

Force and Newton's Laws

chapter preview

sections

- 1 Newton's First Law
 - 2 Newton's Second Law
 - 3 Newton's Third Law
- Lab** *Balloon Races*
Lab *Modeling Motion in Two Directions*



Virtual Labs *What is Newton's second law of motion?*

Moving at a Crawl


This enormous vehicle is a crawler that moves a space shuttle to the launch pad. The crawler and space shuttle together have a mass of about 7,700,000 kg. To move the crawler at a speed of about 1.5 km/h requires a force of about 10,000,000 N. This force is exerted by 16 electric motors in the crawler.

Science Journal Describe three examples of pushing or pulling an object. How did the object move?

Start-Up Activities



Forces and Motion

Imagine being on a bobsled team speeding down an icy run. Forces are exerted on the sled by the ice, the sled's brakes and steering mechanism, and gravity. Newton's laws predict how these forces cause the bobsled to turn, speed up, or slow down. Newton's Laws tell how forces cause the motion of any object to change. 



1. Lean two meter-sticks parallel, less than a marble width apart on three books as shown on the left. This is your ramp.
2. Tap a marble so it rolls up the ramp. Measure how far up the ramp it travels before rolling back.
3. Repeat step 2 using two books, one book, and zero books. The same person should tap with the same force each time.
4. **Think Critically** Make a table to record the motion of the marble for each ramp height. What would happen if the ramp were perfectly smooth and level?

FOLDABLES™ Study Organizer

Newton's Laws Make the following Foldable to help you organize your thoughts about Newton's laws.

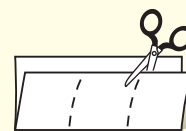
- STEP 1** **Fold** a sheet of paper in half length-wise. Make the back edge about 5 cm longer than the front edge.



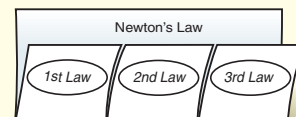
- STEP 2** **Turn** the paper so the fold is on the bottom. Then **fold** it into thirds.



- STEP 3** **Unfold and cut** only the top layer along both folds to make three tabs.



- STEP 4** **Label** the foldable as shown.



Make a Concept Map As you read the chapter, record what you learn about each of Newton's laws in your concept map.



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

Newton's First Law

as you read

What You'll Learn

- **Distinguish** between balanced and net forces.
- **Describe** Newton's first law of motion.
- **Explain** how friction affects motion.

Why It's Important

Newton's first law explains why objects change direction.

Review Vocabulary

velocity: the speed and direction of a moving object

New Vocabulary

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

Force

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

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

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

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

Figure 1 A force is a push or a pull.

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





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



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

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

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

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

Figure 2 When the forces on an object are balanced, no change in motion occurs. A change in motion occurs only when the forces acting on an object are unbalanced.



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

Newton's First Law of Motion

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

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

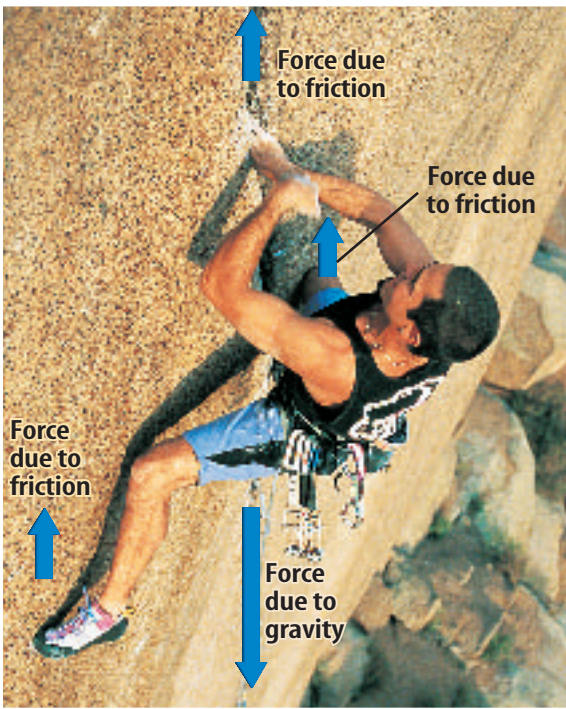
The Italian scientist Galileo Galilei, who lived from 1564 to 1642, was one of the first to understand that a force doesn't need to be constantly applied to an object to keep it moving.

Galileo's ideas helped Isaac Newton to better understand the nature of motion. Newton, who lived from 1642 to 1727, explained the motion of objects in three rules called Newton's laws of motion.

Newton's first law of motion describes how an object moves when the net force acting on it is zero. According to **Newton's first law of motion**, if the net force acting on an object is zero, the object remains at rest, or if the object is already moving, continues to move in a straight line with constant speed.

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

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



Friction

Galileo realized the motion of an object doesn't change until an unbalanced force acts on it. Every day you see moving objects come to a stop. The force that brings nearly everything to a stop is **friction**, which is the force that acts to resist sliding between two touching surfaces, as shown in **Figure 3**. Friction is why you

never see objects moving with constant velocity unless a net force is applied. Friction is the force that eventually brings your skateboard to a stop unless you keep pushing on it. Friction also acts on objects that are sliding or moving through substances such as air or water.

Friction slows down this sliding baseball player.



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

 **Reading Check**

What do the different forms of friction have in common?

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

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



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



Topic: Galileo and Newton

Visit ips.msscience.com for Web links to information about the lives of Galileo and Newton.

Activity Make a time line showing important events in the lives of either Galileo or Newton.

