CHAPTER 2

Force and Newton's Laws

This train can move! Japan's experimental train, the MLX01, can travel at speeds of more than 500 km/h. It can move this fast because the engineers who built it understood the laws of motion that Isaac Newton first proposed more than 300 years ago. In this chapter, you'll learn about force and Newton's laws of motion. You'll learn why some objects move and why some stay still, and how objects exert forces on each other.

What do you think?

Science Journal Look at the picture below with a classmate. Discuss what this might be or what is happening. Here's a hint: *It's a delicate balancing act.* Write your answer or best guess in your Science Journal.

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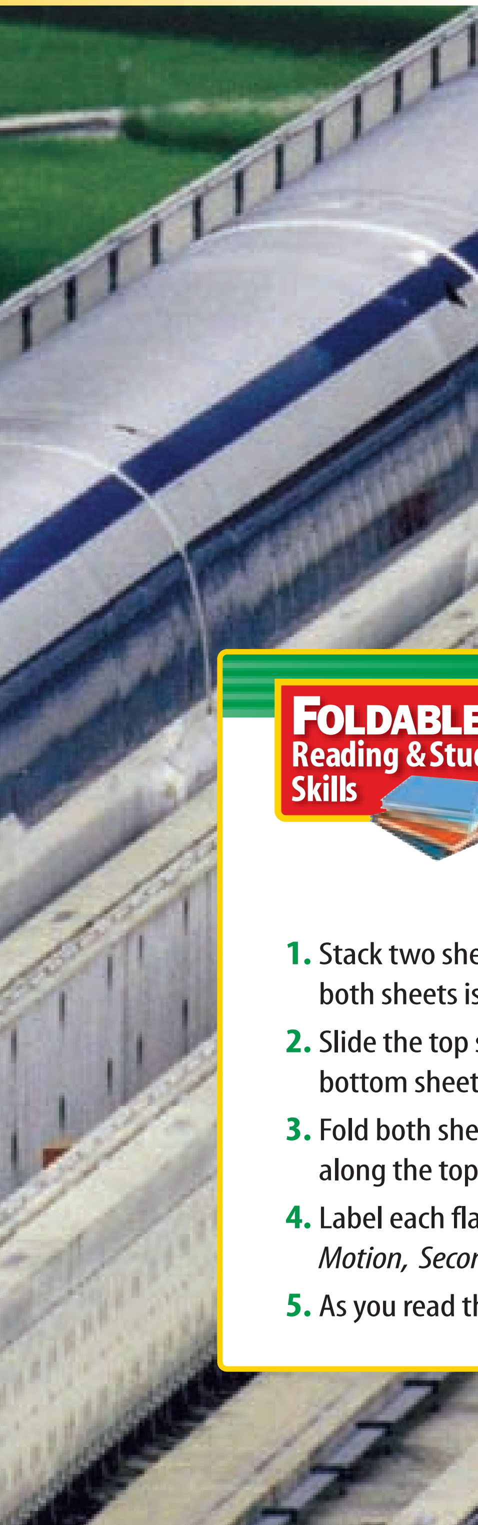


Explore Activity

Imagine being on a bobsled team speeding down an icy run. The force of gravity causes the sled to accelerate as it speeds down the course in a blur. You and your team use your bodies, brakes, and the steering mechanism to exert forces to change the sled's motion, causing it to slow down or turn. The motion of the sled as it speeds up, slows down, and turns can be explained with Newton's laws of motion. These laws tell how forces cause the motion of an object to change.

Analyze motion on a ramp

1. Lean two metersticks on three books as shown to the right. This is your ramp.
2. Tap a marble so it rolls up the ramp. Measure how far up the ramp it travels before rolling back.
3. Repeat step 2 using two books, one book, and zero books. The same person should tap with the same force each time.

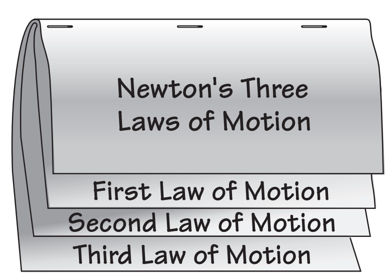
Observe

Make a table to record the motion of the marble for each ramp height. What would happen if the ramp were perfectly smooth and level?

Before You Read

FOLDABLES Reading & Study Skills

Making an Organizational Study Fold **When information is grouped into clear categories, it is easier to make sense of what you are learning. Make the following Foldable to help you organize your thoughts about Newton's Three Laws of Motion.**



1. Stack two sheets of paper in front of you so the short side of both sheets is at the top.
2. Slide the top sheet up so that about four centimeters of the bottom sheet show.
3. Fold both sheets top to bottom to form four tabs and staple along the topfold as shown.
4. Label each flap *Newton's Three Laws of Motion, First Law of Motion, Second Law of Motion,* and *Third Law of Motion* as shown.
5. As you read the chapter, record what you learn about the laws of motion under the tabs.

SECTION 1

Newton's First Law

As You Read

What You'll Learn

- **Identify** forces at work.
- **Distinguish** between balanced and net forces.
- **Demonstrate** Newton's first law of motion.
- **Explain** how friction works.

Vocabulary

force
net force
balanced forces
unbalanced forces
Newton's first law of motion
friction

Why It's Important

Newton's first law helps you understand why objects slow down and stop.

Force

A soccer ball sits on the ground, motionless, until you kick it. Your science book sits on the table until you pick it up. If you hold your book above the ground, then let it go, gravity pulls it to the floor. In every one of these cases, the motion of the ball or book was changed by something pushing or pulling on it. An object will speed up, slow down, or turn only if something is pushing or pulling on it.

A **force** is a push or a pull. Examples of forces are shown in **Figure 1.** Think about throwing a ball. Your hand exerts a force on the ball, and the ball accelerates forward until it leaves your hand. After the ball leaves your hand, gravity's force on it causes its path to curve downward. When the ball hits the ground, the ground exerts a force, stopping the ball.

A force can be exerted in different ways. For instance, a paper clip can be moved by the force a magnet exerts, the pull of Earth's gravity, or the force you exert when you pick it up. These are all examples of forces acting on the paper clip.

Figure 1
A force is a push or a pull.

A This golf club exerts a force by pushing on the golf ball.

B The magnet on the crane pulls the pieces of scrap metal upward.

A This door is not moving because the forces exerted on it are equal and in opposite directions.

B The door is closing because the force pushing the door closed is greater than the force pushing it open.

Figure 2
When the forces on an object are balanced, no change in motion occurs, but when the forces on an object are unbalanced, a change in motion does occur.

Combining Forces More than one force can act on an object at the same time. If you hold a paper clip near a magnet, you, the magnet, and gravity all exert forces on the paper clip. The combination of all the forces acting on an object is the **net force.** When more than one force is acting on an object, the net force determines the motion of the object. In this example, the paper clip is not moving, so the net force is zero.

How do forces combine to form the net force? If the forces are in the same direction, they add together to form the net force. If two forces are in opposite directions, then the net force is the difference between the two forces, and it is in the direction of the larger force.

Balanced and Unbalanced Forces A force can act on an object without causing it to accelerate if other forces cancel the push or pull of the force. Look at **Figure 2.** If you and your friend push on a door with the same force in opposite directions, the door does not move. Because you both exert forces of the same size in opposite directions on the door, the two forces cancel each other. Two or more forces exerted on an object are **balanced forces** if their effects cancel each other and they do not cause a change in the object's motion. If the forces on an object are balanced, the net force is zero. If the forces are **unbalanced forces,** their effects don't cancel each other. Any time the forces acting on an object are unbalanced, the net force is not zero and the motion of the object changes.

Life Science INTEGRATION

Whether you run, jump, or sit, forces are being exerted on different parts of your body. Biomechanics is the study of how the body exerts forces and how it is affected by forces acting on it. Research how biomechanics has been used to reduce job-related injuries. Write a paragraph on what you've learned in your Science Journal.

Newton's First Law of Motion

If you stand on a skateboard and someone gives you a push, then you and your skateboard will start moving. You began to move when the force was applied. An object at rest—like you on your skateboard—remains at rest unless an unbalanced force acts on it and causes it to move.

Because a force had to be applied to make you move when you and your skateboard were at rest, you might think that a force has to be applied continually to keep an object moving. Surprisingly, this is not the case. An object can be moving even if the net force acting on it is zero.

