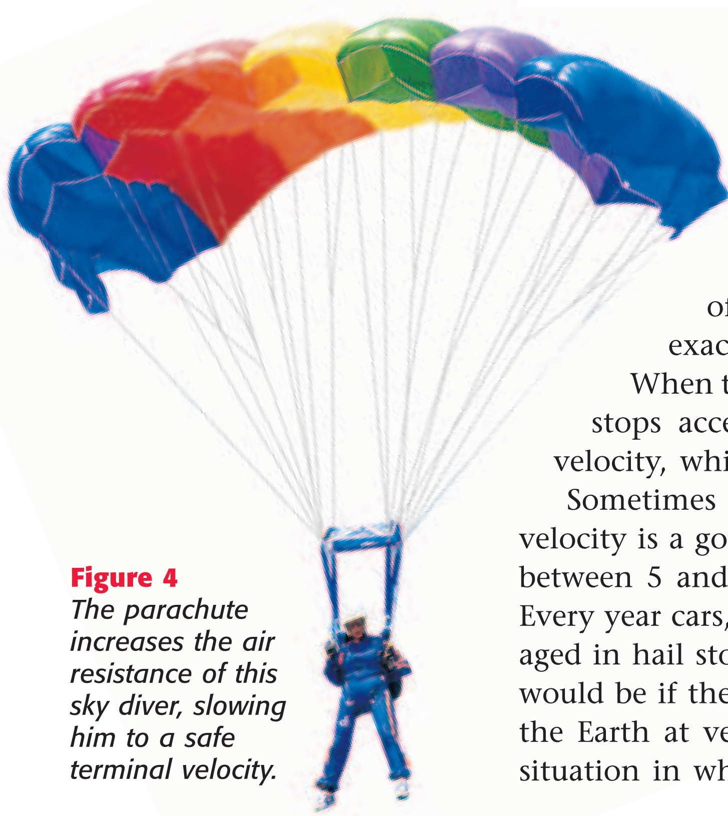


Figure 4 *The parachute increases the air resistance of this sky diver, slowing him to a safe terminal velocity.*

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 (fluid friction), free fall can occur only where there is no air—in a vacuum (a place in which there is no matter) or in space. **Figure 5** shows objects falling in a vacuum. Because there is no air resistance, the two objects are in free fall.

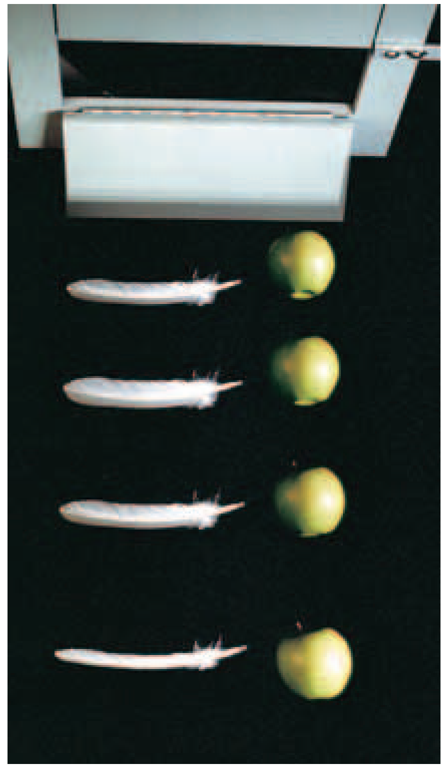


Figure 5 *Air resistance normally causes a feather to fall more slowly than an apple. But in a vacuum, the feather and the apple fall with the same acceleration because both are in free fall.*

Orbiting Objects Are in Free Fall

Look at the astronaut in **Figure 6.** Why is the astronaut floating inside the space shuttle? It might be tempting to say it is because she is "weightless" in space. In fact, you may have read or heard that objects are weightless in space. However, it is impossible to be weightless anywhere in the universe.

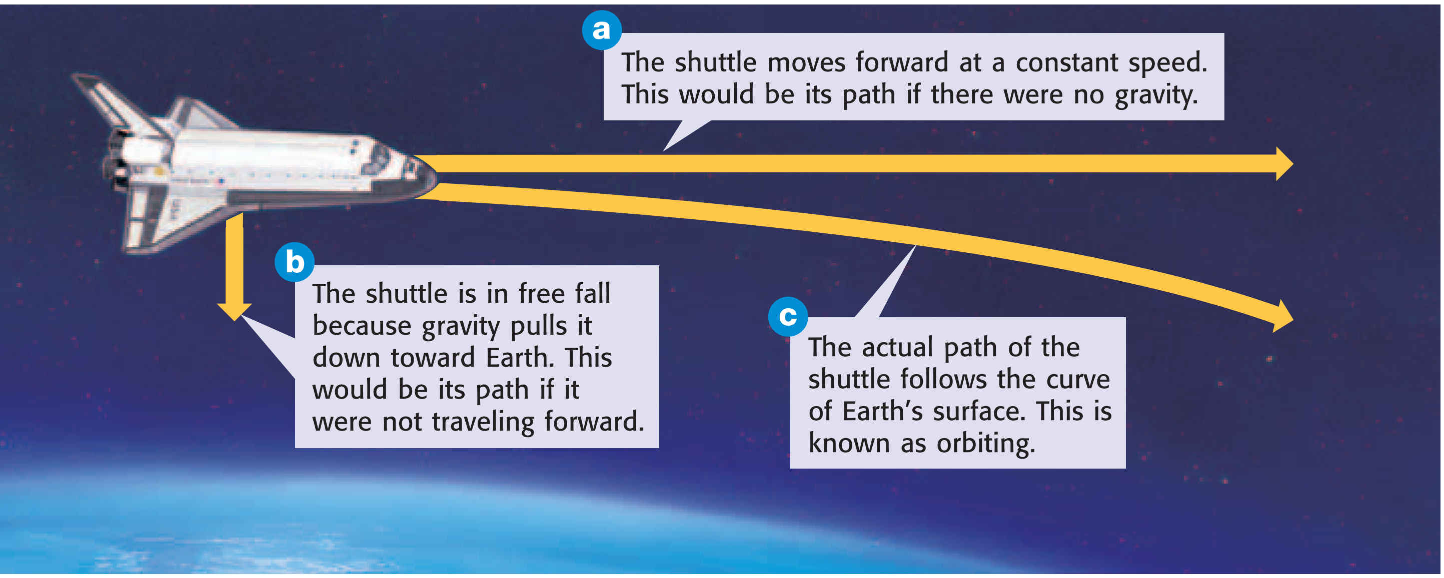
Weight is a measure of gravitational force. The size of the force depends on the masses of objects and the distances between them. If you traveled in space far away from all the stars and planets, the gravitational force acting on you would be almost undetectable because the distance between you and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

Astronauts "float" in orbiting spaceships because of free fall. To understand this better, you need to understand what *orbiting* means and then consider the astronauts inside the ship.

