1

Matter in Motion

About the PHOTO

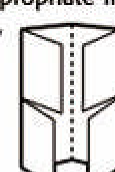
Speed skaters are fast. In fact, some skaters can skate at a rate of 12 m/s! That's equal to a speed of 27 mi/h. To reach such a speed, skaters must exert large forces. They must also use friction to turn corners on the slippery surface of the ice.

PRE-READING ACTIVITY

FOLDNOTES

Four-Corner Fold

Before you read the chapter, create the FoldNote entitled "Four-Corner Fold" described in the **Study Skills** section of the Appendix. Label the flaps of the four-corner fold with "Motion," "Forces," "Friction," and "Gravity." Write what you know about each topic under the appropriate flap. As you read the chapter, add other information that you learn.



START-UP ACTIVITY

The Domino Derby

Speed is the distance traveled by an object in a certain amount of time. In this activity, you will observe one factor that affects the speed of falling dominoes.

Procedure

1. Set up **25 dominoes** in a straight line. Try to keep equal spacing between the dominoes.
2. Use a **meterstick** to measure the total length of your row of dominoes, and record the length.
3. Use a **stopwatch** to time how long it takes for the dominoes to fall. Record this measurement.
4. Predict what would happen to that amount of time if you changed the distance between the dominoes. Write your predictions.
5. Repeat steps 2 and 3 several times using distances between the dominoes that are smaller and larger than the distance used in your first setup. Use the same number of dominoes in each trial.

Analysis

1. Calculate the average speed for each trial by dividing the total distance (the length of the domino row) by the time the dominoes take to fall.
2. How did the spacing between dominoes affect the average speed? Is this result what you expected? If not, explain.

SECTION 1

Measuring Motion

Look around you—you are likely to see something in motion. Your teacher may be walking across the room, or perhaps your friend is writing with a pencil.

Even if you don't see anything moving, motion is still occurring all around you. Air particles are moving, the Earth is circling the sun, and blood is traveling through your blood vessels!

READING WARM-UP

Objectives

- Describe the motion of an object by the position of the object in relation to a reference point.
- Identify the two factors that determine speed.
- Explain the difference between speed and velocity.
- Analyze the relationship between velocity and acceleration.
- Demonstrate that changes in motion can be measured and represented on a graph.

Terms to Learn

motion	velocity
speed	acceleration

READING STRATEGY

Discussion Read this section silently. Write down questions that you have about this section. Discuss your questions in a small group.

Observing Motion by Using a Reference Point

You might think that the motion of an object is easy to detect—you just watch the object. But you are actually watching the object in relation to another object that appears to stay in place. The object that appears to stay in place is a *reference point*. When an object changes position over time relative to a reference point, the object is in **motion.** You can describe the direction of the object's motion with a reference direction, such as north, south, east, west, up, or down.

Reading Check **What is a reference point?** *(See the Appendix for answers to Reading Checks.)*

Common Reference Points

The Earth's surface is a common reference point for determining motion, as shown in **Figure 1.** Nonmoving objects, such as trees and buildings, are also useful reference points.

A moving object can also be used as a reference point. For example, if you were on the hot-air balloon shown in **Figure 1,** you could watch a bird fly by and see that the bird was changing position in relation to your moving balloon.

Figure 1 *During the interval between the times that these pictures were taken, the hot-air balloon changed position relative to a reference point—the mountain.*

Speed Depends on Distance and Time

Speed is the distance traveled by an object divided by the time taken to travel that distance. Look again at **Figure 1.** Suppose the time interval between the pictures was 10 s and that the balloon traveled 50 m in that time. The speed of the balloon is (50 m)/(10 s), or 5 m/s.

The SI unit for speed is meters per second (m/s). Kilometers per hour (km/h), feet per second (ft/s), and miles per hour (mi/h) are other units commonly used to express speed.

motion an object's change in position relative to a reference point

speed the distance traveled divided by the time interval during which the motion occurred

Determining Average Speed

Most of the time, objects do not travel at a constant speed. For example, you probably do not walk at a constant speed from one class to the next. So, it is very useful to calculate *average speed* using the following equation:

$$\textit{average speed} = \frac{\textit{total distance}}{\textit{total time}}$$

Recognizing Speed on a Graph

Suppose a person drives from one city to another. The blue line in the graph in **Figure 2** shows the total distance traveled during a 4 h period. Notice that the distance traveled during each hour is different. The distance varies because the speed is not constant. The driver may change speed because of weather, traffic, or varying speed limits. The average speed for the entire trip can be calculated as follows:

$$\textit{average speed} = \frac{360 \text{ km}}{4 \text{ h}} = 90 \text{ km/h}$$

The red line on the graph shows how far the driver must travel each hour to reach the same city if he or she moved at a constant speed. The slope of this line is the average speed.

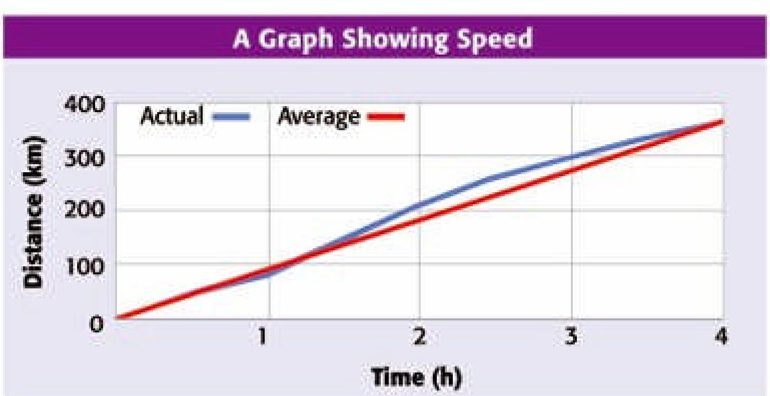


Figure 2 *Speed can be shown on a graph of distance versus time.*

SCHOOL to HOME

What's Your Speed?

Measure a distance of 5 m or a distance of 25 ft inside or outside. Ask an adult at home to use a stopwatch or a watch with a second hand to time you as you travel the distance you measured. Then, find your average speed. Find the average speed of other members of your family in the same way.

ACTIVITY

MATH FOCUS

Calculating Average Speed An athlete swims a distance from one end of a 50 m pool to the other end in a time of 25 s. What is the athlete's average speed?

Step 1: Write the equation for average speed.

$$\textit{average speed} = \frac{\textit{total distance}}{\textit{total time}}$$

Step 2: Replace the total distance and total time with the values given, and solve.

$$\textit{average speed} = \frac{50 \text{ m}}{25 \text{ s}} = 2 \text{ m/s}$$

Now It's Your Turn

1. Kira jogs to a store 72 m away in a time of 36 s. What is Kira's average speed?
2. If you travel 7.5 km and walk for 1.5 h, what is your average speed?
3. An airplane traveling from San Francisco to Chicago travels 1,260 km in 3.5 h. What is the airplane's average speed?

Velocity: Direction Matters

Imagine that two birds leave the same tree at the same time. They both fly at 10 km/h for 5 min, 12 km/h for 8 min, and 5 km/h for 10 min. Why don't they end up at the same place?

Have you figured out the answer? The birds went in different directions. Their speeds were the same, but they had different velocities. **Velocity** (vuh LAHS uh tee) is the speed of an object in a particular direction.

Be careful not to confuse the terms *speed* and *velocity.* They do not have the same meaning. Velocity must include a reference direction. If you say that an airplane's velocity is 600 km/h, you would not be correct. But you could say the plane's velocity is 600 km/h south. **Figure 3** shows an example of the difference between speed and velocity.

Figure 3 *The speeds of these cars may be similar, but the velocities of the cars differ because the cars are going in different directions.*

Changing Velocity

You can think of velocity as the rate of change of an object's position. An object's velocity is constant only if its speed and direction don't change. Therefore, constant velocity is always motion along a straight line. An object's velocity changes if either its speed or direction changes. For example, as a bus traveling at 15 m/s south speeds up to 20 m/s south, its velocity changes. If the bus continues to travel at the same speed but changes direction to travel east, its velocity changes again. And if the bus slows down at the same time that it swerves north to avoid a cat, the velocity of the bus changes, too.

Reading Check **What are the two ways that velocity can change?**

Figure 4 **Finding Resultant Velocity**

When you combine two velocities that are **in the same direction,** add them together to find the resultant velocity.