Mini LAB

Observing Friction

Procedure

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

Analysis

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



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

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

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



Reading Check

What is the difference between static friction and sliding friction?

Figure 5 Microscopic roughness, even on surfaces that seem smooth, such as the tray and metal shelf, causes sliding friction.

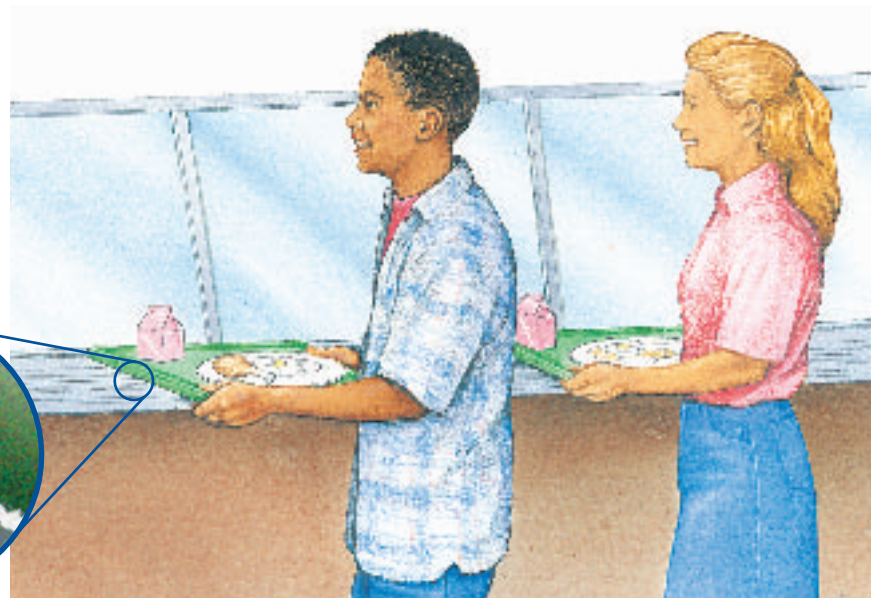
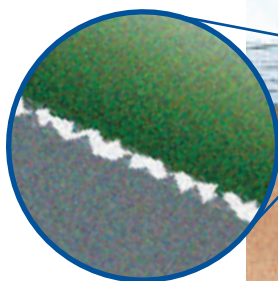




Figure 6 A bicycle uses sliding friction and rolling friction.

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

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

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

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

section 1 review

Summary

Force

- A force is a push or a pull.
- The net force on an object is the combination of all the forces acting on the object.
- The forces acting on an object can be balanced or unbalanced. If the forces are balanced, the net force is zero.

Newton's First Law of Motion

- If the net force on an object at rest is zero, the object remains at rest, or if the object is moving, it continues moving in a straight line with constant speed.

Friction

- Friction is the force that acts to resist sliding between two surfaces that are touching.
- Three types of friction are static friction, sliding friction, and rolling friction.

Self Check

1. **Explain** whether a force is acting on a car that is moving at 20 km/h and turns to the left.
2. **Describe** the factors that cause static friction between two surfaces to increase.
3. **Discuss** why friction made it difficult to discover Newton's first law of motion.
4. **Discuss** whether an object can be moving if the net force acting on the object is zero.
5. **Think Critically** For the following actions, explain whether the forces involved are balanced or unbalanced.
 - a. You push a box until it moves.
 - b. You push a box but it doesn't move.
 - c. You stop pushing a box and it slows down.

Applying Skills

6. **Compare and contrast** static, sliding, and rolling friction.

Newton's Second Law

as you read

What You'll Learn

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

Why It's Important

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

Review Vocabulary

acceleration: the change in velocity divided by the time over which the change occurred

New Vocabulary

- Newton's second law of motion
- weight
- center of mass

Force and Acceleration

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

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

Acceleration Equation

$$\text{acceleration (in meters/second}^2\text{)} = \frac{\text{net force (in newtons)}}{\text{mass (in kilograms)}}$$

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

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

$$F_{\text{net}} = ma$$

Reading Check What is Newton's second law?

Figure 7 The force needed to change the motion of an object depends on its mass.

Predict which grocery cart would be easier to stop.



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

Gravity

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

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

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

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

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

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



Newton and Gravity

Isaac Newton was the first to realize that gravity—the force that made objects fall to Earth—was also the force that caused the Moon to orbit Earth and the planets to orbit the Sun. In 1687, Newton published a book that included the law of universal gravitation. This law showed how to calculate the gravitational force between any two objects. Using the law of universal gravitation, astronomers were able to explain the motions of the planets in the solar system, as well as the motions of distant stars and galaxies.

Table 1 Weight of 60-kg Person on Different Planets

Place	Weight in Newtons If Your Mass Were 60 kg	Percent of Your Weight on Earth
Mars	221	37.6
Earth	588	100.0
Jupiter	1,387	235.9
Pluto	39	6.6

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



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

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



Using Newton's Second Law

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

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

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

Suppose you push a book across a tabletop. When you start pushing, the book speeds up. Sliding friction also acts on the book. After you stop pushing, sliding friction causes the book to slow down and stop.

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

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

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

Applying Math Solving a Simple Equation

ACCELERATION OF A CAR A net force of 4,500 N acts on a car with a mass of 1,500 kg. What is the acceleration of the car?

