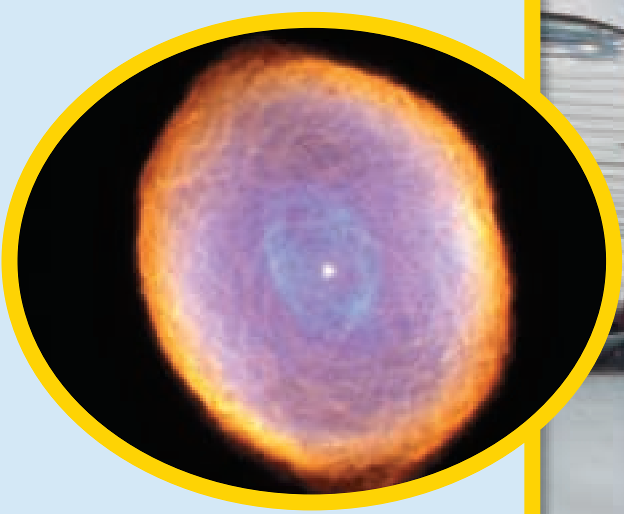
CHAPTER 3

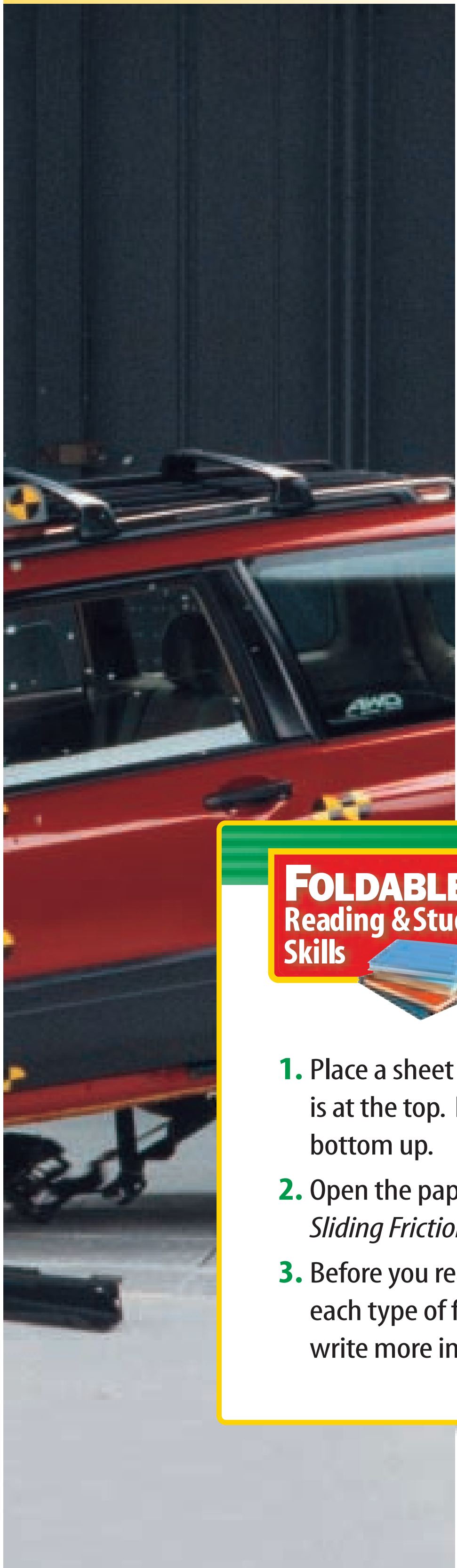
Forces

Crash! What brought this vehicle to its sudden stop? How did the impact affect the car and its driver? Automobile manufacturers consider factors like mass and acceleration to determine the forces on a driver during a crash. This helps them predict whether the driver would survive or be injured. In this chapter, you will learn how forces such as gravity and friction affect motion.

What do you think?

Science Journal Look at the picture below with a classmate. Discuss what this might be or what is happening. Here's a hint: *Gravity gives this object its structure.* Write your answer or best guess in your Science Journal.





Explore Activity

What holds you to Earth, pulls footballs back to the ground, and keeps the Moon in orbit? The force of gravity, of course. But did you know that all objects near Earth's surface would fall with the same acceleration due to gravity? If this is true, why do bowling balls fall faster than feathers? Explore free-falling objects in this activity.

Observe free-falling objects

1. Drop a softball from a height of 2.5 m and use a stopwatch to measure the time it takes for the softball to fall the given distance.
2. Repeat the procedure using a tennis ball, a piece of paper crumpled into a ball, and a flat sheet of paper.

Observe

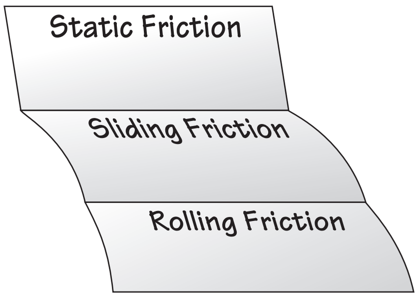
In your Science Journal, write a paragraph comparing the time it took for the four items to drop the 2.5 m. Infer why the crumpled paper fell faster than the flat sheet of paper even though they have the same mass.

Before You Read

Foldables Reading & Study Skills

Making a Compare-and-Contrast Study Fold **Make the following Foldable to help you see how the three types of friction are similar and different.**

1. Place a sheet of paper in front of you so the short side is at the top. Fold the top of the paper down and the bottom up.
2. Open the paper and label the three rows *Static Friction, Sliding Friction,* and *Rolling Friction.*
3. Before you read the chapter, write the definition of each type of friction next to it. As you read the chapter, write more information about each type.



SECTION

1 Newton's Second Law

As You Read

What You'll Learn

- **Explain** how force, mass, and acceleration are related.
- **Describe** the three different types of friction.
- **Observe** the effects of air resistance on falling objects.

Vocabulary

Newton's second law of motion
friction

Why It's Important

Newton's second law explains why some objects move and some objects don't.

Force, Mass, and Acceleration

Newton's first law of motion states that the motion of an object, such as the volleyball in **Figure 1**, changes only if an unbalanced force acts on it. Force and motion are connected. How does force cause motion to change?

Force and Acceleration What's different about throwing a ball as hard as you can and tossing it gently? When you throw hard, you exert a much greater force on the ball. How is the motion of the ball different in each case?

In both cases, the ball was at rest in your hand before it began to move. However, when you throw hard, the ball has a greater velocity when it leaves your hand than it does when you throw gently. Thus the hard-thrown ball has a greater change in velocity, and the change occurs over a shorter period of time. Recall that acceleration is the change in velocity divided by the time it takes for the change to occur. So, a hard-thrown ball has a greater acceleration than a gently thrown ball.

For any object, the greater the force is that's applied to it, the greater its acceleration will be. This is true for anything from the blood cells swirling through your body to the galaxies swirling through outer space.

Figure 1
The motion of the volleyball changes when an unbalanced force is applied to the ball.

Force and Mass If you throw a softball and a baseball as hard as you can, why don't they have the same speed? The difference is due to their masses. The softball has a mass of about 0.20 kg, but a baseball's mass is about 0.14 kg. The softball has less velocity after it leaves your hand than the baseball does, even though you exerted the same force. If it took the same amount of time to throw both balls, the softball has less acceleration. The acceleration of an object depends on its mass as well as the force exerted on it. Force, mass, and acceleration are connected.

Newton's Second Law

Newton's second law of motion describes how force, mass, and acceleration are connected. Recall that if more than one force acts on an object, the forces combine to form a net force. According to **Newton's second law of motion,** the net force acting on an object causes the object to accelerate in the direction of the net force. The acceleration of an object is determined by the size of the net force and the mass of the object according to the equation:

$$\text{acceleration} = \frac{\text{net force}}{\text{mass}}$$

If a stands for the acceleration, F for the net force, and m for the mass, Newton's second law can be written as follows:

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

In SI units, the unit of mass is the kilogram (kg), and the unit of acceleration is meters per second squared (m/s^2). So, according to the second law of motion, force has the units kg $\times$ m/s^2. The unit kg $\times$ m/s^2 is called the newton (N).

SCIENCE Online

Research Visit the Glencoe Science Web site at **science.glencoe.com** for information about how athletic trainers analyze the motions of athletes so they make the best use of Newton's second law. Select a sport and report to your class about some of the findings in that sport.

CLICK HERE

Math Skills Activity

Calculating Acceleration

You are pushing a friend on a sled. You push with a force of 40 N. Your friend and the sled together have a mass of 80 kg. Ignoring friction, what is the acceleration of your friend on the sled?

1. *This is what you know:* force: $F = 40$ N; mass: $m = 80$ kg
2. *This is what you need to know:* acceleration: a
3. *This is the equation you need to use:* $a = F/m$
4. *Substitute the known values:* $a = 40\ \text{N}/80\ \text{kg} = 0.5\ \text{m/s}^2$

Check your answer by multiplying it by the mass. Do you calculate the same force that was given?

Practice Problem

A student pedaling a bicycle applies a net force of 200 N. The mass of the rider and the bicycle is 50 kg. What is the acceleration of the bicycle and the rider?

For more help, refer to the Math Skill Handbook.

Figure 2
The force exerted on the ball by the tennis racket may be more than 500 times greater than the force needed to pick the ball up.

Using Newton's Second Law The second law can be used to calculate the net force on an object if the accleration and mass are known. Suppose a tennis ball like the one in **Figure 2** is accelerated by a tennis racket for five thousandths of a second—the time the racket is in contact with the ball. Because this time period is so short, a ball that leaves the racket at a speed of 100 km/h would have undergone an acceleration of about 5,500 m/s^2. How much force would the tennis racket have to exert to give the ball this acceleration? The ball has a mass of 0.06 kg, so by Newton's second law the force would have to be:

$$F = ma = (0.06\text{ kg})(5{,}500\text{ m/s}^2) = 330\text{ N}$$

Friction

Suppose you give a skateboard a push with your hand. According to Newton's first law of motion, if no forces are acting on a moving object, it continues to move in a straight line with constant speed. What happens to the motion of the skateboard after it leaves your hand? Does it continue to move in a straight line with constant speed?