Newton's first law of motion describes how an object moves when no net force is acting on it. According to **Newton's first law of motion,** if there is no net force acting on an object the object remains at rest, or if the object is already moving, it continues to move in a straight line with constant speed.

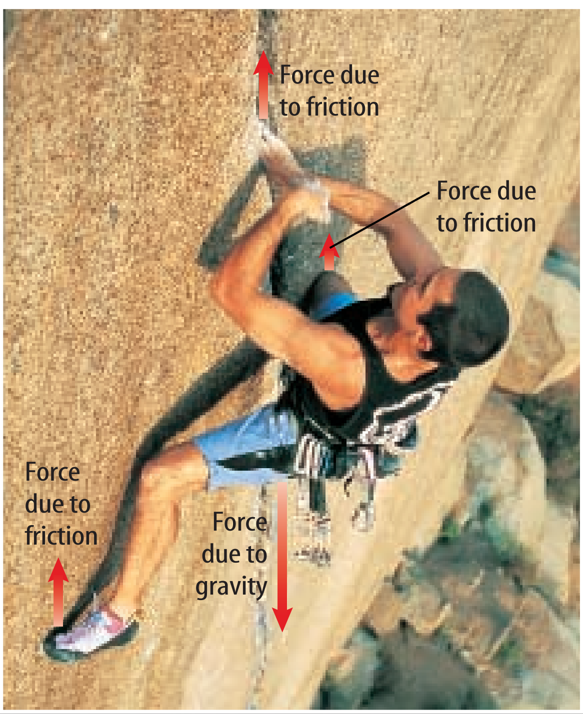
The Italian scientist Galileo Galilei, who lived from 1564 to 1642, was one of the first to understand that a force doesn't need to be constantly applied to an object to keep it moving. Galileo's ideas helped Isaac Newton to better understand the nature of motion. Newton was able to explain the motion of objects in three rules called Newton's laws of motion.

Friction

Galileo realized the motion of an object doesn't change until an unbalanced force acts on it. Every day you see moving objects come to a stop. The force that brings nearly everything to a stop is **friction,** which is the force that acts to resist sliding between two touching surfaces, as shown in **Figure 3.** Friction is why you never see objects moving with constant velocity unless a net force is applied. Friction is the force that eventually brings your skateboard to a stop unless you keep pushing on it. Friction always acts on objects that are sliding or moving through air or water.

Figure 3
When two objects in contact try to slide past each other, friction keeps them from moving or slows them down.

A Without friction, the rock climber would slide down the rock.



B Friction slows down this sliding baseball player.

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Opposing Sliding Although several different forms of friction exist, they all have one thing in common. If two objects are in contact, frictional forces always try to prevent one object from sliding on the other object. If you rub your hand against a tabletop, you can feel the friction push against the motion of your hand. If you rub the other way, you can feel the direction of friction change so it is again acting against your hand's motion. Friction always will slow an object down.

Reading Check *What do the different forms of friction have in common?*

Older Ideas About Motion It took a long time for people to understand motion. One reason was that people did not understand the behavior of friction or understand that friction was a force. Because friction causes moving objects to stop, people thought the natural state of an object was to be at rest. For an object to be in motion, something had to be pushing or pulling it continuously. As soon as the force stopped, nature would bring the object to rest.

Galileo understood that an object in constant motion is as natural as an object at rest. It was usually friction that made moving objects slow down and eventually come to a stop. To keep an object moving, a force had to be applied to overcome the effects of friction. If friction could be removed, an object in motion would continue to move in a straight line with constant speed. **Figure 4** shows motion where there is almost no friction.

SCIENCE Online

Research Visit the Glencoe Science Web site at **science.glencoe.com** for more information about the lives of Galileo and Newton. Communicate to your class what you learn.

CLICK HERE

Figure 4
In an air hockey game, the puck floats on a layer of air, so that friction is almost eliminated. As a result, the puck moves in a straight line with nearly constant speed after it's been hit. *How would the puck move if there was no layer of air?*

TRY AT HOME

Mini LAB

Observing Friction

Procedure

1. Lay a **bar of soap,** a **flat eraser,** and a **key** side by side on one end of a **hard-sided notebook.**
2. At a constant rate, slowly lift the end of notebook with objects on it. Note the order in which the objects start sliding.

Analysis

1. For which object was static friction the greatest? For which object was it the smallest? Explain, based on your observations.
2. Which object slid the fastest? Which slid the slowest? Explain why there is a difference in speed.
3. How could you increase and decrease the amount of friction between two materials?

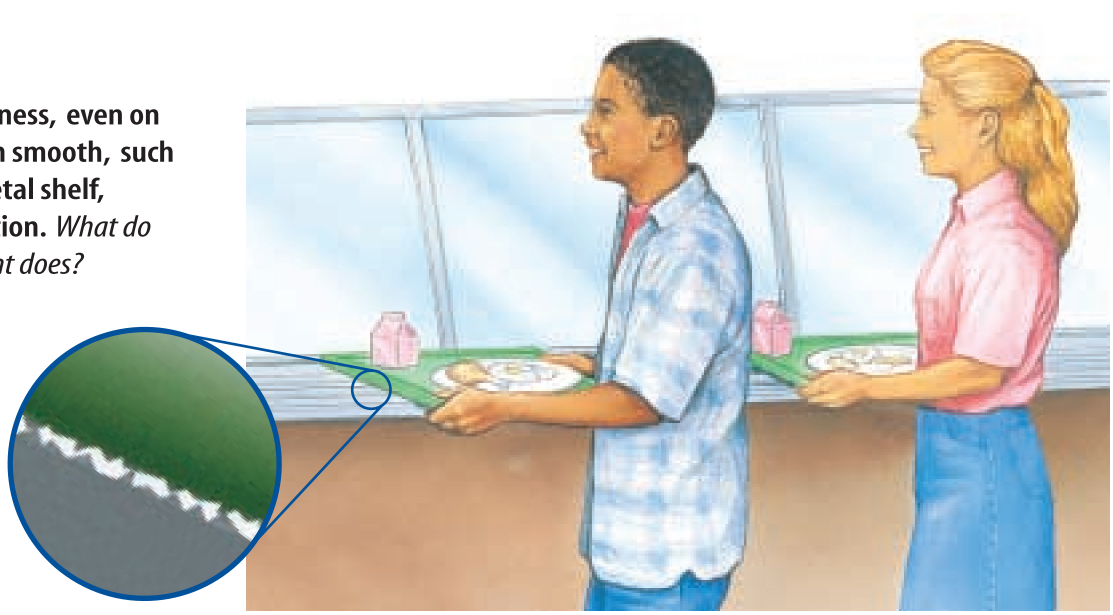
Static Friction If you've ever tried pushing something heavy, like a refrigerator, you might have discovered that nothing happened at first. Then as you push harder and harder, the object suddenly will start to move. When you first start to push, friction between the heavy refrigerator and the floor opposes the force you are exerting and the net force is zero. The type of friction that prevents an object from moving when a force is applied is called static friction.

Static friction is caused by the attraction between the atoms on the two surfaces that are in contact. This causes the surfaces to stick or weld together where they are in contact. Usually, as the surface gets rougher and the object gets heavier, the force of static friction will be larger. To move the object, you have to exert a force large enough to break the bonds holding two surfaces together.

Sliding Friction While static friction keeps an object at rest, sliding friction slows down an object that slides. If you push an object across a room, you notice the sliding friction between the bottom of the object and the floor. You have to keep pushing to overcome the force of sliding friction. Sliding friction is due to the microscopic roughness of two surfaces, as shown in **Figure 5.** A force must be applied to move the rough areas of one surface past the rough areas of the other. The brake pads in a car use sliding friction against the wheels to slow the car. Bicycle brakes, shown in **Figure 6A,** work the same way.

