A powerful storm is approaching. The weather forecast calls for gale-force winds. Many people in the city decide to leave work early in order to get home before things get worse. As shown in Figure 1, a man pushes ahead into a strong wind and shields himself from the driving rain with an umbrella. The strong wind makes it very difficult for him to hold onto his umbrella. To keep the umbrella from being pulled from his hands, he tightly squeezes the umbrella handle. Elsewhere, a store owner attempts to bring in a folding sign that hasn’t blown away because it is chained to a pole.

Wind is but one example of the many forces you experience every day. The study of forces is a very important part of physics. As you read this section you’ll learn what forces are and how they make things move.

What Is a Force?

The man out in the storm is battling the forces of wind. A force is a push or a pull that acts on an object. A force can cause a resting object to move, or it can accelerate a moving object by changing the object’s speed or direction. The force of the wind pushing against the man slows his speed. A strong gust could even change the direction in which he was moving.

Vocabulary
- force
- newton
- net force
- friction
- static friction
- sliding friction
- rolling friction
- fluid friction
- air resistance
- gravity
- terminal velocity
- projectile motion

Figure 1 The wind pushes against the man and his umbrella. The push from the wind is a force.

INSTRUCT

What Is a Force?

Use Visuals

Figure 1 Emphasize that the wind acts as a force because it pushes against the man. Ask, In what ways can the force of the wind alter the man’s motion? (It can change the speed or direction of motion.) Will these changes cause the man to accelerate? (Yes)

Reading Strategy

Relating Text and Visuals Copy the table below. As you read, look carefully at Figures 2, 3, and 5. Complete the table by describing the forces and motion shown in each figure.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Is Net Force 0?</th>
<th>Effect on Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A</td>
<td>a. Yes</td>
<td>b. No motion</td>
</tr>
<tr>
<td>2B</td>
<td>c. Yes</td>
<td>d. No motion</td>
</tr>
<tr>
<td>3</td>
<td>e. Yes</td>
<td>f. No motion</td>
</tr>
<tr>
<td>5A</td>
<td>g. Yes</td>
<td>h. No motion</td>
</tr>
<tr>
<td>5B</td>
<td>i. No</td>
<td>j. Yes</td>
</tr>
</tbody>
</table>

Reading Focus

Build Vocabulary LINCS Have students use the LINCS strategy to learn and review the terms force, friction, air resistance, and gravity. In LINCS exercises, students List the parts that they know (list the word and its definition on an index card). Imagine a picture (create a mental image of the term’s meaning and describe the image using real words). Note a sound-alike word (think of a familiar word that sounds like the term or part of it). Connect the terms (make up a short story about each term’s meaning that uses the sound-alike word). Self-test (quiz themselves).

Reading Focus

Objectives
12.1.1 Describe examples of force and identify appropriate SI units used to measure force.
12.1.2 Explain how the motion of an object is affected when balanced and unbalanced forces act on it.
12.1.3 Compare and contrast the four kinds of friction.
12.1.4 Describe how Earth’s gravity and air resistance affect falling objects.
12.1.5 Describe the path of a projectile and identify the forces that produce projectile motion.

Section Resources

Print
- Reading and Study Workbook With Math Support, Section 12.1
- Transparencies, Chapter Pretest and Section 12.1

Technology
- Interactive Textbook, Section 12.1
- Presentation Pro CD-ROM, Chapter Pretest and Section 12.1
- Go Online, NSTA SciLinks, Forces
Measuring Force Forces are often easy to measure. In fact, if you’ve ever stopped at a grocery store, you may have measured forces using a spring scale like the one shown in Figure 2. The stretch of the spring in the scale depends on the amount of weight (a type of force) acting on it. As more fruit is placed on the scale, the spring is stretched farther and the scale reading increases.

Units of Force Force is measured in newtons, abbreviated as N. One newton is the force that causes a 1-kilogram mass to accelerate at a rate of 1 meter per second each second (1 m/s²). In fact, 1 newton is equal to 1 kilogram-meter per second squared (1 N = 1 kgm/s²). The newton is named after Sir Isaac Newton (1642–1727), the English scientist who explained how force, mass, and acceleration are related. You’ll learn more about forces and mass in the next section.

Representing Force You can use an arrow to represent the direction and strength of a force. The direction of the arrow represents the direction of the force. The length of the arrow represents the strength, or magnitude, of the force.

In Figure 2, the force arrows represent the weight of the items on the scale. Both arrows point down because weight always acts downward. The lengths of the arrows show you that more weight acts on the scale in Figure B than the one in Figure 2A.

Combining Forces Have you ever helped to push a car that has run out of gas? If you have, you were taking advantage of the fact that forces can be combined. The individual force of each person’s push adds with the others into a larger force that allows you to move the car.

You can combine force arrows to show the result of how forces combine. That is, forces in the same direction add together and forces in opposite directions subtract from one another. The net force is the overall force acting on an object after all the forces are combined.

Build Science Skills

Measuring Purpose: Students learn to measure force and sketch force arrows.

Materials 5-N spring scale, centimeter ruler, book, string, 5 objects (such as books) weighing from 1 to 5 newtons

Class Time 30 minutes

Procedure Have students pull each object at a slow, constant speed across a flat surface using the spring scale. They may need to attach the scale to the object using string. Students should record the force required to pull each object. Next, have them draw force arrows for each object. The arrows should be drawn to scale using a scale factor of 1 centimeter per newton of force.

Expected Outcome Students will draw scaled force arrows for each object. Logical

Combining Forces

Build Reading Literacy

Identify Main Ideas/Details Refer to page 98D in Chapter 4, which provides the guidelines for identifying main ideas and details.

Ask students to explain the main concept in the first two short paragraphs under the heading Combining Forces on p. 357. (forces can be combined.) Encourage students to illustrate the main idea with a diagram. Ask, What would be the effect on the direction of the net force if some of the people push the car forward while others push it backwards? (The net force would be in the direction of the people who were pushing with a greater force.) Logical, Portfolio

Customize for English Language Learners

Illustrate Content You may assist English language learners by using diagrams, illustrations, or other visuals to explain the content of the lesson. Students may also benefit from keeping a “picture dictionary” with their own visuals to illustrate important concepts. For example, students may include diagrams to illustrate how forces combine and to show the meaning of balanced force and unbalanced force. This strategy can be especially helpful for students who are in the beginning stages of learning English. Students who have a greater mastery of English may also benefit from sharing their picture dictionaries with each other and explaining the concepts for which they have included visuals.

Answer to . . .

Figure 2 The difference in weight between the two scale readings is about 3 pounds.

The amount of force that accelerates 1 kg at 1 m/s² is one newton.
Sometimes, the net force acting on an object is zero. Look at the tug of war in Figure 3. Each group pulls on the rope with the same amount of force, but they pull in opposite directions. Neither group wins the tug of war because the forces on the rope are balanced. Balanced forces are forces that combine to produce a net force of zero. **Balanced Forces**

In this tug of war, the two groups pull with equal forces in opposite directions. The forces combine by subtracting from each other. **Adding forces**

\[
\text{F}_{\text{total}} = \text{F}_1 + \text{F}_2
\]

**Subtracting forces**

\[
\text{F}_{\text{total}} = \text{F}_1 - \text{F}_2
\]

**Equal and opposite forces**

\[
\text{F}_{\text{total}} = 0
\]

Forces acting in opposite directions can also combine to produce an unbalanced force. When a team of people win a tug of war, they win by pulling with a greater force than the losing team. The two unequal forces act in opposite directions but combine to produce an unbalanced net force. **Unbalanced Forces**

Examples of balanced forces are common. For example, imagine two people locked in an arm wrestling match. Although neither person’s arm may be moving, a pair of equal and opposite balanced forces are acting. An unlimited number of individual forces can act on an object and still produce a net force of zero. As shown in Figure 3, the individual force exerted by each person still results in a zero net force on the rope.

**What is the net force of a pair of balanced forces?**

**Reading Checkpoint**

A knowledge of balanced and unbalanced forces is important for virtual reality applications. Sensors detect the direction and magnitude of force exerted on an object by a user. The system then provides resistive force feedback to the user that corresponds to the desired virtual material. For example, the resistive force can be increased to simulate a stiff material such as hard rubber. The resistive force can be decreased to simulate a soft material such as a cloth.
Friction

All moving objects are subject to friction, a force that opposes the motion of objects that touch as they move past each other. Without friction, the world would be a very different place. In a frictionless world, every surface would be more slippery than a sheet of ice. Your food would slide off your fork, walking would be impossible. Cars would slide around helplessly with their wheels spinning.

