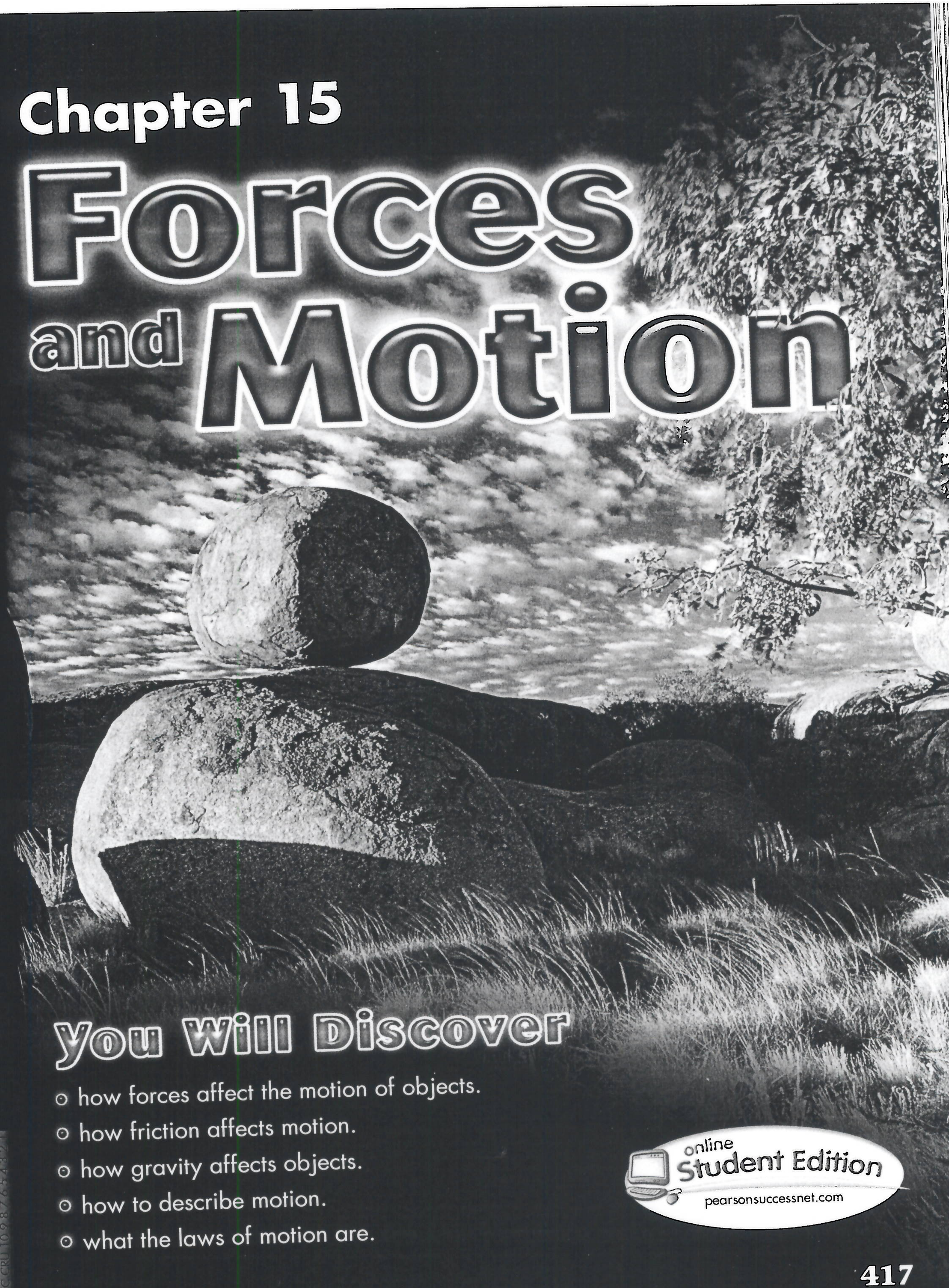

# Chapter 15

# Forces and Motion

## You Will Discover

- how forces affect the motion of objects.
- how friction affects motion.
- how gravity affects objects.
- how to describe motion.
- what the laws of motion are.



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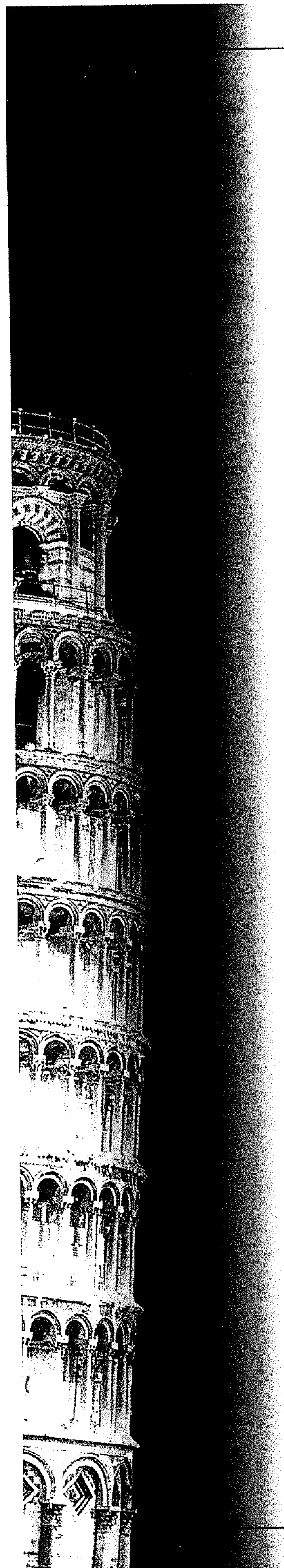
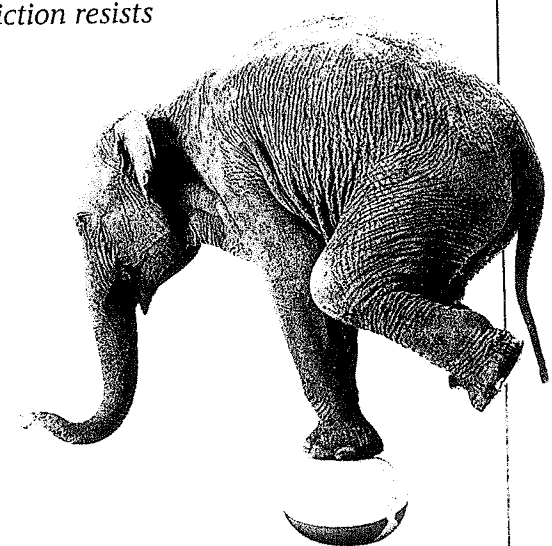
Lesson 1

# What happens when forces act on objects?

*Some forces act only if objects touch. Others can act at a distance. More than one force usually acts on an object. Friction resists the motion of two surfaces past each other.*





The elephant applies a force against the ball.

## Forces

How can this elephant balance on a ball? Like the Leaning Tower of Pisa, the elephant stays upright because of the forces acting on it. A **force** is a push or pull. A force has both size and direction.

Some forces act only if objects touch. For example, when you use your hands to push a heavy box, your hands and the box touch. The elephant touches the ball while pushing down on it. The ball touches the elephant as it pushes upward.

Other forces act even if objects do not touch. Earth's gravity pulls on you when you jump up. Objects with an electrical charge attract or repel each other from a distance. If two magnets are close, you can feel them pushing or pulling on each other without touching.

## Measuring Forces

Forces are measured in units called newtons (N). One newton is the force needed to change the speed of a one-kilogram object by one meter per second each second. You need a force of about one newton to lift a small apple. Force can be measured using a spring scale. You attach an object to one end of the scale and hold up the other end. A spring inside stretches to show the force needed to support the object.

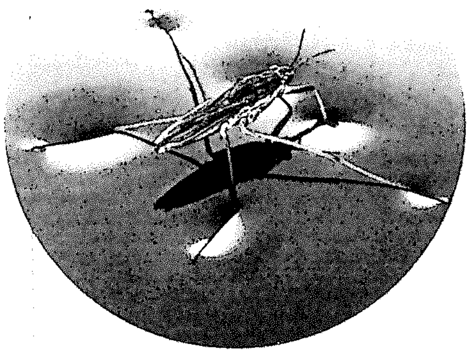
1. **Checkpoint** What two things should you describe about a force that acts on an object?
2. Writing in Science **Descriptive** Tell about a situation in which a force acts when objects touch. Describe another situation in which a force acts at a distance.

## Forces on Objects

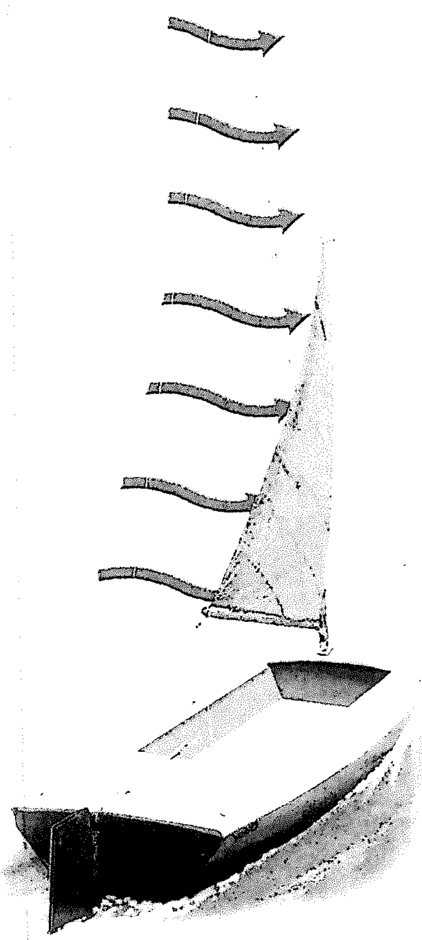
A high-flying kite soars through the air, swerving up and around. What forces are acting on the kite? The weight of the kite pulls it down, and the force of the wind pushes it up. You guide the kite by applying force to the string. Like the kite, most objects have more than one force acting on them.