Person's resultant velocity
15 m/s east + 1 m/s east = 16 m/s east

When you combine two velocities that are **in opposite directions,** subtract the smaller velocity from the larger velocity to find the resultant velocity. The resultant velocity is in the direction of the larger velocity.

Person's resultant velocity
15 m/s east − 1 m/s west = 14 m/s east

Combining Velocities

Imagine that you are riding in a bus that is traveling east at 15 m/s. You and the other passengers are also traveling at a velocity of 15 m/s east. But suppose you stand up and walk down the bus's aisle while the bus is moving. Are you still moving at the same velocity as the bus? No! **Figure 4** shows how you can combine velocities to find the *resultant velocity.*

velocity the speed of an object in a particular direction

acceleration the rate at which velocity changes over time; an object accelerates if its speed, direction, or both change

Acceleration

Although the word *accelerate* is commonly used to mean "speed up," the word means something else in science. **Acceleration** (ak SEL uhr AY shuhn) is the rate at which velocity changes. Velocity changes if speed changes, if direction changes, or if both change. So, an object accelerates if its speed, its direction, or both change.

An increase in velocity is commonly called *positive acceleration*. A decrease in velocity is commonly called *negative acceleration,* or *deceleration*. Keep in mind that acceleration is not only how much velocity changes but also how fast velocity changes. The faster the velocity changes, the greater the acceleration is.

Figure 5 *This cyclist is accelerating at 1 m/s² south.*

MATH PRACTICE

Calculating Acceleration

Use the equation for average acceleration to do the following problem.

A plane passes over point A at a velocity of 240 m/s north. Forty seconds later, it passes over point B at a velocity of 260 m/s north. What is the plane's average acceleration?

Calculating Average Acceleration

You can find average acceleration by using the equation:

$$\text{average acceleration} = \frac{\text{final velocity} - \text{starting velocity}}{\text{time it takes to change velocity}}$$

Velocity is expressed in meters per second (m/s), and time is expressed in seconds (s). So acceleration is expressed in meters per second per second, or (m/s)/s, which equals m/s². For example, look at **Figure 5.** Every second, the cyclist's southward velocity increases by 1 m/s. His average acceleration can be calculated as follows:

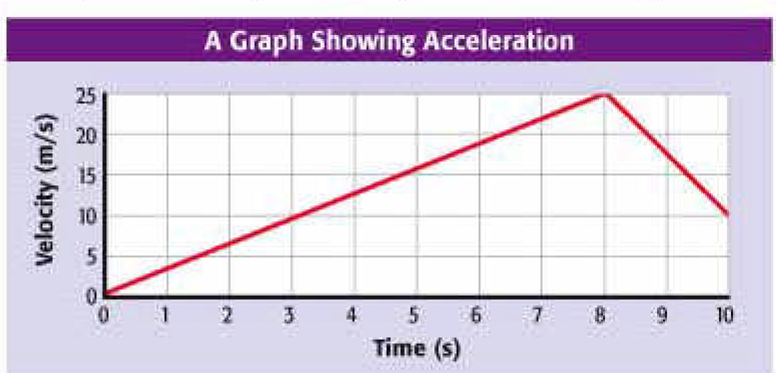
$$\text{average acceleration} = \frac{5\text{ m/s} - 1\text{ m/s}}{4\text{ s}} = 1\text{ m/s}^2\text{ south}$$

Reading Check What are the units of acceleration?

Recognizing Acceleration on a Graph

Suppose that you are riding a roller coaster. The roller-coaster car moves up a hill until it stops at the top. Then, you are off! The graph in **Figure 6** shows your acceleration for the next 10 s. During the first 8 s, you move down the hill. You can tell from the graph that your acceleration is positive for the first 8 s because your velocity increases as time passes. During the last 2 s, your car starts climbing the next hill. Your acceleration is negative because your velocity decreases as time passes.

Figure 6 *Acceleration can be shown on a graph of velocity versus time.*



Circular Motion: Continuous Acceleration

You may be surprised to know that even when you are completely still, you are experiencing acceleration. You may not seem to be changing speed or direction, but you are! You are traveling in a circle as the Earth rotates. An object traveling in a circular motion is always changing its direction. Therefore, its velocity is always changing, so it is accelerating. The acceleration that occurs in circular motion is known as *centripetal acceleration* (sen TRIP uht uhl ak SEL uhr AY shuhn). Centripetal acceleration occurs on a Ferris wheel at an amusement park or as the moon orbits Earth. Another example of centripetal acceleration is shown in **Figure 7.**

Figure 7 *The blades of these windmills are constantly changing direction. Thus, centripetal acceleration is occurring.*

SECTION Review

Summary

- An object is in motion if it changes position over time in relation to a reference point.
- Speed is the distance traveled by an object divided by the time the object takes to travel that distance.
- Velocity is speed in a given direction.
- Acceleration is the rate at which velocity changes.
- An object can accelerate by changing speed, direction, or both.
- Speed can be represented on a graph of distance versus time.
- Acceleration can be represented by graphing velocity versus time.

Using Key Terms

1. In your own words, write definitions for each of the following terms: *motion* and *acceleration*.
2. Use each of the following terms in a separate sentence: *speed* and *velocity*.

Understanding Key Ideas

3. Which of the following is NOT an example of acceleration?
   a. a person jogging at 3 m/s along a winding path
   b. a car stopping at a stop sign
   c. a cheetah running 27 m/s east
   d. a plane taking off
4. Which of the following would be a good reference point to describe the motion of a dog?
   a. the ground
   b. another dog running
   c. a tree
   d. All of the above
5. Explain the difference between speed and velocity.
6. What two things must you know to determine speed?
7. How are velocity and acceleration related?

Math Skills

8. Find the average speed of a person who swims 105 m in 70 s.
9. What is the average acceleration of a subway train that speeds up from 9.6 m/s to 12 m/s in 0.8 s on a straight section of track?

Critical Thinking

10. **Applying Concepts** Why is it more helpful to know a tornado's velocity rather than its speed?
11. **Evaluating Data** A wolf is chasing a rabbit. Graph the wolf's motion using the following data: 15 m/s at 0 s, 10 m/s at 1 s, 5 m/s at 2 s, 2.5 m/s at 3 s, 1 m/s at 4 s, and 0 m/s at 5 s. What does the graph tell you?

SCILINKS. NSTA

For a variety of links related to this chapter, go to www.scilinks.org

Topic: Measuring Motion
SciLinks code: HSM0927

SECTION 2

What Is a Force?

You have probably heard the word force *in everyday conversation. People say things such as "That storm had a lot of force" or "Our football team is a force to be reckoned with." But what, exactly, is a force?*

READING WARM-UP

Objectives

- Describe forces, and explain how forces act on objects.
- Determine the net force when more than one force is acting on an object.
- Compare balanced and unbalanced forces.
- Describe ways that unbalanced forces cause changes in motion.

Terms to Learn

force
newton
net force

READING STRATEGY

Reading Organizer As you read this section, make a table comparing balanced forces and unbalanced forces.

In science, a **force** is simply a push or a pull. All forces have both size and direction. A force can change the acceleration of an object. This acceleration can be a change in the speed or direction of the object. In fact, any time you see a change in an object's motion, you can be sure that the change in motion was created by a force. Scientists express force using a unit called the **newton** (N).

Forces Acting on Objects

All forces act on objects. For any push to occur, something has to receive the push. You can't push nothing! The same is true for any pull. When doing schoolwork, you use your fingers to pull open books or to push the buttons on a computer keyboard. In these examples, your fingers are exerting forces on the books and the keys. So, the forces act on the books and keys. Another example of a force acting on an object is shown in **Figure 1.**

However, just because a force acts on an object doesn't mean that motion will occur. For example, you are probably sitting on a chair. But the force you are exerting on the chair does not cause the chair to move. The chair doesn't move because the floor is also exerting a force on the chair.

Figure 1 *The bulldozer is exerting a force on the pile of soil. But the pile of soil also exerts a force by just sitting on the ground!*

Unseen Sources and Receivers of Forces

It is not always easy to tell what is exerting a force or what is receiving a force, as shown in **Figure 2.** You cannot see what exerts the force that pulls magnets to refrigerators. And you cannot see that the air around you is held near Earth's surface by a force called *gravity.*

Figure 2 *Something that you cannot see exerts a force that makes this cat's fur stand up.*

Determining Net Force

Usually, more than one force is acting on an object. The **net force** is the combination all of the forces acting on an object. So, how do you determine the net force? The answer depends on the directions of the forces.

