TIMELINE

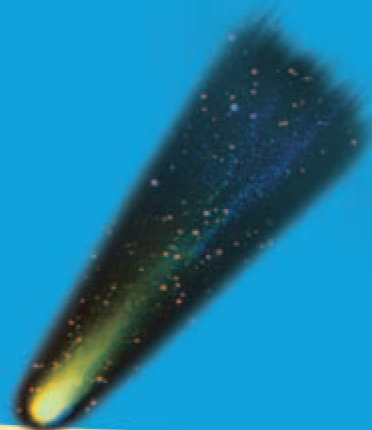
UNIT 2

Motion and Forces

It's hard to imagine a world where nothing ever moves. Without motion or forces to cause motion, life would be very dull! The relationship between force and motion is the subject of this unit. You will learn how to describe the motion of objects, how forces affect motion, and how fluids exert force. This timeline shows some events and discoveries that have occurred as scientists have worked to understand the motion of objects here on Earth and in space.

Around 250 B.C.

Archimedes, a Greek mathematician, develops the principle that bears his name. The principle relates the buoyant force on an object in a fluid to the amount of fluid the object displaces.



Around 240 B.C.

Chinese astronomers are the first to record a sighting of Halley's Comet.

1905

While employed as a patent clerk, German physicist Albert Einstein publishes his special theory of relativity. The theory states that the speed of light is constant, no matter what the reference point is.

1921

Bessie Coleman becomes the first African-American woman licensed to fly an airplane.

1947

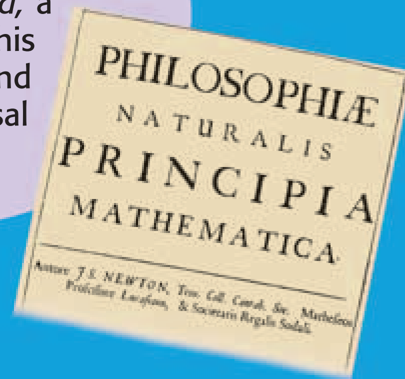
While flying a Bell X-1 rocket-powered airplane, American pilot Chuck Yeager becomes the first human to travel faster than the speed of sound.

1519

Portuguese explorer Ferdinand Magellan begins the first voyage around the world.

1687

Sir Isaac Newton, a British mathematician and scientist, publishes *Principia,* a book describing his laws of motion and the law of universal gravitation.


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

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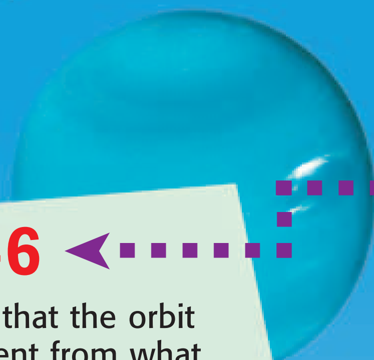


1764

In London, Wolfgang Amadeus Mozart composes his first symphony—at the age of 9.

1846

After determining that the orbit of Uranus is different from what is predicted from the law of universal gravitation, scientists discover Neptune, shown here, whose gravitational force is causing Uranus's unusual orbit.

1971

American astronaut Alan Shepard takes a break from gathering lunar data to play golf on the moon during the *Apollo 14* mission.

1990

The *Magellan* spacecraft begins orbiting Venus for a four-year mission to map the planet. The spacecraft uses the sun's gravitational force to propel it to Venus without burning much fuel.

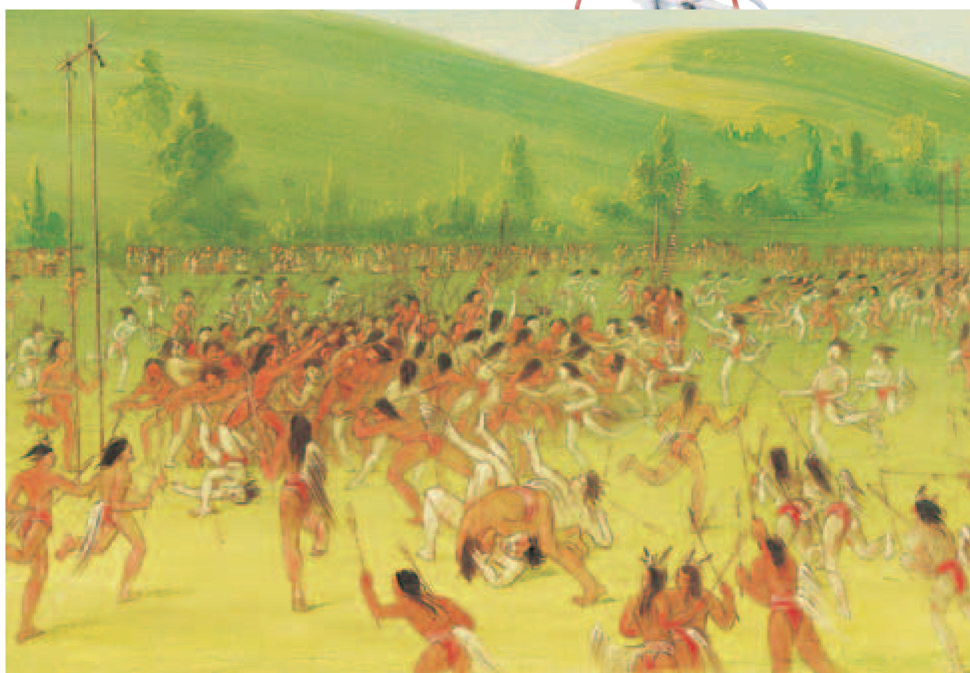
1999

NASA launches the Mars *Polar Lander* spacecraft, one of a series sent to explore Mars.

CHAPTER 5

Matter in Motion

Would You Believe ...?



Detail of *Ball Play of the Choctaw* by George Catlin, National Museum of American Art, Smithsonian Institution, Washington D.C./ Art Resouce, N.Y.

Suppose you were told that there was once a game that could be played by as few as 5 or as many as 1,000 players. The game could be played on a small field for a few hours or on a huge tract of land for several days. The game was not just for fun—in fact, it was so important that it was often used as a substitute for war. One of the few rules was that the players couldn't touch the ball with their hands—they could only catch and throw the ball using a special stick with webbing on one end. Does this game sound unbelievable? Welcome to the history of lacrosse!

Lacrosse is a game that was originally played by Native Americans, as shown above. They called the game *baggataway* (bag AT uh way), which means "little brother of war." Although lacrosse has changed much and is now played by men and women all over the world, the game still requires special webbed sticks.

Using a lacrosse stick, a player can throw the ball at speeds well over 100 km/h. At this speed, you wouldn't want to catch the ball with your bare hands—unless you wanted to experience force firsthand (no pun intended)! You see, in order to move the ball this fast, a large force (push or pull) has to be supplied. Likewise, in order to stop a ball moving this fast, another force has to be supplied. If this force were supplied by your bare hand, it would probably hurt!

Three generations of Native American lacrosse players

Even though you may have never played lacrosse, you have certainly experienced motion and the forces that cause it or prevent it. As you read this chapter, you shouldn't have any trouble thinking of your own examples.

What Do You Think?

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

1. How is motion measured?
2. What is a force?
3. How does friction affect motion?
4. How does gravity affect objects?

Investigate!

The Domino Derby

You are probably familiar with the term *speed*. Speed is the rate at which an object moves. In this activity, you will determine the factors that affect the speed of falling dominoes.

Procedure

1. Set up **25 dominoes** in a straight line. Try to keep equal spacing between the dominoes.
2. Using a **metric ruler,** measure the total length of your row of dominoes, and record it in your ScienceLog.
3. Using a **stopwatch,** time how long it takes for the entire row of dominoes to fall. Record the time in your ScienceLog.
4. Predict what would happen to that amount of time if you shortened or lengthened the distance between the dominoes. Write your predictions in your ScienceLog.
5. Repeat steps 2 and 3 several times, varying the distance between the dominoes each time. Be sure to try several spacings that are smaller and larger than in your original setup.

Analysis

6. Calculate the average speed for each trial by dividing the total distance (the length of the domino row) by the time taken to fall.
7. Comparing all the trials, how did the spacing between dominoes affect the average speed? Did your results confirm your predictions? If not, explain.

Going Further

Make a graph of your results. Explain why your graph has the shape that it does.

Section 1

Measuring Motion

NEW TERMS

motion
speed
velocity
acceleration

OBJECTIVES

- Identify the relationship between motion and a reference point.
- Identify the two factors that speed depends on.
- Determine the difference between speed and velocity.
- Analyze the relationship of velocity to acceleration.
- Interpret a graph showing acceleration.

Look around you—you're likely to see something in motion. Your teacher may be walking across the room, or perhaps a classmate is writing in her ScienceLog. You might even notice a bird flying outside a window. Even if you don't see anything moving, motion is still occurring all around you. Tiny air particles are whizzing around, the moon is circling the Earth, and blood is traveling through your veins and arteries!

Observing Motion

You might think that the motion of an object is easy to detect—you just have to observe the object. But there's more to it than that! You actually must observe 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 when compared with a reference point, the object is in **motion.** When an object is in motion, you can describe the direction of its motion with a reference direction. Typical reference directions are north, south, east, west, or up and down.

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

A moving object can also be used as a reference point. For example, if you were on the hot-air balloon shown below, you could watch a bird flying overhead and see that it was changing position in relation to your moving balloon. Furthermore, Earth itself is a moving reference point—it is moving around the sun.