Solution

- This is what you know:*
 - net force: $F_{\text{net}} = 4,500 \text{ N}^2$
 - mass: $m = 1,500 \text{ kg}$
- This is what you need to find:* acceleration: $a = ? \text{ m/s}^2$
- This is the procedure you need to use:*

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

$$a = \frac{F_{\text{net}}}{m} = \frac{4,500 \text{ N}}{1,500 \text{ kg}} = 3.0 \frac{\text{N}}{\text{kg}} = 3.0 \text{ m/s}^2$$
- Check your answer:* Multiply your answer by the mass, 1,500 kg. The result should be the given net force, 4,500 N.

Practice Problems

- A book with a mass of 2.0 kg is pushed along a table. If the net force on the book is 1.0 N, what is the book's acceleration?
- A baseball has a mass of 0.15 kg. What is the net force on the ball if its acceleration is 40 m/s^2 ?



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

Infer how the ball would move if it were thrown horizontally.



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

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

Circular Motion

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

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

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

Suppose Earth were perfectly smooth and you throw a baseball horizontally. Gravity pulls the baseball downward so it travels in a curved path. If the baseball is thrown faster, its path is less curved, and it travels farther before it hits the ground. If the baseball were traveling fast enough, as it fell, its curved path would follow the curve of Earth's surface as shown in **Figure 11**. Then the baseball would never hit the ground. Instead, it would continue to fall around Earth.

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

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

Air Resistance

Whether you are walking, running, or biking, air is pushing against you. This push is air resistance. Air resistance is a form of friction that acts to slow down any object moving in the air. Air resistance is a force that gets larger as an object moves faster. Air resistance also depends on the shape of an object. A piece of paper crumpled into a ball falls faster than a flat piece of paper falls.

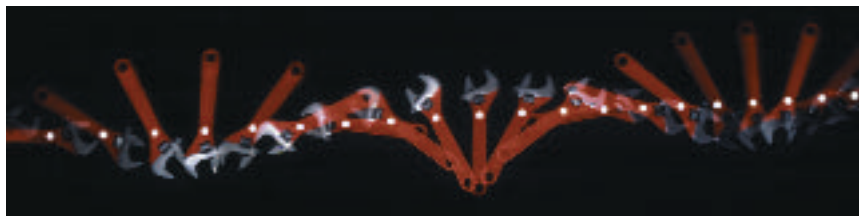
When an object falls it speeds up as gravity pulls it downward. At the same time, the force of air resistance pushing up on the object is increasing as the object moves faster. Finally, the upward air resistance force becomes large enough to equal the downward force of gravity.

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



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

Figure 12 The wrench is spinning as it slides across the table. The center of mass of the wrench, shown by the dots, moves as if the force of friction is acting at that point.



Center of Mass

When you throw a stick, the motion of the stick might seem to be complicated. However, there is one point on the stick, called the center of mass, that moves in a smooth path. The **center of mass** is the point in an object that moves as if all the object's mass were concentrated at that point. For a symmetrical object, such as a ball, the center of mass is at the object's center. However, for any object the center of mass moves as if the net force is being applied there.

Figure 12 shows how the center of mass of a wrench moves as it slides across a table. The net force on the wrench is the force of friction between on the wrench and the table. This causes the center of mass to move in a straight line with decreasing speed.

section 2 review

Summary

Force and Acceleration

- According to Newton's second law, the net force on an object, its mass, and its acceleration are related by

$$F_{\text{net}} = ma$$

Gravity

- The force of gravity between any two objects is always attractive and depends on the masses of the objects and the distance between them.

Using Newton's Second Law

- A moving object speeds up if the net force is in the direction of the motion.
- A moving object slows down if the net force is in the direction opposite to the motion.
- A moving object turns if the net force is at an angle to the direction of motion.

Circular Motion

- A centripetal force exerted toward the center of the circle keeps an object moving in circular motion.

Self Check

1. **Make a diagram** showing the forces acting on a coasting bike rider traveling at 25 km/h on a flat roadway.
2. **Analyze** how your weight would change with time if you were on a space ship traveling away from Earth toward the Moon.
3. **Explain** how the force of air resistance depends on an object's speed.
4. **Infer** the direction of the net force acting on a car as it slows down and turns right.
5. **Think Critically** Three students are pushing on a box. Under what conditions will the motion of the box change?

Applying Math

6. **Calculate Net Force** A car has a mass of 1,500 kg. If the car has an acceleration of 2.0 m/s^2 , what is the net force acting on the car?
7. **Calculate Mass** During a softball game, a softball is struck by a bat and has an acceleration of $1,500 \text{ m/s}^2$. If the net force exerted on the softball by the bat is 300 N, what is the softball's mass?

Newton's Third Law

Action and Reaction

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

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

as you read

What You'll Learn

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

Why It's Important

Newton's third law can explain how birds fly and rockets move.

Review Vocabulary

force: a push or a pull

New Vocabulary

- Newton's third law of motion



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

Figure 14 In this collision, the first car exerts a force on the second. The second exerts the same force in the opposite direction on the first car.

Explain whether both cars will have the same acceleration.



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

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

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

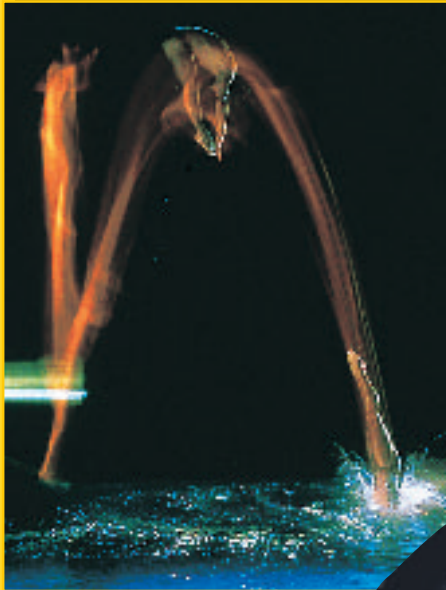
Figure 15 When the child pushes against the wall, the wall pushes against the child.