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

Two Motions Combine to Cause Orbiting An object is said to be orbiting when it is traveling in a circular or nearly circular path around another object. When a spaceship orbits Earth, it is moving forward, but it is also in free fall toward Earth. **Figure 7** shows how these two motions occur together to cause orbiting.

Figure 7 How an Orbit Is Formed



As you can see in the illustration above, 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 the astronaut in Figure 6 is in free fall, she appears to be floating.

The Role of Gravity in Orbiting Besides spaceships and satellites, many other objects in the universe are in orbit. The moon orbits the Earth, Earth and the other planets orbit the sun, and many stars orbit large masses in the center of galaxies. All of these objects are traveling in a circular or nearly circular path. Remember, 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*. 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 circle traced by the moon's orbit.

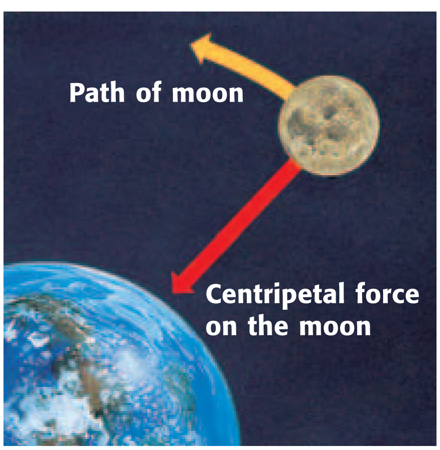


Figure 8 *The moon stays in orbit around the Earth because Earth's gravitational force provides a centripetal force on the moon.*

Projectile Motion and Gravity

The orbit of the space shuttle around the Earth is an example of projectile (proh JEK tuhl) motion. **Projectile motion** is the curved path an object follows when thrown or propelled near the surface of the Earth. The motions of leaping frogs, thrown balls, and arrows shot from a bow are all examples of projectile motion. Projectile motion has two components—horizontal and vertical. The two components are independent; that is, they have no effect on each other. When the two motions are combined, they form a curved path, as shown in **Figure 9.**

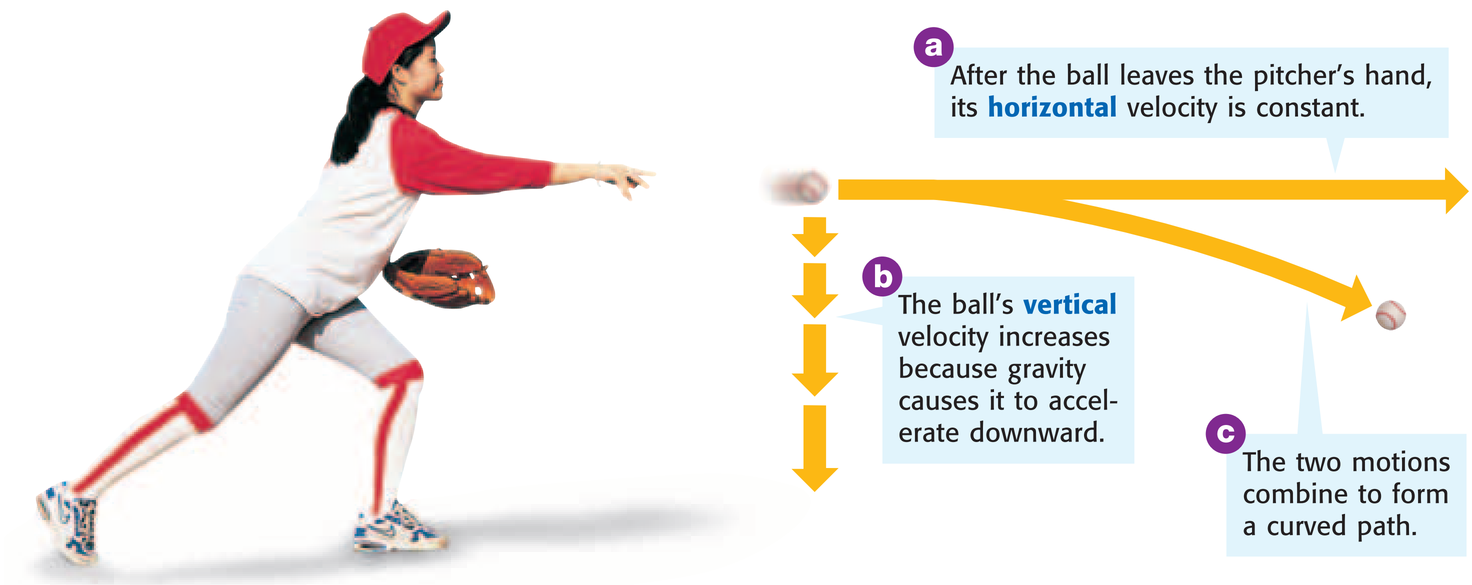


Figure 9 *Two motions combine to form projectile motion.*

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. Horizontal motion is motion that is parallel to the ground.

After you let go of the ball, there are no horizontal forces acting on the ball (if you ignore air resistance). Therefore, 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.

Vertical Motion When you let go of the ball, gravity pulls it downward, giving the ball vertical motion, as shown in Figure 9. Vertical motion is motion that is perpendicular (at a 90° angle) to the ground.

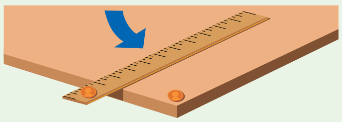
Examples of Objects in Projectile Motion

- A football being passed
- A leaping dancer
- Balls being juggled
- An athlete doing a high jump
- Water sprayed by a sprinkler
- A swimmer diving into water
- A hopping grasshopper

QuickLab

Penny Projectile Motion

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

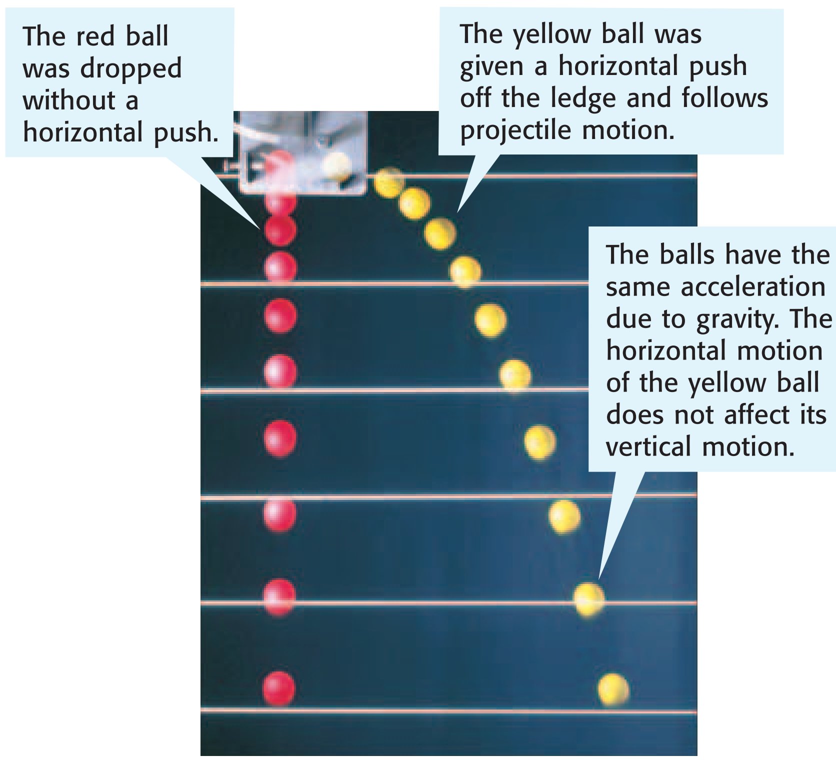


2. Hold the ruler by the end that is on the desk. Move the ruler quickly in the direction shown so that the ruler knocks the penny off the table and so that the other penny also drops. Repeat several times.
3. Which penny travels with projectile motion? In what order do the pennies hit the ground? Record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