Figure 1 *During the time it took for these pictures to be taken, the hot-air balloon changed position compared with a reference point–the mountain. Therefore, the balloon was in motion.*

Speed Depends on Distance and Time

You can tell that the hot-air balloon in Figure 1 traveled a certain distance in the time interval between the two photographs. By dividing the distance traveled by the time it took to travel the distance, you can find the balloon's rate of motion. The rate at which an object moves is its **speed.** Speed depends on the distance traveled and the time taken to travel that distance. Suppose the time interval between the pictures was 10 seconds and the balloon traveled 50 m in that time. The speed (distance divided by time) 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, feet per second, and miles per hour are other units commonly used to express speed.

Determining Average Speed Most of the time, objects do not travel at constant speed. For example, you probably do not travel at a constant speed as you walk from one class to the next. Because objects do not often travel at a constant speed, it is useful to calculate an object's *average speed* using the following equation:

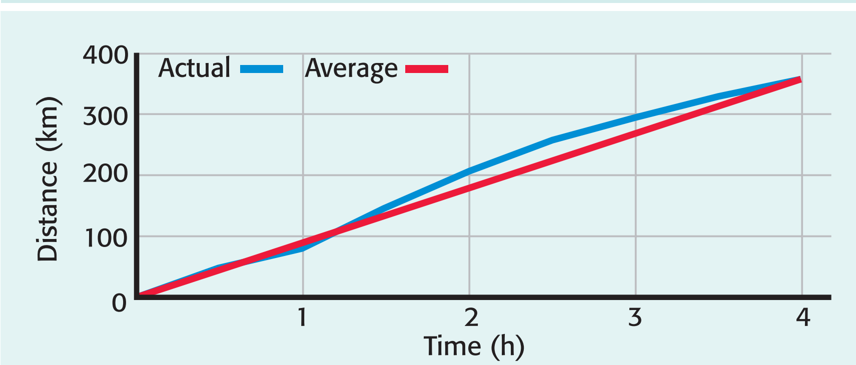
$$\text{Average speed} = \frac{\text{total distance}}{\text{total time}}$$

Suppose a person drives from one city to another. The blue line in the graph below shows the distance traveled every hour. Notice that the distance traveled every hour is different. This is because the speed (distance/time) is not constant—the driver changes speed often because of weather, traffic, or varying speed limits. The average speed can be calculated by adding up the total distance and dividing it by the total time:

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

The red line shows the average distance traveled each hour. The slope of this line is the average speed.

A Graph Showing Speed



BRAIN FOOD

The list below shows a comparison of some interesting speeds:

Cockroach . . . . . . 1.25 m/s
Kangaroo . . . . 15 m/s
Cheetah (the fastest land animal) . . . . 27 m/s
Sound . . . . 330 m/s
Space shuttle . . . 10,000 m/s
Light . . . . . 300,000,000 m/s

MATHBREAK

Calculating Average Speed

Practice calculating average speed in the problems listed below:

1. If you take a walk for 1.5 hours and travel 7.5 km, what is your average speed?
2. A bird flies at a speed of 15 m/s for 10 s, 20 m/s for 10 s, and 25 m/s for 5 s. What is the bird's average speed?

Velocity: Direction Matters

Here's a riddle for you: Two birds leave the same tree at the same time. They both fly at 10 km/h for 1 hour, 15 km/h for 30 minutes, and 5 km/h for 1 hour. Why don't they end up at the same destination?

Have you figured it out? Even though the birds traveled at the same speeds for the same amounts of time, they did not end up at the same place because they went in different directions. In other words, the birds had different velocities. The speed of an object in a particular direction is the object's **velocity** (vuh LAHS uh tee).

Figure 2 *The speeds of these cars may be similar, but their velocities are different because they are going in different directions.*

Be careful not to confuse the terms *speed* and *velocity;* they do not mean the same thing. Because velocity must include direction, it would not be correct to say that an airplane's velocity is 600 km/h. However, you could say the plane's velocity is 600 km/h south. Velocity always includes a reference direction. **Figure 2** further illustrates the difference between speed and velocity.

Velocity Changes as Speed or Direction Changes 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 along a straight line. An object's velocity will change if either its speed or direction changes. For example, if a bus traveling at 15 m/s south speeds up to 20 m/s, a change in velocity has occurred. But a change in velocity also occurs if the bus continues to travel at the same speed but changes direction to travel east.

Self-Check

Which of the following are examples of velocity?

1. 25 m/s forward
2. 1,500 km/h
3. 55 m/h south
4. all of the above

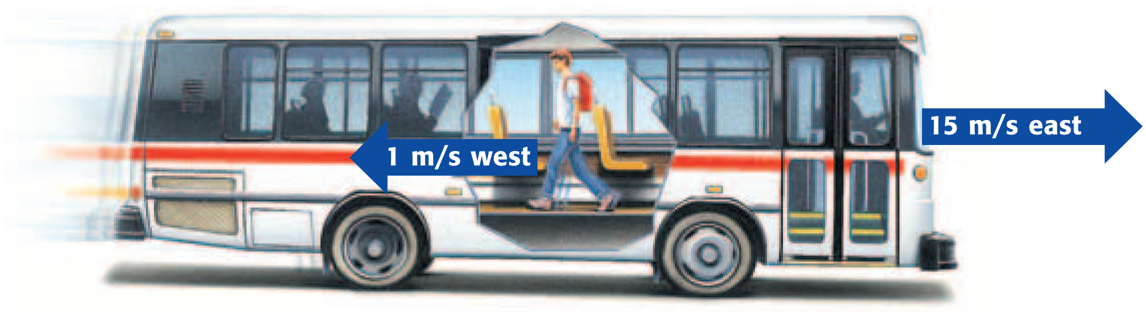
(See page 596 to check your answer.)

Combining Velocities If you're riding in the bus traveling east at 15 m/s, you and all 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 it is moving. Are you still moving at the same velocity as the bus? No! **Figure 3** shows how you can combine velocities to determine the *resultant velocity.*

Figure 3 Determining 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

REVIEW

1. What is a reference point?
2. What two things must you know to determine speed?
3. What is the difference between speed and velocity?
4. **Applying Concepts** Explain why it is important to know a tornado's velocity and not just its speed.

BRAIN FOOD

The space shuttle is always launched in the same direction that the Earth rotates, thus taking advantage of the Earth's rotational velocity (over 1,500 km/h east). This allows the shuttle to use less fuel to reach space than if it had to achieve such a great velocity on its own.

Acceleration: The Rate at Which Velocity Changes

Imagine that you are skating very quickly down the sidewalk on in-line skates. Up ahead, you see a large rock in your path. You slow down and swerve at the same time to keep from hitting the rock. A neighbor out in his yard exclaims, "That was great acceleration! I'm amazed that you could slow down and turn so quickly without falling!" You're puzzled. Doesn't *accelerate* mean to speed up—like when your parent presses the accelerator pedal in the car? But you didn't speed up—you slowed down and turned. So why did your neighbor say that you accelerated?

Although the word *accelerate* is commonly used in everyday language to mean "speed up," there's more to its meaning scientifically. **Acceleration** (ak SEL uhr AY shun) is the rate at which velocity changes. To *accelerate* means to change velocity. You just learned that velocity changes if speed changes, direction changes, or both. So your neighbor was right! Your speed and direction changed, so you accelerated.

Keep in mind that acceleration is not just the amount velocity changes. Acceleration tells you *how fast* velocity changes. The faster velocity changes, the greater the acceleration is.

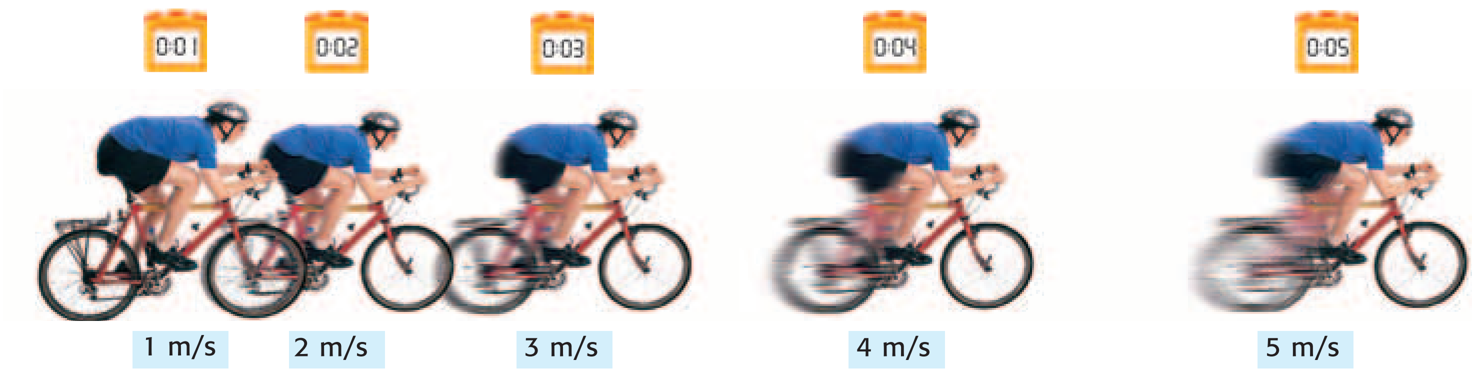
Calculating Acceleration Acceleration is calculated using the following equation:

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

The unit of measurement for velocity is meters per second (m/s), and the unit for time is seconds (s). Therefore, the unit of measurement for acceleration is meters per second per second (m/s/s).

