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The BIG Idea

The change in motion of an object depends on all the forces that act on the object.

SECTION 1

Motion

Main Idea The motion of an object can be described by its speed, velocity, and acceleration.

SECTION 2

Newton's First Law

Main Idea Unbalanced forces cause the motion of an object to change.

SECTION 3

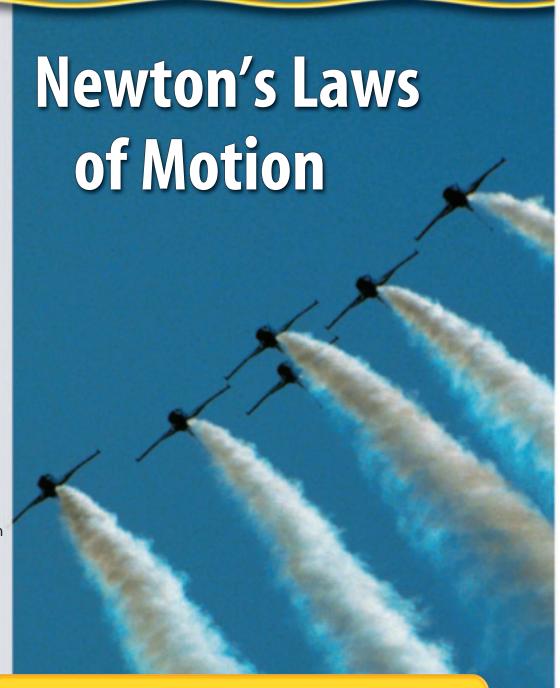
Newton's Second Law

Main Idea The acceleration of an object equals the total force on the object divided by the mass.

SECTION 4

Newton's Third Law

Main Idea Two objects exert forces on each other that are equal in size but in opposite directions.



How do they fly?

Humans have been flying in airplanes since 1903 and spacecraft since the 1960s. Although both planes and space vehicles are incredibly complex machines, their motion is governed by the same principles that explain the motion of a person walking along a sidewalk.

Science Journal List three questions that you would ask an astronaut about space flight.

Start-Up Activities



Observe Motion Along Varying Slopes

Billions of stars orbit around the center of the galaxy. The wind rattles the leaves in a grove of trees creating a cool breeze. A roller coaster plummets down a steep hill. Just three laws of motion explain why objects move the way they do and how different types of forces cause these movements.



- 1. Lean one end of a ruler on top of three books to form a ramp. Use a plastic ruler with a groove down the middle.
- 2. Tap a marble so it rolls up the ramp.

 Measure how far it rolls up the ramp
 before stopping and rolling back down.
- 3. Repeat step 2 using two books, one book, and no books. The same person should tap the marble each time, trying to keep the force constant.
- **4. Think Critically** What would happen if you tapped the marble on a flat surface with no friction? Write your predictions and observations in your Science Journal.



Newton's Laws of Motion
Make the following Foldable
to help you better understand
Newton's laws of motion as you
read the chapter.

Draw a mark at the midpoint of a sheet of paper along the side edge. Then fold the top and bottom edges in to touch the midpoint.



STEP 2 Fold in half from side to side.



vertically. Open
and cut along the
inside fold lines to
form four tabs.



Motion, First Law, Second Law, and Third Law.



Find Main Ideas As you read the chapter, list the main ideas in each section under the appropriate tab.



Preview this chapter's content and activities at qreen.msscience.com

Get Ready to Read

Visualize

Learn It! Visualize by forming mental images of the text as you read. Imagine how the text descriptions look, sound, feel, smell, or taste. Look for any pictures or diagrams on the page that may help you add to your understanding.

Practice It! Read the following paragraph. As you read, use the underlined details to form a picture in your mind.

When you push a heavy door, as in **Figure 18**, you exert a force on the door to move it. The door exerts an equal force back on you. Why don't you move? When you push on the door, your feet are touching Earth, and static friction keeps you from sliding. The reaction force is exerted on you and Earth together.

—from page 703

Based on the description above, try to visualize the forces on a person pushing on a door. Now look at the photo on page 703.

- · How closely does it match your mental picture?
- Reread the passage and look at the picture again. Did your ideas change?
- Compare your image with what others in your class visualized.

Apply It! Read the chapter and list three subjects you were able to visualize. Make a rough sketch showing what you visualized.



Target Your Reading

Use this to focus on the main ideas as you read the chapter.

- **Before you read** the chapter, respond to the statements below on your worksheet or on a numbered sheet of paper.
 - Write an A if you agree with the statement.
 - Write a **D** if you **disagree** with the statement.
- **After you read** the chapter, look back to this page to see if you've changed your mind about any of the statements.
 - If any of your answers changed, explain why.
 - Change any false statements into true statements.
 - Use your revised statements as a study guide.

Before You Read A or D		Statement	After You Read A or D
	1	Speed and velocity are the same.	
	2	An object can be accelerating even if its speed doesn't change.	
	3	An object must be at rest if the forces acting on it are balanced.	
Science	4	The forces on an object are balanced only if all the forces acting on the object cancel.	
Print out a worksheet	5	Gravity acts only on objects that are falling.	
of this page at green.msscience.com	6	Air resistance is a type of friction.	
	7	Sliding friction keeps a book from moving when you gently push on it.	
	8	Objects exert forces on each other only if they are in contact.	
	9	The forces objects exert on each other always cancel.	

Forming your own mental images will help you remember what you read.

as you read

What You'll Learn

- Contrast distance and displacement.
- **Define** speed, velocity, and acceleration.
- **Calculate** speed, velocity, and acceleration.

Why It's Important

You, and many of the things around you, are in motion every day.

Review Vocabulary meter: SI unit of distance equal to approximately 39.37 in

New Vocabulary

- displacementvelocity
- speed
- acceleration

Figure 1 A hiker might be interested in the total distance traveled along a hike or in the displacement. **Infer** whether the displacement can be greater than the total distance.

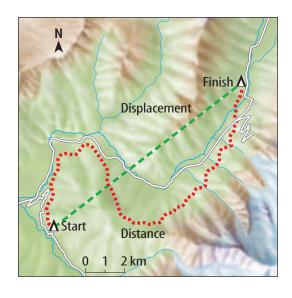
What is motion?

Cars drive past on streets and freeways. Inside you, your heart pumps and sends blood throughout your body. When walking, skating, jumping, or dancing, you are in motion. In fact, motion is all around you. Even massive pieces of Earth's surface move—if only a few centimeters per year.

A person wants to know the distance between home and another place. Is it close enough to walk? The coach at your school wants to analyze various styles of running. Who is fastest? Who can change direction easily in a sprint? To answer these questions, you must be able to describe motion.

Distance and Displacement One way you can describe the motion of an object is by how it changes position. There are two ways to describe how something changes position. One way is to describe the entire path the object travels. The other way is to give only the starting and stopping points. Picture yourself on a hiking trip through the mountains. The path you follow is shown in Figure 1. By following the trail, you walk 22 km but end up only 12 km from where you started. The total distance you travel is 22 km. However, you end up only 12 km northeast of where you started. **Displacement** is the distance and direction between starting and ending positions. Your displacement is 12 km northeast.







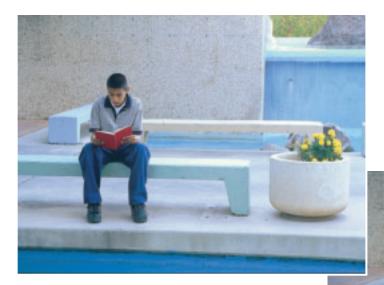
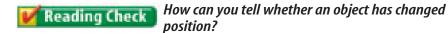


Figure 2 The student has been in motion if he changes position relative to a reference point, such as the plant. **Explain** how the description of the motion depends on the reference point chosen.