Forces in the Same Direction

Suppose the music teacher asks you and a friend to move a piano. You pull on one end and your friend pushes on the other end, as shown in **Figure 3.** The forces you and your friend exert on the piano act in the same direction. The two forces are added to determine the net force because the forces act in the same direction. In this case, the net force is 45 N. This net force is large enough to move the piano—if it is on wheels, that is!

Reading Check **How do you determine the net force on an object if all forces act in the same direction?** (*See the Appendix for answers to Reading Checks.*)

force a push or a pull exerted on an object in order to change the motion of the object; force has size and direction

newton the SI unit for force (symbol, N)

net force the combination of all of the forces acting on an object

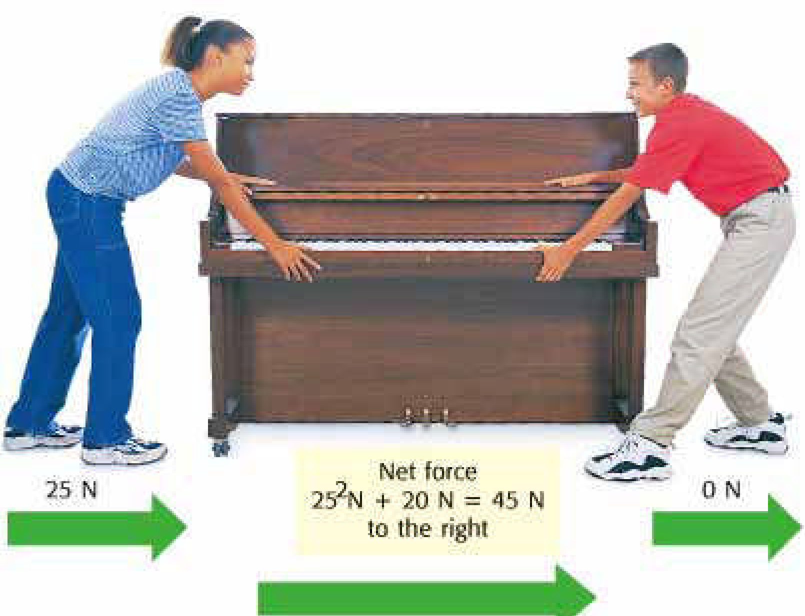


Figure 3 *When forces act in the same direction, you add the forces to determine the net force. The net force will be in the same direction as the individual forces.*

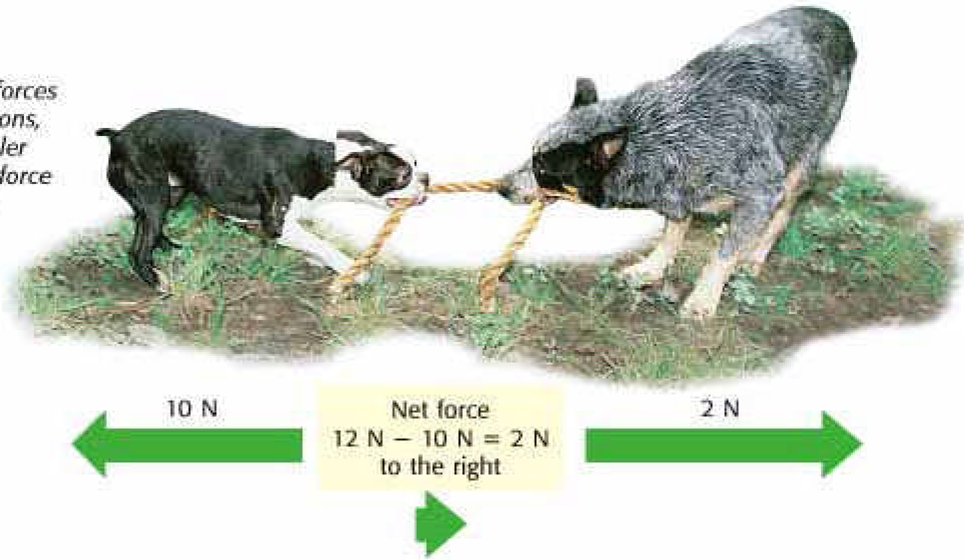


Figure 4 *When two forces act in opposite directions, you subtract the smaller force from the larger force to determine the net force. The net force will be in the same direction as the larger force.*

Forces in Different Directions

Look at the two dogs playing tug of war in **Figure 4.** Each dog is exerting a force on the rope. But the forces are in opposite directions. Which dog will win the tug of war?

Because the forces are in opposite directions, the net force on the rope is found by subtracting the smaller force from the larger one. In this case, the net force is 2 N in the direction of the dog on the right. Give that dog a dog biscuit!

Reading Check **What is the net force on an object when you combine a force of 7 N north with a force of 5 N south?**

Balanced and Unbalanced Forces

If you know the net force on an object, you can determine the effect of the net force on the object's motion. Why? The net force tells you whether the forces on the object are balanced or unbalanced.

Balanced Forces

When the forces on an object produce a net force of 0 N, the forces are *balanced*. Balanced forces will not cause a change in the motion of a moving object. And balanced forces do not cause a nonmoving object to start moving.

Many objects around you have only balanced forces acting on them. For example, a light hanging from the ceiling does not move because the force of gravity pulling down on the light is balanced by the force of the cord pulling upward. A bird's nest in a tree and a hat resting on your head are also examples of objects that have only balanced forces acting on them. **Figure 5** shows another example of balanced forces.

Figure 5 *Because all the forces on this house of cards are balanced, none of the cards move.*

Unbalanced Forces

When the net force on an object is not 0 N, the forces on the object are *unbalanced*. Unbalanced forces produce a change in motion, such as a change in speed or a change in direction. Unbalanced forces are necessary to cause a nonmoving object to start moving.

Unbalanced forces are also necessary to change the motion of moving objects. For example, consider the soccer game shown in **Figure 6.** The soccer ball is already moving when it is passed from one player to another. When the ball reaches another player, that player exerts an unbalanced force—a kick—on the ball. After the kick, the ball moves in a new direction and has a new speed.

An object can continue to move when the unbalanced forces are removed. For example, when it is kicked, a soccer ball receives an unbalanced force. The ball continues to roll on the ground long after the force of the kick has ended.

Figure 6 *The soccer ball moves because the players exert an unbalanced force on the ball each time they kick it.*

SECTION Review

Summary

- A force is a push or a pull. Forces have size and direction and are expressed in newtons.
- Force is always exerted by one object on another object.
- Net force is determined by combining forces. Forces in the same direction are added. Forces in opposite directions are subtracted.
- Balanced forces produce no change in motion. Unbalanced forces produce a change in motion.

Using Key Terms

1. In your own words, write a definition for each of the following terms: *force* and *net force*.

Understanding Key Ideas

2. Which of the following may happen when an object receives unbalanced forces?
   a. The object changes direction.
   b. The object changes speed.
   c. The object starts to move.
   d. All of the above
3. Explain the difference between balanced and unbalanced forces.
4. Give an example of an unbalanced force causing a change in motion.
5. Give an example of an object that has balanced forces acting on it.
6. Explain the meaning of the phrase "Forces act on objects."

Math Skills

7. A boy pulls a wagon with a force of 6 N east as another boy pushes it with a force of 4 N east. What is the net force?

Critical Thinking

8. **Making Inferences** When finding net force, why must you know the directions of the forces acting on an object?
9. **Applying Concepts** List three forces that you exert when riding a bicycle.

SCILINKS. NSTA

For a variety of links related to this chapter, go to www.scilinks.org

Topic: Forces
SciLinks code: HSM0604

SECTION 3

Friction: A Force That Opposes Motion

While playing ball, your friend throws the ball out of your reach. Rather than running for the ball, you walk after it. You know that the ball will stop. But do you know why?

You know that the ball is slowing down. An unbalanced force is needed to change the speed of a moving object. So, what force is stopping the ball? The force is called friction. **Friction** is a force that opposes motion between two surfaces that are in contact. Friction can cause a moving object, such as a ball, to slow down and eventually stop.