Suppose you get on your bicycle and accelerate southward at a rate of 1 m/s/s. (Like velocity, acceleration has size and direction.) This means that every second, your southward velocity increases at a rate of 1 m/s, as shown on the next page.

Figure 4 **Acceleration at 1 m/s/s South**



After 1 second, you have a velocity of 1 m/s south, as shown in **Figure 4.** After 2 seconds, you have a velocity of 2 m/s south. After 3 seconds, you have a velocity of 3 m/s south, and so on. If your final velocity after 5 seconds is 5 m/s south, your acceleration can be calculated as follows:

$$\text{Acceleration} = \frac{5\text{ m/s} - 0\text{ m/s}}{5\text{ s}} = 1\text{ m/s/s south}$$

You can practice calculating acceleration by doing the MathBreak shown here.

Examples of Acceleration In the example above, your velocity was originally zero and then it increased. Because your velocity changed, you accelerated. Acceleration in which velocity increases is sometimes called *positive acceleration.*

Acceleration also occurs when velocity decreases. In the skating example, you accelerated because you slowed down. Acceleration in which velocity decreases is sometimes called *negative acceleration* or *deceleration.*

Remember that velocity has direction, so velocity will change if your direction changes. Therefore, a change in direction is acceleration, even if there is no change in speed. Some more examples of acceleration are shown in the chart below.

Example of Acceleration	How Velocity Changes
A plane taking off	Increase in speed
A car stopping at a stop sign	Decrease in speed
Jogging on a winding trail	Change in direction
Wind gusting	Increase in speed
Driving around a corner	Change in direction
Standing at Earth's equator	Change in direction

MATH BREAK

Calculating Acceleration

Use the equation shown on the previous page to do the following problems. Be sure to express your answer in m/s/s and include direction.

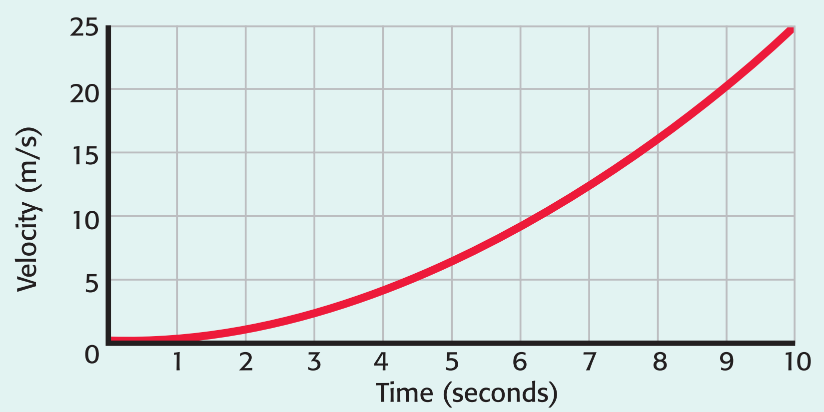
1. A plane passes over Point A with a velocity of 8,000 m/s north. Forty seconds later it passes over Point B at a velocity of 10,000 m/s north. What is the plane's acceleration from A to B?
2. A coconut falls from the top of a tree and reaches a velocity of 19.6 m/s when it hits the ground. It takes 2 seconds to reach the ground. What is the coconut's acceleration?

Figure 5 *The blades of this windmill are constantly changing direction as they travel in a circle. Thus, centripetal acceleration is occurring.*

Circular Motion: Continuous Acceleration Does it surprise you to find out that standing at Earth's equator is an example of acceleration? After all, you're not changing speed, and you're not changing direction . . . or are you? In fact, 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 acceleration is occurring. The acceleration that occurs in circular motion is known as *centripetal* (sen TRIP uht uhl) *acceleration.* Another example of centripetal acceleration is shown in **Figure 5.**

Recognizing Acceleration on a Graph Suppose that you have just gotten on a roller coaster. The roller coaster moves slowly up the first hill until it stops at the top. Then you're off, racing down the hill! The graph below shows your velocity for the 10 seconds coming down the hill. You can tell from this graph that your acceleration is positive because your velocity increases as time passes. Because the graph is not a straight line, you can also tell that your acceleration is not constant for each second.

A Graph Showing Acceleration



LabBook

Use this simple device to "see" acceleration on page 537 of the LabBook.

REVIEW

1. What is acceleration?
2. Does a change in direction affect acceleration? Explain your answer.
3. **Interpreting Graphics** How do you think a graph of deceleration would differ from the graph shown above? Explain your reasoning.

Section 2

What Is a Force?

NEW TERMS

force
net force
newton (N)

OBJECTIVES

- Give examples of different kinds of forces.
- Determine the net force on an object.
- Compare balanced and unbalanced forces.

You often hear the word *force* in everyday conversation:

"That storm had a lot of force!"
"Our basketball team is a force to be reckoned with."
"A flat tire forced me to stop riding my bicycle."
"The inning ended with a force-out at second base."

But what exactly is a force? In science, a **force** is simply a push or a pull. All forces have both size and direction.

Forces are everywhere. In fact, any time you see something moving, you can be sure that its motion was created by a force. Scientists measure force with a unit called the **newton (N).** The more newtons, the greater the force.

Forces Act on Objects

All forces are exerted by one object on another object. 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. However, just because a force is being exerted by one object on another doesn't mean that motion will occur. For example, you are probably sitting on a chair as you read this. But the force you are exerting on the chair does not cause the chair to move. That's because the Earth is also exerting a force on the chair. In most cases, it is easy to determine where the push or pull is coming from, as shown in **Figure 6.**

Figure 6 *It is obvious that the bulldozer is exerting a force on the pile of soil. But did you know that the pile of soil also exerts a force, even when it is just sitting on the ground?*

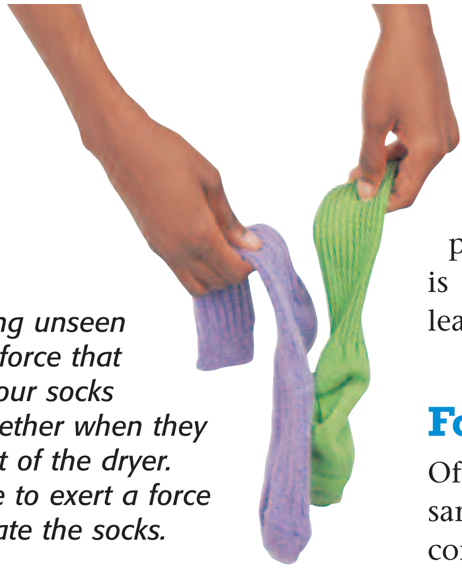


Figure 7 *Something unseen exerts a force that makes your socks cling together when they come out of the dryer. You have to exert a force to separate the socks.*

However, it is not always so easy to tell what is exerting a force or what is receiving a force, as shown in **Figure 7.** You cannot see what exerts the force that pulls magnets to refrigerators, and the air you breathe is an unseen receiver of a force called *gravity.* You will learn more about gravity later in this chapter.

Forces in Combination

Often more than one force is exerted on an object at the same time. The **net force** is the force that results from combining all the forces exerted on an object. So how do you determine the net force? The examples below can help you answer this question.

Forces in the Same Direction Suppose you and a friend are asked to move a piano for the music teacher. To do this, you pull on one end of the piano, and your friend pushes on the other end. Together, your forces add up to enough force to move the piano. This is because your forces are in the same direction. **Figure 8** shows this situation. Because the forces are in the same direction, they can be added together to determine the net force. In this case, the net force is 45 N, which is plenty to move a piano—if it is on wheels, that is!

Figure 8 *When the forces are in the same direction, you add the forces together to determine the net force.*

Net force
25 N + 20 N = 45 N
to the right

Forces in Different Directions Consider two dogs playing tug of war with a short piece of rope. Each is exerting a force, but in opposite directions. **Figure 9** shows this scene. Notice that the dog on the left is pulling with a force of 10 N and the dog on the right is pulling with a force of 12 N. Which dog do you think will win the tug of war?

Because the forces are in opposite directions, the net force is determined 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!

across the sciences CONNECTION

Every moment, forces in several directions are exerted on the Golden Gate Bridge. For example, Earth exerts a powerful downward force on the bridge while elastic forces pull and push portions of the bridge up and down. To learn how the bridge stands up to these forces, turn to page 135.