Relative Motion Something that is in motion changes its position. The position of an object is described relative to another object, which is the reference point. Suppose you look out the window in the morning and see a truck parked next to a tree. When you look out the window later, the truck is parked further down

the street. If you choose the tree as your reference point, then the truck has been in motion because it has changed position relative to the tree. Has the student in **Figure 2** been in motion?



Speed

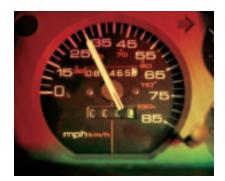
When running, you are interested not only in the distance you travel, but also in how fast you are moving. Your speed describes how quickly or slowly you are moving. **Speed** is the distance traveled divided by the time needed to travel the distance.

Speed Equation
$$speed ext{ (in meters/second)} = \frac{distance ext{ (in meters)}}{time ext{ (in seconds)}}$$
$$s = \frac{d}{t}$$

The unit for speed is a distance unit divided by a time unit. The SI unit for speed is meters per second, which is abbreviated as m/s. However, sometimes it is more convenient to measure distance and time in other units. For example, a speedometer shows a car's speed in units of km/h.



Figure 3 When you read a speedometer, you are finding your instantaneous speed. **Identify** when your instantaneous speed would be the same as your average speed.



Constant Speed If you are riding in a car with the cruise control on, the speed doesn't change. In other words, the car moves at a constant speed. If you are running at a constant speed of 5 m/s, you run 5 m each second. When you are traveling at a constant speed, the speed at any instant of time is the same.

Changing Speed For some motion, speed is not constant. If you are riding your bike, you must slow down for intersections and turns and then pedal faster to resume your speed. Your average speed for your trip would be the total distance traveled divided by the time you were riding. If you wanted to know how fast you were going at just one instant, you would be interested in your instantaneous speed. A car speedometer like the one in **Figure 3** shows instantaneous speed—how fast the car is moving at any moment. When speed is constant, average speed and instantaneous speed are the same.

Applying Math

Solve a Simple Equation

A SWIMMER'S AVERAGE SPEED It takes a swimmer 57.2 s to swim a distance of 100 m. What is the swimmer's average speed?

Solution

1 This is what you know:

distance: d = 100.0 m

• time: t = 57.2 s

2 *This is what you need to find:*

speed: s

3 *This is the procedure you* need to use:

Substitute the known values for distance and time into the speed equation and calculate the speed:

$$s = \frac{d}{t} = \frac{(100.0 \text{ m})}{(57.2 \text{ s})} = 1.75 \text{ m/s}$$

4 Check your answer:

Multiply your answer by the time, 57.2 s. The result should be the given distance, 100.0 m.

Practice Problems

- **1.** A bicycle coasting downhill travels 170.5 m in 21.0 s. What is the bicycle's average speed?
- 2. A car travels a distance of 870 km with an average speed of 91.0 km/h. How many hours were needed to make the trip?



For more practice, visit green.msscience.com/ math practice



Velocity

Sometimes you might be interested not only in how fast you are going, but also in the direction. When direction is important, you want to know your velocity. Velocity is the displacement divided by time. For example, if you were to travel 1 km east in 0.5 h, you would calculate your velocity as follows.

$$velocity = \frac{displacement}{time}$$

$$velocity = \frac{(1 \text{ km east})}{(0.5 \text{ h})}$$

$$velocity = 2 \text{ km/h east}$$



Figure 4 The speedometers and compasses on an airplane instrument panel tell the pilot the airplane's velocity.

Like displacement, velocity includes a direction. Velocity is important to pilots flying airplanes. They rely on control panels like the one in **Figure 4** because they need to know not only how fast they are flying, but also in what direction.

Acceleration

Displacement and velocity describe how far, how fast, and where something is moving. You also might want to know how motion is changing. Is a car speeding up, or is it slowing down? Is it moving in a straight line or changing direction? **Acceleration** is the change in velocity divided by the amount of time required for the change to occur. Because velocity includes speed and direction, so does acceleration. If an object changes its speed, its direction, or both, it is accelerating.

Speeding Up and Slowing Down When you think of an object accelerating, you might think of it moving faster and faster. If someone says a car accelerates, you think of it moving forward and increasing its velocity.

However, when an object slows down, it also is accelerating. Why? Recall that an object is accelerating when its velocity changes. Velocity can change if the speed of an object changes, whether the speed increases or decreases, or if it changes direction. If an object slows down, its speed changes. Therefore, if an object is speeding up or slowing down, it is accelerating.



Measuring Motion

Procedure

- **1.** Measure a fixed distance such as the length of your driveway.
- 2. Use a watch to measure the time it takes you to stroll, rapidly walk, and run this distance.

Analysis

- 1. Calculate your speed in each case.
- 2. Use your results to predict how long it would take you to go 100 m by each method.

Calculating Acceleration If an object changes speed but not direction, you can use the following equation to calculate the object's acceleration.

Acceleration Equation

acceleration (in m/s^2) =

final speed (in m/s) – **initial speed** (in m/s) time (in s)

$$a = \frac{s_{\rm f} - s_{\rm i}}{t}$$

In the acceleration equation, the symbol s_f stands for the final speed and s_i stands for the initial speed. The SI unit for acceleration is m/s^2 , which means meters/(seconds × seconds). The unit m/s^2 is the result when the unit m/s is divided by the unit s.

Applying Math

Solve a Simple Equation

SKATEBOARD ACCELERATION It takes a skateboarder 12.0 s to speed up from 2.0 m/s to 8.0 m/s. What is the skateboarder's acceleration?

Solution

- **1** This is what you know:
- initial speed: $s_f = 2.0 \text{ m/s}$
- final speed: $s_i = 8.0 \text{ m/s}$
- time: t = 12.0 s
- **2** *This is what you need to find:*

acceleration: a

3 *This is the procedure you need* to use:

Substitute the known values for initial speed and time into the acceleration equation, and calculate the acceleration:

$$a = \frac{(s_{\rm f} - s_{\rm i})}{t} = \frac{(8.0 \text{ m/s} - 2.0 \text{ m/s})}{(12.0 \text{ s})} = 0.5 \text{ m/s}^2$$

4 Check your answer:

Multiply your answer by the time 12.0 s and then add the initial speed. The result should be the given final speed, 8.0 m/s.

Practice Problems

- **1.** A horse speeds up from a speed of 11 m/s to 17 m/s in 3 s. What is the horse's acceleration?
- **2.** What is the acceleration of a sports car initially at rest that reaches a speed of 30.0 m/s in 5.0 s?



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When the race starts, the runner accelerates by speeding up.

When rounding the corners of the track, the runner accelerates by turning.

After crossing the finish line, the runner accelerates by slowing down.

Turning When an object turns or changes direction, its velocity changes. This means that any object that changes direction is accelerating. To help understand acceleration, picture running a race, as shown in **Figure 5.** As soon as the race begins, you start from rest and speed up. When you follow the turn in the track, you are changing your direction. After you pass the finish line, you slow down to a steady walk. In each case, you are accelerating.

Figure 5 During a race, a runner accelerates in different ways.

section

review

Summary

What is motion?

- The position of an object is measured relative to a reference point.
- The motion of an object can be described by how the position of an object changes.

Speed

• The speed of an object can be calculated from:

$$s = \frac{d}{t}$$

 Average speed is the total distance traveled divided by the total time; instantaneous speed is the speed at an instant of time.