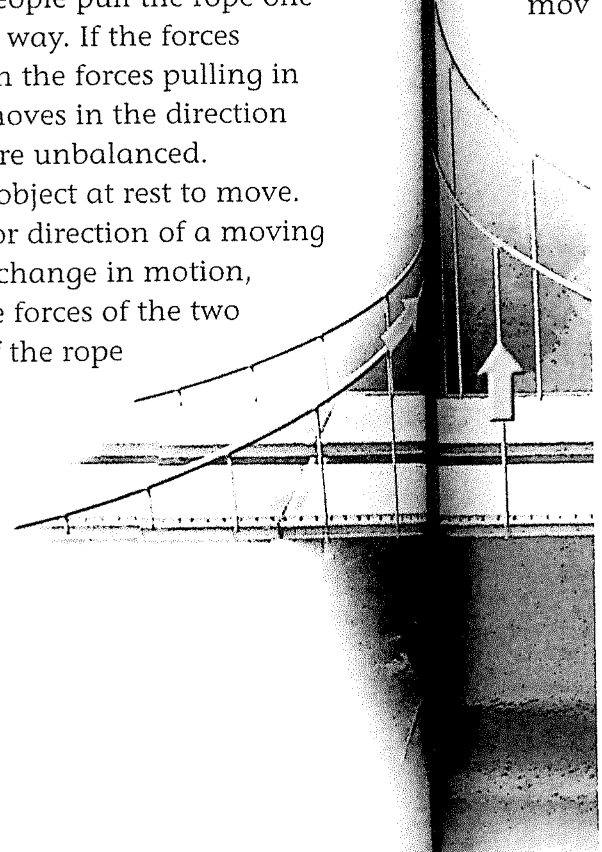
The combination of all of the forces acting on an object determines the effect of the forces. Some forces act in the same direction. Others act in different directions.

You might compare the forces acting on an object to a tug-of-war with a rope. Some people pull the rope one way, and others pull the opposite way. If the forces pulling one way are stronger than the forces pulling in the opposite direction, the rope moves in the direction of the stronger force. The forces are unbalanced. Unbalanced forces can cause an object at rest to move. They can also change the speed or direction of a moving object. Balanced forces cause no change in motion, even if an object is moving. If the forces of the two sides are the same, the motion of the rope doesn't change.

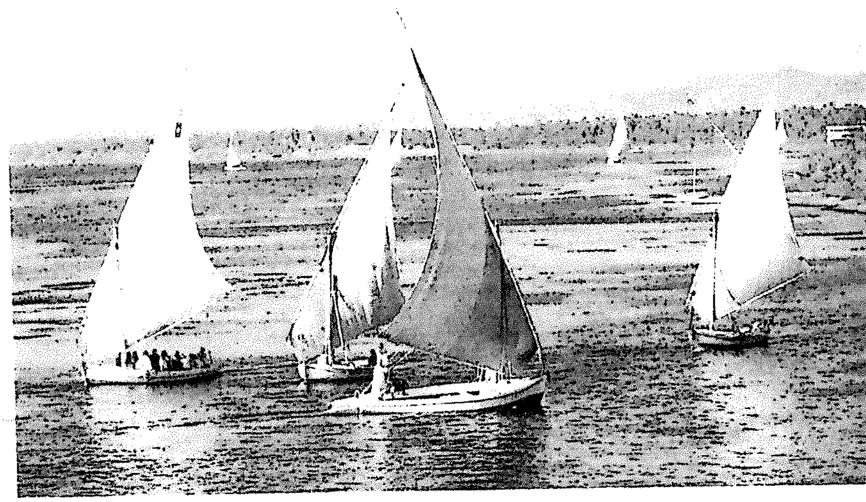


The downward force of a water strider on the water is balanced by the upward force of the water on the water strider.





The force of the wind against the sail causes a sailboat to move through water. By rotating the sail, the sailboat's direction of motion can be changed.



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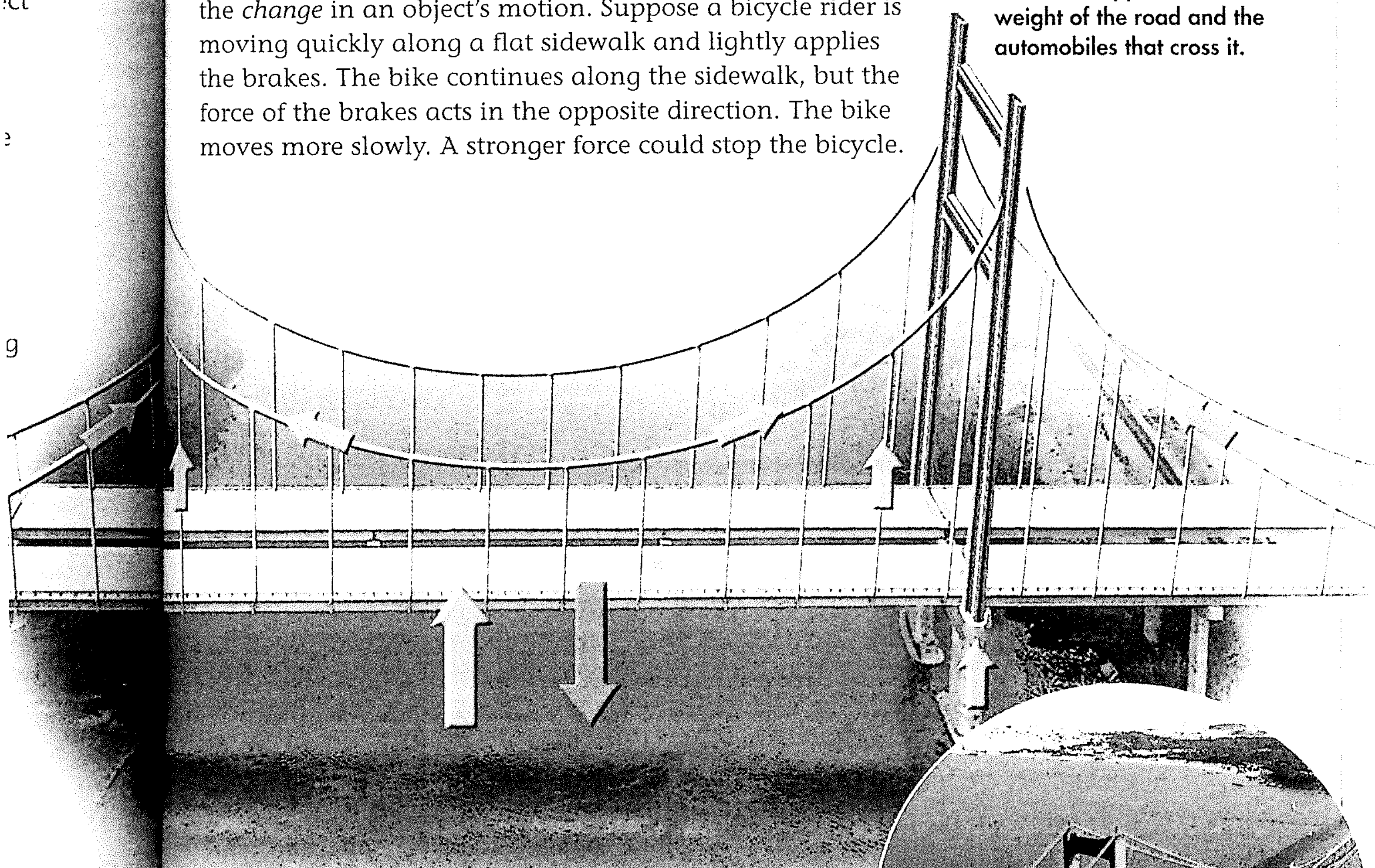
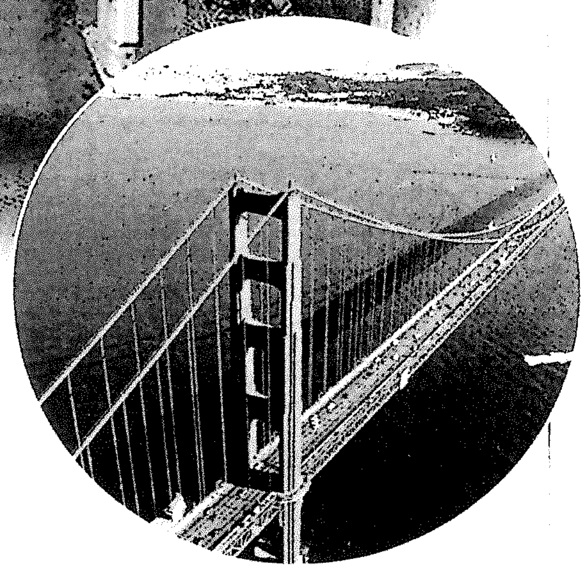
To find the overall effect of forces acting on an object, you add the forces together. The resulting force is called the net force. It works like this: If a 5 N force pulls an object to the right, and a 3 N force pulls to the left, the overall effect is the same as a 2 N force pulling to the right. The net force is 2 N to the right.

