Chapter 17 Forces

Standard Course of Study

This chapter addresses the following North Carolina Objectives:

1.01 Identify and create questions and hypotheses.

1.02 Develop appropriate experimental procedures.

1.03 Identify and create questions and hypotheses.

1.04 Analyze variables.

1.05 Analyze evidence.

1.06 Use mathematics to gather, organize, and present data.

1.08 Use oral and written language.

1.09 Use technologies and information systems.

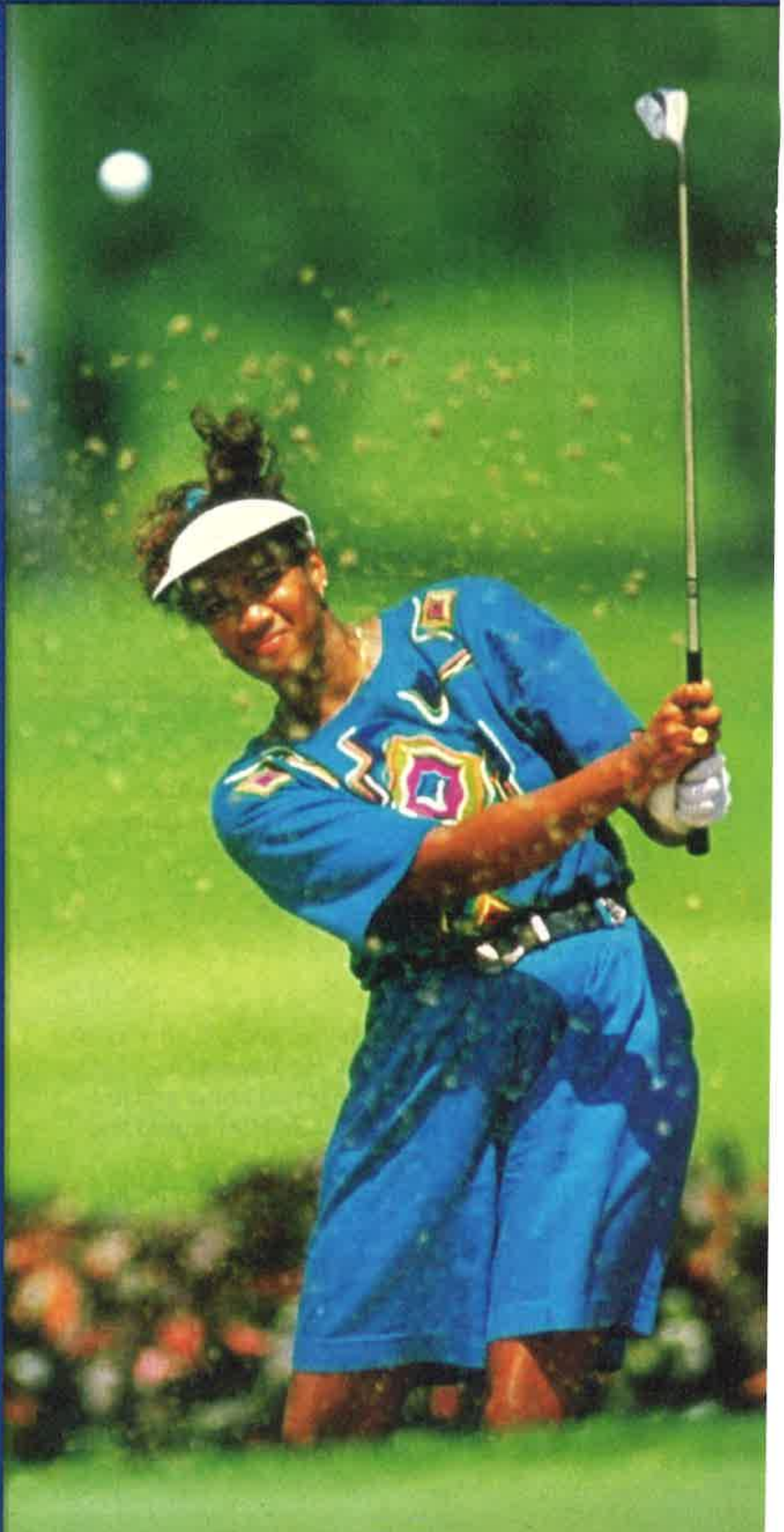
2.03 Evaluate technological designs.

6.03 Evaluate motion in terms of Newton's Laws.

6.05 Describe and measure quantities that characterize moving objects and their interactions.

6.06 Investigate and analyze real-world interactions of balanced and unbalanced forces.

Interactive Textbook



A golfer exerts a force on the golf ball.

End-of-Grade Test Practice

Test-Taking Tip

Converting Units

A test question may ask you to change one unit of measurement to another. You do this by using a conversion factor, a fraction that represents the relationship between the units. For example, to convert meters to centimeters, you need to remember that a meter equals 100 centimeters: 1 m = 100 cm. To figure out the answer, you would multiply by the conversion factor $\frac{100\text{ cm}}{1\text{ m}}$.

Sample Question

A garden measures 3.12 meters wide. How many centimeters wide is the garden?

A 0.312 cm
B 31.2 cm
C 312 cm
D 3,120 cm

Answer

The correct answer is **C.** When you multiply 3.12 m by 100 cm, you get 312 cm.

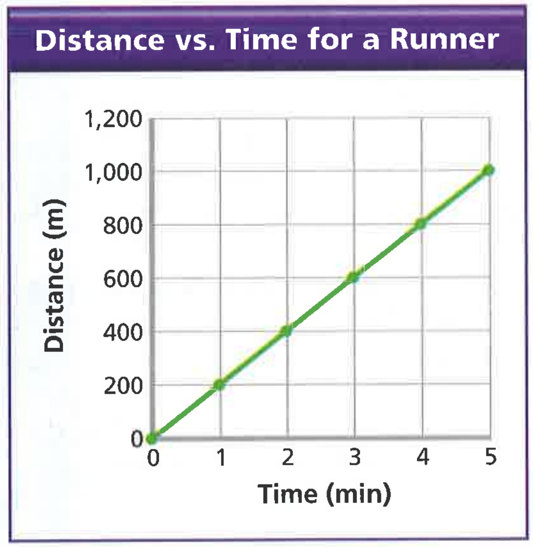
Choose the letter of the best answer.

1. Members of the Fairview Track Club are running a 1.5 km race. What is the distance of the race in meters?
A 0.15 m
B 15 m
C 150 m
D 1,500 m

2. Your father is driving to the beach. He drives at one speed for two hours. He drives at a different speed for another two hours and a third speed for the final hour. How would you find his average speed for all five hours?
A Divide the total driving time by the total distance.
B Multiply the total driving time by the total distance.
C Divide the total distance by the total driving time.
D Subtract the total driving time from the total distance.

3. Two objects traveling at the same speed have different velocities if they
A start at different times.
B travel different distances.
C have different masses.
D move in different directions.

4. The graph below shows the distance versus time for a runner moving at a constant 200 m/min. What could the runner do to make the slope of the line rise?



A stop running
B decrease speed
C maintain the same speed
D increase speed

5. An object used as a reference point to determine motion should be
A accelerating.
B stationary.
C decelerating.
D changing direction.

Constructed Response

6. Explain how speed, velocity, and acceleration are related.

Discovery Channel School

Forces

- Video Preview
- Video Field Trip
- Video Assessment

Lab zone™ Chapter Project

Newton Scooters

Newton's laws of motion describe the relationship between forces and motion. In this Chapter Project, you will use Newton's third law to design a vehicle that moves without the use of gravity or a power source such as electricity. How can you make an object move without pushing or pulling it?

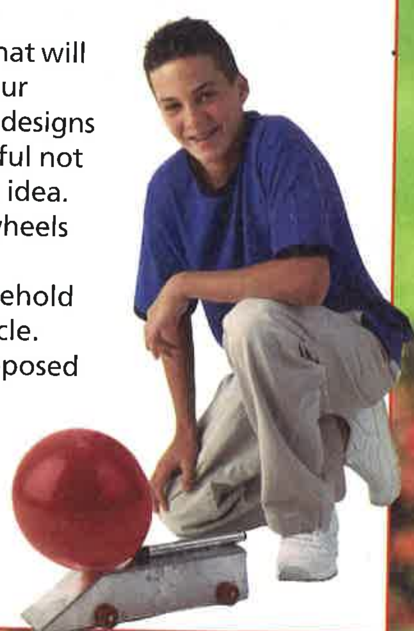
Your Goal To design and build a vehicle that moves without an outside force acting on it

Your vehicle must

- move forward by pushing back on something
- not be powered by any form of electricity or use gravity in order to move
- 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 laws 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

Reading Preview

Key Concepts

- How is a force described?
- How are unbalanced and balanced forces related to an object's motion?