Acceleration

- Acceleration occurs when the speed of an object or its direction of motion changes.
- The acceleration of an object moving in a straight line can be calculated from:

$$a = \frac{s_{\mathsf{f}} - s_{\mathsf{i}}}{t}$$

Self Check

- **1. Evaluate** whether the velocity of a jogger can be determined from the information that the jogger travels 2 km in 10 min.
- **2. Determine** your distance traveled and displacement if you walk 100 m forward and then 35 m backward.
- Describe how a speedometer needle moves when a car is moving with constant velocity, speeding up, and slowing down.
- **4. Think Critically** How could two observers measure a different speed for the same moving object?

Applying Math

- 5. Evaluate Motion Two people swim for 60 s. Each travels a distance of 40 m swimming out from shore, and 40 m swimming back. One swimmer returns to the starting point and the other lands 6 m north of the starting point. Determine the total distance, displacement, and average speed of each swimmer.
- **6. Calculate Acceleration** What is the acceleration of a car moving at 12.0 m/s that comes to a stop in 4 s?



2

Newton's First Law

Michel Hans/Allsport/Getty In

as you read

What You'll Learn

- **Define** force.
- Describe Newton's first law of motion.
- Contrast balanced and unbalanced forces.

Why It's Important

Newton's first law explains why the motion of objects change.

Review Vocabulary

mass: a measure of the amount of matter in an object

New Vocabulary

- force
- first law of motion
- balanced forces
- unbalanced forces

Laws of Motion

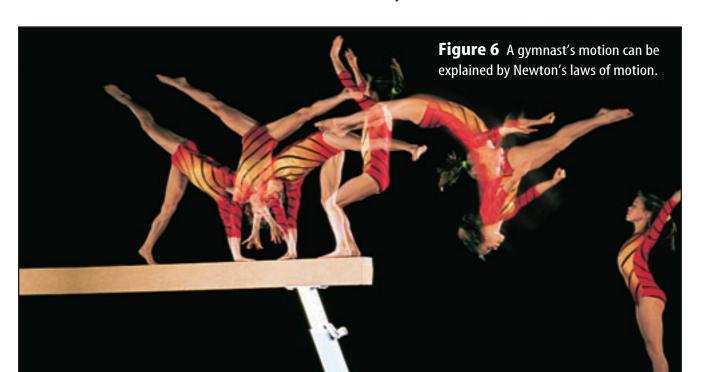
A picture might tell a thousand words, but sometimes it takes a thousand pictures to show a motion. Look at the strobe photo in **Figure 6.** The smoothness of the overall motion is the result of many individual motions—hands move and legs flex. Some trainers who work with athletes use such films to help them understand and improve performance.

What causes such complex motions to occur? Each individual motion can be explained and predicted by a set of principles that were first stated by Isaac Newton. These principles are called Newton's laws of motion.

Force An object's motion changes in response to a force. A **force** is a push or a pull. A force has a size and a direction—both are important in determining an object's motion. For example, pushing this book on one side will slide it across the desk in the same direction. Pushing it harder will make it move faster in the direction of your push. However, if you push the book straight down, it will not move. The force you exert on the book when you push is called a contact force. A contact force is a force that is exerted when two objects are touching each other.

Reading Check

Name two contact forces that act on you when you sit at a table. Include the directions.









Long-Range Forces However, a force can be exerted if two objects are not in contact. If you bring a magnet

close to a paper clip, the paper clip moves toward the magnet, so a force must be acting on the paper clip. The same is true if you drop a ball—the ball will fall downward, even though nothing appears to be touching it. The forces acting on the paper clip and the ball are long-range forces. These forces can cause an object's motion to change without direct contact. Long-range forces include gravity, magnetism, and electricity.

In SI units the unit of force is the newton, which is abbreviated N and named for Isaac Newton. One newton is about the amount of force needed to lift a half cup of water.

Newton's First Law of Motion

When you are riding in a car and it comes to a sudden stop, you feel yourself continuing to move forward. Your seat belt slows you down and pulls you back into your seat. This can be explained by the first law of motion—An object will remain at rest or move in a straight line with constant speed unless it is acted upon by a force. For a long time it was thought that all objects come to rest naturally. It seemed that a force had to be applied continually to keep an object moving. Newton and others theorized that if an object already is moving, it will continue to move in a straight line with constant speed. For the object to slow down, a force has to act on it.

Think about what keeps you in your seat when a car comes to a sudden stop. You can feel yourself moving forward, but the seat belt applies a force to pull you back and stop your motion. If you were to push a cart with boxes on it, as in **Figure 7**, and suddenly stop the cart, the boxes would continue moving and slide off the cart.

Figure 7 If you were to stop the cart suddenly, the boxes would keep moving.

Infer why the boxes move downward after they slide off the cart.



Car Safety Features In a car crash, a car comes to a sudden stop. According to Newton's first law, passengers inside the car will continue to move unless they are held in place. Research the various safety features that have been designed to protect passengers during car crashes. Write a paragraph on what you've learned in your Science Journal.





It is easy to speed up or slow down a small child in a wagon.

Figure 8 The more massive the body is, the more inertia it has. **Apply** How does inertia affect collisions between cars?



Changing the motion of a wagon carrying two children is harder.

Inertia and Mass The first law of motion is sometimes called the law of inertia. Inertia measures an object's tendency to remain at rest or keep moving with constant velocity. Inertia depends on the mass of the object. The more mass an object has, the more inertia it has and the harder it is to change the motion of the object. Look at **Figure 8.** It is easy to get a wagon to start moving if only one small child is sitting in it. You must exert more force to start the wagon moving if it holds more mass. The same is true if you try to stop the wagon after it is moving. You need to exert a larger force to stop the wagon that has more mass.



Topic: Aircraft Carriers

Visit green.msscience.com for Web links to information about how airplanes land on aircraft carriers. Because these airplanes have a large mass, their inertia is also large. This makes the planes hard to stop on the short runway.

Activity Investigate the effects of the large forces encountered in aircraft and spacecraft acceleration on the human body.

Adding Forces

According to Newton's first law, the motion of an object changes only if a force is acting on the object. Sometimes more than one force acts on an object, as when several people push a stalled car to the side of the road. Motion depends upon the size and direction of all the forces.

If two people push in opposite directions on a box with an equal amount of force, the box will not move. Because the forces are equal but in opposite directions, they will cancel each other out and are called balanced forces. When forces on an object are balanced, no change will occur in the object's motion because the total force on the object is zero.

If one force pushing on the box is greater than the other, the forces do not cancel. Instead, the box will move in the direction of the larger force. Forces acting on an object that do not cancel are unbalanced forces. The motion of an object changes only if the forces acting on it are unbalanced. The change in motion is in the direction of the unbalanced force.



Changes in Motion and Forces

How do unbalanced forces affect the motion of an object? Look at the dancer in **Figure 9.** When she jumps, she pushes off the stage with a force greater than the force of gravity pulling her down. This creates an unbalanced force upward, and the dancer moves upward. After she has left the ground and her feet are no longer in contact with the floor, gravity becomes the only force acting on her. The forces on her are unbalanced and her motion changes—she slows down as she rises into the air and speeds up as she returns to the ground.

The motion of an object changes only when unbalanced forces act on the object. Recall that if the motion of

an object changes, the object is accelerating. The object can speed up, slow down, or turn. In all cases, an object acted on by an unbalanced force changes velocity.



Figure 9 Because the motion of this dancer is changing, the forces on her must be unbalanced.

section

review

Summary

Forces

- A force is a push or a pull. An object's motion changes in response to a force.
- A contact force is a force exerted when two objects are touching each other.
- Long-range forces are exerted between objects that are not touching. Gravity and electric and magnetic forces are long-range forces.