You know the answer. The skateboard gradually slows down and finally stops. Recall that when an object slows down, its velocity changes. If its velocity changes, it is accelerating. And if an object is accelerating, a net force must be acting on it.

The force that slows the skateboard and brings it to a stop is friction. **Friction** is the force that opposes motion between two surfaces that are touching each other. The amount of friction between two surfaces depends on two factors—the kinds of surfaces and the force pressing the surfaces together.

Reading Check *The amount of friction between two objects depends on what two factors?*

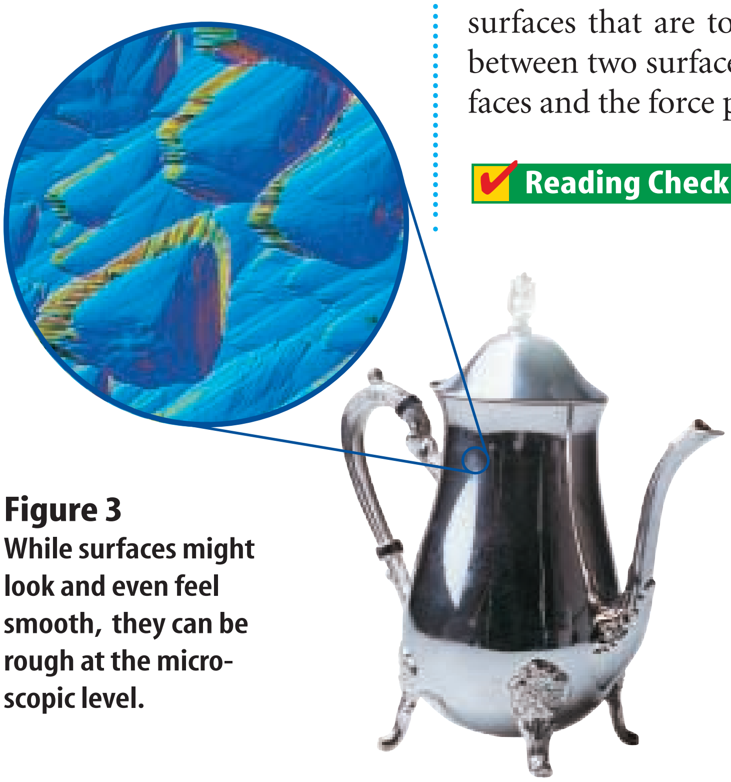


Figure 3
While surfaces might look and even feel smooth, they can be rough at the microscopic level.

What causes friction? Would you believe the surface of a highly polished piece of metal is rough? **Figure 3** shows a microscopic view of the dips and bumps on the surface of a polished silver teapot. If two surfaces, such as two pieces of silver, are pressed tightly together, welding, or sticking, occurs in those areas where the highest bumps come into contact with each other. These areas where the bumps stick together are called microwelds and are the source of friction.

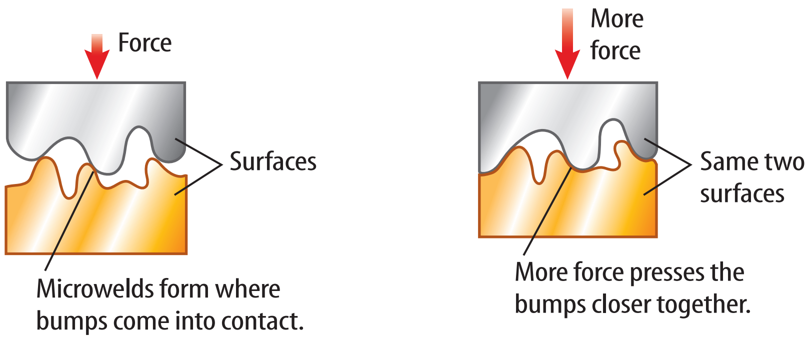


Figure 4
Friction is due to microwelds formed between two surfaces. The larger the force pushing the two surfaces together is, the stronger the microwelds will be.

Sticking Together The stronger the force pushing the two surfaces together is, the stronger these microwelds will be, because more of the surface bumps will come into contact, as shown in **Figure 4.** To break these microwelds and move one surface over the other, a force must be applied.

Static Friction Suppose you have filled a cardboard box, like the one in **Figure 5,** with books and want to move it. It's too heavy to lift, so you start pushing on it, but it doesn't budge. Is that because the mass of the box is too large? If the box doesn't move, then it has zero acceleration. According to Newton's second law, if the acceleration is zero, then the net force on the box is zero. Another force that cancels your push must be acting on the box. That force is friction due to the microwelds that have formed between the bottom of the box and the floor. This type of friction is called static friction. Static friction is the friction between two surfaces that are not moving past each other. In this case, your push is not large enough to break the microwelds, and the box remains stuck to the floor.

Mini LAB

Comparing Friction

Procedure
1. Position an **ice cube, rock, eraser, wood block,** and square of **aluminum foil** at one end of a **metal** or **plastic tray.**
2. Slowly lift the end of the tray with the items.
3. Have a partner use a **metric ruler** to measure the height at which each object slides to the other end of the tray. Record the heights in your **Science Journal.**

Analysis
1. List the height at which each object slid off the tray.
2. Why did the objects slide off at different heights?
3. What type of friction acted on each object?

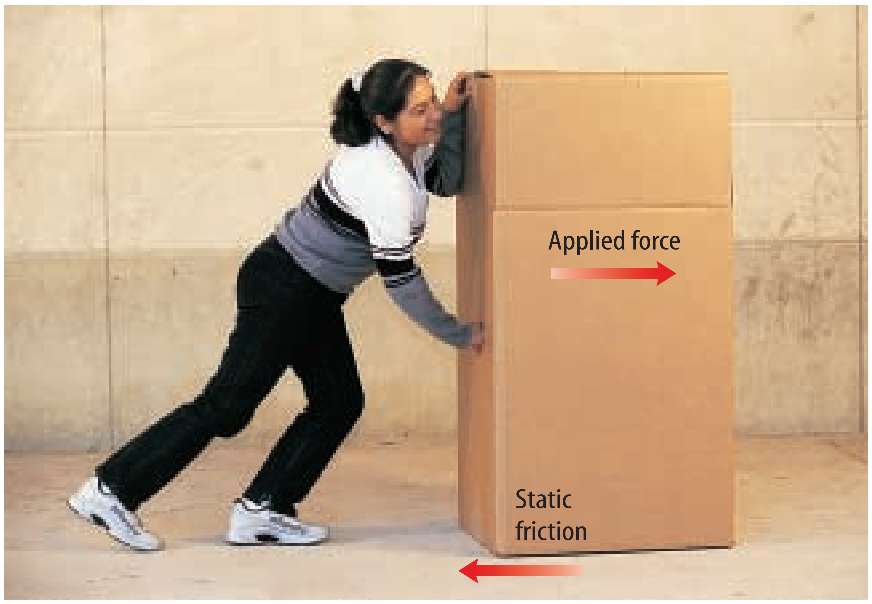


Figure 5
The box doesn't move because static friction cancels the applied force.

Figure 6
Sliding friction acts in the direction opposite the motion of the sliding box.

Sliding Friction To help you move the box, you ask a friend to push with you, as in **Figure 6.** Pushing together, the box starts to move, but it doesn't move easily. Also, if you stop pushing, it quickly comes to a stop. It might even seem as if someone is pushing on it from the opposite direction. But, by exerting enough force, you have broken the microwelds and started the box moving. However, as the box slides across the floor, another force—sliding friction—opposes the motion of the box. Sliding friction is the force that opposes the motion of two surfaces sliding past each other. Sliding friction is caused by microwelds constantly breaking and then forming again as the box slides along the floor. To keep the box moving, you must continually apply a force to overcome sliding friction.

Reading Check ***What's the difference between sliding friction and static friction?***

Rolling Friction You might have watched a car stuck in snow, ice, or mud spinning its wheels. The driver steps on the gas, but the wheels just spin without the car moving. The car doesn't move when the wheels are on the slippery surface because there is not enough friction between the tires and the snow, ice, or mud. One way to make the car move might be to spread sand or gravel under the wheels. By spreading sand or gravel, the friction between the tires and the surface is increased. The friction between a rolling object and the surface it rolls on is rolling friction. As you can see in **Figure 7,** because of rolling friction, the wheels of the train rotate when they come in contact with the track rather than sliding over it. Rolling friction is due partly to the microwelds between a wheel and the surface it rolls over. Microwelds break and then reform as the wheel rolls over the surface. Rolling friction is usually much less than static or sliding friction. This is why it's easier to pull a load in a wagon rather than dragging it along the ground.

Figure 7
Rolling friction is what makes a train's wheels turn on the tracks or a car's wheels turn on the road.

Air Resistance

When an object falls toward Earth, it is pulled downward by the force of gravity. However, another force called air resistance acts on objects that fall through the air. Imagine dropping two identical plastic bags except that one is crumpled into a ball and one is spread out. The crumpled bag falls faster than the spread-out bag. So, the acceleration of the spread-out bag must be less than that of the crumpled bag. Therefore, the net force acting on the spread-out bag is less. This is because the force of air resistance is in the opposite direction to the force of gravity for both bags and is greater on the spread-out bag.

Air resistance affects anything that moves in Earth's atmosphere. Like friction, air resistance acts in the direction opposite to that of the object's motion. In the case of the two falling bags, air resistance is pushing up as gravity is pulling down, as shown in **Figure 8.**

Figure 8
Because of its greater surface area, the spread-out bag has much more air resistance acting on it as it falls.

The amount of air resistance on an object depends on the speed, size, and shape of the object. Air resistance, not the amount of mass in the object, is why feathers, leaves, and pieces of paper fall more slowly than pennies, acorns, and apples. If no air resistance is present, then a feather and an apple fall at the same rate, as shown in **Figure 9.**

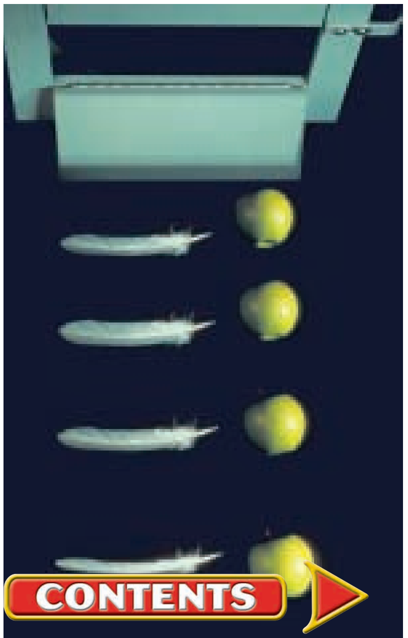


Figure 9
The apple and feather are falling in a vacuum. Because there is no air resistance, they both fall at the same rate.