Key Terms

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

Target Reading Skill

Asking Questions Before you read, preview the red headings. In a graphic organizer like the one below, ask a *what* or *how* question for each heading. As you read, write the answers to your questions.

What Is a Force?

Question	Answer
What is a force?	A force is . . .

Lab zone Discover Activity

Is the Force With You?

1. Attach a spring scale to each end of a skateboard.
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. Why? 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. When one object pushes or pulls another object, you say that the first object exerts a force on the second object. You exert a force on a computer key when you push it and on a chair when you pull it away from a table.

Like velocity and acceleration, a force is described by its strength 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.

The strength of a force is measured in the SI unit called 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 lemon.

The direction and strength of a force can be represented by an arrow. 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.

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

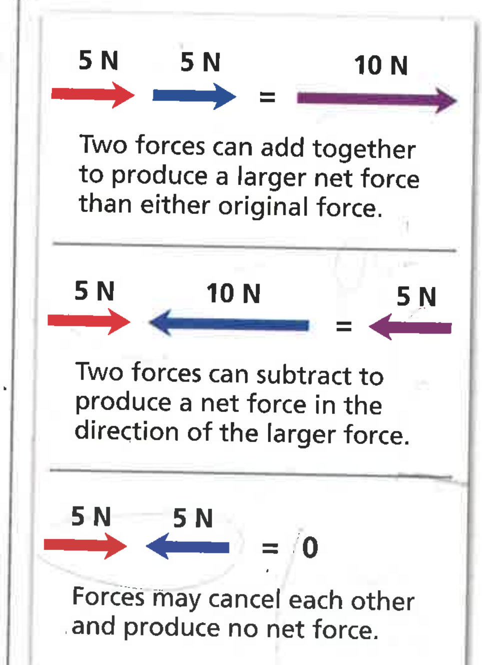
Combining Forces

Often, more than a single force acts on an object at one time. 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 forces act in the same direction, the net force can be found by adding the strengths of the individual forces. In Figure 2, the lengths of the two arrows, which represent two forces, are added together to find the net force.

When forces act in opposite directions, they also combine to produce a net force. However, you must pay attention to 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. So when two forces act in opposite directions, they combine by subtraction. 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. There is no change in the object's motion.

FIGURE 2
Combining Forces
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** can cause an object to start moving, stop moving, or change direction. **Unbalanced forces acting on an object result in a net force and cause a change in the object's motion.**

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 a net, or unbalanced, force acts on the box, 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?**

Balanced Forces When forces are exerted on an object, the object's motion does not always change. In an arm wrestling contest, each person exerts a force on the other's arm, but the two forces are exerted in opposite directions. Even though both people push hard, their arm positions may not change.

Equal forces acting on one object in opposite directions are called **balanced forces.** Each force is balanced by the other.

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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
Balanced and Unbalanced 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?*

Balanced forces acting on an object do not change the object's motion. When equal forces are exerted in opposite directions, the net force is zero. In Figure 3, when two people push on the box with equal force in opposite directions, the forces cancel out. The box does not move.

Section 1 Assessment

Target Reading Skill **Asking Questions** Use the answers to the questions you wrote about the headings to help you answer the questions below.

Reviewing Key Concepts
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?

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. The cards should be able to stand by themselves. In terms of balanced forces, explain to a family member why the cards don't move. Then exert a force on one of the cards. Explain to a family member the role of unbalanced forces in what happens.

Lab zone **Consumer Lab**

Sticky Sneakers

Problem

Friction is a force that acts in the opposite direction to motion. 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 is involved when you start from a stopped position
   - forward-stopping friction, which is involved when you come to a forward stop
   - sideways-stopping friction, which is involved 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. Then 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. You will need to tape a paper clip to each sneaker and then 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. 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. The force necessary to make the sneaker start moving is equal to the friction force. Record the starting friction force in your data table.
6. To measure either type of 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 are the manipulated and responding variables in this experiment? Explain. (See the Skills Handbook to read about experimental variables.)
2. **Observing** 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. **Developing Hypotheses** 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** Draw a diagram for an advertising brochure that shows the forces acting on the sneaker for each type of motion.

Design an Experiment

Wear a pair of your own sneakers. Start running and notice how you press against the floor with your sneaker. How do you think this affects the friction between the sneaker and the floor? Design an experiment that will test for this variable. *Obtain your teacher's permission before carrying out your investigation.*

Section 2 Friction and Gravity

Reading Preview

Key Concepts

- 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?

Key Terms

- friction
- static friction
- sliding friction
- rolling friction
- fluid friction
- gravity
- mass
- weight
- free fall
- air resistance
- terminal velocity
- projectile

Target Reading Skill

Comparing and Contrasting As you read, compare and contrast friction and gravity by completing a table like the one below.

	Friction	Gravity
Effect on motion	Opposes motion	
Depends on		
Measured in		

Lab zone Discover Activity

Which Lands First?

1. Stack three quarters. Place tape between the quarters to hold them tightly together. Place the stack of quarters next to a single quarter near the edge of a desk.
2. Put a ruler flat on the desk behind the coins. Line it up parallel to the edge of the desk and just touching the coins.
3. Keeping the ruler parallel to the edge of the desk, push the coins over the edge at the same time. Observe how long the coins take to land.

Think It Over

Predicting Did you see a difference in the time the coins took to fall? Use what you observed to predict whether a soccer ball will fall more quickly than a marble. Will a pencil fall more quickly than a book? How can you test your predictions?

What happens when you jump on a sled on the side of a snow-covered hill? Without actually doing this, you can predict that the sled will slide down the hill. Now think about what happens at the bottom of the hill. Does the sled keep sliding? Again, without actually riding the sled, you can predict that the sled will slow down and stop.

Why does the sled's motion change on the side of the hill and then again at the bottom? In each case, unbalanced forces act on the sled. The force of gravity causes the sled to accelerate down the hill. The force of friction eventually causes the sled to stop. These two forces affect many motions on Earth.

◀ Friction and gravity both act on the sled.