Newton's First Law of Motion

- Newton's first law of motion states that an object will remain at rest or move with a constant velocity unless it is acted upon by an unbalanced force.
- The tendency of an object to resist a change in motion is inertia, which increases as the mass of the object increases.
- Balanced forces cancel and do not cause a change in motion. Unbalanced forces cause a change in motion.

Self Check

- 1. Apply the first law of motion to the motion of an ice skater sliding across the ice at a constant velocity.
- 2. **Describe** the information that must be given to specify a force.
- **3. Explain** When you sit in a chair, the force of gravity is pulling you downward. Is this a balanced or an unbalanced force?
- 4. Explain why a greater force is needed to move a refrigerator than is needed to move a book.
- 5. Think Critically Explain whether the following statement is true: if an object is moving, there must be a force acting on it.

Applying Skills

6. Analyze It was once thought that the reason objects slowed down and stopped was that there was no force acting on them. A force was necessary to keep an object moving. According to the first law of motion, why do objects slow down and stop?



Newton's Second Law

as you read

What You'll Learn

- Predict changes in motion using Newton's second law.
- Describe the gravitational force between objects.
- Contrast different types of friction.

Why It's Important

Newton's second law explains how motion changes.

Review Vocabulary

solar system: the Sun, together with the planets and other objects that revolve around the Sun

New Vocabulary

- second law of motion
- gravitational force
- friction

The Second Law of Motion

Newton's first law of motion can help predict when an object's motion will change. Can you predict what the change in motion will be? You know that when you kick a ball, as in **Figure 10,** your foot exerts a force on the ball, causing it to move forward and upward. The force of gravity then pulls the ball downward. The motion of the ball can be explained by Newton's second law of motion. According to the **second law of motion,** an object acted on by an unbalanced force will accelerate in the direction of the force with an acceleration given by the following equation.

Newton's Second Law of Motion

acceleration (m/s²) =
$$\frac{\text{force (in N)}}{\text{mass (in kg)}}$$

$$a=\frac{F}{m}$$

If more than one force acts on the object, the force in this formula is the combination of all the forces, or the total force that acts on the object. What is the acceleration if the total force is zero?

Reading Check

In what direction does an object accelerate when acted on by an unbalanced force?

Figure 10 When you kick a ball, the forces on the ball are unbalanced. The ball moves in the direction of the unbalanced force.





Using the Second Law

The second law of motion enables the acceleration of an object to be calculated. Knowing the acceleration helps determine the speed or velocity of an object at any time. For motion in a straight line an acceleration of 5 m/s² means that every second the speed is increasing by 5 m/s.

If you know the mass and acceleration of an object, you can use Newton's second law to find the force. The equation for Newton's second law of motion can be solved for force if both sides of the equation are multiplied by mass as shown below:

$$\frac{F}{m} = a$$

$$\frac{m}{m} \times \frac{F}{m} = m \times a$$

$$F = ma$$

Applying Math

Solve a Simple Equation

THE FORCE ON A BIKE AND RIDER A bike and a rider together have a mass of 60.0 kg. If the bike and rider have an acceleration of 2.0 m/s², what is the force on the bike and rider?

Solution

1 This is what you know:

• mass: m = 60.0 kg

• acceleration: $a = 2.0 \text{ m/s}^2$

2 *This is what you need to find:*

force: F

This is the procedure you need to use:

Substitute the known values for mass and acceleration into the equation for Newton's second law of motion, and calculate force:

 $F = ma = (60.0 \text{ kg})(2.0 \text{ m/s}^2) = 120 \text{ N}$

4 *Check your answer:*

Divide your answer by the mass 60.0 kg. The result should be the given acceleration 2.0 m/s².

Practice Problems

- **1.** You are lifting a backpack with a mass of 12.0 kg so it has an acceleration of 0.5 m/s^2 . What force are you exerting on the backpack?
- **2.** The space shuttle lifts off with an acceleration of 16.0 m/s². If the shuttle's mass is about 2,000,000 kg, what force is being exerted on the shuttle at liftoff?



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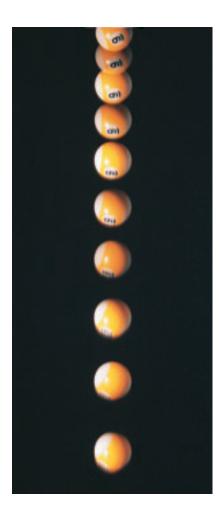


Figure 11 This falling ball has been photographed using a strobe light that flashes on and off at a steady rate. Because the ball is accelerating, its speed is increasing. As a result, the distance it travels between each strobe flash also increases.

The Force of Gravity Every object exerts an attractive gravitational force on every other object. The **gravitational force** between two objects depends on the masses of the objects and the distance between them. This force increases as the objects get closer together or if their masses increase.

You don't notice the gravitational force between you and ordinary objects. Your mass and the masses of these objects are too small for the gravitational force produced to be large enough to feel. However, objects with much greater mass, such as planets and stars, can exert much greater gravitational forces. For example, the gravitational forces between the Sun, planets, and other nearby space objects are large enough to hold the solar system together.

You can feel the gravitational force exerted by Earth because Earth has much more mass than any other nearby object. Gravity causes all objects at or near Earth's surface to be pulled downward toward Earth's center with the same acceleration, 9.8 m/s². The motion of a falling object is shown in **Figure 11.** The gravitational force on a falling object with mass, m, is

$$F = m \times (9.8 \text{ m/s}^2)$$

Even if you are standing on the ground, Earth still is pulling on you with this force. You are at rest because the ground exerts an upward force that balances the force of gravity.

Mass and Weight The force of Earth's gravity on an object near Earth is the weight of that object. The weight of an object is not the same as the object's mass. Weight is a force, just like a push of your hand is a force. Weight changes when the force of gravity changes. For example, your weight on the Moon is less than your weight on Earth because the force of gravity at the Moon's surface is only about 16 percent as large as the force of Earth's gravity. Mass, on the other hand, is a measure of the amount of matter in an object. It is the same no matter where you are. An astronaut would have the same mass on Earth as on the Moon.

Reading Check How are mass and weight different?

Recall that mass is a measure of inertia, which is how hard it is to change the motion of an object. Think of how hard it would be to stop a 130-kg football player rushing at you. Now suppose you were in outer space. If you were far enough from Earth, the force of Earth's gravity would be weak. Your weight and the football player's weight would be small. However, if he were moving toward you, he would be just as hard to stop as on Earth. He still has the same mass and the same inertia, even though he is nearly weightless.

Richard Megna/Fundamental Photographs



Friction

Rub your hands together. You can feel a force between your hands, slowing their motion. If your hands are covered in lotion, making them slippery, the force is weaker. If anything gritty or sticky is on your hands, this force increases. **Friction** is a force that resists sliding motion between surfaces that are touching.

Friction always is present when two surfaces of two objects slide past each other. To keep the objects moving, a force has to be applied to overcome the force of friction. However, friction is also essential to everyday motion. How hard would it be to move without friction? When you walk up a ramp, friction prevents you from sliding to the bottom. When you stand on a skateboard, friction keeps you from sliding off. When you ride a bike, friction enables the wheels to propel the bike forward. Friction sometimes can be reduced by adding oil or grease to the surfaces, but it always is present. There are several types of friction, and any form of motion will include one or more of them.

Static Friction Gently push horizontally on this book. You should be able to push against it without moving it. This is because of the static friction between the cover of the book and the top of the desk. Static friction keeps an object at rest from moving on a surface when a force is applied to the object. When you stand on a slight incline, you don't slide down because of the static friction between your shoes and the ground.