The net force on an object, however, doesn't always determine the direction that an object moves. It determines the *change* in an object's motion. Suppose a bicycle rider is moving quickly along a flat sidewalk and lightly applies the brakes. The bike continues along the sidewalk, but the force of the brakes acts in the opposite direction. The bike moves more slowly. A stronger force could stop the bicycle.

**The arrows show the directions of forces that allow the strong wire cables to support the weight of the road and the automobiles that cross it.**





**Balanced forces are needed for a safe suspension bridge.**

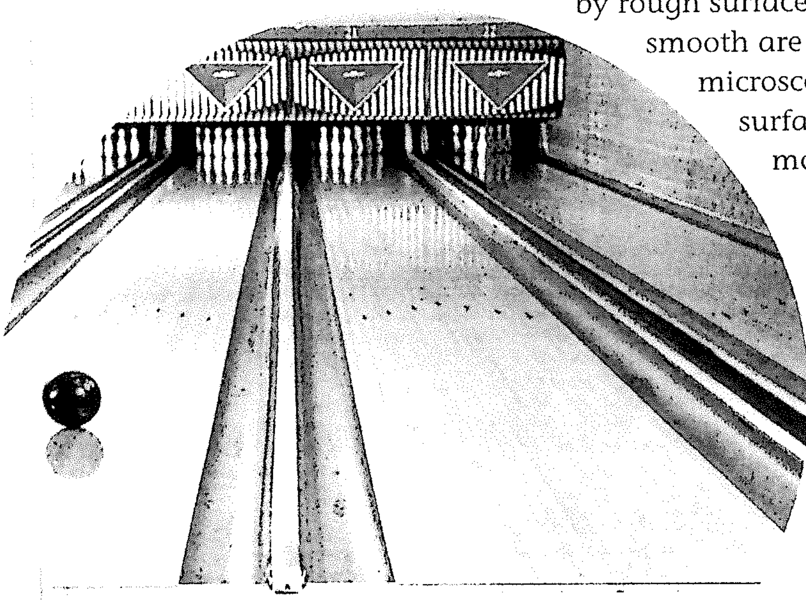
1. ✓ Checkpoint How do balanced forces affect the motion of an object?
2. Predict Draw and label arrows showing forces acting on a ball that is rolling to the right. A 15 N force pushes to the right. A 9 N force pushes to the left. What is the net force on the ball? How will the net force affect the motion of the ball?

## Friction

Why does a soccer ball slow down when you roll it across the ground? Friction is the reason. **Friction** is the force that resists the movement of one surface past another. The rough surface of the ground stops the soccer ball by pushing against it. Friction is a force opposite of the direction of the ball's motion.

The table describes three types of friction. Rolling friction and sliding friction act on objects that are moving. Rolling friction resists the motion of a skateboard's wheels. Pushing a heavy box across the floor is hard because of sliding friction. The box is easier to push, however, after it starts to move. When you first push on the box, static friction resists its movement. Static friction is usually stronger than sliding friction.

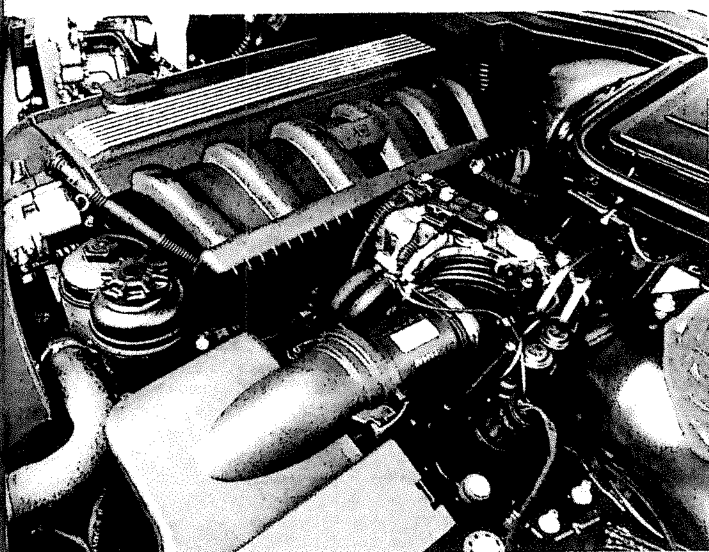
| Type of Friction | Description |
|---|---|
| Rolling | Resists the motion of a rolling object |
| Sliding | Resists the motion of a sliding object |
| Static | Resists the motion of an object just as it begins to move |



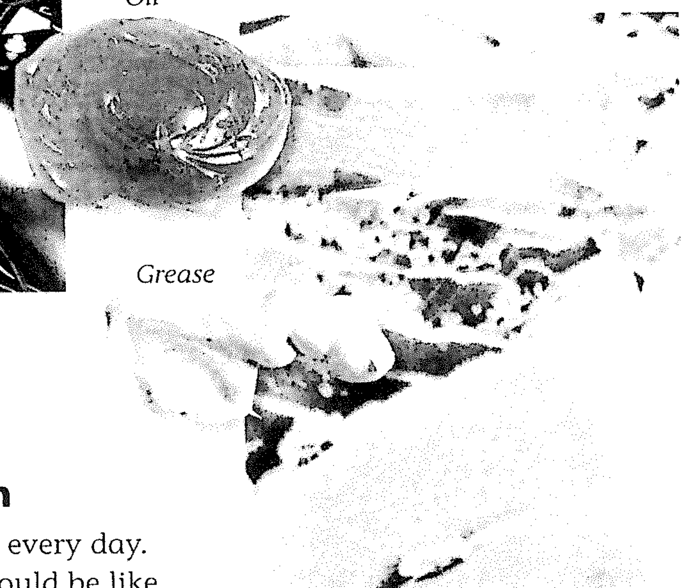
The floor of a bowling lane must be polished to reduce rolling friction between the wood and the ball.

Friction depends on the type of surfaces rubbing against each other and how strongly they are pushed together. Friction is mainly caused by rough surfaces. Even surfaces that seem to be smooth are rough if you look at them with a microscope. Tiny bumps and holes on the surfaces catch on each other, slowing the movement of the surfaces.

Friction usually is greater for rougher surfaces. If both surfaces are very smooth and flat, however, the attraction of their particles increases their friction. A soft or rubbery surface also has more friction because it easily bends. Movement also may be slowed when the particles of the two surfaces attract. The surfaces then stick to each other.



Heat produced by friction can wear out these engine parts and reduce efficiency.




Oil and grease are used on engine parts to decrease friction by reducing contact between rough surfaces.

## Helpful and Harmful Friction

Friction is useful for many things you do every day. Without friction, walking across a room would be like walking on ice. You depend on friction between your feet and the floor to keep you from slipping. If you ride on a scooter, friction between the wheels and the ground keep you from spinning your wheels. Friction also prevents your feet from slipping off the scooter. When the driver of a car applies the brakes, friction of the brake pads against the brake drum slows the car.

Friction can also be harmful. When objects rub together, heat is produced. If you rub your hands together quickly, your hands begin to feel warm. Energy from your hands changes to thermal energy because of the friction of your hands. Heat produced by friction makes engines run less efficiently. Friction between wind and soil can cause erosion. Friction also wears away the rubber on car tires and forms holes in the soles of shoes.

√ Lesson Checkpoint

1. Give an example of static friction on an object.
2. Name a way not mentioned in the text that friction is helpful.
3. Writing in Science **Expository** Explain how the usefulness of machine parts depends on the materials they are made from and how well they fit together.

The metal surface of a car's engine may feel smooth, but this photo, taken with an electron microscope, shows the many bumps and cuts in the surface that can increase friction.

Lesson 2

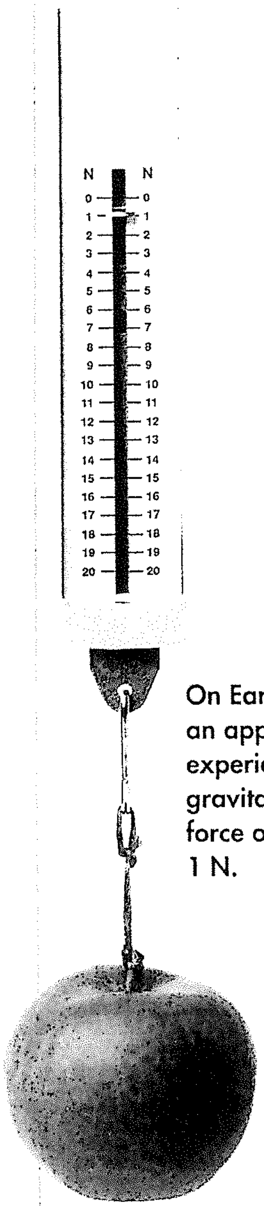
# How does gravity affect objects?

