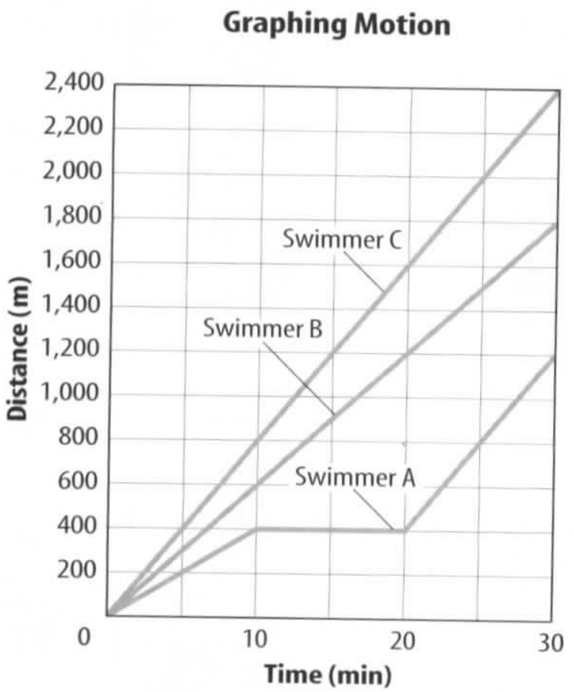
Part 2 Short Response/Grid In

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

Use the graph below to answer questions 11 and 12.



11. The graph shows the motion of three swimmers during a 30-min workout. Which swimmer had the highest average speed over the 30-min time interval?

12. Did all the swimmers swim at a constant speed? Explain how you know.

13. Why is knowing just the speed at which a hurricane is traveling toward land not enough information to be able to warn people to evacuate?

14. If the speedometer on a car indicates a constant speed, can you be sure the car is not accelerating? Explain.

15. If a car is traveling at a speed of 40 km/h and then comes to a stop in 5 s, what is its acceleration in m/s^2?

Part 3 Open Ended

Record your answers on a sheet of paper.

16. Describe three ways that your acceleration could change as you jog along a path through a park.

17. An object in motion slows down and comes to a stop. Use Newton's first law of motion to explain why this happens.

18. Give an example of a force applied to an object that does not change the object's velocity.

19. In an airplane flying at a constant speed, the force exerted by the engine pushing the airplane forward is equal to the opposite force of air resistance. Describe how these forces compare when the plane speeds up and slows down. In which direction is the net force on the airplane in each case?

20. Where would you place the location of a reference point in order to describe the motion of a space probe traveling from Earth to Jupiter? Explain your choice.

Use the table below to answer question 21.

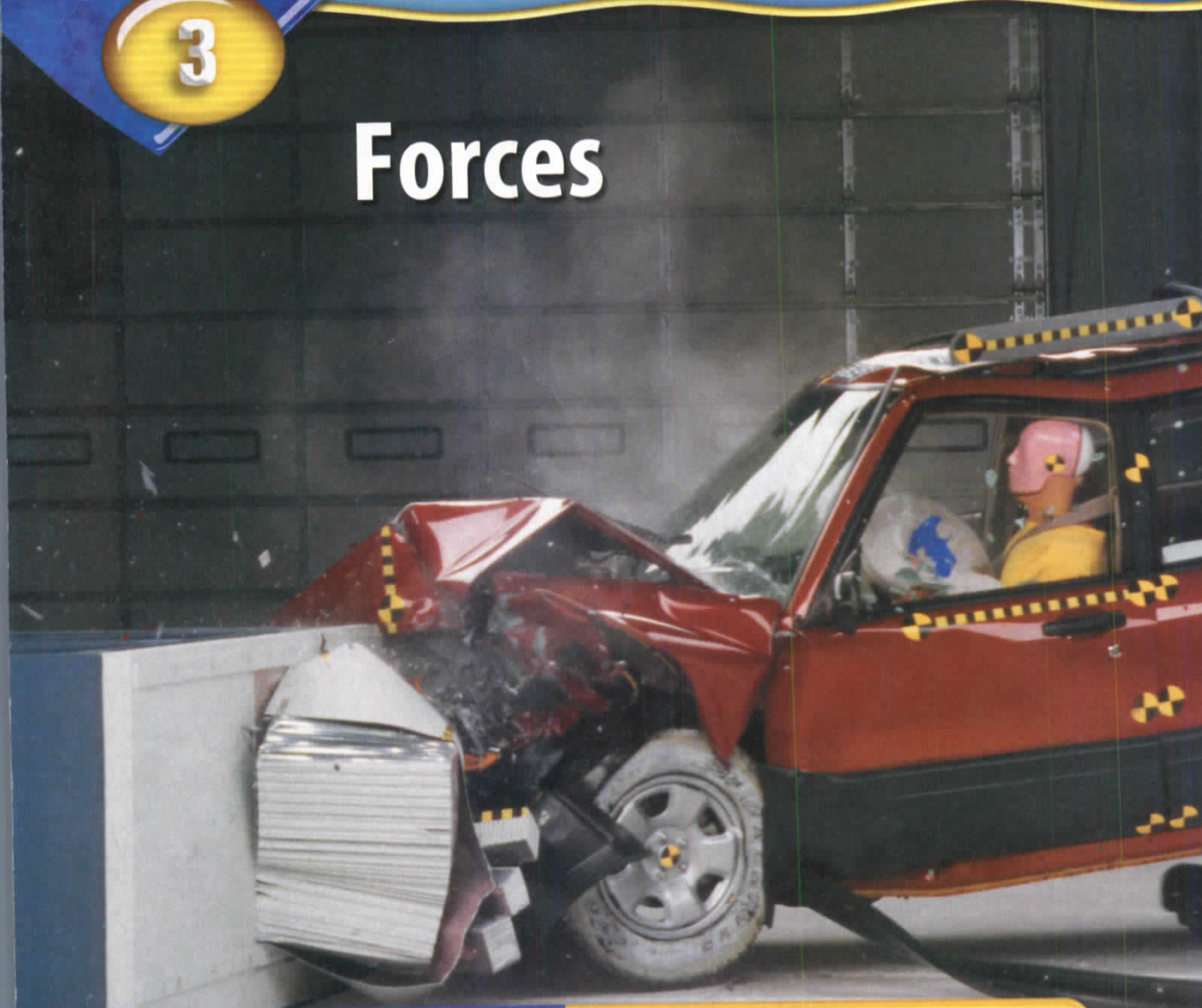
Car	Mass (kg)	Stopping distance(m)
A	1000	80
B	1250	100
C	1500	120
D	2000	160

21. What is the relationship between a car's mass and its stopping distance? How can you explain this relationship?

22. Two cars approach each other. How does the speed of one car relative to the other compare with speed of the car relative to the ground?

chapter 3

Forces



chapter preview

sections

Who's a dummy?

Crunch! This test dummy would have some explaining to do if this were a traffic accident. But in a test crash, the dummy plays an important role. The forces acting on it during a crash are measured and analyzed in order to learn how to make cars safer.

Science Journal Explain which would be a safer car—a car with a front that crumples in a crash, or one with a front that doesn't crumple.

Start-Up Activities

Launch LAB

The Force of Gravity

The force of Earth's gravity pulls all objects downward. However, objects such as rocks seem to fall faster than feathers or leaves. Do objects with more mass fall faster?

1. Measure the mass of a softball, a tennis ball, and a flat sheet of paper. Copy the data table below and record the masses.
2. Drop the softball from a height of 2.5 m and use a stopwatch to measure the time it takes for the softball to hit the floor. Record the time in your data table.
3. Repeat step 2 using the tennis ball and the flat sheet of paper. Record the times in your data table.
4. Crumple the flat sheet of paper into a ball, and measure the time for the crumpled paper to fall 2.5 m. Record the time in your data table.
5. **Think Critically** Write a paragraph comparing the times it took each item to fall 2.5 m. From your data, infer if the speed of a falling object depends on the object's mass.

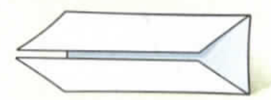
Falling Object Data

Object	Mass	Time
Softball		
Tennis ball		
Flat paper		
Crumpled paper		

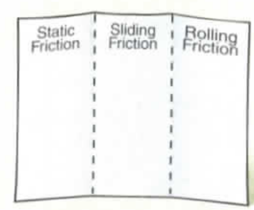
FOLDABLES Study Organizer

The Force of Friction One of the forces you encounter every day is friction. Make the following Foldable to help you compare the three types of friction—static friction, sliding friction, and rolling friction.

STEP 1 **Fold** the top of a vertical piece of paper down and the bottom up to divide the paper into thirds.



STEP 2 **Unfold and label** the rows *Static Friction, Sliding Friction,* and *Rolling Friction.*



Read and Write As you read, write the definition and give examples of each type of friction.

Science Online — Preview this chapter's content and activities at gpscience.com

section 1

Newton's Second Law

Reading Guide

What You'll Learn

- **Define** Newton's second law of motion.
- **Apply** Newton's second law of motion.
- **Describe** the three different types of friction.
- **Observe** the effects of air resistance on falling objects.

Why It's Important

Newton's second law explains how forces cause the motion of objects to change.

Review Vocabulary

net force: the combination of all forces acting on an object

New Vocabulary

- Newton's second law of motion
- friction
- static friction
- sliding friction
- air resistance

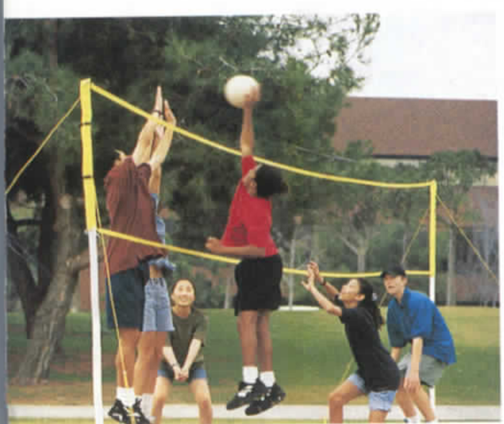
Force, Mass, and Acceleration

The previous chapter discussed Newton's first law of motion which states that the motion of an object changes only if an unbalanced force acts on the object. Newton's second law of motion describes how the forces exerted on an object, like the volleyball in **Figure 1,** its mass, and its acceleration are related.

Force and Acceleration What's different about throwing a ball horizontally as hard as you can and tossing it gently? When you throw hard, you exert a much greater force on the ball. 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.