✔ **Reading Check** ***What is the difference between static friction and sliding friction?***

Figure 5
Microscopic roughness, even on surfaces that seem smooth, such as the tray and metal shelf, causes sliding friction. *What do you think a lubricant does?*



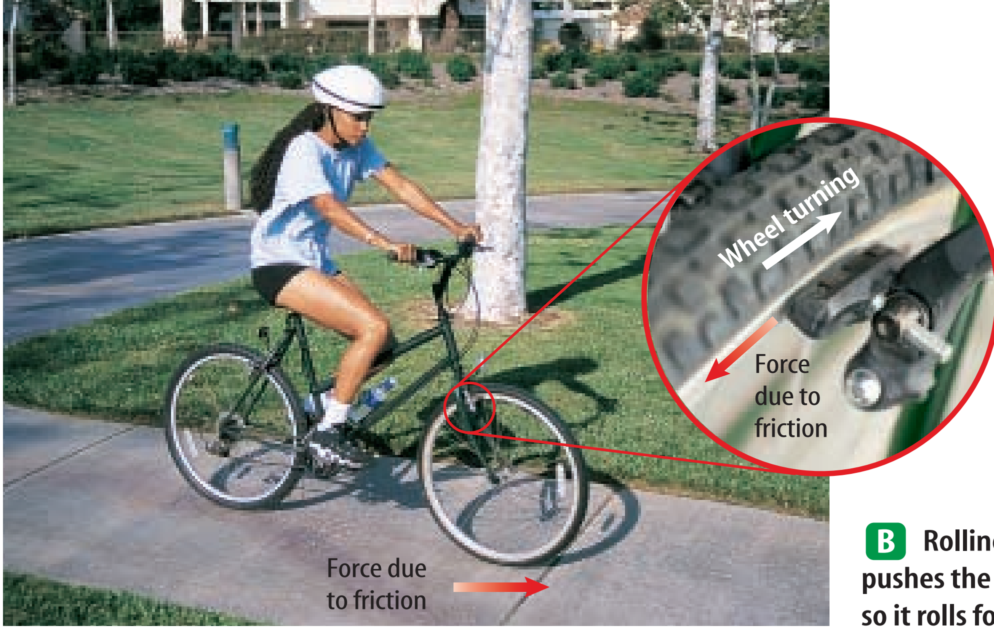


Figure 6
A bicycle uses sliding friction and rolling friction.

A Sliding friction is used to stop this bicycle tire. Friction between the brake pads and the wheel brings the wheel to a stop.

B Rolling friction with the ground pushes the bottom of the bicycle tire, so it rolls forward.

Rolling Friction Another type of friction, rolling friction, is needed to make a wheel or tire turn. Rolling friction occurs between the ground and the part of the tire touching the ground, as shown in **Figure 6B.** Rolling friction keeps the tire from slipping on the ground. If the bicycle tires are rolling forward, rolling friction exerts the force on the tires that pushes the bicycle forward.

It's usually easier to pull a load on a wagon or cart that has wheels rather than to drag the load along the ground. This is because rolling friction between the wheels and the ground is less than the sliding fiction between the load and the ground.

Section 1 Assessment

1. A car turns to the left at 20 km/h. Is a force acting on the car? Explain.
2. Explain why friction made it difficult to discover Newton's first law of motion.
3. If the net force on an object is zero, are the forces acting on it balanced or unbalanced? Explain.
4. What makes static friction increase?
5. **Think Critically** In the following situations, are the forces balanced or unbalanced? How can you tell?
   a. You push a box until it moves.
   b. You push a box at a constant rate.
   c. You stop pushing a box, and it stops.

Skill Builder Activities

6. **Comparing and Contrasting** Compare and contrast static friction, sliding friction, and rolling friction. **For more help, refer to the Science Skill Handbook.**
7. **Communicating** Most of the meteors that reach Earth's atmosphere burn up on the way down. Friction between the meteor and the atmosphere produces a great deal of heat. Research how the space shuttle is protected from friction when it reenters Earth's atmosphere. Report your findings in your Science Journal. **For more help, refer to the Science Skill Handbook.**

SECTION 2

Newton's Second Law

As You Read

What You'll Learn

- **Explain** Newton's second law of motion.
- **Explain** why the direction of force is important.

Vocabulary

Newton's second law of motion
weight

Why It's Important

Newton's second law of motion explains how any object, from a swimmer to a satellite, moves when acted on by forces.

Force and Acceleration

When you go shopping in a grocery store and push a cart, you exert a force to make the cart move. If you want to slow down or change the direction of the cart, a force is required to do this, as well. Would it be easier for you to stop a full or empty grocery cart suddenly, as in **Figure 7?** When the motion of an object changes, the object is accelerating. Acceleration occurs any time an object speeds up, slows down, or changes its direction of motion. Newton's second law describes how forces cause an object's motion to change.

Newton's second law of motion connects force, acceleration, and mass. According to the second law of motion, an object acted upon by a force will accelerate in the direction of the force. The acceleration is given by the following equation

$$\text{acceleration} = \frac{\text{net force}}{\text{mass}}$$

$$a = \frac{F_{net}}{m}$$

In this equation, a is the acceleration, m is the mass, and F_{net} is the net force. If both sides of the above equation are multiplied by the mass, the equation can be written this way:

$$F_{net} = ma$$

Reading Check *What is Newton's second law?*

Figure 7
The force needed to change the motion of an object depends on its mass. *Which grocery cart would be easier to stop suddenly?*

Units of Force Force is measured in newtons, abbreviated N. Because the SI unit for mass is the kilogram (kg) and acceleration has units of meters per second squared (m/s^2), 1 N also is equal to 1 $kg \cdot m/s^2$. In other words, to calculate a force in newtons from the equation shown on the prior page, the mass must be given in kg and the acceleration in m/s^2.

Gravity

One force that you are familiar with is gravity. Whether you're coasting down a hill on a bike or a skateboard or jumping into a pool, gravity is at work pulling you downward. Gravity also is the force that causes Earth to orbit the Sun and the Moon to orbit Earth.

What is gravity? The force of gravity exists between any two objects that have mass. Gravity always is attractive and pulls objects toward each other. A gravitational attraction exists between you and every object in the universe that has mass. However, the force of gravity depends on the mass of the objects and the distance between them. The gravitational force becomes weaker the farther apart the objects are and also decreases as the masses of the objects involved decrease.

For example, there is a gravitational force between you and the Sun and you and Earth. The Sun is much more massive than Earth, but is so far away that the gravitational force between you and the Sun is too weak to notice. Only Earth has enough mass and is close enough to exert a noticeable gravitational force on you. The force of gravity between you and Earth is about 1,650 times greater than between you and the Sun.

Astronomy INTEGRATION

A black hole is a star that has collapsed so that all its mass is compressed into a small region that may be less than 10 km in diameter. Near a black hole, the force of gravity is much stronger than the force of gravity near Earth. Research some of the unusual phenomena that occur near black holes.

Weight The force of gravity causes all objects near Earth's surface to fall with an acceleration of 9.8 m/s^2. By Newton's second law, the gravitational force on any object near Earth's surface is:

$$F = ma = m \times (9.8\ m/s^2)$$

This gravitational force also is called the weight of the object. Your **weight** on Earth is the gravitational force between you and Earth. Your weight would change if you were standing on a different planet than Earth, as shown in **Table 1**. Your weight on a different planet is the gravitational force between you and the planet.

Table 1 Weight of 60 kg Person on Various Planets

Place	Weight in Newtons If Your Mass Were 60 kg	Percent of Your Weight on Earth
Mars	221	38
Earth	587	100
Jupiter	1,387	236
Pluto	39	0.7

Figure 8
The girl is speeding up because she is being pushed in the same direction that she is moving.

Weight and Mass Weight and mass are different. Weight is a force, just like the push of your hand is a force, and is measured in newtons. When you stand on a bathroom scale, you are measuring the pull of Earth's gravity—a force. However, mass is the amount of matter in an object, and doesn't depend on location. A book with a mass of 1 kg has a mass of 1 kg on Earth or on Mars. However, the weight of the book would be different on Earth and Mars. The two planets would exert a different gravitational force on the book.

Figure 9
The boy is slowing down because the force exerted by his feet is in the opposite direction of his motion.

Using Newton's Second Law

How does Newton's second law determine how an object moves when acted upon by forces? The second law tells how to calculate the acceleration of an object if its mass and the forces acting on it are known. You may remember that the motion of an object can be described by its velocity. The velocity tells how fast an object is moving and in what direction. Acceleration tells how velocity changes. If the acceleration of an object is known, then the change in velocity can be determined.