*All objects exert a gravitational pull on all other objects. Gravitational force affects objects on Earth as well as stars, planets, and all other objects in the universe.*

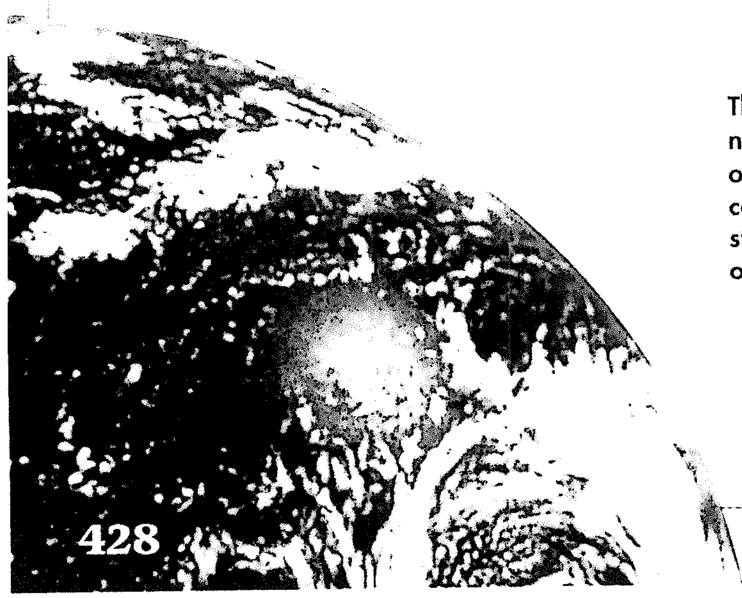
## Gravitational Force

Toss a ball into the air and you know it will fall down. Earth's gravity pulls all objects on Earth toward Earth's center. But the pull of Earth's gravity isn't the only gravitational force. **Gravitational force** is the force of attraction between any object and every other object in the universe. Gravitational force holds water in the oceans and holds the air near Earth. It affects the way plants grow and the way your bones develop. Life on Earth depends on gravity in many ways.

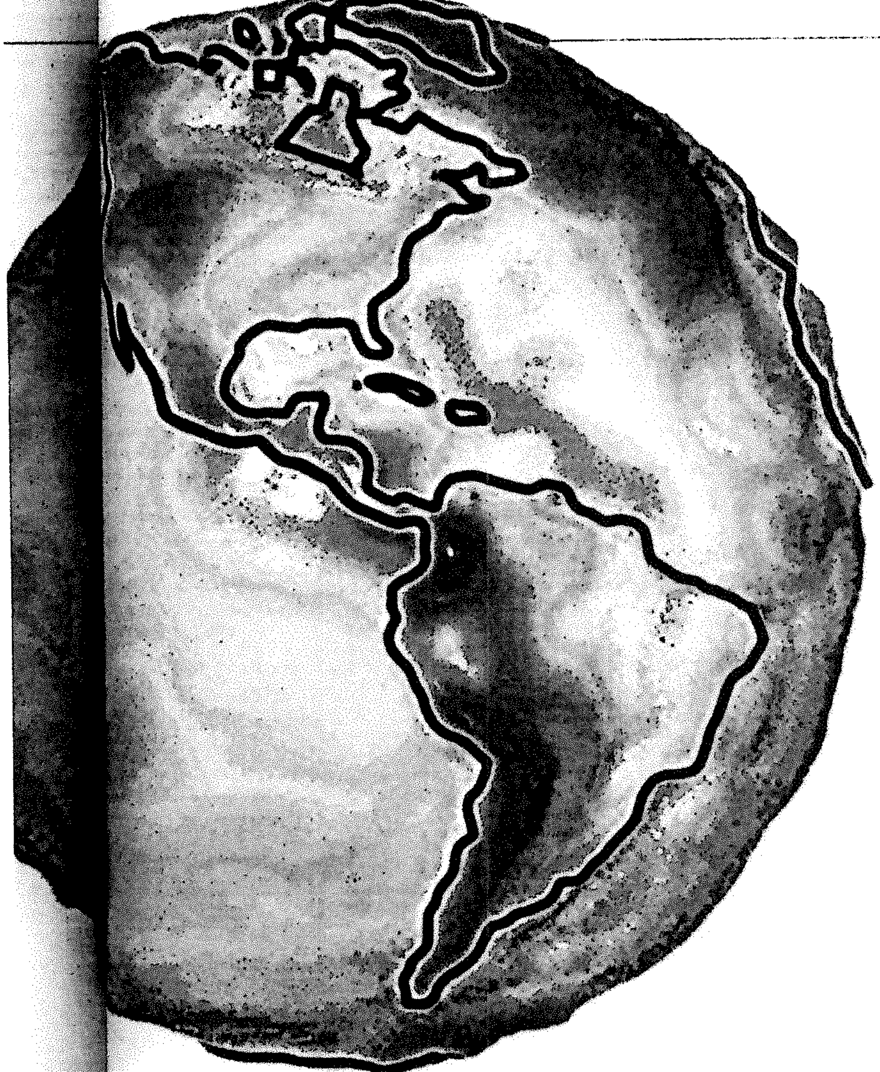
In the 17th century, Isaac Newton, an English scientist, was the first to explain many details about gravity. He realized that gravity depends on the masses of the two objects that exert gravitational forces on each other. The greater the mass of an object, the stronger its gravitational force. The book you are reading pulls on you with a gravitational attraction, and you pull on the book. You don't feel the gravitational pull of the book because both you and the book have low mass. But you feel Earth's gravity because Earth has such a large mass. Astronauts on the Moon experience a lower gravitational force because the Moon has less mass than Earth.



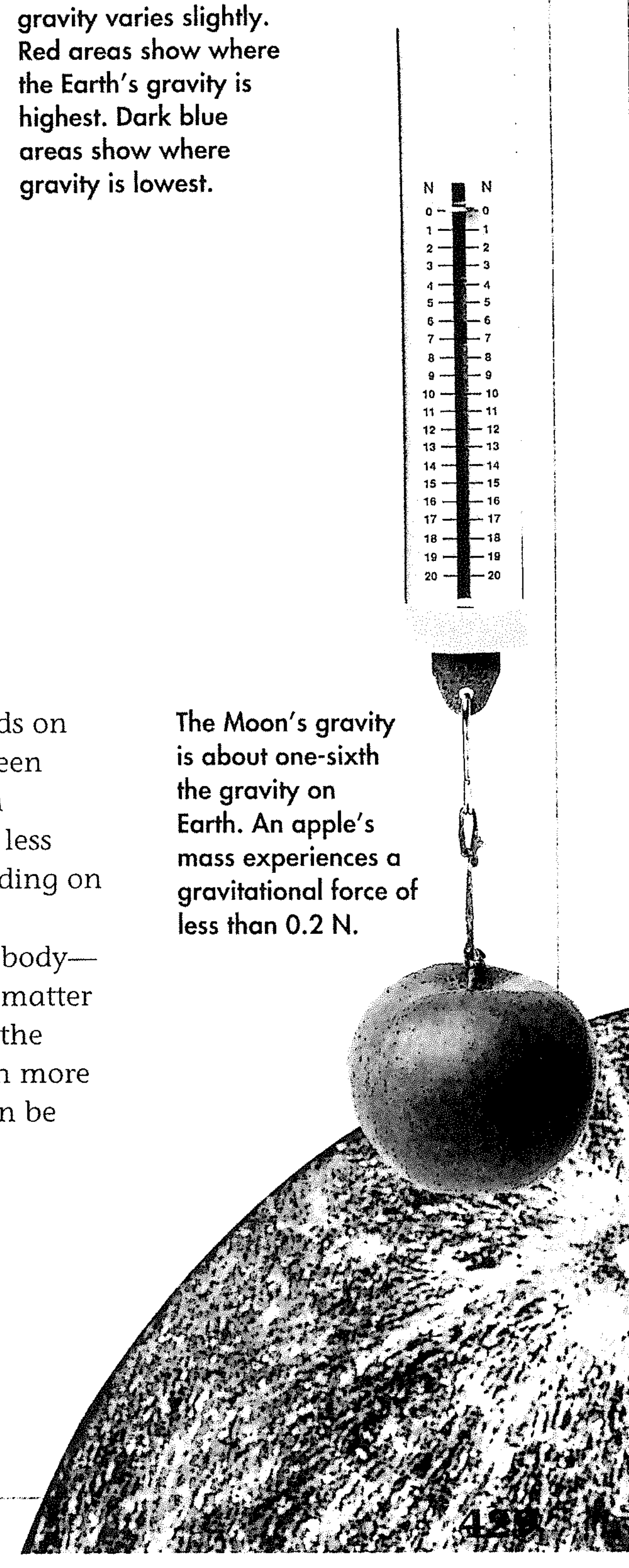

On Earth an apple experiences a gravitational force of about 1 N.



The metric unit of force, a newton, is named in honor of Isaac Newton, the 17th century physicist who studied gravity and other forces.



Gravitational force is not the same at all places on Earth. This gravitational map shows how Earth's gravity varies slightly. Red areas show where the Earth's gravity is highest. Dark blue areas show where gravity is lowest.




The Moon's gravity is about one-sixth the gravity on Earth. An apple's mass experiences a gravitational force of less than 0.2 N.

Newton also realized that gravitational force depends on the distance between two objects. If the distance between objects increases, the gravitational pull between them decreases. Earth's gravitational pull on you is slightly less when you are in an airplane than when you are standing on Earth's surface.

You can measure Earth's gravitational pull on your body—just weigh yourself. An object's mass—the amount of matter that makes up the object—is the same everywhere in the universe. Weight depends on your location. You weigh more on Earth than on the Moon. Like all forces, weight can be measured in newtons.

1. √ **Checkpoint** Why don't you notice the gravitational pull of your school desk?
2. **Health in Science** Explain why your weight would change if you went to the Moon but your mass would not.