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. This is why archers point their arrows above the bull's-eye on a target. If you aimed an arrow directly at a bull's-eye, your arrow would strike the bottom of the target rather than the middle.

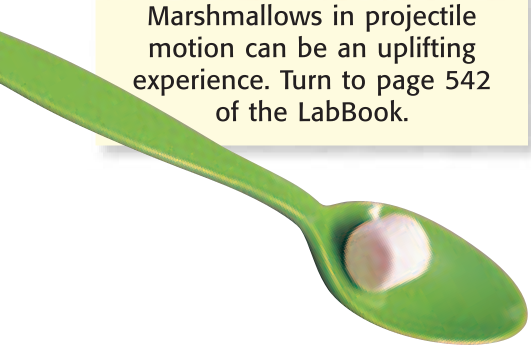
Gravity pulls objects in projectile motion down with an acceleration of 9.8 m/s/s (if air resistance is ignored), just as it does all falling objects. **Figure 10** shows that the downward acceleration of a thrown object and a falling object are identical. Try the QuickLab at left to compare an object in projectile motion with a falling object.

Figure 10 Projectile Motion and Acceleration Due to Gravity



LabBook

Marshmallows in projectile motion can be an uplifting experience. Turn to page 542 of the LabBook.



REVIEW

1. How does air resistance affect the acceleration of falling objects?
2. Explain why an astronaut in an orbiting spaceship floats.
3. How is an orbit formed?
4. **Applying Concepts** Think about a sport you play that involves a ball. Identify at least four different instances in which an object is in projectile motion.

Section 2

Newton's Laws of Motion

NEW TERMS

inertia   momentum

OBJECTIVES

- State and apply Newton's laws of motion.
- Compare the momentum of different objects.
- State and apply the law of conservation of momentum.

In 1686, Sir Isaac Newton published his book *Principia*. In it, he described three laws that relate forces to the motion of objects. Although he did not discover all three of the laws, he explained them in a way that helped many people understand them. Thus, the three laws are commonly known as Newton's laws of motion. In this section, you will learn about these laws and how they influence the motion of objects.

Newton's First Law of Motion

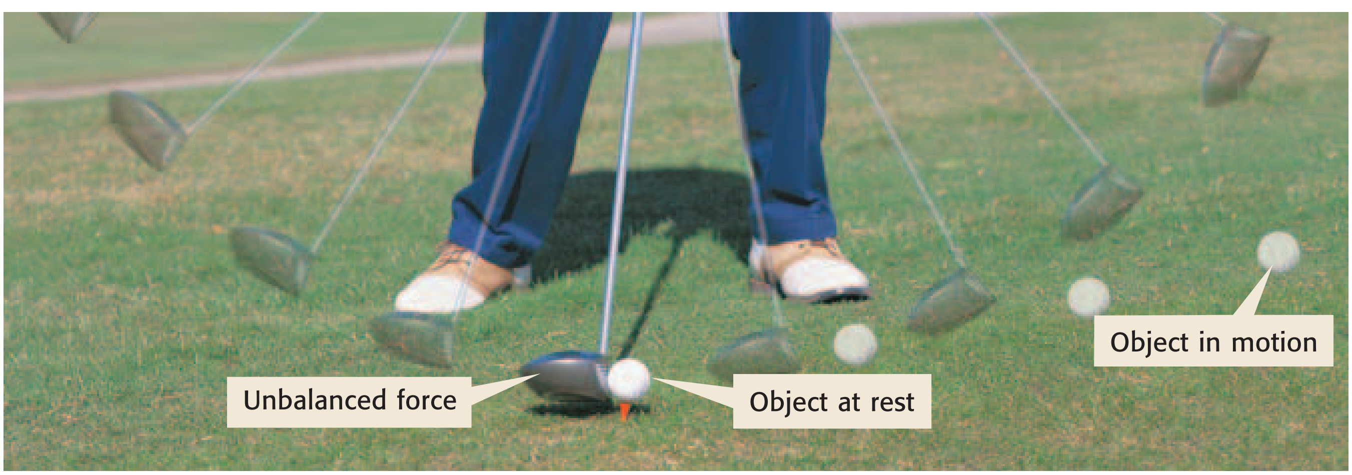
An object at rest remains at rest and an object in motion remains in motion at constant speed and in a straight line unless acted on by an unbalanced force.

Newton's first law of motion describes the motion of an object that has a net force of zero acting on it. This law may seem complicated when you first read it, but it's easy to understand when you consider its two parts separately.

Part 1: Objects at Rest What does it mean for an object to be at rest? Objects don't get tired! An object that is not moving is said to be at rest. Objects are at rest all around you. A plane parked on a runway, a chair on the floor, and a golf ball balanced on a tee are all examples of objects at rest.

Newton's first law says that objects at rest will remain at rest unless they are acted on by an unbalanced force. That means that objects will not start moving until a push or a pull is exerted on them. A plane won't soar in the air unless it is pushed by the exhaust from its jet engines, a chair won't slide across the room unless you push it, and a golf ball won't move off the tee unless struck by a golf club, as shown in **Figure 11.**

Figure 11 *A golf ball will remain at rest on a tee until it is acted on by the unbalanced force of a moving club.*