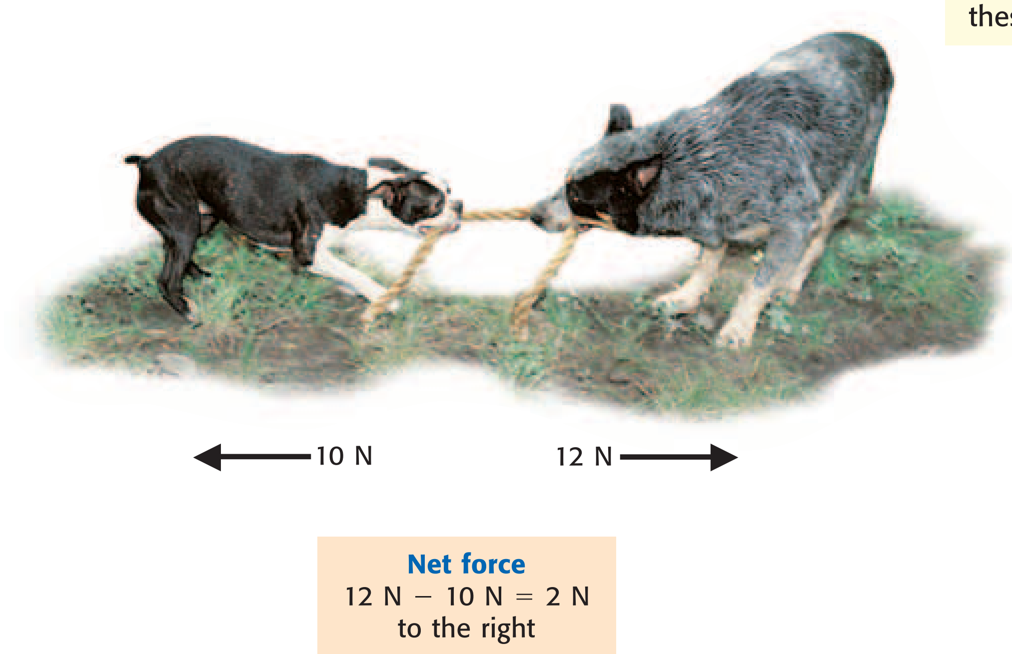


Figure 9 *When the forces are in different directions, you subtract the smaller force from the larger force to determine the net force.*

Unbalanced and Balanced Forces

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

Unbalanced Forces Produce a Change in Motion In the examples shown in Figures 8 and 9, the net force on the object is greater than zero. When the net force on an object is not zero, the forces on the object are *unbalanced.* Unbalanced forces produce a change in motion (acceleration). In the two previous examples, the receivers of the forces—the piano and the rope—move. Unbalanced forces are necessary to cause a nonmoving object to start moving.

Self-Check

What is the net force when you combine a force of 7 N north with a force of 5 N south? *(See page 596 to check your answer.)*

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

Keep in mind that an object can continue to move even when the unbalanced forces are removed. A soccer ball, for example, receives an unbalanced force when it is kicked. However, the ball continues to roll along the ground long after the force of the kick has ended.

Balanced Forces Produce No Change in Motion When the forces applied to an object produce a net force of zero, the forces are *balanced.* Balanced forces do not cause a nonmoving object to start moving. Furthermore, balanced forces will not cause a change in the motion of a moving object.

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 an elastic force due to tension that pulls the light up. A bird's nest in a tree and a hat resting on your head are also examples of objects with only balanced forces acting on them. **Figure 10** shows another case where the forces on an object are balanced. Because all the forces are balanced, the house of cards does not move.

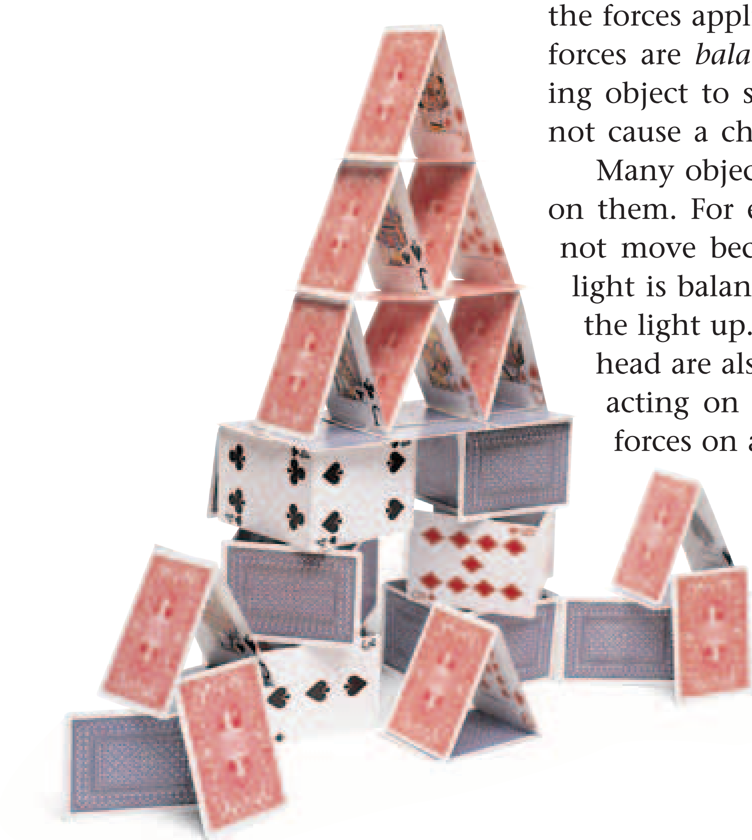
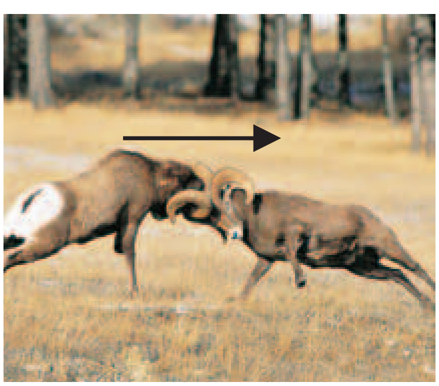


Figure 10 *The forces on this house of cards are balanced. An unbalanced force on one of the cards would cause motion—and probably a mess!*

REVIEW



1. Give four examples of a force being exerted.
2. Explain the difference between balanced and unbalanced forces and how each affects the motion of an object.
3. **Interpreting Graphics** In the picture at left, two bighorn sheep push on each other's horns. The arrow shows the direction the two sheep are moving. Describe the forces the sheep are exerting and how the forces combine to produce the sheep's motion.

Section 3

Friction: A Force That Opposes Motion

NEW TERMS

friction

OBJECTIVES

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

Picture a warm summer day. You are enjoying the day by wearing shorts and tossing a ball with your friends. By accident, one of your friends tosses the ball just out of your reach. You have to make a split-second decision to dive for it or not. You look down and notice that if you dove for it, you would most likely slide across pavement rather than the surrounding grass. What would you decide?

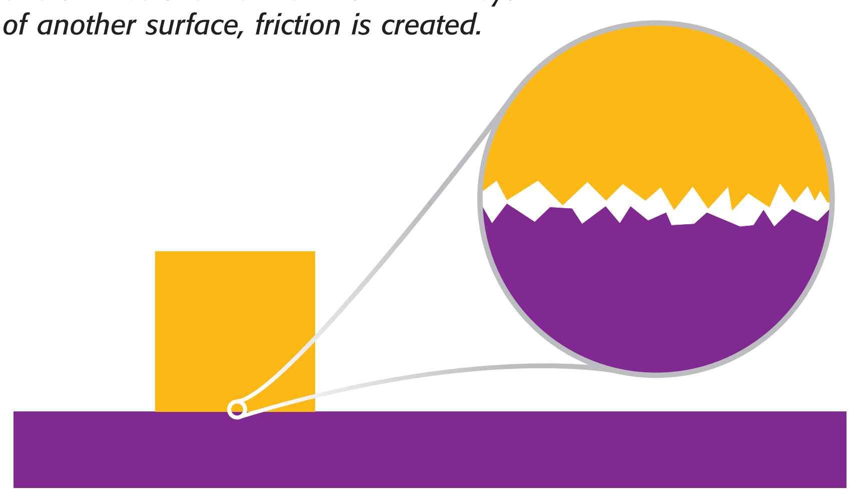
Unless you enjoy scraped knees, you probably would not want to slide on the pavement. The painful difference between sliding on grass and sliding on pavement has to do with friction. **Friction** is a force that opposes motion between two surfaces that are touching.

The Source of Friction

Friction occurs because the surface of any object is rough. Even surfaces that look or feel very smooth are actually 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 11.** This contact causes friction even when the surfaces appear smooth.

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

Figure 11 *When the hills and valleys of one surface stick to the hills and valleys of another surface, friction is created.*



QuickLab

The Friction 500

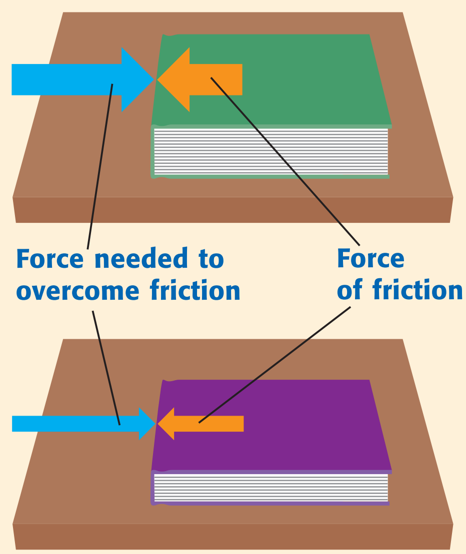
1. Make a short ramp out of a **piece of cardboard** and **one or two books** on a table.
2. Put a **toy car** at the top of the ramp and let go. If necessary, adjust the ramp height so that your car does not roll off the table.
3. Put the car at the top of the ramp again and let go. Record the distance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

Rougher Surfaces Create More Friction Rougher surfaces have more microscopic hills and valleys. Thus, the rougher the surface, the greater the friction. Think back to the example on the previous page. Pavement is much rougher than grass. Therefore, more friction is produced when you slide on the pavement than when you slide on grass. This increased friction is more effective at stopping your sliding, but it is also more painful! On the other hand, if the surfaces are smooth, there is less friction. If you were to slide on ice instead of on grass, your landing would be even more comfortable—but also much colder!