Figure 10
The force of air resistance on an open parachute is large. This causes the sky diver to fall slowly.

Terminal Velocity The force of air resistance increases with speed. As an object falls, it accelerates and its speed increases. So the force of air resistance increases until it becomes large enough to cancel the force of gravity. Then the forces on the falling object are balanced, and the object no longer accelerates. It then falls with a constant speed called the terminal velocity. This terminal velocity is the highest velocity that a falling object will reach. A low terminal velocity enables a sky diver, such as the one shown in **Figure 10,** to land safely on the ground.

Section 1 Assessment

1. What is Newton's second law of motion?
2. The same force acts on two objects with different masses. Why does the object with less mass have a larger acceleration?
3. What is the difference between static friction and sliding friction?
4. A squirrel runs across a branch on an oak tree and knocks an acorn and a leaf loose. Why does the acorn hit the ground first?
5. **Think Critically** To reduce the friction in a metal door hinge, you might try coating it with oil. Why does oil reduce friction?

Skill Builder Activities

6. **Drawing Conclusions** Boxes of equal size are resting on the floor. Applying the same force on each box, you find that you can accelerate the first one 1 m/s^2, the second 4 m/s^2, and the third 6 m/s^2. What can you infer about the total mass of each box? What other factors might have influenced your results? **For more help, refer to the Science Skill Handbook.**
7. **Communicating** Describe activities in which friction would be useful. **For more help, refer to the Science Skill Handbook.**

SECTION

2 Gravity

The Law of Gravitation

There's a lot about you that's attractive. At this moment, you are exerting an attractive force on everything around you—your desk, your classmates, even the planet Jupiter millions of kilometers away. It's the attractive force of gravity.

Anything that has mass is attracted by the force of gravity. According to the **law of gravitation,** any two masses exert an attractive force on each other. The attractive force depends on the mass of the two objects and the distance between them. This force increases as the mass of either object increases, as shown in **Figure 11A.** Also, **Figure 11B** shows that the force of gravity increases as the objects move closer.

You can't feel any gravitational attraction between you and this book because the force is weak. Only Earth is close enough and has a large enough mass that you can feel its gravitational attraction. While the Sun has much more mass than Earth, the Sun is too far away to exert a noticeable gravitational attraction on you. And while this book is close, it doesn't have enough mass to exert an attraction you can feel.

Gravity—A Basic Force Gravity is one of the four basic forces. The other basic forces are the electromagnetic force, the strong nuclear force, and the weak nuclear force. The nuclear forces only act on particles in the nuclei of atoms. Electricity and magnetism are caused by the electromagnetic force. Chemical interactions between atoms and molecules also are due to the electromagnetic force.

As You Read

What You'll Learn

- **Describe** gravitational force.
- **Distinguish** between mass and weight.
- **Explain** why objects that are thrown or shot will follow a curved path.
- **Compare** motion in a straight line with circular motion.

Vocabulary

law of gravitation
weight
centripetal acceleration
centripetal force

Why It's Important

No matter where you might be in the universe, gravity will affect you.

Figure 11 The gravitational force between two objects depends on their masses and the distance between them.

A If the mass of either of the objects increases, the gravitational force between them increases.

B If the objects are closer together, the gravitational force between them increases.

Figure 12
Gravity is at work in the formation of galaxies like this spiral galaxy.

The Range of Gravity You might think that a star in another galaxy is too far away to exert a gravitational force on you, but you'd be wrong. Despite the distance between two objects, the gravitational attraction between them never disappears. Gravity is a long-range force. All the stars in a galaxy, such as the one shown in **Figure 12,** exert a gravitational force on each other. These forces help give the galaxy its shape. In fact, a gravitational force exists between all matter in the universe. Gravity is the force that gives the universe its structure.

SCIENCE Online

Data Update Visit the Glencoe Science Web site at **science.glencoe.com** for data comparing the gravitational accelerations objects would experience on different planets. Discuss with your class why the gravitational acceleration is greater on some planets than on others.

CLICK HERE

Gravitational Acceleration

Near Earth's surface, the gravitational attraction of Earth causes all falling objects to have an acceleration of 9.8 m/s^2. By Newton's second law, the net force, mass, and acceleration are related according to the following formula:

$$F = ma$$

According to the second law, the force on an object that has an acceleration of 9.8 m/s^2 is as follows:

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

This is the force of gravity on an object near Earth's surface. This force depends only on the object's mass. A force has a direction associated with it. The force of Earth's gravity is always downward.

When an object is influenced only by the force of gravity, it is said to be in free fall. Suppose you were to drop a bowling ball and a marble from a bridge at the same time. Which would hit the water below first? Would it be the bowling ball because it has more mass?

Inertia and Gravity It's true that the force of gravity would be greater on the bowling ball because of its larger mass. But the larger mass also means the bowling ball has more inertia, so more force is needed to change its velocity. The gravitational force on the marble is smaller because it has less mass, but the inertia of the marble is smaller, too, so less force is needed to change its velocity. As a result, all objects fall with the same acceleration, no matter how large or small their mass is. Although the blue ball in **Figure 13** is more massive than the green one, they fall at the same rate.

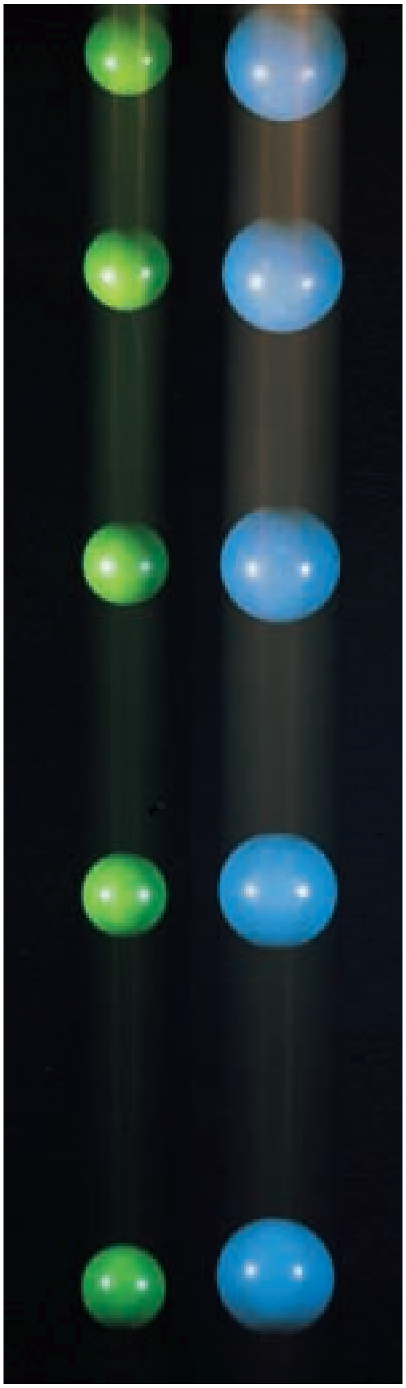


Figure 13
High-speed photography shows that two balls of different masses fall at the same rate.

Weight

If you are standing on the floor of your classroom, your acceleration is zero. According to Newton's second law, if your acceleration is zero, the net force on you must be zero. Does this mean Earth's gravitational attraction for you has disappeared? No. Earth still pulls you downward, but the floor also exerts an upward force that keeps you from falling.

Whether you are standing, jumping, or falling, Earth exerts a gravitational force on you. The gravitational force exerted on an object is called the object's **weight.** The symbol *W* stands for the weight. You can find gravitational force, or weight, using Newton's second law, as follows:

$$\text{gravitational force} = \text{mass} \times \begin{bmatrix}\text{acceleration} \\ \text{due to gravity}\end{bmatrix}$$

Because the gravitational force is the same as the weight and the acceleration due to gravity on Earth is 9.8 m/s^2, this equation can be written as follows:

$$W = m \times 9.8 \text{ m/s}^2$$

In other words, a mass of 1 kg weighs 1 kg × 9.8 m/s^2, or 9.8 N. You could calculate your weight in newtons if you knew your mass. For example, a person with a mass of 50 kg would have a weight of 490 N. On Earth, a cassette tape weighs about 0.5 N, a backpack full of books weighs about 40 N, and a jumbo jet weighs about 3.4 million N.

Reading Check *How much does a person with a mass of 70 kg weigh on Earth?*

Losing Weight What would happen to your weight if you were far from Earth? Recall that the gravitational attraction between two objects becomes weaker as they move farther apart. So if you were to travel away from Earth, your weight would decrease.

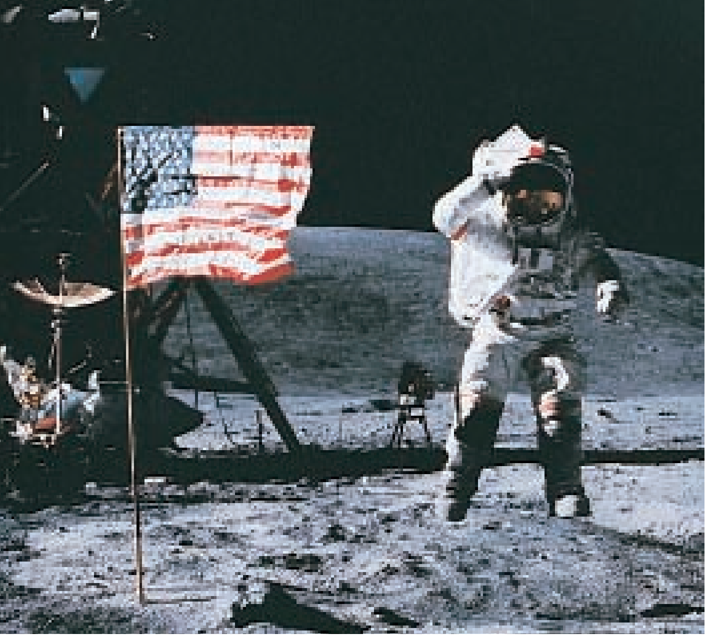


Figure 14
The astronaut was able to take longer steps on the Moon because the gravitational attraction on him there is less than on Earth.