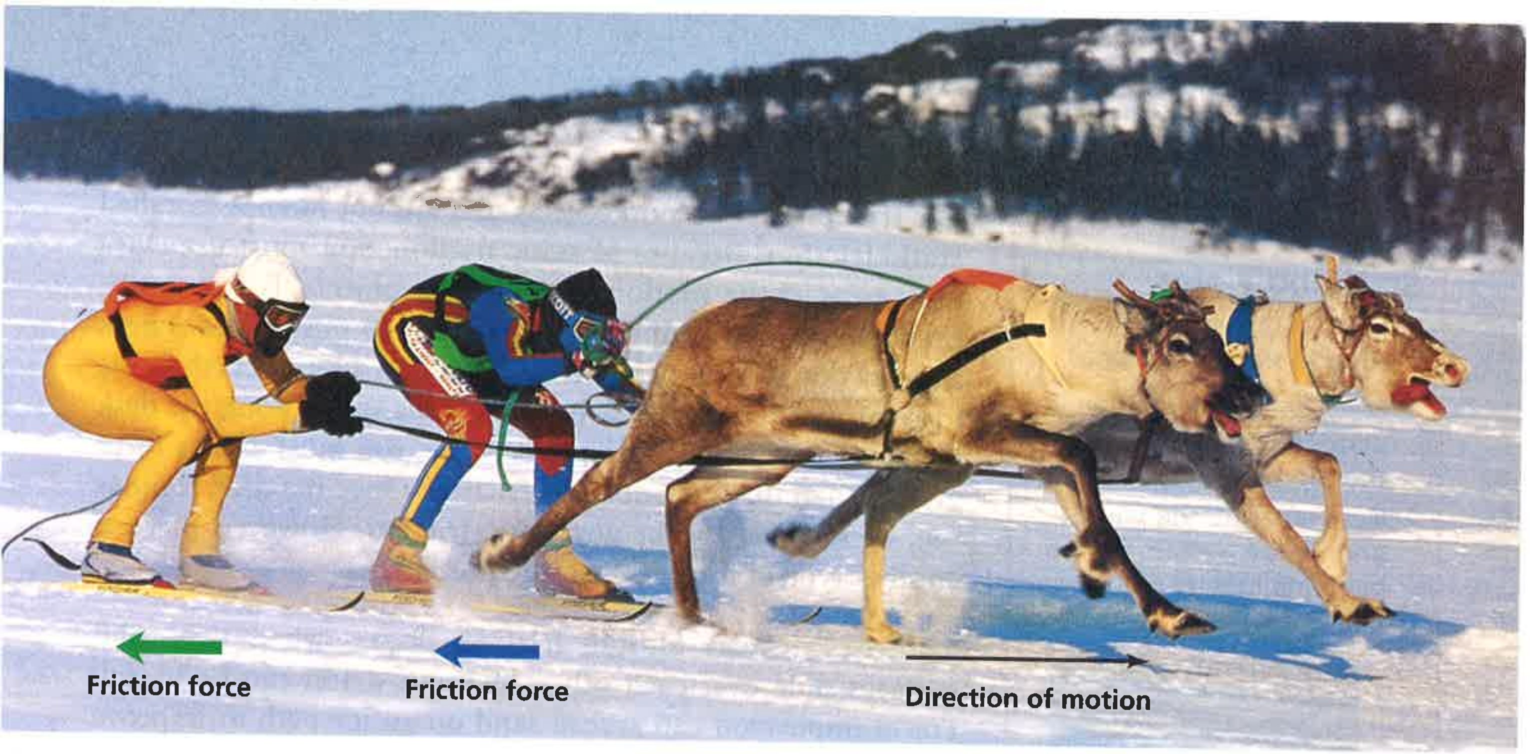

FIGURE 4
Friction and Smooth Surfaces The smooth surfaces of the skis make for a fast ride for these Finnish skiers.
Relating Diagrams and Photos *How does the direction of friction compare to the direction of motion?*

Friction

When a sled moves across snow, the bottom of the sled rubs against the surface of the snow. In the same way, the skin of a firefighter's hands rubs against the polished metal pole during the slide down the pole. The force that two surfaces exert on each other when they rub against each other is called **friction.**

The Causes of Friction In general, smooth surfaces produce less friction than rough surfaces. **The strength of the force of friction depends on two factors: how hard the surfaces push together and the types of surfaces involved.** 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.

A snow-packed surface or a metal firehouse pole 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. Friction acts in a direction opposite to the direction of the object's motion. Without friction, a moving object might not stop until it strikes another object.

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 What applications can you think of for the rolling friction modeled in this activity?

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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. 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 slide against the tire surfaces, causing the wheels to slow and eventually stop. On the other hand, sliding friction is a problem if you fall off your bike and skin your knee!

Rolling Friction When an object rolls across a surface, **rolling friction** occurs. Rolling friction is easier to overcome than sliding friction for similar materials. This type of friction is important to engineers who design certain products. For example, skates, skateboards, and bicycles need wheels that move freely. So 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. Like rolling friction, fluid friction is easier to overcome 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?

FIGURE 6

Types of Friction

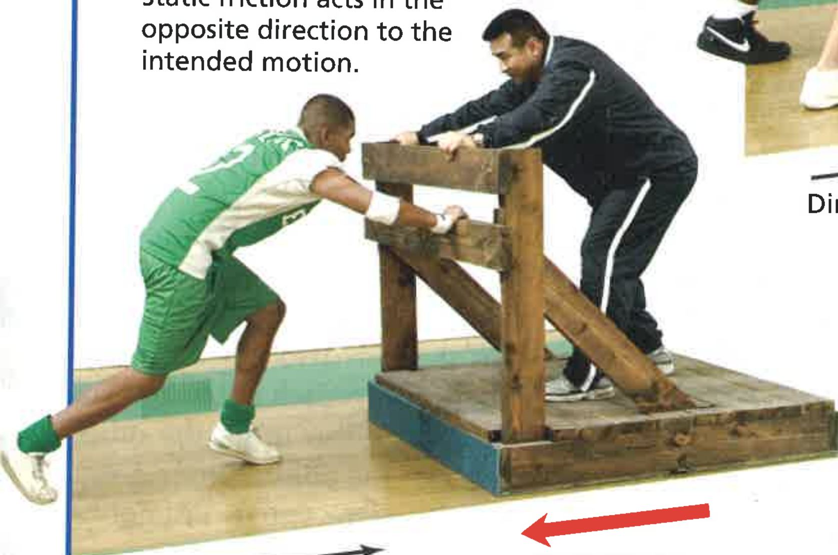
Types of friction include static, sliding, rolling, and fluid friction. **Making Generalizations** *In what direction does friction act compared to an object's motion?*

Direction of motion

Sliding friction

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.

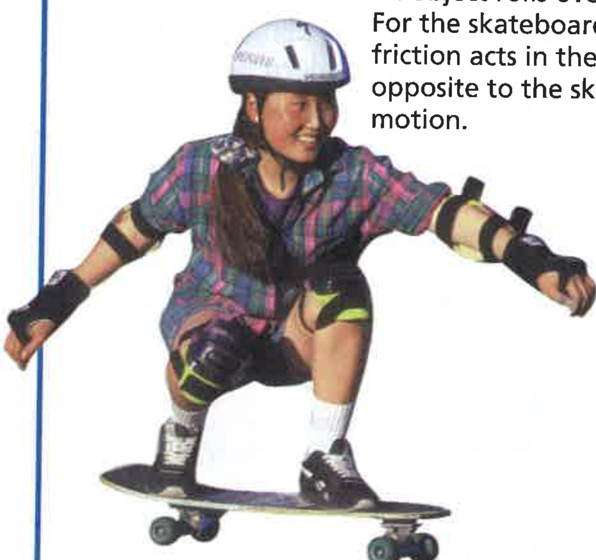
Static Friction ▼
To make the sled move, the athlete first has to overcome the force of static friction. Static friction acts in the opposite direction to the intended motion.



Intended direction of motion

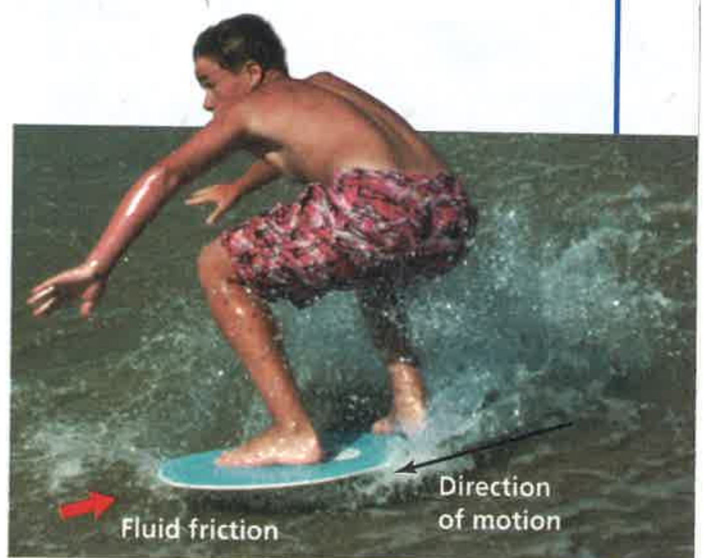
Static friction

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.