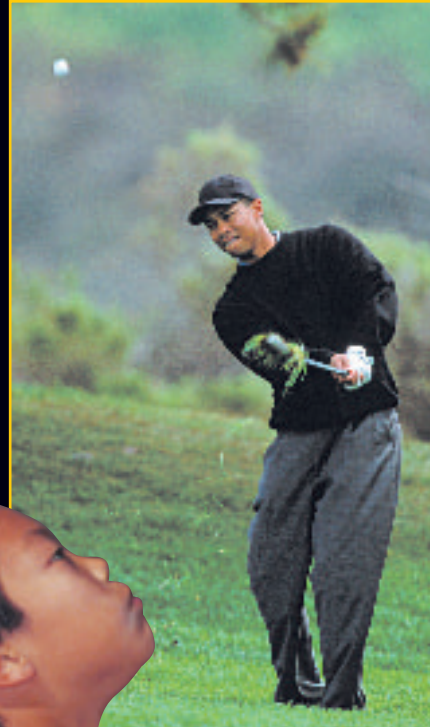
Birds and other flying creatures also use Newton's third law. When a bird flies, its wings push in a downward and a backward direction. This pushes air downward and backward. By Newton's third law, the air pushes back on the bird in the opposite directions—upward and forward. This force keeps a bird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

Figure 16

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



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



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

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

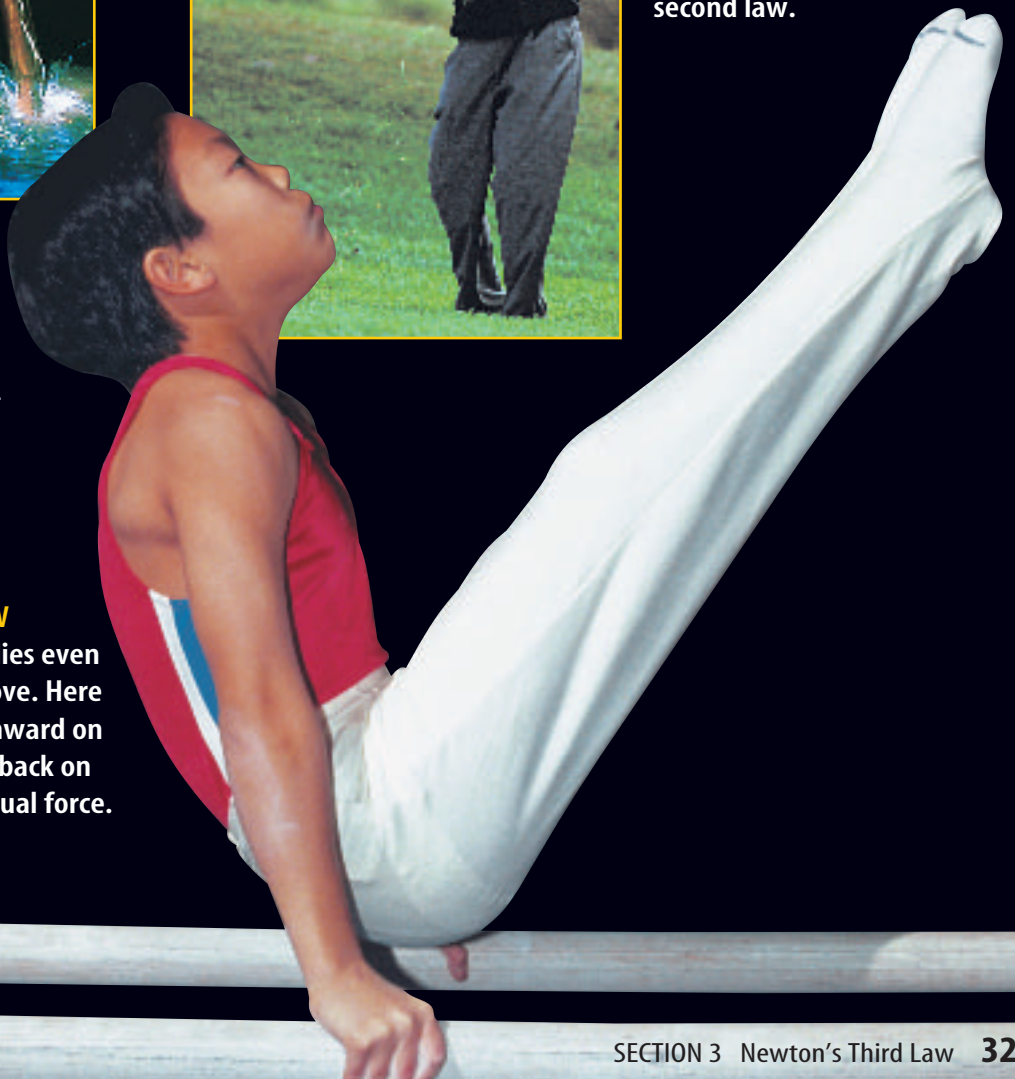


Figure 17 The force of the ground on your foot is equal and opposite to the force of your foot on the ground. If you push back harder, the ground pushes forward harder.

