Chapter

10 Forces

CALIFORNIA Standards Preview

S 8.2 Unbalanced forces cause changes in velocity. As a basis for understanding this concept:

a. Students know a force has both direction and magnitude.

b. Students know when an object is subject to two or more forces at once, the result is the cumulative effect of all the forces.

c. Students know when the forces on an object are balanced, the motion of the object does not change.

d. Students know how to identify separately the two or more forces that are acting on a single static object, including gravity, elastic forces due to tension or compression in matter, and friction.

e. Students know that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction).

f. Students know the greater the mass of an object, the more force is needed to achieve the same rate of change in motion.

S 8.9 Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

c. Distinguish between variable and controlled parameters in a test.

e. Construct appropriate graphs from data and develop quantitative statements about the relationships between variables.

A softball player exerts a force on the softball. ▶

Video Preview

Discovery Channel School

Forces

Focus on the **BIG Idea**

S 8.2

What causes an object's velocity to change?

Check What You Know

You drop a tennis ball and a baseball at the same time. Why do the balls fall to the floor?

Build Science Vocabulary

The images shown here represent some of the key terms in this chapter. You can use this vocabulary skill to help you understand the meaning of some key terms in this chapter.

Vocabulary Skill

Latin Word Origins

Many science words come to English from Latin. In this chapter you will learn the word *compress. Compress* comes from the Latin words *com* meaning "together" and *premere* meaning "to press." Compress means "to press together."

com	+	**premere**	=	**compress**
together		press		to press together

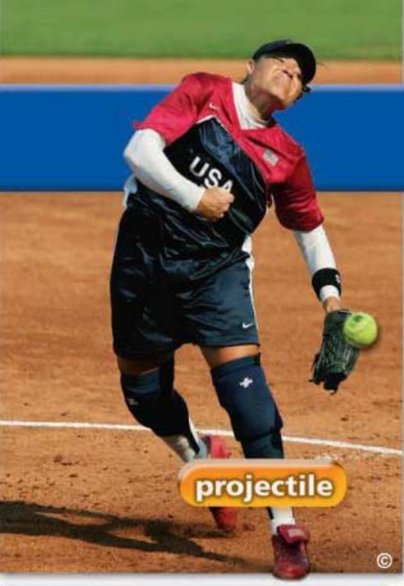
Learn these Latin words to help you remember the key terms.

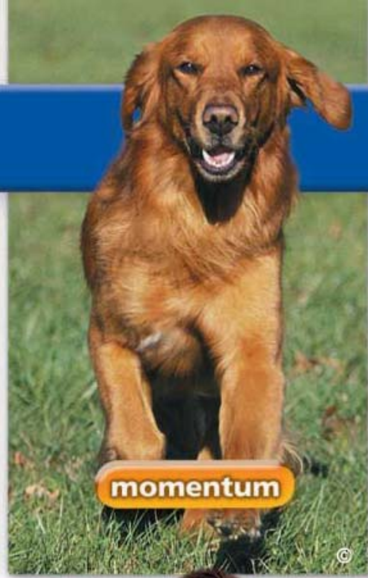
Latin Origin	Meaning	Key Term
centri-	Center	Centripetal force
com-	Together, with	Compression
jacere	Throw	Projectile
premere	Press	Compression
pro-	Forward, before	Projectile
tensus	Stretch	Tension

Apply It!

Look at *pro-* and *jacere* and predict the meaning of *projectile.* Revise your definition as needed as you read the chapter.

Look for words with these Latin origins as you read the chapter.





Chapter 10 Vocabulary

Section 1 (page 374)
force
newton
net force
unbalanced forces
balanced forces

Section 2 (page 380)
friction
static friction
sliding friction
rolling friction
fluid friction
gravity
mass
weight
free fall
air resistance
projectile
compression
tension

Section 3 (page 389)
inertia

Section 4 (page 393)
momentum
law of conservation of momentum

Section 5 (page 402)
satellite
centripetal force

Interactive Textbook
Build Science Vocabulary *Online*
Visit: PHSchool.com
Web Code: cxj-3100

How to Read Science

Reading Skill

Take Notes

Science chapters are packed with information. Each section needs to be read at least twice. After finding the main idea and important details in a section, take notes so you have something to study. In your notebook, create a two-column note-taking organizer.

- Label the left side "Recall Clues and Questions."
- Label the right side "Notes."
- Under "Notes," write key ideas, using phrases and abbreviations; include a few important details.
- Under "Recall Clues and Questions," write review and study questions.
- Write a summary statement for each red heading.

Look at the following example for Section 1 in this chapter.

Recall Clues & Questions	Notes
What is force?	Force—a push or pull • A vector quantity • Describes magnitude and direction • Arrows show direction and strength of force
What are the SI units for force?	SI unit called newton (N) Summary Statement: A force is described by its magnitude and by the direction in which it acts.

Apply It!

What are two important ideas found in the notes? What questions in the left column help you recall the content?

Take notes as you read each section in this chapter.

Lab zone

Standards Investigation

S 8.2.a, 8.2.e

Newton Scooters

Have you ever wondered what force pushes a rocket upward? As you will learn in this chapter, an object will accelerate only when a net force acts on it. The rocket accelerates upward because it is acted on by a net force from the gases it pushes outward. This is an example of Newton's third law. In this investigation, you will use Newton's third law to design a vehicle.

Your Goal

To design and build a vehicle that moves without the use of gravity, electricity, or a person pushing or pulling it.

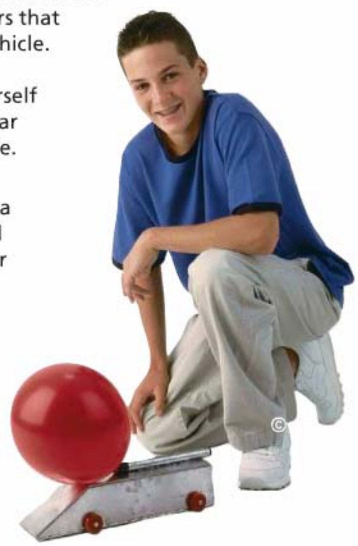
Your vehicle must

- move forward by pushing back on something
- travel a minimum distance of 1.5 meters
- be built following the safety guidelines in Appendix A

Plan It!

Preview the chapter to find out about Newton's third law of motion. Determine factors that will affect the acceleration of your vehicle. Brainstorm possible designs for your vehicle, but be careful not to lock yourself into a single idea. Remember that a car with wheels is only one type of vehicle.

Think of ways to use household materials to build your vehicle. Draw a diagram of your proposed design and identify the force that will propel your vehicle. Have your teacher approve your design. Then build your vehicle and see if it works!



Section 1

The Nature of Force

CALIFORNIA Standards Focus

S 8.2.a Students know a force has both direction and magnitude.

S 8.2.c Students know when the forces on an object are balanced, the motion of the object does not change.

How is a force described?

How do balanced and unbalanced forces affect an object's velocity?

Key Terms

- force
- newton
- net force
- unbalanced forces
- balanced forces

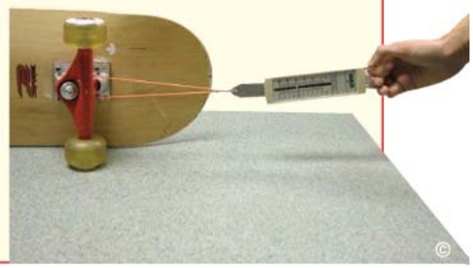
Lab zone Standards Warm-Up

Is the Force With You?

1. Attach a spring scale to each end of a skateboard. Place the skateboard upright.
2. Gently pull on one spring scale with a force of 4 N, while your partner pulls on the other with the same force. Observe the motion of the skateboard.
3. Now try to keep your partner's spring scale reading at 2 N while you pull with a force of 4 N. Observe the motion of the skateboard.

Think It Over

Observing Describe the motion of the skateboard when you and your partner pulled with the same force. How was the motion of the skateboard affected when you pulled with more force than your partner?



A hard kick sends a soccer ball shooting down the field toward the goal. Just in time, the goalie leaps forward, stops the ball, and quickly kicks it in the opposite direction. In a soccer game, the ball is rarely still. Its motion is constantly changing. What causes an object to start moving, stop moving, or change direction? The answer is force.

What Is a Force?

In science, the word *force* has a simple and specific meaning. A **force** is a push or a pull. You use a force to open a door, to stretch a rubber band, and to carry your backpack. When one object pushes or pulls another object, you say that the first object exerts a force on the second object.

Like velocity and acceleration, force is a vector quantity. **A force is described by its magnitude and by the direction in which it acts.** If you push on a door, you exert a force in a different direction than if you pull on the door.

FIGURE 1
Force and Motion
The force of the kick changes the direction of the soccer ball.

You can use an arrow to represent the direction and strength of a force. The arrow points in the direction of a force. The length of the arrow tells you the strength of a force—the longer the arrow, the greater the force.

The SI unit for the magnitude, or strength, of a force is the **newton** (N). This unit is named after the English scientist and mathematician Isaac Newton. You exert about one newton of force when you lift a small apple.

Reading Checkpoint **What SI unit is used to measure the strength of a force?**

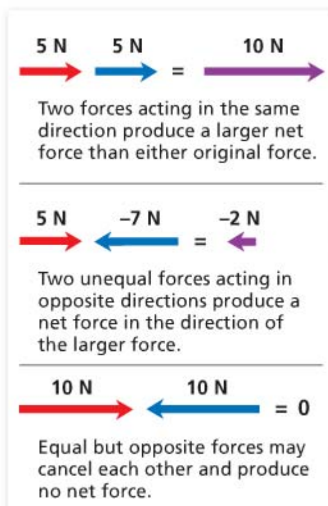
Combining Forces

Often, more than a single force acts on an object at one time. When an object is subject to two or more forces at once, the result is the combination, or cumulative effect, of all the forces. The combination of all forces acting on an object is called the **net force.** The net force determines whether an object moves and also in which direction it moves.

When two or more forces act in the same direction, the net force is found by adding the strengths of the individual forces. In Figure 2, the lengths of the two arrows, are added together to find the net force. The net force acts in the same direction as the individual forces.

When two or more forces act in opposite directions, the net force is also found by adding the strengths of the forces. However, you must note the direction of each force. Adding a force acting in one direction to a force acting in the opposite direction is the same as adding a positive number to a negative number. The net force always acts in the direction of the greater force. If the opposing forces are of equal strength, there is no net force.

FIGURE 2
Combining Force Vectors
The strength and direction of the individual forces determine the net force. **Calculating** *How do you find the net force when two forces act in opposite directions?*



Unbalanced Forces in the Same Direction
When two forces act in the same direction, the net force is the sum of the two individual forces. The box moves to the right.