Direction of motion

Rolling friction



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

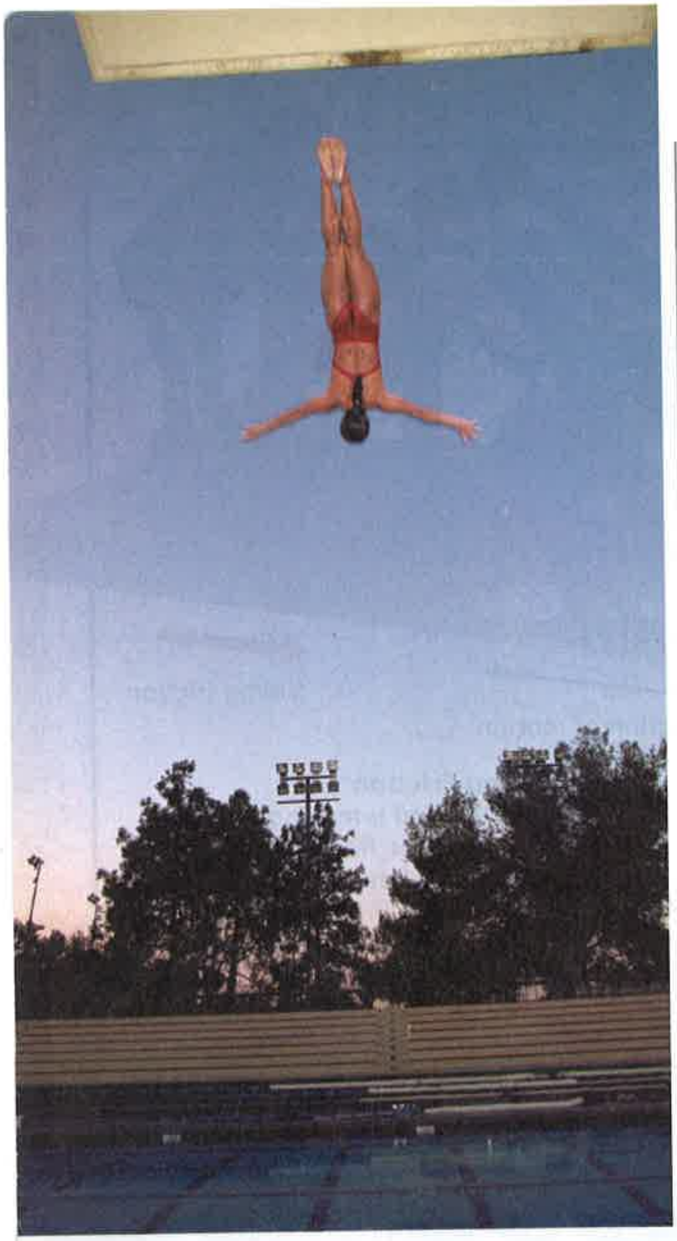


FIGURE 7
Gravity and Acceleration
Divers begin accelerating as soon as they leap from the platform.

Gravity

Would you be surprised if you let go of a pen you were holding and it did not fall? You are so used to objects falling that you may not have thought about why they fall. 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. **Gravity** is a force that pulls objects toward each other.

Universal Gravitation Newton realized that gravity acts everywhere in the universe, not just on Earth. It is the force that makes an apple fall to the ground. It is 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 law of universal gravitation. The law of universal 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.

Factors Affecting Gravity **Two factors affect the gravitational attraction between objects: mass and distance.** **Mass** is a measure of the amount of matter in an object. The SI unit of mass is the kilogram. One kilogram is the mass of about 400 modern pennies. Everything that has mass is made up of matter.

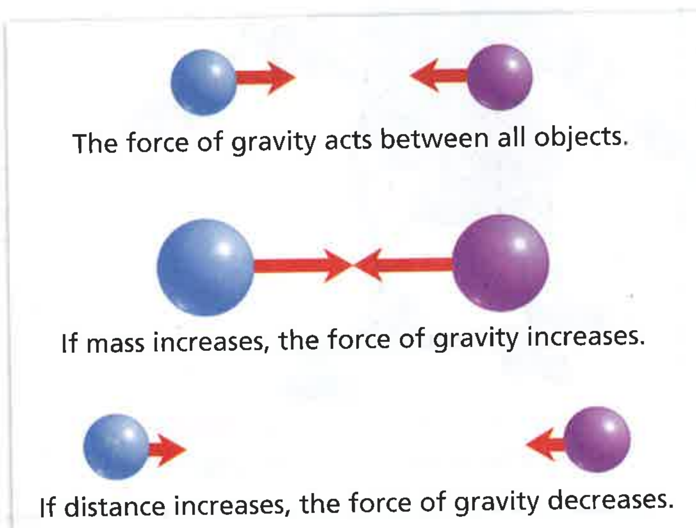


FIGURE 8
Gravitational Attraction
Gravity increases with mass and decreases with distance. **Inferring** *What happens to the force of gravity between two objects if the distance between them decreases?*

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. That's one reason why the planets orbit the sun.

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.

Weight and Mass Mass is sometimes confused with weight. Mass is a measure of the amount of matter in an object; weight is a measure of the gravitational force exerted on an object. The force of gravity on a person or object at the surface of a planet is known as **weight.** So, when you step on a bathroom scale, you are determining the gravitational force Earth is exerting on you.

Weight varies with the strength of the gravitational force but mass does not. Suppose you weighed yourself on Earth to be 450 newtons. Then you traveled to the moon and weighed yourself again. You might be surprised to find out that you weigh only about 75 newtons—the weight of about 8 kilograms 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

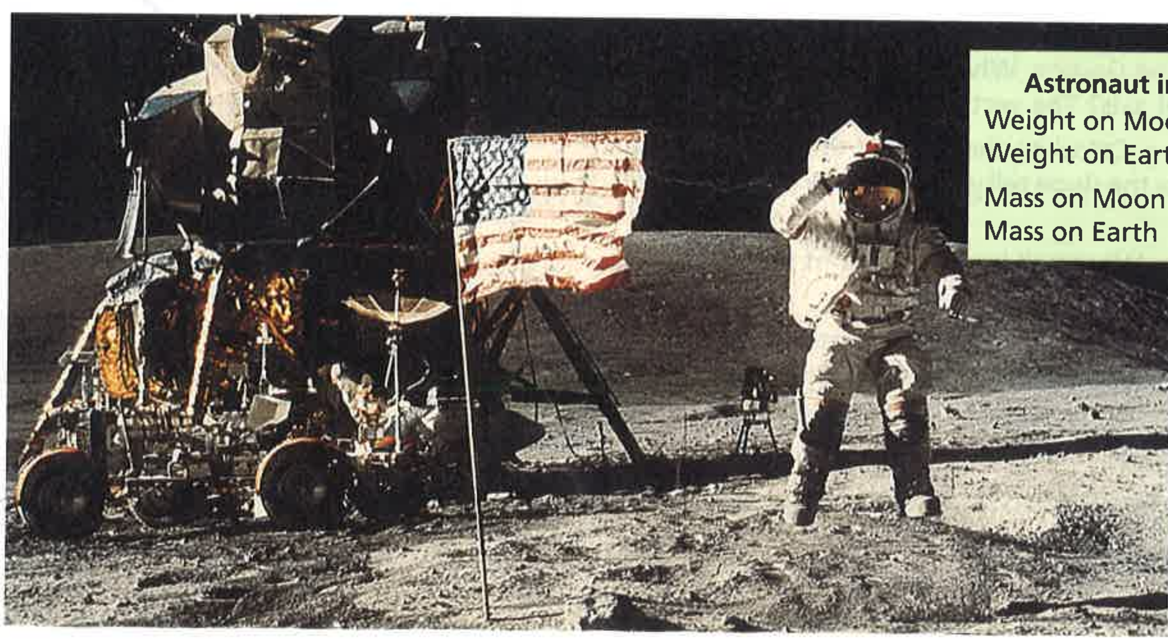
Calculating

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. Multiply each mass by 9.8 m/s^2 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

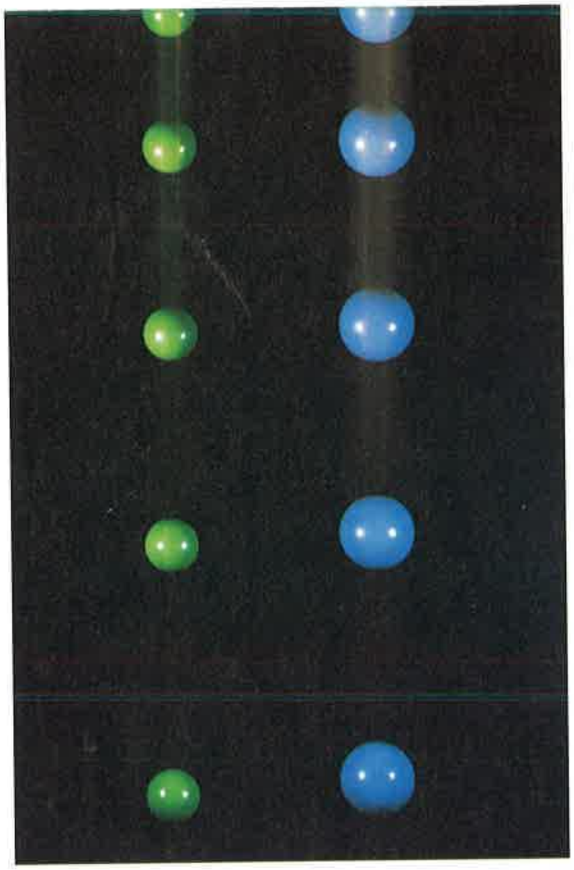


FIGURE 10
Free Fall
In the absence of air, two objects with different masses fall at exactly the same rate.