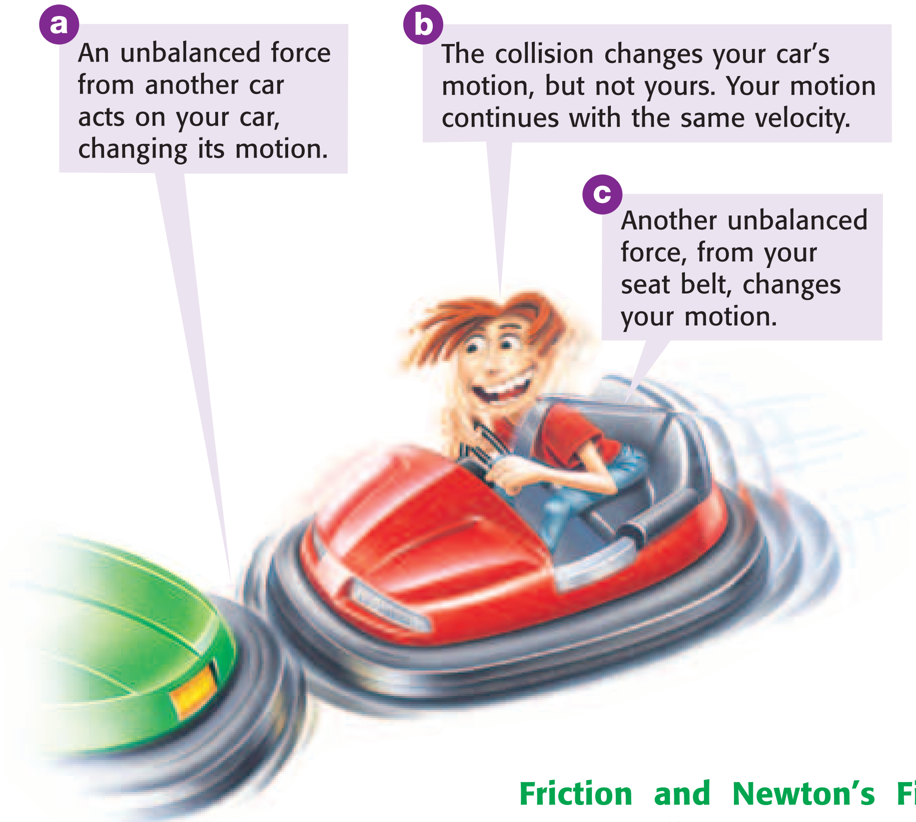


Figure 12 *Bumper cars let you have fun with Newton's first law.*

Part 2: Objects in Motion

Think about riding in a bumper car at an amusement park. Your ride is pleasant as long as you are driving in an open space. But the name of the game is bumper cars, so sooner or later you are likely to run into another car, as shown in **Figure 12.**

The second part of Newton's first law explains that an object moving at a certain velocity will continue to move *forever* at the same speed and in the same direction unless some unbalanced force acts on it. Thus, your bumper car stops, but you continue to move forward until your seat belt stops you.

Friction and Newton's First Law Because an object in motion will stay in motion forever unless it is acted on by an unbalanced force, you should be able to give your desk a small push and send it sailing across the floor. If you try it, you will find that the desk quickly comes to a stop. What does this tell you?

There must be an unbalanced force that acts on the desk to stop its motion. That unbalanced force is friction. The friction between the desk and the floor works against the motion of the desk. Because of friction, it is often difficult to observe the effects of Newton's first law on the motion of everyday objects. For example, friction will cause a ball rolling on grass to slow down and stop. Friction will also make a car decelerate on a flat surface if you let up on the gas pedal. Because of friction, the motion of these objects changes.

APPLY

The dummy in this crash test is wearing a seat belt, but the car does not have an air bag. Explain why Newton's first law of motion could lead to serious injuries in accidents involving cars without air bags.

Inertia Is Related to Mass Newton's first law of motion is often summed up in one sentence: Matter resists any change in motion. The tendency of all objects to resist any change in motion is called **inertia** (in UHR shuh). Due to inertia, an object at rest will remain at rest until something makes it move. Likewise, inertia is why a moving object stays in motion with the same velocity unless a force acts on it to change its speed or direction. Because Newton's first law can be explained in terms of inertia, it is sometimes called the law of inertia.

Because of inertia, you slide toward the side of a car when the driver makes a sharp turn. Inertia is also why it is impossible for a plane, car, or bicycle to stop instantaneously. Brakes must be applied well before stopping.

Mass is a measure of inertia. An object with a small mass has less inertia than an object with a large mass. Therefore, it is easier to start and to change the motion of an object with a small mass. For example, a softball has less mass and therefore less inertia than a bowling ball. Because the softball has a small amount of inertia, it is easy to pitch a softball and to change its motion by hitting it with a bat. Imagine how difficult it would be to play softball with a bowling ball! The inertia of the bowling ball would make it hard to pitch and hard to change its motion with a bat. **Figure 13** further illustrates the relationship between mass and inertia. Try the QuickLab at right to test the relationship yourself.

QuickLab

First-Law Magic

1. On a table or desk, place a **large, empty plastic cup** on top of a **paper towel.**
2. Without touching the cup or tipping it over, remove the paper towel from under the cup. What did you do to accomplish this?
3. Repeat the first two steps a few times until you are comfortable with the procedure.
4. Fill the cup half full with **water,** and place the cup on the paper towel.
5. Once again, remove the paper towel from under the cup. Was it easier or harder to do this? Explain your answer in terms of mass and inertia.
6. Record your observations and explanations in your ScienceLog.

Figure 13 *Inertia makes it harder to push a car than to push a bicycle. Inertia also makes it easier to stop a moving bicycle than a moving car.*

Self-Check

When you stand while riding a bus, why do you tend to fall backward when the bus starts moving?

(See page 596 to check your answer.)

Newton's Second Law of Motion

The acceleration of an object depends on the mass of the object and the amount of force applied.

environmental science CONNECTION

Modern cars do not pollute the air as much as older cars did. One reason for this is that modern cars are lighter (less massive) than older models and have considerably smaller engines. According to Newton's second law, a less massive object requires less force to achieve the same acceleration as a more massive object. This is why a smaller car can have a smaller engine and still have acceptable acceleration. And because smaller engines use less fuel, they pollute less.

Newton's second law describes the motion of an object when an unbalanced force is acting on it. As with Newton's first law, it is easier to consider the parts of this law separately.

Part 1: Acceleration Depends on Mass Suppose you are pushing a shopping cart at the grocery store. At the beginning of your shopping trip, you have to exert only a small force on the cart to roll it quickly down the aisles. But when the cart is full, its acceleration is not as large when you exert the same amount of force as before, as shown in **Figure 14.** This example illustrates that an object's acceleration *decreases* as its mass *increases*. Conversely, an object's acceleration *increases* as its mass *decreases* when acted on by the same force.

Figure 14 *If the force applied is the same, the acceleration of the empty cart is greater than the acceleration of the full cart.*

Part 2: Acceleration Depends on Force Now suppose you give the cart a hard push, as shown in **Figure 15.** The cart will start moving faster than if you only gave it a soft push. This illustrates that an object's acceleration *increases* as the force on it *increases*. Conversely, an object's acceleration *decreases* as the force on it *decreases*.

An example of a large force causing a large acceleration is a baseball pitcher throwing a fastball. An example of a small force causing a small acceleration is the gentle tap on a golf ball that makes the ball roll slowly to the hole.

The acceleration of an object is always in the same direction as the force applied. The shopping cart, baseball, and golf ball all moved forward because the pushes were in the forward direction. To change the direction of an object, you must exert a force in the direction you want the object to go.