Friction acts at the surface where objects are in contact. Note that “in contact” includes solid objects that are directly touching one another as well as objects moving through a liquid or a gas. There are four main types of friction: static friction, sliding friction, rolling friction, and fluid friction.

Static Friction Imagine trying to push a large potted tree across a patio. Although you apply force to the pot by pushing on it, you can’t get the pot to move. As shown in Figure 5A, the force of static friction opposes your push. Static friction is the friction force that acts on objects that are not moving. Static friction always acts in the direction opposite to that of the applied force.

You experience static friction every time you take a step. As you push off with each step, static friction between the ground and your shoe keeps your shoe from sliding.

Sliding Friction With the help of a friend, you push on the pot with enough force to overcome the static friction. The pot slides across the patio as shown in Figure 5B. Once the pot is moving, static friction no longer acts on it. Instead, a smaller friction force called sliding friction acts on the sliding pot. Sliding friction is a force that opposes the direction of motion of an object as it slides over a surface. Because sliding friction is less than static friction, less force is needed to keep an object moving than to start it moving.

Figure 5 Different types of friction act on moving and nonmoving objects. A Static friction acts opposite the direction of the force you apply to move the plant. B When you push with more force, the potted tree begins to slide. Sliding friction acts to oppose the direction of motion.

Friction

Use Community Resources

Ask a civil engineer to visit your class and talk about the effects of friction between road surfaces and the tires of a moving car. Have the engineer emphasize the necessity of friction in controlling a car. Suggest that the engineer explain to the students what happens when a car hydroplanes because of lack of friction between the tires and the surface of the road. Encourage students to ask questions about how engineers take friction into account when designing roads and bridges.

Interpersonal

Go Online

Download a worksheet on forces for students to complete, and find additional teacher support from NSTA SciLinks.
Ball bearings like those shown in Figure 6 are often used to reduce friction in machines. A ball bearing is made up of a set of round balls located between two smooth surfaces. The balls roll as the surfaces move past each other. Friction is greatly reduced between the surfaces because rolling friction replaces sliding friction. Inline skates, skateboards, bicycles, and automobiles are just a few of the many machines that use ball bearings.

Fluid Friction Friction also acts on a submarine moving through water and on an airplane flying through air. Water and a mixture of gases such as air are known as fluids. The force of fluid friction opposes the motion of an object through a fluid. You feel fluid friction when stirring thick cake batter. The motion of the spoon through the batter is slowed by fluid friction. Fluid friction increases as the speed of the object moving through the fluid increases. Thus the faster you stir, the greater the friction is.

Fluid friction acting on an object moving through the air is known as air resistance. At higher speeds, air resistance can become a significant force. For this reason, bicyclists and speed skaters often wear slick racing suits to reduce air resistance.

**Facts and Figures**

**Friction and Tennis** You may mention to the students that, if they have ever played tennis on a clay court, they may have discovered that clay courts are covered with a layer of fine sand. The sand granules act as ball bearings for a short distance and then cause the player to slide. Ask, With clay courts, what types of friction is the player experiencing? (The player first experiences rolling friction when the sand granules are still rolling. The player then experiences sliding friction when the granules stop rolling and start sliding. The sliding friction is actually occurring between the grains of sand and the surface below the sand, as the sand sticks to the shoes of the player.)
Gravity
Why do leaves fall to the ground? The answer is gravity. Gravity is a force that acts between any two masses. Gravity is an attractive force, that is, it pulls objects together. Earth's gravitational force exerts a force of attraction on every other object that is near Earth. That includes you—the force of Earth's gravity holds you on the ground. Note that the force of gravity does not require objects to be in contact for it to act on them. Unlike friction, gravity can act over large distances.

Earth's gravity acts downward toward the center of Earth. Fortunately, an upward force usually balances the downward force of gravity. What forces act on the boulder in Figure 7? Gravity pulls down on the boulder. An upward force supplied by the supporting rock acts upward and balances the downward gravitational force. Because the forces on the boulder are balanced, it remains at rest as it has for thousands of years.

Falling Objects
What forces affect the motion of a dollar bill dropped from the top of a tall building? Both gravity and air resistance affect the motion of a falling object. Gravity causes objects to accelerate downward, whereas air resistance acts in the direction opposite to the motion and reduces acceleration.

In Figure 8, a flying squirrel has jumped from a tree and is falling toward the ground. As you can see, the squirrel has positioned its body parallel to Earth's surface and spread its arms and legs. By doing this, the squirrel creates a very large surface area. The large area maximizes the force of air resistance acting to slow the squirrel's downward acceleration. Because of the squirrel's slower downward acceleration, it is able to travel farther through the air than would otherwise be possible.

As objects fall to the ground, they accelerate and gain speed. With increasing speed comes increasing air resistance. If an object falls for a long time, the upward force of air resistance becomes equal to the downward force of gravity. At this point, the forces acting on the object are balanced. Acceleration is zero and the object continues falling at a constant velocity. Terminal velocity is the constant velocity of a falling object when the force of air resistance equals the force of gravity. Read the Concepts in Action pages later in this chapter to learn how sky divers reach terminal velocity.

Facts and Figures
Flying Squirrels
Southern flying squirrels are found mostly from southern Ontario to the Gulf Coast. The length of an adult squirrel, including the tail, is about 23 to 25 cm, and its weight is usually between 55 and 110 g. Its fur is long, soft, and silky. On each side of the squirrel's body is a gliding membrane between the wrist of the front leg and the ankle of the hind leg. When the front and hind legs are extended, the membranes help the squirrel to glide in a motion that appears to be flying, giving the animal the name “flying squirrel.” The tail acts as a rudder and helps to stabilize the squirrel as it glides.

Answer to . . .

Figure 7 The net force on the boulder is zero.

Answers may include stirring cake batter and air resistance.
Section 12.1 (continued)

Projectile Motion

Use Visuals

Figure 9  Have students read the text under Projectile Motion. Then, ask questions to reinforce the idea that projectile motion is the result of the initial horizontal velocity and the vertical force of gravity. Ask, Why does the yellow ball in Figure 9B continue downward at the same rate as the blue and green balls in Figure 9A? (They all accelerate downward by the force of gravity, approximately 9.8 m/s².) Why does the yellow ball (in 9B) continue horizontally? (The ball’s initial horizontal velocity is not affected by the downward force of gravity.) Visual, Logical

3 ASSESS

Evaluate Understanding

Have students write a review question and its answer for each objective at the beginning of this section. Students should also be able to discuss the section objectives.

Reteach

Have students use Figure 4 to summarize the concepts of balanced and unbalanced forces. Use Figures 5 and 8 to review friction, gravity, and air resistance.

Connecting Concepts

Students’ sketches should show constant horizontal velocity, steadily increasing downward velocity, and constant downward acceleration.

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 12.1.

Answer to . . .

Figure 9  Forces acting on both of the falling balls are air resistance and gravity. In addition, the projectile in Figure 9B was briefly acted on by the force that gave it its initial horizontal velocity.

Section 12.1 Assessment

Reviewing Concepts

1. How is the motion of an object affected when a force acts on it?
2. List the four types of friction.
3. How does air resistance affect the acceleration of a falling object?
4. Earth’s gravitational force acts in what direction?
5. Describe why a projectile follows a curved path.
6. Comparing and Contrasting  Compare the strengths of static, sliding, and rolling friction.
7. Applying Concepts Explain why falling leaves often do not fall in a straight-line path to the ground.
8. Predicting Two coins are knocked off a table at the same time by different forces. Which coin will hit the floor first?

Connecting Concepts

Velocity and Acceleration  Make sketches of Figures 9A and 9B. Use them to relate the concepts of velocity and acceleration from Section 11.3 to falling objects. Add velocity and acceleration arrows at three locations on each sketch.