Unbalanced Forces in the Opposite Direction
When two forces act in opposite directions, the net force is the difference between the two individual forces. The box moves to the right.

Unbalanced Forces Whenever there is a net force acting on an object, the forces are unbalanced. **Unbalanced forces** will cause the velocity of an object to change. The object can speed up, slow down, or change direction. **Unbalanced forces acting on an object result in a net force and cause a change in the object's velocity.**

Figure 3 shows two people exerting forces on a box. When they both push a box to the right, their individual forces add together to produce a net force in that direction. Since unbalanced forces act on the box, there is a net force and the box moves to the right.

When the two people push the box in opposite directions, the net force on the box is the difference between their individual forces. Because the boy pushes with a greater force than the girl, their forces are unbalanced and a net force acts on the box to the right. As a result, the box moves to the right.

Reading Checkpoint **What is the result of unbalanced forces acting on an object?**

Go Online
SCI LINKS NSTA
For: Links on force
Visit: www.SciLinks.org
Web Code: scn-1321

Balanced Forces In a tug-of-war between two people, each person pulls on opposite ends of the rope. If each person pulls with equal force, neither the rope nor the people will move. Equal forces acting on one object in opposite directions are called **balanced forces.**

Balanced Forces in Opposite Directions
When two equal forces act in opposite directions, they cancel each other out. The box doesn't move.

FIGURE 3
Unbalanced and Balanced Forces
When the forces acting on an object are unbalanced, a net force acts on the object. The object will move. When balanced forces act on an object, no net force acts on the object. The object's motion remains unchanged.
Predicting *If both girls pushed the box on the same side, would the motion of the box change? Why or why not?*

When equal forces are exerted in opposite directions, there is no net force. **Balanced forces acting on an object do not change the object's velocity.** In Figure 3, when two people push on the box with equal force in opposite directions, the forces are balanced. The box does not move.

Section 1 Assessment

S 8.2.a, S 8.2.c
E-LA: Reading 8.2.4

Target Reading Skill **Take Notes** Review your notes for this section. What are two important ideas that you noted under Combining Forces?

Reviewing Key Concepts

HINT
HINT
HINT
HINT
HINT

1. a. **Defining** What is a force?
   b. **Explaining** How is a force described?
   c. **Interpreting Diagrams** In a diagram, one force arrow is longer than the other arrow. What can you tell about the forces?
2. a. **Reviewing** How can you find the net force if two forces act in opposite directions?
   b. **Comparing and Contrasting** How do balanced forces acting on an object affect its motion? How do unbalanced forces acting on an object affect its motion?
   c. **Calculating** You exert a force of 120 N on a desk. Your friend exerts a force of 150 N in the same direction. What net force do you and your friend exert on the desk? HINT

Lab zone At-Home Activity

House of Cards Carefully set two playing cards upright on a flat surface so that their top edges lean on each other. In terms of balanced forces, explain to a family member why the cards are able to stand by themselves. Then push one of the cards. Explain to a family member the role of unbalanced forces in what happens.

Lab zone **Consumer Lab**

Sticky Sneakers

S 8.2.a, 8.9.c

Problem

Friction is a force that opposes an object's motion. Friction can be useful. For example, friction between sneakers and the ground can help an athlete to start and stop running. How does the amount of friction between a sneaker and a surface compare for different brands of sneakers?

Skills Focus

controlling variables, interpreting data

Materials

- three or more different brands of sneakers
- 2 spring scales, 5-N and 20-N, or force sensors
- mass set(s)
- tape
- 3 large paper clips
- balance

Procedure

1. Sneakers are designed to deal with various friction forces, including these:
   - starting friction, which occurs when you start from a stopped position
   - forward-stopping friction, which occurs when you come to a forward stop
   - sideways-stopping friction, which occurs when you come to a sideways stop
2. Prepare a data table in which you can record each type of friction for each sneaker.
3. Place each sneaker on a balance. Put masses in each sneaker so that the total mass of the sneaker plus the masses is 1,000 g. Spread the masses out evenly inside the sneaker.
4. Tape a paper clip to each sneaker and attach a spring scale to the paper clip. (If you are using force sensors, see your teacher for instructions.)
   To measure
   - starting friction, attach the paper clip to the back of the sneaker
   - forward-stopping friction, attach the paper clip to the front of the sneaker
   - sideways-stopping friction, attach the paper clip to the side of the sneaker

Data Table

Sneaker	Starting Friction (N)	Sideways-Stopping Friction (N)	Forward-Stopping Friction (N)
A			
B			

5. The force necessary to make the sneaker start moving is equal to the starting friction force. To measure starting friction, pull the sneaker backward until it starts to move. Use the 20-N spring scale first. If the reading is less than 5 N, use a 5-N scale. Record the starting friction force in your data table.
6. To measure either sideways or forward stopping friction, use the spring scale to pull each sneaker at a slow, constant speed. Record the stopping friction force in your data table.
7. Repeat Steps 4–6 for the remaining sneakers.

Analyze and Conclude

1. **Controlling Variables** What variables are controlled? Explain your answers. What are the manipulated and responding variables? Explain your answers. (See the Skills Handbook to read about experimental variables.)
2. **Applying Concepts** Why is the reading on the spring scale equal to the friction force in each case?
3. **Interpreting Data** Which sneaker had the most starting friction? Which had the most forward-stopping friction? Which had the most sideways-stopping friction?
4. **Drawing Conclusions** Do you think that using a sneaker with a small amount of mass in it is a fair test of the friction of the sneakers? Why or why not? (*Hint*: Consider that sneakers are used with people's feet inside them.)
5. **Inferring** Why did you pull the sneaker at a slow speed to test for stopping friction? Why did you pull a sneaker that wasn't moving to test starting friction?
6. **Drawing Conclusions** Can you identify a relationship between the brand of sneaker and the amount of friction you observed? If so, describe the relationship. What do you observe that might cause one sneaker to grip the floor better than another?
7. **Communicating** Choose one of the brands of sneakers that you tested. In a paragraph, explain why this sneaker is the best one to wear while playing a particular sport or activity. Be sure to include the results of this lab in your explanation.

Design an Experiment

The strength of the friction force is determined by both the design of the sneaker and the type of surface it presses against. Design an experiment to find out how various types of surfaces affect the force of friction acting upon the sneaker. *Obtain your teacher's permission before carrying out your investigation.*

Section 2

Friction, Gravity, and Elastic Forces

California Standards Focus

S 8.2.b Students know when an object is subject to two or more forces at once, the result is the cumulative effect of all the forces.

S 8.2.d Students know how to identify separately the two or more forces that are acting on a single static object, including gravity, elastic forces due to tension or compression in matter, and friction.

- What factors determine the strength of the friction force between two surfaces?
- What factors affect the gravitational force between two objects?
- Why do objects accelerate during free fall?
- When is matter considered to be elastic?

Key Terms

- friction
- static friction
- sliding friction
- rolling friction
- fluid friction
- gravity
- mass
- weight
- free fall
- air resistance
- projectile
- compression
- tension

Lab zone Standards Warm-Up

The Flexible Meter Stick

1. Place a meter stick across two desks so that it spans the gap between the desks.
2. Rest a book on top of the meter stick. Using another ruler, measure how much the meter stick sags under the book's weight.
3. Place another book on top of the first book. Measure how much the meter stick sags under the weight of two books.

Think It Over

Observing Did the meter stick sag more with two books resting on it? Why? Why doesn't the meter stick break?

Have you ever pulled your little sister in a sled up the side of a snow-covered hill and then watched as she raced down it? Have you ever thought about some of the forces at work? The tension in the rope allows you to apply the force necessary to pull the sled up the hill. Gravity causes the sled to accelerate down the hill. Friction ultimately brings the sled to a stop at the bottom of the hill. All the while the snow is compressing under the sled's weight. You will learn about friction, gravity, compression, and tension forces in this chapter.

◄ **Friction and gravity act on the sled.**

FIGURE 4
Friction and Smooth Surfaces The smooth surfaces of the skis make for a fast ride for these Finnish skiers.
Relating Diagrams and Photos *How does the direction of friction compare to the direction of motion?*

Friction

A classmate is sitting at the end of a long table and asks to see your book. You slide it toward her, but it slows down and stops before it reaches her. Why does it stop sliding? A force called friction acts in a direction opposite to the motion of objects. **Friction** is a force that two surfaces exert on each other when they rub against each other. Without friction or another unbalanced force, a moving object will not stop until it strikes another object.

The Causes of Friction In general, smooth surfaces produce less friction than rough surfaces. A piece of metal may seem quite smooth. But, as you can see in Figure 5, even the smoothest objects have irregular, bumpy surfaces. When the irregularities of one surface come into contact with those of another surface, friction occurs.

The strength of the force of friction depends on the types of surfaces involved and on how hard the surfaces push together. The skiers in Figure 4 get a fast ride because there is very little friction between their skis and the snow. The reindeer would not be able to pull them easily over a rough surface such as sand. Friction also increases if surfaces push hard against each other. If you rub your hands together forcefully, there is more friction than if you rub your hands together lightly.

FIGURE 5
A Smooth Surface?
If you look at the polished surface of an aluminum alloy under a powerful microscope, you'll find that it is actually quite rough.

Lab zone Try This Activity

Spinning Plates

You can compare rolling friction to sliding friction.

1. Stack two identical pie plates together. Try to spin the top plate.
2. Now separate the plates and fill the bottom of one pie plate loosely with marbles.

3. Place the second plate in the plate with marbles.
4. Try to spin the top plate again. Observe the results.

Drawing Conclusions How does sliding friction compare to rolling friction? How do you know? Is it possible to get the top plate to spin forever?

Static Friction Four types of friction are shown in Figure 6. The friction that acts on objects that are not moving is called **static friction.** Because of static friction, you must use extra force to start the motion of stationary objects. For example, think about what happens when you try to push a heavy desk across a floor. If you push on the desk with a force less than the force of static friction between the desk and the floor, the desk will not move. To make the desk move, you must exert a force greater than the force of static friction. Once the desk is moving, there is no longer any static friction. However, there is another type of friction—sliding friction.

Sliding Friction **Sliding friction** occurs when two solid surfaces slide over each other. When an object is pulled at a constant velocity across a level surface, the pulling force equals the sliding friction. This is another example of balanced forces. Sliding friction can be useful. For example, you can spread sand on an icy path to improve your footing. Ballet dancers apply a sticky powder to the soles of their ballet slippers so they won't slip on the dance floor. And when you stop a bicycle with hand brakes, rubber pads push against the metal rim of the wheel, causing the wheels to slow and eventually stop.