Determine *In what direction does the ground push on you if you are standing still?*



(c)David Madison, (d)NASA

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



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

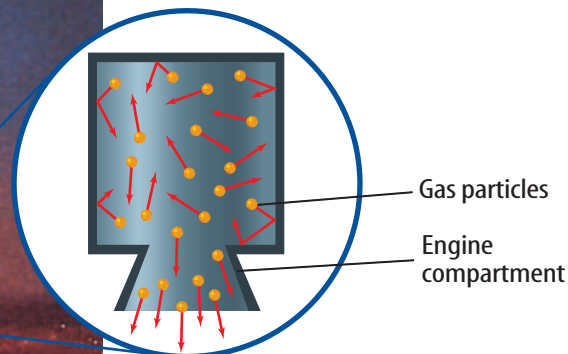


Figure 18 Newton's third law enables a rocket to fly. The rocket pushes the gas molecules downward, and the gas molecules push the rocket upward.

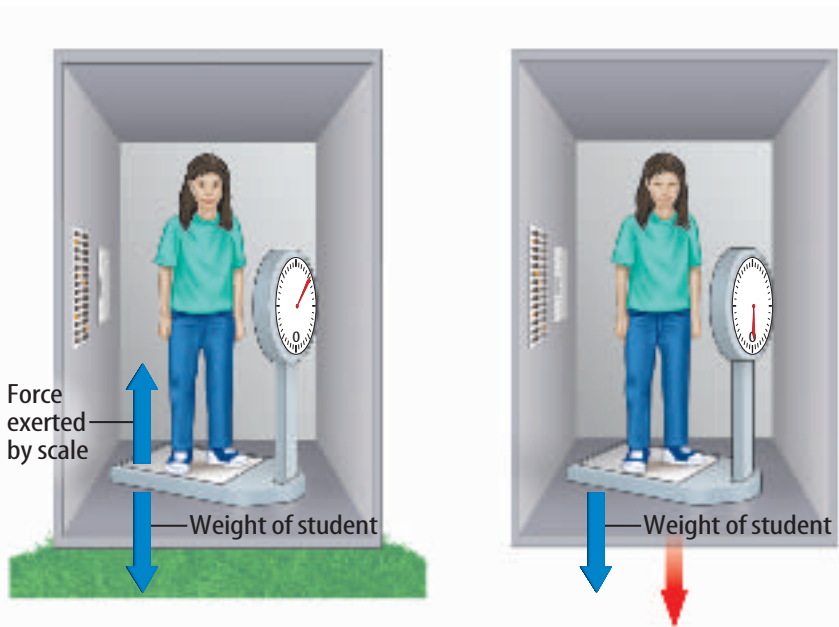


Figure 19 Whether you are standing on Earth or falling, the force of Earth's gravity on you doesn't change. However, your weight measured by a scale would change.

Weightlessness

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

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

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

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

Mini LAB

Measuring Force Pairs

Procedure

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

Analysis

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



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

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

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

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

section 3 review

Summary

Action and Reaction

- According to Newton's third law, when one object exerts a force on another object, the second object exerts the same size force on the first object.
- Either force in an action-reaction force pair can be the action force or the reaction force.
- Action and reaction force pairs don't cancel because they are exerted on different objects.
- When action and reaction forces are exerted by two objects, the accelerations of the objects depend on the masses of the objects.

Weightlessness

- A falling object is in free fall if the only force acting on it is gravity.
- Weightlessness occurs in free fall when the weight of an object seems to be zero.
- Objects orbiting Earth appear to be weightless because they are in free fall in a curved path around Earth.

Self Check

1. **Evaluate** the force a skateboard exerts on you if your mass is 60 kg and you push on the skateboard with a force of 60 N.
2. **Explain** why you move forward and a boat moves backward when you jump from a boat to a pier.
3. **Describe** the action and reaction forces when a hammer hits a nail.
4. **Infer** You and a child are on skates and you give each other a push. If the mass of the child is half your mass, who has the greater acceleration? By what factor?
5. **Think Critically** Suppose you are walking in an airliner in flight. Use Newton's third law to describe the effect of your walk on the motion on the airliner.

Applying Math

6. **Calculate Acceleration** A person standing in a canoe exerts a force of 700 N to throw an anchor over the side. Find the acceleration of the canoe if the total mass of the canoe and the person is 100 kg.

BALLOON RACES

Real-World Question

The motion of a rocket lifting off a launch pad is determined by Newton's laws of motion. Here you will make a balloon rocket that is powered by escaping air. How do Newton's laws of motion explain the motion of balloon rockets?

Goals

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

Materials

balloons	meterstick
drinking straws	stopwatch
string	*clock
tape	*Alternate materials

Safety Precautions

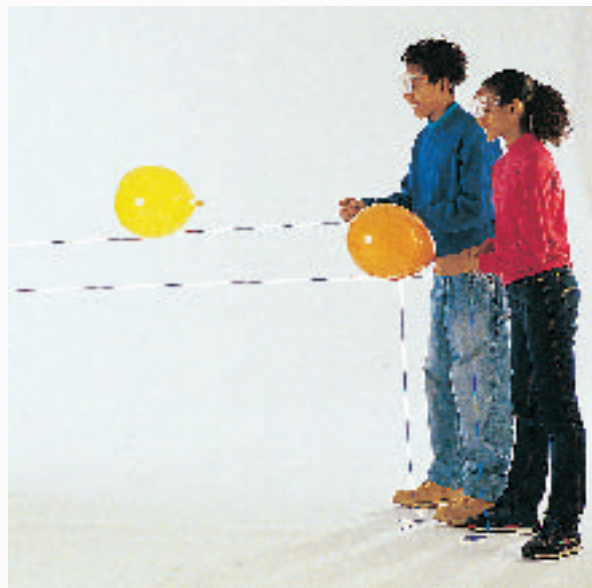


Procedure

1. Make a rocket path by threading a string through a drinking straw. Run the string across the classroom and fasten at both ends.
2. Blow up a balloon and hold it tightly at the end to prevent air from escaping. Tape the balloon to the straw on the string.
3. Release the balloon so it moves along the string. Measure the distance the balloon travels and the time it takes.
4. Repeat steps 2 and 3 with different balloons.