Section 12.1 Assessment

1. A force can set an object at rest into motion, or it can accelerate a moving object by changing its speed or direction.
2. Static friction, sliding friction, rolling friction, and fluid friction
3. It acts opposite the direction of motion and slows the acceleration of a falling object.
4. Downward toward the center of Earth
5. The combination of initial horizontal velocity and downward vertical force causes a projectile to follow a curved path.
6. The force of static friction is greater than that of sliding friction. The force of sliding friction is generally greater than that of rolling friction.
7. Varying air resistance acting on the leaf results in a fluttering motion.
8. Both coins hit the ground at the same time.
12.2 Newton’s First and Second Laws of Motion

**Key Concepts**
- How does Newton’s first law relate change in motion to a zero net force?
- How does Newton’s second law relate force, mass, and acceleration?
- How are weight and mass related?

**Vocabulary**
- inertia
- mass
- weight

**Reading Strategy**
**Building Vocabulary** Copy the table below. Then as you read the section, write a definition for each vocabulary term in your own words.

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>inertia</td>
<td>?</td>
</tr>
<tr>
<td>mass</td>
<td>?</td>
</tr>
<tr>
<td>weight</td>
<td>?</td>
</tr>
</tbody>
</table>

Why do some cars accelerate faster than others? How does an ice skater glide far across the ice after pushing off only once? The answers to these questions involve the concepts of mass and inertia.

**Aristotle, Galileo, and Newton**
Modern scientists understand the relationships between force and motion. However, it took about 2000 years to develop this understanding.

**Aristotle** The ancient Greek scientist and philosopher Aristotle (384 B.C.–322 B.C.) made many scientific discoveries through careful observation and logical reasoning. He was not always correct. Aristotle incorrectly proposed that force is required to keep an object moving at constant speed. This error held back progress in the study of motion for almost two thousand years.

**Galileo** Italian scientist Galileo Galilei (1564–1642) experimented to find out about the world. By rolling balls down wooden ramps, he studied how gravity produces constant acceleration. Galileo concluded that moving objects not subjected to friction or any other force would continue to move indefinitely. Galileo’s portrait and the title page from the book that presented his work are shown in Figure 10.

**Figure 10**
Galileo’s work helped correct misconceptions about force and motion that had been widely held since Aristotle’s time.

**INSTRUCT**

**Aristotle, Galileo, and Newton**
Integrate Social Studies
Aristotle did not correctly explain why an object falls toward Earth. Later, Galileo’s observations led him to confirm that Earth is one of many planets, all governed by the same laws of gravity.

**Vocabulary Rating Chart** Have students make a four-column chart with the headings Term, Can Define or Use It, Heard or Seen It, and Don’t Know. Have them put inertia, mass, and weight in the first column, rating their knowledge of each term by putting a checkmark in one of the other columns. Give students a purpose for reading by asking them to check their expectations as they read. Ask them to make another chart after they have read the section.

**Reading Strategy**

- a. The tendency of an object to resist a change in its motion
- b. Mass
- c. The amount of matter an object contains as measured by its inertia
- d. Weight
- e. The force of gravity acting on an object

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**Section Resources**

**Print**
- Lab Manual, Investigations 12A and 12B
- Reading and Study Workbook With Math Support, Section 12.2 and Math Skill: Calculating Acceleration
- Math Skills and Problem Solving Workbook, Section 12.2
- Transparencies, Section 12.2

**Technology**
- Interactive Textbook, Section 12.2
- Presentation Pro CD-ROM, Section 12.2
- Go Online, NSTA SciLinks, Mass

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Section 12.2 (continued)

Build Science Skills

**Inferring** Before studying Newton's first law of motion, have students look at Figures 12A and 12B. Ask, What would have happened to the test dummy if the air bag had not deployed and the dummy had not been wearing a seatbelt? (Students should infer from the photos that the dummy's forward motion continues after the crash, and that the dummy might have gone through the windshield.) Visual, Logical

**Newton's First Law of Motion**

Use Visuals

Figures 12A and 12B Have students examine Figures 12A and 12B. Ask, What is the effect of inertia on the cart? (Inertia causes the mass of the car to continue forward, crushing the front of the car.) What effect does inertia have on the dummy? (After the car stops, the dummy continues to move forward until it is stopped by the air bag and seatbelt.) How is the mass of a passenger related to the passenger's inertia? (Passengers with greater mass have more inertia. It is harder to stop the forward motion of passengers with greater mass.) Visual, Logical

**Quick Lab**

**Investigating Inertia**

**Objective**

After completing this activity, students will be able to

- use the concept of inertia to explain the movement of objects.

**Address Misconceptions**

This lab can help to correct the misconception that inertia refers to the tendency of objects to resist motion, rather than the tendency to resist a change in motion. Use student answers to Question 1 as the basis of a discussion about the nature of inertia.

**Skills Focus** Observing, Formulating Hypotheses

**Prep Time** 5 minutes

**Materials** index card, coin

**Advance Prep** Checkers may be substituted for coins.

**Class Time** 5 minutes

**Expected Outcome** Fast changes in the movement of the card can occur with little effect on the movement of the coin. When the card moves slowly, it carries the coin along.

**Analyze and Conclude**

1. In Step 1, the inertia of the coin resisted acceleration by the card. The force of friction was not strong enough to hold the coin in place on the accelerating card. In Step 2, the acceleration of the card was not as great. Therefore, the force of friction was strong enough to hold the coin in place on the card. In Step 3, the situation was identical to that in Step 2 at first. However, when the card suddenly stopped moving, the inertia of the coin was great enough to keep it moving in the same direction, in spite of the force of friction.

2. If the mass of the coin were greater, its inertia also would be greater. Therefore, the coin would again have resisted acceleration in Step 1 and moved with the card in Step 2 if the card was not moving too quickly. In Step 3, the coin would have continued moving longer after the card stopped moving. Logical

**Newton** In 1665, the plague broke out in London, forcing Isaac Newton to leave Trinity College in Cambridge, England, where he was a student. Over the next two years, Newton built on the work of scientists such as Galileo. He published his results many years later in a book entitled *Principia*. In this important work, Newton first had to define mass and force. He then introduced his laws of motion. Newton's portrait and the title page of *Principia* are shown in Figure 11.

**Newton's First Law of Motion**

Newton summarized his study of force and motion in several laws of motion. According to Newton's first law of motion, the state of motion of an object does not change as long as the net force acting on the object is zero. Thus, unless an unbalanced force acts, an object at rest remains at rest, and an object in motion remains in motion with the same speed and direction. For example, a soccer ball resting on the grass remains motionless until a force is applied to it in the form of a kick. The kicked ball begins rolling. Because friction between the grass and the ball acts on the ball as it rolls, the ball slows. The force of friction slows the ball and brings it to a stop.

Newton's first law of motion is sometimes called the law of inertia (in Ur shu). Inertia is the tendency of an object to resist a change in its motion. In other words, an object at rest tends to remain at rest, and an object in motion tends to remain in motion with the same direction and speed. Note that as the soccer ball sat motionless in the grass, the forces acting on it were balanced. The ball remained at rest until an unbalanced force acted on it. The ball has inertia.

**Reading Checkpoint**

How does a zero net force affect an object's motion?

**Figure 11** Isaac Newton published his work on force and motion in the book entitled *Principia*.

**Figure 12**

This crash sequence illustrates inertia—the tendency of an object in motion to remain in motion.

At impact, the air bag deploys. Note that the test dummy continues its forward motion as the collision begins to slow the car.
Think about what happens if you are in a moving car that is involved in a front-end collision. The collision makes the car stop suddenly. What happens to you? Because you have inertia, you continue moving forward. The series of photos in Figure 12 shows you how dangerous a front-end collision can be. If a seat belt and airbag had not restrained the test dummy, it would have crashed into the steering wheel and windshield with great force. The seat belt and airbag work by exerting force against the body of the dummy, opposing its forward motion.

**Newton's Second Law of Motion**

How do unbalanced forces affect the motion of an object? An unbalanced force causes an object's velocity to change. In other words, the object accelerates. For example, you apply a net force to a ball when you throw it. The harder you throw, the more the ball accelerates. In fact, the acceleration of the ball is directly proportional to the net force acting on it. If you double the force, the acceleration of the ball doubles as well. Newton also learned that the acceleration of an object depends upon its mass. Mass is a measure of the inertia of an object and depends on the amount of matter the object contains. According to Newton's second law of motion, the acceleration of an object is equal to the net force acting on it divided by the object's mass. Thus, doubling the mass of an object cuts its acceleration in half. Newton was able to put these ideas into a single formula.