Mass and Acceleration 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. A 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 takes the same amount of time to throw both balls, the softball would have less acceleration. The acceleration of an object depends on its mass as well as the force exerted on it. Force, mass, and acceleration are related.

Figure 1 A volleyball's motion changes when an unbalanced force acts on it.



Newton's Second Law

Newton's second law of motion states that the acceleration of an object is in the same direction as the net force on the object, and that the acceleration can be calculated from the following equation:

Newton's Second Law of Motion

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

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

Science Online

Topic: Motion in Sports

Visit gpscience.com for Web links to information about methods used to analyze the motions of athletes.

Activity Choose a sport and write a report on how analyzing the motions involved in the sport can improve performance and reduce injuries.

Applying Math — Solve a Simple Equation

THE ACCELERATION OF A SLED You push a friend on a sled. Your friend and the sled together have a mass of 70 kg. If the net force on the sled is 35 N, what is the sled's acceleration?

IDENTIFY known values and the unknown value

Identify the known values:

The net force on the sled is 35 N → means → $F_{net} = 35$ N

Your friend and the sled together have a mass of 70 kg → means → $m = 70$ kg

Identify the unknown value:

What is the sled's acceleration? → means → $a = ?$ m/s²

SOLVE the problem

Substitute the known values $F_{net} = 35$ N and $m = 70$ kg into the equation for Newton's second law of motion:

$$a = \frac{F_{net}}{m} = \frac{35\text{ N}}{70\text{ kg}} = 0.5\,\frac{\text{N}}{\text{kg}} = 0.5\,\frac{\cancel{\text{kg}}\,\text{m}}{\text{s}^2} \times \frac{1}{\cancel{\text{kg}}} = 0.5\text{ m/s}^2$$

CHECK the answer

Does your answer seem reasonable? Check your answer by multiplying the acceleration you calculated by the mass given in the problem. The result should be the net force given in the problem.

Practice Problems

1. If the mass of a helicopter is 4,500 kg, and the net force on it is 18,000 N, what is the helicopter's acceleration?
2. What is the net force on a dragster with a mass of 900 kg if its acceleration is 32.0 m/s²?
3. A car is being pulled by a tow truck. What is the car's mass if the net force on the car is 3,000 N and it has an acceleration of 2.0 m/s²?

For more practice problems go to page 834, and visit gpscience.com/extra_problems.

Figure 2 The tennis racket exerts a force on the ball that causes it to accelerate.

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

Calculating Net Force with the Second Law Newton's second law also can be used to calculate the net force if mass and acceleration are known. To do this, the equation for Newton's second law must be solved for the net force, *F*. To solve for the net force, multiply both sides of the above equation by the mass:

$$\cancel{m} \times \frac{F_{net}}{\cancel{m}} = ma$$

The mass, *m*, on the left side cancels, giving the equation:

$$F_{net} = ma$$

For example, when the tennis player in **Figure 2** hits a ball, the ball might be in contact with the racket for only a few thousandths of a second. Because the ball's velocity changes over such a short period of time, the ball's acceleration could be as high as 5,000 m/s^2. The ball's mass is 0.06 kg, so the net force exerted on the ball would be:

$$F_{net} = ma = (0.06 \text{ kg})\ (5{,}000 \text{ m/s}^2) = 300 \text{ kg m/s}^2 = 300 \text{ N}$$

Friction

Suppose you give a skateboard a push with your hand. According to Newton's first law of motion, if the net force acting on a moving object is zero, it will continue to move in a straight line with constant speed. Does the skateboard keep moving with constant speed after it leaves your hand?

You know the answer. The skate board slows down and finally stops. Recall that when an object slows down it is accelerating. By Newton's second law, if the skateboard is accelerating, there must be a net force acting on it.

The force that slows the skateboard and brings it to a stop is friction. **Friction** is the force that opposes the sliding motion of 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 *What does the force of friction between two objects in contact depend on?*

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 are in contact, welding or sticking occurs where the bumps touch each other. These microwelds are the source of friction.

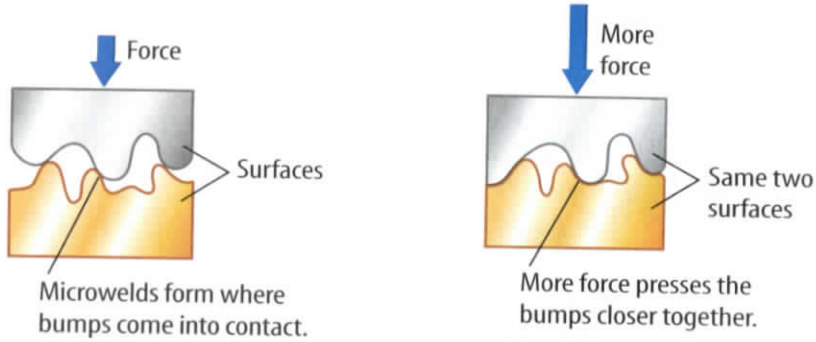


Figure 4 Friction is due to microwelds formed between two surfaces. The larger the force pushing the two surfaces together is, the stronger the microwelds will be.
Explain *how the area of contact between the surfaces changes when they are pushed together.*

Sticking Together The larger 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 move one surface over the other, a force must be applied to break the microwelds.

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 frictional force that prevents two surfaces from sliding past each other. In this case, your push is not large enough to break the microwelds, and the box does not move.

Mini LAB

Comparing Friction

Procedure

1. Place an **ice cube,** a **rock,** an **eraser,** a **wood block,** and a 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 of the raised end of the tray at which each object slides to the other end. 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 is equal to the applied force.
Infer *the net force on the box.*

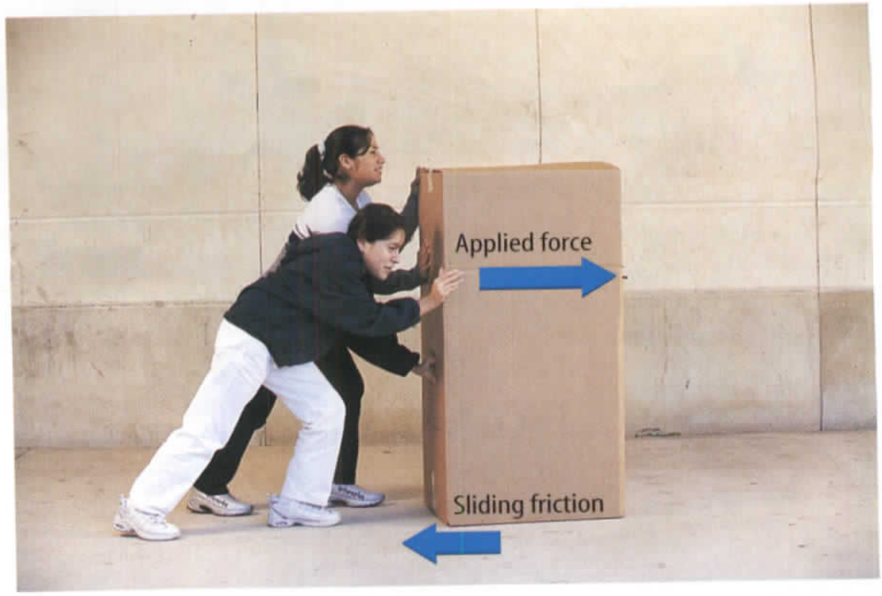


Figure 6 Sliding friction acts in the direction opposite the motion of the sliding box.

Sliding Friction You ask a friend to help you move the box, as in **Figure 6.** Pushing together, the box moves. Together you and your friend have exerted enough force to break the microwelds between the floor and the bottom of the box. But if you stop pushing, the box quickly comes to a stop. This is because 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 causes sliding friction?*

Rolling Friction You may have watched a car stuck in snow, ice, or mud spin its wheels. The driver steps on the gas, but the wheels just spin without the car moving. To make the car move, sand or gravel may be spread under the wheels. When a wheel is spinning there is sliding friction between the wheels and surface. Spreading sand or gravel on the surface increases the sliding friction until the wheel stops slipping and begins rolling.

As a wheel rolls over a surface, the wheel digs into the surface, causing both the wheel and the surface to be deformed. Static friction acts over the deformed area where the wheel and surface are in contact, producing a frictional force called rolling friction. Rolling friction is the frictional force between a rolling object and the surface it rolls on. Rolling friction would cause the train in **Figure 7** to slow down and come to a stop, just as sliding friction causes a sliding object to slow down and come to a stop.

Figure 7 Rolling friction between the train's wheels and the track is reduced by making both from steel. This reduces the deformation that occurs as the wheel rolls on the track.

Air Resistance

When an object falls toward Earth, it is pulled downward by the force of gravity. However, a friction-like force called **air resistance** opposes the motion of objects that move through the air. Air resistance causes objects to fall with different accelerations and different speeds. If there were no air resistance, then all objects, like the apple and the feather shown in **Figure 8,** would fall with the same acceleration.

Air resistance acts in the opposite direction to the motion of an object through air. If the object is falling downward, air resistance acts upward on the object. The size of the air resistance force also depends on the size and shape of an object. Imaging dropping two identical plastic bags. One is crumpled into a ball and the other is spread out. When the bags are dropped, the crumbled bag falls faster than the spread out-bag. The downward force of gravity on both bags is the same, but the upward force of air resistance on the crumpled bag is less. As a result, the net downward force on the crumpled bag is greater, as shown in **Figure 9.**

The amount of air resistance on an object depends on the speed, size, and shape of the object. Air resistance, not the object's mass, is why feathers, leaves, and pieces of paper fall more slowly than pennies, acorns, and apples.

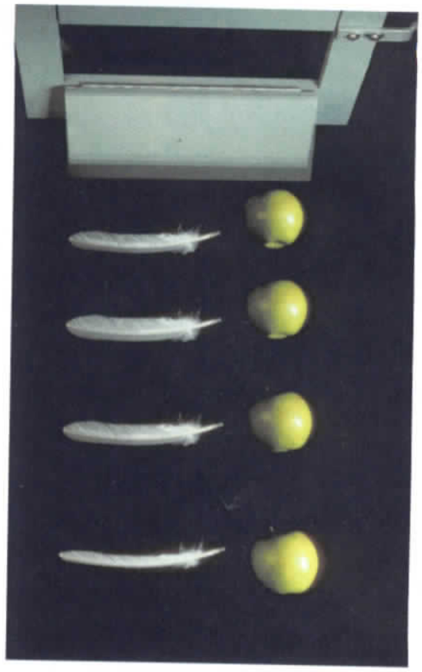


Figure 8 This photograph shows an apple and feather falling in a vacuum. The photograph was taken using a strobe light that flashes on and off at a steady rate. Because there is no air resistance in a vacuum, the feather and the apple fall with the same acceleration.