Rolling Friction When an object rolls across a surface, **rolling friction** occurs. Rolling friction is less than sliding friction for similar materials. This type of friction is important to engineers who design skates, skateboards, and bicycles which need wheels that move freely. Engineers use ball bearings to reduce the friction between the wheels and the rest of the product. These ball bearings are small, smooth steel balls that reduce friction by rolling between moving parts.

Fluid Friction Fluids, such as water, oil, or air, are materials that flow easily. **Fluid friction** occurs when a solid object moves through a fluid. Fluid friction is usually less than sliding friction. This is why the parts of machines that must slide over each other are often bathed in oil. In this way, the solid parts move through the fluid instead of sliding against each other. When you ride a bike, fluid friction occurs between you and the air. Cyclists often wear streamlined helmets and specially designed clothing to reduce fluid friction.

Reading Checkpoint What are two ways in which friction can be useful?

Go Online
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For: Links on friction
Visit: www.SciLinks.org
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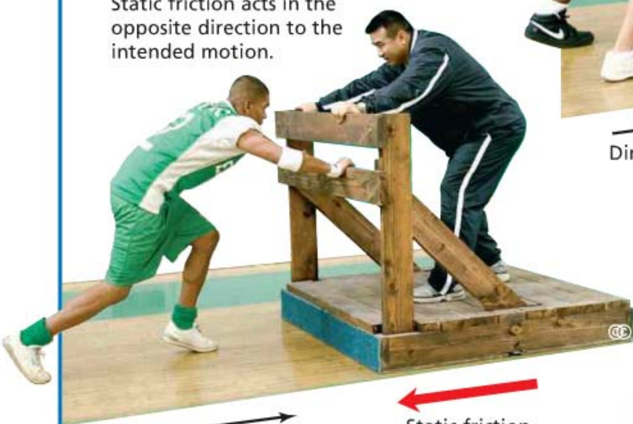
FIGURE 6
Types of Friction

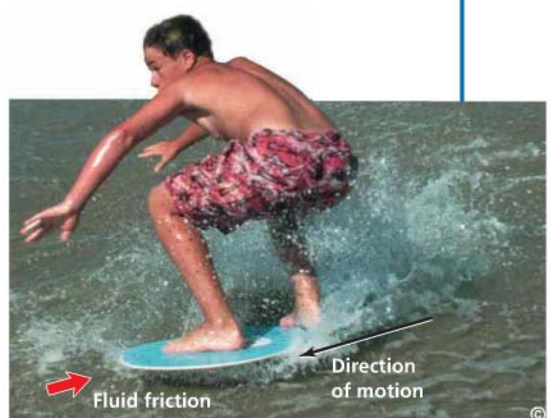
Types of friction include static, sliding, rolling, and fluid friction. **Making Generalizations** *In what direction does friction act compared to an object's motion?*

Static Friction ▼
To make the sled move, the athlete first has to overcome the force of static friction. Static friction acts in the opposite direction to the intended motion.



Sliding Friction ▲
Once the sled is moving, it slides over the floor. Sliding friction acts between the sled and the floor in the opposite direction to the sled's motion.

Rolling Friction ▼
Rolling friction occurs when an object rolls over a surface. For the skateboarder, rolling friction acts in the direction opposite to the skateboard's motion.



Fluid Friction ▲
When an object pushes fluid aside, friction occurs. The surfer must overcome the fluid friction of the water.

FIGURE 7
Gravity and Earth
The diver falls into the pool because gravity is pulling her toward the center of Earth.

Gravity

When you drop a ball, it falls down. Have you ever thought about why it falls down and not up? One person who thought about it was Isaac Newton. He concluded that a force acts to pull objects straight down toward the center of Earth. This force is called gravity. **Gravity** is a force that pulls objects toward each other.

Newton realized that gravity acts everywhere in the universe, not just on Earth. It is also the force that keeps the moon orbiting around Earth. It is the force that keeps all the planets in our solar system orbiting around the sun.

What Newton realized is now called the Universal Law of Gravitation. The Universal Law of Gravitation states that the force of gravity acts between all objects in the universe. This means that any two objects in the universe, without exception, attract each other. You are attracted not only to Earth but also to all the other objects around you. Earth and the objects around you are attracted to you as well. However, you do not notice the attraction among objects because these forces are small compared to the force of Earth's attraction.

Mass and Distance **The force of gravity between objects increases with greater mass and decreases with greater distance.** The measure of the amount of matter in an object is its **mass**. The SI unit of mass is the kilogram. One kilogram is the mass of about 400 modern pennies.

Look at Figure 8. The more mass an object has, the greater its gravitational force. Because the sun's mass is so great, it exerts a large gravitational force on the planets. This causes the planets to orbit the sun.

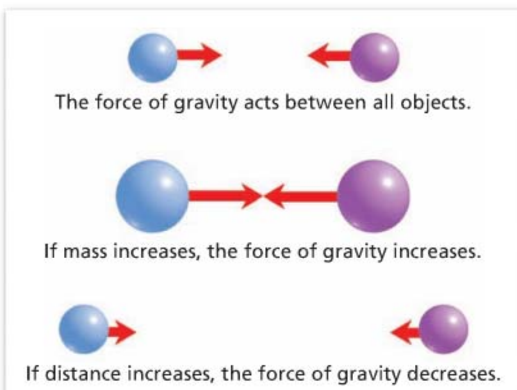


FIGURE 8
Gravity Between Objects
Gravity increases with mass and decreases with distance. **Inferring** *What happens to the force of gravity between two objects if the distance between them decreases?*

In addition to mass, gravitational force depends on the distance between the objects. The farther apart two objects are, the lesser the gravitational force between them. For a spacecraft traveling toward Mars, Earth's gravitational pull decreases as the spacecraft's distance from Earth increases. Eventually the gravitational pull of Mars becomes greater than Earth's, and the spacecraft is more attracted toward Mars.

Gravity and Weight The gravitational force exerted on a person or object at the surface of a planet is known as **weight**. When you step on a bathroom scale, you are determining the gravitational force Earth is exerting on you. Objects that have a greater mass will have a greater weight. You can calculate the weight of an object by using a formula.

$$\text{Weight} = \text{Mass} \times \text{Acceleration due to gravity}$$

Weight is measured in newtons and mass in kilograms. The acceleration due to gravity is 9.8 m/s^2 at Earth's surface. For example, a 50-kg person weighs $50 \text{ kg} \times 9.8 \text{ m/s}^2 = 490 \text{ N}$.

Unlike mass, weight varies with the strength of the gravitational force. The strength of the gravitational force exerted on an object or a person by the moon is one sixth of the force exerted by Earth. Suppose you weighed yourself on Earth to be 450 newtons. Then you traveled to the moon and weighed yourself again. You would weigh only about 75 newtons or one sixth your weight on Earth. You weigh less on the moon because the moon's mass is only a fraction of Earth's.

Reading Checkpoint **What is the difference between weight and mass?**

Lab zone Skills Activity

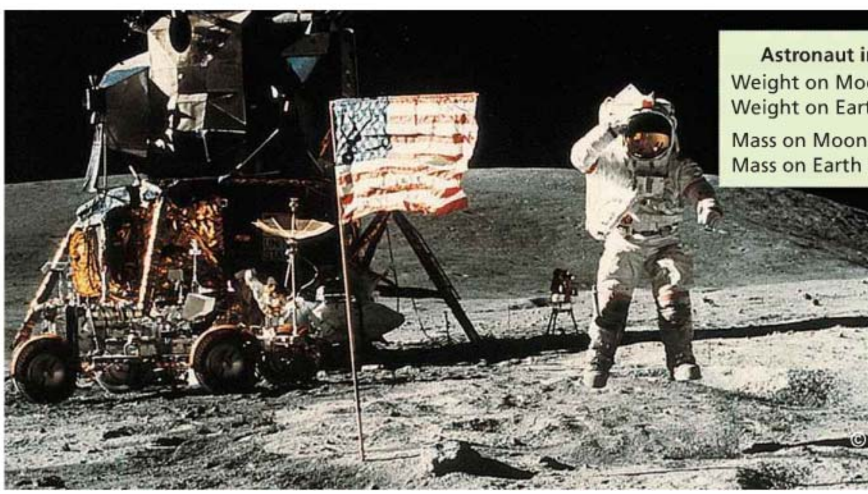
Calculating

You can determine the weight of an object if you measure its mass.

1. Estimate the weight of four objects. (*Hint:* A small lemon weighs about 1 N.)
2. Use a balance to find the mass of each object. If the measurements are not in kilograms, convert them to kilograms.
3. Use the formula on this page to find the weight in newtons.

How close to actual values were your estimates?

FIGURE 9
Mass and Weight This astronaut jumps easily on the moon.
Comparing and Contrasting *How do his mass and weight on the moon compare to his mass and weight on Earth?*



Astronaut in Spacesuit		
Weight on Moon	=	270 N
Weight on Earth	=	1,617 N
Mass on Moon	=	165 kg
Mass on Earth	=	165 kg

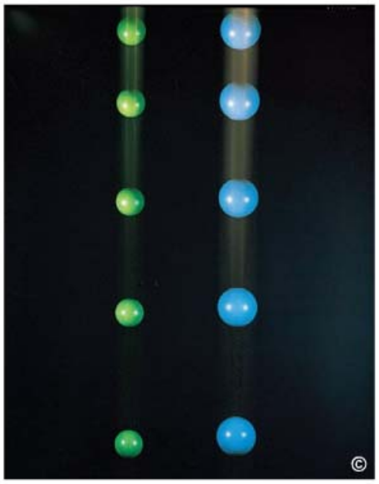


FIGURE 10
Free Fall
When gravity is the only force present, two objects with different masses fall at exactly the same rate.

Gravity and Motion

If you drop a ball, it falls straight down. If you throw a ball outward, it travels out while it falls down. An acorn drops steadily to the ground while a leaf flutters slowly. Gravity and air resistance are the two forces responsible for these motions.

Free Fall When the only force acting on an object is gravity, the object is said to be in **free fall.** An object in free fall is accelerating. Do you know why? **In free fall, the force of gravity alone causes an object to accelerate in the downward direction.**

How much do objects accelerate as they fall? Near the surface of Earth, the acceleration due to gravity is 9.8 m/s^2. This means that for every second an object is falling, its velocity increases by 9.8 m/s. For example, suppose an object is dropped from the top of a building. Its starting velocity is 0 m/s. After one second, its velocity has increased to 9.8 m/s. After two seconds, its velocity is 19.6 m/s (9.8 m/s + 9.8 m/s). The velocity continues to increase by 9.8 m/s each second as the object falls.