When you carry a tray of food to a table and stop to sit down, Newton's first law predicts that the food on the tray will keep moving and slide off the tray. Happily, static friction keeps the food from sliding off the tray, allowing you to sit down and enjoy your meal. Another example of static friction is shown in **Figure 12.**





Visit green.msscience.com for Web links to information about the force of gravity on other planets and moons in the solar system.

Activity Make a table showing your weight in newtons on the other planets of the solar system.

Figure 12 The rubber mat increases the static friction acting on the computer. This static friction keeps the computer from sliding.

Explain what would happen when the cart stopped if there were no static friction.

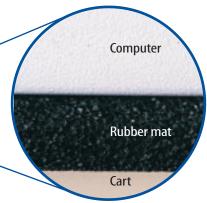






Figure 13 Sliding friction between the rider's shoe and the sidewalk slows the skateboarder down.

Compare and contrast *static and sliding friction.*

Sliding Friction Push on your book again so that it slides. Notice that once the book is in motion and leaves your hand, it comes to a stop. Sliding friction is the force that slows the book down. Sliding friction occurs when two surfaces slide past each other. To keep the book moving, you have to keep applying a force to overcome sliding friction.

The friction between a skier and the snow, a sliding baseball player and the ground, and your shoes and the skin where a blister is forming are examples of sliding friction. When you apply the brakes to a bike, a car, or the skateboard shown in **Figure 13**, you use sliding friction to slow down.

Rolling Friction A car stuck in snow or mud spins its wheels but doesn't move. Rolling friction makes a wheel roll forward or backward. If the rolling friction is large enough, a wheel will roll without slipping. The car that is stuck doesn't move because mud or snow makes the ground too slippery. Then there is not enough rolling friction to keep the wheels from slipping.

Because rolling friction is the force that enables a wheel to roll on a surface, the force of rolling friction is in the same direction as the wheel is rolling. If the wheel is rolling forward, the rolling friction force also points forward, as shown in **Figure 14.** Some of the ways that static, sliding, and rolling friction are useful to a bike rider are shown in **Figure 15.**

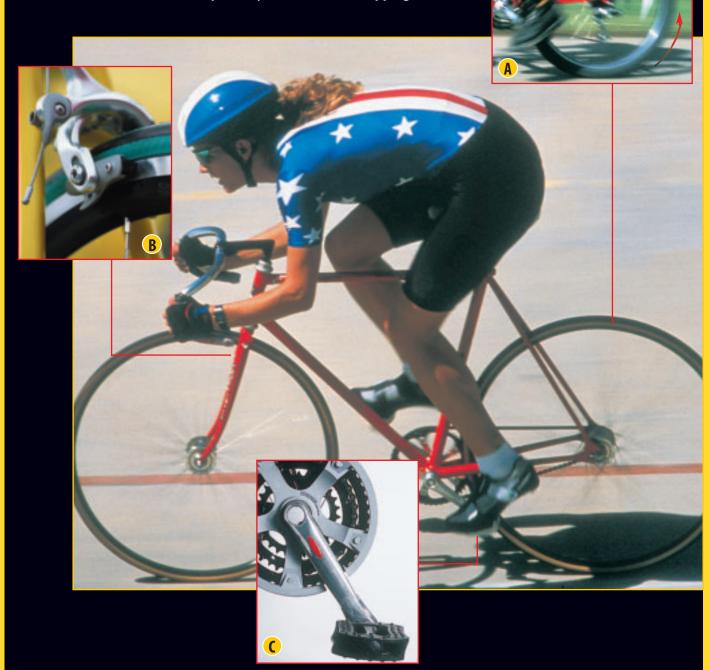


Figure 14 Rolling friction is needed for this wheel to roll forward. Without rolling friction, it would slip.



Figure 15

riction is a force that opposes motion. But sometimes friction can be used to your advantage. For example, you could not ride a bicycle without friction. A: The rolling friction between the tires and the pavement pushes the bottom of the tires forward; this helps rotate the tires and propels the cyclist forward. B: Brake pads push against the rim of the tire; this creates sliding friction, which slows the wheel. C: Bicycle pedals have a rough surface that increases static friction and keeps the cyclist's feet from slipping off.





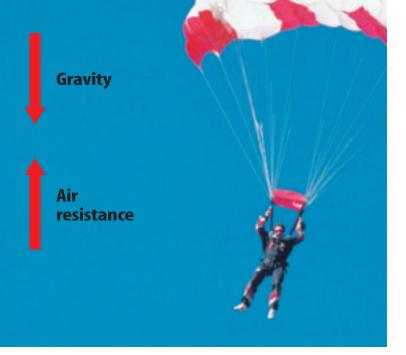


Figure 16 Gravity and air resistance are the forces acting on a parachutist. When the forces balance each other, the parachutist falls at a constant velocity.

Air Resistance Do you know why it is harder to walk in deep water than in shallow water? It's because the deeper the water is, the more of it you have to push out of your way to move forward. The same is true for walking on dry land. To move forward, you must push air out of your way.

Molecules in air collide with the forward-moving surface of an object, slowing its motion. This is called air resistance. Air resistance is less for a narrow, pointed object than for a large, flat object. Air resistance increases as the speed of an object increases. Because air resistance is a type of friction, it acts in the direction opposite to an object's motion.

Before the sky diver in **Figure 16** opens the parachute, his air resistance is small. The force of air resistance is upward, but it is not large enough to balance the downward force of gravity. As a result, the sky diver falls rapidly. When he opens his parachute, the air resistance is much greater because the parachute has a large surface area. Then the force of air resistance is large enough to slow his fall and balance the force of gravity.

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Summary

Newton's Second Law

 The second law states that an object's acceleration can be calculated from this equation:

$$a = \frac{F}{m}$$

Gravitational Force and Friction

- The gravitational force between two objects depends on the masses of the objects and the distance between them.
- The weight of an object on Earth is the gravitational force exerted by Earth on the object and is given by:

$$F = m(9.8 \text{ m/s}^2)$$

- Friction is a force that resists motion between surfaces that are in contact.
- Static friction acts between surfaces that are not sliding, sliding friction acts between surfaces that are sliding past each other.

Self Check

- Identify the force that keeps a box from sliding down an angled conveyor belt that slopes upward.
- **2. Identify** the force that causes a book to slow down and stop as it slides across a table top.
- **3. Explain** why you feel Earth's gravitational force, but not the gravitational force exerted by this book.
- **4. Determine** how the acceleration of an object changes when the total force on the object increases.
- Think Critically A 1-kg book is at rest on a desk.Determine the force the desk exerts on the book.

Applying Math

- **6. Calculate Weight** A student has a mass of 60 kg. What is the student's weight?
- 7. Calculate Acceleration A sky diver has a mass of 70 kg. If the total force on the sky diver is 105 N, what is the sky diver's acceleration?





Static and Sliding Friction

Static friction can hold an object in place when you try to push or pull it. Sliding friction explains why you must continually push on something to keep it sliding across a horizontal surface.

Real-World Question-

How do the forces of static friction and sliding friction compare?

Goals

- **Observe** static and sliding friction.
- **Measure** static and sliding frictional forces.
- Compare and contrast static and sliding friction.

Materials

spring scale block of wood or other material tape

Safety Precautions



Procedure

 Attach a spring scale to the block and set it on the table. Experiment with pulling the block with the scale so you have an idea of how hard you need to pull to start it in motion and continue the motion.

Communicating Your Data

Compare your conclusions with those of other students in your class.

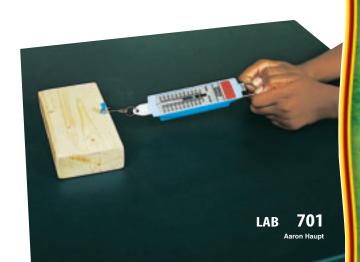
- **2. Measure** the force needed just to start the block moving. This is the force of static friction.
- **3. Measure** the force needed to keep the block moving at a steady speed. This is the force of sliding friction on the block.
- **4.** Repeat steps 2 and 3 on a different surface, such as carpet. Record your measurements in your Science Journal.