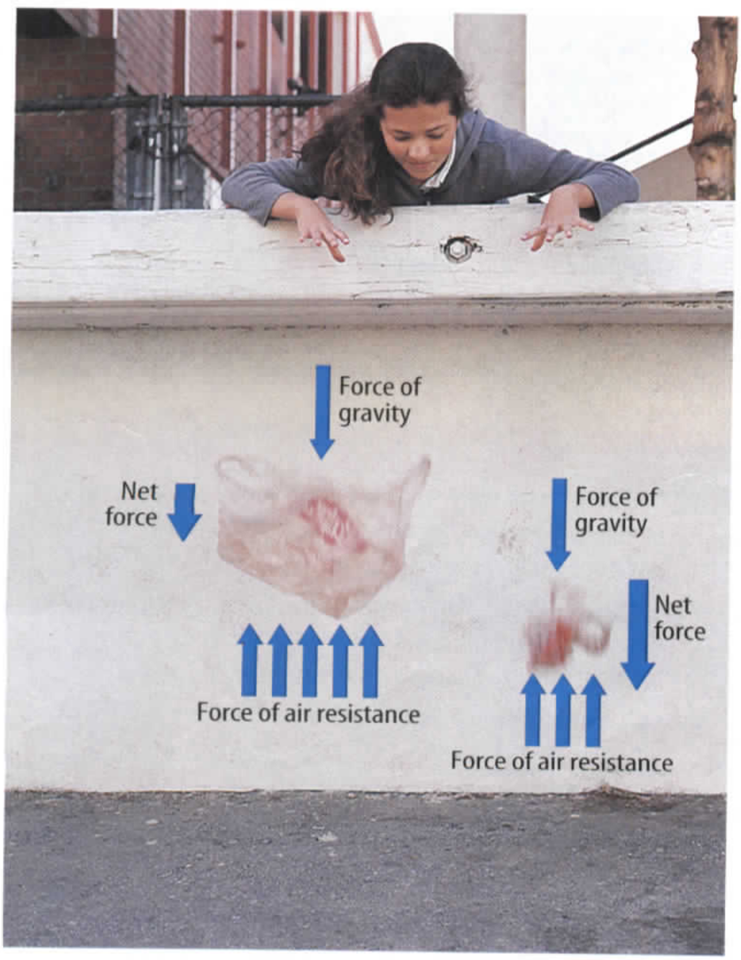


Figure 9 Because of its greater surface area, the bag on the left has more air resistance acting on it as it falls.

Figure 10 The force of air resistance on an open parachute balances the force of gravity on the sky diver when the parachute is falling slowly.

Terminal Velocity As an object falls, the downward force of gravity causes the object to accelerate. For example, after falling 2,000 m, without the effects of air resistance the sky diver's speed would be almost 200 m/s, or over 700 km/h.

However, as an object falls faster, the upward force of air resistance increases. This causes the net force on a sky diver to decrease as the sky diver falls. Finally, the upward air resistance force becomes large enough to balance the downward force of gravity. This means the net force on the object is zero. Then the acceleration of the object is also zero, and the object falls with a constant speed called the terminal velocity. The terminal velocity is the highest speed a falling object will reach.

The terminal velocity depends on the size, shape, and mass of a falling object. The air resistance force on an open parachute, like the one in **Figure 10,** is much larger than the air resistance on the sky diver with a closed parachute. With the parachute open, the terminal velocity of the sky diver becomes small enough that the sky diver can land safely.

section 1 review

Summary

Force, Mass, and Acceleration

- The greater the force on an object, the greater the object's acceleration.
- The acceleration of an object depends on its mass as well as the force exerted on it.

Newton's Second Law

- Newton's second law of motion states that the acceleration of an object is in the direction of the net force on the object, and can be calculated from this equation:

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

Friction

- Friction is the force that opposes motion between two surfaces that are touching each other.
- Friction depends on the types of surfaces and the force pressing the surfaces together.
- Friction results from the microwelds formed between surfaces that are in contact.

Air Resistance

- Air resistance is a force that acts on objects that move through the air.

Self Check

1. **State** Newton's second law of motion.
2. **Infer** why an object with a smaller mass has a larger acceleration than a larger mass if the same force acts on each.
3. **Explain** why the frictional force between two surfaces increases if the force pushing the surfaces together increases.
4. **Compare** the force of air resistance and the force of gravity on an object falling at its terminal velocity.
5. **Think Critically** Why does coating surfaces with oil reduce friction between the surfaces?

Applying Math

6. **Convert Units** show that the units N/kg can be written using only units of meters (m) and seconds (s). Is this a unit of mass, acceleration or force?
7. **Calculate Mass** You push yourself on a skateboard with a force of 30 N and accelerate at 0.5 m/s^2. Find the mass of the skateboard if your mass is 58 kg.
8. **Calculate Sliding Friction** You push a 2-kg book with a force of 5 N. Find the force of sliding friction on the book if it has an acceleration of 1.0 m/s^2.

Science Online gpscience.com/self_check_quiz

section 2

Gravity

Reading Guide

What You'll Learn

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

Why It's Important

There is a gravitational force between you and every other object in the universe.

Review Vocabulary

acceleration: the rate of change of velocity which occurs when an object changes speed or direction

New Vocabulary

- gravity
- weight
- centripetal acceleration
- centripetal force

What is gravity?

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.

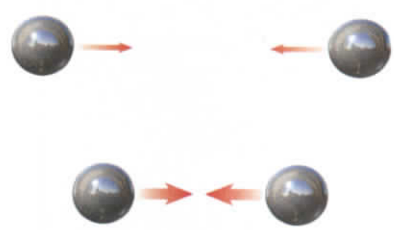
Anything that has mass is attracted by the force of gravity. **Gravity** is an attractive force between any two objects that depends on the masses of the objects and the distance between them. This force increases as the mass of either object increases, or as the objects move closer, as shown in **Figure 11.**

You can't feel any gravitational attraction between you and this book because the force is weak. Only Earth is both 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 two 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.

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

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



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

Science Online

Topic: Gravity on Other Planets

Visit gpscience.com Web links to information about the gravitational acceleration near the surface of different planets in the solar system.

Activity Make a graph with the gravitational acceleration on the *y*-axis, and the planet's mass on the *x*-axis. Infer from your graph how the gravitational acceleration depends on a planet's mass.

The Law of Universal Gravitation

For thousands of years people everywhere have observed the stars and the planets in the night sky. Gradually, data were collected on the motions of the planets by a number of observers. Isaac Newton used some of these data to formulate the law of universal gravitation, which he published in 1687. This law can be written as the following equation.

The Law of Universal Gravitation

$$\text{gravitational force} = (\text{constant}) \times \frac{(\text{mass 1}) \times (\text{mass 2})}{(\text{distance})^2}$$

$$F = G\frac{m_1 m_2}{d^2}$$

In this equation G is a constant called the universal gravitational constant, and d is the distance between the two masses, m_1 and m_2. The law of universal gravitation enables the force of gravity to be calculated between any two objects if their masses and the distance between them are known.

The Range of Gravity According to the law of universal gravitation, the gravitational force between two masses decreases rapidly as the distance between the masses increases. For example, if the distance between two objects increases from 1 m to 2 m, the gravitational force between them becomes one fourth as large. If the distance increases from 1 m to 10 m, the gravitational force between the objects is one hundredth as large.

However, no matter how far apart two objects are, the gravitational force between them never completely goes to zero. Because the gravitational force between two objects never disappears, gravity is called a long-range force.

INTEGRATE Astronomy

Finding Other Planets Earth's motion around the Sun is affected by the gravitational pulls of the other planets in the solar system. In the same way, the motion of every planet in the solar system is affected by the gravitational pulls of all the other planets.

In the 1840s the most distant planet known was Uranus. The motion of Uranus calculated from the law of universal gravitation disagreed slightly with its observed motion. Some astronomers suggested that there must be an undiscovered planet affecting the motion of Uranus. Using the law of universal gravitation and Newton's laws of motion, two astronomers independently calculated the orbit of this planet. As a result of these calculations, the planet Neptune, shown in **Figure 12,** was found in 1846.

Figure 12 The location of the planet Neptune in the night sky was correctly predicted using Newton's laws of motion and the law of universal gravitation.

Earth's Gravitational Acceleration

If you dropped a bowling ball and a marble at the same time, which would hit the ground first? Suppose the effects of air resistance are small enough to be ignored. When all forces except gravity acting on an a falling object can be ignored, the object is said to be in free fall. Then all objects near Earth's surface would fall with the same acceleration, just like the two balls in **Figure 13.**

Close to Earth's surface, the acceleration of a falling object in free fall is about 9.8 m/s^2. This acceleration is given the symbol g and is sometimes called the acceleration of gravity. By Newton's second law of motion, the force of Earth's gravity on a falling object is the object's mass times the acceleration of gravity. This can be expressed by the equation:

Force of Earth's Gravity

force of gravity (N) = mass (kg) × acceleration of gravity (m/s^2)

$$F = mg$$

For example, the gravitational force on a sky diver with a mass of 60 kg would be

$$F = mg = (60 \text{ kg})\ (9.8 \text{ m/s}^2) = 588 \text{ N}$$

Weight Even if you are not falling, the force of Earth's gravity still is pulling you downward. If you are standing on a floor, the net force on you is zero. The force of Earth's gravity pulls you downward, but the floor exerts an upward force on you that balances gravity's downward pull.

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.** Because the weight of an object on Earth is equal to the force of Earth's gravity on the object, weight can be calculated from this equation:

Weight Equation

weight (N) = mass (kg) × acceleration of gravity (m/s^2)

$$W = mg$$

On Earth where g equals 9.8 m/s^2, a cassette tape weighs about 0.5 N; a backpack full of books could weigh 100 N, and a jumbo jet weighs about 3.4 million N. A sky diver with a mass of 60 kg has a weight of 588 N. Under what circumstances would the net force on the sky diver equal the sky diver's weight?