Speeding Up Think about a soccer ball sitting on the ground. If you kick the ball, it starts moving. You exert a force on the ball, and the ball accelerates only while your foot is in contact with the ball. If you look back at all of the examples of objects speeding up, you'll notice that something is pushing or pulling the object in the direction it is moving, as in **Figure 8.** The direction of the push or pull is the direction of the force. It also is the direction of the acceleration.

Calculating Acceleration Newton's second law of motion can be used to calculate acceleration. For example, suppose you pull a 10-kg sled so that the net force on the sled is 5 N. The acceleration can be found as follows:

$$a = \frac{F_{net}}{m} = \frac{5\ \text{N}}{10\ \text{kg}} = 0.5\ \text{m/s}^2$$

The sled keeps accelerating as long as you keep pulling on it. The acceleration does not depend on how fast the sled is moving. It depends only on the net force and the mass of the sled.

Slowing Down If you wanted to slow down an object, you would have to push or pull it against the direction it is moving. An example is given in **Figure 9.** Here the force is opposite to the velocity or the direction of motion.

Suppose you push a book so it slides across a tabletop. You exert a force on the book when your hand is in contact with it, and the book speeds up. Sliding friction also acts on the book as it starts to move. After the book is no longer in contact with your hand, friction acts in the opposite direction to the book's motion. This causes the book to slow down and come to a stop.

Field GUIDE

How does acceleration affect how you feel on a roller coaster? To find out more about acceleration and amusement park rides, see the **Amusement Park Rides Field Guide** at the back of the book.

Math Skills Activity

Calculating Force Using Newton's Second Law

Example Problem

A car with a mass of 1,500 kg has an acceleration of 3 m/s^2. Find the force acting on the car.

Solution

1. *This is what you know:* acceleration: $a = 3\ \text{m/s}^2$
   mass: $m = 1{,}500$ kg
2. *This what you need to find:* Force: F
3. *This is the equation you need to use:* $F = ma$
4. *Substitute the known values:* $F = (1{,}500\ \text{kg}) \times (3\ \text{m/s}^2) = 4{,}500\ \text{N}$

Check your answer by dividing the force you calculate by the acceleration that was given. Do you calculate the same mass that was given?

Practice Problem

You throw a baseball with a mass of 0.15 kg so it has an acceleration of 40 m/s^2. Find the force you exerted on the baseball.

For more help, refer to the Math Skill Handbook.

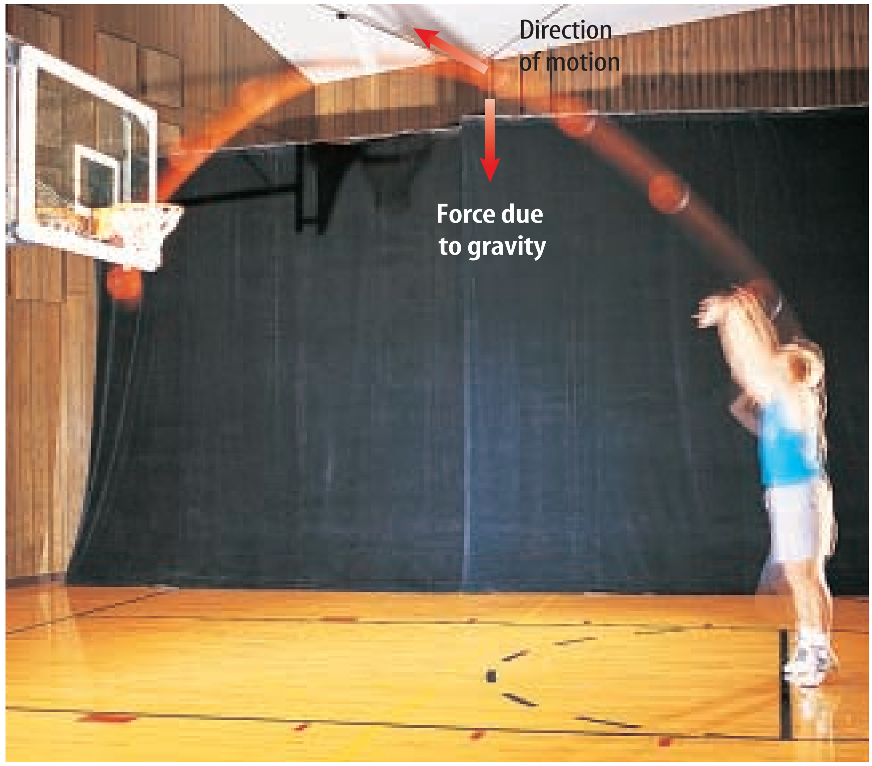


Figure 10
When the ball is thrown, it doesn't keep moving in a straight line. Gravity exerts a force downward that makes it move in a curved path.

Turning Sometimes forces and motion are not in a straight line. If a net force acts at an angle to the direction an object is moving, the object will follow a curved path. The object might be going slower, faster, or at the same speed after it turns.

For example, when you shoot a basketball, the ball doesn't continue to move in a straight line after it leaves your hand. Instead it starts to curve downward, as shown in **Figure 10.** The force of gravity pulls the ball downward. The ball's motion is a combination of its original motion and the downward motion due to gravity. This causes the ball to move in a curved path.

Circular Motion

A rider on a merry-go-round ride moves in a circle. This type of motion is called circular motion. If you are in circular motion, your direction of motion is constantly changing. This means you are constantly accelerating. According to Newton's second law of motion, if you are constantly accelerating, there must be a force acting on you the entire time.

Think about an object on the end of a string whirling in a circle. The force that keeps the object moving in a circle is exerted by the string. The string pulls on the object to keep it moving in a circle. The force exerted by the string is the centripetal force and always points toward the center of the circle. In circular motion the centripetal force is always perpendicular to the motion.

Satellite Motion Objects that orbit Earth are satellites of Earth. Satellites go around Earth in nearly circular orbits, with the centripetal force being gravity. If gravity is pulling satellites toward Earth, why doesn't a satellite fall to Earth like a baseball does? Actually, a satellite is falling to Earth just like a baseball.

Suppose Earth were perfectly smooth with no mountains or hills. Imagine you throw a baseball horizontally. Gravity pulls the baseball downward so it travels in a curved path. If the baseball is thrown faster, its path is less curved, and it travels farther before it hits the ground, as shown in **Figure 11.** If the baseball were traveling fast enough, as it fell, its curved path would follow the curve of Earth's surface. Then the baseball would never hit the ground. Instead, it would continue to fall around Earth.

Figure 11
The faster a ball is thrown, the farther it travels before gravity pulls it to Earth. If the ball is traveling fast enough, Earth's surface curves away from it as fast as it falls downward. Then the ball never hits the ground.

Satellites in orbit are being pulled toward Earth just as baseballs are. The difference is that satellites are moving so fast horizontally that Earth's surface curves downward at the same rate that the satellites are falling downward. The speed at which a object must move to go into orbit near Earth's surface is about 8 km/s, or about 29,000 km/h.

To place a satellite into orbit, a rocket carries the satellite to the desired height. Then the rocket fires again to give the satellite the horizontal speed it needs to stay in orbit.

Air Resistance

Whether you are walking, running, or biking, air is pushing against you. This push is air resistance. Air resistance is a form of friction that acts to slow down any object moving in the air. Air resistance gets larger as an object moves faster.

When an object falls it speeds up as gravity pulls it downward. At the same time, the force of air resistance pushing up on the object is increasing as the object moves faster. Finally, the upward air resistance force becomes large enough to equal the downward force of gravity.

When the air resistance force equals the weight, the net force on the object is zero. By Newton's second law, the object's acceleration then is zero, and its speed no longer increases. The constant speed a falling object reaches when air resistance balances the force of gravity is the terminal velocity.

A

B

Figure 12
Sky divers can change their air resistance by changing the position of their arms and legs. A In a spread-eagle position, the air resistance of the sky diver is greater. B With the legs closed and the arms tucked back against the body, the sky diver's shape is narrower and the air resistance is less.