🔘 Analyze Your Data

- 1. Compare the forces of static friction and sliding friction on both horizontal surfaces. Which force is greater?
- **2.** On which horizontal surface is the force of static friction greater?
- **3.** On which surface is the force of sliding friction greater?

Conclude and Apply

- **1. Draw Conclusions** Which surface is rougher? How do static and sliding friction depend on the roughness of the surface?
- **2. Explain** how different materials affect the static and sliding friction between two objects.







Newton's Third Law

as you read

What You'll Learn

- Interpret motion using Newton's third law.
- Analyze motion using all three laws.

Why It's Important

The third law of motion explains how objects exert forces on each other.

Review Vocabulary contact force: force exerted when two objects are touching each other

New Vocabulary

third law of motion

The Third Law of Motion

When you push off the side of a pool, you accelerate. By Newton's laws of motion, when you accelerate, a force must be exerted on you. Where does this force come from?

Newton's first two laws explain how forces acting on a single object affect its motion. The third law describes the connection between the object receiving a force and the object supplying that force. According to the **third law of motion**, forces always act in equal but opposite pairs. This idea often is restated—for every action, there is an equal but opposite reaction. For example, if object A exerts a force on object B, then object B exerts a force of the same size on object A.

Reading Check What is Newton's third law of motion?

Action and Reaction Forces Newton's third law means that when you lift your book bag, your book bag pulls back. When you jump, you push down on the ground, which pushes up on you. When you walk, you push back on the ground, and the ground pushes forward on you. When you throw a ball, you push forward on the ball, and it pushes back on your hand. Figure 17 shows that when you exert a force on the floor, the floor exerts an equal force on you in the opposite direction.

> The same is true for any two objects, regardless of whether the force between the objects is a contact force or a long-range force. For example, if you place two bar magnets with opposite poles facing one another, they will move toward each other. Each magnet applies a force to the other, even though they are not in direct contact. No matter how one object exerts a force on another, the other object always exerts an equal force on the first object in the opposite direction.

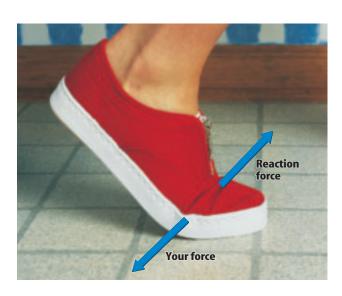
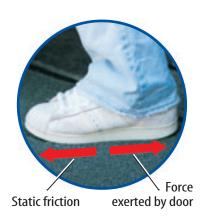


Figure 17 When you walk, you exert a backward force on the ground, yet you move forward. This is because the ground is exerting an equal force forward on you.





Figure 18 Static friction between your shoes and the ground makes it possible to push a heavy door forward. Without static friction, pushing the door would make you slide backwards.



Applying the Third Law

Action and reaction forces are not the same as balanced forces. Recall that balanced forces are forces that act on the same object and cancel each other. Action and reaction forces act on different objects. When you kick a soccer ball, your force on the ball equals the ball's force on you. The harder you kick, the greater the force the ball exerts on your foot. A hard kick can hurt because the ball exerts a large force on your foot. Unlike balanced forces, action and reaction forces can cause the motion of objects to change.



How do balanced forces differ from action and reaction forces?

Using Friction When you push a heavy door, as in **Figure 18**, you exert a force on the door to move it. The door exerts an equal force back on you. Why don't you move? When you push on the door, your feet are touching Earth, and static friction keeps you from sliding. The reaction force is exerted on you and Earth together. You don't move because the door doesn't exert a large enough reaction force to move both you and Earth.

However, if you wear slippery shoes, or if the floor is very smooth, your feet might slide when you push on the door. Because static friction is smaller when the surfaces are smooth, the static friction force might not be large enough to keep you attached to Earth. Then the reaction force exerted by the door acts only on you, and not on you and Earth together.





Observing the Laws of Motion

Procedure

- 1. Incline one end of a board to a height of 20 cm.
- 2. Lay a meterstick on the floor with one end flush to the board and place a softball where the board and meterstick meet.
- 3. Hold a baseball 10 cm up the slope and roll it into the softball. Measure the distance the softball is pushed.
- 4. Repeat step 3 from different heights.

Analysis

- 1. Compare the distances the baseball pushes the softball.
- 2. Use the laws of motion to explain your results.

Figure 19 Newton's laws of motion apply to the billions of stars in these distant galaxies.

Motion Caused by Force Pairs Although the action and § reaction forces in a force pair are the same size, they can have different effects on the objects they act upon. Suppose a 50-kg student and a 20-kg box are in the middle of an ice-skating rink. The student pushes on the box with a force of 10 N, and the box slides on the ice. The reaction force is the box pushing on the student with a force of 10 N, and the student slides in the opposite direction. These forces are exerted only while the student and the box are in contact.

Although the same size force is acting on the student and the box, they will have different accelerations because their masses are different. The acceleration of each can be calculated using Newton's second law. The acceleration of the box is:

acceleration =
$$\frac{\text{force}}{\text{mass}} = \frac{10 \text{ N}}{20 \text{ kg}} = 0.5 \text{ m/s}^2$$

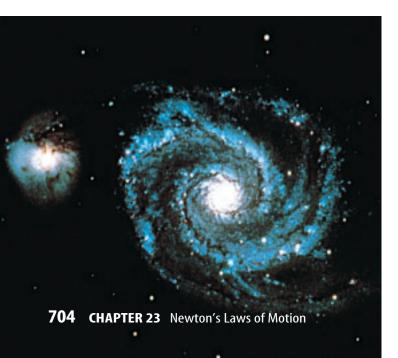
The acceleration of the student can be calculated by replacing 20 kg with 50 kg in the above formula and is only 0.2 m/s^2 . The student and the box accelerate only while they are in contact. As a result, the student moves more slowly than the box moves.

Gravity and the Third Law Gravity is pulling you down to the ground. According to the third law, you aren't just pulled toward Earth—Earth also is pulled toward you. When you jump into a swimming pool, how far does Earth move? The force you exert on Earth is the same as the force Earth exerts on you. However, Earth is trillions of times more massive than you are. Because Earth has such a large mass, the force you exert on it doesn't have a noticeable effect.



Newton's laws of motion apply to all objects, even

the distant galaxies shown in **Figure 19.** The Sun exerts a gravitational force on Earth, so according to the third law of motion Earth exerts an equal force on the Sun. This force has a small effect on the motion of the Sun. Planets that might be orbiting stars other than the Sun are too far away to be seen from Earth. But they also affect the motion of the stars they orbit. Astronomers look for variations in the motions of stars that might be caused by an orbiting planet. More than 100 planets have been detected around stars other than the Sun using this method.





Combining the Laws

The laws of motion describe how any object moves when forces act on it. Consider what happens during a jump, as shown in **Figure 20.**

First, when you push on the ground, the ground pushes up on you with an equal and opposite force. Therefore, two forces are acting on you—gravity pulls you down, and the force from the ground pushes you up. The overall force is upward, so as the second law predicts, you accelerate upward as your foot pushes against the ground.

When your feet leave the ground, gravity is the only force acting on you. Again according to the second law, you accelerate in the direction of this unbalanced force. This downward acceleration slows you until you stop at the top of your jump and then causes you to increase your speed downward until you reach the ground.