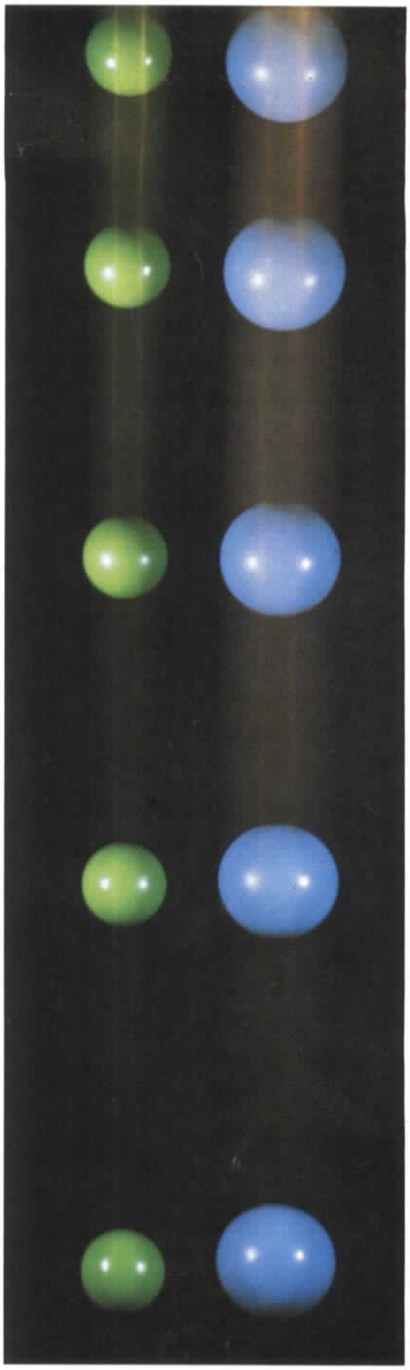


Figure 13 Time-lapse photography shows that two balls of different masses fall at the same rate.

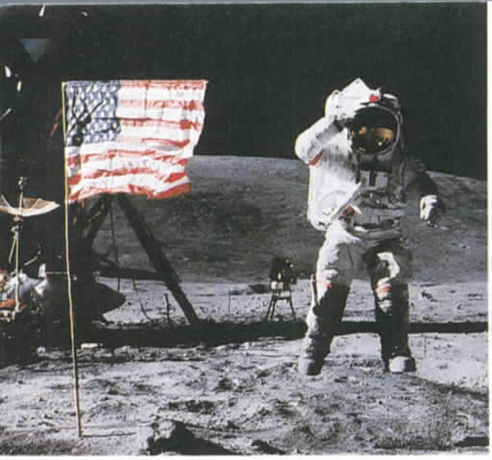


Figure 14 On the Moon, the gravitational force on the astronaut is less than it is on Earth. As a result, the astronaut can take longer steps and jump higher than on Earth.

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, according to the weight equation on the previous page, weight and mass are related. Weight increases as mass increases.

The weight of an object usually is the gravitational force between the object and Earth. But the weight of an object can change, depending on the gravitational force on the object. For example, the acceleration of gravity on the Moon is 1.6 m/s^2, about one sixth as large as Earth's gravitational acceleration. As a result, a person, like the astronaut in **Figure 14,** would weigh only about one sixth as much on the Moon as on Earth. **Table 1** shows how various weights on Earth would be different on the Moon and some of the planets.

Reading Check *How are weight and mass related?*

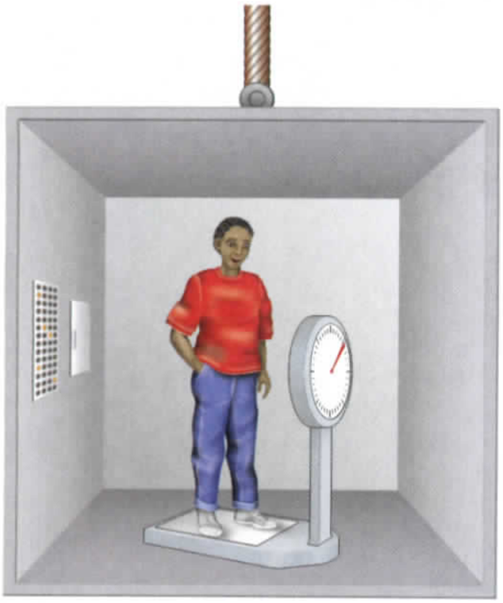
Weightlessness and Free Fall

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

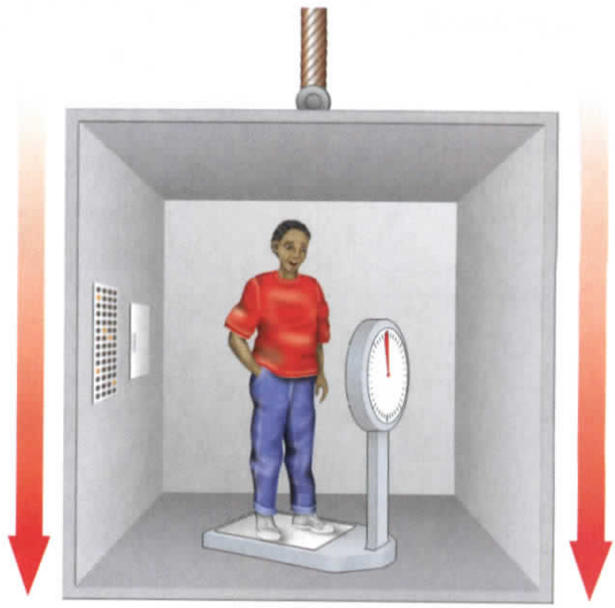
However, for a typical mission, the shuttle orbits Earth at an altitude of about 400 km. According the law of universal gravitation, at 400-km altitude the force of Earth's gravity is about 90 percent as strong as it is at Earth's surface. So an astronaut with a mass of 80 kg still would weigh about 700 N in orbit, compared with a weight of about 780 N at Earth's surface.

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
700	119	630	266	1,778	812
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 in free fall, the scale would show a zero weight.

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

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. 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.

A space shuttle in orbit is in free fall, but it is falling around Earth, rather than straight downward. Everything in the orbiting space shuttle is falling around Earth at the same rate, in the same way you and the scale were falling in the elevator. Objects in the shuttle seem to be floating because they are all falling with the same acceleration.

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 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. Earth's gravity causes projectiles to follow a curved path.

INTEGRATE Earth Science

Gravity and Earth's Atmosphere 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, 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.

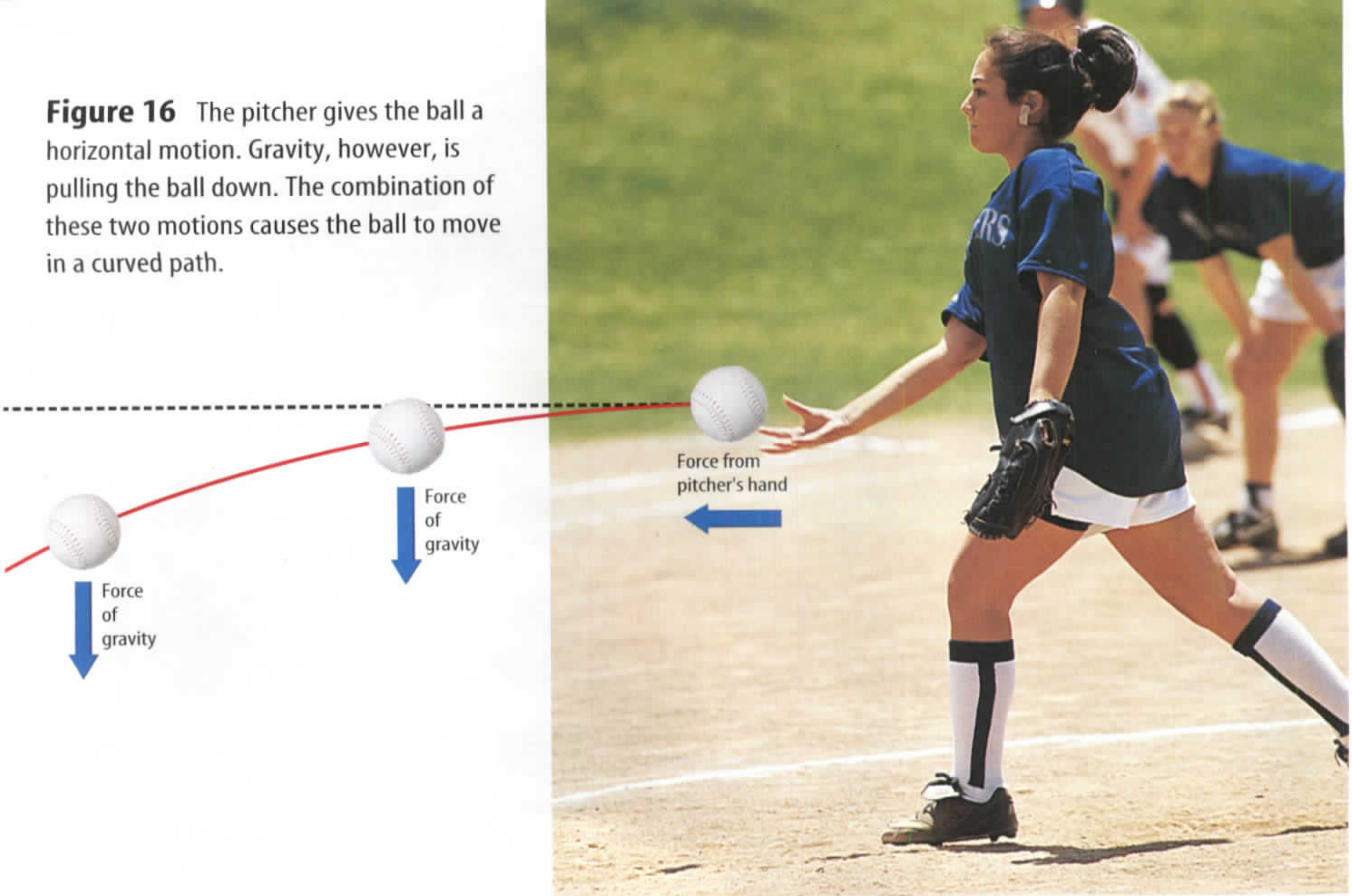
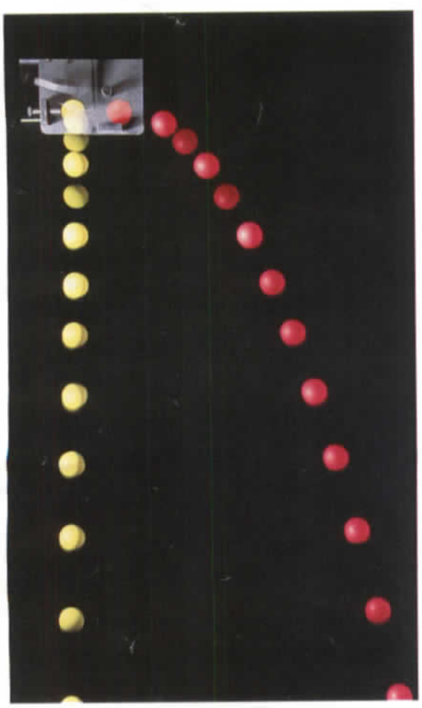


Figure 17 Multiflash photography shows that each ball has the same acceleration downward, whether it's thrown or dropped.