Air Resistance and Shape

The amount of air resistance depends on the object's shape, as well as its speed. Moving at the same speed, the air resistance on a pointed, narrow object is less than on a broad, flat object, such as a leaf or a piece of paper. A falling sky diver in a spread-eagle position, as shown in **Figure 12A,** might reach a terminal velocity of about 200 km/h. But with the arms tucked backward and the legs closed, air resistance is less, and the skydiver might reach a terminal velocity of over 300 km/h. When the skydiver opens the parachute, the force of air resistance on an open parachute is so large that the skydiver's terminal velocity quickly is reduced to about 20 km/h.

Section 2 Assessment

1. A human cannonball with a mass of 80 kg is fired out of a cannon with a force of 2,400 N. Find the acceleration.
2. A bike rider traveling at 20 km/h on a flat roadway stops pedaling. Make a diagram showing the forces acting on the coasting bike and rider. Using Newton's second law, explain how the bike's motion will change.
3. Suppose you were in a spaceship traveling away from Earth. How would your weight change as you moved farther from Earth?
4. What happens when the air resistance force equals the weight of a falling object?
5. **Think Critically** Explain how you can determine the direction of a force by watching an object's change in motion.

Skill Builder Activities

6. **Drawing Conclusions** Three students are pushing on a box. Two students are pushing on the left side, and one is pushing on the right side. One student on the left pushes with a force of 10 N and the other pushes with a force of 15 N. The student of the right pushes with a force of 20 N. In what direction will the box move? Explain your answer. **For more help, refer to the Science Skill Handbook.**
7. **Solving One-Step Equations** A 1-kg ball is moving at 2 m/s. A force stops the ball in 4 s. Find the acceleration of the ball by dividing the change in speed on the ball by the time needed to stop. Then find the force. **For more help, refer to the Math Skill Handbook.**

SECTION 3

Newton's Third Law

Action and Reaction

Newton's first two laws of motion explain how the motion of a single object changes. If the forces acting on the object are balanced, the object will remain at rest or stay in motion with constant velocity. If the forces are unbalanced, the object will accelerate in the direction of the net force. Newton's second law tells how to calculate the acceleration, or change in motion, of an object if the net force acting on it is known.

Newton's third law describes something else that happens when one object exerts a force on another object. Suppose you push on a wall. It may surprise you to learn that if you push on a wall, the wall also pushes on you. According to **Newton's third law of motion,** forces always act in equal but opposite pairs. Another way of saying this is for every action, there is an equal but opposite reaction. This means that when you push on a wall, the wall pushes back on you with a force equal in strength to the force you exerted. When one object exerts a force on another object, the second object exerts the same size force on the first object, as shown in **Figure 13.**

As You Read

***What* You'll Learn**

- **Identify** the relationship between the forces that objects exert on each other.

Vocabulary

Newton's third law of motion

***Why* It's Important**

Newton's third law can help you predict how objects will affect one another.

Figure 13
The car jack is pushing up on the car with the same amount of force with which the car is pushing down on the jack.

Figure 14
In this collision, the first car exerts a force on the second. The second exerts the same force in the opposite direction on the first car. *Which car do you think accelerates more?*

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Action and Reaction Forces Don't Cancel The forces exerted by two objects on each other are often called an action-reaction force pair. Either force can be considered the action force or the reaction force. You might think that because action-reaction forces are equal and opposite that they cancel. However, action and reaction force pairs don't cancel because they act on different objects. Forces can cancel only if they act on the same object.

For example, imagine you're driving a bumper car and are about to ram a friend in another car, as shown in **Figure 14.** When the two cars collide, your car pushes on the other car. By Newton's third law, that car pushes on your car with the same force, but in the opposite direction. This force causes you to slow down. One force of the action-reaction force pair is exerted on your friend's car, and the other force of the force pair is exerted on your car. Another example of an action-reaction pair is shown in **Figure 15.**

You constantly use action-reaction force pairs as you move about. When you jump, you push down on the ground. The ground then pushes up on you. It is this upward force that pushes you into the air. **Figure 16** shows some examples of how Newton's laws of motion are demonstrated in sporting events.

Figure 15
When the child pushes against the wall, the wall pushes against the child.

Life Science INTEGRATION Birds and other flying creatures also use Newton's third law. When a bird flies, its wings push in a downward and a backward direction. This pushes air downward and backward. By Newton's third law, the air pushes back on the bird in the opposite directions—upward and forward. This force keeps a bird in the air and propels it forward.

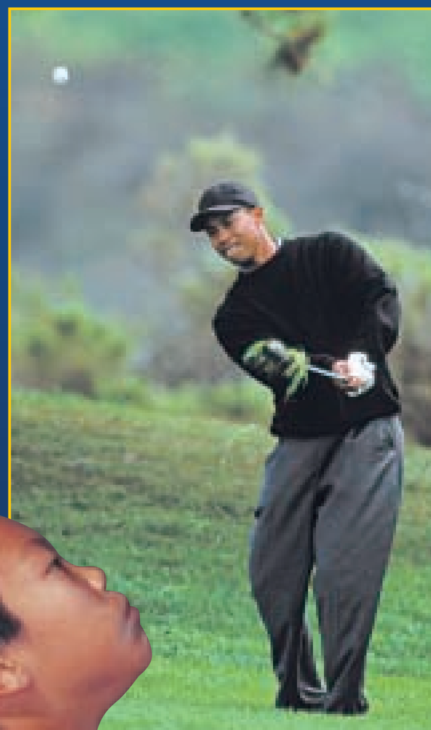
NATIONAL GEOGRAPHIC

VISUALIZING NEWTON'S LAWS IN SPORTS

Figure 16

Although it is not obvious, Newton's laws of motion are demonstrated in sports activities all the time. According to the first law, if an object is in motion, it moves in a straight line with constant speed unless a net force acts on it. If an object is at rest, it stays at rest unless a net force acts on it. The second law states that a net force acting on an object causes the object to accelerate in the direction of the force. The third law can be understood this way—for every action force, there is an equal and opposite reaction force.

NEWTON'S FIRST LAW According to Newton's first law, the diver does not move in a straight line with constant speed because of the force of gravity.



NEWTON'S SECOND LAW As Tiger Woods hits a golf ball, he applies a force that will drive the ball in the direction of that force—an example of Newton's second law.

NEWTON'S THIRD LAW Newton's third law applies even when objects do not move. Here a gymnast pushes downward on the bars. The bars push back on the gymnast with an equal force.

Figure 17
The force of the ground on your foot is equal and opposite to the force of your foot on the ground. If you push back harder, the ground pushes forward harder.

Field GUIDE

How do astronauts live under conditions of weightlessness? To find out more about the effects of weightlessness, see the **Living in Space Field Guide** at the end of the book.

Large and Small Objects Sometimes it's easy not to notice an action-reaction pair is because one of the objects is often much more massive and appears to remain motionless when a force acts on it. It has so much inertia, or tendency to remain at rest, that it hardly accelerates. Walking is a good example. When you walk forward, you push backward on the ground. Your shoe pushes Earth backward, and Earth pushes your shoe forward, as shown in **Figure 16.** Earth has so much mass compared to you that it does not move noticeably when you push it. If you step on something that has less mass than you do, like a skateboard, you can see it being pushed back.

A Rocket Launch The launching of a space shuttle is a spectacular example of Newton's third law. Three rocket engines supply the force, called thrust, that lifts the rocket. When the rocket fuel is ignited, a hot gas is produced. As the gas molecules collide with the inside engine walls, the walls exert a force that pushes them out of the bottom of the engine, as shown in **Figure 18.** This downward push is the action force. The reaction force is the upward push on the rocket engine by the gas molecules. This is the thrust that propels the rocket upward.