**Newton's Second Law**

\[ \text{Acceleration} = \frac{\text{Net force}}{\text{Mass}}, \quad \text{or} \quad a = \frac{F}{m} \]

**Quick Lab**

**Investigating Inertia**

**Procedure**

1. Place an index card on a flat table. Place a coin in the middle of the card. As quickly as you can, try to pull the card out from under the coin. Observe what happens to the coin.
2. Repeat Step 1 while moving the card slowly.
3. Repeat Step 1 again. This time, slowly accelerate the card, and then suddenly bring it to a stop.

**Analyze and Conclude**

1. **Applying Concepts** Use the concepts of inertia and friction to explain the behavior of the coin each time you moved the card.
2. **Predicting** How would your observations be different with a coin of greater mass? Test your predictions.

**Figure 12** The crushing of the car's body absorbs much of the energy. The air bag and seatbelt also absorb crash energy.

**Answer to . . .**

The object's motion does not change.
Crash-Test Dummies

Defining the way a body will respond to a crash is difficult because different parts of the human body behave in different ways in a crash. For that reason, developing a crash-test dummy that behaves like a human body in a crash has been difficult.

Early automotive crash test dummies were based on dummies used in aerospace. Because head, spine, and neck injuries can be life-threatening, dummies’ heads, necks, and spines were a major focus of research. In 1973, dummies were improved. Injuries to lower extremities are rarely fatal, but they can reduce a person’s quality of life. Further research and development of crash-test dummies will focus on lower extremities.

Interpreting Diagrams Forces from both the seatbelt and the air bag slow the dummy’s movement.

For Enrichment

Have students research the methods used by the National Highway Traffic Safety Administration (NHTSA) to test a vehicle’s crash worthiness and its likelihood of rolling over. Also have students create tables explaining the meaning of the star rating system used by the NHTSA. Select a method for students to use to present their findings to the class.

Logical

Use Community Resources

Arrange for a police officer to speak to your class about seatbelt safety laws. Have the officer reinforce the importance of seatbelts in preventing injury. The police department may have a video that could visually reinforce the concept of seatbelt safety and its relationship to Newton’s first law of motion in sudden stops.

Logical, Visual

Facts and Figures

Bike Helmets You may help your students understand that Newton’s first law of motion is a reason for wearing helmets when cycling. During an accident, the foam padding in a helmet is deformed, absorbing the energy of the impact. Explain that each year, almost 400,000 children ages 14 and under are treated in emergency rooms for bicycle-related injuries. Head injuries account for more than two thirds of bicycle-related hospital admissions and more than half of bicycle-related deaths. If each child wore a bicycle helmet, between 39,000 and 45,000 head injuries, and between 18,000 and 55,000 scalp and face injuries could be prevented annually.
The acceleration of an object is always in the same direction as the net force. In using the formula for Newton’s second law, it is helpful to realize that the units N/kg and m/s² are equivalent. The Math Skills box reinforces this relationship.

Note that Newton’s second law also applies when a net force acts in the direction opposite to the object’s motion. In this case, the force produces a deceleration that reduces the speed. This is the principle used by automobile seat belts. In a collision, the seat belt applies a force that opposes a passenger’s forward motion. This force decelerates the passenger in order to prevent serious injury.

Newton’s Second Law

An automobile with a mass of 1000 kilograms accelerates when the traffic light turns green. If the net force on the car is 4000 newtons, what is the car’s acceleration?

1. Read and Understand
   What information are you given?
   Mass, \( m = 1000 \text{ kg} \)
   Force, \( F = 4000 \text{ N} \) (in the forward direction)

2. Plan and Solve
   What are you trying to calculate?
   Acceleration, \( a \)?
   What formula contains the given quantities and the unknown?
   \( \text{Acceleration} = \frac{\text{Net force}}{\text{Mass}}, \, a = \frac{F}{m} \)
   Replace each variable with its known value and solve.
   \( a = \frac{4000 \text{ N}}{1000 \text{ kg}} = \frac{4 \text{ kg}}{\text{kg}} = 4 \text{ m/s}^2 \)
   \( a = 4 \text{ m/s}^2 \) in the forward direction

3. Look Back and Check
   Is your answer reasonable?
   Powerful sports cars can accelerate at 6 m/s² or more. Thus, a smaller acceleration of 4 m/s² seems reasonable.

1. A boy pushes forward a cart of groceries with a total mass of 40.0 kg. What is the acceleration of the cart if the net force on the cart is 60.0 N?
2. What is the upward acceleration of an airplane with a mass of 5000 kg if a force of 10,000 N acts on it in an upward direction?
3. An automobile with a mass of 1200 kg accelerates at a rate of 3.0 m/s² in the forward direction. What is the net force acting on the automobile? (Hint: Solve the acceleration formula for force.)
4. A 25-N force accelerates a boy in a wheelchair at 0.5 m/s². What is the mass of the boy and the wheelchair? (Hint: Solve Newton’s second law for mass.)

For Extra Help
Remind students that they first need to solve the equation \( a = \frac{F}{m} \) for the unknown. Also ask students to identify all the known and unknown variables before using the equation. Logical

Direct students to the Math Skills in the Skills and Reference Handbook at the end of the student text for additional help.

Additional Problems
1. A 20-N net force acts on an object with a mass of 2.0 kg. What is the object’s acceleration? (10 m/s²)
2. A box has a mass of 150 kg. If a net force of 3000 N acts on the box, what is the box’s acceleration? (20 m/s²)
3. What is the acceleration of a 1000 kg car subject to a 500 N net force? (0.5 m/s²)

Forces and Motion 367

Newton’s Second Law of Motion

Purpose Students observe that acceleration is inversely proportional to mass. \( \left( a = \frac{F}{m} \right) \)

Materials wind-up toy car, 3 metal washers, tape

Procedure Have students wind the toy car completely and observe its motion along a flat surface. Next, have them tape metal washers to the car, wind it, and watch its motion along the flat surface again.

Expected Outcome Students will notice that the car’s acceleration decreases because of the increased mass.

Visual

Solutions
1. \( a = \frac{F}{m} = \frac{60.0 \text{ N}}{40.0 \text{ kg}} = 1.50 \text{ m/s}^2 \)
2. \( a = \frac{F}{m} = \frac{10,000 \text{ N}}{5000 \text{ kg}} = 2 \text{ m/s}^2 \)
3. \( a = \frac{F}{m}; \, F = ma = 1200 \text{ kg} \times 3.0 \text{ m/s}^2 = 3600 \text{ N} \)
4. \( a = \frac{F}{m}; \, F = ma = 25 \text{ N} / 0.50 \text{ m/s}^2 = 50 \text{ kg} \)

Logical

For Extra Help
Remind students that they first need to solve the equation \( a = \frac{F}{m} \) for the unknown. Also ask students to identify all the known and unknown variables before using the equation. Logical

Direct students to the Math Skills in the Skills and Reference Handbook at the end of the student text for additional help.

Additional Problems
1. A 20-N net force acts on an object with a mass of 2.0 kg. What is the object’s acceleration? (10 m/s²)
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Forces and Motion 367
Section 12.2 (continued)

Use Visuals

Figure 13 Use this figure to be sure that students understand the equation $F = ma$ before asking the following question about the mass-acceleration ratio. Ask, Why would one cart accelerate eight times as fast as the chain of eight carts with the same force applied in each case? Explain using the second-law equation. (If the force remains the same in the equation $F = ma$, then as mass increases, the acceleration has to decrease in proportion to the increase in mass.) How would the force have to change in order to have the same acceleration for eight carts as for one cart? (The force would have to be eight times greater.) How would another force directed to the left on the cart affect the cart’s acceleration? (The acceleration would depend on the net force acting on the cart. The net force would be the force acting to the right minus the force acting to the left.)

Build Reading Literacy

Visualize Refer to page 354D in Chapter 12, which provides the guidelines for visualizing. Tell students that forming a mental image of concepts they are learning helps them remember new concepts. For example, this section discusses weight in newtons, but students may think of weight in terms of pounds. Help students to visualize that a pound equals 4.448 newtons. Tell them, that in approximate weights, 1 pound is slightly more than one newton. Encourage students to think of something the size of a pound, such as a pound of butter. If the butter is divided into four sticks, each stick is slightly more than the weight of one newton. Likewise, a quarter-pound hamburger could be called a “newton” burger.