All objects in free fall accelerate at the same rate regardless of their masses. This means that two objects dropped at the same time will strike the ground at the same time. Look at Figure 10. The ball on the right has more mass than the ball on the left, yet the balls remain side by side as they fall.

Reviewing Math: Algebra and Functions 7.3.3

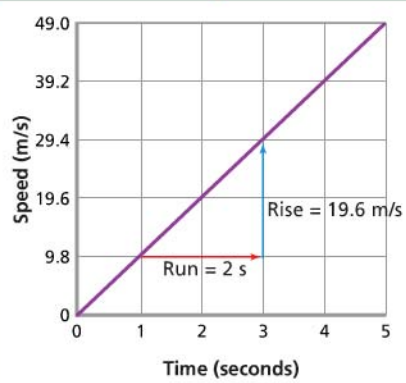
Math Analyzing Data

Free Fall

The graph shows how the speed of an object in free fall changes with time. Use the graph to answer the following questions.

1. **Interpreting Graphs** What is the speed of the object at 1 second? At 3 seconds?
2. **Calculating** Calculate the slope of the graph. What does this number represent?
3. **Predicting** Use the slope that you calculated in Step 2 to predict the object's speed at 6 seconds.
4. **Drawing Conclusions** The graph has a constant slope. What does the slope tell you about the object's motion?

Motion of an Object in Free Fall



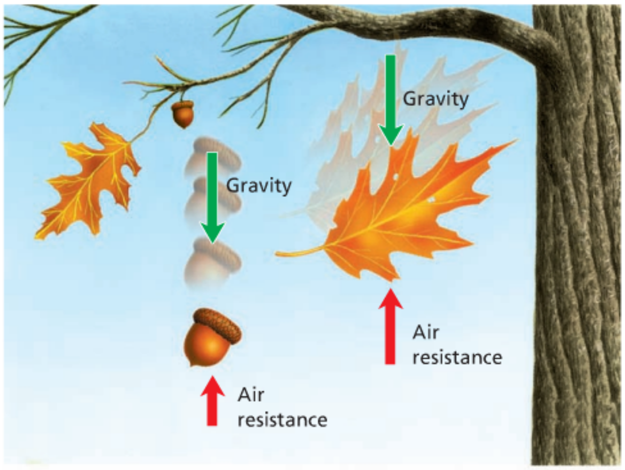


FIGURE 11
Air Resistance
Falling objects with a greater surface area experience more air resistance. If the leaf and the acorn fall from the tree at the same time, the acorn will hit first. **Comparing and Contrasting** *If the objects fall in a vacuum, which one will hit first? Why?*

Air Resistance In a vacuum, where there is no air, all objects fall with exactly the same rate of acceleration. So why does an oak leaf flutter slowly to the ground, while an acorn drops straight down? A type of fluid friction called **air resistance** acts on objects falling through air. Remember that friction acts in the direction opposite to motion. Air resistance is an upward force exerted on falling objects. Objects with a greater surface area experience more air resistance as they fall. A leaf falls more slowly than an acorn because the leaf has a larger surface area.

You can see the effect of air resistance if you drop a flat piece of paper and a crumpled piece of paper at the same time. Even though the two pieces of paper have the same mass, the flat piece has a greater surface area, so it experiences greater air resistance and falls more slowly. In a vacuum, both pieces of paper would fall at the same rate.

Projectile Motion Rather than dropping a ball straight down, what happens if you throw it horizontally? An object that is thrown is called a **projectile** (pro JEK tul). Will a projectile that is thrown horizontally land on the ground at the same time as an object that is dropped?

Look at Figure 12. The yellow ball was given a horizontal push at the same time as the red ball was dropped. Even though the yellow ball moves horizontally, gravity continues to act on it in the same way it acts on the red ball. The yellow ball falls at the same rate as the red ball. Thus, both balls will hit the ground at exactly the same time.

Reading Checkpoint **How does gravity affect objects that are moving horizontally?**

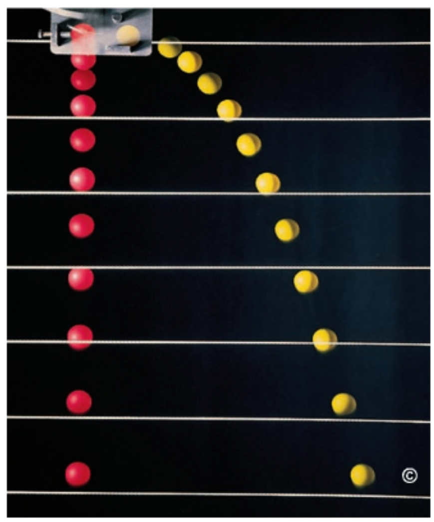


FIGURE 12
Projectile Motion
One ball is dropped vertically and a second ball is thrown horizontally at the same time.
Making Generalizations *Does the horizontal velocity of the ball affect how fast it falls? Why?*

FIGURE 13
Tension
Tension on the fishing line acts in opposite directions. The shoe does not fall because the forces are balanced.
Interpreting Photos *What force causes the downward tension on the line?*

Elastic Forces

When you squeeze a sponge, the sides of the sponge come together, but it does not break. To pull on a pair of gym shorts, you stretch the waistband. It doesn't break either. Why don't the sponge and the waistband break? They are elastic. **Matter is considered elastic if it returns to its original shape after it is squeezed or stretched.**

Compression and tension are two types of elastic forces. **Compression** is an elastic force that squeezes or pushes matter together. When you sit on a couch, you exert a compression force on the cushion. The cushion comes close together and pushes back with an equal compression force in the opposite direction. The forces are balanced. You don't move after you sit down because the force of the cushion pushing up balances your weight pushing down.

An elastic force that stretches or pulls matter is called **tension.** Look at Figure 13. A shoe hanging from the line on a fishing pole exerts a downward tension force on the line. At the same time, the fishing pole exerts an equal upward tension force on the line. The line is pulled in both directions. The shoe does not move up or down because the upward force of tension balances the shoe's weight. Other examples of tension are the strings on a guitar and the cables holding up a suspension bridge.

Section 2 Assessment

S 8.2.b, 8.2.d E-LA: Reading 8.1.2, Writing 8.2.0

Vocabulary Skill **Latin Word Origins** Review the word origins of *compression* and *tension.* How do the word origins help you tell the difference between the two words?

Reviewing Key Concepts

HINT 1. a. **Summarizing** What factors affect the friction force between two surfaces?
HINT b. **Listing** What are the four types of friction?
HINT c. **Classifying** What types of friction occur when you ride a bike through a puddle?
HINT 2. a. **Identifying** What is the law of universal gravitation?
HINT b. **Explaining** How do mass and distance affect the force of gravity between objects?
HINT c. **Predicting** How would your weight change on the surface of an Earth-sized planet whose mass was greater than Earth's? Why?
HINT 3. a. **Reviewing** Why does an object accelerate when it falls toward Earth's surface?
b. **Describing** How does the mass of an object affect its acceleration during free fall? HINT
c. **Applying Concepts** What force changes when a sky diver's parachute opens? What force stays the same? HINT
4. a. **Listing** What are two types of elastic forces? HINT
b. **Applying Concepts** Describe the forces on a rope that support a tire swing when a child sits on the tire. HINT

Writing in Science

Relating Cause-and-Effect Suppose Earth's gravitational force were decreased by half. How would this change affect a game of basketball? Write a paragraph explaining how the motion of the players and the ball would be different.

Section 3

Newton's First and Second Laws

CALIFORNIA Standards Focus

S 8.2.e Students know that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction).

S 8.2.f Students know the greater the mass of an object, the more force is needed to achieve the same rate of change in motion.

- What is Newton's first law of motion?
- What is Newton's second law of motion?

Key Term

- inertia

Lab zone Standards Warm-Up

What Changes Motion?

1. Stack several metal washers on top of a toy car.
2. Place a heavy book on the floor near the car.
3. Predict what will happen to both the car and the washers if you roll the car into the book. Test your prediction.

Think It Over

Observing What happened to the car when it hit the book? What happened to the washers? What force(s) could account for any difference between the motions of the car and the washers?

How and why objects move as they do has fascinated scientists for thousands of years. In the early 1600s, the Italian astronomer Galileo Galilei suggested that, once an object is in motion, force is needed only to change the motion of an object. A force is not necessary to keep it moving. Galileo's ideas paved the way for Isaac Newton. Newton proposed the three basic laws of motion in the late 1600s.

Isaac Newton

The First Law of Motion

Newton's first law restates Galileo's ideas about force and motion. **Newton's first law of motion states that an object will remain at rest or moving at a constant velocity unless it is acted upon by an unbalanced force.** An unbalanced force will cause an object to speed up, slow down, or change direction.

If an object is not moving, it will not move until a force acts on it. The clothes on the floor of your room will stay there unless you pick them up. You provide the force to move your clothes. A tennis ball flies through the air once you hit it with a racket. A moving object, such as the tennis ball, will move at a constant velocity until a force acts to change its speed or direction. On Earth, gravity and air resistance are forces that will change the tennis ball's velocity as it flies through the air.

FIGURE 14
Inertia The inertia of the objects on the table keeps them from moving.
Inferring *Why should the girl use a slippery tablecloth?*

Inertia Whether an object is moving or not, it resists any change to its motion. Galileo's concept of the resistance to a change in motion is called inertia. **Inertia** (in UR shuh) is the tendency of an object to resist a change in motion. Newton's first law of motion is also called the law of inertia.

Inertia explains many common events, such as why you move forward in your seat when a car stops suddenly. When a car stops, inertia keeps you moving forward. A force, such as the pull of a seat belt, is required to change your motion.

Inertia Depends on Mass Suppose you need to move an empty aquarium and an aquarium full of water. Obviously, the full aquarium is harder to move than the empty one, because it has more mass. The greater the mass of an object is, the greater its inertia, and the greater the force required to change its motion. The full aquarium is more difficult to move because it has more inertia than the empty aquarium.

Reading Checkpoint How is mass related to inertia?

Lab zone Try This Activity

Around and Around

An object moving in a circle has inertia.

1. Tape one end of a length of thread (about 1 m) to a table tennis ball.
2. Suspend the ball in front of you and swing it in a horizontal circle, keeping it 2–3 cm above the floor.
3. Let go of the thread and observe how the ball rolls.

Observing Describe how the ball moves when you let go of the thread. Explain why it moves in this way.

The Second Law of Motion

Suppose you are baby-sitting two children who love wagon rides. Their favorite part is when you accelerate quickly. Recall that acceleration is the rate at which velocity changes. When you get tired and sit in the wagon, one of the children pulls you. He soon finds he cannot accelerate the wagon nearly as fast as you can. How is the wagon's acceleration related to the force pulling it? How is the acceleration related to the wagon's mass?