The Source of Friction

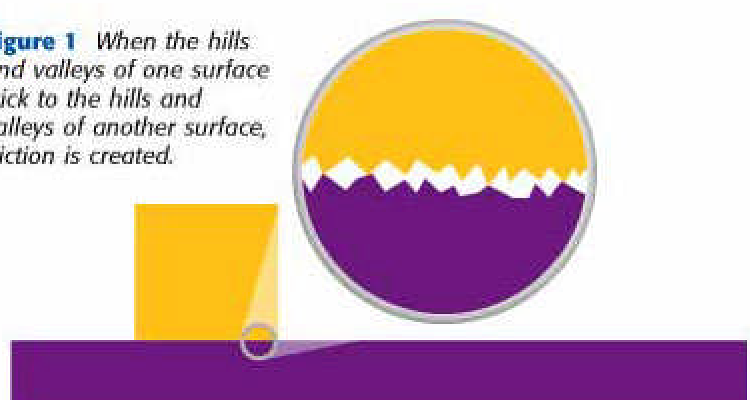
Friction occurs because the surface of any object is rough. Even surfaces that feel smooth are covered with microscopic hills and valleys. When two surfaces are in contact, the hills and valleys of one surface stick to the hills and valleys of the other surface, as shown in **Figure 1.** This contact causes friction.

The amount of friction between two surfaces depends on many factors. Two factors include the force pushing the surfaces together and the roughness of the surfaces.

The Effect of Force on Friction

The amount of friction depends on the force pushing the surfaces together. If this force increases, the hills and valleys of the surfaces can come into closer contact. The close contact increases the friction between the surfaces. Objects that weigh less exert less downward force than objects that weigh more do, as shown in **Figure 2.** But changing how much of the surfaces come in contact does not change the amount of friction.

Figure 1 *When the hills and valleys of one surface stick to the hills and valleys of another surface, friction is created.*



READING WARM-UP

Objectives

- Explain why friction occurs.
- List the two types of friction, and give examples of each type.
- Explain how friction can be both harmful and helpful.

Terms to Learn

friction

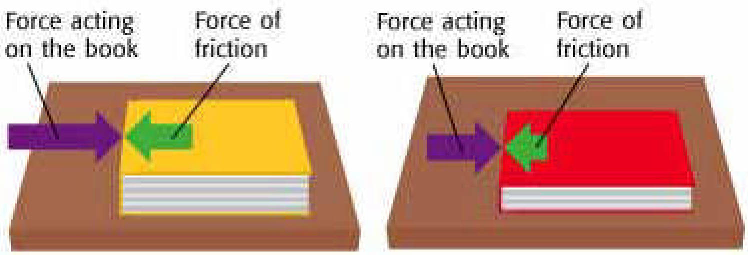
READING STRATEGY

Brainstorming The key idea of this section is friction. Brainstorm words and phrases related to friction.

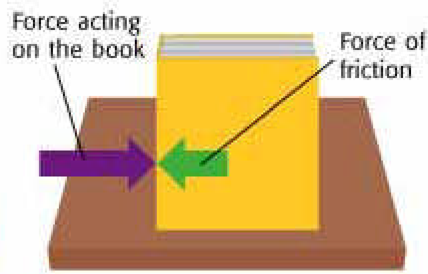
friction a force that opposes motion between two surfaces that are in contact

Figure 2 **Force and Friction**

a There is more friction between the book with more weight and the table than there is between the book with less weight and the table. A harder push is needed to move the heavier book.



b Turning a book on its edge does not change the amount of friction between the table and the book.



The Effect of Rougher Surfaces on Friction

Rough surfaces have more microscopic hills and valleys than smooth surfaces do. So, the rougher the surface is, the greater the friction is. For example, a ball rolling on the ground slows down because of the friction between the ball and the ground. A large amount of friction is produced because the ground has a rough surface. But imagine that you were playing ice hockey. If the puck passed out of your reach, it would slide across the ice for a long while before stopping. The reason the puck would continue to slide is that the ice is a smooth surface that has very little friction.

Reading Check **Why is friction greater between surfaces that are rough?** *(See the Appendix for answers to Reading Checks.)*

Quick Lab

The Friction 500

1. Make a short ramp out of **a piece of cardboard** and **one or two books** on a table.
2. Put a **toy car** at the top of the ramp, and let go of the car. If necessary, adjust the ramp height so that your car does not roll off the table.
3. Put the car at the top of the ramp again, and let go of the car. Record the distance the car travels after leaving the ramp.
4. Repeat step 3 two more times, and calculate the average for your results.
5. Change the surface of the table by covering the table with **sandpaper.** Repeat steps 3 and 4.
6. Change the surface of the table one more time by covering the table with **cloth.** Repeat steps 3 and 4 again.
7. Which surface had the most friction? Why? What do you predict would happen if the car were heavier?

Types of Friction

There are two types of friction. The friction you observe when sliding books across a tabletop is called *kinetic friction*. The other type of friction is *static friction*. You observe static friction when you push on a piece of furniture and it does not move.

Kinetic Friction

The word *kinetic* means "moving." So, kinetic friction is friction between moving surfaces. The amount of kinetic friction between two surfaces depends in part on how the surfaces move. Surfaces can slide past each other. Or a surface can roll over another surface. Usually, the force of sliding kinetic friction is greater than the force of rolling kinetic friction. Thus, it is usually easier to move objects on wheels than to slide the objects along the floor, as shown in **Figure 3.**

Kinetic friction is very useful in everyday life. You use sliding kinetic friction when you apply the brakes on a bicycle and when you write with a pencil or a piece of chalk. You also use sliding kinetic friction when you scratch a part of your body that is itchy!

Rolling kinetic friction is an important part of almost all means of transportation. Anything that has wheels—bicycles, in-line skates, cars, trains, and planes—uses rolling kinetic friction.

SCHOOL to HOME

Comparing Friction

Ask an adult at home to sit on the floor. Try to push the adult across the room. Next, ask the adult to sit on a chair that has wheels and to keep his or her feet off the floor. Try pushing the adult and the chair across the room. If you do not have a chair that has wheels, try pushing the adult on different kinds of flooring. Explain why there was a difference between the two trials in your **science journal.**

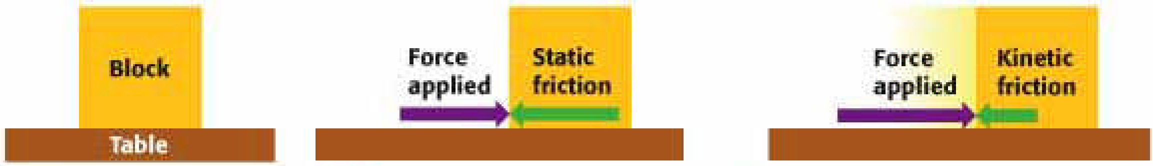
ACTIVITY

Figure 3 **Comparing Kinetic Friction**

a Moving a heavy piece of furniture in your room can be hard work because **the force of sliding kinetic friction is large.**

b Moving a heavy piece of furniture is easier if you put it on wheels. **The force of rolling kinetic friction is smaller** and easier to overcome.

Figure 4 **Static Friction**



a There is no friction between the block and the table when no force is applied to the block.

b If a small force (purple arrow) is exerted on the block, the block does not move. The force of static friction (green arrow) balances the force applied.

c When the force exerted on the block is greater than the force of static friction, the block starts moving. When the block starts moving, all static friction is gone, and only kinetic friction (green arrow) opposes the force applied.

Static Friction

When a force is applied to an object but does not cause the object to move, *static friction* occurs. The word *static* means "not moving." The object does not move because the force of static friction balances the force applied. Static friction can be overcome by applying a large enough force. Static friction disappears as soon as an object starts moving, and then kinetic friction immediately occurs. Look at **Figure 4** to understand under what conditions static friction affects an object.

Reading Check What does the word *static* mean?

Friction: Harmful and Helpful

Think about how friction affects a car. Without friction, the tires could not push against the ground to move the car forward, and the brakes could not stop the car. Without friction, a car is useless. However, friction can also cause problems in a car. Friction between moving engine parts increases their temperature and causes the parts to wear down. A liquid coolant is added to the engine to keep the engine from overheating. And engine parts need to be changed as they wear out.