Conclude and Apply

1. **Compare and contrast** the distances traveled. Which rocket went the greatest distance?



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

Communicating Your Data

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

MODELING MOTION IN TWO DIRECTIONS

Goals

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

Possible Materials

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

Safety Precautions**Real-World Question**

When you move a computer mouse across a mouse pad, how does the rolling ball tell the computer cursor to move in the direction that you push the mouse? Inside the housing for the mouse's ball are two or more rollers that the ball rubs against as you move the mouse. They measure up-and-down and back-and-forth motions. The motion of the cursor on the screen is based on the movement of the up-and-down rollers and the back-and-forth rollers. Can any object be moved along a path by a series of motions in only two directions?

Form a Hypothesis

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

Test Your Hypothesis**Make a Plan**

1. Lay out a course that involves two directions, such as always moving forward or left.
2. Attach two spring scales to the skid. One always will pull straight forward. One always will pull to one side. You cannot turn the skid. If one scale is pulling toward the door of your classroom, it always must pull in that direction. (It can pull with zero force if needed, but it can't push.)
3. How will you handle movements along diagonals and turns?
4. How will you measure speed?



Using Scientific Methods

- 5. Experiment** with your skid. How hard do you have to pull to counteract sliding friction at a given speed? How fast can you accelerate? Can you stop suddenly without spilling the golf ball, or do you need to slow down?
- 6. Write** a plan for moving your golf ball along the course by pulling only forward or to one side. Be sure you understand your plan and have considered all the details.

Follow Your Plan

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

Analyze Your Data

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

Conclude and Apply

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



Communicating Your Data

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



Air Bag Safety

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

The car in front of yours stops suddenly. You hear the crunch of car against car and feel your seat belt grab you. Your mom is covered with, not blood, thank goodness, but with a big white cloth. Your seat belts and air bags worked perfectly.

Popcorn in the Dash

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

Newton and the Air Bag

When you're traveling in a car, you move with it at whatever speed it is going. According

to Newton's first law, you are the object in motion, and you will continue in motion unless acted upon by a force, such as a car crash.

Unfortunately, a crash stops the car, but it doesn't stop you, at least, not right away. You continue moving forward if your car doesn't have air bags or if you haven't buckled your seat belt. You stop when you strike the inside of the car. You hit the dashboard or steering wheel while traveling at the speed of the car. When an air bag inflates, you come to a stop more slowly, which reduces the force that is exerted on you.



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

Measure Hold a paper plate 26 cm in front of you. Use a ruler to measure the distance. That's the distance drivers should have between the chest and the steering wheel to make air bags safe. Inform adult drivers in your family about this safety distance.

Science **online**

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

Reviewing Main Ideas

Section 1 Newton's First Law

1. A force is a push or a pull.
2. Newton's first law states that objects in motion tend to stay in motion and objects at rest tend to stay at rest unless acted upon by a nonzero net force.
3. Friction is a force that resists motion between surfaces that are touching each other.

Section 2 Newton's Second Law

1. Newton's second law states that an object acted upon by a net force will accelerate in the direction of this force.
2. The acceleration due to a net force is given by the equation $a = F_{\text{net}}/m$.

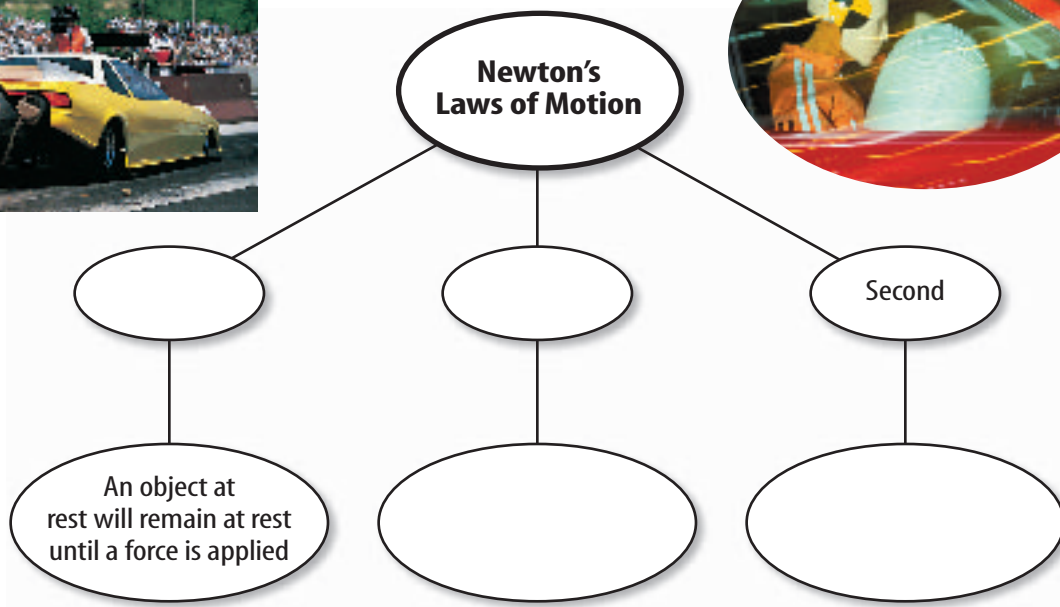
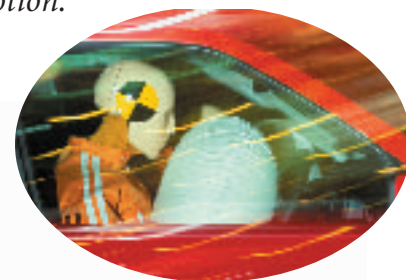
3. The force of gravity between two objects depends on their masses and the distance between them.
4. In circular motion, a force pointing toward the center of the circle acts on an object.