Weight and Mass Weight and mass are not the same. Weight is a force, and mass is a measure of the amount of matter an object contains. However, weight and mass are related. The greater an object's mass is, the stronger the gravitational force between the object and Earth is. So the more mass an object has, the more it will weigh at the same location.

The weight of an object usually means the gravitational force between the object and Earth. But objects can have different weights, depending on what's pulling on them. For example, a person weighing about 480 N on Earth would weigh only about 80 N on the Moon. Does this mean the astronaut in **Figure 14** would have less mass on the Moon than on Earth? The answer is no, the mass of the astronaut would be unchanged. His weight is less than on Earth because the Moon has less mass and exerts a weaker gravitational force. **Table 1** shows how an object's weight depends upon the object's location.

Reading Check *How are weight and mass related?*

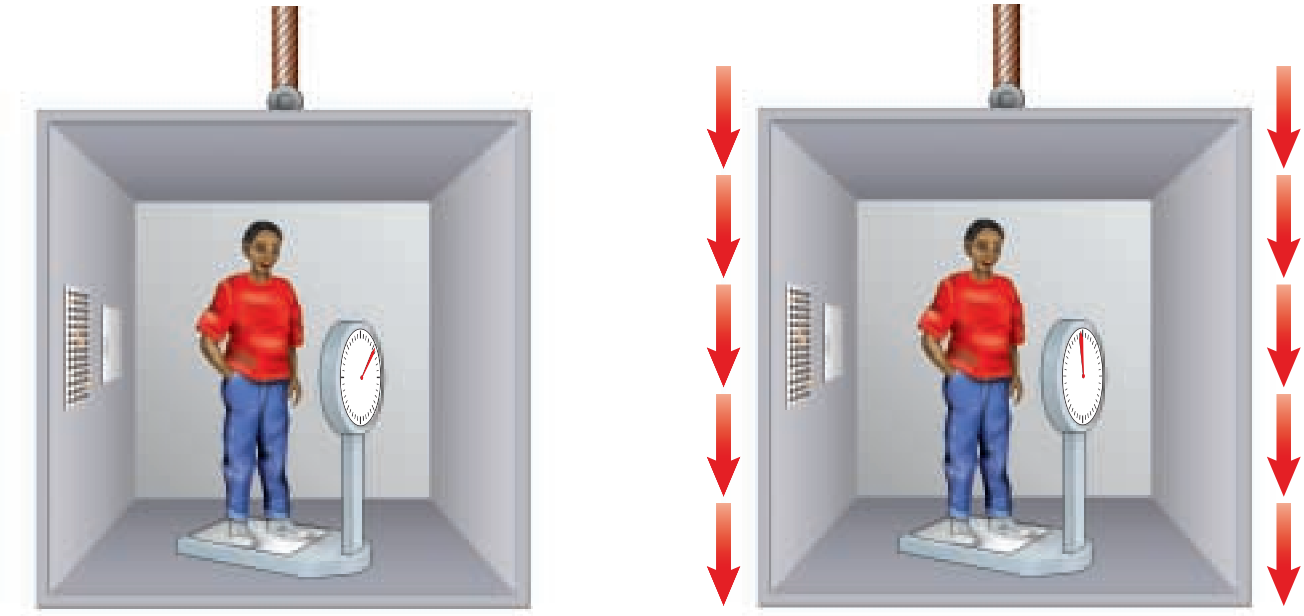
Weightlessness and Free Fall

You've probably seen pictures of astronauts and equipment floating inside the space shuttle. Any item that is not fastened down in the shuttle floats throughout the cabin. They are said to be experiencing the sensation of weightlessness.

To be nearly weightless, the astronauts would have to be far from Earth to be significantly free from the effects of its gravity. Even while orbiting 400 km above Earth, the force of gravity pulling on the shuttle is still about 90 percent as strong as it is at Earth's surface, so they are not weightless.

Table 1 Weight Comparison Table

Weight on Earth (N)	Weight on Other Bodies in the Solar System (N)				
	Moon	Venus	Mars	Jupiter	Saturn
75	12	68	28	190	87
100	17	90	38	254	116
150	25	135	57	381	174
500	84	450	190	1,270	580
2,000	333	1,800	760	5,080	2,320



A When the elevator is stationary, the scale shows the boy's weight.

B If the elevator were falling, the scale would show a smaller weight.

Floating in Space So what does it mean to say that something is weightless in orbit? Think about how you measure your weight. When you stand on a scale, as in **Figure 15A,** you are at rest and the net force on you is zero. So the scale supports you and balances your weight by exerting an upward force. The dial on a scale shows the upward force exerted by the scale, which is your weight. Now suppose you stand on a scale in an elevator that is falling, as in **Figure 15B.** If you and the scale were in free fall, then you no longer would push down on the scale at all. The scale dial would say you have zero weight, even though the force of gravity on you hasn't changed.

Everything in the orbiting space shuttle is falling downward toward Earth at the same rate, in the same way you and the scale were falling in the elevator. Because objects in the shuttle have no force supporting them, they seem to be floating.

Projectile Motion

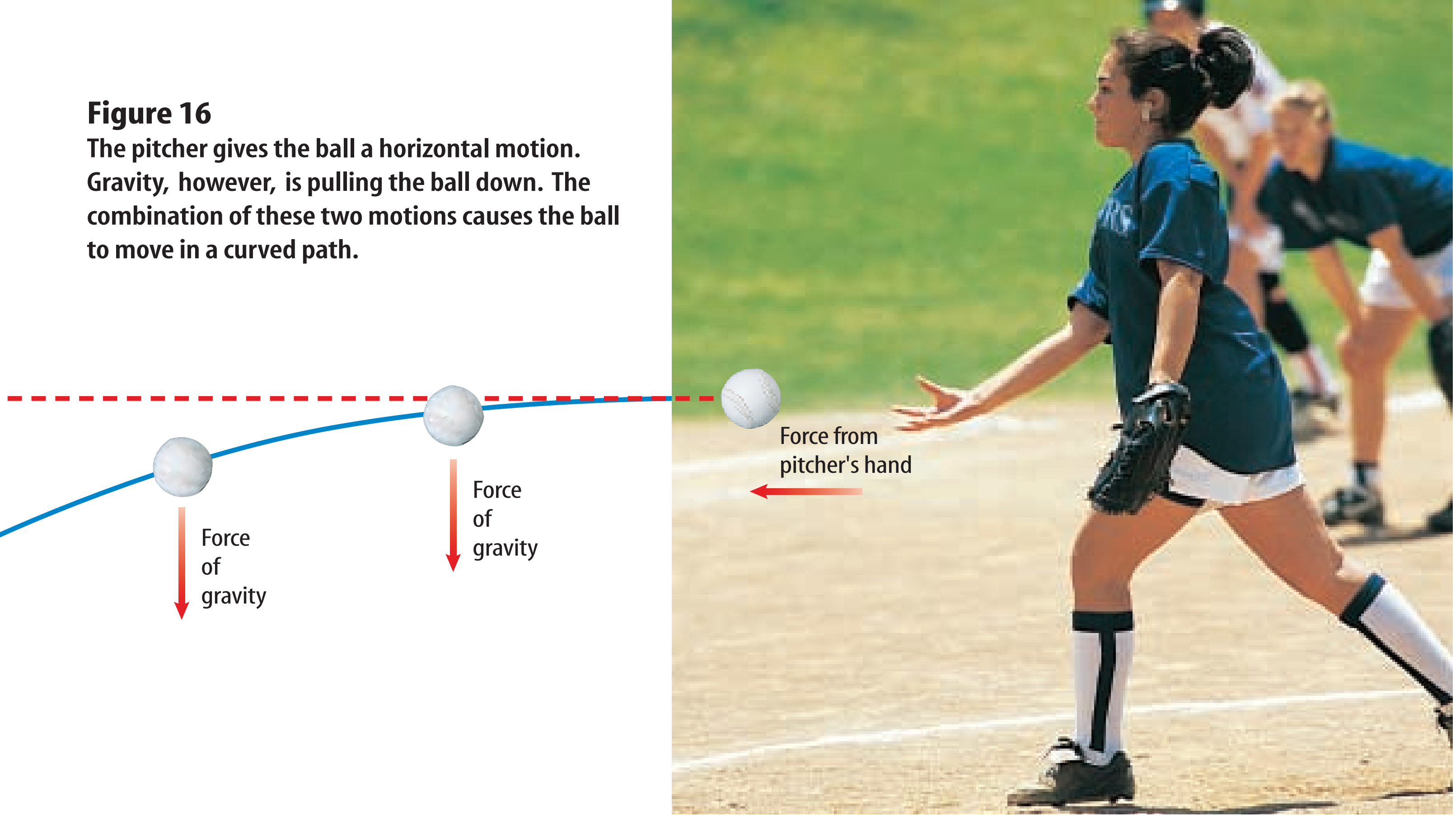
If you've tossed a ball to someone, you've probably noticed that thrown objects don't always travel in straight lines. They tend to curve downward. That's why quarterbacks, dart players, and archers aim above their targets. Anything that's thrown or shot through the air is called a projectile. Because of Earth's gravitational pull and their own inertia, projectiles follow a curved path. This is because they have horizontal and vertical velocities.

Figure 15
The boy pushes down on the scale with less force when he and the scale are falling at the same rate.

Earth Science INTEGRATION

Apart from simply keeping your feet on the ground, gravity is important for life on Earth for other reasons, too. Because Earth has a sufficient gravitational pull, for example, it can hold around it the oxygen/nitrogen atmosphere necessary for sustaining life. Research other ways in which gravity has played a role in the formation of Earth.

Figure 16
The pitcher gives the ball a horizontal motion. Gravity, however, is pulling the ball down. The combination of these two motions causes the ball to move in a curved path.