Friction is both harmful and helpful to you and the world around you. Friction can cause holes in your socks and in the knees of your jeans. Friction by wind and water can cause erosion of the topsoil that nourishes plants. On the other hand, friction between your pencil and your paper is necessary to allow the pencil to leave a mark. Without friction, you would just slip and fall when you tried to walk. Because friction can be both harmful and helpful, it is sometimes necessary to decrease or increase friction.

INTERNET ACTIVITY

For another activity related to this chapter, go to **go.hrw.com** and type in the keyword **HP5MOTW.**

CONNECTION TO Social Studies

WRITING SKILL **Invention of the Wheel** Archeologists have found evidence that the first vehicles with wheels were used in ancient Mesopotamia sometime between 3500 and 3000 BCE. Before wheels were invented, people used planks or sleds to carry loads. In your **science journal,** write a paragraph about how your life would be different if wheels did not exist.

Quick Lab

Reducing Friction

1. Stack **two or three heavy books** on a table. Use one finger to push the books across the table.
2. Place **five round pens or pencils** under the books, and push the books again.
3. Compare the force used in step 1 with the force used in step 2. Explain.
4. Open a **jar** with your hands, and close it again.
5. Spread a small amount of **liquid soap** on your hands.
6. Try to open the jar again. Was the jar easier or harder to open with the soap? Explain your observations.
7. In which situation was friction helpful? In which situation was friction harmful?

Some Ways to Reduce Friction

One way to reduce friction is to use lubricants (LOO bri kuhnts). *Lubricants* are substances that are applied to surfaces to reduce the friction between the surfaces. Some examples of common lubricants are motor oil, wax, and grease. Lubricants are usually liquids, but they can be solids or gases. An example of a gas lubricant is the air that comes out of the tiny holes of an air-hockey table. **Figure 5** shows one use of a lubricant.

Friction can also be reduced by switching from sliding kinetic friction to rolling kinetic friction. Ball bearings placed between the wheels and axles of in-line skates and bicycles make it easier for the wheels to turn by reducing friction.

Another way to reduce friction is to make surfaces that rub against each other smoother. For example, rough wood on a park bench is painful to slide across because there is a large amount of friction between your leg and the bench. Rubbing the bench with sandpaper makes the bench smoother and more comfortable to sit on. The reason the bench is more comfortable is that the friction between your leg and the bench is reduced.

Reading Check **List three common lubricants.**

Figure 5 *When you work on a bicycle, watch out for the chain! You might get dirty from the grease or oil that keeps the chain moving freely. Without this lubricant, friction between the sections of the chain would quickly wear the chain out.*

Some Ways to Increase Friction

One way to increase friction is to make surfaces rougher. For example, sand scattered on icy roads keeps cars from skidding. Baseball players sometimes wear textured batting gloves to increase the friction between their hands and the bat so that the bat does not fly out of their hands.

Another way to increase friction is to increase the force pushing the surfaces together. For example, if you are sanding a piece of wood, you can sand the wood faster by pressing harder on the sandpaper. Pressing harder increases the force pushing the sandpaper and wood together. So, the friction between the sandpaper and wood increases. **Figure 6** shows another example of friction increased by pushing on an object.

Figure 6 *No one likes cleaning dirty pans. To get this chore done quickly, press down with the scrubber to increase friction.*

SECTION Review

Summary

- Friction is a force that opposes motion.
- Friction is caused by hills and valleys on the surfaces of two objects touching each other.
- The amount of friction depends on factors such as the roughness of the surfaces and the force pushing the surfaces together.
- Two kinds of friction are kinetic friction and static friction.
- Friction can be helpful or harmful.

Using Key Terms

1. In your own words, write a definition for the term *friction*.

Understanding Key Ideas

2. Why is it easy to slip when there is water on the floor?

- **a.** The water is a lubricant and reduces the friction between your feet and the floor.
- **b.** The friction between your feet and the floor changes from kinetic to static friction.
- **c.** The water increases the friction between your feet and the floor.
- **d.** The friction between your feet and the floor changes from sliding kinetic friction to rolling kinetic friction.

3. Explain why friction occurs.

4. How does the roughness of surfaces that are touching affect the friction between the surfaces?

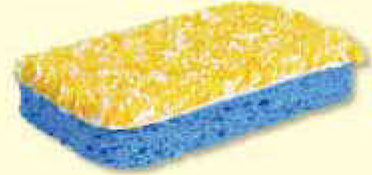
5. Describe how the amount of force pushing two surfaces together affects friction.

6. Name two ways in which friction can be increased.

7. List the two types of friction, and give an example of each.

Interpreting Graphics

8. Why do you think the sponge shown below has a layer of plastic bristles attached to it?



Critical Thinking

9. Applying Concepts Name two ways that friction is harmful and two ways that friction is helpful to you when riding a bicycle.

10. Making Inferences Describe a situation in which static friction is useful.

SCILINKS. NSTA

For a variety of links related to this chapter, go to www.scilinks.org

Topic: Force and Friction
SciLinks code: HSM0601

SECTION 4

Gravity: A Force of Attraction

READING WARM-UP

Objectives

- Describe gravity and its effect on matter.
- Explain the law of universal gravitation.
- Describe the difference between mass and weight.

Terms to Learn

gravity
weight
mass

READING STRATEGY

Paired Summarizing Read this section silently. In pairs, take turns summarizing the material. Stop to discuss ideas that seem confusing.

Have you ever seen a video of astronauts on the moon? They bounce around like beach balls even though they wear big, bulky spacesuits. Why is leaping on the moon easier than leaping on Earth?

The answer is gravity. **Gravity** is a force of attraction between objects that is due to their masses. The force of gravity can change the motion of an object by changing its speed, direction, or both. In this section, you will learn about gravity and its effects on objects, such as the astronaut in **Figure 1.**

gravity a force of attraction between objects that is due to their masses

The Effects of Gravity on Matter

All matter has mass. Gravity is a result of mass. Therefore, all matter is affected by gravity. That is, all objects experience an attraction toward all other objects. This gravitational force pulls objects toward each other. Right now, because of gravity, you are being pulled toward this book, your pencil, and every other object around you.

These objects are also being pulled toward you and toward each other because of gravity. So why don't you see the effects of this attraction? In other words, why don't you notice objects moving toward each other? The reason is that the mass of most objects is too small to cause a force large enough to move objects toward each other. However, you are familiar with one object that is massive enough to cause a noticeable attraction—the Earth.

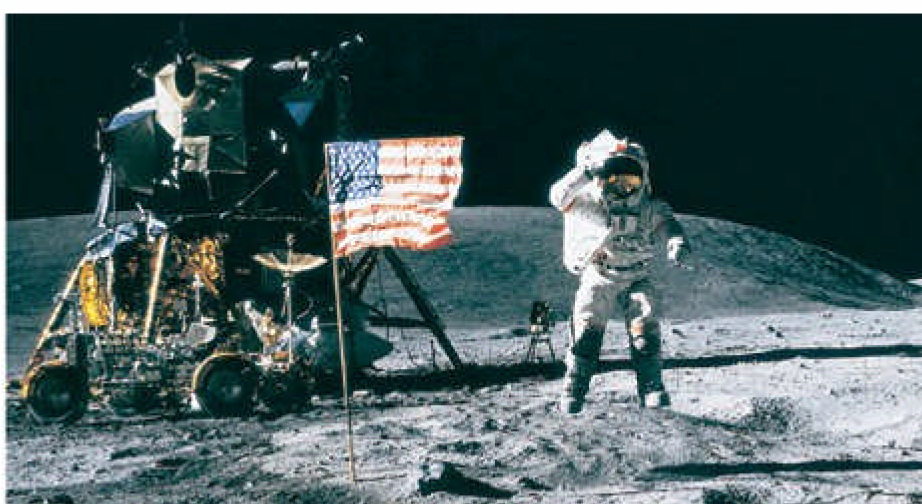


Figure 1 *Because the moon has less gravity than the Earth does, walking on the moon's surface was a very bouncy experience for the Apollo astronauts.*

The Size of Earth's Gravitational Force

Compared with all objects around you, Earth has a huge mass. Therefore, Earth's gravitational force is very large. You must apply forces to overcome Earth's gravitational force any time you lift objects or even parts of your body.

Earth's gravitational force pulls everything toward the center of Earth. Because of this force, the books, tables, and chairs in the room stay in place, and dropped objects fall to Earth rather than moving together or toward you.