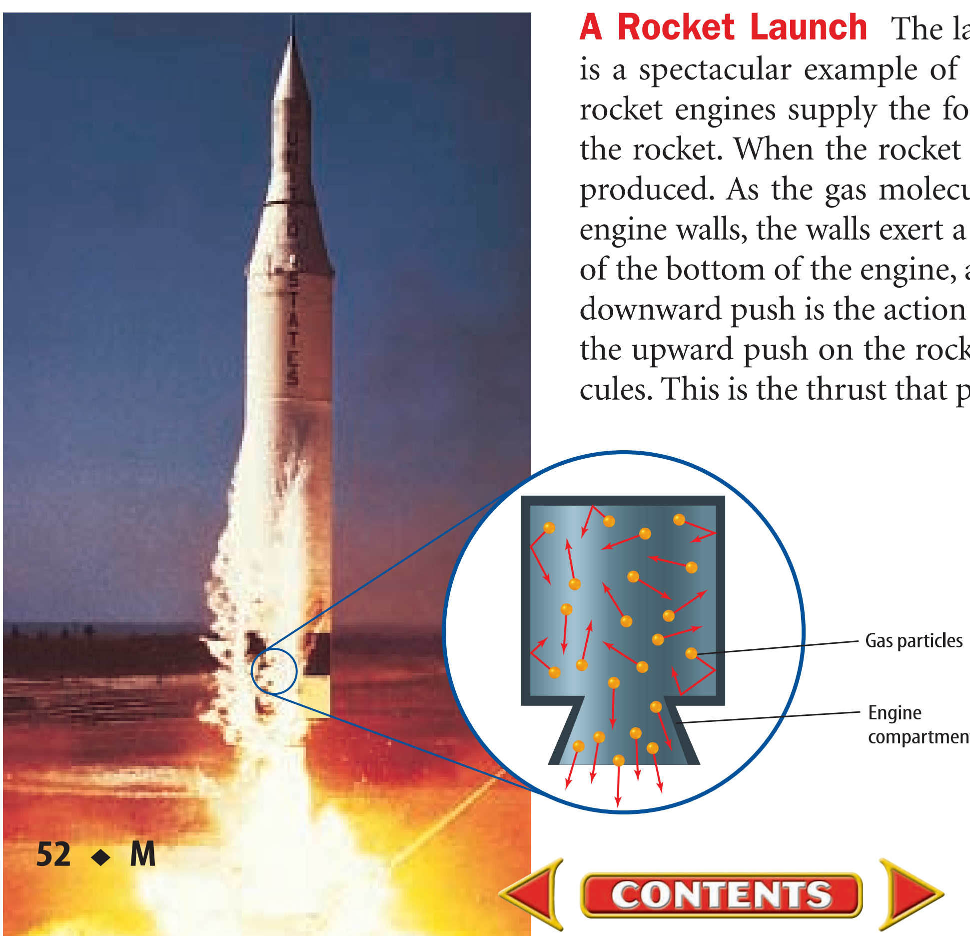


Figure 18
Newton's third law enables a rocket to fly. The rocket pushes the gas molecules downward, and the gas molecules push the rocket upward.

CONTENTS

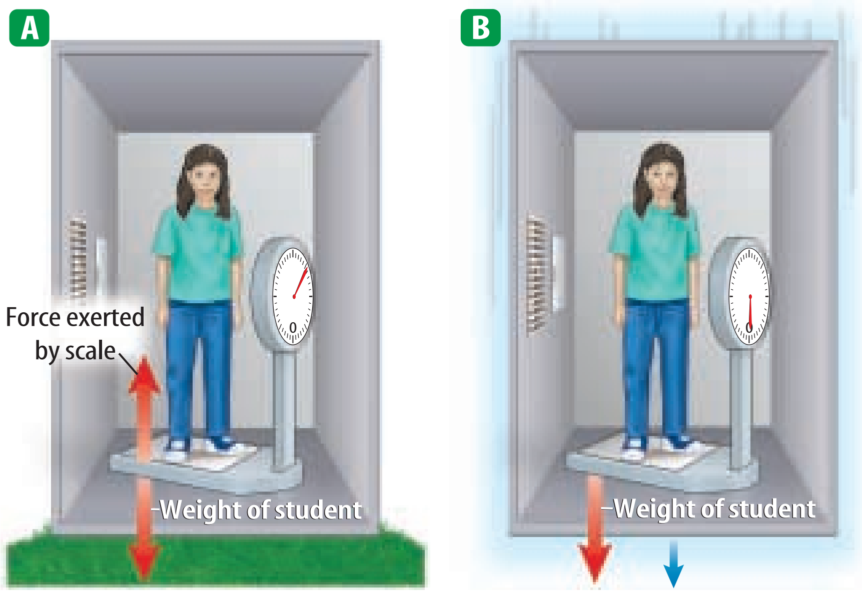


Figure 19
Your weight measured by a scale changes when you are falling. **A** When you stand on a scale on Earth, the reading on the scale is your weight. **B** If you were to stand on a scale in a falling elevator, the scale would read zero.

Weightlessness

You may have seen pictures of astronauts floating inside a space shuttle as it orbits Earth. The astronauts are said to be weightless, as if Earth's gravity were no longer pulling on them. Yet the force of gravity on the shuttle is still about 90 percent as large as at Earth's surface. Newton's laws of motion can explain why the astronauts float as if there were no forces acting on them.

Measuring Weight Think about how you measure your weight. When you stand on a scale, your weight pushes down on the scale and causes the springs in the scale to compress. The scale pointer moves from zero and points to your weight. At the same time, by Newton's third law the scale pushes up on you with a force equal to your weight, as shown in **Figure 19A.** This force balances the downward pull of gravity on you.

Free Fall and Weightlessness Now suppose you were standing on a scale in an elevator that is falling, as shown in **Figure 19B.** A falling object is in free fall when the only force acting on the object is gravity. Inside the free-falling elevator, you and the scale are both in free fall. Because the only force acting on you is gravity, the scale no longer is pushing up on you. According to Newton's third law, you no longer push down on the scale. So the scale pointer stays at zero and you seem to be weightless. **Weightlessness** is the condition that occurs in free fall when the weight of an object seems to be zero.

However, you are not really weightless in free fall because Earth is still pulling down on you. With nothing to push up on you, such as your chair, you would have no sensation of weight.

Mini LAB

Measuring Force Pairs

Procedure

1. Work in pairs. Each person needs a **spring scale.**
2. Hook the two scales together. Each person should pull back on a scale. Record the two readings. Pull harder and record the two readings.
3. Continue to pull on both scales, but let the scales move toward one person. Do the readings change?
4. Try to pull in such a way that the two scales have different readings.

Analysis

1. What can you conclude about the pair of forces in each situation?
2. Explain how this experiment demonstrates Newton's third law.

Weightlessness in Orbit To understand how objects move in the orbiting space shuttle, imagine you were holding a ball in the free-falling elevator. If you let the ball go, the position of the ball relative to you and the elevator wouldn't change, because you, the ball, and the elevator are moving at the same speed.

However, suppose you give the ball a gentle push downward. While you are pushing the ball, this downward force adds to the downward force of gravity. According to Newton's second law, the acceleration of the ball increases. So while you are pushing, the acceleration of the ball is greater than the acceleration of both you and the elevator. This causes the ball to speed up relative to you and the elevator. After it speeds up, it continues moving faster than you and the elevator, and it drifts downward until it hits the elevator floor.

Figure 20
These oranges seem to be floating because they are falling around Earth at the same speed as the space shuttle and the astronauts. As a result, they don't seem to be moving relative to the astronauts in the cabin.

When the space shuttle orbits Earth, the shuttle and all the objects in it are in free fall. They are falling in a curved path around Earth, instead of falling straight downward. As a result, objects in the shuttle appear to be weightless, as shown in **Figure 20.** A small push causes an object to drift away, just as a small downward push on the ball in the free-falling elevator caused it to drift to the floor.

Section 3 Assessment

1. You push a skateboard with a force of 6 N. If your mass is 60 kg, what is the force that the skateboard exerts on you?
2. You jump from a boat to a pier. As you move forward the boat moves backward. Explain.
3. What are the action and reaction forces when a hammer hits a nail?
4. Suppose you and a child that has half your mass are on skates. If the child gives you a push, who will have the greater acceleration? By how much?
5. **Thinking Critically** Suppose you are walking down the aisle of an airliner in flight. Use Newton's third law to describe the effect of your walk on the motion of the airliner.

Skill Builder Activities

6. **Solving One-Step Equations** A person standing on a canoe throws a cement block over the side. The action force on the cement block is 60 N. The reaction force is on the person and canoe. Their total mass is 100 kg. What is their acceleration? **For more help, refer to the Math Skill Handbook.**
7. **Communicating** Some people have trouble understanding Newton's third law. They reason, "If every action has an equal and opposite reaction, nothing ever will move." Explain why objects still can move. (Consider whether the forces act on the same or different objects.) **For more help, refer to the Science Skill Handbook.**

Activity

Balloon Races

A balloon and a rocket lifting off the launch pad have something in common. Both use Newton's third law. In this experiment, you will compare different balloon rocket designs. The balloon rocket is powered by escaping air, and its motion is determined by Newton's first, second, and third laws.