Horizontal and Vertical Motions When you throw a ball, like the pitcher in **Figure 16,** the force from your hand makes the ball move forward. It gives the ball horizontal motion or motion parallel to Earth's surface. After you let go of the ball, no other force accelerates it forward, so its horizontal velocity is constant, if you ignore air resistance.

Figure 17
Time-lapse photography shows that each ball has the same acceleration downward, whether it's thrown or dropped.

However, when you let go of the ball, something else happens. Gravity can now pull it downward, giving it vertical motion, or motion perpendicular to Earth's surface. Now the ball has constant horizontal velocity but increasing vertical velocity. Gravity exerts an unbalanced force on the ball, changing the direction of its path from only forward to forward and downward. The result of these two motions is that the ball appears to travel in a curve, even though its horizontal and vertical motions are completely independent of each other.

If you were to throw a ball as hard as you could from shoulder height in a perfectly horizontal direction, would it take longer to reach the ground than if you dropped a ball from the same height? Surprisingly, it won't. A thrown ball and one dropped will hit the ground at the same time. If you have a hard time believing this, **Figure 17** might help. The two balls have the same acceleration due to gravity—9.8 m/s^2 downward. How would a thrown ball's path look on the Moon?

Centripetal Force

Recall that acceleration is the rate of change of velocity due to a change in speed, direction, or both. Now, look at the path the ball follows as it travels through the pipe maze in **Figure 18.** The ball may accelerate in the straight sections of the pipe maze if it speeds up or slows down. However, when the ball enters a curve, even if its speed does not change, it is accelerating because its direction is changing. When the ball goes around a curve, the change in the direction of the velocity is toward the center of the curve. Acceleration toward the center of a curved or circular path is called **centripetal acceleration.** The word *centripetal* means to "move toward the center."

For the ball to be accelerating toward the center, an unbalanced force, called **centripetal force,** must be acting on it in a direction toward the center. The centripetal force acting on the ball running through the maze is exerted by the outside wall pushing against it and keeping it from going straight.

When a car rounds a sharp curve on a highway, the centripetal force is the friction between the tires and the road surface. If the road is icy or wet and the tires lose their grip, the centripetal force might not be enough to overcome the car's inertia. Then the car would keep moving in a straight line in the direction that it was traveling at the spot where it lost traction. Anything that moves in a circle, such as the people on the amusement park ride in **Figure 19,** is doing so because a centripetal force is accelerating it toward the center.

Figure 18
When the ball moves through the circular portions of the maze, it is accelerating because its velocity is changing. *Would you expect the ball to be traveling faster or slower if more curves were in the maze?*

Figure 19
Centripetal force keeps these riders moving in a circle.

TRY AT HOME
Mini LAB

Observing Centripetal Force

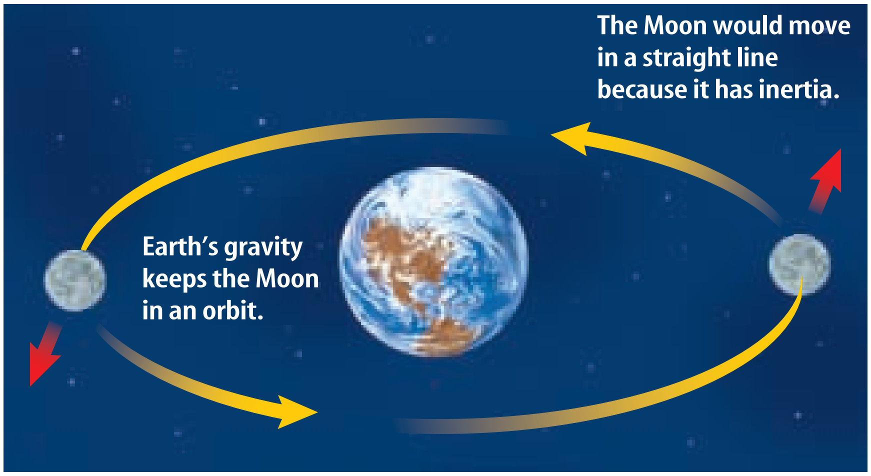
Procedure

1. Fill a **bucket** that has a secure handle with **water** to a level of about 3 cm.
2. Go outside and stand several meters away from any person or object.
3. Swing the bucket quickly in a circle. It should be upside down for just an instant.

Analysis

1. Why didn't you get wet?
2. What force did the bottom of the bucket exert on the water when you swung the bucket above you?
3. What would happen if you swung the bucket slowly?

Figure 20
The Moon would move in a straight line except that Earth's gravity keeps pulling it toward Earth. This gives the Moon its circular orbit.



The Moon Is Falling A satellite is anything that moves around another body in a generally circular path called an orbit. Earth and the other planets are satellites because they orbit the Sun. The Moon is a natural satellite of Earth. The *International Space Station* is another of Earth's satellites. Because it was made here on Earth, it is an artificial satellite. Why do satellites move the way they do?

Imagine whirling an object tied to a string above your head. The string exerts a centripetal force on the object that keeps it moving in a circular path. In the same way, Earth's gravity exerts a centripetal force on the Moon that keeps it moving in a circular orbit, as shown in **Figure 20.**

Section 2 Assessment

1. What is gravity, and how does the size of two objects and the distance between them affect the gravitational force?
2. How is an object's mass different from its weight? Do objects always weigh the same? Explain.
3. What two motions contribute to the path of a projectile?
4. How do the planets stay in orbit around the Sun?
5. **Think Critically** Suppose that on a planet you weigh two-thirds as much as you do on Earth. Is the planet's mass greater than or less than Earth's? Explain.

Skill Builder Activities

6. **Using a Word Processor** Use a computer to make a table showing important characteristics of projectile motion, circular motion, and free fall. Table headings should include: *Kind of Motion, Shape of Path,* and *Laws or Forces Involved.* You can add other headings. **For more help, refer to the Technology Skill Handbook.**
7. **Communicating** Write a paragraph describing a situation in which you experienced something close to free fall or a feeling of weightlessness. Think about amusement park rides, elevators, athletic events, or even movie scenes. **For more help, refer to the Science Skill Handbook.**

SECTION 3

The Third Law of Motion

Newton's Third Law

Push against a wall and what happens? If the wall is sturdy enough, usually nothing happens. Now, think about what would happen if you pushed against a wall while wearing roller skates. You would go rolling backwards, of course. The harder you pushed, the more you would roll backwards. Your action on the wall produced a reaction—movement backwards. This is a demonstration of Newton's third law of motion.

Newton's third law of motion describes action-reaction pairs this way: When one object exerts a force on a second object, the second one exerts a force on the first that is equal in size and opposite in direction. Another way to say this is "to every action force there is an equal and opposite reaction force."

Action and Reaction When a force is applied in nature, a reaction to it occurs. When you jump on a trampoline, for example, you exert a downward force on the trampoline. The trampoline then exerts an equal force upward, sending you high into the air.

Action and reaction forces are acting on the two skaters in **Figure 21.** The male skater is pulling upward on the female skater, while the female skater is pulling downward on the male skater. The two forces are equal, but in opposite directions.

As You Read

What You'll Learn

- **Identify** when action and reaction forces occur.
- **Calculate** momentum.
- **Demonstrate** how momentum is conserved.

Vocabulary

Newton's third law of motion
momentum

Why It's Important

From walking across the floor to a rocket speeding through space, all motion occurs because every action has a reaction.

Figure 21
According to Newton's third law of motion, the two skaters exert forces on each other. The two forces are equal, but in opposite directions.

How You Move If action and reaction forces are equal, you might wonder how some things ever happen. For example, how does a swimmer move through the water in a pool if each time she pushes on the water, the water pushes back on her? An important point to remember when dealing with Newton's third law is that *action-reaction forces are acting on different objects.* Thus, even though the forces are equal, they are not balanced because they act on different objects. In the case of the swimmer, as she "acts" on the water, the "reaction" of the water pushes her forward. Thus, a net force, or unbalanced force, acts on her so a change in her motion occurs. Why is it harder for a swimmer to swim against a tide?

Reading Check *How is a swimmer able to move in the water?*

Health INTEGRATION

Astronauts who stay in outer space for extended periods of time may develop health problems. Their muscles, for example, may begin to weaken because they don't have to exert as much force to get the same reaction as they do on Earth. A branch of medicine called space medicine deals with the possible health problems that astronauts may experience. Research some other health risks that are involved in going into outer space. Do trips into outer space have any positive health benefits?

Rocket Propulsion Suppose you were standing on skates holding a softball. You exert a force on the softball when you throw the softball. According to Newton's third law, the softball exerts a force on you. This force pushes you in the direction opposite the softball's motion. Rockets use the same principle to move even in the vacuum of outer space. In the rocket engine, burning fuel produces hot gases. The rocket engine exerts a force on these gases and causes them to escape out the back of the rocket. By Newton's third law, the gases exert a force on the rocket and push it forward. The car in **Figure 22** uses a rocket engine to propel it forward. **Figure 23** shows how rockets move through space.

Figure 22
If more gas is ejected from the rocket engine, or expelled at a greater velocity, the rocket engine will push the car faster.

VISUALIZING ROCKET MOTION

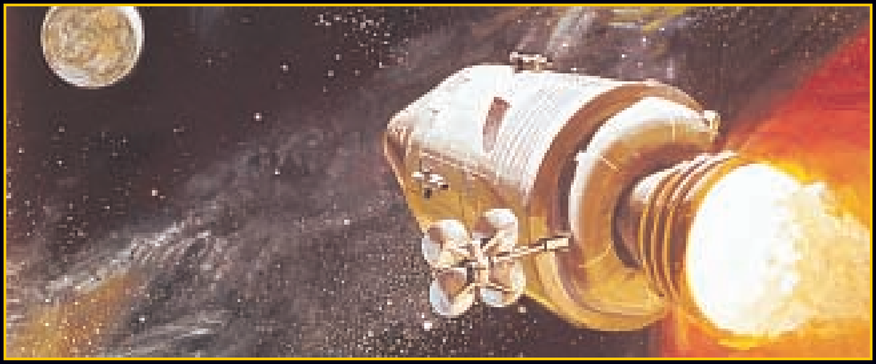
Figure 23

On the afternoon of July 16, 1969, *Apollo 11* lifted off from Cape Kennedy, Florida, bound for the Moon. Eight days later, the spacecraft returned to Earth, splashing down safely in the Pacific Ocean. The motion of the spacecraft to the Moon and back is governed by Newton's laws of motion.