Reading Check **Why must you exert a force to pick up an object?** (*See the Appendix for answers to Reading Checks.*)

CONNECTION TO Biology

Seeds and Gravity Seeds respond to gravity. The ability to respond to gravity causes seeds to send roots down and the green shoot up. But scientists do not understand how seeds can sense gravity. Plan an experiment to study how seedlings respond to gravity. After getting your teacher's approval, do your experiment and report your observations in a poster.

ACTIVITY

Newton and the Study of Gravity

For thousands of years, people asked two very puzzling questions: Why do objects fall toward Earth, and what keeps the planets moving in the sky? The two questions were treated separately until 1665 when a British scientist named Sir Isaac Newton realized that they were two parts of the same question.

The Core of an Idea

The legend is that Newton made the connection between the two questions when he watched a falling apple, as shown in **Figure 2.** He knew that unbalanced forces are needed to change the motion of objects. He concluded that an unbalanced force on the apple made the apple fall. And he reasoned that an unbalanced force on the moon kept the moon moving circularly around Earth. He proposed that these two forces are actually the same force—a force of attraction called *gravity*.

The Birth of a Law

Newton summarized his ideas about gravity in a law now known as the *law of universal gravitation*. This law describes the relationships between gravitational force, mass, and distance. The law is called *universal* because it applies to all objects in the universe.

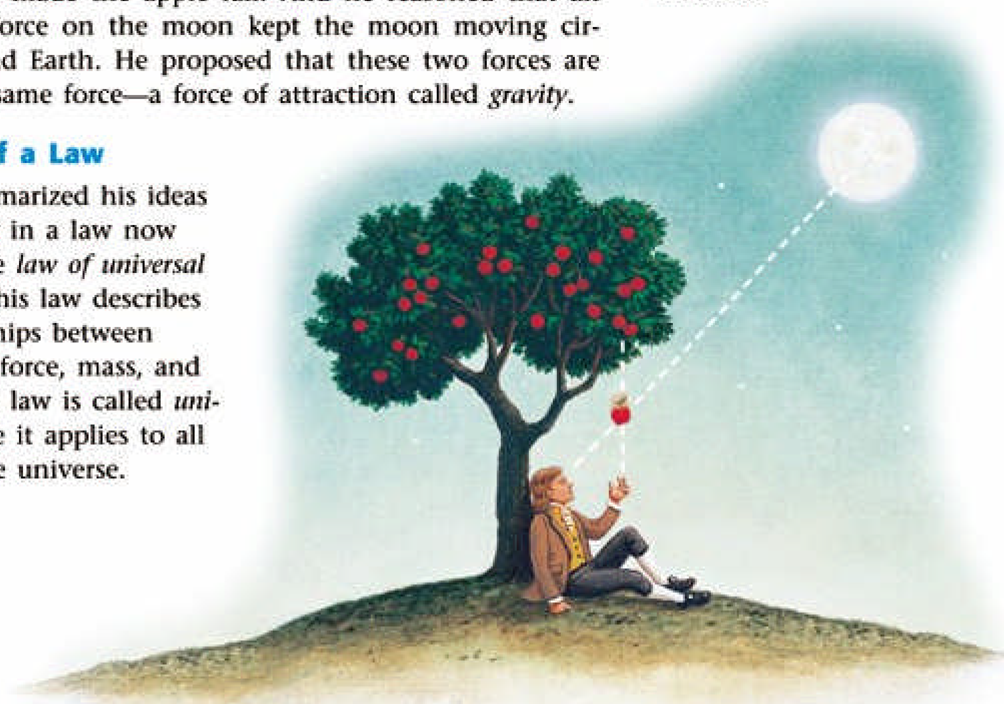


Figure 2 *Sir Isaac Newton realized that the same unbalanced force affected the motions of the apple and the moon.*

The Law of Universal Gravitation

The law of universal gravitation is the following: All objects in the universe attract each other through gravitational force. The size of the force depends on the masses of the objects and the distance between the objects. Understanding the law is easier if you consider it in two parts.

Part 1: Gravitational Force Increases as Mass Increases

Imagine an elephant and a cat. Because an elephant has a larger mass than a cat does, the amount of gravity between an elephant and Earth is greater than the amount of gravity between a cat and Earth. So, a cat is much easier to pick up than an elephant! There is also gravity between the cat and the elephant, but that force is very small because the cat's mass and the elephant's mass are so much smaller than Earth's mass. **Figure 3** shows the relationship between mass and gravitational force.

This part of the law of universal gravitation also explains why the astronauts on the moon bounce when they walk. The moon has less mass than Earth does. Therefore, the moon's gravitational force is less than Earth's. The astronauts bounced around on the moon because they were not being pulled down with as much force as they would have been on Earth.

Reading Check How does mass affect gravitational force?

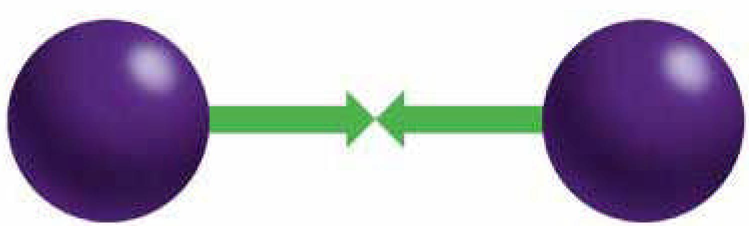
CONNECTION TO Astronomy

WRITING SKILL **Black Holes** Black holes are 4 times to 1 billion times as massive as our sun. So, the gravitational effects around a black hole are very large. The gravitational force of a black hole is so large that objects that enter a black hole can never get out. Even light cannot escape from a black hole. Because black holes do not emit light, they cannot be seen. Research how astronomers can detect black holes without seeing them. Write a one-page paper that details the results of your research.

Figure 3 **How Mass Affects Gravitational Force**

The gravitational force between objects increases as the masses of the objects increase. The arrows indicate the gravitational force between two objects. The length of the arrows indicates the strength of the force.

a Gravitational force is small between objects that have small masses.



b Gravitational force is large when the mass of one or both objects is large.

Part 2: Gravitational Force Decreases as Distance Increases

The gravitational force between you and Earth is large. Whenever you jump up, you are pulled back down by Earth's gravitational force. On the other hand, the sun is more than 300,000 times more massive than Earth. So why doesn't the sun's gravitational force affect you more than Earth's does? The reason is that the sun is so far away.

You are about 150 million kilometers (93 million miles) away from the sun. At this distance, the gravitational force between you and the sun is very small. If there were some way you could stand on the sun, you would find it impossible to move. The gravitational force acting on you would be so great that you could not move any part of your body!

Although the sun's gravitational force on your body is very small, the force is very large on Earth and the other planets, as shown in **Figure 4.** The gravity between the sun and the planets is large because the objects have large masses. If the sun's gravitational force did not have such an effect on the planets, the planets would not stay in orbit around the sun. **Figure 5** will help you understand the relationship between gravitational force and distance.

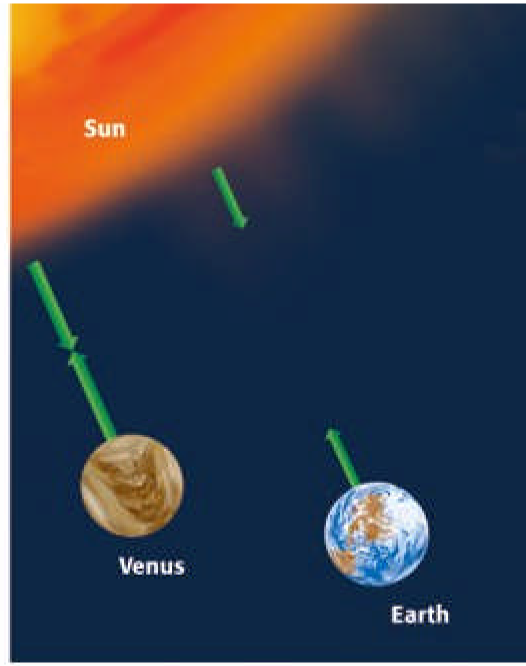


Figure 4 *Venus and Earth have approximately the same mass. But because Venus is closer to the sun, the gravitational force between Venus and the sun is greater than the gravitational force between Earth and the sun.*

Figure 5 How Distance Affects Gravitational Force

The gravitational force between objects decreases as the distance between the objects increases. The length of the arrows indicates the strength of the gravitational force between two objects.

a Gravitational force is strong when the distance between two objects is small.

b If the distance between two objects increases, the gravitational force pulling them together decreases rapidly.