Figure 15 *Acceleration will increase when a larger force is exerted. The acceleration is always in the direction of the force applied.*

Expressing Newton's Second Law Mathematically The relationship of acceleration (a) to mass (m) and force (F) can be expressed mathematically with the following equation:

$$a = \frac{F}{m}$$

This equation is often rearranged to the following form:

$$F = m \times a$$

Both forms of the equation can be used to solve problems. Try the MathBreak at right to practice using the equations.

Newton's Second Law and Falling Objects In **Figure 16,** you can see how Newton's second law explains why objects fall to Earth with the same acceleration.

Figure 16 **Newton's Second Law and Acceleration Due to Gravity**

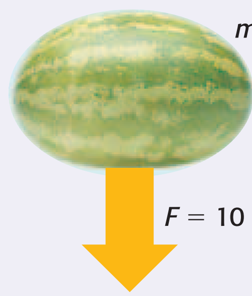
The **apple** has less mass, so the gravitational force on it is smaller. However, the apple also has less inertia and is easier to move.

$m = 0.102$ kg

$F = 1$ N

1 N = 1 kg · m/s/s

The **watermelon** has more mass and therefore more inertia, so it is harder to move.



$m = 1.02$ kg

$F = 10$ N

10 N = 10 kg · m/s/s

The larger weight of the watermelon is offset by its greater inertia. Thus, the accelerations of the watermelon and the apple are the same when you put the numbers into the equation $a = F/m$.

$$a = \frac{1\ \cancel{kg} \cdot m/s/s}{0.102\ \cancel{kg}} = 9.8\ m/s/s$$

$$a = \frac{10\ \cancel{kg} \cdot m/s/s}{1.02\ \cancel{kg}} = 9.8\ m/s/s$$

REVIEW

1. How is inertia related to Newton's first law of motion?
2. Name two ways to increase the acceleration of an object.
3. **Making Predictions** If the acceleration due to gravity were somehow doubled to 19.6 m/s/s, what would happen to your weight?

MATH BREAK

Second-Law Problems

You can rearrange the equation $F = m \times a$ to find acceleration and mass as shown below.

$$a = \frac{F}{m} \qquad m = \frac{F}{a}$$

1. What is the acceleration of a 7 kg mass if a force of 68.6 N is used to move it toward Earth?
2. What force is necessary to accelerate a 1,250 kg car at a rate of 40 m/s/s?
3. What is the mass of an object if a force of 34 N produces an acceleration of 4 m/s/s?

Newton's Third Law of Motion

Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.

Newton's third law can be simply stated as follows: All forces act in pairs. If a force is exerted, another force occurs that is equal in size and opposite in direction. The law itself addresses only forces. But the way that force pairs interact affects the motion of objects.

What is meant by "forces act in pairs"? Study **Figure 17** to learn how one force pair helps propel a swimmer through water.

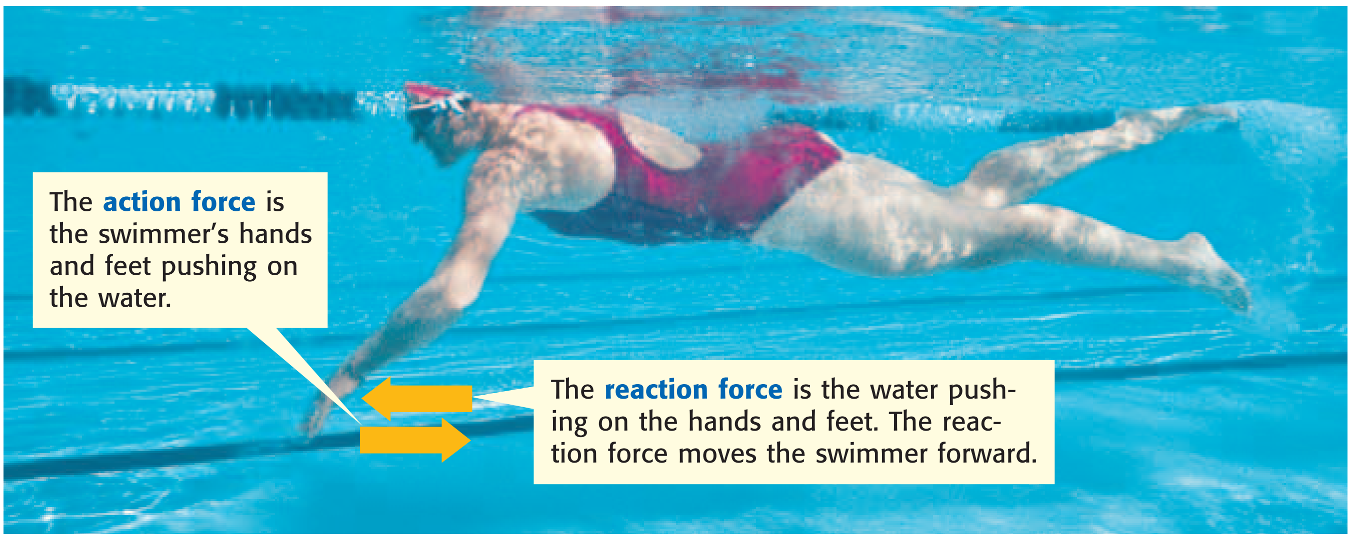


Figure 17 *The action force and reaction force are a pair. The two forces are equal in size but opposite in direction.*

Action and reaction force pairs occur even when there is no motion. For example, you exert a force on a chair when you sit on it. Your weight pushing down on the chair is the action force. The reaction force is the force exerted by the chair that pushes up on your body and is equal to your weight.

Force Pairs Do Not Act on the Same Object You know that a force is always exerted by one object on another object. This is true for all forces, including action and reaction forces. However, it is important to remember that action and reaction forces in a pair do not act on the same object. If they did, the net force would always be zero and nothing would ever move! To understand this better, look back at Figure 17. In this example, the action force was exerted on the water by the swimmer's hands and feet. But the reaction force was exerted on the swimmer's hands and feet by the water. The forces did not act on the same object.

Explore

Choose a sport that you enjoy playing or watching. In your ScienceLog, list five ways that Newton's laws of motion are involved in the game you selected.

The Effect of a Reaction Can Be Difficult to See Another example of a force pair is shown in **Figure 18.** Remember, gravity is a force of attraction between objects that is due to their masses. If you drop a ball off a ledge, the force of gravity pulls the ball toward Earth. This is the action force exerted by Earth on the ball. But the force of gravity also pulls Earth toward the ball. That is the reaction force exerted by the ball on Earth.

It's easy to see the effect of the action force—the ball falls to Earth. Why don't you notice the effect of the reaction force—Earth being pulled upward? To find the answer to this question, think back to Newton's second law. It states that the acceleration of an object depends on the force applied to it and on the mass of the object. The force on Earth is equal to the force on the ball, but the mass of Earth is much *larger* than the mass of the ball. Therefore, the acceleration of Earth is much *smaller* than the acceleration of the ball. The acceleration is so small that you can't even see it or feel it. Thus, it is difficult to observe the effect of Newton's third law on falling objects.