Gravity and Motion

On Earth, gravity is a downward force that affects all objects. When you hold a book, you exert a force that balances the force of gravity. When you let go of the book, gravity becomes an unbalanced force and the book falls.

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 is an unbalanced force, which causes an object to accelerate.**

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 as the object falls.

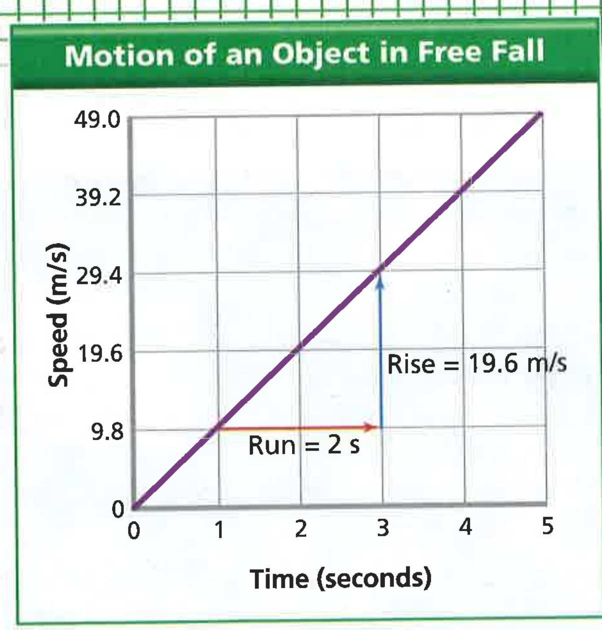
While it may seem hard to believe at first, all objects in free fall accelerate at the same rate regardless of their masses. The two falling objects in Figure 10 demonstrate this principle.

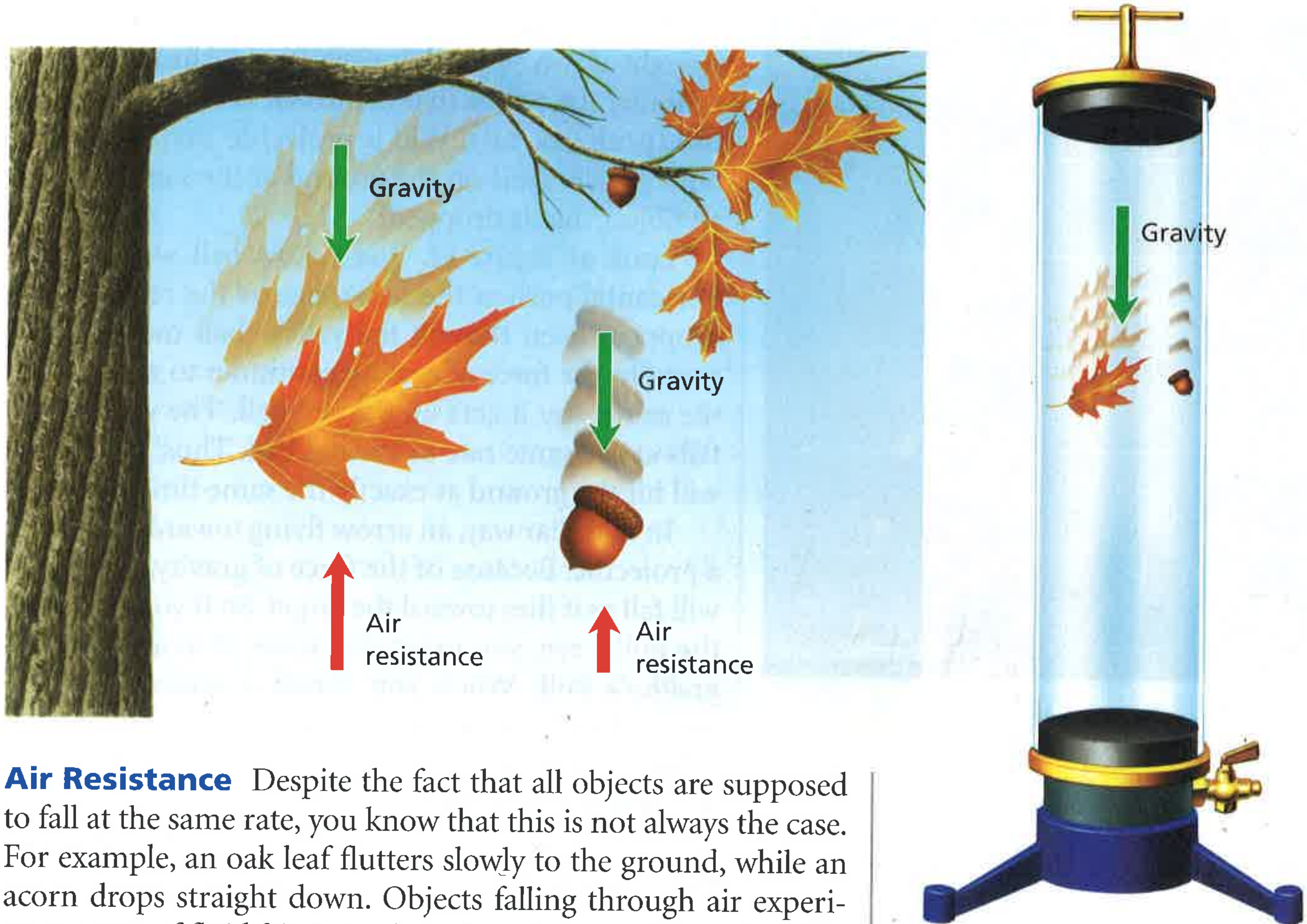
Math Analyzing Data

Free Fall

Use the graph to answer the following questions.

1. **Interpreting Graphs** What variable is on the horizontal axis? The vertical axis?
2. **Calculating** Calculate the slope of the graph. What does the slope tell you about the object's motion?
3. **Predicting** What will be the speed of the object at 6 seconds?
4. **Drawing Conclusions** Suppose another object of the same size but with a greater mass was dropped instead. How would the speed values change?





Air Resistance Despite the fact that all objects are supposed to fall at the same rate, you know that this is not always the case. For example, an oak leaf flutters slowly to the ground, while an acorn drops straight down. Objects falling through air experience a type of fluid friction called **air resistance.** Remember that friction is in the direction opposite to motion, so air resistance is an upward force exerted on falling objects. Air resistance is not the same for all objects. Falling objects with a greater surface area experience more air resistance. That is why a leaf falls more slowly than an acorn. In a vacuum, where there is no air, all objects fall with exactly the same rate of acceleration.

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. Since the flat paper has a greater surface area, it experiences greater air resistance and falls more slowly. In a vacuum, both pieces of paper would fall at the same rate.

Air resistance increases with velocity. As a falling object speeds up, the force of air resistance becomes greater and greater. Eventually, a falling object will fall fast enough that the upward force of air resistance becomes equal to the downward force of gravity acting on the object. At this point the forces on the object are balanced. Remember that when forces are balanced, there is no acceleration. The object continues to fall, but its velocity remains constant. The greatest velocity a falling object reaches is called its **terminal velocity.** Terminal velocity is reached when the force of air resistance equals the weight of the object.

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?*

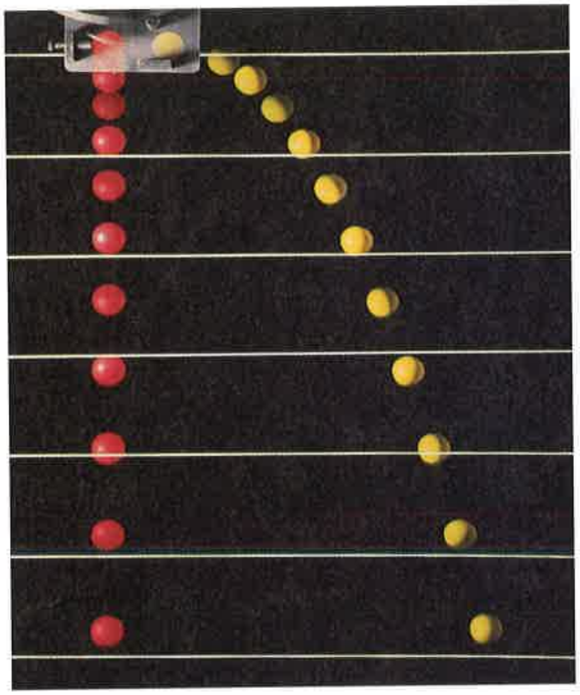


FIGURE 12
Projectile Motion
One ball is dropped vertically and a second ball is thrown horizontally at the same time.
Making Generalizations *Does the horizontal velocity of the ball affect how fast it falls?*

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** (pruh 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, the force of 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.