Weight as a Measure of Gravitational Force

Gravity is a force of attraction between objects. **Weight** is a measure of the gravitational force on an object. When you see or hear the word *weight,* it usually refers to Earth's gravitational force on an object. But weight can also be a measure of the gravitational force exerted on objects by the moon or other planets.

CONNECTION TO Language Arts

WRITING SKILL **Gravity Story** Suppose you had a device that could increase or decrease the gravitational force of Earth. In your **science journal,** write a short story describing what you might do with the device, what you would expect to see, and what effect the device would have on the weight of objects.

The Differences Between Weight and Mass

Weight is related to mass, but they are not the same. Weight changes when gravitational force changes. **Mass** is the amount of matter in an object. An object's mass does not change. Imagine that an object is moved to a place that has a greater gravitational force—such as the planet Jupiter. The object's weight will increase, but its mass will remain the same. **Figure 6** shows the weight and mass of an astronaut on Earth and on the moon. The moon's gravitational force is about one-sixth of Earth's gravitational force.

Gravitational force is about the same everywhere on Earth. So, the weight of any object is about the same everywhere. Because mass and weight are constant on Earth, the terms *weight* and *mass* are often used to mean the same thing. This can be confusing. Be sure you understand the difference!

weight a measure of the gravitational force exerted on an object; its value can change with the location of the object in the universe

mass a measure of the amount of matter in an object

Reading Check **How is gravitational force related to the weight of an object?**

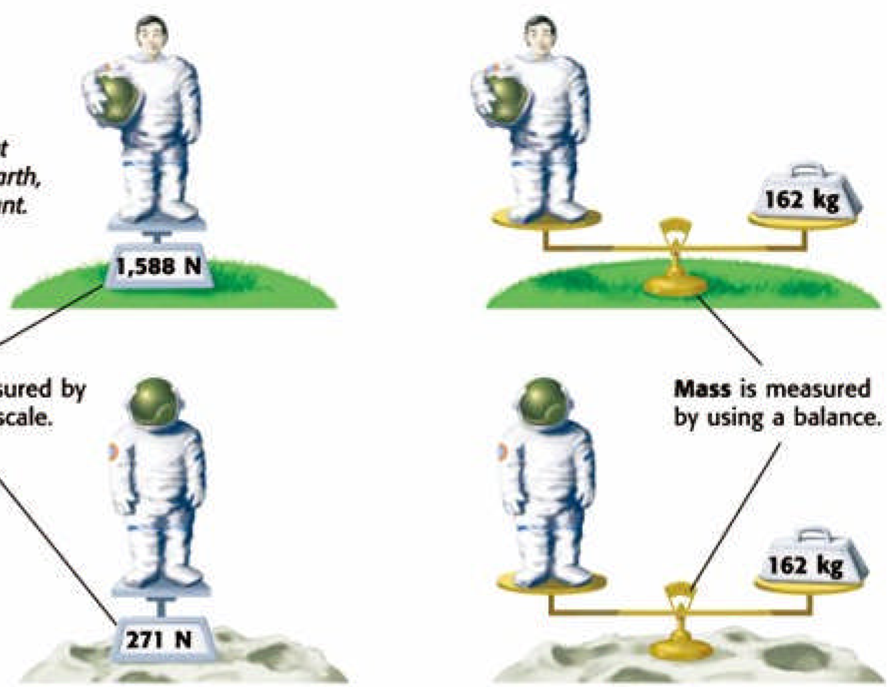


Figure 6 *The astronaut's weight on the moon is about one-sixth of his weight on Earth, but his mass remains constant.*

Units of Weight and Mass

You have learned that the SI unit of force is a newton (N). Gravity is a force, and weight is a measure of gravity. So, weight is also measured in newtons. The SI unit of mass is the kilogram (kg). Mass is often measured in grams (g) and milligrams (mg) as well. On Earth, a 100 g object, such as the apple shown in **Figure 7,** weighs about 1 N.

When you use a bathroom scale, you are measuring the gravitational force between your body and Earth. So, you are measuring your weight, which should be given in newtons. However, many bathroom scales have units of pounds and kilograms instead of newtons. Thus, people sometimes mistakenly think that the kilogram (like the pound) is a unit of weight.

Figure 7 *A small apple weighs approximately 1 N.*

SECTION Review

Summary

- Gravity is a force of attraction between objects that is due to their masses.
- The law of universal gravitation states that all objects in the universe attract each other through gravitational force.
- Gravitational force increases as mass increases.
- Gravitational force decreases as distance increases.
- Weight and mass are not the same. Mass is the amount of matter in an object. Weight is a measure of the gravitational force on an object.

Using Key Terms

1. In your own words, write a definition for the term *gravity*.
2. Use each of the following terms in a separate sentence: *mass* and *weight*.

Understanding Key Ideas

3. If Earth's mass doubled without changing its size, your weight would
   - **a.** increase because gravitational force increases.
   - **b.** decrease because gravitational force increases.
   - **c.** increase because gravitational force decreases.
   - **d.** not change because you are still on Earth.
4. What is the law of universal gravitation?
5. How does the mass of an object relate to the gravitational force that the object exerts on other objects?
6. How does the distance between objects affect the gravitational force between them?
7. Why are mass and weight often confused?

Math Skills

8. The gravitational force on Jupiter is approximately 2.3 times the gravitational force on Earth. If an object has a mass of 70 kg and a weight of 686 N on Earth, what would the object's mass and weight on Jupiter be?

Critical Thinking

9. **Applying Concepts** Your friend thinks that there is no gravity in space. How could you explain to your friend that there must be gravity in space?
10. **Making Comparisons** Explain why it is your weight and not your mass that would change if you landed on Mars.

Skills Practice Lab

Detecting Acceleration

OBJECTIVES

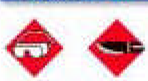
Build an accelerometer.

Explain how an accelerometer works.

MATERIALS

- container, 1 L, with watertight lid
- cork or plastic-foam ball, small
- modeling clay
- pushpin
- scissors
- string
- water

SAFETY



Have you ever noticed that you can "feel" acceleration? In a car or in an elevator, you may notice changes in speed or direction—even with your eyes closed! You are able to sense these changes because of tiny hair cells in your ears. These cells detect the movement of fluid in your inner ear. The fluid accelerates when you do, and the hair cells send a message about the acceleration to your brain. This message allows you to sense the acceleration. In this activity, you will build a device that detects acceleration. This device is called an *accelerometer* (ak SEL uhr AHM uht uhr).

Procedure

1. Cut a piece of string that reaches three-quarters of the way into the container.
2. Use a pushpin to attach one end of the string to the cork or plastic-foam ball.
3. Use modeling clay to attach the other end of the string to the center of the inside of the container lid. The cork or ball should hang no farther than three-quarters of the way into the container.
4. Fill the container with water.
5. Put the lid tightly on the container. The string and cork or ball should be inside the container.
6. Turn the container upside down. The cork should float about three-quarters of the way up inside the container, as shown at right. You are now ready to detect acceleration by using your accelerometer and completing the following steps.
7. Put the accelerometer on a tabletop. The container lid should touch the tabletop. Notice that the cork floats straight up in the water.
8. Now, gently push the accelerometer across the table at a constant speed. Notice that the cork quickly moves in the direction you are pushing and then swings backward. If you did not see this motion, repeat this step until you are sure you can see the first movement of the cork.

9. After you are familiar with how to use your accelerometer, try the following changes in motion. For each change, record your observations of the cork's first motion.

   a. As you move the accelerometer across the table, gradually increase its speed.

   b. As you move the accelerometer across the table, gradually decrease its speed.

   c. While moving the accelerometer across the table, change the direction in which you are pushing.

   d. Make any other changes in motion you can think of. You should make only one change to the motion for each trial.

Analyze the Results

1. **Analyzing Results** When you move the bottle at a constant speed, why does the cork quickly swing backward after it moves in the direction of acceleration?