Lesson 3

# How can you describe motion?

*A description of motion depends on the frame of reference from which the motion is viewed. Speed, velocity, and acceleration are used to describe motion.*

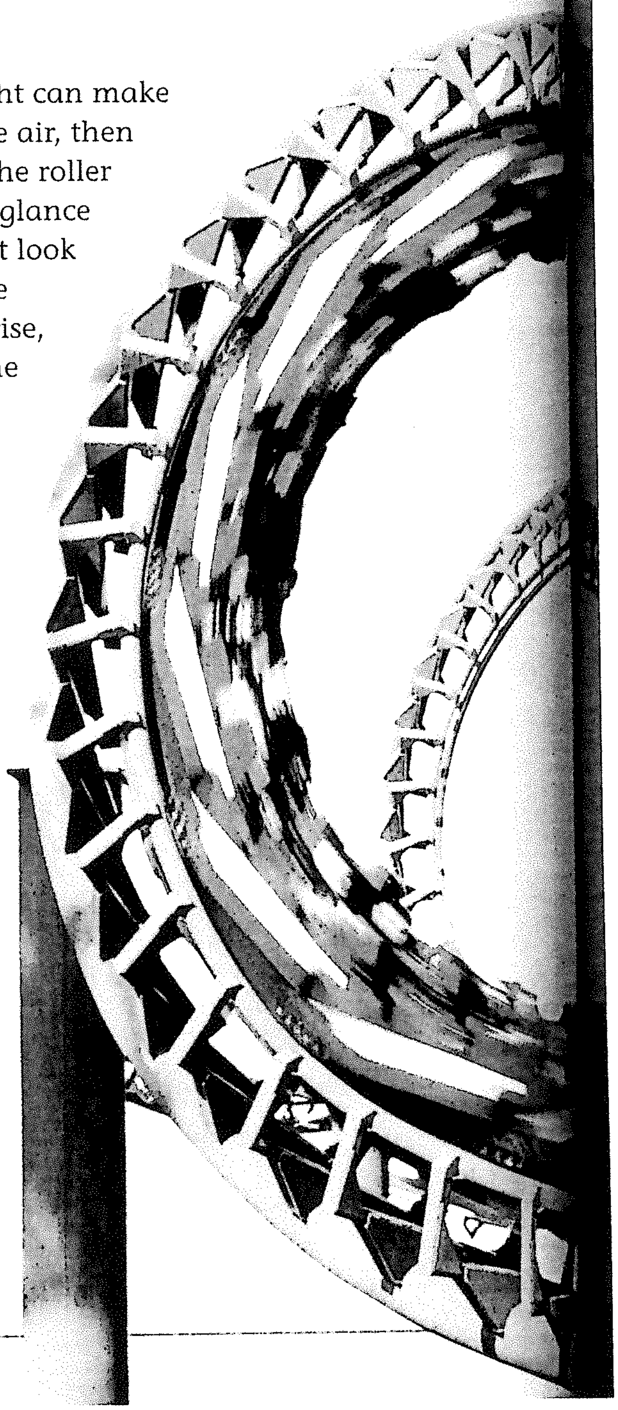
## Observing Motion

Riding on a roller coaster like the one to the right can make you feel as if you are flying. You rise high into the air, then down again, over and over. What do you see as the roller coaster moves around? At the highest point, you glance down and see other rides, games, and people that look very small. As you loop downward, objects on the ground seem to move toward you. Then, as you rise, objects on the ground seem to move away. Are the objects on the ground actually moving?

In order to determine an object's motion, you must view it in relation to another object that appears to stay in place. In other words, the way you describe motion depends on your frame of reference. A frame of reference is the object an observer uses to detect motion.

When riding on a roller coaster, the seat in which you ride may be your frame of reference. In that case, you aren't moving relative to the seat. If you use the ground as your frame of reference, however, the ground seems perfectly still. The chair in which you are riding appears to move up, around, and down.

How would you describe your motion right now? Motion is usually described using Earth as a frame of reference. If you are sitting still, you are not in motion relative to Earth. Relative to the Sun, however, Earth is whirling through space. Earth is also spinning on its axis. You are not aware of these motions because objects around you are also motionless in this frame of reference.



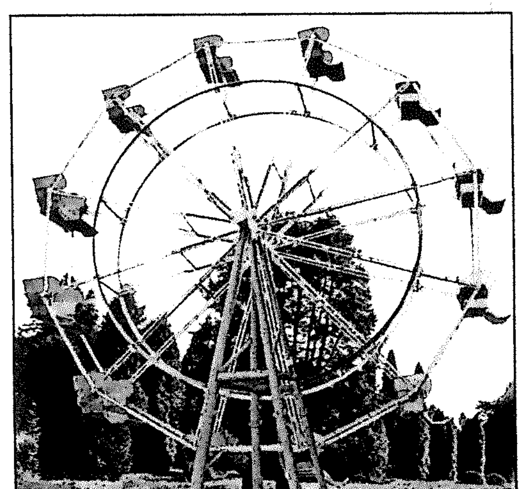
## Kinds of Motion

How would you describe the motion of one of the seats on the Ferris wheel? Its path is called circular motion. Circular motion takes place around a central point. The central point for the seat's motion is the axle of the ride. When a roller coaster travels in its loops, it too is using circular motion. Other examples of circular motion include the orbits of planets around the Sun and the wheel of a bicycle as it turns to move the bike.

Although the wheel of the bicycle moves in a circular pattern, the bike itself travels in a straight line. Straight-line motion can be seen as you watch a parade move down a street or when someone makes a "bee line" for the door.

Circular motion and straight-line motion may be easy to observe. Vibrational motion can be more difficult to see. A vibration is a rapid back-and-forth movement. The strings on a cello vibrate to make sounds, as do your vocal cords.

**A person observing this Ferris wheel from the ground probably would say the seats are moving. How does using the red supports that hold up the wheel as a frame of reference show motion?**



**If you were riding in the blue seat at the top left and using the seat as your frame of reference, the ground would appear to first move farther away and then move closer.**

1. √ **Checkpoint** Describe the motion of a bus from the point of reference of a person riding on the bus.
2. Writing in Science **Narrative** Write a short paragraph describing the motion of a boy on a skateboard zooming past a cat. Write from the frame of reference of the boy. Then write another paragraph from the frame of reference of the cat.

## Calculating Speed

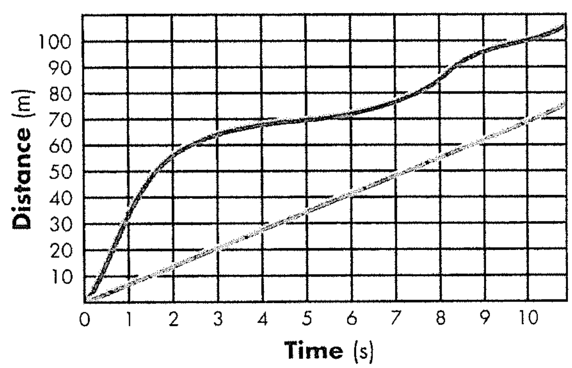
The bus below is winding its way along the hilly road. How can you figure out its speed? **Speed** is a measure of how fast an object is moving.

You can find speed by dividing the distance traveled by the time needed to move that distance. Speed is often measured in kilometers per hour. If the bus travels between two points that are 9 kilometers apart in 10 minutes, you can find its speed using this equation:

$$\text{average speed} = \frac{\text{distance}}{\text{time}} = \frac{9 \text{ km}}{10 \text{ min}} \times \frac{60 \text{ min}}{1 \text{ h}} = 54 \text{ km/h}$$

This speed for the entire trip—54 km/h—is the average speed of the trip. But the bus probably didn't travel at the same speed during the entire trip. An object's speed at any moment is instantaneous speed. The speedometer of a car tells the instantaneous speed that the car is traveling.

**From a distance/time graph, you can infer whether a moving object's instantaneous speed is changing. A straight line indicates constant speed.**




## Velocity

How does the bus's motion change if it makes the trip in the opposite direction? The distance traveled is the same. It may also have the same travel time. So the bus's average speed would remain the same. The direction of motion, however, is different. Its velocity also changes.

**Velocity** is the speed of an object in a particular direction. On the bus's first trip, its velocity would be 54 km/h east. On the return trip, its velocity would be 54 km/h west. A change in either speed or direction causes a change in velocity.

The velocity of an object moving along a curved path constantly changes even if the speed of the object is constant. The velocity changes because the direction of the object is always changing.