Apollo 11 roars toward the Moon. At launch, a rocket's engines must produce enough force and acceleration to overcome the pull of Earth's gravity. A rocket's liftoff is an illustration of Newton's third law: For every action there is an equal and opposite reaction.

As *Apollo* rises, it burns fuel and ejects its rocket booster engines. This decreases its mass, and helps *Apollo* move faster. This is Newton's second law in action: As mass decreases, acceleration can increase.

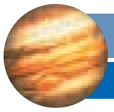
The lunar module uses other engines to slow down and ease into a soft touchdown on the Moon. A day later, the same engines lift the lunar module again into outer space.



After the lunar module returns to *Apollo,* the rocket fires its engines to set it into motion toward Earth. The rocket then shuts off its engines, moving according to Newton's first law. As it nears Earth, the rocket accelerates at an increasing rate because of Earth's gravity.

Figure 24
The location of the planet Neptune was predicted correctly using Newton's laws.

Finding Planets with Newton's Laws



Astronomy INTEGRATION

The gravitational force between Earth and the Sun causes Earth to orbit the Sun. However, Earth's orbit is also affected by the gravitational pulls of the other planets in the solar system. Each planet pulls on Earth with a force determined by its mass and its distance from Earth. In the same way, the orbit of every planet in the solar system is affected by the gravitational pulls from all the other planets.

In the 1840s, the most distant planet known was Uranus. Astronomers noticed that its orbit couldn't be explained by the forces exerted by the Sun and the other known planets. They concluded that there must be another planet affecting the orbit of Uranus that hadn't been discovered. Using Newton's laws of motion, Urbain Jean Leverrier and John Adams independently calculated where it must be located. The planet, shown in **Figure 24,** was found in 1846 where Leverrier and Adams said it would be, and named it Neptune.

Momentum

You know that a slow-moving bicycle is easier to stop than a fast-moving one. Also, a slow-moving bicycle is easier to stop than a car traveling at the same speed. Increasing either the speed or mass of an object makes it harder to stop.

A moving object has a property called momentum that is related to how much force is needed to change its motion. The **momentum** of an object is the product of its mass and velocity. Momentum is given the symbol p and can be calculated with this equation:

$$\text{momentum} = \text{mass} \times \text{velocity}$$
$$p = m \times v$$

The unit for momentum is kg m/s. Notice that momentum has a direction because velocity has a direction.

The two trucks in **Figure 25** might have the same velocity, but the bigger truck has more momentum because of its greater mass. An archer's arrow can have a large momentum because of its high velocity, even though its mass is small. A walking elephant may have a low velocity, but because of its large mass, it has a large momentum.

Force and Changing Momentum If you catch a fast-moving baseball, your hand might sting, even if you use a baseball glove. Your hand stings because the baseball exerted a force on your hand when it came to a stop, and its momentum changed.

Recall that acceleration is the difference between the initial and final velocity, divided by the time. Also, from Newton's second law, the net force on an object equals its mass times its acceleration. By combining these two relationships, Newton's second law can be written in this way:

$$F = (mv_f - mv_i)/t$$

In this equation mv_f is the final momentum and mv_i is the initial momentum. So the equation says that the net force exerted on an object can be calculated by dividing its change in momentum by the time over which the change occurs. When you catch a ball, your hand exerts a force on the ball that stops it. Here the final velocity is zero. The force depends on the mass and speed of the ball and how long it takes to come to a stop.

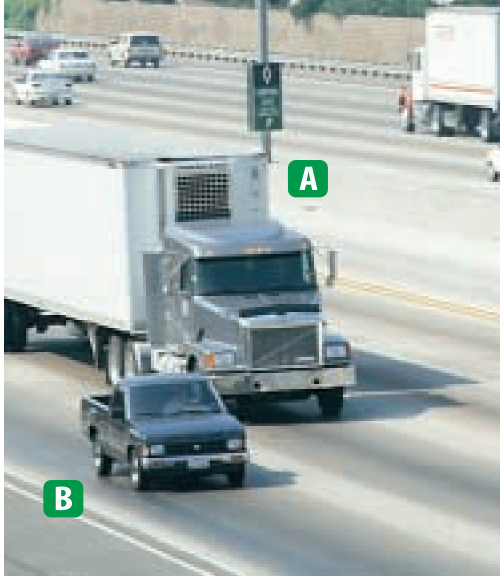
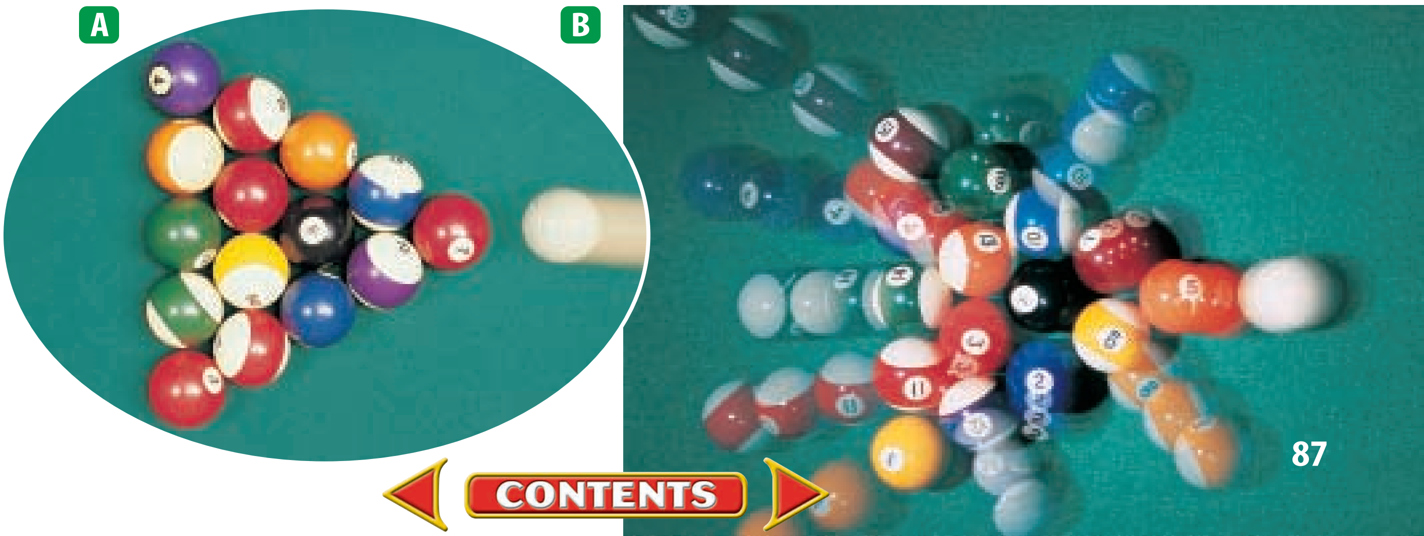


Figure 25
Suppose both trucks have the same speed. Truck A has more momentum than the smaller truck B because the larger truck has more mass.
Under what conditions would the smaller truck have a momentum greater than the big truck?

Law of Conservation of Momentum The momentum of an object doesn't change unless its mass, velocity, or both change. Momentum, however, can be transferred from one object to another. Consider the game of pool shown in **Figure 26.** Before the game starts, all the balls are motionless. The total momentum of the balls is, therefore, zero.

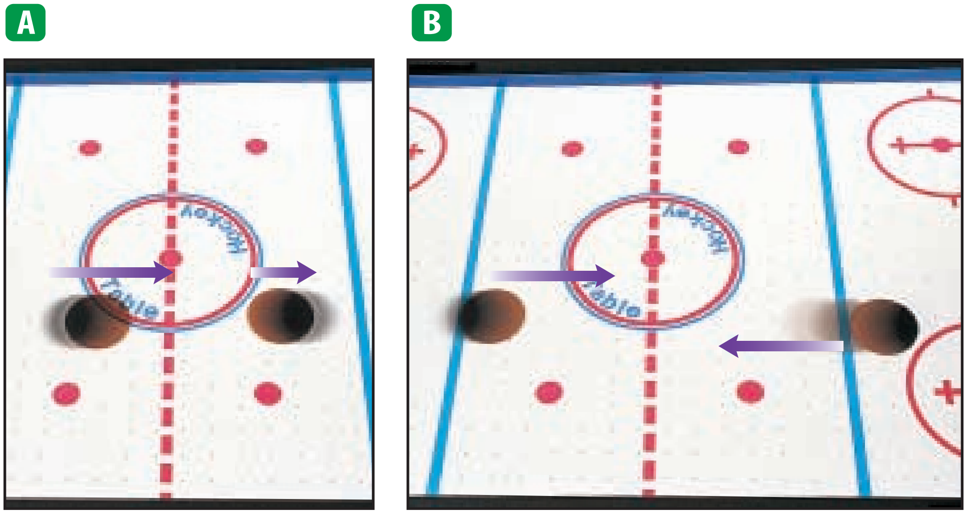
What happens when the cue ball hits the group of balls that are motionless? The cue ball slows down and the rest of the balls begin to move. The total momentum of all the balls just before and after the collision would be the same. The momentum the group of balls gained is equal to the momentum that the cue ball lost. If no other forces act on the balls, their total momentum is conserved—it isn't lost or created. This is the law of conservation of momentum—if a group of objects exerts forces only on each other, their total momentum doesn't change.

Figure 26
Momentum is transferred in collisions.
A At the start, the cue ball has all the momentum. The other balls have no momentum because they are not moving.
B When the cue ball strikes the other balls, it transfers some of its momentum to them.



CONTENTS

Figure 27
The results of a collision depend on the momentum of each object. A When the first puck hits the second puck from behind, it gives the second puck momentum in the same direction. B If the pucks are speeding toward each other with the same speed, the total momentum is zero. *How will they move after they collide?*



When Objects Collide Look at the pictures of the air-hockey table in **Figure 27.** Suppose one of the pucks was moving along the table in one direction and another struck it from behind. The puck that was struck would continue to move in the same direction but more quickly. The second puck has given it additional momentum in the same direction. What if the two pucks had the same mass and were moving toward each other with the same speed? Each would have the same momentum, but in opposite directions. So the total momentum would be zero. After the pucks collided, they would reverse direction, and move with the same speed. The total momentum would again be zero.