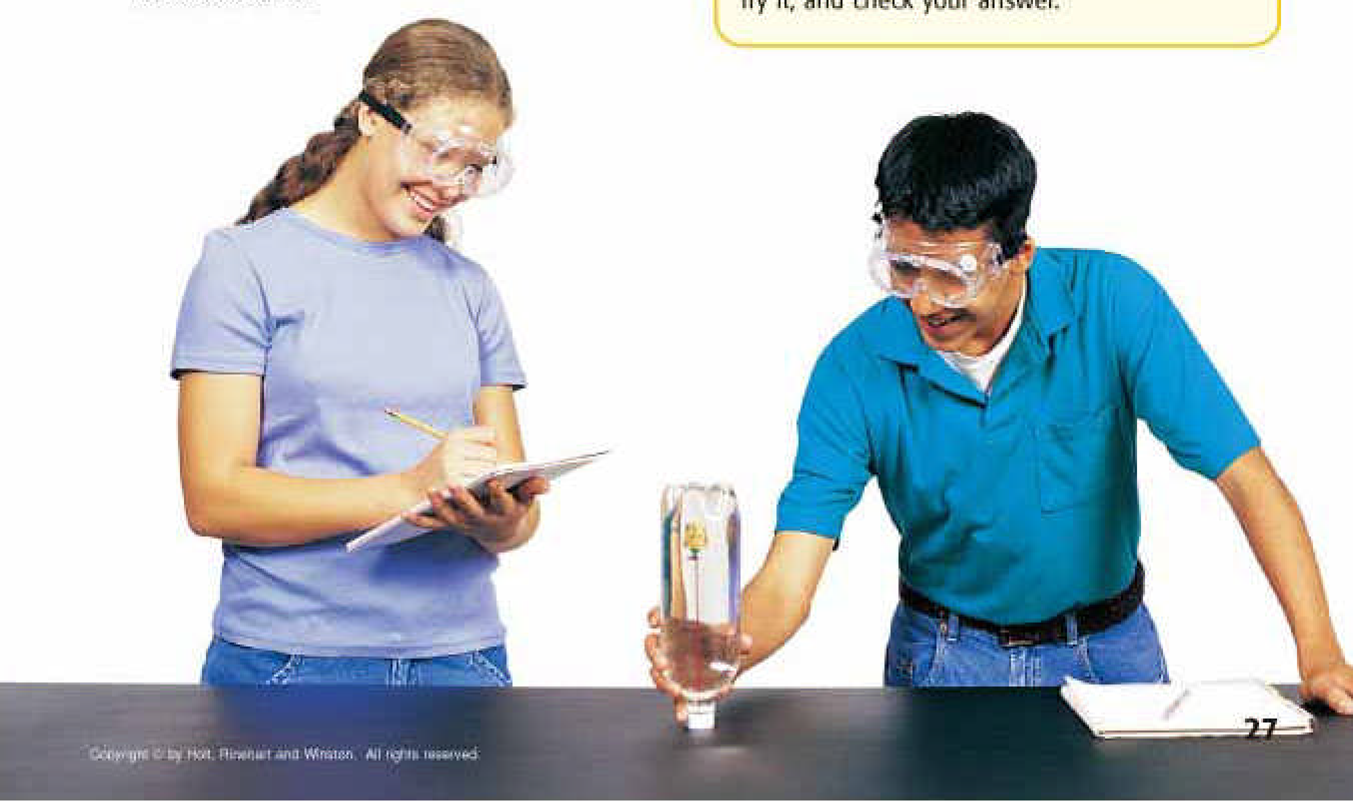
2. **Explaining Events** The cork moves forward (in the direction you were moving the bottle) when you speed up but moves backward when you slow down. Explain why the cork moves this way. (Hint: Think about the direction of acceleration.)

Draw Conclusions

3. **Making Predictions** Imagine you are standing on a corner and watching a car that is waiting at a stoplight. A passenger inside the car is holding some helium balloons. Based on what you observed with your accelerometer, what do you think will happen to the balloons when the car begins moving?

Applying Your Data

If you move the bottle in a circle at a constant speed, what do you predict the cork will do? Try it, and check your answer.



Chapter Review

USING KEY TERMS

Complete each of the following sentences by choosing the correct term from the word bank.

mass	gravity
friction	weight
speed	velocity
net force	newton

1. ___ opposes motion between surfaces that are touching.
2. The ___ is the unit of force.
3. ___ is determined by combining forces.
4. Acceleration is the rate at which ___ changes.
5. ___ is a measure of the gravitational force on an object.

UNDERSTANDING KEY IDEAS

Multiple Choice

6. If a student rides her bicycle on a straight road and does not speed up or slow down, she is traveling with a
   a. constant acceleration.
   b. constant velocity.
   c. positive acceleration.
   d. negative acceleration.

7. A force
   a. is expressed in newtons.
   b. can cause an object to speed up, slow down, or change direction.
   c. is a push or a pull.
   d. All of the above

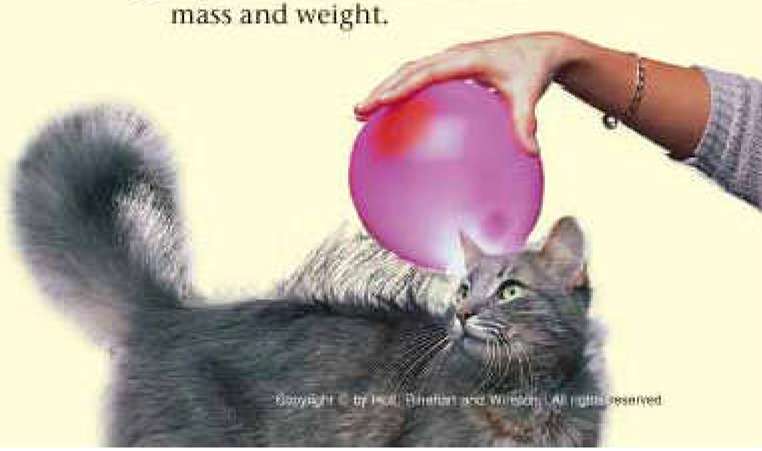
8. If you are in a spacecraft that has been launched into space, your weight would
   a. increase because gravitational force is increasing.
   b. increase because gravitational force is decreasing.
   c. decrease because gravitational force is decreasing.
   d. decrease because gravitational force is increasing.

9. The gravitational force between 1 kg of lead and Earth is ___ the gravitational force between 1 kg of marshmallows and Earth.
   a. greater than
   b. less than
   c. the same as
   d. None of the above

10. Which of the following is a measurement of velocity?
    a. 16 m east
    b. 25 m/s^2
    c. 55 m/h south
    d. 60 km/h

Short Answer

11. Describe the relationship between motion and a reference point.
12. How is it possible to be accelerating and traveling at a constant speed?
13. Explain the difference between mass and weight.



Math Skills

14 A kangaroo hops 60 m to the east in 5 s. Use this information to answer the following questions.

a. What is the kangaroo's average speed?

b. What is the kangaroo's average velocity?

c. The kangaroo stops at a lake for a drink of water and then starts hopping again to the south. Each second, the kangaroo's velocity increases 2.5 m/s. What is the kangaroo's acceleration after 5 s?

CRITICAL THINKING

15 **Concept Mapping** Use the following terms to create a concept map: *speed, velocity, acceleration, force, direction,* and *motion.*

16 **Applying Concepts** Your family is moving, and you are asked to help move some boxes. One box is so heavy that you must push it across the room rather than lift it. What are some ways you could reduce friction to make moving the box easier?

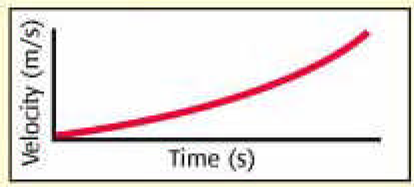
17 **Analyzing Ideas** Considering the scientific meaning of the word *acceleration,* how could using the term *accelerator* when talking about a car's gas pedal lead to confusion?

18 **Identifying Relationships** Explain why it is important for airplane pilots to know wind velocity and not just wind speed during a flight.

INTERPRETING GRAPHICS

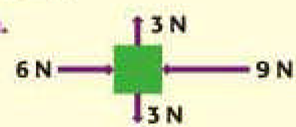
Use the figures below to answer the questions that follow.

19 Is the graph below showing positive acceleration or negative acceleration? How can you tell?



20 You know how to combine two forces that act in one or two directions. The same method can be used to combine several forces acting in several directions. Look at the diagrams, and calculate the net force in each diagram. Predict the direction each object will move.

a.



b.

c.