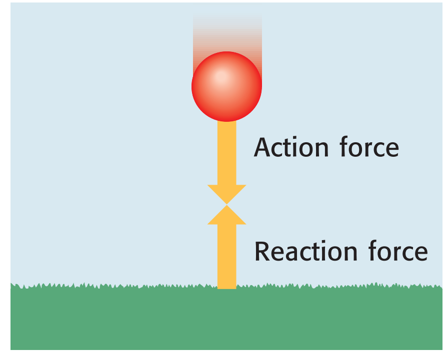
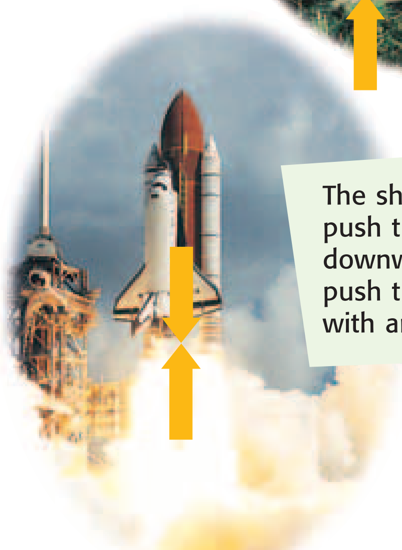


Figure 18 *The force of gravity between Earth and a falling object is a force pair.*

More Examples of Action and Reaction Force Pairs The examples below illustrate a variety of action and reaction force pairs. In each example, notice which object exerts the action and which object exerts the reaction forces.

The rabbit's legs exert a force on Earth. Earth exerts an equal force on the rabbit's legs, causing the rabbit to accelerate upward.

The bat exerts a force on the ball, sending the ball into the outfield. The ball exerts an equal force on the bat, but the bat does not fly toward the catcher because the batter is exerting another force on the bat.



The shuttle's thrusters push the exhaust gases downward as the gases push the shuttle upward with an equal force.

When you hit a table with your hand, your hand will hurt. This is because the table meets your hand with a force equal in size to the force you exerted.

Momentum Is a Property of Moving Objects

If a compact car and a large truck are traveling with the same velocity, it takes longer for the truck to stop than it does for the car if the same braking force is applied. Likewise, it takes longer for a fast moving car to stop than it does for a slow moving car with the same mass. The truck and the fast moving car have more momentum than the compact car and the slow moving car.

Momentum is a property of a moving object that depends on the object's mass and velocity. The more momentum an object has, the harder it is to stop the object or change its direction. Although the compact car and the truck are traveling with the same velocity, the truck has more mass and therefore more momentum, so it is harder to stop than the car. Similarly, the fast moving car has a greater velocity and thus more momentum than the slow moving car.

Jumping beans appear to leap into the air with no forces acting on them. However, inside each bean is a small insect larva. When the larva moves suddenly, it applies a force to the shell of the bean. The momentum of the larva is transferred to the bean, and the bean "jumps."

Momentum Is Conserved When a moving object hits another object, some or all of the momentum of the first object is transferred to the other object. If only some of the momentum is transferred, the rest of the momentum stays with the first object.

Imagine you hit a billiard ball with a cue ball so that the billiard ball starts moving and the cue ball stops, as shown in **Figure 19.** The cue ball had a certain amount of momentum before the collision. During the collision, all of the cue ball's momentum was transferred to the billiard ball. After the collision, the billiard ball moved away with the same amount of momentum the cue ball had. This example illustrates the *law of conservation of momentum.* Any time two or more objects interact, they may exchange momentum, but the total amount of momentum stays the same.

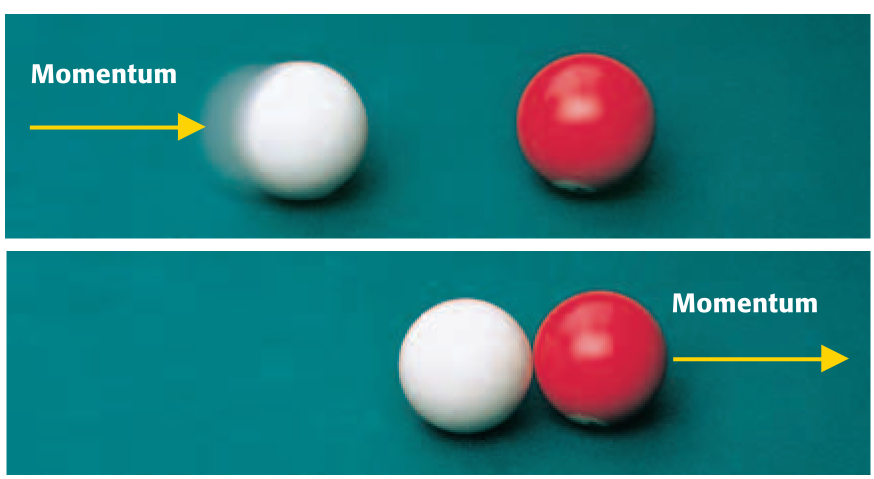


Figure 19 *The momentum before a collision is equal to the momentum after the collision.*

Bowling is another example of how conservation of momentum is used in a game. The bowling ball rolls down the lane with a certain amount of momentum. When the ball hits the pins, some of the ball's momentum is transferred to the pins and the pins move off in different directions. Furthermore, some of the pins that were hit by the ball go on to hit other pins, transferring the momentum again.

Conservation of Momentum and Newton's Third Law

Conservation of momentum can be explained by Newton's third law. In the example with the billiard ball, the cue ball hit the billiard ball with a certain amount of force. This was the action force. The reaction force was the equal but opposite force exerted by the billiard ball on the cue ball. The action force made the billiard ball start moving, and the reaction force made the cue ball stop moving, as shown in **Figure 20.** Because the action and reaction forces are equal and opposite, momentum is conserved.

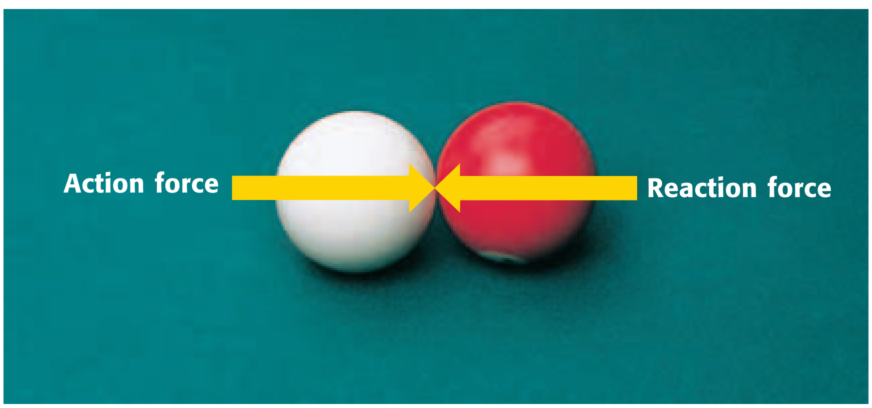


Figure 20 *The action force makes the billiard ball begin moving, and the reaction force stops the cue ball's motion.*

REVIEW

1. Name three action and reaction force pairs involved in doing your homework. Name what object is exerting and what object is receiving the forces.
2. Which has more momentum, a mouse running at 1 m/s north or an elephant walking at 3 m/s east? Explain your answer.
3. **Applying Concepts** When a truck pulls a trailer, the trailer and truck accelerate forward even though the action and reaction forces are the same size but in opposite directions. Why don't these forces balance each other out?