Horizontal and Vertical Motions When you throw a ball, like the pitcher in **Figure 16,** the force exerted by your hand pushes the ball forward. This force gives the ball horizontal motion. After you let go of the ball, no force accelerates it forward, so its horizontal velocity is constant, if you ignore air resistance.

However, when you let go of the ball, gravity can pull it downward, giving it vertical motion. 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.

Horizontal and Vertical Distance 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. Both balls in **Figure 17** travel the same vertical distance in the same amount of time. However, the ball thrown horizontally travels a greater horizontal distance than the ball that is dropped.

Centripetal Force

Look at the path the ball follows as it travels through the curved tube 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.**

According to the second law of motion, when the ball has centripetal acceleration, the direction of the net force on the ball also must be toward the center of the curved path. The net force exerted toward the center of a curved path is called a **centripetal force.** For the ball moving through the tube, the centripetal force is the force exerted by the walls of the tube on the ball.

Centripetal Force and Traction When a car rounds a curve on a highway, a centripetal force must be acting on the car to keep it moving in a curved path. This centripetal force is the frictional force, or the traction, between the tires and the road surface. If the road is slippery and the frictional force is small, the centripetal force might not be large enough to keep the car moving around the curve. Then the car will slide in a straight line. 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.

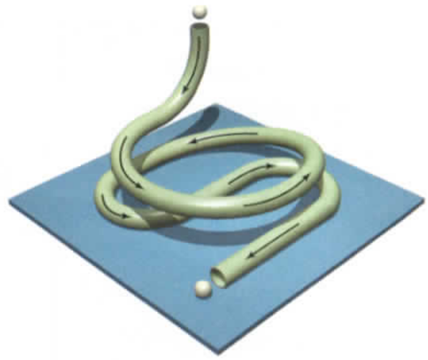


Figure 18 When the ball moves through the curved portions of the tube, it is accelerating because its velocity is changing. **Identify** *the forces acting on the ball as it falls through the tube.*

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

Mini LAB

Observing Centripetal Force

Procedure

1. Thread a **string** about 1 m long through the holes of a **plastic, slotted golf ball.**
2. Swing the ball in a vertical circle.
3. Swing the ball at different speeds and observe the motion of the ball and the tension in the string.

Analysis

1. What force does the string exert on the ball when the ball is at the top, sides, and bottom of the swing?
2. How does the tension in the string depend on the speed of the ball?

Try at Home

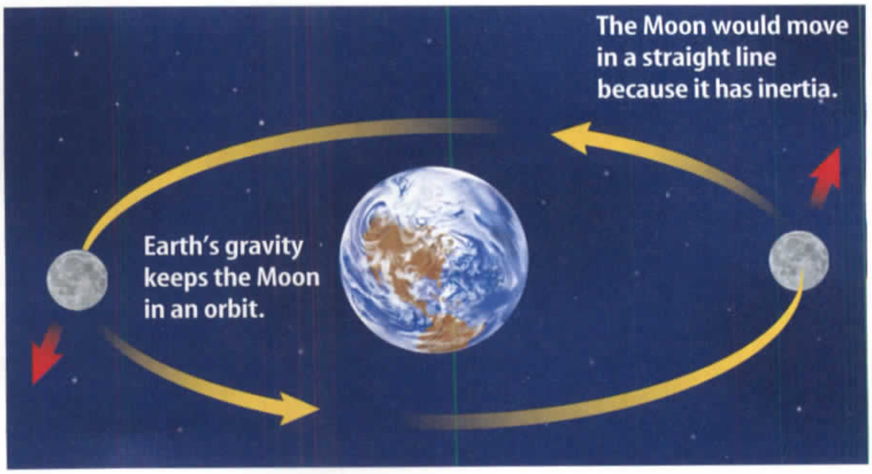


Figure 20 The Moon would move in a straight line except that Earth's gravity keeps pulling it toward Earth. This gives the Moon a nearly circular orbit.

Gravity Can Be a Centripetal Force 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 nearly circular orbit, as shown in **Figure 20.**

section 2 review

Summary

Gravity

- According to the law of universal gravitation, the gravitational force between two objects depends on the masses of the objects and the distance between them.
- The acceleration due to gravity near Earth's surface has the value 9.8 m/s^2.
- Near Earth's surface, the gravitational force on an object with mass, m, is given by:

$$F = mg$$

Weight

- The weight of an object is related to its mass according to the equation:

$$W = mg$$

- An object in orbit seems to be weightless because it is falling around Earth.

Projectile Motion and Centripetal Force

- Projectiles follow a curved path because their horizontal motion is constant, but gravity causes the vertical motion to be changing.
- The net force on an object moving in a circular path is called the centripetal force.

Self Check

1. **Describe** how the gravitational force between two objects depends on the mass of the objects and the distance between them.
2. **Distinguish** between the mass of an object and the object's weight.
3. **Explain** what causes the path of a projectile to be curved.
4. **Describe** the force that causes the planets to stay in orbit around the Sun.
5. **Think Critically** Suppose Earth's mass increased, but Earth's diameter didn't change. How would the acceleration of gravity near Earth's surface change?

Applying Math

6. **Calculate Weight** On Earth, what is the weight of a large-screen TV that has a mass of 75 kg?
7. **Calculate Gravity on Mars** Find the acceleration of gravity on Mars if a person with a mass of 60.0 kg weighs 222 N on Mars.
8. **Calculate Force** Find the force exerted by a rope on a 10-kg mass that is hanging from the rope.

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section 3

The Third Law of Motion

Reading Guide

What You'll Learn
- **State** Newton's third law of motion.
- **Identify** action and reaction forces.
- **Calculate** momentum.
- **Recognize** when momentum is conserved.

Why It's Important

The third law of motion explains how you affect Earth when you walk, and how Earth affects you.

Review Vocabulary

velocity: describes the speed and direction of a moving object

New Vocabulary
- Newton's third law of motion
- momentum

Newton's Third Law

Push against a wall and what happens? If the wall is sturdy enough, usually nothing happens. If you pushed against a wall while wearing roller skates, you would go rolling 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 strength 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 force occurs at the same time. When you jump on a trampoline, for example, you exert a downward force on the trampoline. Simultaneously, the trampoline 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.

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.

Action and Reaction Forces Don't Cancel 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? According to the third law of motion, action and reaction forces act 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. As the swimmer moves forward in the water, how does she make the water move?

Reading Check *Why don't action and reaction forces cancel?*

Rocket Propulsion Suppose you are 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 were used to travel to the Moon.

INTEGRATE Health

Space 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?

Figure 22 If more gas is ejected from the rocket engine, or expelled at a greater velocity, the rocket engine will exert a larger force on the car.

NATIONAL GEOGRAPHIC VISUALIZING ROCKET MOTION

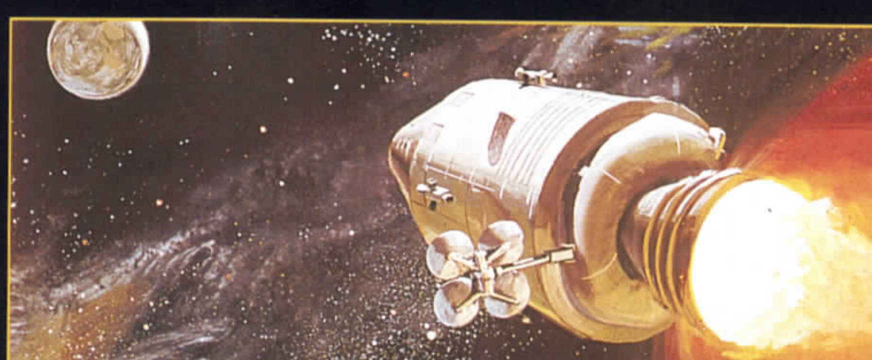
Figure 23

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.**

Momentum

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 the following equation:

Momentum Equation

momentum (kg m/s) = **mass** (kg) × **velocity** (m/s)

$$p = mv$$

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

Applying Math — Solve a Simple Equation

THE MOMENTUM OF A SPRINTER At the end of a race, a sprinter with a mass of 80 kg has a speed of 10 m/s. What is the sprinter's momentum?

IDENTIFY known values and the unknown value

Identify the known values:

a sprinter with a mass of 80 kg → means → $m = 80$ kg

has a speed of 10 m/s → means → $v = 10$ m/s

Identify the unknown value:

What is the sprinter's momentum? → means → $p = ?$ kg•m/s

SOLVE the problem

Substitute the known values $m = 80$ kg and $v = 10$ m/s into the momentum equation:

$$p = mv = (80\ \text{kg})\ (10\ \text{m/s}) = 800\ \text{kg•m/s}$$

CHECK the answer

Does your answer seem reasonable? Check your answer by dividing the momentum you calculated by the mass given in the problem. The result should be the speed given in the problem.

Practice Problems

1. What is the momentum of a car with a mass of 1,300 kg traveling at a speed of 28 m/s?
2. A baseball thrown by a pitcher has a momentum of 6.0 kg•m/s. If the baseball's mass is 0.15 kg, what is the baseball's speed?
3. What is the mass of a person walking at a speed of 0.8 m/s if their momentum is 52.0 kg•m/s?

For more practice problems go to page 834, and visit gpscience.com/extra_problems.

Force and Changing Momentum If you catch a 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. 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. The force you exert on the ball equals the force the ball exerts on your hand. This force depends on the mass and initial velocity of the ball, and how long it takes the ball to stop.

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 24.**

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 momentum the group of balls gained is equal to the momentum that the cue ball lost. The total momentum of all the balls just before and after the collision would be the same. 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 24 Momentum is transferred in collisions. **A** Before the collision, only the cue ball has momentum. **B** When the cue ball strikes the other balls, it transfers some of its momentum to them.