Section 3 Newton's Third Law

1. According to Newton's third law, the forces two objects exert on each other are always equal but in opposite directions.
2. Action and reaction forces don't cancel because they act on different objects.
3. Objects in orbit appear to be weightless because they are in free fall around Earth.

Visualizing Main Ideas

Copy and complete the following concept map on Newton's laws of motion.



Using Vocabulary

balanced forces p.311	Newton's second law of motion p.316
center of mass p.322	Newton's third law of motion p.323
force p.310	unbalanced forces p.311
friction p.312	weight p.317
net force p.311	
Newton's first law of motion p.312	

Explain the differences between the terms in the following sets.

- force— inertia—weight
- Newton's first law of motion—Newton's third law of motion
- friction—force
- net force—balanced forces
- weight—weightlessness
- balanced forces—unbalanced forces
- friction—weight
- Newton's first law of motion—Newton's second law of motion
- friction—unbalanced force
- net force—Newton's third law of motion

Checking Concepts

Choose the word or phrase that best answers the question.

- Which of the following changes when an unbalanced force acts on an object?

A) mass	C) inertia
B) motion	D) weight
- Which of the following is the force that slows a book sliding on a table?

A) gravity
B) static friction
C) sliding friction
D) inertia
- Two students are pushing on the left side of a box and one student is pushing on the right. The diagram above shows the forces they exert. Which way will the box move?

A) up	C) down
B) left	D) right
- What combination of units is equivalent to the newton?

A) m/s^2	C) $kg \cdot m/s^2$
B) $kg \cdot m/s$	D) kg/m
- Which of the following is a push or a pull?

A) force	C) acceleration
B) momentum	D) inertia
- An object is accelerated by a net force in which direction?

A) at an angle to the force
B) in the direction of the force
C) in the direction opposite to the force
D) Any of these is possible.
- You are riding on a bike. In which of the following situations are the forces acting on the bike balanced?

A) You pedal to speed up.
B) You turn at constant speed.
C) You coast to slow down.
D) You pedal at constant speed.
- Which of the following has no direction?

A) force	C) weight
B) acceleration	D) mass

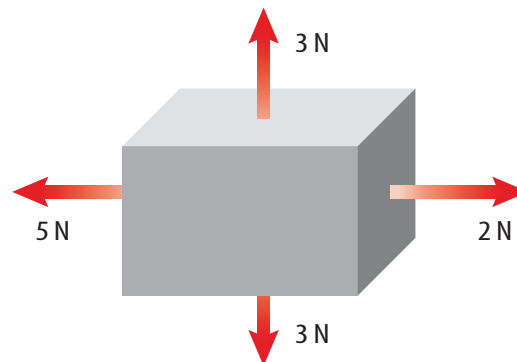
Use the illustration below to answer question 13.



Thinking Critically

19. **Explain** why the speed of a sled increases as it moves down a snow-covered hill, even though no one is pushing on the sled.
20. **Explain** A baseball is pitched east at a speed of 40 km/h. The batter hits it west at a speed of 40 km/h. Did the ball accelerate?
21. **Form a Hypothesis** Frequently, the pair of forces acting between two objects are not noticed because one of the objects is Earth. Explain why the force acting on Earth isn't noticed.
22. **Identify** A car is parked on a hill. The driver starts the car, accelerates until the car is driving at constant speed, drives at constant speed, and then brakes to put the brake pads in contact with the spinning wheels. Explain how static friction, sliding friction, rolling friction, and air resistance are acting on the car.
23. **Draw Conclusions** You hit a hockey puck and it slides across the ice at nearly a constant speed. Is a force keeping it in motion? Explain.
24. **Infer** Newton's third law describes the forces between two colliding objects. Use this connection to explain the forces acting when you kick a soccer ball.
25. **Recognize Cause and Effect** Use Newton's third law to explain how a rocket accelerates upon takeoff.
26. **Predict** Two balls of the same size and shape are dropped from a helicopter. One ball has twice the mass of the other ball. On which ball will the force of air resistance be greater when terminal velocity is reached?

Use the figure below to answer question 27.



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

Performance Activities

28. **Oral Presentation** Research one of Newton's laws of motion and compose an oral presentation. Provide examples of the law. You might want to use a visual aid.
29. **Writing in Science** Create an experiment that deals with Newton's laws of motion. Document it using the following subject heads: *Title of Experiment, Partners' Names, Hypothesis, Materials, Procedures, Data, Results, and Conclusion.*

Applying Math

30. **Acceleration** If you exert a net force of 8 N on a 2-kg object, what will its acceleration be?
31. **Force** You push against a wall with a force of 5 N. What is the force the wall exerts on your hands?
32. **Net Force** A 0.4-kg object accelerates at 2 m/s^2 . Find the net force.
33. **Friction** A 2-kg book is pushed along a table with a force of 4 N. Find the frictional force on the book if the book's acceleration is 1.5 m/s^2 .