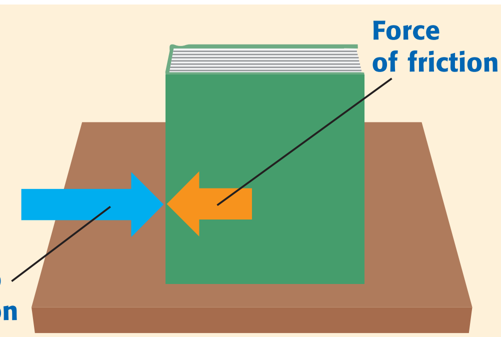
Greater Force Creates More Friction The amount of friction also depends on the force pushing the surfaces together. If this force is increased, the hills and valleys of the surfaces can come into closer contact. This causes the friction between the surfaces to increase. Less massive objects exert less force on surfaces than more massive objects do, as illustrated in **Figure 12.** However, changing the amounts of the surfaces that touch does not change the amount of friction.

Figure 12 Force and Friction

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



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



Types of Friction

The friction you observe when sliding books across a tabletop is called sliding friction. Other types of friction include rolling friction, fluid friction, and static friction. As you will learn, the name of each type of friction is a big clue as to the conditions where it can be found.

Sliding Friction If you push an eraser across your desk, the eraser will move for a short distance and then stop. This is an example of *sliding friction*. Sliding friction is very effective at opposing the movement of objects and is the force that causes the eraser to stop moving. You can feel the effect of sliding friction when you try to move a heavy dresser by pushing it along the floor. You must exert a lot of force to overcome the sliding friction, as shown in **Figure 13.**

You use sliding friction when you go sledding, when you apply the brakes on a bicycle or a car, or when you write with a piece of chalk.

Rolling Friction If the same heavy dresser were on wheels, you would have an easier time moving it. The friction between the wheels and the floor is an example of *rolling friction*. The force of rolling friction is usually less than the force of sliding friction. Therefore, it is generally easier to move objects on wheels than it is to slide them along the floor, as shown at right.

Rolling friction is an important part of almost all means of transportation. Anything with wheels—bicycles, in-line skates, cars, trains, and planes—uses rolling friction between the wheels and the ground to move forward.

Figure 13 **Comparing Sliding Friction and Rolling Friction**

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

It is easier to move a heavy piece of furniture if you put it on wheels. The force of rolling friction is smaller and easier to overcome.

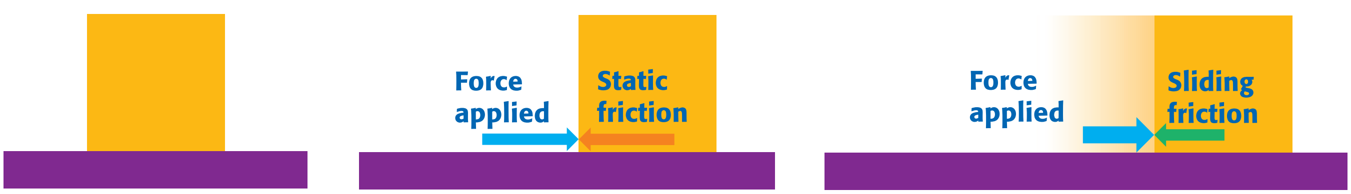
Figure 14 *Swimming provides a good workout because you must exert force to overcome fluid friction.*

Fluid Friction Why is it harder to walk on a freshly mopped floor than on a dry floor? The reason is that on the wet floor the sliding friction between your feet and the floor is replaced by *fluid friction* between your feet and the water. In this case, fluid friction is less than sliding friction, so the floor is slippery. You may think of *fluid* as another name for liquid, but fluids include liquids and gases; water, milk, and air are all fluids.

Fluid friction opposes the motion of objects traveling through a fluid, as illustrated in **Figure 14.** For example, fluid friction between air and a fast moving car is the largest force opposing the motion of the car. You can observe this friction by holding your hand out the window of a moving car.

Static Friction When a force is applied to an object but does not cause the object to move, *static friction* occurs. The object does not move because the force of static friction balances the force applied. Static friction disappears as soon as an object starts moving, and then another type of friction immediately occurs. Look at **Figure 15** to understand when static friction affects an object.

Figure 15 **Static Friction**



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

b If a small force—shown in blue—is exerted on the block, the block does not move because the force of static friction—shown in orange—exactly balances the force applied.

c When the force exerted on the block is greater than the force of static friction, the block starts moving. Once the block starts moving, all static friction is gone, but work must be done against sliding friction—shown in green.

Self-Check

What type of friction was involved in the imaginary situation at the beginning of this section? *(See page 596 to check your answer.)*

Friction Can Be Harmful or Helpful

Think about how friction affects a car. Without friction, the tires would not be able to push off the ground and move the car forward, the brakes would not work to stop the car, and you would not even be able to grip the door handle to get inside! Without friction, a car is useless.

However, friction can cause problems in a car too. Friction between moving engine parts increases their temperature and causes the parts to wear down. Coolant must be regularly added to the engine to keep it from overheating from friction, and engine parts need to be changed as they wear out.

Friction is both harmful and helpful to you and the world around you. Without friction, you could not do homework, play games, or even walk. Friction between your pencil and your paper is necessary for the pencil to leave a mark. Without friction, balls and other sports equipment would slip from your fingers when you tried to pick them up, and you would just slip and fall when you tried to walk. But friction is also responsible for putting holes in your socks and in the knees of your bluejeans. Friction by wind and water contributes to the erosion of the topsoil that nourishes plants. Because friction can be both harmful and helpful, it is sometimes necessary to reduce or increase friction.

LabBook

Have some fun with friction! Investigate three types of friction on page 540 of the LabBook.

Some Ways to Reduce Friction One way to reduce friction is to use lubricants. *Lubricants* (LOO bri kuhnts) are substances that are applied to surfaces to reduce the friction between them. Some examples of common lubricants are motor oil, wax, and grease. **Figure 16** shows why lubricants are important to maintaining car parts.

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

BRAIN FOOD

Lubricants are usually liquids, but they can be solids or gases too. Graphite is a shiny black solid that is used in pencils. Graphite dust is very slippery and is often used as a lubricant for ball bearings in bicycle and skate wheels. An example of a gas lubricant is the air that comes out of the tiny holes of an air-hockey table.

Figure 16 *Motor oil is used as a lubricant in car engines. Without oil, engine parts would wear down quickly, as the connecting rod on the bottom has.*

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 it smoother and more comfortable to sit on because the friction between your leg and the bench is reduced.

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, you can ensure that your magazine will not blow away at the park by putting a heavy rock on it. The added mass of the rock increases the friction between the magazine and the ground. Or if you are sanding a piece of wood, you can sand the wood faster by pressing harder on the sandpaper. **Figure 17** shows another situation where friction is increased by pushing on an object.

Figure 17 *No one enjoys cleaning pans with baked-on food! To make this chore pass quickly, press down with the scrubber to increase friction.*

REVIEW

1. Explain why friction occurs.
2. Name two ways in which friction can be increased.
3. Give an example of each of the following types of friction: sliding, rolling, and fluid.
4. **Applying Concepts** Name two ways that friction is harmful and two ways that friction is helpful to you when riding a bicycle.

The tire shown here was used for more than 80,000 km. What effect did friction have on the rubber? What kind of friction is mainly responsible for the tire's appearance? Why are car owners warned to change their car tires after using them for several thousand kilometers?

Section 4

Gravity: A Force of Attraction

NEW TERMS

gravity
mass
weight

OBJECTIVES

- Define *gravity.*
- State the law of universal gravitation.
- Describe the difference between mass and weight.

If you watch videotape of astronauts on the moon, you will notice that when the astronauts tried to walk on the lunar surface, they bounced around like beach balls instead.

Why did the astronauts—who were wearing heavy spacesuits—bounce so easily on the moon (as shown in **Figure 18**), while you must exert effort to jump a few centimeters off Earth's surface? The answer has to do with gravity. **Gravity** is a force of attraction between objects that is due to their masses. In this section, you will learn about gravity and the effects it has on objects.

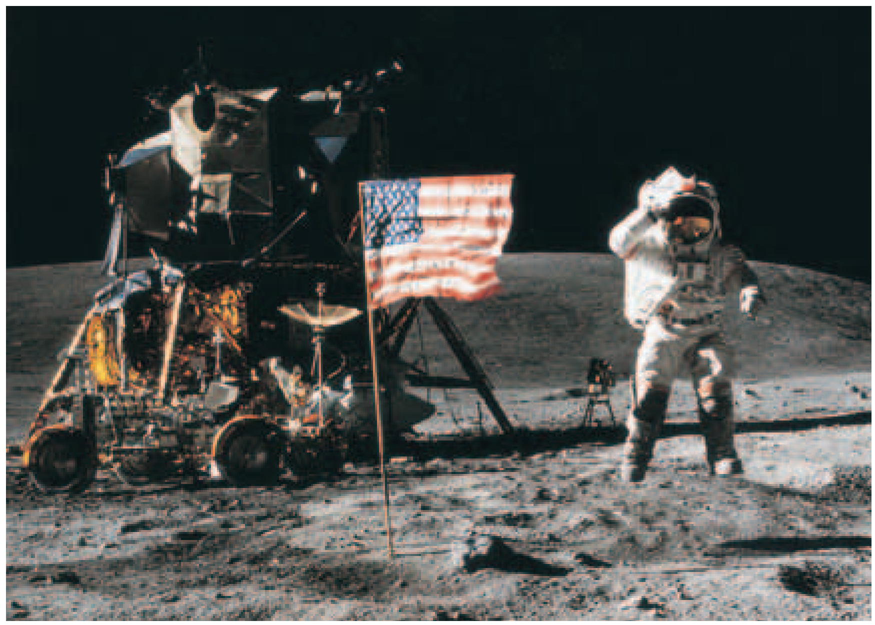


Figure 18 *Because gravity is less on the moon than on Earth, walking on the moon's surface was a very bouncy experience for the Apollo astronauts.*

All Matter Is Affected by Gravity

All matter has mass. Gravity is a result of mass. Therefore, all matter experiences 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 an attraction 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.

life science CONNECTION

Scientists think seeds can "sense" gravity. The ability to sense gravity is what causes seeds to always send roots down and the green shoot up. But scientists do not understand just *how* seeds do this. Astronauts have grown seedlings during space shuttle missions to see how seeds respond to changes in gravity. So far, there are no definite answers from the results of these experiments.