A B

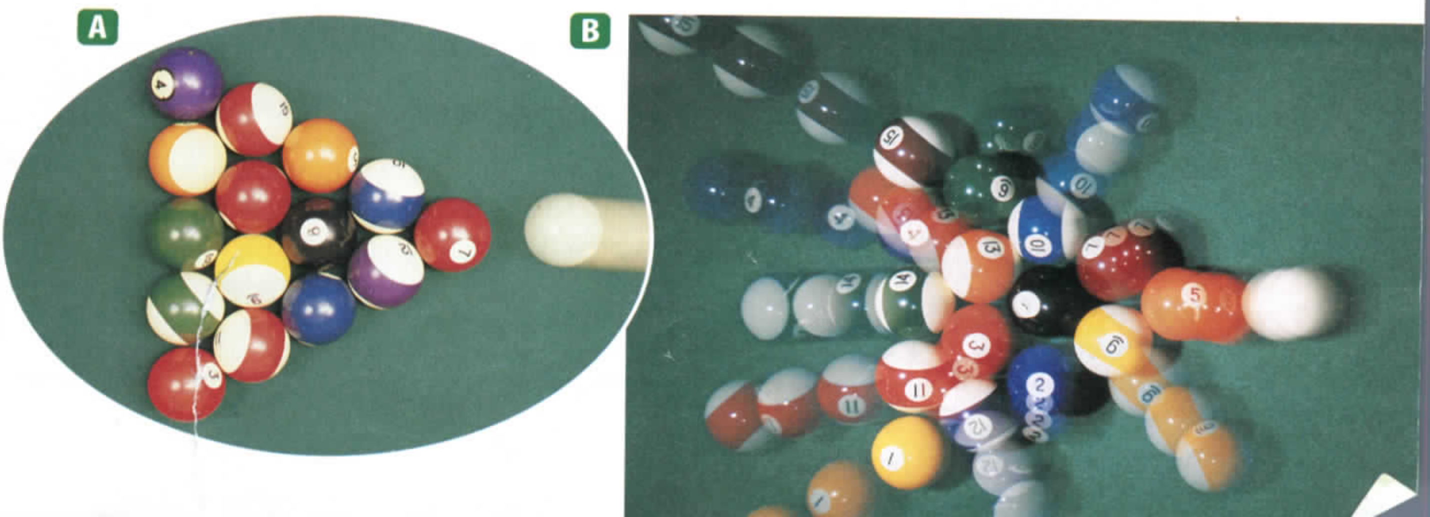
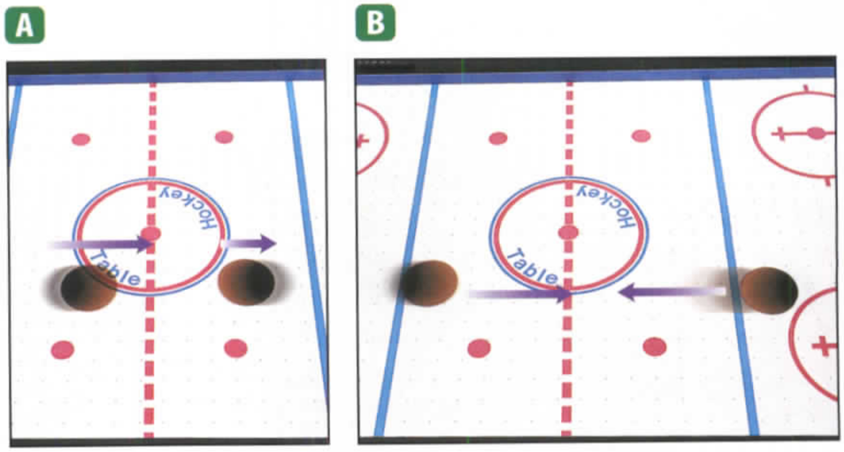


Figure 25 The results of a collision depend on the momentum of each object. **A** When the first puck hits the second puck from behind, it gives the second puck momentum in the same direction. **B** If the pucks are speeding toward each other with the same speed, the total momentum is zero.
Predict *how the pucks will move after they collide.*



When Objects Collide Collisions of two air hockey pucks are shown in **Figure 25.** Suppose one of the pucks was moving in one direction and another struck it from behind. The first puck would continue to move in the same direction but more quickly. The second puck has given it more momentum in the same direction. What if two pucks of equal mass were moving toward each other with the same speed? They would have the same momentum, but in opposite directions. So the total momentum would be zero. After the pucks collide, each would reverse direction, and move with the same speed. The total momentum would be zero again.

section 3 review

Summary

Newton's Third Law

- According to Newton's third law of motion, for every action force, there is an equal and opposite reaction force.
- Action and reaction forces act on different objects.

Momentum

- The momentum of an object is the product of its mass and velocity:

$$p = mv$$

- The net force on an object can be calculated by dividing its change in momentum by the time over which the change occurs.

The Law of Conservation of Momentum

- According to the law of conservation of momentum, if objects exert forces only on each other, their total momentum is conserved.
- In a collision, momentum is transferred from one object to another.

Self Check

1. **Determine** You push against a wall with a force of 50 N. If the wall doesn't move, what is the net force on you?
2. **Explain** how a rocket can move through outer space where there is no matter for it to push on.
3. **Compare** the momentum of a 6,300-kg elephant walking 0.11 m/s and a 50-kg dolphin swimming 10.4 m/s.
4. **Describe** what happens to the momentum of two billiard balls that collide.
5. **Think Critically** A ballet director assigns slow, graceful steps to larger dancers, and quick movements to smaller dancers. Why is this plan successful?

Applying Math

6. **Calculate Momentum** What is the momentum of a 100-kg football player running at a speed of 4 m/s?
7. **Calculate Force** What is the force exerted by a catcher's glove on a 0.15-kg baseball moving at 35 m/s that is stopped in 0.02 s?

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LAB

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 a feather will not hit the ground at the same time. Air resistance slows the feather down.

Real-World Question

How does air resistance affect the acceleration of falling objects?

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.

Materials

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

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.

Effects of Air Resistance

Paper Type	Time
Flat paper	Do not write in this book.
Loosely crumpled paper	
Tightly crumpled paper	
Your paper design	

4. Crumple a sheet of paper into a loose ball and repeat step 3.
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. **Explain** why the different-shaped papers fell at different speeds.
3. **Explain** how your design caused the force of air resistance on the paper to be greater than the air resistance on the other paper shapes.

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.

LAB

The Momentum of Colliding Objects

Goals

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

Materials

meterstick
softball
racquetball
tennis ball
baseball
stopwatch
masking tape
balance

Safety Precautions

Real-World Question

Many scientists hypothesize that dinosaurs became extinct 65 million years ago when an asteroid collided with 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 have caused such damage 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. How do the mass and velocity of a moving object affect its momentum?

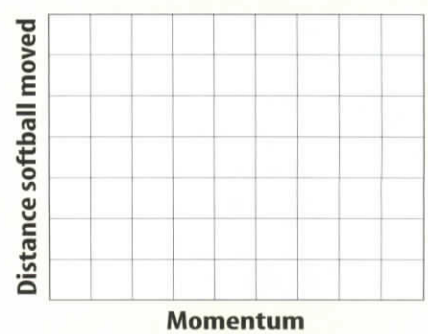
Momentum of Colliding Balls

Action	Time	Velocity	Mass	Momentum	Distance softball moved
Racquetball rolled slowly				Do not write in this book.	
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. Measure a 2-m distance on the floor and mark it 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 toward the center of the softball.
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 and record the distance the racquetball moved the softball.
7. Repeat steps 4–6, rolling the racquetball quickly.
8. Repeat steps 4–6, rolling the tennis ball slowly, then quickly.
9. Repeat steps 4–6, rolling the baseball slowly, then quickly.

Distance Softball Moved and Momentum of Colliding Ball



Analyze Your Data

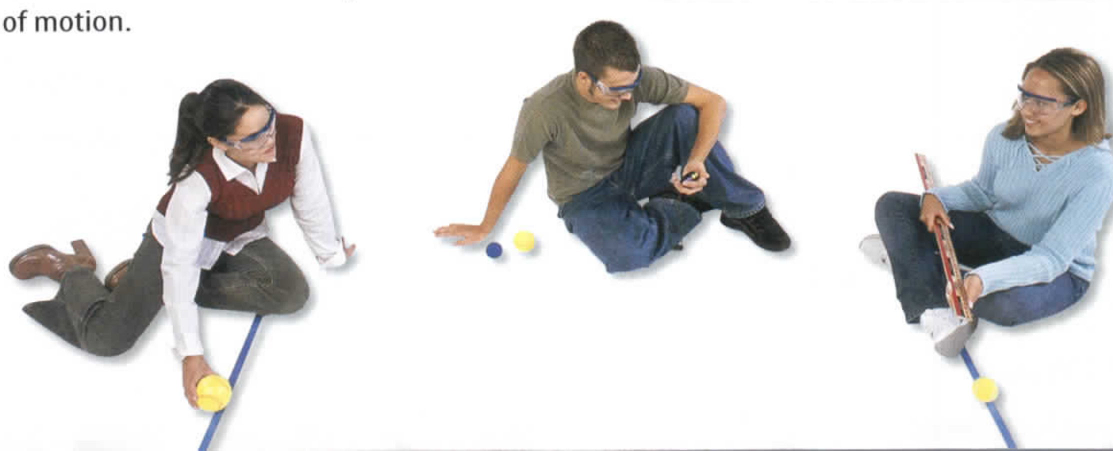
1. **Calculate** the momentum for each type of ball and action using the formula $p = mv$. Record your calculations in the data table.
2. **Graph** the relationship between the momentum of each ball and the distance the softball was moved using a graph like the one shown.

Conclude and Apply

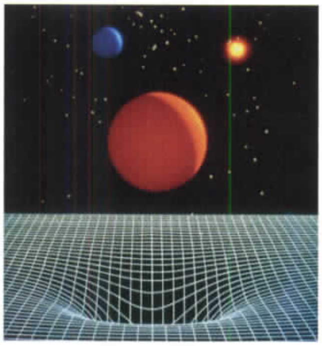
1. **Infer** from your graph how the distance the softball moves after each collision depends on the momentum of the ball that hits it.
2. **Explain** how the motion of the balls after they collide can be determined by Newton's laws of motion.

Communicating Your Data

Compare your graph with the graphs made by other students in your class. **Discuss** why the graphs might look different.



Newton and the Plague

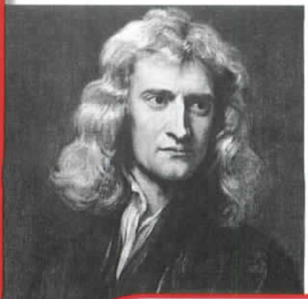


In Einstein's theory of general relativity, gravity is due to a distortion in space-time.