What You'll Investigate

How do Newton's laws explain the motion of different balloon rockets?

Materials

balloons of different sizes and shapes
drinking straws
string
tape
meterstick
stopwatch*
**clock*
**Alternate materials*

Safety Precautions

Goals

- **Measure** the speed of a balloon rocket.
- **Describe** how Newton's laws explain a rocket's motion.

Procedure

1. Run a string across the classroom to make a rocket path. Leave one end loose so you can place the rockets on the string easily.
2. Make a balloon rocket according to the diagram. Don't tie the balloon. Let it run down the track. Measure the distance it travels and the time it takes.
3. Repeat step 2 with different balloons.

Conclude and Apply

1. **Compare and contrast** the distances traveled. Which rocket went the greatest distance?
2. **Calculate** the average speed for each rocket. Compare and contrast them. Which rocket has the greatest average speed?
3. **Infer** which aspects of these rockets made them travel far or fast.
4. **Draw** a diagram showing all the forces acting on a balloon rocket.
5. Use Newton's laws of motion to explain the motion of a balloon rocket from launch until it comes to a stop.

Communicating Your Data

Discuss with classmates which balloon rocket traveled the farthest. Why? **For more help, refer to the Science Skill Handbook.**

Activity Design Your Own Experiment

Modeling Motion in Two Directions

When you move a computer mouse across a mouse pad, how does the rolling ball tell the computer cursor to move in the direction that you push the mouse? Inside the housing for the mouse's ball are two or more rollers that the ball rubs against as you move the mouse. They measure up-and-down and back-and-forth motions. What happens to the rollers when you move diagonally and at different angles?

Recognize the Problem

Can you move a golf ball from one point to another using forces in only two directions?

Form a Hypothesis

How can you combine forces to move in a straight line, along a diagonal, or around corners? Place a golf ball on something that will slide, such as a plastic lid. The plastic lid is called a skid. Lay out a course to follow on the floor. Write a plan for moving your golf ball along the path without having the golf ball roll away.

Possible Materials

masking tape
stopwatch*
** watch or clock with a second hand*
meterstick*
**metric tape measure*
spring scales marked in newtons (2)
plastic lid
golf ball*
**tennis ball*
**Alternate materials*

Goals

- **Move** the skid across the ground using two forces.
- **Measure** how fast the skid can be moved.
- **Determine** how smoothly the direction can be changed.

Safety Precautions

Test Your Hypothesis

Plan

1. Lay out a course that involves two directions, such as always moving forward or left.
2. Attach two spring scales to the skid. One always will pull straight forward. One always will pull to one side. You cannot turn the skid. If one scale is pulling toward the door of your classroom, it always must pull in that direction. (It can pull with zero force if needed, but it can't push.)
3. How will you handle movements along diagonals and turns?
4. How will you measure speed?
5. **Experiment** with your skid. How hard do you have to pull to counteract sliding friction at a given speed? How fast can you accelerate? Can you stop suddenly without spilling the golf ball, or do you need to slow down?
6. **Write** a plan for moving your golf ball along the course by pulling only forward or to one side. Be sure you understand your plan and have considered all the details.

Do

1. Make sure your teacher approves your plan before you start.
2. Move your golf ball along the path.
3. Modify your plan, if needed.
4. **Organize** your data so they can be used to run your course and write them in your Science Journal.
5. **Test** your results with a new route.

Analyze Your Data

1. What was the difference between the two routes? How did this affect the forces you needed to use on the golf ball?
2. How did you separate and control variables in this experiment?
3. Was your hypothesis supported? Explain.

Draw Conclusions

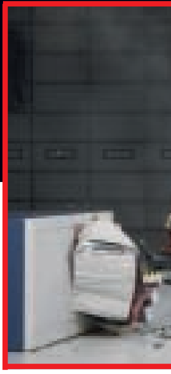
1. What happens when you combine two forces at right angles?
2. If you could pull on all four sides (front, back, left, right) of your skid, could you move anywhere along the floor? Make a hypothesis to explain your answer.

Communicating Your Data

Compare your conclusions with those of other students in your class. **For more help, refer to the Science Skill Handbook.**

Air Bag Safety

After complaints and injuries, air bags in cars are helping all passengers



The car in front of yours stops suddenly. Your mom slams on the brakes, but not fast enough. You hear the crunch of car against car and feel your seat belt grab you. You look up at your mom in the front seat. She's covered with, not blood, thank goodness, but with a big white cloth. You are both okay. Your seat belts and air bags worked perfectly.

Popcorn in the Dash

Air bags have saved more than a thousand lives since 1992. They are like having a giant popcorn kernel in the dashboard that pops and becomes many times its original size. But unlike popcorn, an air bag is triggered by impact, not heat. When the air bag sensor picks up the vibrations of a crash, a chemical reaction is started. The reaction produces a gas that expands in a split second, inflating a balloonlike bag to cushion the driver and possibly the front-seat passenger. The bag deflates just as quickly so it doesn't trap people in the car.

Newton and the Air Bag

When you're traveling in a car, you move with it at whatever speed it is going. According to Newton's first law, you are the object in motion, and you will continue in motion unless acted upon by a force, such as a car crash.

Unfortunately, a crash stops the car, but it doesn't stop you, at least, not right away. You continue moving forward if your car doesn't have air bags or if you haven't buckled your seat belt. You stop when you strike the inside of the car. You hit the dashboard or steering wheel while traveling at the speed of the car. When an air bag inflates, it becomes the force acting on the moving object—you—and it stops you more gently.

A test measures the speed at which an air bag deploys.

Car manufacturers perform safety tests using dummies and air bags. The dummy is wearing a seat belt to simulate a human driver.

Unexpected Impact

"Our biggest issue was that air bags were not only helpful but dangerous—small children were being harmed by air bags," notes Betsy Ancker-Johnson, a spokesperson for an automobile-maker. She was referring to the fact that air bags pop out with so much force that they have sometimes hurt or killed children and small adults. For this reason, children under the age of 12 should ride in the back seat only, with seat belts buckled. Small adults may have their air bags turned off. Car makers are developing "smart" air bags that will expand just enough to protect a passenger no matter what the size or weight.

CLICK HERE

CONNECTIONS Measure Draw a steering wheel on a paper plate. Ask classmates to hold it 26 cm in front of them. That's the length drivers should have between the chest and the wheel to make air bags safe. Use a tape measure to check. Inform adult drivers in your family about this safety distance.

SCIENCE Online
For more information, visit science.glencoe.com

Chapter 2 Study Guide

Reviewing Main Ideas

Section 1 Newton's First Law

1. A force is a push or a pull.
2. The net force is the combination of all the forces acting on an object.
3. Newton's first law states that objects in motion tend to stay in motion and objects at rest tend to stay at rest unless acted upon by a net force. *Why don't objects in motion on Earth, like a soccer ball, stay in motion forever?*

4. Friction is a force that resists motion between surfaces that are touching each other.

Section 2 Newton's Second Law

1. Newton's second law states that an object acted upon by a net force will accelerate in the direction of this force.
2. The acceleration due to a net force is given by the equation $a = F_{net}/m$. *If a baseball bat hits a bowling ball, why doesn't the bowling ball accelerate as quickly as a baseball that is hit just as hard?*

3. The force of gravity between two objects depends on their masses and the distance between them.
4. In circular motion, a force pointing toward the center of the circle acts on an object.

Section 3 Newton's Third Law

1. According to Newton's third law, the forces two objects exert on each other are always equal but in opposite directions. *What are the action and reaction forces acting on the skaters below?*

2. Action and reaction forces don't cancel because they act on different objects.
3. Action and reaction forces are involved in actions such as walking and jumping. Objects in orbit appear to be weightless because they are in free fall around Earth.