In a similar way, an arrow flying toward a target is a projectile. Because of the force of gravity, the arrow will fall as it flies toward the target. So if you try to hit the bull's-eye, you must aim above it to account for gravity's pull. When you throw a projectile at an upward angle, the force of gravity reduces its vertical velocity. Eventually, the upward motion of the projectile will stop, and gravity will pull it back toward the ground. From this point, the projectile will fall at the same rate as any dropped object.

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

Section 2 Assessment

Target Reading Skill

Comparing and Contrasting Use the information in your table about friction and gravity to help you answer the questions below.

Reviewing Key Concepts

1. a. Listing What are the four types of friction?
b. Summarizing What factors affect the friction force between two surfaces?
c. Classifying What types of friction occur when you ride a bike through a puddle?

2. a. Identifying What is the law of universal gravitation?
b. Explaining How do mass and distance affect the gravitational attraction between objects?
c. Predicting How would your weight change on the surface of an Earth-sized planet whose mass was greater than Earth's? Why?

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?
c. Applying Concepts What force changes when a sky diver's parachute opens? What force stays the same?

Writing in Science

Cause-and-Effect Paragraph 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

Reading Preview

Key Concepts

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

Key Term

- inertia

Target Reading Skill

Outlining As you read, make an outline about Newton's first and second laws. Use the red headings for the main topics and the blue headings for the subtopics.

Newton's First and Second Laws
I. The first law of motion
A. Inertia
B.
II. The second law of motion
A.

Isaac Newton ▼

Lab zone **Discover Activity**

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 might be the reason 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, no force is needed to keep it moving. Force is needed only to change the motion of an object. Galileo's ideas paved the way for Isaac Newton. Newton proposed the three basic laws of motion in the late 1600s.

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 at rest will remain at rest, and an object moving at a constant velocity will continue moving at a constant velocity, unless it is acted upon by an unbalanced force.**

If an object is not moving, it will not move until a force acts on it. Clothes on the floor of your room, for example, will stay there unless you pick them up. If an object is already moving, it will continue to move at a constant velocity until a force acts to change either its speed or direction. For example, a tennis ball flies through the air once you hit it with a racket. If your friend doesn't hit the ball back, the forces of gravity and friction will eventually stop the ball. On Earth, gravity and friction are unbalanced forces that often change an object's motion.

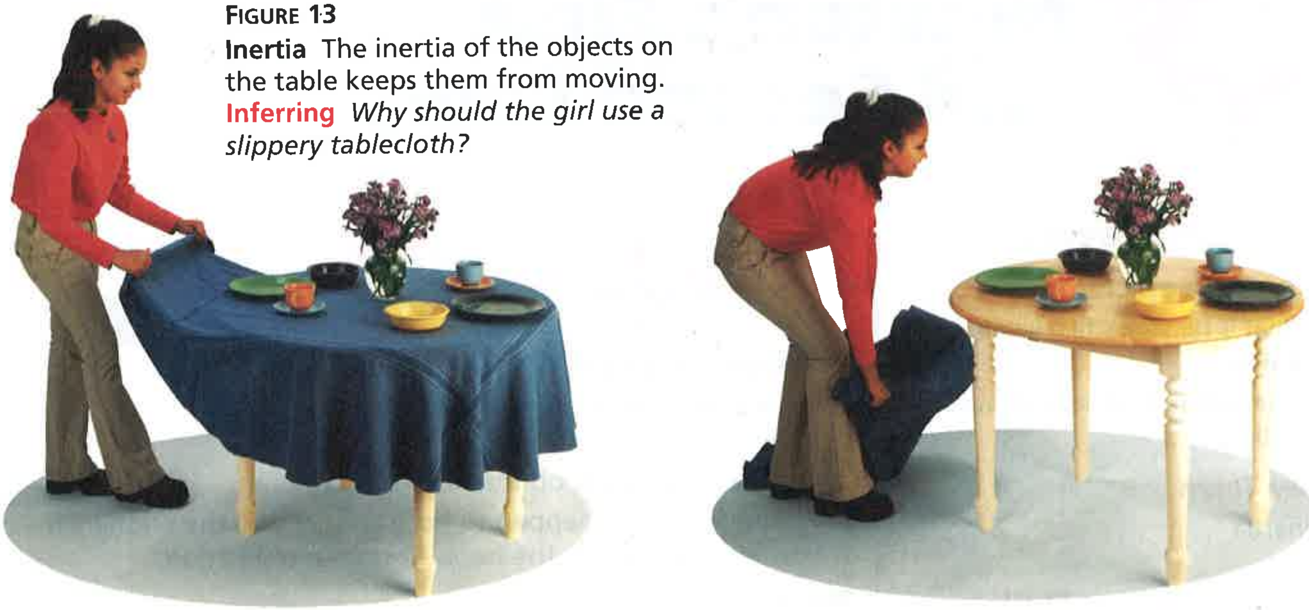


Figure 13
Inertia The inertia of the objects on the table keeps them from moving.
Inferring *Why should the girl use a slippery tablecloth?*

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 the 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 Some objects have more inertia than other objects. For example, suppose you needed 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 the direction in which the ball rolls.
4. Repeat this several times, letting go of the thread at different points.

Inferring At what point do you need to let go of the thread if you want the ball to roll directly away from you? Toward you? Draw a diagram as part of your answer.

The Second Law of Motion

Suppose you are baby-sitting two children who love wagon rides. Their favorite part is when you accelerate quickly. 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?

Determining Acceleration **According to Newton's second law of motion, acceleration depends on the object's mass and on the net force acting on the object.** This relationship can be written as an equation.

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

Acceleration is measured in meters per second per second (m/s^2), and mass is measured in kilograms (kg). According to Newton's second law, then, force is measured in kilograms times meters per second per second ($kg{\cdot}m/s^2$). The short form for this unit of force is the newton (N). Recall that a newton is the SI unit of force. You can think of 1 newton as the force required to give a 1-kg mass an acceleration of 1 m/s^2.

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Math Sample Problem

Calculating Force

A speedboat pulls a 55-kg water-skier. The force causes the skier to accelerate 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.

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

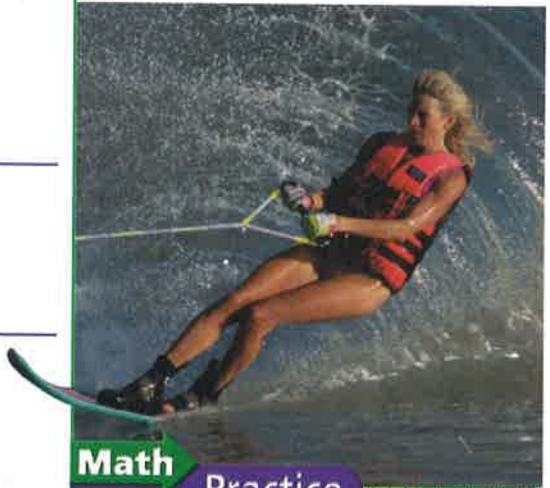
$F = 110 \text{ kg} \cdot \text{m/s}^2$

$F = 110 \text{ N}$

3 Look Back and Check

Does your answer make sense?

A net force of 110 N is required to accelerate the water-skier. This may not seem like enough force, but it does not include the force of the speedboat's pull 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?

FIGURE 14
Force and Mass
The force of the boy's pull and the mass of the wagon determine the wagon's acceleration.

Changes in Force and Mass How can you increase the acceleration of the wagon? Look again at the equation. One way to increase acceleration is by changing the force. If the mass is constant, acceleration and force change in the same way. So to increase the acceleration of the wagon, you can increase the force used to pull it.

Another way to increase acceleration is to change the mass. According to the equation, acceleration and mass change in opposite ways. If the force is constant, an increase in mass causes a decrease in acceleration. The opposite is also true: A decrease in mass causes an increase in acceleration with a constant force. To increase the acceleration of the wagon, you can decrease its mass. So, instead of you, the children should ride in the wagon.