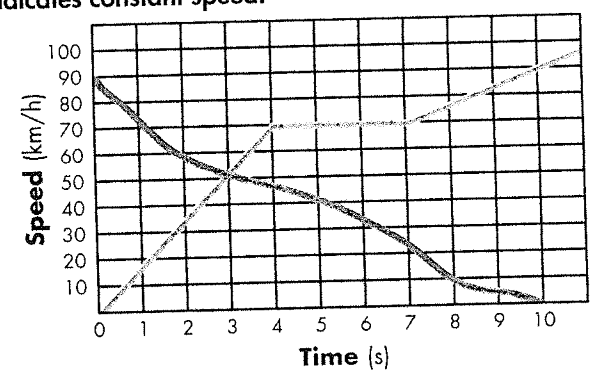
## Acceleration

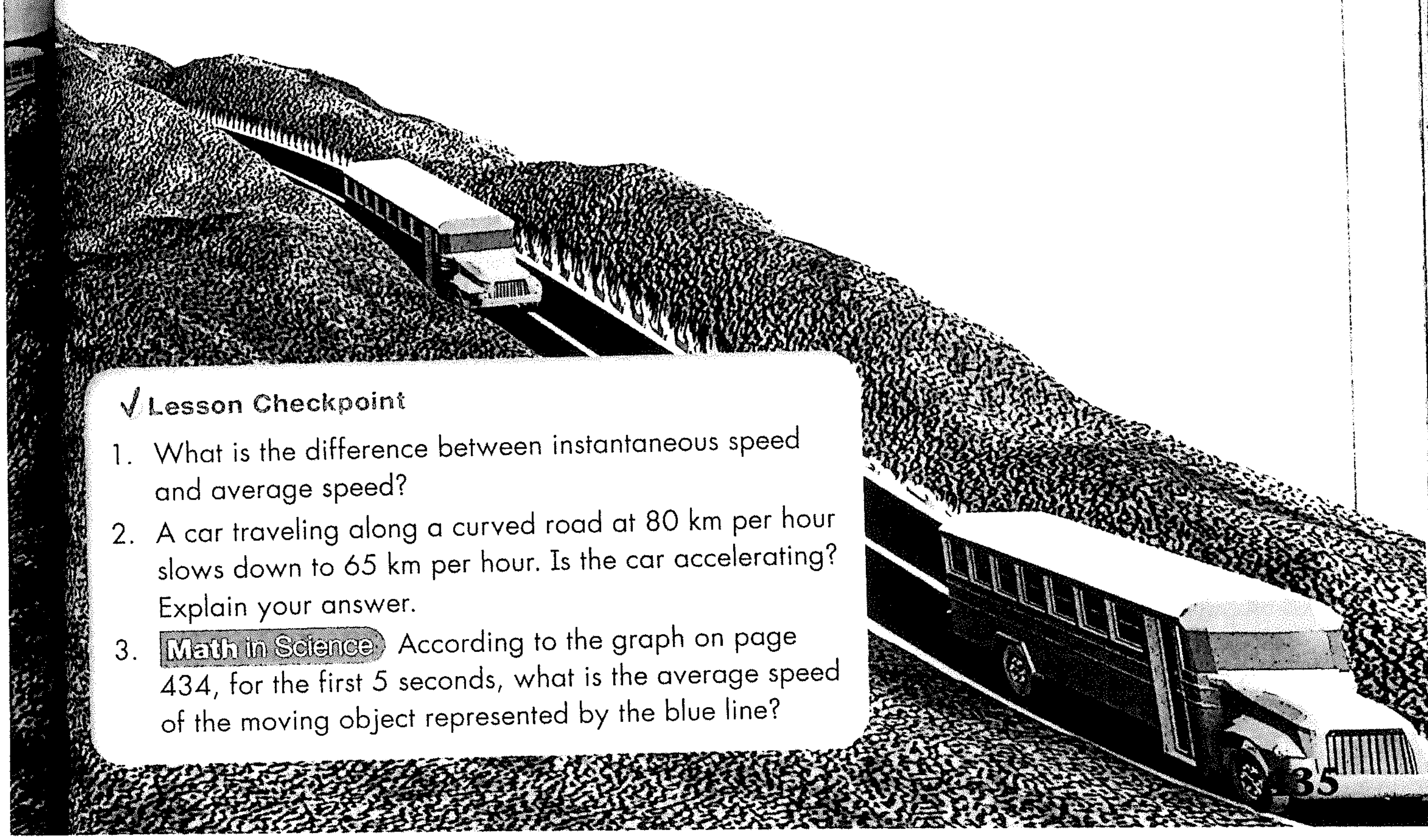
The motion of moving objects usually isn't constant. The instantaneous speed and direction of motion may change. **Acceleration** is the rate at which velocity changes. The bus in the picture accelerates when it speeds up.

Acceleration isn't just going faster. Acceleration also happens when an object slows down or changes direction. Each time the bus moves slower or travels around a curve, it is accelerating.

The velocity of an object can only change if a force acts on the object. Acceleration is therefore the result of unbalanced forces acting on the object.

**A speed/time graph shows the speed of an object at any time. You can infer whether the object is accelerating. A straight line indicates constant acceleration. A curved line indicates changing acceleration. A horizontal line indicates constant speed.**



√ **Lesson Checkpoint**

1. What is the difference between instantaneous speed and average speed?
2. A car traveling along a curved road at 80 km per hour slows down to 65 km per hour. Is the car accelerating? Explain your answer.
3. **Math in Science** According to the graph on page 434, for the first 5 seconds, what is the average speed of the moving object represented by the blue line?

Lesson 4

# What are the laws of motion?

*A force is needed to change an object's motion. An object accelerates in response to an unbalanced force. A force on an object causes an equal but opposite reaction force.*

Galileo Galilei

## Studying Motion

For hundreds of years, scientists tried different experiments to try to explain motion. One of those scientists was Galileo Galilei, who in the 1600s studied falling objects and the idea of gravity. At the time, people thought that objects slowed down and stopped by themselves. They did not yet understand friction.

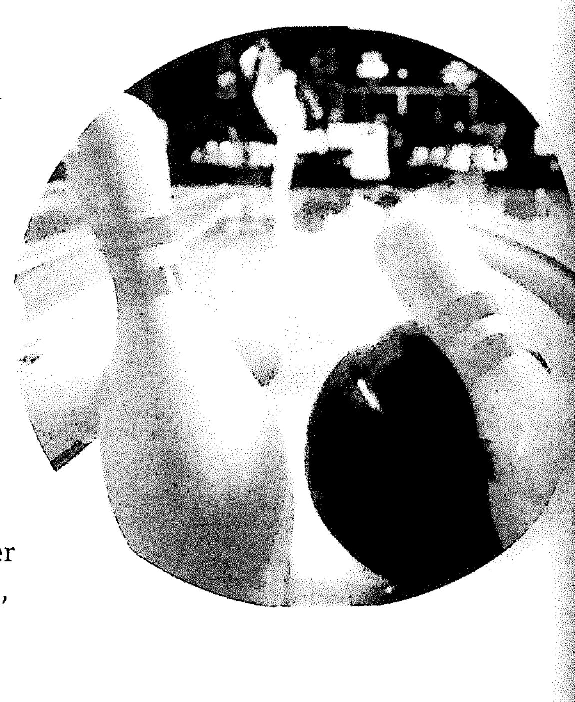
It wasn't until 1686 that Isaac Newton published his book *Principia*. In it he related forces to the motion of objects. Newton's book put the ideas of many scientists together in a way that people could understand them.

## First Law of Motion

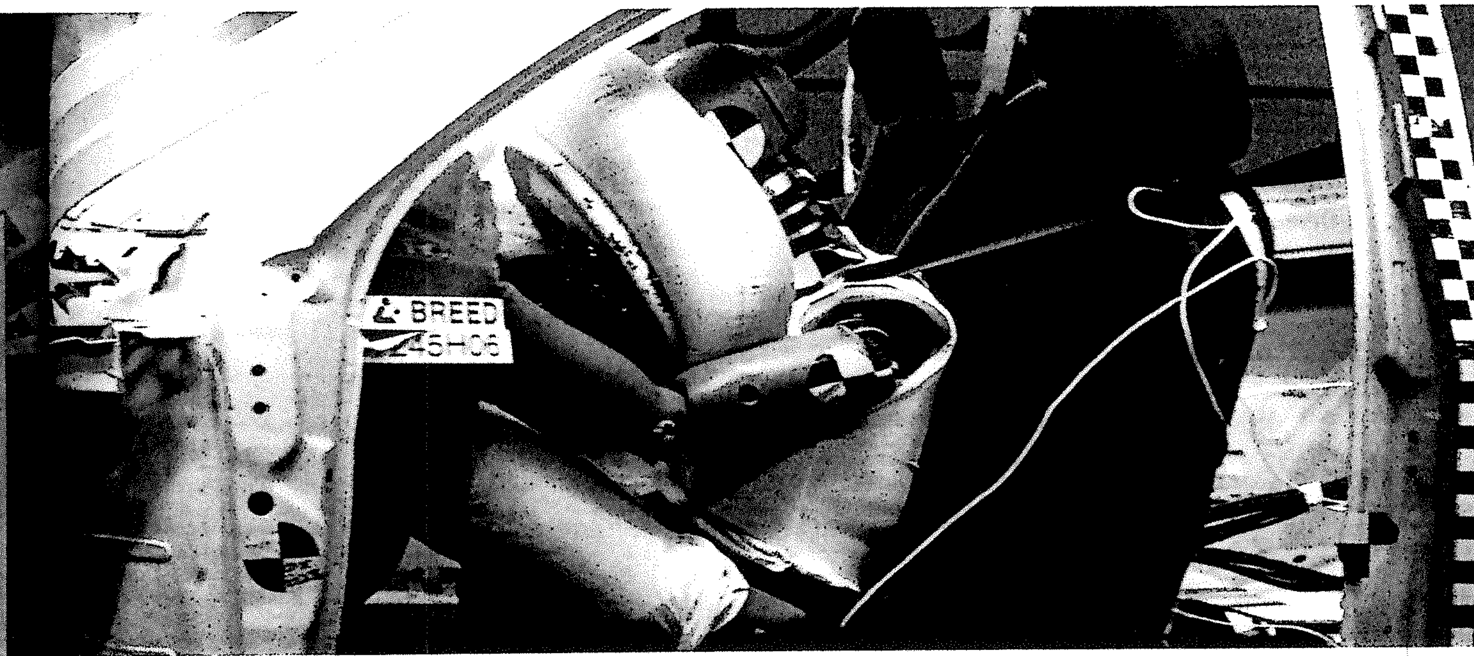
Newton's first law of motion describes the motion of an object that has equal forces acting on it.

### Newton's First Law of Motion

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



The first part of this law is not surprising. You know that if you place your book on a desk, the book will not move unless you pick it up or another force acts on it. If you place a soccer ball on a field, you have to kick the ball to move it.




This crash-test dummy shows the effect of inertia. If a car stops suddenly, the forward motion of people in the car continues. The force that stopped the car does not stop the people. The force of a seat belt or air bag stops a person's forward motion.

The second part of the law may surprise you—an object stays in motion. Motion in your everyday life doesn't seem to obey Newton's first law. If you kick a soccer ball, it moves for a while and then gradually slows down and stops. To keep your bicycle moving, you have to continually push on the pedals.