Part 1 Multiple Choice

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

- Which of the following descriptions of gravitational force is *not* true?
 - It depends on the mass of objects.
 - It is a repulsive force.
 - It depends on the distance between objects.
 - It exists between all objects.

Use the table below to answer questions 2 and 3.

Mass of Common Objects	
Object	Mass (g)
Cup	380
Book	1,100
Can	240
Ruler	25
Stapler	620

- Which object would have an acceleration of 0.89 m/s^2 if you pushed on it with a force of 0.55 N ?
 - book
 - can
 - ruler
 - stapler
- Which object would have the greatest acceleration if you pushed on it with a force of 8.2 N ?
 - can
 - stapler
 - ruler
 - book

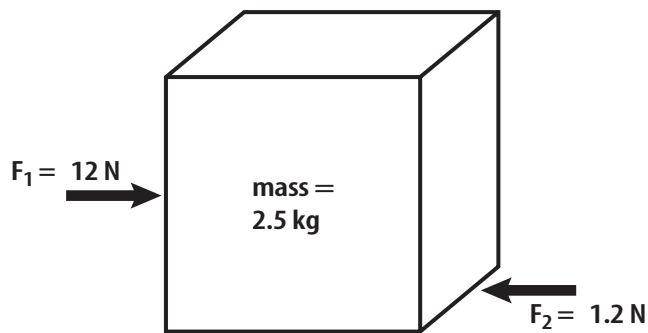
Test-Taking Tip

Check Symbols Be sure you understand all symbols on a table or graph before answering any questions about the table or graph.

Question 3 The mass of the objects are given in grams, but the force is given in newtons which is a $\text{kg}\cdot\text{m/s}^2$. The mass must be converted from grams to kilograms.

- What is the weight of a book that has a mass of 0.35 kg ?
 - 0.036 N
 - 3.4 N
 - 28 N
 - 34 N
- If you swing an object on the end of a string around in a circle, the string pulls on the object to keep it moving in a circle. What is the name of this force?
 - inertial
 - centripetal
 - resistance
 - gravitational
- What is the acceleration of a 1.4-kg object if the gravitational force pulls downward on it, but air resistance pushes upward on it with a force of 2.5 N ?
 - 11.6 m/s^2 , downward
 - 11.6 m/s^2 , upward
 - 8.0 m/s^2 , downward
 - 8.0 m/s^2 , upward

Use the figure below to answer questions 7 and 8.



- The figure above shows the horizontal forces that act on a box that is pushed from the left with a force of 12 N . What force is resisting the horizontal motion in this illustration?
 - friction
 - gravity
 - inertia
 - momentum
- What is the acceleration of the box?
 - 27 m/s^2
 - 4.8 m/s^2
 - 4.3 m/s^2
 - 0.48 m/s^2

Part 2 Short Response/Grid In

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

9. A skater is coasting along the ice without exerting any apparent force. Which law of motion explains the skater's ability to continue moving?
10. After a soccer ball is kicked into the air, what force or forces are acting on it?
11. What is the force on an 8.55-kg object that accelerates at 5.34 m/s^2 .

Use the figure below to answer questions 12 and 13.



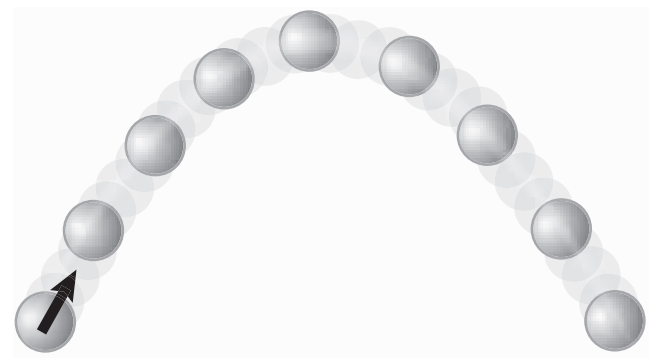
12. Two bumper cars collide and then move away from each other. How do the forces the bumper cars exert on each other compare?
13. After the collision, determine whether both bumper cars will have the same acceleration.
14. Does acceleration depend on the speed of an object? Explain.
15. An object acted on by a force of 2.8 N has an acceleration of 3.6 m/s^2 . What is the mass of the object?
16. What is the acceleration a 1.4-kg object falling through the air if the force of air resistance on the object is 2.5 N?
17. Name three ways you could accelerate if you were riding a bicycle.

Part 3 Open Ended

Record your answers on a sheet of paper.

18. When astronauts orbit Earth, they float inside the spaceship because of weightlessness. Explain this effect.
19. Describe how satellites are able to remain in orbit around Earth.

Use the figure below to answer questions 20 and 21.



20. The figure above shows the path a ball thrown into the air follows. What causes the ball to move along a curved path?
21. What effect would throwing the ball harder have on the ball's path? Explain.
22. How does Newton's second law determine the motion of a book as you push it across a desktop?
23. A heavy box sits on a sidewalk. If you push against the box, the box moves in the direction of the force. If the box is replaced with a ball of the same mass, and you push with the same force against the ball, will it have the same acceleration as the box? Explain.
24. According to Newton's third law of motion, a rock sitting on the ground pushes against the ground, and the ground pushes back against the rock with an equal force. Explain why this force doesn't cause the rock to accelerate upward from the ground according to Newton's second law.