Reading Checkpoint **What are two ways to increase the acceleration of an object?**

Section 3 Assessment

Target Reading Skill Outlining Use the information in your outline about Newton's first and second laws of motion to help you answer the questions below.

Reviewing Key Concepts

1. a. **Reviewing** What does Newton's first law of motion state?
   b. **Explaining** Why is Newton's first law of motion sometimes called the law of inertia?
   c. **Inferring** Use what you know about inertia to explain why you feel pressed back into the seat of a car when it accelerates.
2. a. **Defining** State Newton's second law of motion in your own words.
   b. **Problem Solving** How could you keep an object's acceleration the same if the force acting on the object were doubled?
   c. **Applying Concepts** Using what you know about Newton's second law, 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** Find the force it would take to accelerate an 800-kg car at a rate of 5 m/s^2.
4. **Calculating Force** What is the net force acting on a 0.15-kg hockey puck accelerating at a rate of 12 m/s^2?

Section 4

Newton's Third Law

Reading Preview

Key Concepts

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

Key Terms

- momentum
- law of conservation of momentum

Target Reading Skill

Previewing Visuals Before you read, preview Figure 18. Then write two questions that you have about the diagram in a graphic organizer like the one below. As you read, answer your questions.

Conservation of Momentum

Q.	What happens when two moving objects collide?
A.	
Q.	

Lab zone Discover Activity

How Pushy Is a Straw?

1. Stretch a rubber band around the middle of the cover of a medium-size hardcover book.
2. Place four marbles in a small square on a table. Place the book on the marbles so that the cover with the rubber band is on top.
3. Hold the book steady by placing one index finger on the binding. 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.

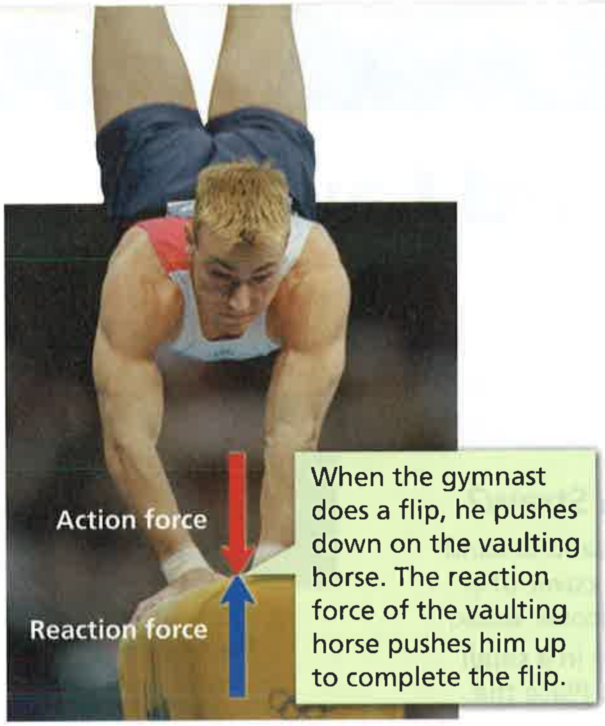
Think It Over

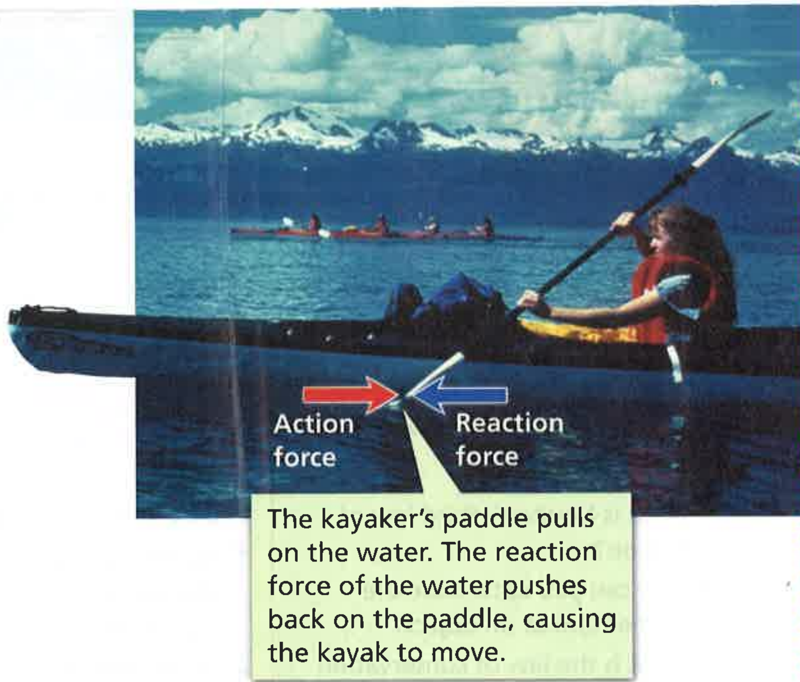
Developing Hypotheses What did you observe about the motion of the book and the straw? Write a hypothesis to explain what happened in terms of the forces on the book and the straw.

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 these movements you need to know 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.





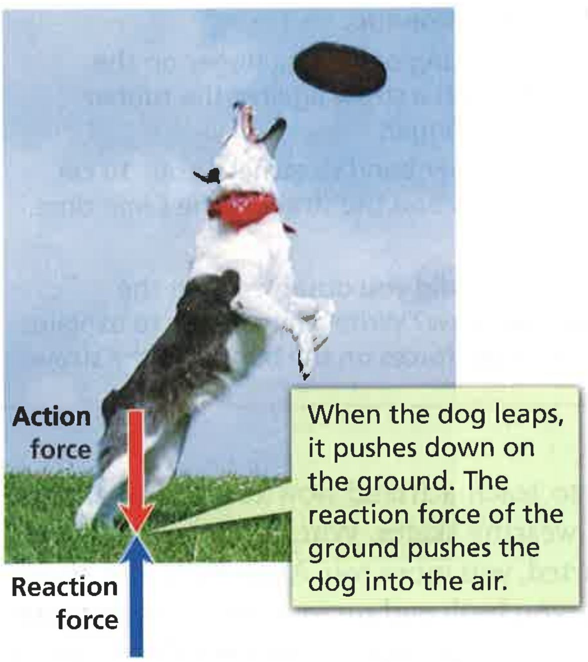


FIGURE 15
Action-Reaction Pairs
Action-reaction pairs explain how a gymnast can flip over a vaulting horse, how a kayaker can move through the water, and how a dog can leap off the ground. **Observing** *Name some other action-reaction pairs that you have observed.*

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 move upward when you jump because the ground is pushing you! In a similar way, a kayaker moves forward 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 move 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 Earth's equal and opposite reaction. 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 motion. 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 16. 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?**