Changes in Force and Mass How do you get a wagon to speed up, slow down, or turn a corner? You apply a force to it. What if you want the wagon to speed up, slow down, or turn a corner at a faster rate? You apply even more force. An increase in force results in an increase in acceleration.

Another way to increase acceleration is to change the mass. Suppose your friend gets into the wagon with you. The wagon now has more mass. If the child pulls with the same force as before, the wagon will move very slowly, if at all. For a constant force, an increase in the mass will result in a decrease in the acceleration.

Determining Acceleration **Newton's second law of motion states that acceleration depends on the net force acting on the object and on the object's mass.** This relationship can be written as a formula.

$$\text{Acceleration} = \frac{\text{Net force}}{\text{Mass}}$$

Acceleration is measured in meters per second per second (m/s^2), net force is measured in newtons (N), and mass is measured in kilograms (kg). You can also write this formula as Net force = Mass × Acceleration. You can think of 1 newton as the force required to give a 1-kg mass an acceleration of 1 m/s^2.

Reading Checkpoint **What does the acceleration of an object depend upon?**

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Visit: PHSchool.com
Web Code: cgd-3023

FIGURE 15
Force and Mass
The force of the boy's pull and the mass of the wagon determine the wagon's acceleration.
Predicting *If more mass is added to the wagon and if the boy pulls with the same force, how will its acceleration change?*

Math: Algebra I: 8.15.0

Math Sample Problem

Calculating Force

A speedboat pulls a 55-kg water-skier. The skier accelerates at 2.0 m/s^2. Calculate the net force that causes this acceleration.

1 Read and Understand

What information are you given?

Mass of the water-skier (m) = 55 kg

Acceleration of the water-skier (a) = 2.0 m/s^2

2 Plan and Solve

What quantity are you trying to calculate?

The net force (F_{net}) = ■

What formula contains the given quantities and the unknown quantity?

$$a = \frac{F_{net}}{m} \quad \text{or} \quad F_{net} = m \times a$$

Perform the calculation.

$$F_{net} = m \times a = 55\ \text{kg} \times 2.0\ \text{m/s}^2$$
$$F = 110\ \text{kg} \cdot \text{m/s}^2$$
$$F = 110\ \text{N}$$

3 Look Back and Check

Does your answer make sense?

A net force of 110 N is required. This does not include the force that overcomes friction.

Math Practice

1. **Calculating Force** What is the net force on a 1,000-kg object accelerating at 3 m/s^2?
2. **Calculating Force** What net force is needed to accelerate a 25-kg cart at 14 m/s^2?

Section 3 Assessment

S 8.2.e, 8.2.f, E-LA: Reading 8.1.2

Vocabulary Skill Latin Word Origins The word *inertia* comes from two Latin words—*in* meaning "not" and *ars* meaning "moving" or "active." How does the word origin help you remember the term *inertia*?

Reviewing Key Concepts

HINT
1. a. **Reviewing** What is Newton's first law of motion?
   HINT
   b. **Explaining** Why is Newton's first law of motion sometimes called the law of inertia?
   HINT
   c. **Inferring** Use inertia to explain why you feel pressed back into the seat of a car when it accelerates.

HINT
2. a. **Defining** State Newton's second law of motion.
   HINT
   b. **Problem Solving** How could you keep an object's acceleration the same if the force acting on the object were doubled?
   HINT
   c. **Applying Concepts** Explain why a car with a large mass might use more fuel than a car with a smaller mass. Assume both cars drive the same distance.

Math Practice

3. **Calculating Force** What is the net force acting on a 0.15-kg hockey puck accelerating at a rate of 12 m/s^2?
4. **Calculating Acceleration** Find the acceleration of an 800-kg car that has a net force of 4,000 N acting upon it.

Section 4

Newton's Third Law

CALIFORNIA Standards Focus

S 8.2.e Students know that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction).

- What is Newton's third law of motion?
- How can you calculate the momentum of an object?
- What is the law of conservation of momentum?

Key Terms

- momentum
- law of conservation of momentum

Lab zone Standards Warm-Up

How Pushy Is a Straw?

1. Stretch a rubber band around the middle of the front cover of a medium-size hardcover book.
2. Place four marbles in a small square on a table. Place the book on the marbles face up so that the cover with the rubber band is on top.
3. Hold the book steady by placing one index finger on the spine. Then, as shown, push a straw against the rubber band with your other index finger.
4. Push the straw until the rubber band stretches about 10 cm. Then let go of both the book and the straw at the same time.

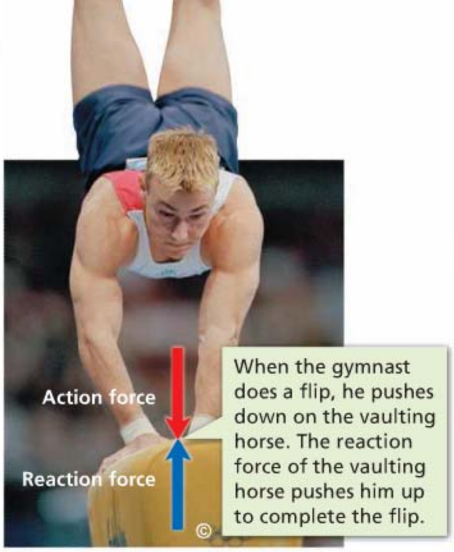
Think It Over

Developing Hypotheses What did you observe about the motion of the book and the straw? Write a hypothesis to explain what happened in terms of the forces on the book and the straw.

Have you ever tried to teach a friend how to roller-skate? It's hard if you are both wearing skates. When your friend pushes against you to get started, you move too. And when your friend runs into you to stop, you both end up moving! To understand why this happens you need to know about Newton's third law of motion and the law of conservation of momentum.

Newton's Third Law of Motion

Newton proposed that whenever one object exerts a force on a second object, the second object exerts a force back on the first object. The force exerted by the second object is equal in strength and opposite in direction to the first force. Think of one force as the "action" and the other force as the "reaction." **Newton's third law of motion states that if one object exerts a force on another object, then the second object exerts a force of equal strength in the opposite direction on the first object.** Another way to state Newton's third law is that for every action there is an equal but opposite reaction.



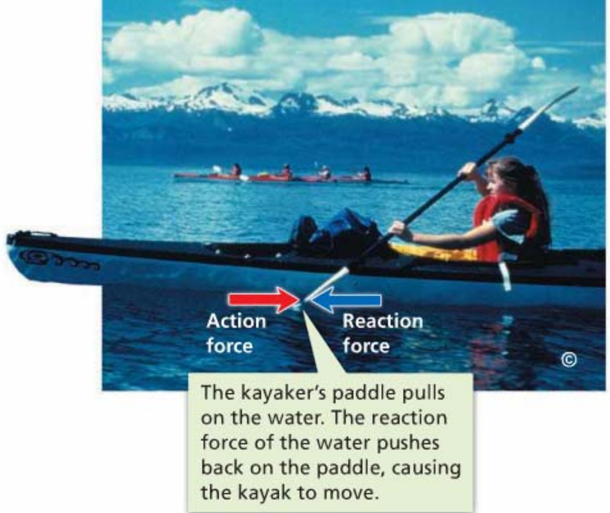


FIGURE 16
Action-Reaction Pairs
Action-reaction pairs explain how a gymnast can flip over a vaulting horse, how a kayaker can move through the water, and how a dog can leap off the ground. **Interpreting Photos** *Describe how the velocities of the gymnast, the kayaker, and the dog change as a result of reaction forces.*

Action-Reaction Pairs You're probably familiar with many examples of Newton's third law. Pairs of action and reaction forces are all around you. When you jump, you push on the ground with your feet. This is an action force. The ground pushes back on your feet with an equal and opposite force. This is the reaction force. You speed up and move in an upward direction when you jump because the ground is pushing you! In a similar way, the kayaker speeds up by exerting an action force on the water with a paddle. The water pushes back on the paddle with an equal reaction force that propels the kayak forward.

Now you can understand what happens when you teach your friend to roller-skate. Your friend exerts an action force when he pushes against you to start. You exert a reaction force in the opposite direction. As a result, both of you speed up in opposite directions.

Detecting Motion Can you always detect motion when paired forces are in action? The answer is no. For example, when Earth's gravity pulls on an object, you cannot detect the equal and opposite reaction of Earth. Suppose you drop your pencil. Gravity pulls the pencil downward. At the same time, the pencil pulls Earth upward with an equal and opposite reaction force. You don't see Earth accelerate toward the pencil because Earth's inertia is so great that its acceleration is too small to notice.

Do Action-Reaction Forces Cancel? Earlier you learned that if two equal forces act in opposite directions on an object, the forces are balanced. Because the two forces add up to zero, they cancel each other out and produce no change in velocity. Why then don't the action and reaction forces in Newton's third law of motion cancel out as well? After all, they are equal and opposite.

The action and reaction forces do not cancel out because they are acting on different objects. Look at the volleyball player on the left in Figure 17. She exerts an upward action force on the ball. In return, the ball exerts an equal but opposite downward reaction force back on her wrists. The action and reaction forces act on different objects.

On the other hand, the volleyball players on the right are both exerting a force on the *same* object—the volleyball. When they hit the ball from opposite directions, each of their hands exerts a force on the ball equal in strength but opposite in direction. The forces on the volleyball are balanced and the ball does not move either to the left or to the right.