Section 3 Assessment

1. What is Newton's third law of motion?
2. How can a rocket move through outer space where no matter exists for it to push on?
3. Compare the momentum of a 50-kg dolphin swimming 10.4 m/s and a 6,300-kg elephant walking 0.11 m/s.
4. When two pool balls collide, what happens to the momentum of each?
5. **Think Critically** Some ballet directors assign larger dancers to perform slow, graceful steps and smaller dancers to perform quick movements. Does this plan make sense? Why?

Skill Builder Activities

6. **Predicting** You are a crane operator using a wrecking ball to demolish an old building. You can choose to use a 100-kg ball or a 150-kg ball. Which ball would knock the walls down faster? Which ball would be easier for you to control? Explain. **For more help, refer to the Science Skill Handbook.**
7. **Communicating** In your Science Journal, use the law of conservation of momentum to explain the results of a particular collision you have witnessed. For example, think of games, sports, or amusement park rides or contests. **For more help, refer to the Science Skill Handbook.**

Activity

Measuring the Effects of Air Resistance

If you dropped a bowling ball and a feather from the same height on the Moon, they would both hit the surface at the same time. All objects dropped on Earth are attracted to the ground with the same acceleration. But on Earth, a bowling ball and feather will not hit the ground at the same time. Air resistance slows the feather down.

What You'll Investigate

How does air resistance affect the acceleration of falling objects?

Materials

paper (4 sheets of equal size)
scissors
meterstick
stopwatch
masking tape

Goals

- **Measure** the effect of air resistance on sheets of paper with different shapes.
- **Design** and create a shape from a piece of paper that maximizes air resistance.

Safety Precautions

Procedure

1. Copy the data table above in your Science Journal, or create it on a computer.
2. Measure a height of 2.5 m on the wall and mark the height with a piece of masking tape.
3. Have one group member drop the flat sheet of paper from the 2.5 m mark. Use the stopwatch to time how long it takes for the paper to reach the ground. Record your time in your data table.
4. Crumple a sheet of paper into a loose ball and repeat step 3.

Effects of Air Resistance

Paper Type	Time
Flat paper	
Loosely crumpled paper	
Tightly crumpled paper	
Your paper design	

5. Crumple a sheet of paper into a tight ball and repeat step 3.
6. Use scissors to shape a piece of paper so that it will fall slowly. You may cut, tear, or fold your paper into any design you choose.

Conclude and Apply

1. **Compare** the falling times of the different sheets of paper.
2. **Infer** the relationship between the falling time and the acceleration of each sheet of paper.
3. **Explain** why the different-shaped papers fell at different speeds.
4. **Explain** how your design maximized the effect of air resistance on your paper's gravitational acceleration.
5. **Infer** why a sky diver will fall in a spread-eagle position before opening her parachute.

Communicating Your Data

Compare your paper design with the designs created by your classmates. As a class, compile a list of characteristics that increase air resistance.

Activity

The Momentum of Colliding Objects

Many scientists hypothesize that dinosaurs became extinct 65 million years ago when an asteroid slammed into Earth. The asteroid's diameter was probably no more than 10 km. Earth's diameter is more than 12,700 km. How could an object that size change Earth's climate enough to cause the extinction of animals that had dominated life on Earth for 140 million years? The asteroid could because it may have been traveling at a velocity of 50 m/s, and had a huge amount of momentum. The combination of an object's velocity and mass will determine how much force it can exert. Explore how mass and velocity determine an object's momentum during this activity.

What You'll Investigate

How do the mass and velocity of a moving object affect its momentum?

Materials

meterstick
softball
racquetball
tennis ball
baseball
stopwatch
masking tape
balance

Goals

- **Observe and calculate** the momentum of different balls.
- **Compare** results of collisions involving different amounts of momentum.

Safety Precautions

Momentum of Colliding Balls

Action	Time	Velocity	Mass	Momentum	Distance ball moved softball
Racquetball rolled slowly					
Racquetball rolled quickly					
Tennis ball rolled slowly					
Tennis ball rolled quickly					
Baseball rolled slowly					
Baseball rolled quickly					

Procedure

1. Copy the data table on the previous page in your Science Journal.
2. Use the balance to measure the mass of the racquetball, tennis ball, and baseball. Record these masses in your data table.
3. Use your meterstick to measure a 2-m distance on the floor. Mark this distance with two pieces of masking tape.
4. Place the softball on one piece of tape. Starting from the other piece of tape, slowly roll the racquetball the 2-m distance so that it hits the softball squarely.
5. Use a stopwatch to time how long it takes the racquetball to roll the 2-m distance and hit the softball. Record this time in your data table.
6. Measure the distance the racquetball moved the softball. Record this distance in your data table.
7. Repeat steps 4-6, rolling the racquetball quickly.
8. Repeat steps 4-6, rolling the tennis ball quickly and then slowly.
9. Repeat steps 4-6, rolling the baseball quickly and then slowly.

Conclude and Apply

1. Using the formula $p = mv$, calculate the momentum for each type of ball and action. Record your calculations in the data table.
2. **Compare** the momentums you calculated. Which action had the greatest momentum? Which had the smallest momentum?
3. **Infer** the relationship between the momentum of each ball and the distance the softball was moved.
4. **Explain** why the baseball will have a greater momentum than the tennis ball even if both are traveling with an equal velocity.
5. **Explain** how you observed Newton's third law of motion occurring during this activity.

Communicating Your Data

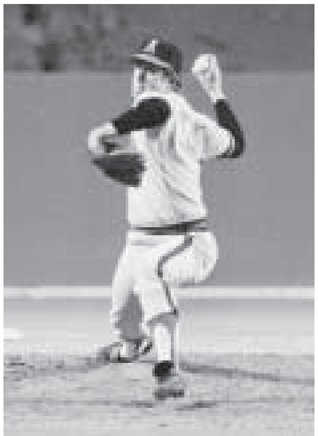
Use what you have learned about momentum to discuss the differences between the sports of softball and baseball.

Science Stats

Moving and Forcing

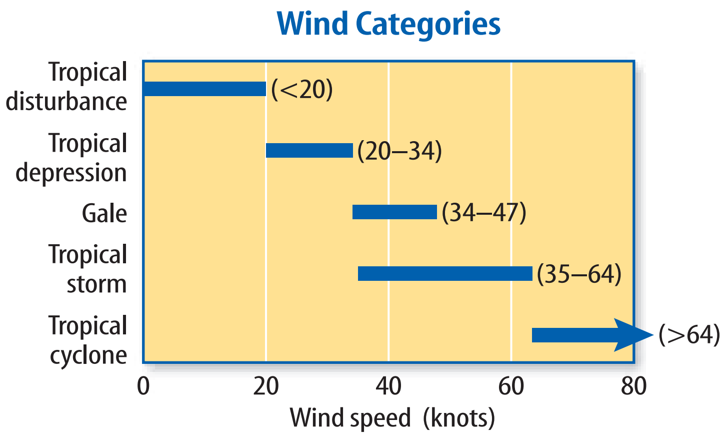
Did you know...

...The fastest baseball pitch on record was thrown at 162.3 km/h. This superfast pitch was thrown by the California Angels' Nolan Ryan during a major league game in 1974.



Nolan Ryan

...The Sun moves in a circular path around the center of the galaxy at about 250 km/s. At this rate, the Sun could make a trip from New York to Los Angeles in about 18 s.



1 knot = 1.85 kilometers per hour

...Ocean waves are powerful. The Atlantic hurls an average of 10,000 kg of water per square meter at the shore in winter. During one storm, the waves ripped away a 1,496,880-kg steel-and-concrete portion of a breakwater. During a later storm, its 2,358,720-kg replacement met with the same fate.

Connecting To Math

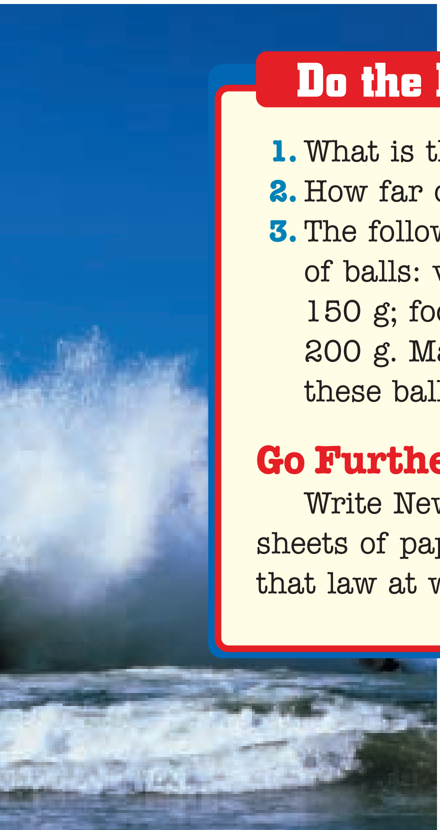
Space shuttle

...The force exerted by the space shuttle's solid rocket booster engines

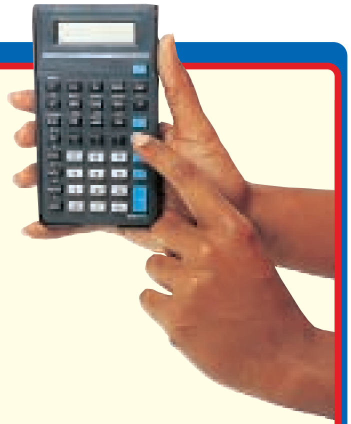
when lifting off from Earth equals the force exerted by the engines of 35 jumbo jets. To escape Earth's gravity, a spacecraft must reach a speed through the atmosphere of more than 40,320 km/h. This is about 455 times faster than a typical highway speed limit of 88.5 km/h.

747 jumbo jet

...The force needed to stop a jumbo jet is equal to the frictional force applied by 1 million automobile brakes. Even so, the airplane has to travel a distance of almost 1 km on the ground before it stops.