Discovery Channel School

Forces

Video Preview
▶ Video Field Trip
Video Assessment

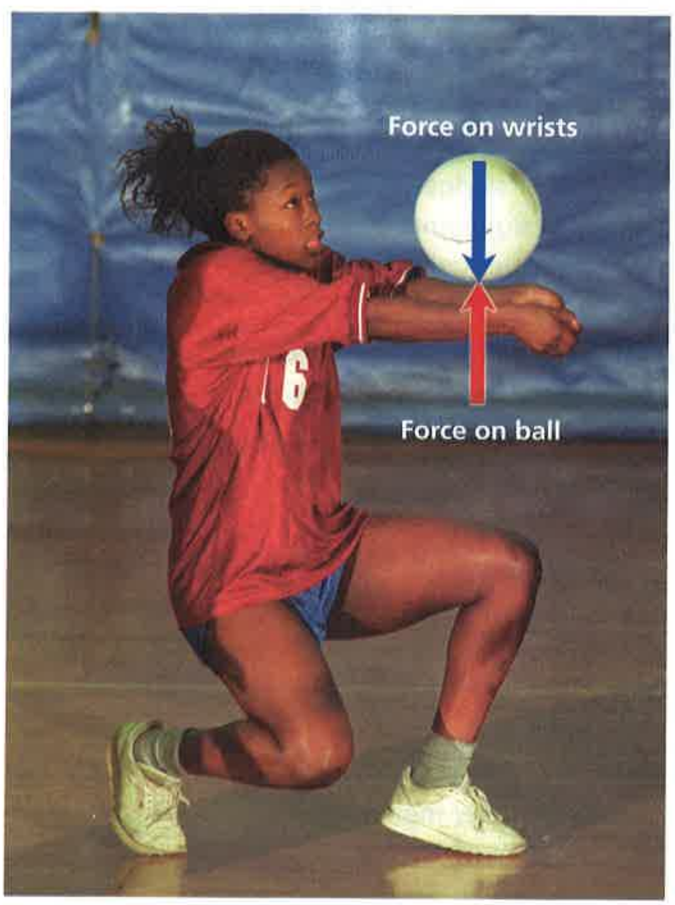
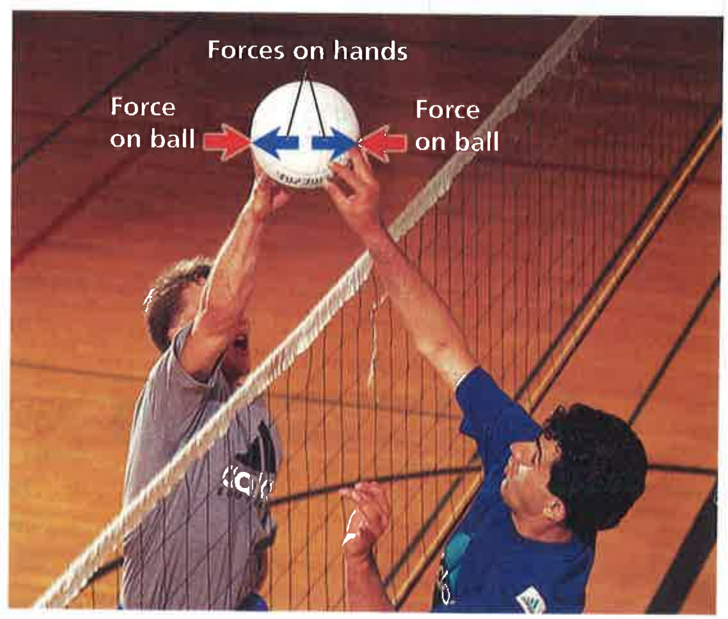


FIGURE 16
Action-Reaction Forces
In the photo on the left, the player's wrists exert the action force. In the photo below, the ball exerts reaction forces on both players.
Interpreting Diagrams *In the photo below, which forces cancel each other out? What force is not cancelled? What will happen to the ball?*



Momentum

All moving objects have what Newton called a "quantity of motion." What is this quantity of motion? Today we call it momentum. **Momentum** (moh MEN tum) is a characteristic of a moving object that is related to the mass and the velocity of the object. **The momentum of a moving object can be determined 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.

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?

The 3.0-kg hammer has more momentum than the 4.0-kg one. This answer makes sense because it is swung at 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 17
Momentum
An object's momentum depends on velocity and mass.
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 stop. The mass of an object affects the amount of momentum the object has. For example, you can catch a baseball moving at 20 m/s, but you cannot stop a car moving at the same speed. The car has more momentum because it has a greater mass. The velocity of an object also affects the amount of momentum an object has. For example, an arrow shot from a bow has a large momentum because, although it has a small mass, it travels at a high velocity.

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

Conservation of Momentum

The word *conservation* has a special meaning in physical science. In everyday language, conservation means saving resources. You might conserve water or fossil fuels, for example. In physical science, conservation 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 amount of momentum objects have is conserved when they collide. Momentum may be transferred from one object to another, but none is lost. This fact 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

Momentum is always conserved—even by toys!

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. 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 in this case? Test your prediction.

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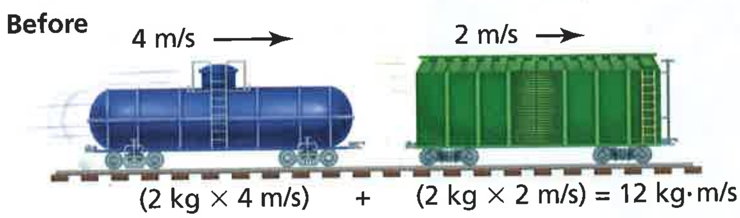
FIGURE 18

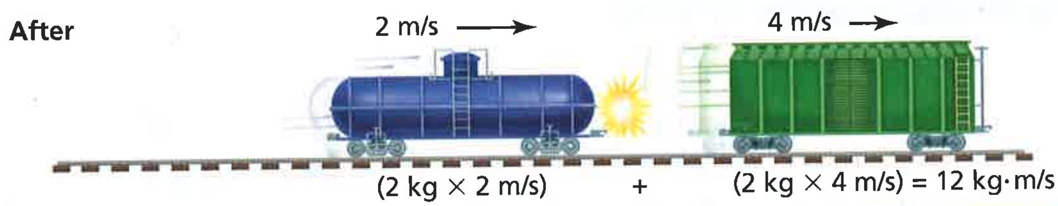
Conservation of Momentum

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

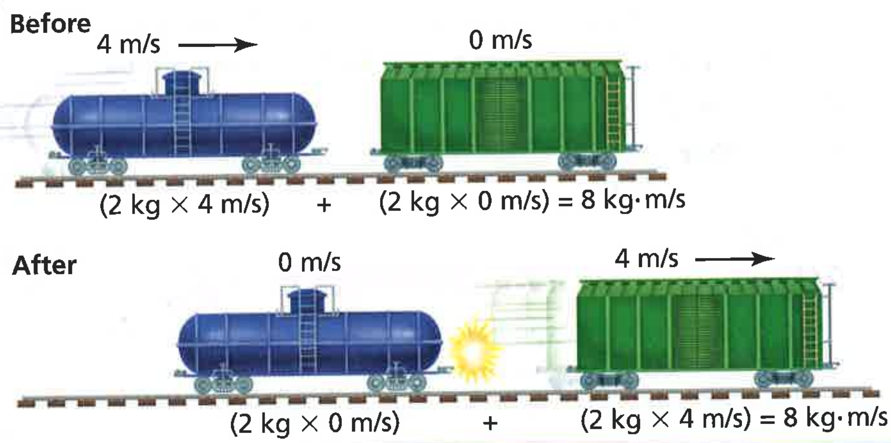


Before the collision, the blue car moves faster than the green car. Afterward, the green car moves faster. The total momentum stays the same.

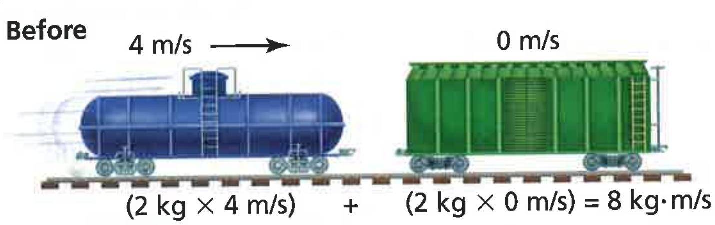


B One Moving Object

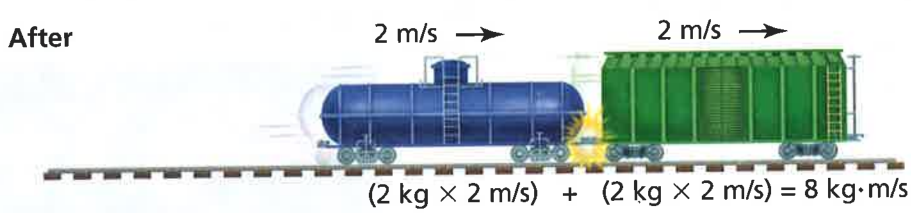
When the green car is at rest before the collision, all of the blue car's momentum is transferred to it. Momentum is conserved.



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 18A, a train car travels at 4 m/s down the same track as another 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 18B, 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 18C? 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.

Reading Checkpoint **What happens to the momentum of two objects after they collide?**

Section 4 Assessment

Target Reading Skill **Previewing Visuals** Refer to your questions and answers about Figure 18 to help you answer Question 3 below.

Reviewing Key Concepts

1. a. **Reviewing** State Newton's third law of motion.
   b. **Summarizing** According to Newton's third law of motion, how are action and reaction forces related?
   c. **Applying Concepts** What would happen if you tried to catch a ball when you were standing on roller skates?
2. a. **Defining** What is momentum?
   b. **Predicting** What is the momentum of a parked car?
   c. **Relating Cause and Effect** Why is it important for drivers to allow more distance between their cars when they travel at faster speeds?
3. a. **Identifying** What is conservation of momentum?
   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

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 long 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)