Reading Checkpoint **Why don't action and reaction forces cancel each other?**

Video Field Trip
Discovery Channel School
Forces

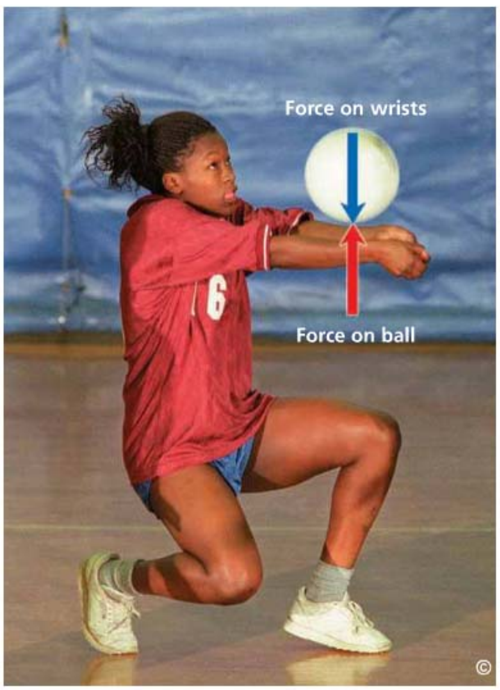
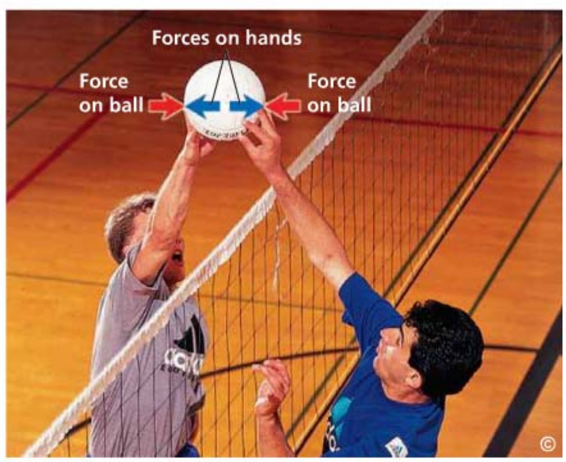


FIGURE 17
Action-Reaction Forces
In the photo on the left, the player's wrists exert the action force. In the photo below, the ball exerts reaction forces on both players.
Interpreting Diagrams *In the photo below, will the volleyball's velocity change? Why?*



Momentum

All moving objects have what Newton called a "quantity of motion." Another name for this quantity is momentum. **Momentum** (moh MEN tum) is a characteristic of a moving object that depends on both the mass and the velocity of the object. **You can calculate the momentum of a moving object by multiplying the object's mass and velocity.**

Momentum = Mass × Velocity

Since mass is measured in kilograms and velocity is measured in meters per second, the unit for momentum is kilogram-meters per second (kg·m/s). Like velocity, acceleration, and force, momentum is described by its direction as well as its quantity. The momentum of an object is in the same direction as its velocity.

Reviewing Math: Measurement and Geometry 7.1.3

Math Sample Problem

Calculating Momentum

Which has more momentum: a 3.0-kg sledgehammer swung at 1.5 m/s, or a 4.0-kg sledgehammer swung at 0.9 m/s?

1 Read and Understand

What information are you given?

Mass of smaller sledgehammer = 3.0 kg
Velocity of smaller sledgehammer = 1.5 m/s
Mass of larger sledgehammer = 4.0 kg
Velocity of larger sledgehammer = 0.9 m/s

2 Plan and Solve

What quantities are you trying to calculate?

The momentum of each sledgehammer = ■

What formula contains the given quantities and the unknown quantity?

Momentum = Mass × Velocity

Perform the calculations.

Smaller sledgehammer: 3.0 kg × 1.5 m/s = 4.5 kg·m/s
Larger sledgehammer: 4.0 kg × 0.9 m/s = 3.6 kg·m/s

3 Look Back and Check

Does your answer make sense?

It is possible for the 3.0-kg hammer to have more momentum than the 4.0-kg one because it has a greater velocity.

Math Practice

1. **Calculating Momentum** A golf ball travels at 16 m/s, while a baseball moves at 7 m/s. The mass of the golf ball is 0.045 kg and the mass of the baseball is 0.14 kg. Which has greater momentum?
2. **Calculating Momentum** What is the momentum of a bird with a mass of 0.018 kg flying at 15 m/s?

Figure 18
Momentum
An object's momentum is the product of the object's mass and velocity.
Problem Solving *If both dogs have the same velocity, which one has the greater momentum?*

The more momentum a moving object has, the harder it is to change its velocity. For example, it is easier to change the velocity of a baseball moving at 20 m/s than it is to change the velocity of a car moving at 20 m/s. The car has more momentum because it has a greater mass. It is however harder to change the velocity of a baseball moving at 20 m/s than it is to change the velocity of a baseball moving at 5 m/s. The baseball moving at 20 m/s has more momentum because it has a greater velocity.

Reading Checkpoint **What must you know to determine an object's momentum?**

Conservation of Momentum

In everyday language, conservation means saving resources. You might conserve water or fossil fuels, for example. In physical science, the word *conservation* has a more specific meaning. It refers to the conditions before and after some event. An amount that is conserved is the same amount after an event as it was before.

The total amount of momentum objects have is conserved when they collide. Momentum may be transferred from one object to another as the velocity of the objects change, but none is lost. This is called the law of conservation of momentum.

The **law of conservation of momentum** states that, in the absence of outside forces, the total momentum of objects that interact does not change. The amount of momentum is the same before and after they interact. **The total momentum of any group of objects remains the same, or is conserved, unless outside forces act on the objects.** Friction is an example of an outside force.

Lab zone Try This Activity

Colliding Cars

1. Find two nearly identical toy cars that roll easily.
2. Make two loops out of masking tape (sticky side out). Put one loop on the front of one of the cars and the other loop on the back of the other car.
3. Place on the floor the car that has tape on the back. Then gently roll the other car into the back of the stationary car. How do each of the cars' velocities change? Was momentum conserved? How do you know?

Predicting What will happen if you put masking tape on the fronts of both cars and roll them at each other with equal speeds? Will momentum be conserved? Test your prediction.

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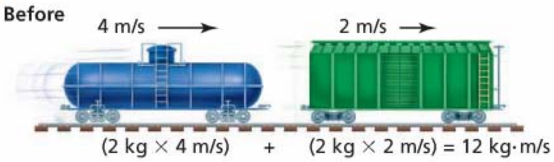
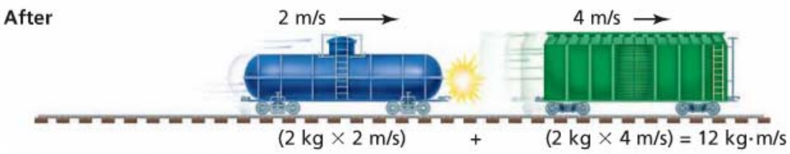
FIGURE 19
Conservation of Momentum
In the absence of friction, momentum is conserved when two train cars collide. **Interpreting Diagrams** *In which diagram is all of the momentum transferred from the blue car to the green car?*

A Two Moving Objects

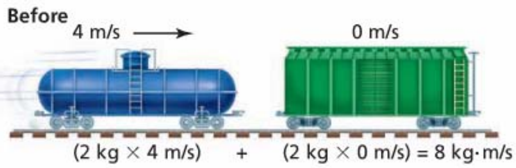


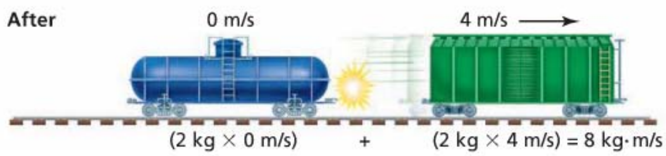
Before the collision, the blue car moves faster than the green car. Afterward, the green car moves faster. The total momentum stays the same.



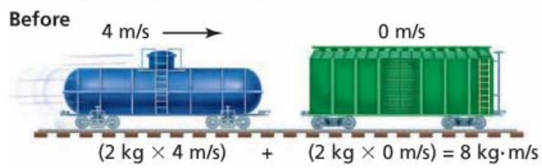
B One Moving Object

When the green car is at rest before the collision, all of the blue car's momentum is transferred to it. Momentum is conserved.

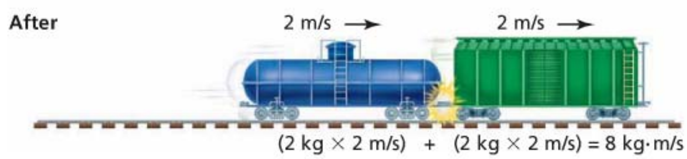




C Two Connected Objects



If the two cars couple together, momentum is still conserved. Together, the cars move slower than the blue car did before the collision.



Collisions With Two Moving Objects In Figure 19A, the blue train car travels at 4 m/s down the same track as the green train car traveling at only 2 m/s. The two train cars have equal masses. The blue car catches up with the green car and bumps into it. During the collision, the speed of each car changes. The blue car slows down to 2 m/s, and the green car speeds up to 4 m/s. Momentum is conserved—the momentum of one train car decreases while the momentum of the other increases.

Collisions With One Moving Object In Figure 19B, the blue car travels at 4 m/s but the green car is not moving. Eventually the blue car hits the green car. After the collision, the blue car is no longer moving, but the green car travels at 4 m/s. Even though the situation has changed, momentum is conserved. All of the momentum has been transferred from the blue car to the green car.

Collisions With Connected Objects Suppose that, instead of bouncing off each other, the two train cars couple together when they hit. Is momentum still conserved in Figure 19C? After the collision, the coupled train cars make one object with twice the mass. The velocity of the coupled trains is 2 m/s—half the initial velocity of the blue car. Since the mass is doubled and the velocity is divided in half, the total momentum remains the same.

Section 4 Assessment

S 8.2.e, Math: 7 MG 1.3
E-LA: Reading 8.2.4

Target Reading Skill **Take Notes** Review your notes for this section. What three important ideas did you include about Newton's Third Law of Motion?

Reviewing Key Concepts

HINT
1. a. **Reviewing** State Newton's third law of motion.

HINT
   b. **Summarizing** According to Newton's third law of motion, how are action and reaction forces related?

HINT
   c. **Applying Concepts** A boy catches a ball while standing on roller skates. What happens to the boy's velocity and the ball's velocity?

HINT
2. a. **Defining** What is momentum?

HINT
   b. **Predicting** What is the momentum of a parked car?

HINT
   c. **Relating Cause and Effect** Why is it important for drivers to allow more distance between their cars when they travel at faster speeds?

HINT
3. a. **Identifying** What is meant by "conservation of momentum"?

HINT
   b. **Inferring** The total momentum of two marbles before a collision is 0.06 kg·m/s. No outside forces act on the marbles. What is the total momentum of the marbles after the collision?

Math Practice

4. **Calculating Momentum** What is the momentum of a 920-kg car moving at a speed of 25 m/s?
5. **Calculating Momentum** Which has more momentum: a 250-kg dolphin swimming at 4 m/s, or a 350-kg manatee swimming at 2 m/s?

Lab zone **Skills Lab**

Forced to Accelerate

S 8.2.f, 8.9.e

Problem

How is the acceleration of a skateboard related to the force that is pulling it?