When your feet hit the ground, the ground exerts an upward force on you. The force must be greater than the downward force of gravity to slow you down. When you stop moving, all of the forces on you are balanced. As the first law predicts, you remain at rest.



Figure 20 All of Newton's laws apply to a simple jump. **Identify** the forces that are acting in each

section

Summary

The Third Law of Motion

- Forces always occur in equal and opposite pairs called action and reaction forces.
- Newton's third law of motion states that if object A exerts a force on object B, object B exerts an equal force in the opposite direction on object A.

Applying the Third Law

- Action and reaction forces are not balanced forces because they act on different objects.
- Even though the forces in an action-reaction force pair are equal in size, the motion of the objects they act on depends on the masses of the objects.
- The gravitational force you exert on Earth has no noticeable effect because Earth's mass is so large.

Self Check

part of this jump.

review

- 1. **Identify** the action and reaction forces acting on this book when it rests on your hands.
- **2. Explain** why, when you jump from a boat, the boat moves back as you move forward.
- 3. Infer You and a child with half your mass are standing on ice. If the child pushes you, who will have the larger acceleration?
- Compare and contrast the first two laws of motion with the third law of motion.
- **5. Think Critically** Identify the force that causes you to move forward when you walk on a floor.

Applying Math

6. Calculate Acceleration A skater standing on ice skates pushes on the side of a skating rink with a force of 100 N. If the skater's mass is 60 kg, what is the skater's resulting acceleration?





Design Your Own

Bailanced and Unbalanced Forces

Goals

- Describe how to create balanced and unbalanced forces on an object.
- Demonstrate forces that change the speed and the direction of an object's motion.

Possible Materials

block book pieces of string (2) spring scales (2)

Safety Precautions



Real-World Question

Newton's laws tell you that to change the velocity of an object, there must be an unbalanced force acting on the object. Changing the velocity can involve changing the speed of the object, changing the direction of motion, or changing both. How can you apply an unbalanced force to an object? How does the motion change when you exert a force in different ways?

Form a Hypothesis

Predict how the motion of a block will change when different forces are applied to it. Consider both speed and direction.



Test Your Hypothesis

Make a Plan

- **1. Describe** how you are going to exert forces on the block using the available materials.
- 2. List several different ways to exert forces or combinations of forces on the block. Think about how strong each force will need to be to change the motion of the block. Include at least one force or combination of forces that you think will not change the object's motion.
- **3. Predict** which forces will change the object's direction, its speed, both, or neither. Are the forces balanced or unbalanced?

Check Your Plan

- **1.** Make sure that your teacher approves your plans before going any further.
- **2. Compare** your plans for exerting forces with those of others in your class. Discuss why each of you chose the forces you chose.

Follow Your Plan

- 1. Set up your model so that you can exert each of the forces that you listed.
- **2. Collect data** by exerting each of the forces in turn and recording how each one affects the object's motion.

Analyze Your Data

- **1. Identify Variables** For each of the forces or combinations of forces that you applied to the object, list all of the forces acting on the object. Was the number of forces acting always the same? Was there a situation when only a single force was being applied? Explain.
- **2. Record Observations** What happened when you exerted balanced forces on the object? Were the results for unbalanced forces the same for different combinations of forces? Why or why not?

Conclude and Apply

- 1. Were your predictions correct? Explain how you were able to predict the motion of the block and any mistaken predictions you might have made.
- 2. **Summarize** Which of Newton's laws of motion did you demonstrate in this lab?
- **3. Apply** Suppose you see a pole that is supposed to be vertical, but is starting to tip over. What could you do to prevent the pole from falling over? Describe the forces acting on the pole as it starts to tip and after you do something. Are the forces balanced or unbalanced?



TIME

SCIENCE AND SOCIETY

SCIENCE ISSUES THAT AFFECT YOU!



f you've been to an amusement park lately, you know that roller coasters are taller and faster than ever. The thrill of their curves and corkscrews makes them incredibly popular. However, the increasingly daring designs have raised concerns about safety.

Dangerous Coasters

said one lawmaker.

The 1990s saw a sharp rise in amusement park injuries, with 4,500 injuries (many on coasters) in 1998 alone. A new 30-story-high roller coaster will drop you downhill at speeds nearing 160 km/h. The excitement of such a high-velocity coaster is undeniable, but skeptics argue that, even with safety measures, accidents on supercoasters will be more frequent and more severe. "Technology and ride design are outstripping our understanding of the health effects of high forces on riders,"

Safe As Can Be

Supporters of new rides say that injuries and deaths are rare when you consider the hundreds of millions of annual riders. They also note that most accidents or deaths result from breakdowns or foolish rider behavior, not bad design.

Designers emphasize that rides are governed by Newton's laws of motion. Factors such as the bank and tightness of a curve are carefully calculated according to these laws to safely balance the forces on riders.

The designs can't account for riders who don't follow instructions, however. The forces on a standing rider might be quite different

from those on a seated rider that is strapped in properly, and might cause the standing rider to be ejected.

Supercoasters are here to stay, but with accidents increasing, designers and riders of roller coasters must consider both safety and thrills.

Research Choose an amusement park ride. Visit the link at the right to research how forces act on you while you're on the ride to give you thrills but still keep you safe. Write a report with diagrams showing how the forces work.



For more information, visit green.msscience.com/time

Reviewing Main Ideas

Section 1 Motion

- **1.** Motion occurs when an object changes its position relative to a reference point.
- 2. Distance is the path length an object travels. Displacement is the distance and direction between start and end points.
- **3.** Speed is the distance divided by the time. Velocity is the displacement divided by the time. Acceleration is the change in velocity divided by the time.

Section 2

Newton's First Law

- **1.** A force is a push or a pull. Forces are balanced if they cancel.
- 2. The first law of motion states that the

motion of an object does not change unless it is acted upon by an unbalanced force.

Section 3

Newton's Second Law

- 1. The second law of motion states acceleration is in the direction of the unbalanced force and equals the force divided by the mass.
- **2.** Friction resists the sliding motion between two surfaces in contact.

Section 4

Newton's Third Law

- 1. The third law states that forces always act in equal but opposite pairs.
- 2. Action and reaction forces do not cancel because they act on different objects.

Visualizing Main Ideas

Copy and complete the following table on the laws of motion.

Laws of Motion						
	First Law	Second Law	Third Law			
Statement	An object will remain at rest or in motion at constant velocity until it is acted upon by an unbalanced force.					
Describes Relation Between What?		motion of object and force on object				

Using Vocabulary

acceleration p.687 balanced forces p.692 displacement p.684 first law of motion p.691 force p.690 friction p.697 gravitational force p.696 second law of motion p.694 speed p.685 third law of motion p.702 unbalanced forces p.692 velocity p.687

For each set of vocabulary words below, explain the relationship that exists.

- 1. displacement and velocity
- 2. force and third law of motion
- 3. speed and velocity
- 4. force and friction
- 5. unbalanced forces and second law of motion
- 6. balanced forces and first law of motion
- 7. acceleration and second law of motion
- **8.** acceleration and force

Checking Concepts

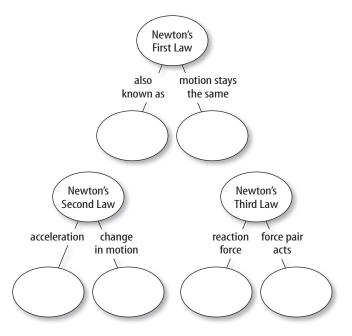
Choose the word or phrase that best answers the question.