In 1665, the bubonic plague swept through England and other parts of Europe. Isaac Newton, then a 23-year-old university student, returned to his family's farm until Cambridge university reopened. To occupy his time, Newton made a list of 22 questions. During the next 18 months, Newton buried himself in the search for answers. And in that brief time, Newton developed calculus, the three laws of motion, and the universal law of gravitation!

The Laws of Motion

Earlier philosophers thought that force was necessary to keep an object moving. By analyzing the data collected by Galileo and others, Newton realized that forces did not cause motion. Instead, forces cause a change in motion. Newton came to understand that force and acceleration were related and that objects exert equal and opposite forces on each other. Newton's three laws of motion were able to explain how all things moved, from an apple falling from a tree to the motions of the moon and the planets, in terms of force, mass, and acceleration.



Isaac Newton was a university student when he developed the laws of motion.

What is gravity?

Using the calculus and data on the motion of the planets, Newton deduced the law of universal gravitation. This law enabled the force of gravity between any two objects to be calculated, if their masses and the distance between them were known.

Newton was able to show mathematically that the law of universal gravitation predicted that the planets' orbits should be ellipses, just as Johannes Kepler had discovered two generations earlier. The application of Newton's laws of motion and the law of universal gravitation also were able to explain phenomena such as tides, the motion of the moon and the planets, and the bulge at the Earth's equator.

A Different View of Gravity

In 1916, Albert Einstein proposed a different model for gravity called the general theory of relativity. In Einstein's model, objects create distortions in space-time, like a bowling ball dropped on a sheet. What we see as the force of gravity is the motion of an object on distorted space-time. Today, Einstein's theory is used to help explain the nature of the big bang and the structure of the universe.

Investigate Research how both Newton's law of gravitation and Einstein's general theory of relativity have been used to develop the current model of the universe.

Science Online
For more information, visit gpscience.com/time

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 and that the acceleration is given by

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

2. Friction is a force opposing the sliding motion of two surfaces in contact. Friction is caused by microwelds that form where the surfaces are in contact.

3. Air resistance opposes the motion of objects moving through the air.

Section 2 Gravity

1. Gravity is an attractive force between any two objects with mass. The gravitational force depends on the masses of the objects and the distance between them.
2. The gravitational acceleration, g, near Earth's surface equals 9.8 m/s^2. The force of gravity on an object with mass, m, is:

$$F = mg$$

3. The weight of an object near Earth's surface is:

$$W = mg$$

4. Projectiles travel in a curved path because of their horizontal motion and vertical acceleration due to gravity.
5. The centripetal force is the net force on an object in circular motion and is directed toward the center of the circular path.

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 $p = mv$.

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

FOLDABLES Use the Foldable that you made at the beginning of this chapter to help you review the different types of friction.

chapter 3 Review

Using Vocabulary

- air resistance p. 73
- centripetal acceleration p. 81
- centripetal force p. 81
- friction p. 70
- gravity p. 75
- momentum p. 86
- Newton's 2nd law of motion p. 69
- Newton's 3rd law of motion p. 83
- sliding friction p. 72
- static friction p. 71
- weight p. 77

Complete each statement using a word(s) from the vocabulary list above.

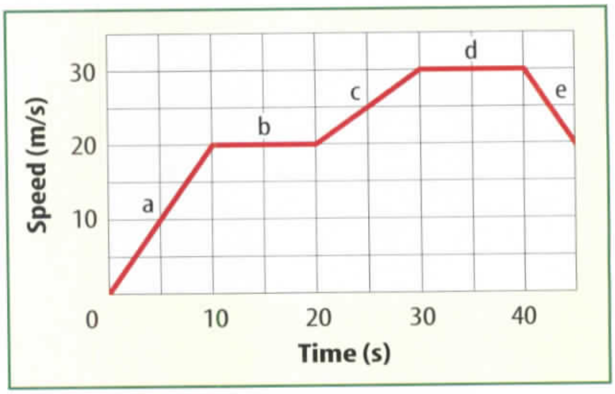
1. The way in which objects exert forces on each other is described by ________.
2. ________ prevents surfaces in contact from sliding past each other.
3. The ________ of an object is different on other planets in the solar system.
4. When an object moves in a circular path, the net force is called a(n) ________.
5. The attractive force between two objects that depends on their masses and the distance between them is ________.
6. ________ relates the net force exerted on an object to its mass and acceleration.

Checking Concepts

Choose the best answer for each question.

7. What is the gravitational force exerted on an object called?
   - **A)** centripetal force
   - **B)** friction
   - **C)** momentum
   - **D)** weight
8. Which of the following best describes why projectiles move in a curved path?
   - **A)** They have horizontal velocity and vertical acceleration.
   - **B)** They have momentum.
   - **C)** They have mass.
   - **D)** They have weight.
9. Which of the following explains why astronauts seem weightless in orbit?
   - **A)** Earth's gravity is much less in orbit.
   - **B)** The space shuttle is in free fall.
   - **C)** The gravity of Earth and the Sun cancel.
   - **D)** The centripetal force on the shuttle balances Earth's gravity.
10. Which of the following exerts the strongest gravitational force on you?
    - **A)** the Moon
    - **B)** Earth
    - **C)** the Sun
    - **D)** this book

Use the graph below to answer question 11.

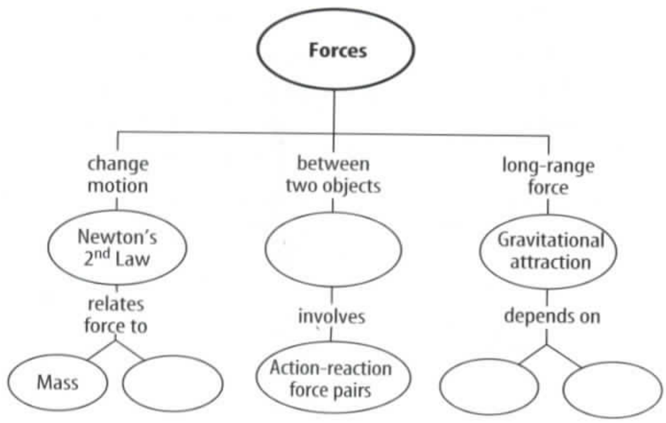


11. The graph shows the speed of a car moving in a straight line. Over which segments are the forces on the car balanced?
    - **A)** A and C
    - **B)** B and D
    - **C)** C and E
    - **D)** D only
12. Which of the following is true about an object in free fall?
    - **A)** Its acceleration depends on its mass.
    - **B)** It has no inertia.
    - **C)** It pulls on Earth, and Earth pulls on it.
    - **D)** Its momentum is constant.
13. The acceleration of an object is in the same direction as which of the following?
    - **A)** net force
    - **B)** air resistance
    - **C)** static friction
    - **D)** gravity
14. Which of the following is NOT a force?
    - **A)** weight
    - **B)** friction
    - **C)** momentum
    - **D)** air resistance

Science Online gpscience.com/vocabulary_puzzlemaker

Interpreting Graphics

15. Copy and complete the following concept map on forces.



Use the table below to answer questions 16–18.

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

16. If the objects in the data table above all fell the same distance, which object fell with the greatest average speed?

17. Explain why all four objects don't fall with the same speed.

18. On which object was the force of air resistance the greatest?

Thinking Critically

19. Determine the direction of the net force on a book sliding on a table if the book is slowing down.

20. Explain whether there can be any forces acting on a car moving in a straight line with constant speed.

21. Explain You pull a door open. If the force the door exerts on you is equal to the force you exert on the door, why don't you move?

22. Predict Suppose you are standing on a bathroom scale next to a sink. How does the reading on the scale change if you push down on the sink?

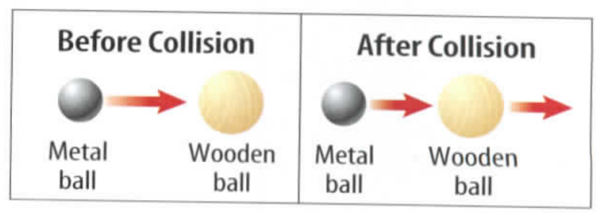
23. Describe the action and reaction force pairs involved when an object falls toward Earth. Ignore the effects of air resistance.

Applying Math

24. Calculate Mass Find your mass if a scale on Earth reads 650 N when you stand on it.

25. Calculate Acceleration of Gravity You weigh yourself at the top of a high mountain and the scale reads 720 N. If your mass is 75 kg, what is the acceleration of gravity at your location?

Use the figure below to answer question 26.



26. Calculate Speed The 2-kg metal ball moving at a speed of 3 m/s strikes a 1-kg wooden ball that is at rest. After the collision, the speed of the metal ball is 1 m/s. Assuming momentum is conserved, what is the speed of the wooden ball?

27. Calculate Mass Find the mass of a car that has a speed of 30 m/s and a momentum of 45,000 kg,m/s.

28. Calculate Sliding Friction A box being pushed with a force of 85 N slides along the floor with a constant speed. What is the force of sliding friction on the box?

chapter 3 Standardized Test Practice

Part 1 Multiple Choice

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

1. The net force on an object moving with constant speed in circular motion is in which direction?

A. downward
B. opposite to the object's motion
C. toward the center of the circle
D. in the direction of the object's velocity

Use the table below to answer questions 2–4.

Object in Free Fall with Air Resistance	
Time (s)	**Speed (m/s)**
0	0
1	9.1
2	15.1
3	18.1
4	19.3
5	19.9

2. According to the trend in these data, which of the following values is most likely the speed of the object after falling for 6 s?

A. 26.7 m/s
B. 15.1 m/s
C. 20.1 m/s
D. 0 m/s

3. Over which of the following time intervals is the acceleration of the object the greatest?

A. 0 s to 1 s
B. 1 s to 2 s
C. 4 s to 5 s
D. The acceleration is constant.

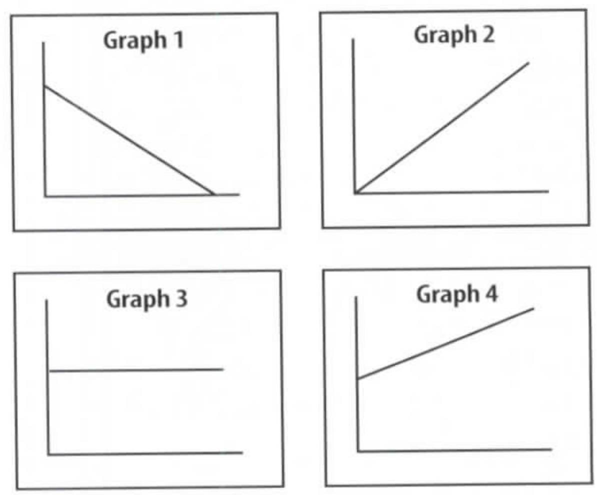
4. Over which of the following time intervals is the force on the object the smallest?