Skills Focus

calculating, graphing, interpreting data

Materials

- skateboard
- meter stick
- string
- stopwatch
- masking tape
- spring scale, 5-N
- several bricks or other large mass(es)

Procedure

1. Attach a loop of string to a skateboard. Place the bricks on the skateboard.
2. Using masking tape, mark off a one-meter distance on a level floor. Label one end "Start" and the other "Finish."
3. Attach a spring scale to the loop of string. Pull it so that you maintain a force of 2.0 N. Be sure to pull with the scale straight out in front. Practice applying a steady force to the skateboard as it moves.
4. Copy the data table into your notebook.
5. Find the smallest force needed to pull the skateboard at a slow, constant speed. Do not accelerate the skateboard. Record this force on the first line of the table.
6. Add 0.5 N to the force in Step 5. This will be enough to accelerate the skateboard. Record this force on the second line of the table.
7. Have one of your partners hold the front edge of the skateboard at the starting line. Then pull on the spring scale with the force you found in Step 6.
8. When your partner says "Go" and releases the skateboard, maintain a constant force until the skateboard reaches the finish line. A third partner should time how many seconds it takes the skateboard to go from start to finish. Record the time in the column labeled Trial 1.
9. Repeat Steps 7 and 8 twice more. Record your results in the columns labeled Trial 2 and Trial 3.
10. Repeat Steps 7, 8, and 9 using a force 1.0 N greater than the force you found in Step 5.
11. Repeat Steps 7, 8, and 9 twice more. Use forces that are 1.5 N and 2.0 N greater than the force you found in Step 5.

Data Table

Force (N)	Trial 1 Time (s)	Trial 2 Time (s)	Trial 3 Time (s)	Average Time (s)	Average Speed (m/s)	Final Speed (m/s)	Acceleration (m/s^2)

Analyze and Conclude

1. **Calculating** For each force, find the average of the three times that you measured. Record the average time in your data table.
2. **Calculating** For each force, find the average speed of the skateboard. Use this formula:

   Average speed = 1 m ÷ Average time

   Record this value for each force.
3. **Calculating** To obtain the final speed of the skateboard, multiply each average speed by 2. Record the result in your data table.
4. **Calculating** To obtain the acceleration, divide each final speed you found by the average time. Record the acceleration in your data table.
5. **Graphing** Make a line graph. Show the force on the *x*-axis and the acceleration on the *y*-axis. The *x*-axis should go from 0 N to 3.0 N. The *y*-axis scale should go from 0 m/s^2 to about 1 m/s^2. If your data points seem to form a straight line, draw a line through them.
6. **Interpreting Data** Your first data point is the pulling force required for an acceleration of zero. If the acceleration is zero, what is the net force on the skateboard? Explain.
7. **Interpreting Data** According to your graph, how is the acceleration of the skateboard related to the pulling force?
8. **Communicating** Write a paragraph in which you identify the manipulated variable and the responding variable in this experiment. Explain why the mass of the skateboard is kept constant. (See the Skills Handbook to read about experimental variables.)

Design an Experiment

Design an experiment to test how the acceleration of the loaded skateboard depends on its mass. Think about how you would vary the mass of the skateboard. What quantity would you need to measure that you did not measure in this experiment? What quantity would you keep constant? Do you have the equipment to make that measurement? If not, what other equipment would you need? *Obtain your teacher's permission before carrying out your investigation.*

Integrating Space Science

Rockets and Satellites

California Standards Focus

S 8.2.e Students know that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction).

- How does a rocket lift off the ground?
- What keeps a satellite in orbit?

Key Terms

- satellite
- centripetal force

Lab zone Standards Warm-Up

What Makes an Object Move in a Circle?

1. Tie a small mass, such as an empty thread spool, to the end of a string no more than one meter long.
2. Swing the object around in a circle that is perpendicular to the floor. Make sure no one is near the swinging object, and don't let it go!

Think It Over

Observing Is there a net force acting on the object? How do you know?

In October 1957, 14-year-old Homer Hickam looked upward and saw a speck of light move across the sky. It was the Russian satellite *Sputnik*, the first artificial satellite. It was propelled into space by a powerful rocket. This sight inspired Homer and his friends. They spent the next three years designing, building, and launching rockets in their hometown of Coalwood, West Virginia. Many of their first attempts failed, but they did not give up. Eventually, they built a rocket that soared to a height of almost ten kilometers. Their hard work paid off. In 1960, they won first place in the National Science Fair. Since then, rocket launches have become more familiar, but they are still an awesome sight.

◀ **Homer Hickam holds a rocket that he and his friends designed.**

How Do Rockets Lift Off?

A space shuttle like the one in Figure 20 has a mass of more than 2 million kilograms when loaded with fuel. An incredible amount of force is required to get the shuttle to overcome Earth's gravity and rise into space. Rockets and space shuttles lift into space using Newton's third law of motion. They burn fuel and push the exhaust gases downward at a high velocity as they lift off. In turn, the gases push upward on the rocket. **A rocket can rise into the air because the gases it expels with a downward action force exert an equal but opposite reaction force on the rocket.** As long as this upward force, called thrust, is greater than the downward pull of gravity, there is an unbalanced force in the upward direction that causes a change in the rocket's velocity. As a result, the rocket accelerates upward into space.

What Is a Satellite?

Rockets are often used to carry satellites into space. A **satellite** is any object that orbits another object in space. The moon is a satellite because it orbits Earth. An artificial satellite is a device that is launched into orbit. Artificial satellites are designed for many purposes, such as communications, military intelligence, weather analysis, and geographical surveys.

Circular Motion Artificial satellites travel around Earth in an almost circular path. An object traveling in a circle is constantly changing direction so it is accelerating. If an object is accelerating, an unbalanced force must be acting on it. Any force that causes an object to move in a circular path is a **centripetal force** (sen TRIP ih tul). The word *centripetal* means "center-seeking." The centripetal force acts in a direction perpendicular to the direction the object is moving at any given point.

In the Standards Warm-Up, the string supplies the centripetal force. The string pulls the object toward the center, and thereby keeps it moving in a circular path. For a satellite, the centripetal force that pulls the satellite toward the center of Earth is gravity.

Reading Checkpoint **What type of force causes an object to move in a circular path?**

FIGURE 20
A Rocket Launch
The action force pushes the rocket's exhaust gases downward. The reaction force of the gases sends the rocket into space. **Predicting** *As the rocket ascends, how will its mass change?*

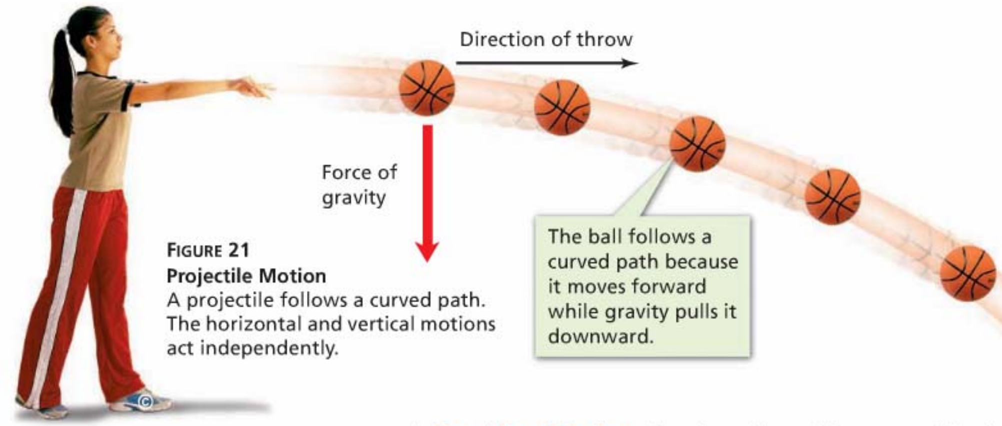


FIGURE 21
Projectile Motion
A projectile follows a curved path. The horizontal and vertical motions act independently.

Satellite Motion Gravity pulls satellites toward Earth. So why don't satellites fall to the ground, as a ball thrown through the air would? The answer is that satellites have a greater horizontal velocity than a ball would have. Instead of falling to Earth, satellites fall around Earth.

If you throw a ball horizontally, as shown in Figure 21, the ball will move away from you at the same time that the unbalanced force, gravity, causes a change in direction. The horizontal and vertical motions act independently, and the ball follows a curved path toward the ground. If you throw the ball faster, it will land even farther in front of you. The faster you throw a projectile, the farther it travels before it lands.

Now suppose, as Isaac Newton did, what would happen if you were on a high mountain and could throw a ball as fast as you wanted. The faster you threw it, the farther away it would land. But, at a certain speed, the path of the ball would match the curve of Earth. Although the ball would keep falling due to gravity, Earth's surface would curve away from the ball at the same rate. Thus the ball would fall around Earth in a circle, as shown in Figure 22.

Satellites in orbit around Earth continuously fall toward Earth, but because Earth is curved they travel around it. In other words, a satellite is a falling projectile that keeps missing the ground! It falls around Earth rather than into it. A satellite does not need fuel because it continues to move ahead due to its inertia. At the same time, the unbalanced force, gravity, continuously changes the satellite's direction. The speed with which an object must be thrown in order to orbit Earth turns out to be about 7,900 m/s!

FIGURE 22
Satellite Motion
The faster a projectile is thrown, the farther it travels before it hits the ground. A projectile with enough velocity moves in a circular orbit. **Interpreting Diagrams** *How does the direction of gravity compare to the direction of the orbiting projectile's motion at any point?*

Satellite Location Some satellites, such as mapping and observation satellites, are put into low orbits of less than 1,000 kilometers. In a low orbit, satellites complete a trip around Earth in less than two hours. Other satellites are sent into higher orbits. At those distances, a satellite travels more slowly, taking longer to circle Earth. For example, communications satellites travel about 36,000 kilometers above Earth's surface. At that height, they circle Earth once every 24 hours. Because Earth rotates once every 24 hours, a satellite above the equator always stays at the same point above Earth as it orbits.

Reading Checkpoint **How does gravity help keep satellites in orbit?**

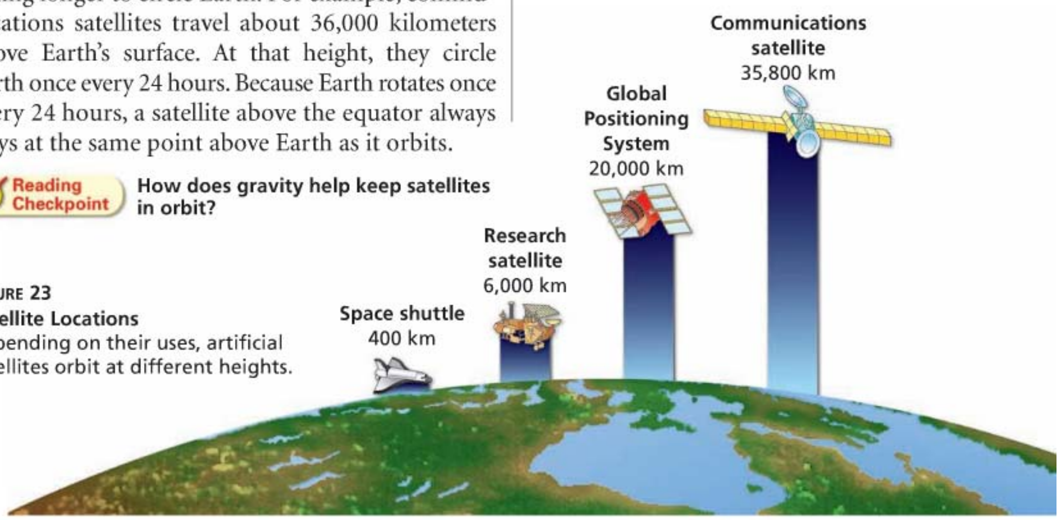


FIGURE 23
Satellite Locations
Depending on their uses, artificial satellites orbit at different heights.