Why do the objects slow down? Friction is one explanation. Objects in motion can be stopped by friction. When bicycle wheels touch the ground, the ground exerts a frictional force. Air friction also slows the motion as air particles push against the bicycle. Other forces, such as gravity, may also slow an object's movement.

## Inertia

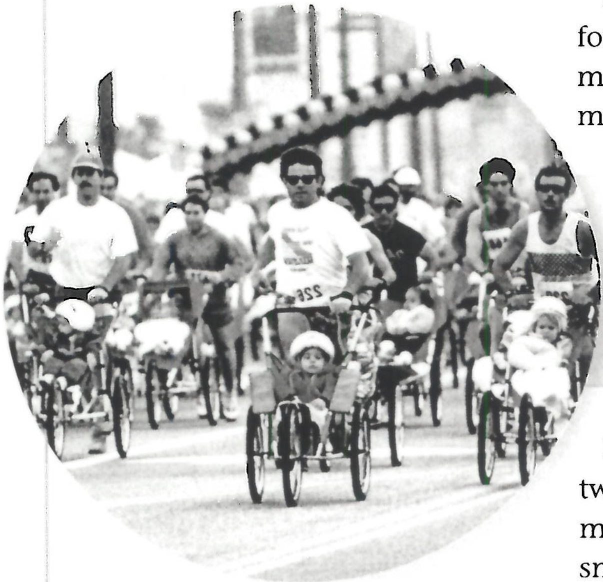
Newton's first law of motion is sometimes called the law of inertia. **Inertia** is the tendency of an object to remain at rest or in constant motion unless a force acts on it. Because ice has little friction, inertia allows an ice skater to glide long distances. A rock sitting on the ground stays still because of inertia.

Suppose you had two jars of the same size. One is filled with feathers and the other is filled with pennies. Which jar would be harder to move? If you said the pennies, you are right. But why? Both are the same size.The jar of pennies is more difficult to move because it has more mass. The amount of inertia an object has depends on its mass. The greater the mass of an object, the greater its inertia.

1. √ **Checkpoint** What does Newton's first law say about a moving object if the forces on the object are balanced?
2. Writing in Science **Expository** Write a paragraph explaining the forces on a baseball flying through the air. Use Newton's first law of motion to explain the ball's motion.

## Second Law of Motion

Newton's first law of motion states that unbalanced forces cause a change in motion, but how does the motion change? According to Newton's second law of motion, a force causes an object to accelerate.



### Newton's Second Law of Motion

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

First, consider how mass affects motion. Look at the two dogs in the wagons. The large dog has greater mass than the smaller dog. You have to exert only a small force to pull the wagon with the small dog. But the same force applied to the wagon with the large dog will not accelerate the wagon as much. In other words, if you apply the same force, the greater the mass, the smaller the acceleration.

Now suppose you give the wagon with the small dog a push. The wagon will travel at a certain speed. If you give the same wagon a harder push, it will move faster. Stated another way, an object's acceleration will increase as the net force increases. Likewise, the acceleration will decrease as the net force decreases.

**What effect would pulling on these two wagons with equal force have on the wagons?**


The force of the snowplow causes the ice and snow to accelerate. If the force of friction equals the force of the snowplow, the ice and snow will not accelerate.

## Using an Equation

The second law of motion can be written as an equation.

$$\text{acceleration} = \text{force} \div \text{mass}$$

In the equation, force refers to the net force applied to the object. Mass refers to the object's mass, and acceleration to the object's acceleration. The equation shows that both force and mass affect acceleration.

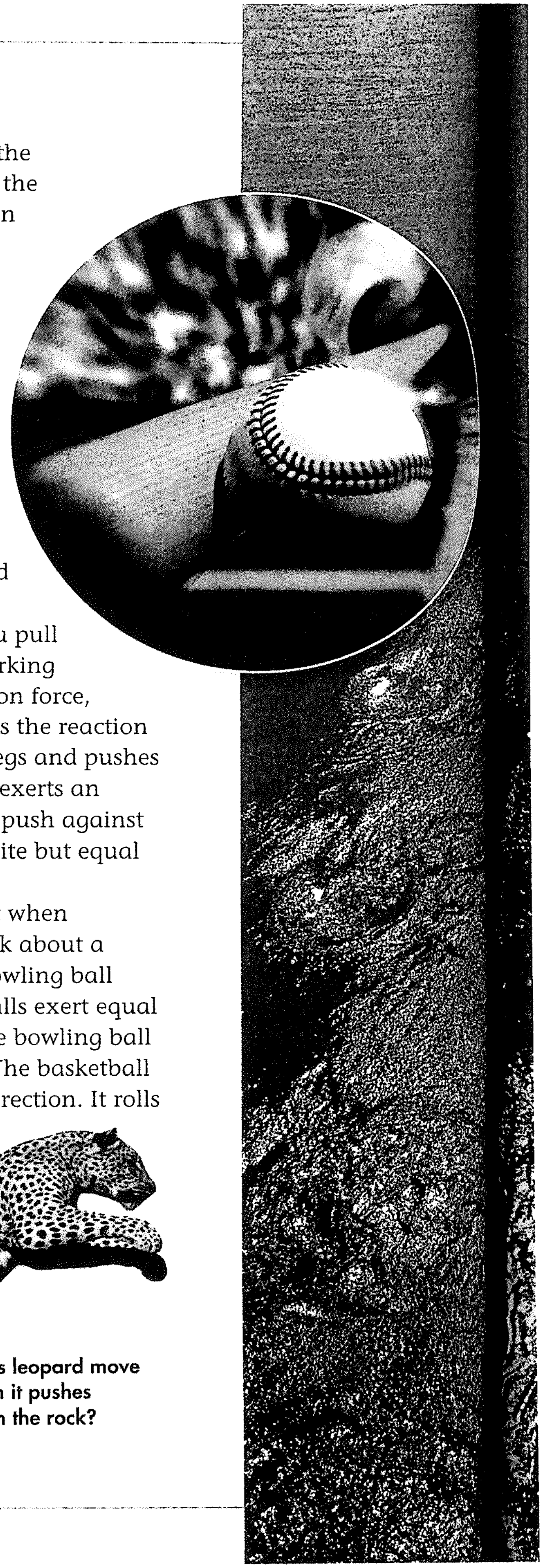
Not all forces cause a change in motion. Only unbalanced forces cause an object to accelerate. If you and a friend push on opposite sides of a box with the same force, the box will not move. However, if you push with a greater force than your friend does, the box will begin to accelerate. It will continue to accelerate as long as the forces on the box are not balanced.

The direction of an object's acceleration depends on the direction of the forces on the object. Place a coin on a desk and give it a small push. The coin accelerates in the direction of the force. If you push on it from two directions, it accelerates in the direction of the unbalanced force.

1. √ **Checkpoint** Newton's second law shows the relationship among which three quantities?
2. **Predict** Suppose you are riding on a bicycle. You stop to place a heavy object on the back of the bike. How will the increased mass affect the bike's acceleration if you pedal with the same force? Explain your reasoning.

## Third Law of Motion

Why does a rubber ball bounce if you toss it on the ground? The force of your hand is downward, but the ball bounces upward. Newton's third law of motion explains the motion of the ball.



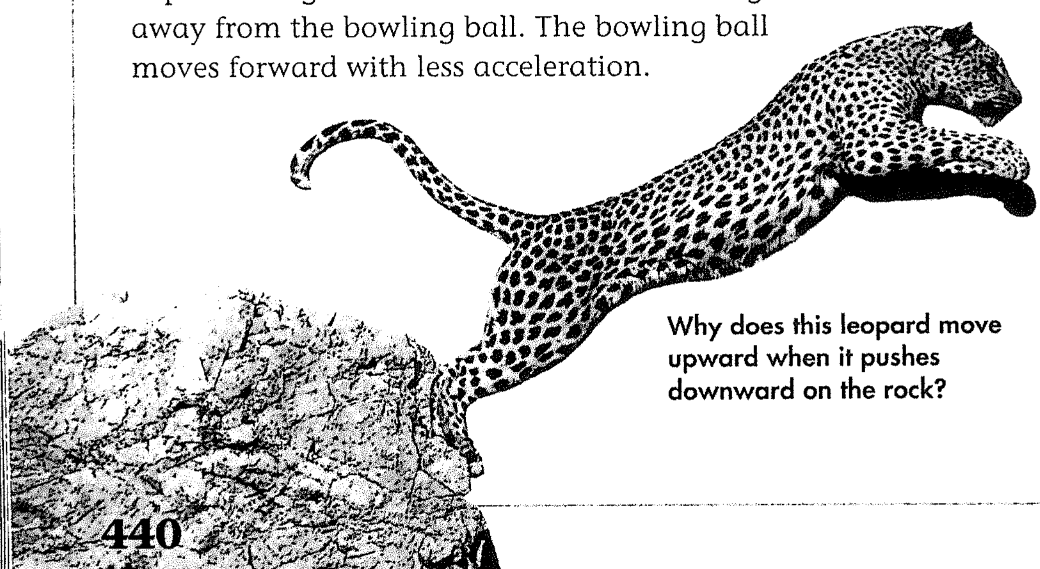
### Newton's Third Law of Motion

When a force is applied to an object, the object exerts an equal force in the opposite direction.