After You Read

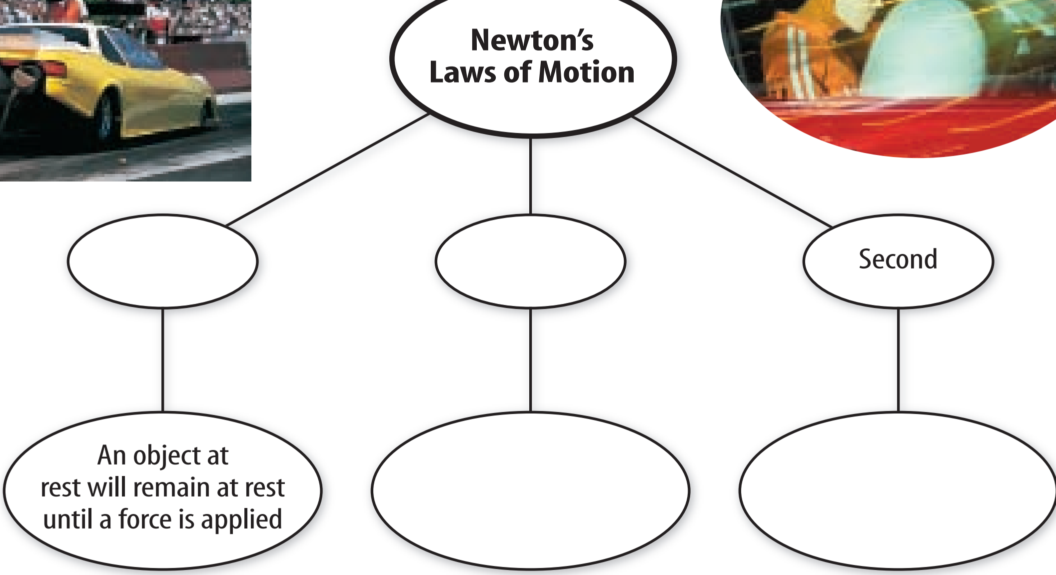
FOLDABLES Reading & Study Skills

Use the information in your Foldable to help you think of concrete examples for each law of motion. Write them under the tabs.

Chapter 2 Study Guide

Visualizing Main Ideas

Fill in the following concept map on Newtons's laws of motion.



Vocabulary Review

Vocabulary Words

a. balanced forces
b. force
c. friction
d. net force
e. Newton's first law of motion
f. Newton's second law of motion
g. Newton's third law of motion
h. unbalanced forces
i. weight
j. weightlessness

THE PRINCETON REVIEW

Study Tip

When you read a chapter, make a list of things you find confusing or do not completely understand. Then ask your teacher to explain them.

Using Vocabulary

Explain the differences between the terms in the following sets.

1. force, inertia, weight
2. Newton's first law of motion, Newton's third law of motion
3. friction, force
4. net force, balanced forces
5. weight, weightlessness
6. balanced forces, unbalanced forces
7. friction, weight
8. Newton's first law of motion, Newton's second law of motion
9. friction, unbalanced force
10. net force, Newton's third law of motion

Chapter 2 Assessment

Checking Concepts

Choose the word or phrase that best answers the question.

1. Which of the following changes when an unbalanced force acts on an object?
A) mass
B) motion
C) inertia
D) weight

2. Which of the following is the force that slows a book sliding on a table?
A) gravity
B) static friction
C) sliding friction
D) inertia

3. What combination of units is equivalent to the newton?
A) m/s^2
B) $kg \cdot m/s$
C) $kg \cdot m/s^2$
D) kg/m

4. What is a push or pull a definition of?
A) force
B) momentum
C) acceleration
D) inertia

5. What is the type of friction that is important to walking?
A) static friction
B) sliding friction
C) rolling friction
D) air resistance

6. An object is accelerated by a net force in which direction?
A) at an angle to the force
B) in the direction of the force
C) in the direction opposite to the force
D) Any of these is possible.

7. If you exert a net force of 8 N on a 2-kg object, what will its acceleration be?
A) 4 m/s^2
B) 6 m/s^2
C) 12 m/s^2
D) 16 m/s^2

8. You are riding on a bike. In which of the following situations are the forces acting on the bike balanced?
A) You pedal to speed up.
B) You turn at constant speed.
C) You coast to slow down.
D) You pedal at constant speed.

9. Which of the following has no direction?
A) force
B) acceleration
C) weight
D) mass

10. You push against a wall with a force of 5 N. What is the force the wall exerts on your hands?
A) 0 N
B) 2.5 N
C) 5 N
D) 10 N

Thinking Critically

11. A baseball is pitched east at a speed of 40 km/h. The batter hits it west at a speed of 40 km/h. Did the ball accelerate? Explain.

12. Frequently, the pair of forces acting between two objects are not noticed because one of the objects is Earth. Explain why the force acting on Earth isn't noticed.

13. A car is parked on a hill. The driver starts the car, accelerates until the car is driving at constant speed, drives at constant speed, and then brakes to put the brake pads in contact with the spinning wheels. Explain how static friction, sliding friction, rolling friction, and air resistance are acting on the car.

14. You hit a hockey puck and it slides across the ice at nearly a constant speed. Is a force keeping it in motion? Explain.

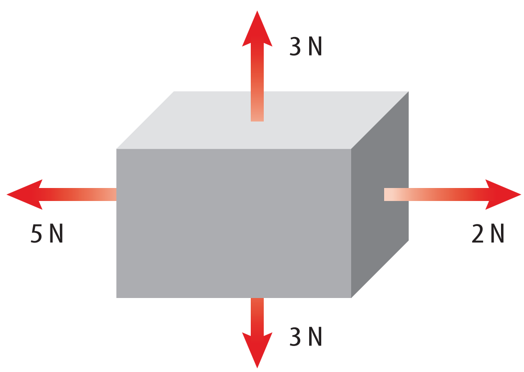
15. Newton's third law describes the forces between two colliding objects. Use this connection to explain the forces acting when you kick a soccer ball.

Developing Skills

16. Recognizing Cause and Effect Use Newton's third law to explain how a rocket accelerates upon takeoff.

17. Prediciting Two balls of the same size and shape are dropped from a helicopter. One ball has twice the mass of the other ball. On which ball will the force of air resistance be greater when terminal velocity is reached?

18. Interpreting Scientific Illustrations Is the force on the box balanced? Explain.



19. Solving One-Step Equations A 0.4-kg object accelerates at 2 m/s^2. Find the force.

Performance Assessment

20. Oral Presentation Research one of Newton's laws of motion and compose an oral presentation. Provide examples of the law. You might want to use a visual aid.

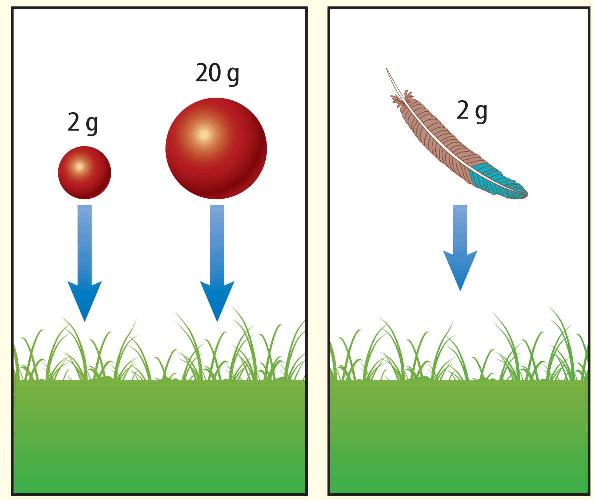
21. Writing in Science Create an experiment that deals with Newton's laws of motion. Document it using the following subject heads: *Title of Experiment, Partners' Names, Hypothesis, Materials, Procedures, Data, Results,* and *Conclusion.*

Technology

Go to the Glencoe Science Web site at **science.glencoe.com** or use the **Glencoe Science CD-ROM** for additional chapter assessment.

THE PRINCETON REVIEW Test Practice

The following diagram shows an experiment in which data were collected about falling objects.



Study the diagram above and then answer the following questions about the experiment.

1. Which of these is the most likely hypothesis for the experiment depicted in the box on the left above?

A) The more mass an object has, the faster it will travel.

B) The less mass an object has, the faster it will travel.

C) Objects with less mass travel faster than objects with more mass.

D) Objects of different masses can still travel at the same speed.

2. The feather is traveling at a different speed than the balls because the feather _____.

F) has more gravity acting upon it

G) has less gravity acting upon it

H) has more friction acting upon it

J) has less friction acting upon it