Do the Math



1. What is the distance from New York to Los Angeles?
2. How far does the Sun travel in 5 min?
3. The following is a list of the masses of several types of balls: volleyball, 280 g; tennis ball, 60 g; baseball, 150 g; football, 425 g; basketball, 650 g; and softball, 200 g. Make a bar graph that compares the masses of these balls.

Go Further

Write Newton's first, second, and third laws of motion on three separate sheets of paper. Under each, write a paragraph or make a sketch that shows that law at work in some common situation.

Chapter 3 Study Guide

Reviewing Main Ideas

Section 1 Newton's Second Law

1. Newton's second law of motion states that a net force causes an object to accelerate in the direction of the net force, with an acceleration equal to the net force divided by the mass.

2. Friction is caused by the microwelds that develop between the microscopic bumps on two surfaces. The three types of friction are static, sliding, and rolling. *What type of friction is at work in this picture?*

3. All objects are attracted to Earth with the same acceleration. Air resistance exerts an upward force on objects falling through the atmosphere.

Section 2 Gravity

1. Gravity is the force of attraction that exists between any two objects having mass. The size of the gravitational force is determined by the mass of the objects and their distance from each other.

2. Projectiles have a horizontal and a vertical motion that makes them travel in a curved path. Circular motion is caused by a centripetal, or center-seeking force. *What exerts the center-seeking force in the photo?*

3. Weight is the measure of the gravitational force exerted on an object by Earth. Weight is expressed in newtons, N. You use the following equation to calculate weight

$$W = m \times 9.8 \text{ m/s}^2$$

where m is the mass of the object.

Section 3 The Third Law of Motion

1. Newton's third law of motion states that for every action there is an equal and opposite reaction.

2. The momentum of an object can be calculated by the equation $p = mv$. *If the objects in this photo are moving, which probably has the greatest momentum?*

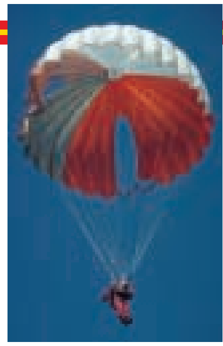
3. When two objects collide, momentum can be conserved. Some of the momentum from one object is transferred to the other.

After You Read

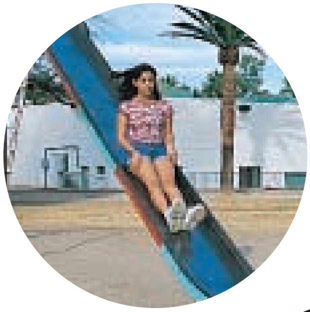
FOLDABLES Reading & Study Skills

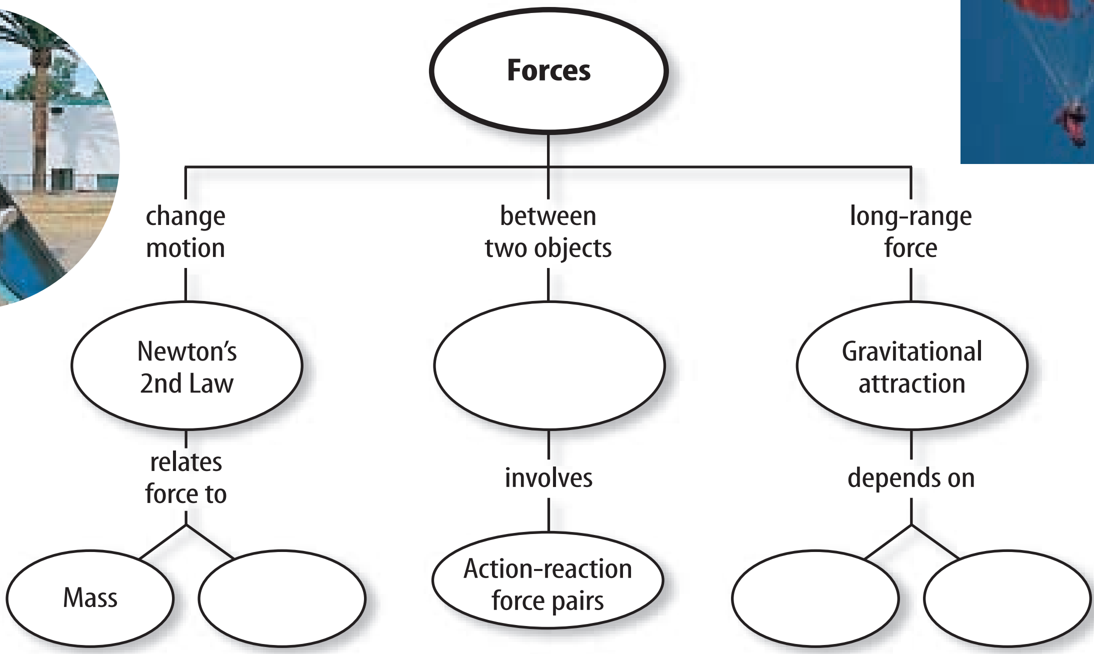
Use the information on your Foldable to compare and contrast the types of friction. Write similarities and differences on the back of your Foldable.

Visualizing Main Ideas



Complete the following concept map on forces.





Vocabulary Review

Vocabulary Words

a. centripetal acceleration
b. centripetal force
c. friction
d. law of gravitation
e. momentum
f. Newton's second law of motion
g. Newton's third law of motion
h. weight

Study Tip

THE PRINCETON REVIEW

Make a note of anything you can't understand so that you'll remember to ask your teacher about it.

Using Vocabulary

Using the vocabulary words list, replace the underlined words with the correct words.

1. The microwelds that form between the surfaces of two objects sometimes make objects hard to move.
2. The Moon's acceleration toward the center of its circular path is caused by Earth's gravity.
3. For every action, there is an equal and opposite reaction.
4. The force of gravity exerted on an object is different on different planets.
5. The combined mass and velocity of the runaway train made it dangerous.
6. The acceleration of an object equals the net force divided by the mass.

Chapter 3 Assessment

Checking Concepts

Choose the word or phrase that best answers the question.

1. What will happen to an object when a net force acts on it?
   A) fall **C)** accelerate
   B) stop **D)** go in a circle

2. Which is Newton's second law?
   A) $F = 1/2ma^2$ **C)** $p = mv$
   B) $F = 2\ ma$ **D)** $a = F/m$

3. What is the force of gravity on an object known as?
   A) centripetal force **C)** momentum
   B) friction **D)** weight

4. Which of the following is NOT a type of friction?
   A) static **C)** centripetal
   B) sliding **D)** rolling

5. What's true about an object falling toward Earth?
   A) It falls faster the heavier it is.
   B) It falls faster the lighter it is.
   C) Earth pulls on it, and it pulls on Earth.
   D) It has no weight.

6. Why do projectiles follow a curved path?
   A) They have a horizontal and a vertical motion.
   B) They have centripetal force.
   C) They have momentum.
   D) They have inertia.

7. What is the product of mass and velocity known as?
   A) gravity **C)** friction
   B) momentum **D)** weight

8. Which body exerts the weakest gravitational force on Earth?
   A) the Moon **C)** Pluto
   B) Mars **D)** Venus

9. When a leaf falls, what force opposes gravity?
   A) air resistance **C)** friction
   B) terminal velocity **D)** weight

10. In circular motion, the centripetal force is in what direction?
    A) forward **C)** toward the center
    B) backward **D)** toward the side

Thinking Critically

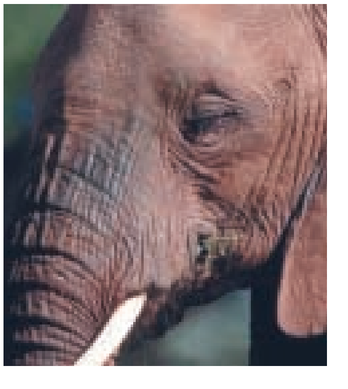
11. What is the weight on Earth of a person with a mass of 65 kg?

12. Some people put chains on their tires in the winter. Why?

13. List some ways an astronaut could keep her supplies from floating away from her while she is in orbit around Earth.

14. As you in-line skate around the block, what action and reaction forces keep you moving?

15. Which one of the following would have the most momentum—a charging elephant, a jumbo jet sitting on the runway, or a baseball traveling at 100 km/h? Explain.



Developing Skills

16. **Classifying** Classify the following as examples of static, sliding, or rolling friction: sledding down a hill, sitting in a chair, pushing a grocery cart, standing on a steep slope, and rowing a boat.

17. Drawing Conclusions A race car is moving in a circle at a constant speed around a track. Does a centripetal foce act on the car?

18. Recognizing Cause and Effect Suppose you stand on a scale next to a sink. What happens to the reading on the scale if you push down on the sink?

19. Interpreting Data The following table contains data about four objects that were dropped to Earth at the same time.

a. Which object fell fastest? Slowest?
b. Which object has the greatest weight?
c. Is air resistance stronger on A or B?
d. Why are the times different?

Time of Fall for Dropped Objects

Object	Mass (g)	Time of Fall (s)
A	5.0	2.0
B	5.0	1.0
C	30.0	0.5
D	35.0	1.5

Performance Assessment

20. Poem Write a poem about a falling leaf. Include the terms *gravity, free fall, air resistance,* and *terminal velocity.*

21. Oral Presentation Prepare a presentation to explain Newton's third law of motion to a group of first-grade students.

Technology

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THE PRINCETON REVIEW

Test Practice

Tiffany learned that the acceleration of a free-falling body is 9.8 m/s^2. She wanted to find out what speed a sky diver reaches after several seconds. Her calculations are shown in the table below.

Speed of a Falling Sky Diver

Time (s)	Speed (m/s)
0	0
1	9.8
2	19.6
3	29.4
4	39.2
5	?

Study the table and answer the following questions.

1. According to these data, about how fast will the speed of a falling sky diver be after 5 s?

A) 39.8 m/s
B) 44.2 m/s
C) 49.0 m/s
D) 54.0 m/s

2. Which of these causes falling sky divers to accelerate?

F) gravity
G) inertia
H) rotation of Earth on its axis
J) the tilt of Earth on its axis

3. If Tiffany extended her table, what would the sky diver's speed be after 14 s?

A) 107.8 m/s
B) 78.4 m/s
C) 147.0 m/s
D) 137.2 m/s

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