The shopping carts in Figure 13 further illustrate Newton’s second law. What happens if you push on a single shopping cart? The unbalanced force causes the cart to accelerate. What happens when you push with the same force on a chain of eight shopping carts? The acceleration of the chain of eight carts is less than that of the single cart. The chain of carts accelerates less because it has more mass.

Weight and Mass

Do you sometimes talk about weight and mass as if they were the same thing? Although related to each other, mass and weight are not the same. Weight is the force of gravity acting on an object. An object’s weight is the product of the object’s mass and acceleration due to gravity acting on it.

Weight Formula

$W = mg$

The weight formula is basically Newton’s second law. However, weight ($W$) is substituted for force ($F$) and acceleration due to gravity ($g$) is substituted for acceleration ($a$). In other words, $W = mg$ is a different form of $a = \frac{F}{m}$, that is when the equation is solved for force, $F = ma$. The value of $g$ in the formula is 9.8 m/s$^2$.

In using the weight formula or Newton’s second-law formula, make sure you use the correct units. The force ($F$ or $W$) should be in newtons, the acceleration ($a$ or $g$) in meters per second squared, and the mass ($m$) in kilograms. The following example shows how to use the weight formula.

If an astronaut has a mass of 112 kilograms, what is his weight on Earth where the acceleration due to gravity is 9.8 m/s$^2$?

$W = \text{Mass} \times \text{Acceleration due to gravity}$

$= 112 \text{ kg} \times 9.8 \text{ m/s}^2$

$= 1100 \text{ kg \cdot m/s}^2 = 1100 \text{ N}$

Go Online

For: Links on mass
Visit: www.SciLinks.org
Web Code: ccc-2122

368 Chapter 12
Assessment

Mass is a measure of the inertia of an object; weight is a measure of the force of gravity acting on an object. Consider the same astronaut shown on Earth and on the moon in Figure 14. On the moon, the acceleration due to gravity is about \(3.7 \text{ m/s}^2\), how much would the astronaut weigh?

If you study the weight formula, you’ll see that mass and weight are proportional. Doubling the mass of an object also doubles the object’s weight.

1. **Mass is a measure of the inertia of an object; weight is a measure of the force of gravity acting on an object.** Consider the same astronaut shown on Earth and on the moon in Figure 14. On the moon, the acceleration due to gravity is only about one sixth that on Earth. Thus, the astronaut weighs only about one sixth as much on the moon as on Earth. In both locations, the mass of the astronaut is the same.

### Section 12.2 Assessment

#### Reviewing Concepts

1. State Newton’s first law of motion in your own words.
2. **What equation states Newton’s second law of motion?**
3. **How is mass different from weight?**

#### Critical Thinking

4. **Applying Concepts** Describe several examples of Newton’s first and second laws that you observe during a normal day.
5. **Making Judgments** A steel ball is the same size as a wooden ball, but weighs twice as much. If both balls are dropped from an airplane, which of them will reach terminal velocity more quickly? Explain.

6. During a test crash, an air bag inflates to stop a dummy’s forward motion. The dummy’s mass is 75 kg. If the net force on the dummy is 825 N toward the rear of the car, what is the dummy’s deceleration?

7. A bicycle takes 8.0 seconds to accelerate at a constant rate from rest to a speed of 4.0 m/s. If the mass of the bicycle and rider together is 85 kg, what is the net force acting on the bicycle? (Hint: First calculate the acceleration.)

### 3. ASSES

#### Evaluate Understanding

Have students work in pairs to write three math problems (with solutions) based on Newton’s second law, \(a = \frac{F}{m}\). Then have them do the same for the weight equation, \(W = mg\). Ask students to present their problems and solutions in class.

#### Reteach

Use Figure 12 to review inertia and its relationship to Newton’s first law of motion. Use Figure 13 to review Newton’s second law of motion. Use Figure 14 to review how Newton’s second law is related to the weight formula.

#### Solutions

6. \(a = \frac{F}{m} = \frac{825 \text{ N}}{75 \text{ kg}} = 11 \text{ m/s}^2\), toward the rear of the car.

7. \(\Delta v = \frac{4.0 \text{ m/s}}{8.0 \text{ s}} = 0.50 \text{ m/s}^2\). If the mass of the bicycle and rider together is 85 kg, the net force acting on the bicycle is \(F = ma = 85 \text{ kg} \times 0.50 \text{ m/s}^2 = 43 \text{ N}\).

### Math Practice

1. Students should paraphrase the following:

   - According to Newton’s first law of motion, the state of motion of an object does not change as long as the net force acting on the object is zero.
   - \(a = \frac{F}{m}\)
   - Mass is a measure of the inertia of an object; weight is a measure of the force of gravity acting on an object.

   - Students should cite examples in which objects at rest remain at rest or tend to continue moving (first law) and in which a net force acting on an object causes a change in the object’s state of motion (second law).

   - The heavier steel ball will take longer to reach terminal velocity. A greater speed is needed to produce the air resistance required to balance the steel ball’s greater weight. The steel ball must fall for a longer period of time in order to reach this greater speed.

### Answer to . . .

**Figure 13** The two-cart chain would accelerate at half the rate of the single cart.

**Figure 14** 330 N
Terminal Speed

Background
The sky diver's weight, the gravitational force downward, is constant and is calculated with the formula \( W = mg \). The variable \( g \) is 9.8 m/s\(^2\), usually written 9.8 m/s\(^2\). The opposing drag force, \( D \), from the air, continues to increase until terminal velocity is reached. The drag force depends on the shape and position of the sky diver. Drag is calculated from a complex formula.

The sky diver's net force is weight minus drag, \( W - D \). Using net force \( W - D \) for \( F \), acceleration is found as follows:

\[
a = \frac{F}{m} = \frac{(W - D)}{m}.
\]

When weight equals drag, \( W = D \) becomes zero; therefore, acceleration becomes zero. The sky diver stops accelerating and reaches maximum velocity, which is called terminal velocity.

Build Science Skills

Observing
Purpose Students investigate air resistance and its effect on the rate of acceleration.

Materials sheet of paper, stopwatch, auditorium stage

Class Time 25 minutes

Procedure Have one student drop the flat sheet of paper from the auditorium stage while another times the paper's descent with the stopwatch. A third student can record the time.

Repeat the experiment, but this time have the student crumple the sheet of paper. Compare the descent times. Ask,

What variables remained constant and what variables changed? (Air resistance changed. Weight (mass) and acceleration due to gravity, \( g \), remained the same.) Why are the times different? (A greater air resistance force acts on the flat sheet, causing it to fall more slowly.) If both the flat and crumpled sheets were dropped in a vacuum where there is no air resistance, what would happen? (The time it takes the sheet to fall would be the same.)

Expected Outcome The increased force of air resistance acting on the flat sheet causes it to fall more slowly than the crumpled sheet.

Visual, Logical

Terminal Speed

Imagine you are a sky diver about to step out of a plane and fall through the air. What forces will you experience during your fall? How can you use these forces to combine an exhilarating experience with a safe landing?

Sky diving relies on two principles of physics. First, if there is nothing to support you, the force of gravity will cause you to accelerate downward. Second, all fluids—including air—produce a drag force that opposes the motion of an object moving through the fluid. The speed of a falling object increases until the drag force equals the force of gravity. At this point, the net force is zero and the sky diver falls at a constant, terminal speed.

The actual terminal speed depends on several factors. For example, an object with greater mass has a greater gravitational force on it, increasing its terminal speed. Thinner air, such as air at very high altitudes, increases velocity by decreasing the drag force. A sky diver can also partially control the drag force, and terminal speed, by changing shape. Opening the parachute dramatically increases the drag force and lowers the terminal speed to about 4.5 meters per second—a speed suitable for landing.
The Sky Diving Sequence

No matter what the starting altitude, any sky dive consists of the same basic stages, starting with the jump from the plane.

- **Jumping out** Upon jumping, the sky diver begins accelerating at a rate of 9.8 meters per second per second in free fall. Within a few seconds she will reach maximum speed.

- **Falling freely** Sky divers usually jump from a height of about 3000 meters and fall freely for about 45 seconds before opening the parachute. The top speed reached, known as terminal speed, is about 52 meters per second. Falling from very high altitudes, where the air is thinner and the drag force is less, can produce higher terminal speeds.

- **Slowing the fall** Usually the parachute is fully open by the time the sky diver is 300 meters above the ground. The parachute causes rapid deceleration and allows the sky diver to make a steady descent, using the control lines to steer.