Earth's Gravitational Force Is Large Compared with all the objects around you, Earth has an enormous mass. Because it is so massive, Earth's gravitational force is very large. You must constantly apply forces to overcome Earth's gravitational force. In fact, any time you lift objects or parts of your body, you are resisting this force.

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

Self-Check

What is gravity? *(See page 596 to check your answer.)*

The Law of Universal Gravitation

For thousands of years, two of the most puzzling scientific questions were "Why do objects fall toward Earth?" and "What keeps the planets in motion in the sky?" The two questions were treated as separate topics until Sir Isaac Newton (1642–1727) realized that they were two parts of the same question. Newton was a British scientist whose work on forces and light was very important to the development of science.

Legend has it that Newton made the connection between the two questions when he observed a falling apple during a summer night, as shown in **Figure 19.** He knew that unbalanced forces are necessary to move or change the motion of objects. He concluded that there had to be an unbalanced force on the apple to make it fall, just as there had to be an unbalanced force on the moon to keep it moving in a circle around Earth. He realized that the force pulling the apple to Earth and the force pulling the moon in a circular path around Earth are the same force—a force of attraction called gravity.

Newton generalized his observations on gravity in a law now known as the *law of universal gravitation*. The law of universal gravitation describes the relationships between gravitational force, mass, and distance. It is called universal because it applies to all objects in the universe, from the tiniest speck of dust to the largest star. In fact, gravitational force between gas and dust particles in space sometimes plays a part in the formation of stars and planets.

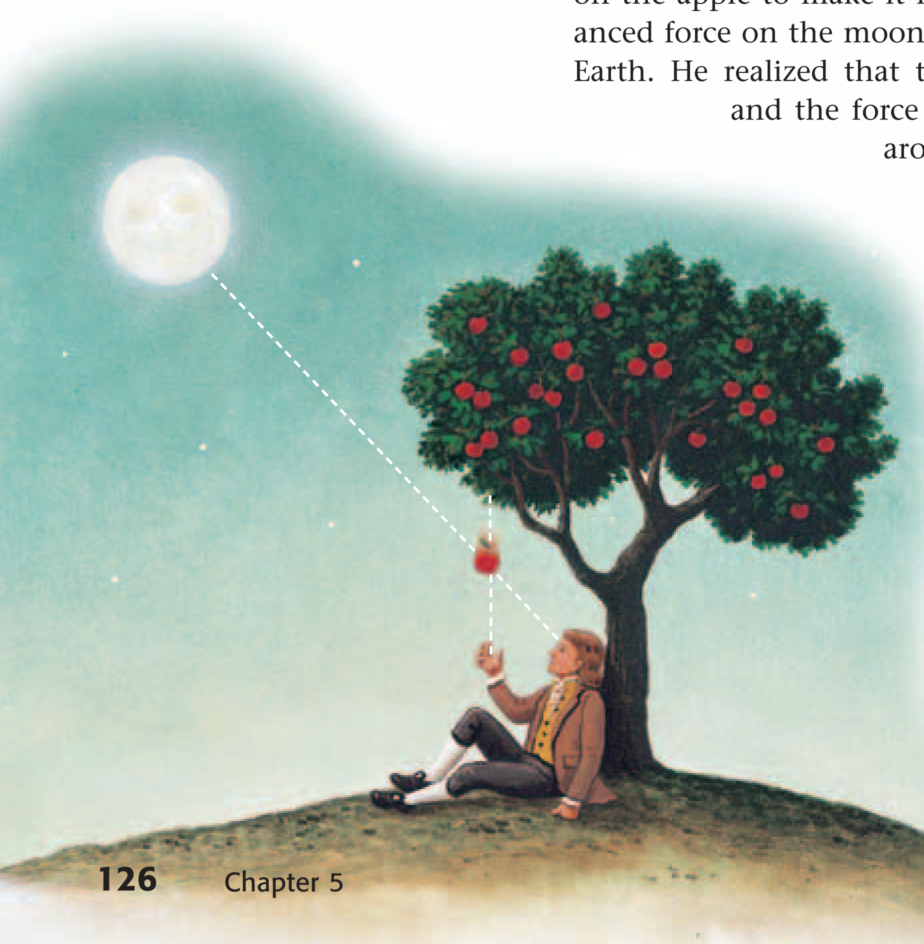


Figure 19
Newton Makes the Connection

The law of universal gravitation states the following: All objects in the universe attract each other through gravitational force. As shown in **Figure 20,** the size of the force depends on the masses of the objects and the distance between them.

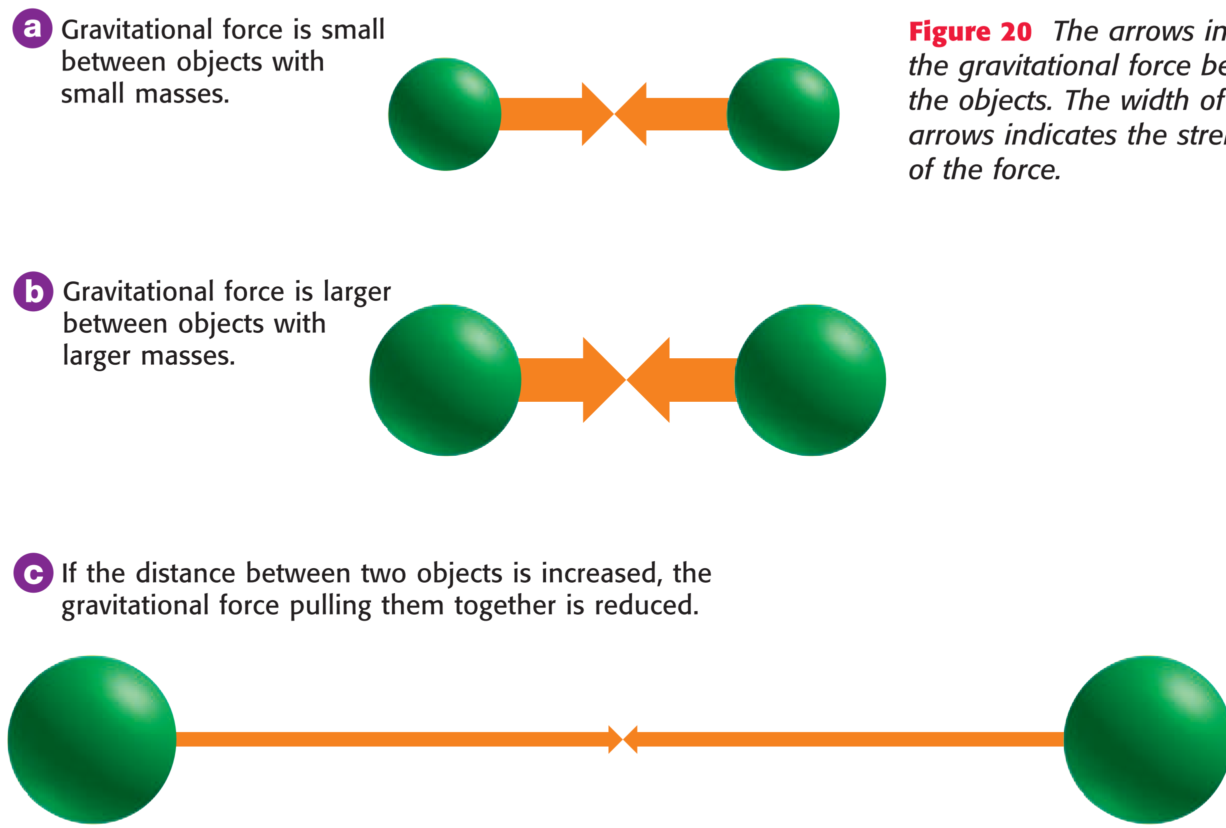


Figure 20 *The arrows indicate the gravitational force between the objects. The width of the arrows indicates the strength of the force.*

The law of universal gravitation can also be expressed mathematically. If two objects have masses m_1 and m_2 and are separated by a distance r, then the gravitational force can be calculated according to the following equation:

$$F = G \times \frac{m_1 \times m_2}{r^2}$$

G is a universal constant called the constant of universal gravitation. It has been measured experimentally and its value is the following:

$$G = 6.673 \times 10^{-11} \frac{\mathrm{N{\bullet}m^2}}{\mathrm{kg^2}}$$

Part 1: Gravitational Force Increases as Mass Increases

The moon has less mass than Earth. Therefore, the moon's gravitational force is less than Earth's. Remember the astronauts on the moon? They bounced around as they walked because they were not being pulled down with as much force as they would have been on Earth.

astronomy CONNECTION

Black holes are formed when massive stars collapse. Black holes are 10 times to 1 billion times more massive than our sun. Thus, their gravitational force is incredibly large. The gravity of a black hole is so large that an object that enters 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—hence their name.