Section 5 Assessment

S 8.2.e, E-LA: Reading 8.1.2

Vocabulary Skill **Latin Word Origins** How does knowing the meaning of the word origin of *centr-* help you remember the meaning of *centripetal*?

Reviewing Key Concepts

HINT
1. a. **Identifying** Which of Newton's three laws of motion explains how a rocket lifts off?

HINT
   b. **Explaining** How do action-reaction pairs explain how a rocket lifts off?

HINT
   c. **Applying Concepts** As a rocket travels upward from Earth, air resistance decreases along with the force of gravity. The rocket's mass also decreases as its fuel is used up. If thrust remains the same, how do these factors affect the rocket's acceleration?

HINT
2. a. **Defining** What is a satellite?

HINT
   b. **Relating Cause and Effect** What causes satellites to stay in orbit rather than falling toward Earth?

   c. **Inferring** In Figure 22, a projectile is thrown with enough velocity to orbit Earth. What would happen if the projectile were thrown with a greater velocity? HINT

Lab zone At-Home Activity

Swing the Bucket Fill a small plastic bucket halfway with water and take it outdoors. Challenge a family member to swing the bucket in a vertical circle. Explain that the water won't fall out at the top if the bucket is moving fast enough. Tell your family member that if the bucket falls as fast as the water, the water will stay in the bucket. Relate this activity to a satellite that also falls due to the unbalanced force of gravity, yet remains in orbit.

Chapter 10 Study Guide

The BIG Idea An unbalanced force will cause a change in an object's velocity.

1 The Nature of Force

Key Concepts S 8.2.a, 8.2.c

- A force is described by its magnitude and by the direction in which it acts.
- Unbalanced forces on an object result in a net force and change an object's velocity.
- Balanced forces acting on an object do not change the object's velocity.

Key Terms

- force
- newton
- net force
- unbalanced forces
- balanced forces

2 Friction, Gravity, and Elastic Forces

Key Concepts S 8.2.b, 8.2.d

- The strength of the force of friction depends on the types of surfaces involved and on how hard the surfaces are pushed together.
- Gravity between objects increases with greater mass and decreases with greater distance.
- In free fall, the force of gravity alone causes an object to accelerate in the downward direction.
- Matter is considered elastic if it returns to its original shape after it is squeezed or stretched.

Key Terms

- friction
- static friction
- sliding friction
- rolling friction
- fluid friction
- gravity
- mass
- weight
- free fall
- air resistance
- projectile
- compression
- tension

3 Newton's First and Second Laws

Key Concepts S 8.2.e, 8.2.f

- Newton's first law of motion states that an object will remain at rest or moving at a constant velocity unless it is acted upon by an unbalanced force.
- Newton's second law of motion states that acceleration depends on the net force acting on the object and on the object's mass.

$$\text{Acceleration} = \frac{\text{Net force}}{\text{Mass}}$$

Key Term

inertia

4 Newton's Third Law

Key Concepts S 8.2.e

- Newton's third law of motion states that if one object exerts a force on another object, then the second object exerts a force of equal strength in the opposite direction on the first object.
- You can calculate the momentum of a moving object by multiplying the object's mass and velocity.

$$\text{Momentum} = \text{Mass} \times \text{Velocity}$$

- The total momentum of any group of objects remains the same, or is conserved, unless outside forces act on the objects.

Key Terms

momentum
law of conservation of momentum

5 Rockets and Satellites

Key Concepts S 8.2.e

- A rocket can rise into the air because the gases it expels with a downward action force exert an equal but opposite reaction force on the rocket.
- Satellites in orbit around Earth continuously fall toward Earth, but because Earth is curved they travel around it.

Key Terms

satellite
centripetal force

Review and Assessment

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Target Reading Skill

Take Notes In your notebook, create a two-column note-taking organizer for Section 4. Include summary statements.

Recall Clues & Questions	Notes
What is friction?	Friction—a force that two surfaces exert on each other Strength depends on • types of surfaces • how hard they are pushed together

Reviewing Key Terms

Choose the letter of the best answer.

HINT **1.** When an unbalanced force acts on an object, the force
a. changes the motion of the object.
b. is canceled by another force.
c. does not change the motion of the object.
d. is equal to the weight of the object.

HINT **2.** Which of the following is an elastic force?
a. friction
b. gravity
c. tension
d. air resistance

HINT **3.** Which of the following is not a projectile?
a. a satellite
b. a thrown ball
c. a ball on the ground
d. a soaring arrow

HINT **4.** The resistance of an object to any change in its motion is called
a. inertia.
b. friction.
c. gravity.
d. weight.

HINT **5.** The product of an object's mass and its acceleration is called the
a. net force.
b. weight.
c. momentum.
d. gravitation.

Complete the following sentences so that your answers clearly explain the key terms.

6. When two people push on a box and the box does not move, this is an example of **balanced forces,** which are __________ . HINT

7. **Friction** depends upon how hard the surfaces are pushed together and __________ . HINT

8. A force that pulls objects toward each other is called **gravity,** which depends upon __________ . HINT

9. The force of **air resistance** is greater on a leaf than an acorn because __________ . HINT

10. The **momentum** of an object depends on ___. HINT

Writing in Science

Descriptive Paragraph Suppose you have been asked to design a new amusement park ride. Write a description of how you will design it. Explain the role that friction and gravity will play in the ride's design.

Video Assessment
Discovery Channel School
Forces

Review and Assessment

Checking Concepts

11. Four children pull on the same toy at the same time, yet there is no net force on the toy. How is that possible?

12. Why are parts of machines that slide over each other often bathed in oil?

13. A yo-yo is hanging motionless from a string. Identify and describe the forces exerted on the string.

14. Explain how force, mass, and acceleration are related by Newton's second law of motion.

15. Suppose you are an astronaut making a space walk outside your space station when your jet pack runs out of fuel. How can you use your empty jet pack to get you back to the station?

16. Draw a diagram showing the motion of a satellite around Earth. Draw the force vectors acting on the satellite. Is the satellite accelerating?

Thinking Critically

17. Classifying What is the name of the force you exert on a sponge when you squeeze it?

18. Applying Concepts You are moving fast on a skateboard when your wheel gets stuck in a crack on the sidewalk. Using the term *inertia*, explain what happens.

19. Problem Solving Look at the diagram below of two students pulling a bag of volleyball equipment. The friction force between the bag and the floor is 15 N. What is the net force acting on the bag? What is the acceleration of the bag?

20. Relating Cause and Effect If you push a book across a table at a constant velocity, is the friction force less than, equal to, or more than your pushing force? How do you know?

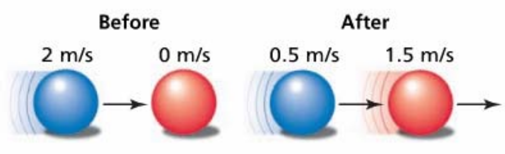
Math Practice

21. Calculating Force A 7.3-kg bowling ball accelerates at a rate of 3.7 m/s^2. What force acts on the bowling ball?

22. Calculating Momentum A 240-kg snowmobile travels at 16 m/s. The mass of the driver is 75 kg. What is the momentum of the snowmobile and driver?

Applying Skills

Use the illustration showing a collision between two balls to answer Questions 23–25.



23. Calculating Use the formula for momentum to find the momentum of each ball before and after the collision. Assume the mass of each ball is 0.4 kg.

24. Inferring Find the total momentum before and after collision. Is the law of conservation of momentum satisfied in this collision? Explain.

25. Designing Experiments Design an experiment in which you could show that momentum is not conserved between the balls when friction is strong.

Lab zone Standards Investigation

Performance Assessment Test your vehicle to make sure it will work on the type of floor in your classroom. Will the vehicle stay within the bounds set by your teacher? Identify all the forces acting on the vehicle. What was the most significant source of friction for your vehicle? List at least three features you included in the design of the vehicle that led to an improvement in its performance. For example, did you give it a smooth shape for low air resistance?

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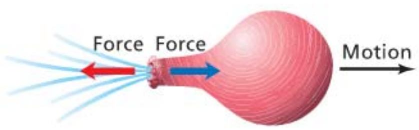
Choose the letter of the best answer.

1. Which of the following is determined by the force of gravity?
A weight
B momentum
C mass
D distance
S 8.2.d

2. When an object is pulled across a level surface at a constant velocity, what force is the pulling force equal to?
A gravity
B friction
C inertia
D an unbalanced force
S 8.2.e

3. What force makes it less likely for a person to slip on a dry sidewalk as opposed to an icy sidewalk?
A air resistance
B friction
C inertia
D momentum
S 8.2.e

Use the diagram below to answer questions 4 and 5.



4. What conclusion can you draw by looking at the diagram?
A Air resistance in front of the balloon pushes it backward.
B Gravity forces air out of the balloon's open end.
C The force of the air leaving the balloon causes it to accelerate forward.
D Friction causes the balloon's acceleration to decrease.
S 8.2.a

5. In the diagram above, why don't the two forces cancel each other out?
A They are not equal.
B They both act on the air.
C They both act on the balloon.
D They act on different objects.
S 8.2.e

6. The table below shows the mass of and net force on four objects. Which object has the greatest acceleration?

Calculating Acceleration

Object	Net Force (N)	Mass (kg)
Boulder	1,000	100
Suitcase	20	20
Shopping cart	25	50
Book	2	1

A boulder
B suitcase
C shopping cart
D book
S 8.2.f

7. In a game of tug-of-war, you pull on the rope with a force of 100 N to the right and your friend pulls on the rope with a force of 100 N to the left. What is the net force on the rope?
A 200 N to the right
B 200 N to the left
C 0 N
D 100 N to the right
S 8.2.c

Apply the BIG Idea

8. Two dogs are pulling on opposite ends of a bone. One dog pulls to the right with a force of 50 N while the other pulls to the left with a force of 40 N. Are the forces on the bone balanced or unbalanced? How do you know? What is the net force on the bone? Would the bone's velocity change? Why?
S 8.2.b, S 8.2.f