- **Landing** The sky diver pulls down on the control lines to achieve a safe and steady low-speed landing.

**Going Further**

- Research the development and use of the parachute and prepare a poster presentation of your findings. Be sure to include a development time line listing names and dates of significant contributions and advances.
- Take a Discovery Channel Video Field Trip by watching “Air Forces.”

**Discovery Channel Video Field Trip**

**Air Forces**

After students have viewed the Video Field Trip, ask them the following questions: What is the net force on the sky diver just before stepping out of the plane? Explain your answer. (Zero. The force of gravity is balanced by the force the aircraft exerts so that the sky diver is not yet accelerating.) How do the force of gravity and air resistance compare as the sky diver is falling and gaining speed? Explain your answer. (The force of gravity is greater than the air resistance because the gravitational force is downward and the air resistance is upward, resulting in a net force downward.) How does the force of air resistance change as the sky diver gains speed while falling? (The air resistance increases.) What happens to the sky diver’s speed when the force of air resistance becomes equal to the force of gravity? Explain your answer. (The sky diver’s speed stays the same. Gravity and air resistance balance each other. Because the net force is zero, there is no acceleration.) How does the force of air resistance change when the sky diver’s parachute opens? (It suddenly increases.)

Students may think that objects in a vacuum fall at a constant speed. Help them to realize that objects accelerate as they fall. Earth’s gravitational acceleration in a vacuum is approximately 9.8 m/s², meaning that the velocity increases 9.8 m/s every second, or 9.8 m/s², as the object falls.

Without a vacuum, however, air resistance increases as the object falls until the object reaches terminal velocity. Reinforce that all objects in a vacuum accelerate at the same rate, but that they do not fall at a constant speed until they reach terminal velocity.

**Logical**

**Going Further**

Student poster presentations may include references to Leonardo da Vinci, Fausto Veranzio, and Joseph and Jacques Montgolfier. Visual, Verbal
Think physics the next time you go to an amusement park. There is no better place than an amusement park to see Newton's laws in action. As you experience sudden starts, stops, changes in direction, and possibly even free fall, you can be sure that the laws of physics control your motion. The bumper cars in Figure 15 illustrate momentum and Newton's third law of motion, the subjects of this section.

If you have ever driven a bumper car, you know your goal is to slam into another car head on. When you collide with the other car, you do so with enough force to jolt the other driver almost out of the seat. There are two parts to this collision, however—the collision also causes your own car to rebound sharply. Newton's third law of motion explains the behavior of the bumper cars during a collision.

**Figure 15** When this bumper car collides with another car, two forces are exerted. Each car in the collision exerts a force on the other.
**Newton’s Third Law**

A force cannot exist alone. Forces always exist in pairs. According to Newton’s third law of motion, whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first object. These two forces are called action and reaction forces.

**Action and Reaction Forces** The force your bumper car exerts on the other car is the action force. The force the other car exerts on your car is the reaction force. These two forces are equal in size and opposite in direction.

Pressing your hand against a wall also produces a pair of forces. As you press against the wall, your hand exerts a force on the wall. This is the action force. The wall exerts an equal and opposite reaction force against your hand. This is the reaction force.

A similar situation occurs when you use a hammer to drive a nail into a piece of wood. When the hammer strikes the nail, it applies a force to the nail. This action force drives the nail into the piece of wood. Is there a reaction force? According to Newton’s third law there must be an equal and opposite reaction force. The nail supplies the reaction force by exerting an equal and opposite force on the hammer. It is this reaction force that brings the motion of the hammer to a stop.

**Action-Reaction Forces and Motion**

Can you determine the action and reaction forces occurring in Figure 16? The swimmer uses her arms to push against the water and create an action force. The action force causes the water to move in the direction of the action force. However, the water also exerts its equal and opposite reaction force on the swimmer. The reaction force acts on the swimmer and pushes her forward through the water.

Unlike the swimmer in Figure 16, not all action and reaction forces produce motion. Pushing against the wall with your hand is an example of an action-reaction force pair that does not result in motion.

**Action-Reaction Forces Do Not Cancel** You may be wondering why the action and reaction forces acting on the swimmer in Figure 16 do not cancel each other and produce a net force of zero. The reason is that the action and reaction forces do not act on the same object. The action force acts on the water, and the reaction force acts on the swimmer. Only when equal and opposite forces act on the same object do they result in a net force of zero.

**Why don’t action and reaction forces cancel each other out?**

**Customize for English Language Learners**

**Use Interaction**

One of the best ways to teach science content and language to all students, including English language learners, is to encourage verbal interaction, such as that which occurs in a group. You may help English language learners by using group activities in this section, as the section lends itself well to activities involving action-reaction forces. Since all force involves action-reaction, you may start with activities that make the concept easy to learn. For example, demonstrate that standing on the floor results in a reaction force of the floor, which is actually pushing back. Encourage students to work in groups to list other action-reaction forces.
Momentum

Imagine a loaded shopping cart and a small glass marble are both slowly rolling toward you at the same speed. The marble is easier to stop. Intuitively, you know that a loaded shopping cart is harder to stop because it has a greater mass. If the marble were moving 100 times faster than the shopping cart, which would be easier to stop? **Momentum** is the product of an object's mass and its velocity. An object with large momentum is hard to stop. An object has a large momentum if the product of its mass and velocity is large. The momentum for any object at rest is zero. A huge rocket such as the space shuttle has zero momentum as it sits on the launch pad. A small 1-kilogram meteor traveling at the very high speed of 20 kilometers per second has a very large momentum.

**Amusement Park Rides**

For more than a hundred years, engineers have been designing rides that subject riders to jarring motions, large accelerations, terrifying heights, sinkings, or free falls.

**Momentum**

The first true roller coaster in America appears at Coney Island, New York.

The George Ferris Giant Wheel, named after the inventor, debuts at the Columbian Exposition in Chicago. A ride costs 50 cents.

Trolley companies build amusement parks to encourage weekend travel.
You can calculate momentum by multiplying an object’s mass (in kilograms) and its velocity (in meters per second).

**Momentum Formula**

\[
\text{Momentum} = \text{Mass} \times \text{Velocity}
\]

Momentum is measured in units of kilogram-meters per second.

Which has more momentum, a 0.046-kilogram golf ball with a speed of 60.0 meters per second, or a 7.0-kilogram bowling ball with a speed of 6.0 meters per second?

- **Momentum (golf ball)** = \(0.046 \times 60.0 = 2.8\) kg\(\cdot\)m/s
- **Momentum (bowling ball)** = \(7.0 \times 6.0 = 42\) kg\(\cdot\)m/s

The bowling ball has considerably more momentum than the golf ball.

**Amusement Park Rides**

Have students read about the amusement park inventions shown in the timeline. Then, ask them what other science-related events they would add to the timeline. Suggestions may include these events: Orville and Wilbur Wright’s first flight at Kitty Hawk, North Carolina, in 1903; Henry Ford’s initial Model-T production in 1908; the opening of the 50-mile Panama Canal in 1914; or Charles Lindbergh’s 33-hour, non-stop flight in a monoplane from New York to Paris in 1927. Then, ask students how all of the events in the timeline affected both science and society, including those events that students have added.

**Build Math Skills**

**Equations and Formulas**

Many students have difficulty relating the description of a relationship given in the text with the equation used to solve problems. Have students read Momentum. Ask them to use the description from the text to write the momentum equation (Momentum = Mass \(\times\) Velocity). Once they have written the equation, have them practice solving the equation for each of the three possible unknowns: momentum, mass, and velocity. Tell them that it is important to practice working with the units (kg\(\cdot\)m/s).

Refer students to the text samples on this page.

**Logical, Portfolio**

Direct students to the Math Skills in the Skills and Reference Handbook at the end of the student text for additional help.

Explanations describing the forces and resulting motion that occur as a sequence of events will vary depending on which amusement park ride is chosen. Paragraphs should discuss forces, acceleration, and momentum.