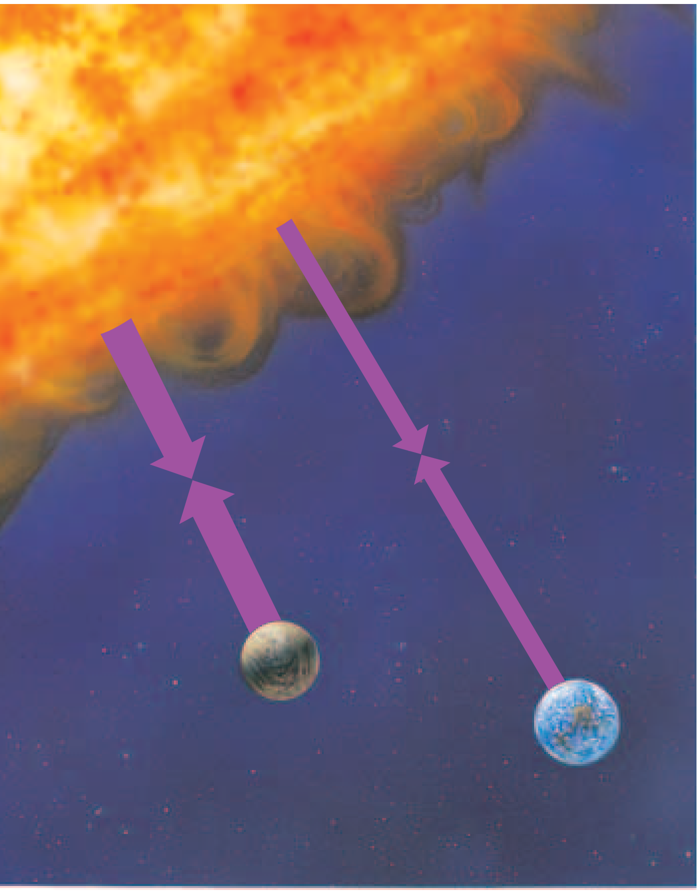


Figure 21 *Venus and Earth have approximately the same mass. However, Venus is closer to the sun. Thus, the gravity between Venus and the sun is greater than the gravity between Earth and the sun.*

Part 2: Gravitational Force Decreases as Distance Increases The gravity 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.

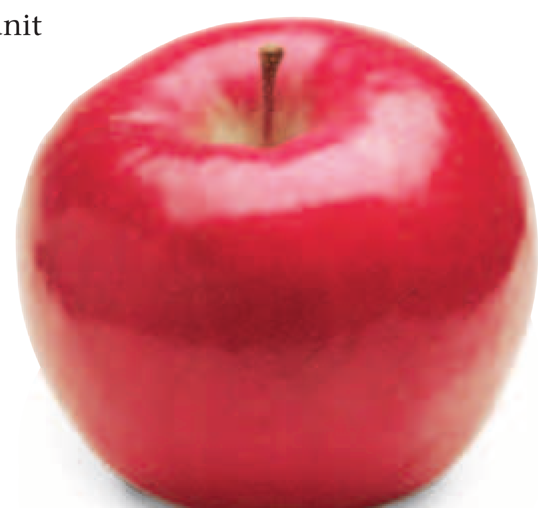
You are approximately 150 million kilometers away from the sun. At this distance, the gravity between you and the sun is very small. If there were some way you could stand on the sun (and not burn up), you would find it impossible to jump or even walk. The gravitational force acting on you would be so great that your muscles could not lift any part of your body!

Although the sun's gravitational force does not have much of an effect on your body here, it does have a big effect on Earth itself and the other planets, as shown in **Figure 21.** 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.

Weight Is a Measure of Gravitational Force

You have learned that gravity is a force of attraction between objects that is due to their masses. **Weight** is a measure of the gravitational force exerted 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.

You have learned that the unit of force is a newton. Because gravity is a force and weight is a measure of gravity, weight is also expressed in newtons (N). On Earth, a 100 g object, such as a medium-sized apple, weighs approximately 1 N.



Explore

Suppose you had a device that could increase or decrease the gravitational force of objects around you (including small sections of Earth). In your ScienceLog, describe 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.

Weight and Mass Are Different Weight is related to mass, but the two are not the same. Weight changes when gravitational force changes. **Mass** is the amount of matter in an object, and its value does not change. If an object is moved to a place with a greater gravitational force—like Jupiter—its weight will increase, but its mass will remain the same. **Figure 22** shows the weight and mass of an object on Earth and a place with a smaller gravitational force.

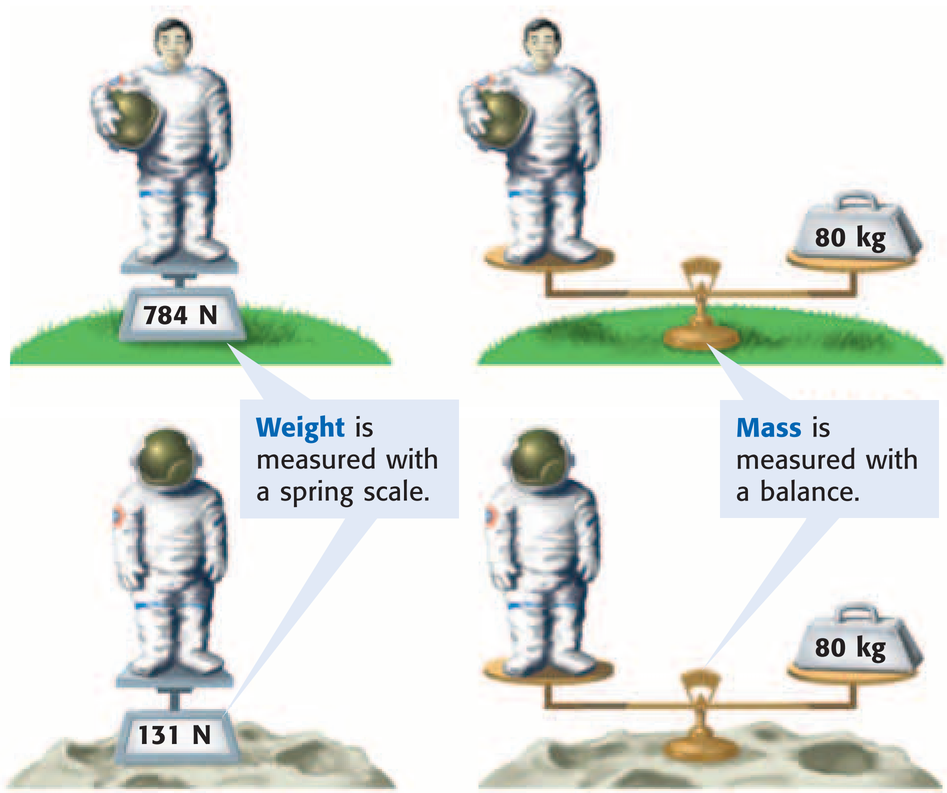


Figure 22 *Weight can change, but mass remains constant.*

The astronaut's weight and mass on Earth are shown on the spring scale and balance.

The astronaut has the same mass on the moon, but his weight is one-sixth of his weight on Earth. This is because the moon's gravitational force is one-sixth that of Earth's.

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 are often used to mean the same thing. This can lead to confusion. Be sure you understand the difference!

REVIEW

1. How does the mass of an object relate to the gravitational force the object exerts on other objects?
2. How does the distance between objects affect the gravity between them?
3. **Comparing Concepts** Explain why your weight would change if you orbited Earth in the space shuttle but your mass would not.

Chapter Highlights

SECTION 1

Vocabulary

motion *(p. 108)*
speed *(p. 109)*
velocity *(p. 110)*
acceleration *(p. 112)*

Section Notes

- An object is in motion if it changes position over time when compared with a reference point.

- The speed of a moving object depends on the distance traveled by the object and the time taken to travel that distance.
- Speed and velocity are not the same thing. Velocity is speed in a given direction.
- Acceleration is the rate at which velocity changes.
- An object can accelerate by changing speed, changing direction, or both.
- Acceleration is calculated by subtracting starting velocity from final velocity, then dividing by the time required to change velocity.

Labs

Built for Speed *(p. 536)*
Detecting Acceleration *(p. 537)*

SECTION 2

Vocabulary

force *(p. 115)*
newton (N) *(p. 115)*
net force *(p. 116)*

Section Notes

- A force is a push or a pull.
- Forces are expressed in newtons.
- Force is always exerted by one object on another object.
- Net force is determined by combining forces.
- Unbalanced forces produce a change in motion. Balanced forces produce no change in motion.

Skills Check

Math Concepts

ACCELERATION An object's acceleration can be determined using the following equation:

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

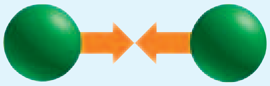
For example, suppose a cheetah running at a velocity of 27 m/s slows down. After 15 seconds, the cheetah has stopped.

$$\text{Acceleration} = \frac{0 \text{ m/s} - 27 \text{ m/s}}{15 \text{ s}} = -1.8 \text{ m/s/s}$$

Visual Understanding

THE SOURCE OF FRICTION Even surfaces that look or feel very smooth are actually rough at the microscopic level. To understand how this roughness causes friction, review Figure 11 on page 119.

THE LAW OF UNIVERSAL GRAVITATION This law explains that the gravity between objects depends on their masses and the distance between them. Review the effects of this law by looking at Figure 20 on page 127.