LabBook

Catapult forward! Or is it backward? Find out on page 546 of the LabBook.

Chapter Highlights

SECTION 1

Vocabulary

terminal velocity *(p. 140)*
free fall *(p. 141)*
projectile motion *(p. 143)*

Section Notes

- All objects accelerate toward Earth at 9.8 m/s/s.
- Air resistance slows the acceleration of falling objects.
- An object is in free fall if gravity is the only force acting on it.
- An orbit is formed by combining forward motion and free fall.
- 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 and vertical. Gravity affects only the vertical motion of projectile motion.

Labs

A Marshmallow Catapult
(p. 542)

Skills Check

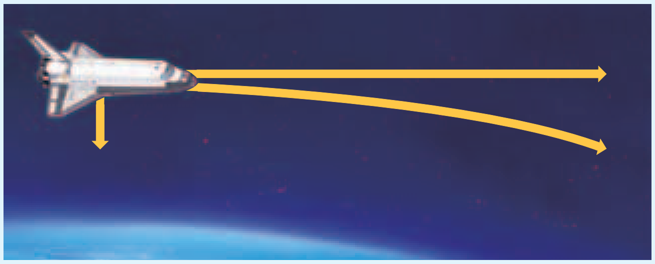
Math Concepts

NEWTON'S SECOND LAW The equation $a = F/m$ on page 149 summarizes Newton's second law of motion. The equation shows the relationship between the acceleration of an object, the force causing the acceleration, and the object's mass. For example, if you apply a force of 18 N to a 6 kg object, the object's acceleration is

$$a = \frac{F}{m} = \frac{18\text{ N}}{6\text{ kg}} = \frac{18\ \cancel{\text{kg}} \cdot \text{m/s/s}}{6\ \cancel{\text{kg}}} = 3\text{ m/s/s}$$

Visual Understanding

HOW AN ORBIT IS FORMED An orbit is a combination of two motions—forward motion and free fall. Figure 7 on page 142 shows how the two motions combine to form an orbit.



SECTION 2

Vocabulary

inertia *(p. 147)*
momentum *(p. 152)*

Section Notes

- Newton's first law of motion states that the motion of an object will not change if no unbalanced forces act on it.
- Inertia is the tendency of matter to resist a change in motion. Mass is a measure of inertia.
- Newton's second law of motion states that the acceleration of an object depends on its mass and on the force exerted on it.
- Newton's third law of motion states that whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.
- Momentum is the property of a moving object that depends on its mass and velocity.
- When two or more objects interact, momentum may be exchanged, but the total amount of momentum does not change. This is the law of conservation of momentum.

Labs

Blast Off! *(p. 543)*
Inertia-Rama! *(p. 544)*
Quite a Reaction *(p. 546)*

internetconnect

go.hrw.com **GO TO:** go.hrw.com

Visit the **HRW** Web site for a variety of learning tools related to this chapter. Just type in the keyword:

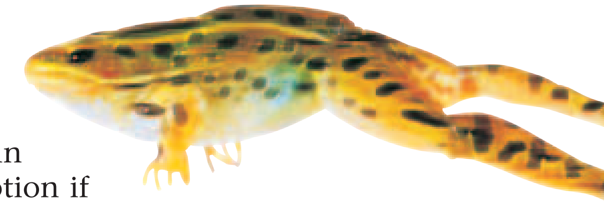
KEYWORD: HSTFOR

SCILINKS NSTA **GO TO:** www.scilinks.org

Visit the **National Science Teachers Association** on-line Web site for Internet resources related to this chapter. Just type in the ***sci*LINKS** number for more information about the topic:

TOPIC: The Force of Gravity	***sci*LINKS NUMBER:** HSTP130
TOPIC: Gravity and Orbiting Objects	***sci*LINKS NUMBER:** HSTP135
TOPIC: Projectile Motion	***sci*LINKS NUMBER:** HSTP140
TOPIC: Newton's Laws of Motion	***sci*LINKS NUMBER:** HSTP145

Chapter Review



USING VOCABULARY

To complete the following sentences, choose the correct term from each pair of terms listed below:

1. An object in motion tends to stay in motion because it has ___?___. (*inertia* or *terminal velocity*)
2. Falling objects stop accelerating at ___?___. (*free fall* or *terminal velocity*)
3. ___?___ is the path that a thrown object follows. (*Free fall* or *Projectile motion*)
4. A property of moving objects that depends on mass and velocity is ___?___. (*inertia* or *momentum*)
5. ___?___ only occurs when there is no air resistance. (*Momentum* or *Free fall*)

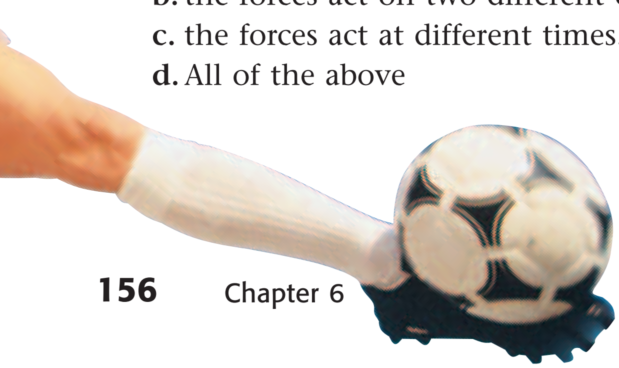
UNDERSTANDING CONCEPTS

Multiple Choice

6. A feather and a rock dropped at the same time from the same height would land at the same time when dropped by
   a. Galileo in Italy.
   b. Newton in England.
   c. an astronaut on the moon.
   d. an astronaut on the space shuttle.
7. When a soccer ball is kicked, the action and reaction forces do not cancel each other out because
   a. the force of the foot on the ball is bigger than the force of the ball on the foot.
   b. the forces act on two different objects.
   c. the forces act at different times.
   d. All of the above
8. An object is in projectile motion if
   a. it is thrown with a horizontal push.
   b. it is accelerated downward by gravity.
   c. it does not accelerate horizontally.
   d. All of the above
9. Newton's first law of motion applies
   a. to moving objects.
   b. to objects that are not moving.
   c. to objects that are accelerating.
   d. Both (a) and (b)
10. Acceleration of an object
    a. decreases as the mass of the object increases.
    b. increases as the force on the object increases.
    c. is in the same direction as the force on the object.
    d. All of the above
11. A golf ball and a bowling ball are moving at the same velocity. Which has more momentum?
    a. the golf ball, because it has less mass
    b. the bowling ball, because it has more mass
    c. They both have the same momentum because they have the same velocity.
    d. There is no way to know without additional information.