**Verbal, Portfolio**
Conservation of Momentum

Use Visuals

Figure 17 To help teach conservation of momentum, point out to students that each car’s momentum is written on the car, and its velocity is written above the car. Ask students to describe the motion in 17A before and after the collision. (The blue car, going in the same direction as the green car, but faster, catches the green car and collides with it. After the collision, part of the momentum from the blue car is transferred to the green car, but the total momentum is still the same.) Ask, What is the momentum of the blue car and the green car before and after the collision in 17A? (Before the collision, the blue car’s momentum is 300,000 kg·m/s and the green car’s momentum is 150,000 kg·m/s. After the collision, the blue car’s momentum is 150,000 kg·m/s and the green car’s momentum is 300,000 kg·m/s.) What is the sum of the momentum before and after the collision? (The total momentum is 450,000 kg·m/s before and after the collision.) How does this show conservation of momentum? (The total momentum doesn’t change.) Repeat the above questions for Figures 17B and 17C.

Visual, Logical

Conservation of Momentum

What happens to momentum when objects collide? Look at the collisions in Figure 17. Under certain conditions, collisions obey the law of conservation of momentum. In physics, the word conservation means that something has a constant value. That is, conservation of momentum means that momentum does not increase or decrease.

Imagine two trains colliding as shown in Figure 17A. If the two cars are part of a closed system, then momentum is conserved. A closed system means other objects and forces cannot enter or leave a system. Objects within the system, however, can exert forces on one another. According to the law of conservation of momentum, if no net force acts on a system, then the total momentum of the system does not change.

Thus, if we consider the two train cars as a closed system, the cars can exert forces on each other. But overall, the total momentum of the system is conserved. In a closed system, the loss of momentum of one object equals the gain in momentum of another object—momentum is conserved.

For: Activity on momentum
Visit: PHSchool.com
Web Code: ccp-2123

Students can interact with simulations of momentum and conservation of momentum online.
A class studied the speed and momentum of a 0.25-kilogram ball dropped from a bridge. The graph shows the momentum of the ball from the time it was dropped until the time it hit the river flowing below the bridge.

Three different closed systems are shown in Figure 17. Each system consists of two train cars with the same mass that collide. In Figures 17A and 17B, the train cars collide and then bounce apart. In Figure 17C, the cars collide and then join together. Examine the momentum of each train car before and after the collision. Note that the total momentum before and after each collision does not change. The momentum is conserved.

### Section 12.3 Assessment

#### Reviewing Concepts
1. Using Newton’s third law, explain what is meant by action and reaction pairs of forces.
2. State in your own words the formula for momentum.
3. What is a necessary condition for the conservation of momentum?
4. If an eagle and a bumblebee are traveling at 8 km/hr, which has more momentum? Explain.

#### Critical Thinking
5. A friend tells you that a rowboat is propelled forward by the force of its oars against the water. First, explain whether the statement is correct, and then identify the action and reaction forces.

#### Inferring
6. Explain how Newton’s third law of motion is at work when you walk.

#### Applying Concepts
7. Explain in terms of Newton’s third law why someone who tries to jump from a canoe to a riverbank may fall into the water.

#### For Extra Help
Show students how they can locate the desired momentum value by moving their finger up the vertical axis until they reach the value. Then, they can move horizontally to the right until they hit the plotted line. Finally, they can move down to the horizontal axis and determine the time. For question 3, have students find the momentum for a time of 1.25 s. Then, demonstrate how students can find the ball’s velocity by rewriting the momentum equation as velocity equals momentum divided by mass. Logical

Student paragraphs will vary but must mention that forces always exist in pairs, and that according to Newton’s third law, every action force has an equal and opposite reaction force.

#### Answer to . . .

Figure 17  30,000 kg
12.4 Universal Forces

1 FOCUS

Objectives
12.4.1 Identify the forms of electromagnetic force that can both attract and repel.
12.4.2 Identify and describe the universal forces acting within the nucleus.
12.4.3 Define Newton’s law of universal gravitation and describe the factors affecting gravitational force.
12.4.4 Describe centripetal force and the type of motion it produces.

Reading Focus

Build Vocabulary

Compare-Contrast Table
Have students each make a table similar to the table on p. 378. Have students use electromagnetic force, nuclear forces, and gravitational force as the entries under the heading Force. For Relative Strength, have students use words such as weak, weaker, weakest, strong, stronger, and strongest. Suggest that students make this table as they read in order to help them learn the section’s content.

Reading Strategy

a. Neutrons and protons
b. Very short (decreases rapidly beyond the diameter of a few protons)
c. Very strong (100 times stronger than electrical repulsion force at that distance)
d. All particles
e. Short f. Weaker than the strong nuclear force.

2 INSTRUCT

Electromagnetic Forces

Build Reading Literacy

Relate Cause and Effect
Refer to page 260D in Chapter 9, which provides the guidelines on relating cause and effect.
Encourage students to make a list of cause-and-effect relationships as they read about electromagnetic forces. Then, have students compare their lists. Students may list the behavior of charged objects when they approach one another, the clinging of clothes that have become charged, and the repulsion or attraction of magnetic poles. Verbal, Logical

Reading Focus

Key Concepts
- What force can attract and repel?
- What force holds the nucleus together?
- What is Newton’s law of universal gravitation?

Vocabulary
- electromagnetic force
- strong nuclear force
- weak nuclear force
- gravitational force
- centripetal force

Reading Strategy

Comparing and Contrasting
Copy the table below. After reading the section, compare the two universal nuclear forces by completing the table.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong nuclear</td>
<td>a.</td>
<td>b.</td>
<td>c.</td>
</tr>
<tr>
<td>Weak nuclear</td>
<td>d.</td>
<td>e.</td>
<td>f.</td>
</tr>
</tbody>
</table>

If you could travel to a distant planet in another galaxy, what would you expect to find? The scene shown in Figure 18 is one possibility. Although this world looks so different from the one you know, some things on this distant planet would be familiar—the forces.

Observations of planets, stars, and galaxies strongly suggest four different forces exist throughout the universe. These forces are known as universal forces. The four universal forces are the electromagnetic, strong nuclear, weak nuclear, and gravitational. All the universal forces act over a distance between particles of matter, which means that the particles need not be in contact in order to affect one another. In addition, each of these forces is affected by the distance between the particles of matter.

Electric and magnetic force are two different aspects of the electromagnetic force. 

Electromagnetic force is associated with charged particles. Electric force and magnetic force are the only forces that can both attract and repel. To understand electric and magnetic forces, recall what you learned about charged particles in Chapter 4.

Section Resources

Print
- Reading and Study Workbook With Math Support, Section 12.4
- Transparencies, Section 12.4

Technology
- Interactive Textbook, Section 12.4
- Presentation Pro CD-ROM, Section 12.4
- Go Online, NSTA SciLinks, Gravity
Electric Forces Electric forces act between charged objects or particles such as electrons and protons. Objects with opposite charges—positive and negative—attract one another. Objects with like charges repel one another. Figure 19 shows that clothes often cling together when they are removed from a dryer. Some clothes, such as cotton socks, lose electrons easily and become positively charged. Other clothes, such as polyester shirts, gain electrons easily and become negatively charged. Because the oppositely charged particles attract one another, the clothes cling together.

Magnetic Forces Magnetic forces act on certain metals, on the poles of magnets, and on moving charges. Magnets have two poles, north and south, that attract each other. Two poles that are alike repel each other. If you have handled magnets, you know that when opposite magnetic poles are brought close, they almost seem to jump together. On the other hand, when two similar poles approach each other, you can feel them pushing apart.

Figure 20 shows a child’s wooden train set whose cars are linked with magnets. Each car has a north pole on one end and a south pole on the other. Children quickly learn that if a train car won’t stick to the one in front of it, the car must be turned around.

What type of force acts between particles with the same electrical charge?

Nuclear Forces

Think about the nucleus of an atom, with its protons crammed into an incredibly small space. Because protons are positively charged, you would expect that an electric force of repulsion would break the nucleus apart. Scientists believe the nucleus would fly apart if there were not another, much stronger, attractive force holding the protons within the nucleus.

Two forces, the strong nuclear force and the weak nuclear force, act within the nucleus to hold it together. The strong nuclear force overcomes the electric force of repulsion that acts among the protons in the nucleus. The weak nuclear force is involved in certain types of radioactive processes.

Strong Nuclear Force The strong nuclear force is a powerful force of attraction that acts only on the neutrons and protons in the nucleus, holding them together. The range over which the strong nuclear forces acts is approximately equal to the diameter of a proton ($10^{-15}$ m). Although this force acts over only extremely short distances, it is 100 times stronger than the electric force of repulsion at these distances.

Address Misconceptions

Some students may think that for an object to become positively charged, it must gain one or more protons. Reinforce the concept that electron transfer leads to charged particles. Electrons have a negative charge. Therefore, gaining electrons makes an object more negative, and losing electrons makes an object more positive.