SECTION 3

Vocabulary

friction *(p. 119)*

Section Notes

- Friction is a force that opposes motion.
- Friction is caused by "hills and valleys" touching on the surfaces of two objects.
- The amount of friction depends on factors such as the roughness of the surfaces and the force pushing the surfaces together.
- Four kinds of friction that affect your life are sliding friction, rolling friction, fluid friction, and static friction.
- Friction can be harmful or helpful.

Labs

Science Friction *(p. 540)*

SECTION 4

Vocabulary

gravity *(p. 125)*
weight *(p. 128)*
mass *(p. 129)*

Section Notes

- 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. The size of the force depends on the masses of the objects and the distance between them.
- Weight and mass are not the same. Mass is the amount of matter in an object; weight is a measure of gravitational force on an object.

Labs

Relating Mass and Weight *(p. 541)*

internetconnect

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: HSTMOT

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: Measuring Motion — ***sci*LINKS NUMBER:** HSTP105
TOPIC: Force and Friction — ***sci*LINKS NUMBER:** HSTP110
TOPIC: Matter and Gravity — ***sci*LINKS NUMBER:** HSTP115
TOPIC: Virtual Reality — ***sci*LINKS NUMBER:** HSTP120
TOPIC: The Science of Bridges — ***sci*LINKS NUMBER:** HSTP125

Chapter Review

USING VOCABULARY

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

1. ___?___ opposes motion between surfaces that are touching. *(Friction* or *Gravity)*

2. Forces are expressed in ___?___. *(newtons* or *mass)*

3. A ___?___ is determined by combining forces. *(net force* or *newton)*

4. ___?___ is the rate at which ___?___ changes. *(Velocity* or *Acceleration/velocity* or *acceleration)*

UNDERSTANDING CONCEPTS

Multiple Choice

5. A student riding her bicycle on a straight, flat road covers one block every 7 seconds. If each block is 100 m long, she is traveling at
   a. constant speed.
   b. constant velocity.
   c. 10 m/s.
   d. Both (a) and (b)

6. Friction is a force that
   a. opposes an object's motion.
   b. does not exist when surfaces are very smooth.
   c. decreases with larger mass.
   d. All of the above

7. Rolling friction
   a. is usually less than sliding friction.
   b. makes it difficult to move objects on wheels.
   c. is usually greater than sliding friction.
   d. is the same as fluid friction.

8. If Earth's mass doubled, your weight would
   a. increase because gravity increases.
   b. decrease because gravity increases.
   c. increase because gravity decreases.
   d. not change because you are still on Earth.

9. 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

10. The amount of gravity between 1 kg of lead and Earth is ______ the amount of gravity between 1 kg of marshmallows and Earth.
    a. greater than
    b. less than
    c. the same as
    d. None of the above

Short Answer

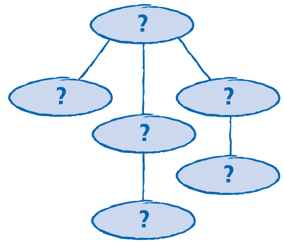
11. Describe the relationship between motion and a reference point.

12. How is it possible to be accelerating and traveling at a constant speed?

13. Explain the difference between mass and weight.

Concept Mapping

14. Use the following terms to create a concept map: speed, velocity, acceleration, force, direction, motion.



CRITICAL THINKING AND PROBLEM SOLVING

15. 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?

16. Explain how using the term *accelerator* when talking about a car's gas pedal can lead to confusion, considering the scientific meaning of the word *acceleration.*

17. Explain why it is important for airplane pilots to know wind velocity, not just wind speed, during a flight.

MATH IN SCIENCE

18. A kangaroo hops 60 m to the east in 5 seconds.

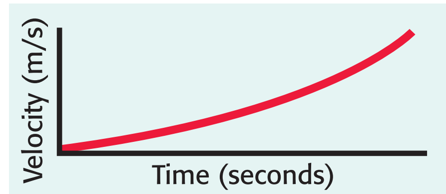
a. What is the kangaroo's speed?

b. What is the kangaroo's velocity?

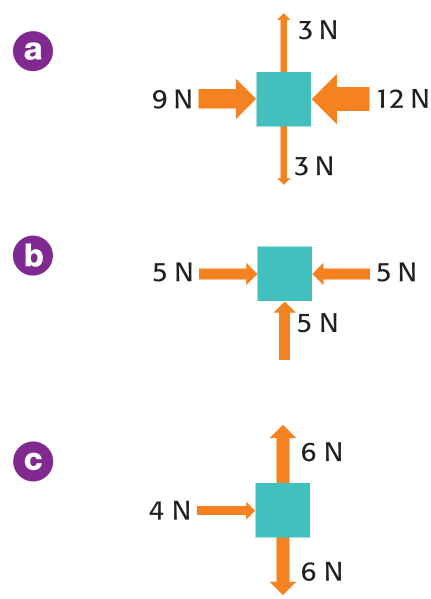
c. The kangaroo stops at a lake for a drink of water, then starts hopping again to the south. Every second, the kangaroo's velocity increases 2.5 m/s. What is the kangaroo's acceleration after 5 seconds?

INTERPRETING GRAPHICS

19. Is this a graph of positive 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 you learned can be used to combine several forces acting in several directions. Examine the diagrams below, and predict with how much force and in what direction the object will move.



NOW What Do You Think?

Take a minute to review your answers to the ScienceLog questions on page 107. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.

Science, Technology, and Society

Is It Real . . . or Is It Virtual?

You stand in the center of a darkened room and put on a helmet. The helmet covers your head and face, making it impossible for you to see or hear anything from outside. Wires run from the helmet to a series of computers, carrying information about how your head is positioned and where you are looking. Other wires carry back to you the sights and sounds the computer wants you to "see" and "hear." All of a sudden you find yourself driving a race car around a tricky course at 300 km/h. Then in another instant, you are in the middle of a rain forest staring at a live snake!

It's All an Illusion

Such simulated-reality experiences were once thought the stuff of science fiction alone. But today devices called motion simulators can stimulate the senses of sight and sound to create illusions of movement.

Virtual-reality devices, as these motion simulators are called, were first used during World War II to train pilots. Mock-ups of fighter-plane cockpits, films of simulated terrain, and a joystick that manipulated large hydraulic arms simulated the plane in "virtual flight." Today's jet pilots train with similar equipment, except the simulators use extremely sophisticated computer graphics instead of films.

Fooled You!

Virtual-reality hoods and gloves take people into a variety of "realities." Inside the hood, two small television cameras or computer-graphic images fool the wearer's sense of vision. The brain perceives the image as three-dimensional because one image is placed in front of each eye. As the images change, the computer adjusts the scene's perspective so that it appears to the viewer as though he or she is moving through the scene. When the position of the head changes, the computer adjusts the scene to account for the movement. All the while, sounds coming through the headphones trick the wearer's ears into thinking he or she is moving too.

In addition to hoods, gloves, and images, virtual-reality devices may have other types of sensors. Driving simulators, for instance, often have a steering wheel, a gas pedal, and a brake so that the participant has the sensation of driving. So whether you want spine-tingling excitement or on-the-job training, virtual reality could very well take *you* places!

▲ ***Wearing a virtual-reality helmet helps to lessen the pain this burn patient feels while his dressings are changed.***

Explore New Realities

▶ What other activities or skills could be learned or practiced with virtual reality? What are some problems with relying on this technology? Record your ideas in your ScienceLog.

PHYSICAL SCIENCE • EARTH SCIENCE

The Golden Gate Bridge

Have you ever relaxed in a hammock? If so, you may have noticed how tense the strings got when the hammock supported your weight. Now imagine a hammock 1,965 m long supporting a 20-ton roadway with more than 100,000 cars traveling along its length each day. That describes the Golden Gate Bridge! Because of the way the bridge is built, it is very much like a giant hammock.

Tug of War

The bridge's roadway is suspended from main cables 2.33 km long that sweep from one end of the bridge to the other and that are anchored at each end. Smaller cables called *hangers* connect the main cables to the roadway. Tension, the force of being pulled apart, is created as the cables are pulled down by the weight of the roadway while being pulled up by their attachment to the top of each tower.

▲ *The Golden Gate Bridge spans the San Francisco Bay.*

Towering Above

Towers 227 m tall support the cables over the long distance across San Francisco Bay, making the Golden Gate the tallest bridge in the world. The towers receive a force that is the exact opposite of tension—compression. Compression is the force of being pushed together. The main cables holding the weight of the roadway push down on the top of the towers while Earth pushes up on the bottom.

Stretching the Limits

Tension and compression are elastic forces, which means they are dependent on elasticity, the ability of an object to return to its original shape after being stretched or compressed. If an object is not very elastic, it breaks easily or becomes permanently deformed when subjected to an elastic force. The cables and towers of the Golden Gate Bridge are made of steel, a material with great elastic strength. A single steel wire 2.54 mm thick can support over half a ton without breaking!

On the Road

The roadway of the Golden Gate Bridge is subjected to multiple forces at the same time, including friction, gravity, and elastic forces. Rolling friction is caused by the wheels of each vehicle moving across the roadway's surface. Gravity pulls down on the roadway but is counteracted by the support of the towers and cables. This causes each roadway span to bend slightly and experience both tension and compression. The bottom of each span is under tension because the cables and towers pull up along the road's sides, while gravity pulls down at its center. These same forces cause compression of the top of each span. Did you ever imagine that so many forces were at work on a bridge?

Bridge the Gap

▶ Find out more about another type of bridge, such as an arch, a beam, or a cable-stayed bridge. How do forces such as friction, gravity, tension, and compression affect these types of bridges?