A. 0 s to 1 s
B. 1 s to 2 s
C. 4 s to 5 s
D. The force is constant.

5. Which of the following would cause the gravitational force between object A and object B to increase?

A. Decrease the distance between them.
B. Increase the distance between them.
C. Decrease the mass of object A.
D. Decrease the mass of both objects.

Use the graphs below to answer questions 6–7.



6. Which of the graphs above shows how the force on an object changes if the mass increases and the acceleration stays constant?

A. Graph 1
B. Graph 2
C. Graph 3
D. Graph 4

7. Which of the graphs above shows how the force on an object changes if the acceleration increases and the mass stays constant?

A. Graph 1
B. Graph 2
C. Graph 3
D. Graph 4

Test-Taking Tip

Keep Track of Time If you are taking a timed test, keep track of time during the test. If you find you are spending too much time on a multiple-choice question, mark your best guess and move on.

Part 2 Short Response/Grid In

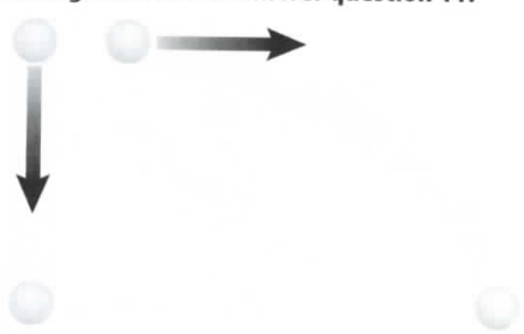
Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

8. You are pushing a 30-kg wooden crate across the floor. The force of sliding friction on the crate is 90 N. How much force must you exert on the crate to keep it moving with a constant velocity?

9. A sky diver with a mass of 60 kg jumps from an airplane. Five seconds after jumping the force of air resistance on the sky diver is 300 N. What is the sky diver's acceleration five seconds after jumping?

10. A pickup truck is carrying a load of gravel. The driver hits a bump and gravel falls out, so that the mass of the truck is one half as large after hitting the bump. If the net force on the truck doesn't change, how does the truck's acceleration change?

Use the figure below to answer question 11.



11. Two balls are at the same height. One ball is dropped and the other initially moves horizontally, as shown in the figure above. After one second, which ball has fallen the greatest vertical distance?

12. How does the acceleration of gravity 5,000 km above Earth's surface compare with the acceleration of gravity at Earth's surface?

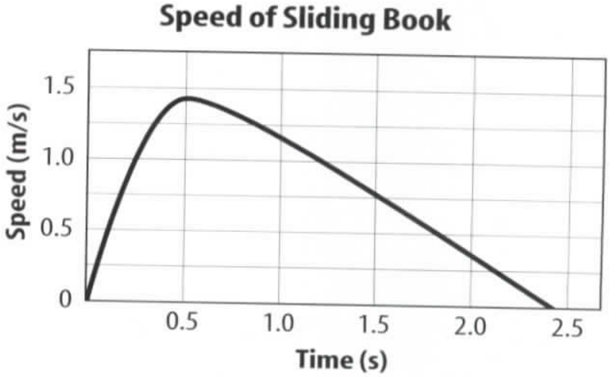
Part 3 Open Ended

Record your answers on a sheet of paper.

13. You push on a rolling ball so that the direction of your push is different from the direction of the ball's motion. After you push, will the ball be moving in the same direction that you pushed? Explain.

14. Two balls are dropped from an airplane. Both balls are the same size, but one has a mass ten-times greater than the other. The force of air resistance on each ball depends on the ball's speed. Explain whether both balls will reach the same terminal velocity.

Use the graph below to answer question 15.



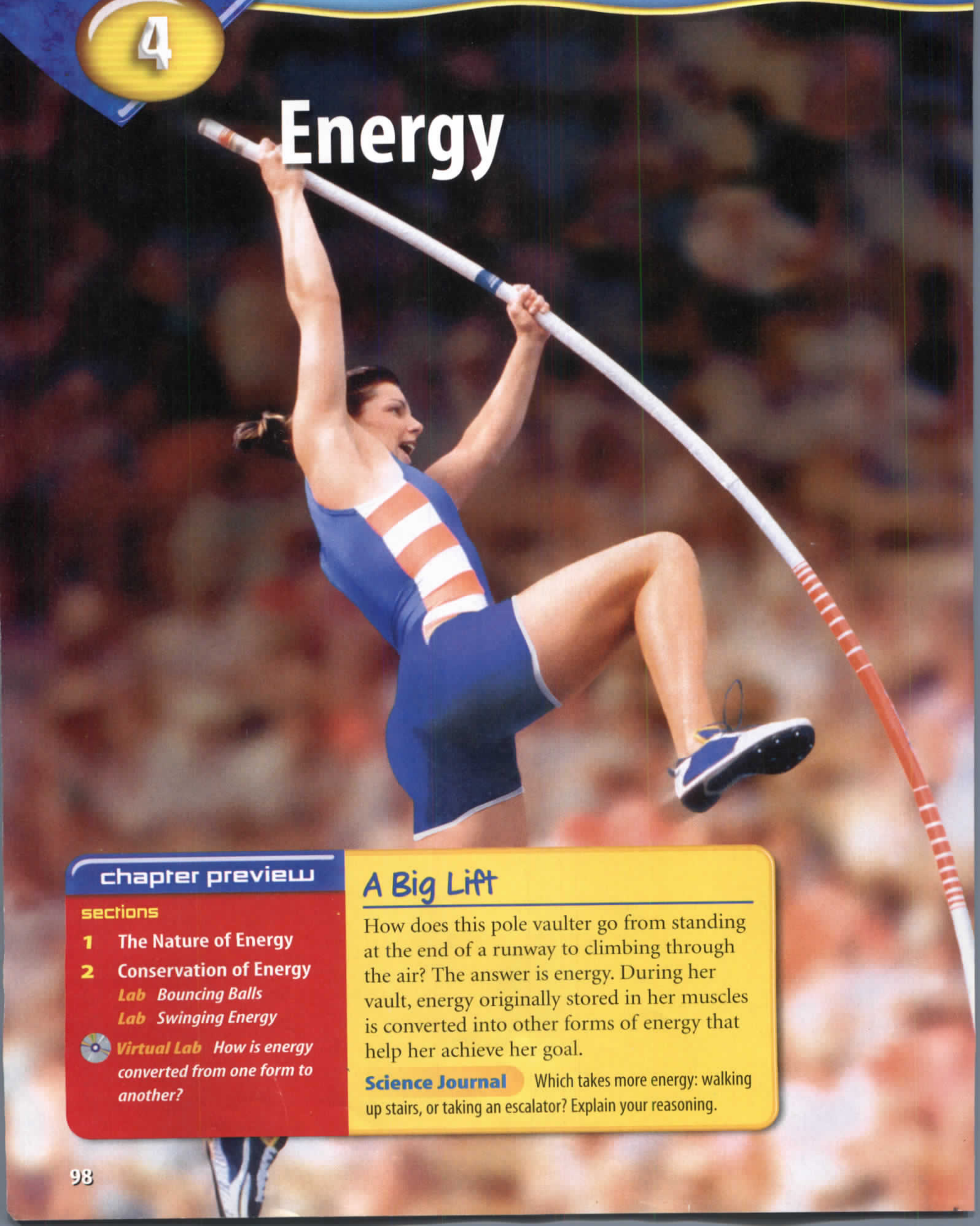
15. The graph above shows the how the speed of a book changes as it slides across a table. Over what time interval is the net force on the book in the opposite direction of the book's motion?

16. When the space shuttle is launched from Earth, the rocket engines burn fuel and apply a constant force on the shuttle until they burn out. Explain why the shuttles acceleration increases while the rocket engines are burning fuel.

17. Catching a hard-thrown baseball with your bare hand can cause your hand to sting. Explain why using a baseball glove reduces the sting when you catch a ball.

chapter 4

Energy



chapter preview

sections

1. The Nature of Energy
2. Conservation of Energy
   - *Lab* *Bouncing Balls*
   - *Lab* *Swinging Energy*

Virtual Lab *How is energy converted from one form to another?*

A Big Lift

How does this pole vaulter go from standing at the end of a runway to climbing through the air? The answer is energy. During her vault, energy originally stored in her muscles is converted into other forms of energy that help her achieve her goal.

Science Journal Which takes more energy: walking up stairs, or taking an escalator? Explain your reasoning.

Start-Up Activities

Launch LAB

Energy Conversions

One of the most useful inventions of the nineteenth century was the electric lightbulb. Being able to light up the dark has enabled people to work and play longer. A lightbulb converts electrical energy to heat energy and light, another form of energy. The following lab shows how electrical energy is converted into other forms of energy.

WARNING: *Steel wool can become hot—connect to battery only for a brief time.*

1. Obtain two D-cell batteries, two non-coated paper clips, tape, metal tongs and some steel wool. Separate the steel wool into thin strands and straighten the paper clips.
2. Tape the batteries together and then tape one end of each paper clip to the battery terminals.
3. While holding the steel wool with the tongs, briefly complete the circuit by placing the steel wool in contact with both the paper clip ends.
4. **Think Critically** In your Science Journal, describe what happened to the steel wool. What changes did you observe?

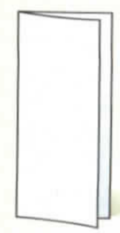
Science Online

Preview this chapter's content and activities at gpscience.com

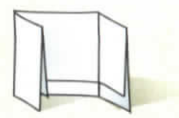
FOLDABLES™ Study Organizer

Energy Make the following Foldable to help you identify what you already know, what you want to know, and what you learned about energy.

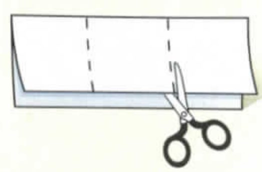
STEP 1 **Fold** a vertical sheet of paper from side to side. Make the front edge about 1 cm shorter than the back edge.



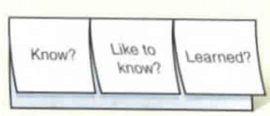
STEP 2 **Turn** lengthwise and **fold** into thirds.



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



STEP 4 **Label** each tab as shown.



Question Before you read this chapter, write what you already know about energy under the left tab of your Foldable, and write questions about what you'd like to know under the center tab. After you read the chapter, list what you learned under the right tab.