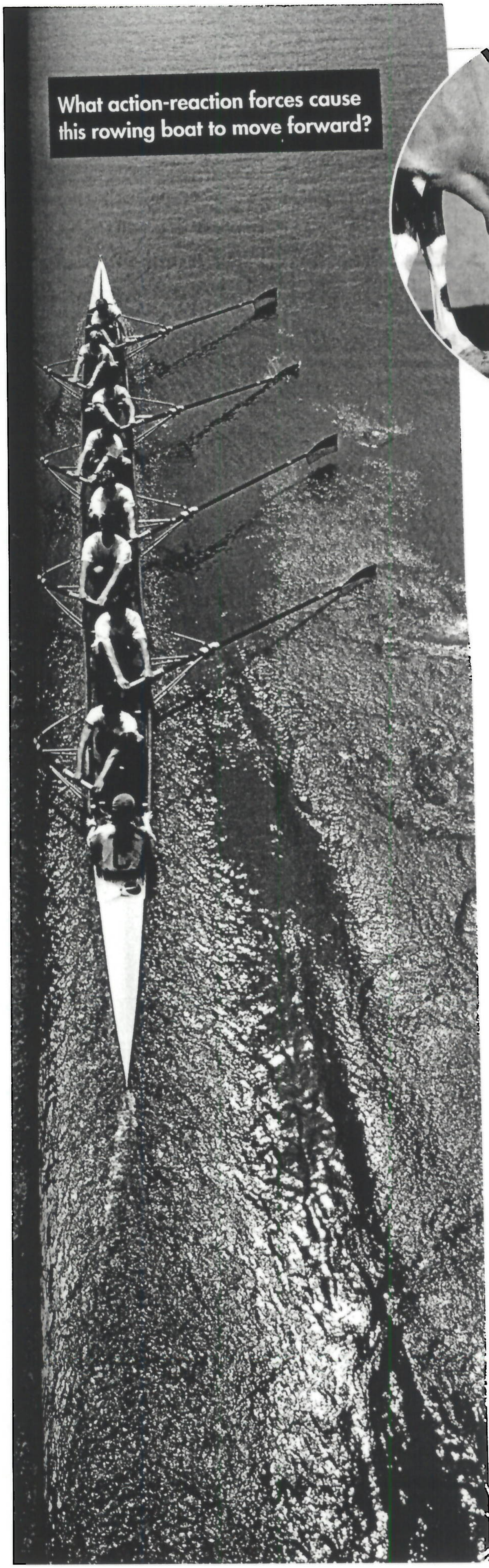
A falling ball exerts a downward force on the ground, and the ground exerts an equal but upward force on the ball. The push of the ground causes the ball to bounce upward.

Newton's third law of motion is sometimes called the law of action and reaction. For every action, there is an equal and opposite reaction. When you pull on a doorknob to open a door, you feel a force working against you. Your pull on the doorknob is the action force, and the doorknob's pull in the opposite direction is the reaction force. When a cat jumps into the air, it bends its legs and pushes its feet very hard against the ground. The ground exerts an equal force, pushing the cat into the air. The cat's push against the ground is the action force. The ground's opposite but equal push is the reaction force.

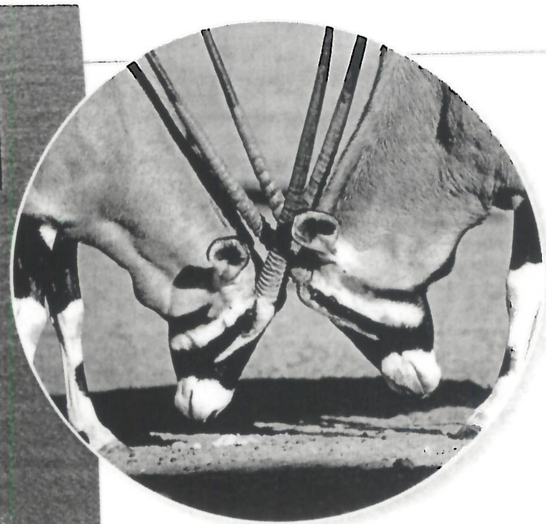
Newton's third law of motion explains the result when two objects collide, or hit against each other. Think about a basketball rolling along the ground. It strikes a bowling ball that is sitting still. During the collision, the two balls exert equal and opposite forces on each other. The mass of the bowling ball is much greater than the mass of the basketball. The basketball experiences greater acceleration and it changes direction. It rolls away from the bowling ball. The bowling ball moves forward with less acceleration.



**Why does this leopard move upward when it pushes downward on the rock?**



What action-reaction forces cause this rowing boat to move forward?



These oryx are applying equal but opposite force.

## Momentum

The difference in the reactions of the basketball and the bowling ball is explained by momentum. **Momentum** can be used to find the force needed to stop a moving object. An object's momentum depends on its mass and velocity. The more momentum an object has, the harder it is to stop the object or change its direction.

When a moving object hits another object, some or all of the momentum of the first object is transferred to the other object. The total momentum before the collision equals the total momentum afterwards. This is known as the law of conservation of momentum.

The momentum of the basketball before it hits the bowling ball must equal the momentum of the basketball and bowling ball after the collision. The bowling ball starts moving because it gets some momentum from the basketball.

### √ Lesson Checkpoint

1. A bowling ball rolls down a lane and strikes a bowling pin. Which is greater, the force of the ball on the pin or the force of the pin on the ball? Explain.
2. Which has greater momentum, a car sitting still or a pebble rolling down a hill? Explain.
3. Predict An adult and a child are ice skating. The child pushes away from the adult. The child moves backward. What will happen to the adult?

# Chapter 15 Review and Test Prep

## Use Vocabulary

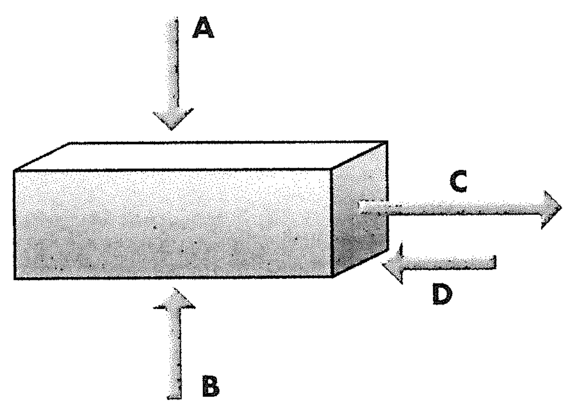
| | |
|---|---|
| **acceleration** (p. 435) | **inertia** (p. 437) |
| **force** (p. 423) | **momentum** (p. 441) |
| **friction** (p. 426) | **speed** (p. 434) |
| **gravitational force** (p. 428) | **velocity** (p. 435) |

Use the vocabulary term from the list above that best completes each sentence.

1. The mass and acceleration of an object determines its ______.
2. A force that opposes the motion of a ball rolling across the ground is ______.
3. Your weight is the ______ that pulls you toward Earth.
4. The speed and direction of an object is its ______.
5. The product of mass and velocity is ______.
6. An object remains at rest unless a force acts on it because of its ______.
7. A measure of how fast an object moves is ______.
8. Unbalanced forces on an object cause ______.

## Explain Concepts

9. After reading Newton's first law of motion, a student claims that an object moving at a constant speed in a straight line has no forces acting on it. Is the student correct? Explain your answer.
10. Identify the effect of each of the actions below. Use Newton's laws to explain the results.
    A. You pushed against a wall.
    B. An unbalanced force acts on an object.
    C. An empty grocery cart runs into a parked car.
11. The length of the force arrows in the picture below shows the relative strength of the forces acting on the box. If the box were sitting still on a table, what would be the result of all the forces acting on the box?



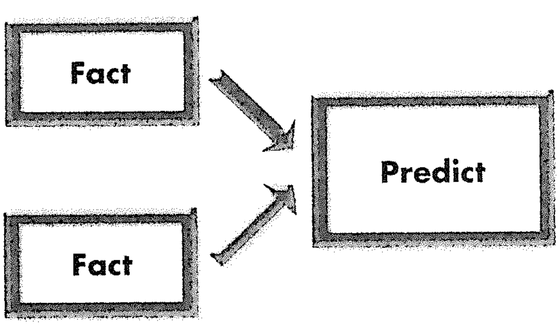
## Process Skills

**12. Communicate** Prepare and give a presentation to the class about how friction is important in football, gymnastics, or some other sport.

**13. Make a Hypothesis** Make a ramp by supporting one end of a long board with a book. Attach a rubber band to a toy car and pull the rubber band to move the car up the ramp. Note how far the rubber band stretches as you pull on the car. How far do you think the rubber band will stretch if you cover the board with sandpaper? Test your prediction and explain the results.

## Predict

**14.** An object weighs 100 N. Predict how the object's weight would change if it were placed on Mars. Use a graphic organizer like the one below.




## Test Prep

Choose the letter that best completes the statement or answers the question.

**15.** Which type of friction acts on a box that is moving down a ramp?
- Ⓐ gliding
- Ⓑ rolling
- Ⓒ sliding
- Ⓓ static

**16.** Which is a force that keeps planets in orbit?
- Ⓕ friction
- Ⓖ inertia
- Ⓗ gravity
- Ⓘ speed

**17.** Which can be used to figure out the force needed to stop a moving object?
- Ⓐ acceleration
- Ⓑ friction
- Ⓒ momentum
- Ⓓ speed

**18.** Which is the unit of force?
- Ⓕ m/s
- Ⓖ kilogram
- Ⓗ newton
- Ⓘ km/h

**19.** Explain why the answer you chose for Question 17 is best. For each of the answers you did not choose, give a reason why it is not the best choice.

**20.** Writing in Science **Persuasive** Write a paragraph in support of having airbags in cars. Use Newton's second law of motion to support your argument.