- **9.** Which does NOT change when an unbalanced force acts on an object?
 - A) displacement
- **C)** mass
- **B)** velocity
- **D)** motion
- **10.** What is the force that keeps you from sliding off a sled when it starts moving?
 - **A)** sliding friction
- c) air resistance
- **B)** static friction
- **D)** rolling friction
- **11.** Which of the following indicates that the forces on an object are balanced?
 - **A)** The object speeds up.
 - **B)** The object slows down.
 - **c)** The object moves at a constant velocity.
 - **D)** The object turns.

- **12.** Which of the following includes direction?
 - A) mass
- **C)** velocity
- B) speed
- **D)** distance
- **13.** The inertia of an object increases when which of the following increases?
 - A) speed
- c) mass
- **B)** force
- **D)** acceleration
- **14.** The unbalanced force on a football is 5 N downward. Which of the following best describes its acceleration?
 - A) Its acceleration is upward.
 - **B)** Its acceleration is downward.
 - **C)** Its acceleration is zero.
 - **D)** Its acceleration depends on its motion.
- **15.** Which of the following exerts the force that pushes you forward when you walk?
 - **A)** static friction
- **C)** gravity
- **B)** sliding friction
- **D)** air resistance
- **16.** If the action force on an object is 3 N to the left, what is the reaction force?
 - **A)** 6 N left
- c) 3 N right
- **B)** 3 N left
- **D)** 6 N right
- **17.** Which of the following forces is not a long-range force?
 - A) gravitational force
 - **B)** friction
 - **c)** electric force
 - **D)** magnetic force
- **18.** The gravitational force between two objects depends on which of the following?
 - A) their masses and their velocities
 - **B)** their masses and their weights
 - c) their masses and their inertia
 - **D)** their masses and their separation
- **19.** Which of the following depends on the force of gravity on an object?
 - A) inertia
- c) mass
- **B)** weight
- **D)** friction

Thinking Critically

- **20.** Apply You are skiing down a hill at constant speed. What do Newton's first two laws say about your motion?
- **21.** Explain how an object can be moving if there is no unbalanced force acting on it.
- **22.** Compare and Contrast When you come to school, what distance do you travel? Is the distance you travel greater than your displacement from home?
- **23. Draw Conclusions** If the gravitational force between Earth and an object always causes the same acceleration, why does a feather fall more slowly than a hammer does?
- **24.** Recognize Cause and Effect Why does a baseball thrown from the outfield to home plate follow a curved path rather than a straight line?
- **25. Concept Map** Copy and complete the concept maps below on Newton's three laws of motion.



Performance Activities

- **26.** Make a poster identifying all the forces acting in each of the following cases. When is there an unbalanced force? How do Newton's laws apply?
 - **a.** You push against a box; it doesn't move.
 - **b.** You push harder, and the box starts to move.
 - **c.** You push the box across the floor at a constant speed.
 - **d.** You don't touch the box. It sits on the floor.

Applying Math

- **27. Acceleration of a Ball** A bowling ball has a mass of 6.4 kg. If a bowler exerts an unbalanced force of 16.0 N on the ball, what is its acceleration?
- **28. Distance Walked** A person walks at a speed of 1.5 m/s. How far does the person walk in 0.5 h?
- **29.** Force on a Ball A tennis ball has a mass of 57 g and has an acceleration of 300 m/s² when it hits the tennis racket. What is the force exerted on the ball by the tennis racket?
- **30.** Acceleration of a Car A car has a speed of 20.0 m/s. If the speed of the car increases to 30.0 m/s in 5.0 s, what is the car's acceleration?

Use the table below to answer question 31.

Speed of Sound in Different Materials					
Material	Speed (m/s)				
Air	335				
Water	1,554				
Wood	3,828				
Iron	5,103				

31. The Speed of Sound Sound travels a distance of 1.00 m through a material in 0.003 s. According to the table above, what is the material?

Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

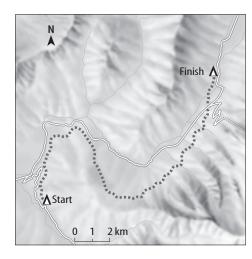
- **1.** What is the difference in the force of gravity on an object with a mass of 23.5 kg and on an object with a mass of 14.7 kg?
 - **A.** 86.2 N

c. 1.1 N

B. 8.8 N

D. no difference

Use the illustration below to answer questions 2 and 3.



- **2.** The illustration above shows a mountain hiking path. What is the approximate displacement of a hiker who travels from Start to Finish?
 - **A.** 22 km southwest
 - **B.** 22 km northeast
 - **c.** 12 km southwest
 - **D.** 12 km northeast
- **3.** About how long would it take a hiker to travel along the path from Start to Finish if the hiker's average speed were 2.6 km/h?
 - **A.** 2.3 h

c. 4.6 h

B. 4.3 h

D. 8.5 h

- **4.** What force makes it difficult to start a box moving across the floor?
 - **A.** inertia

c. rolling friction

B. static friction

D. sliding friction

5. A person pushes against a 8.3-kg box with a force of 12 N. The frictional force on the box is 2.5 N. What is the acceleration of the box?

A. 0.87 m/s^2

C. 1.4 m/s^2

B. 1.1 m/s^2

D. 1.7 m/s^2

6. What is the acceleration of a 4-kg ball tossed vertically upward when the ball is at its highest point?

A. 39.2 m/s^2

c. 9.8 m/s^2

B. 19.6 m/s²

D. no acceleration

Use the table below to answer questions 7 and 8.

Distance (m)	Time (m)
0	0
4	2
8	4
14	6
20	8
26	10
32	12

7. The table above shows the distances traveled by an object every 2 s for 12 s. What is the average speed of the object over the time interval 6 s to 12 s?

A. 2.0 m/s

c. 3.0 m/s

B. 2.7 m/s

D. 5.3 m/s

8. Over which time interval did the object accelerate?

A. 2 to 6 s

c. 6 to 10 s

B. 4 to 8 s

D. 8 to 12 s

9. A train moves along a straight section of track at a velocity of 95 km/h north. A person walks toward the back of the train with a velocity of 3 km/h south. What is the velocity of the person relative to the ground?

A. 92 km north

c. 98 km north

B. 92 km south

D. 98 km south

Part 2 | Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

- **10.** Earth exerts a gravitational force on an apple falling from a tree. Use Newton's third law of motion of describe the gravitational pull that the apple exerts on Earth.
- 11. Do astronauts in orbit around Earth experience the same gravitational force that they do when they are on the ground? Explain why or why not.

Use the photograph below to answer questions 12 and 13.



- **12.** If the runners in the photograph above are moving at a constant speed, are they accelerating? Explain.
- **13.** What force prevents the runners from sliding as they go around the curve?
- **14.** What is the acceleration of a 12-kg object if the net force on it is 32 N?
- **15.** According to Newton's third law of motion, for every action there is an equal but opposite reaction. Explain why the action and reaction forces don't cancel and result in no movement of an object.

Part 3 Open Ended

Record your answers on a sheet of paper.

- **16.** Use Newton's laws to describe the forces that cause a ball thrown against the ground to bounce.
- 17. Three objects, all with the same mass, fall from the same height. One object is narrow and pointed, another is spherical, and the third is shaped like a box. Compare the speeds of the objects as they fall.
- **18.** A 70-kg adult and a 35-kg child stand on ice facing each other. They push against each other with a force of 9.5 N. Assuming there is no friction, describe and compare the acceleration they each experience.

Use the photograph below to answer questions 19 and 20.



- **19.** Name and describe the forces that enable the boy in the photograph to ride his bicycle.
- **20.** Explain how Newton's first law of motion influences the movement of the bike.

Test-Taking Tip

Answer all Parts of the Question Make sure each part of the question is answered when listing discussion points. For example, if the question asks you to compare and contrast, make sure you list both similarities and differences.

Question 18 Be sure to describe and compare the acceleration of each person.