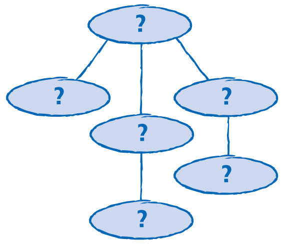
Short Answer

12. Explain how an orbit is formed.
13. Describe how gravity and air resistance combine when an object reaches terminal velocity.
14. Explain why friction can make observing Newton's first law of motion difficult.



Concept Mapping

15. Use the following terms to create a concept map: gravity, free fall, terminal velocity, projectile motion, air resistance.



CRITICAL THINKING AND PROBLEM SOLVING

16. During a shuttle launch, about 830,000 kg of fuel is burned in 8 minutes. The fuel provides the shuttle with a constant thrust, or push off the ground. How does Newton's second law of motion explain why the shuttle's acceleration increases during takeoff?

17. When using a hammer to drive a nail into wood, you have to swing the hammer through the air with a certain velocity. Because the hammer has both mass and velocity, it has momentum. Describe what happens to the hammer's momentum after the hammer hits the nail.

18. Suppose you are standing on a skateboard or on in-line skates and you toss a backpack full of heavy books toward your friend. What do you think will happen to you and why? Explain your answer in terms of Newton's third law of motion.

MATH IN SCIENCE

19. A 12 kg rock falls from rest off a cliff and hits the ground in 1.5 seconds.
    - **a.** Ignoring air resistance, what is the rock's velocity just before it hits the ground?
    - **b.** What is the rock's weight after it hits the ground? (Hint: Weight is a measure of the gravitational force on an object.)

INTERPRETING GRAPHICS

20. The picture below shows a common desk toy. If you pull one ball up and release it, it hits the balls at the bottom and comes to a stop. In the same instant, the ball on the other side swings up and repeats the cycle. How does conservation of momentum explain how this toy works?

NOW What Do You Think?

Take a minute to review your answers to the ScienceLog questions on page 137. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.

Eureka!

A Bat with Dimples

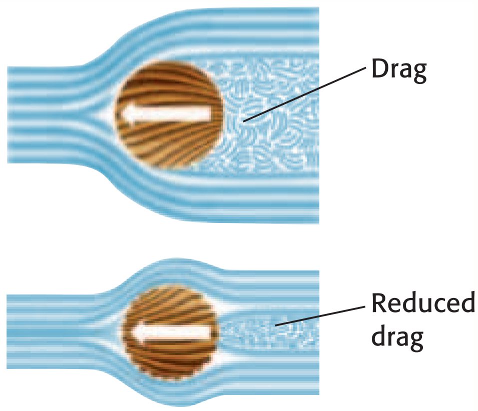
Wouldn't it be nice to hit a home run every time? Jeff DiTullio, a teacher at MIT, in Cambridge, Massachusetts, has found a way for you to get more bang from your bat. Would you believe *dimples?*

Building a Better Bat

If you look closely at the surface of a golf ball, you'll see dozens of tiny craterlike dimples. When air flows past these dimples, it gets stirred up. By keeping air moving near the surface of the ball, the dimples help the golf ball move faster and farther through the air.

DiTullio decided to apply this same idea to a baseball bat. His hypothesis was that dimples would allow a bat to move more easily through the air. This would help batters swing the bat faster and hit the ball harder. To test his hypothesis, DiTullio pressed hundreds of little dimples about 1 mm deep and 2 mm across into the surface of a bat.

When DiTullio tested his dimpled bat in a wind tunnel, he found that it could be swung 3 to 5 percent faster. That may not sound like much, but it could add about 5 m to a fly ball!



▲ *By reducing the amount of drag behind the bat, dimples help the bat move faster through the air.*

Safe . . . or Out?

As you might imagine, many baseball players would love to have a bat that could turn a long fly ball into a home run. But are dimpled baseball bats legal?

The size and shape of every piece of equipment used in Major League Baseball games are regulated. A baseball bat, for instance, must be no more than 107 cm long and no more than 7 cm across at its widest point. When DiTullio designed his dimpled bat, there was no rule stating that bats had to be smooth. But when Major League Baseball found out about the new bat, they changed the rules! Today official rules require that all bats be smooth, and they prohibit any type of "experimental" bat. Someday the rules may be revised to allow DiTullio's dimpled bat. When that happens, fans of the dimpled baseball bat will all shout, "Play ball!"

Dimple Madness

▶ Now that you know how dimples can improve baseball bats, think of other uses for dimples. How might dimples improve the way other objects move through the air? Draw a sketch of a dimpled object, and describe how the dimples improve the design.

▶ *Jeff DiTullio, pictured with his dimpled baseball bat, is an aeronautical engineer—someone who studies both the way air moves and the way things move through air.*

CAREERS

ROLLER COASTER DESIGNER

Roller coasters have fascinated **Steve Okamoto** ever since his first ride on one. "I remember going to Disneyland as a kid. My mother was always upset with me because I kept looking over the sides of the rides, trying to figure out how they worked," he laughs. To satisfy his curiosity, Okamoto became a mechanical engineer. Today he uses his scientific knowledge to design and build machines, systems, and buildings. But his specialty is roller coasters.

His West Coaster, which sits on the Santa Monica pier in Santa Monica, California, towers five stories above the Pacific Ocean. The cars on the Steel Force, at Dorney Park, in Pennsylvania, reach speeds of over 120 km/h and drop more than 60 m to disappear into a 37 m long tunnel. The Mamba, at Worlds of Fun, in Missouri, sends cars flying along as high and as fast as the Steel Force does, but it also has two giant back-to-back hills, a fast spiral, and five "camelback" humps. The camelbacks are designed to pull riders' seats out from under them, giving the riders "air time."

Coaster Motion

Roller-coaster cars really do coast along the track. A motor pulls the cars up a high hill to start the ride. After that, the cars are powered by gravity alone. As the cars roll downhill, they pick up enough speed to whiz through the rest of the curves, loops, twists, and bumps in the track.

Designing a successful coaster is no simple task. Steve Okamoto has to calculate the cars' speed and acceleration on each part of the track. "The coaster has to go fast enough to make it up the next hill," he explains. Okamoto uses his knowledge of geometry and physics to create safe but scary curves, loops, humps, and dips. Okamoto must also keep in mind that the ride's towers and structures need to be strong enough to support both the track and the speeding cars full of people. The cars themselves need special wheels to keep them locked onto the track and seat belts or bars to keep passengers safely inside. "It's like putting together a puzzle, except the pieces haven't been cut out yet," says Okamoto.

▲ *The Wild Thing, in Shakopee, Minnesota, was designed by Steve Okamoto.*

Take the Challenge

▶ Step outside for a moment. Gather some rope and a medium-sized plastic bucket half-full of water. Can you get the bucket over your head and upside down without any water escaping? How does this relate to roller coasters?