Logical

Nuclear Forces

Purpose Students observe forces representing the strong force in an atom’s nucleus and the electric force between protons.

Materials 2 magnetic toy train cars or any 2 magnets, wide adhesive tape on a roll (or rubber band)

Procedure Use the toy train cars or magnets to show students that like poles repel. With the cars touching each other, bind them together with adhesive tape. Be sure to tape the cars in such a way that the tape can be easily cut to free the cars. Tell students that the toy train cars are like protons, whose electric charges repel each other, and that the tape is like the strong nuclear force, overcoming the electric charge of the protons. Cut the tape and have students observe the energy released as the cars push away from each other. Relate this to the force released in a nuclear explosion when the nucleus of an atom is split.

Expected Outcome The students realize that the strong nuclear force in an atom’s nucleus is stronger than the electric force between protons.

Visual, Logical

Customize for Inclusion Students

Physically Challenged

To accommodate students who have physical challenges, look for opportunities to include them in tasks that are suited to their motor skills. For example, have students with limited body movements explain the similarities in the way electrically charged particles attract and repel each other and the behavior of opposite magnetic poles. Then, provide them with bar magnets and ask them to demonstrate attractive and repulsive magnetic forces.
Section 12.4 (continued)

Gravitational Force

Investigating Force and Distance

Objective
After completing this activity, students will be able to
• describe how the force of electrostatic attraction is affected by distance.

Skills Focus
Observing, Formulating Hypotheses
Prep Time 5 minutes

Advance Prep
Select a day when the relative humidity is moderate or low to perform this lab.

Class Time 5 minutes

Teaching Tips
• Demonstrate how to charge the balloon and hold it above the bubble.
• Some hair products will interfere with the balloon. In this case, have students rub the balloon against their clothes.

Expected Outcome
The bubbles will be attracted to the charged balloon. The force of this attraction will increase as students bring the balloon closer to the bubbles.

Analyze and Conclude
1. There is very little electrical interaction between objects that are far apart. As the distance is decreased, the attraction between the two objects becomes stronger.
2. If the balloon were brought closer to the bubble, the force of attraction would increase and the bubble would move upwards toward the balloon.

Visual, Logical

Quick Lab

Investigating Force and Distance

Materials
balloon, bubble solution, bubble wand

Procedure
1. Inflate a balloon and then make a knot in its neck to close it. Rub the balloon back and forth against your hair to charge it.
2. Blow several bubbles into the air and hold the charged balloon above them. Observe how the distance between the balloons affects the speed at which the bubbles fall. CAUTION: Quickly wipe up any spilled bubble solution to avoid slips and falls.
3. Try to temporarily suspend a bubble in the air without touching it with the balloon.

Analyze and Conclude
1. Drawing Conclusions
   How does the distance between two objects affect the force of attraction between them?
2. Predicting
   If a bubble were suspended below the balloon, what do you think would happen when you moved the balloon closer to the bubble?

Facts and Figures

Law of Universal Gravitation
Newton came to the conclusion that any two objects in the universe exert a gravitational force of attraction on each other. The force is directed along a line joining the objects’ centers. Newton concluded that the gravitational attraction \( F \) is proportional to the product of the objects’ masses \( m_1 \) and \( m_2 \) and inversely proportional to the square of the distance \( d \) between them. That equation is

\[
F = \frac{G m_1 m_2}{d^2}.
\]

Because the value of \( G \) is very small, the gravitational force is only significant if one or both objects has a large mass and the distance between the objects is not very large. Earth’s gravitational acceleration \( g \) is related to the equation of universal gravitation by the expression \( g = \frac{G m}{r^2} \), where \( m \) is Earth’s mass. In this case, the equation for universal gravitation reduces to the familiar equation \( F = mg \).

Weak Nuclear Force

The other powerful force in the nucleus is the weak nuclear force. As the name implies, the weak force is weaker in strength than the strong nuclear force. The weak nuclear force is an attractive force that acts only over a short range. The short range over which the weak nuclear force acts, about \( 10^{-18} \) meters, is less than the range of the strong nuclear force.

Gravitational Force

Gravity, the weakest universal force, is so much a part of your life that you probably take it for granted. You know from experience that objects fall toward Earth. It was Newton who discovered that gravity affects all objects in the universe. The same force acting on a falling apple is also acting on the moon to keep it in its orbit.

Gravitational force involves much more than just Earth’s gravitational field. Gravitational force is an attractive force that acts between any two masses. Newton’s law of universal gravitation states that every object in the universe attracts every other object.

Thus, Earth exerts a force on an apple, and the apple exerts an equal force on Earth. You exert a gravitational force on your textbook, and your textbook exerts an equal gravitational force on you. The reason you don’t notice gravity pulling your textbook toward you is that your mass and the mass of the textbook are so small. It takes a huge mass such as Earth’s to exert a large gravitational force. The attractive force of gravity acting between two objects is shown in Figure 21.
Gravity Acts Over Large Distances The gravitational force between two objects is proportional to their masses and decreases rapidly as the distance between the masses increases. The greater the mass of the objects, the greater is the gravitational force. Gravitational force decreases with the square of the distance between the objects. As shown in Figures 21A and 21C, if the distance between masses doubles, the force of gravity is only one fourth as strong.

Gravity is the weakest universal force, but it is the most effective force over long distances. Gravity holds you on Earth. It keeps the moon in orbit around Earth, the planets in orbit around the sun, and the stars in orbit in their galaxies. The sun's mass is about 300,000 times the mass of Earth, so the sun's gravitational force is much stronger than that of Earth. The influence of the sun's gravitational force extends well beyond Earth, Pluto, which is almost 40 times farther from the sun than Earth is, has its orbit determined by the gravitational pull of the sun.

What factors affect gravitational force?

The Earth, Moon, and Tides How is the moon kept in orbit around Earth? Recall that the moon has inertia, so according to Newton’s first law, it should continue to move along a straight path until acted upon by a force. That force is Earth’s gravitational force, which acts continuously to pull the moon toward it, as shown in Figure 22.

Earth’s gravitational attraction keeps the moon in a nearly circular orbit around Earth. It works in much the same way that a string tied to an eraser allows you to twirl the eraser in a circle over your head. As you twirl the eraser, the string exerts a centripetal force on the eraser. A centripetal force is a center-directed force that continuously changes the direction of an object to make it move in a circle. This center-directed force causes a continuous change in the direction of the eraser. The result is a circular path. The center-directed force of Earth’s gravity pulls the moon into a nearly circular orbit around Earth.

If you have spent time at the seashore, you have probably noticed that the level of the tide changes throughout the day. The gravitational pull from the moon produces two bulges in Earth’s oceans. One bulge is on the side of Earth closest to the moon. The other bulge is on the side of Earth farthest from the moon. Earth rotates once per day beneath these two bulges. This rotation results in two high and two low tides per day on Earth.

Figure 22 The moon’s inertia and the gravitational pull of Earth result in a nearly circular orbit. The gravitational pull of the moon is the primary cause of Earth’s ocean tides.

Build Science Skills
Observing Take students outside. Tie a string around an eraser, as described in the second paragraph of The Earth, Moon, and Tides. Ask a volunteer to twirl the eraser over his or her head. CAUTION Make sure the students observe this demo stand far away from the student twirling the eraser. Have students observe that the eraser follows a circular orbit. Remind students that inertia causes an object to resist change in motion. Explain that this means that the eraser would travel in a straight path if a force did not pull it into an orbit. Ask the volunteer to slowly twirl the eraser and then let go of the string. Have students observe what happens. Ask, What force kept the eraser moving in a circular orbit? (The centripetal force from the string kept the eraser moving in a circular orbit.) What proof do you have that a centripetal force was acting on the twirling eraser to change its motion? (As soon as the string was released, the eraser moved in a straight line path.) As the eraser is twirled at a constant speed, is it accelerating? Explain your answer. (Yes, acceleration occurs because the eraser is constantly changing direction.)

Visual, Logical
Use Visuals
Figure 22 Use Figure 22 to reinforce the concept of centripetal force and inertia, as discussed in Build Science Skills. Help students to see that gravitational pull is the centripetal (center-directed) force in planetary orbits. Ask, What is the direction of the moon’s velocity in Figure 22? (The moon’s velocity is tangent to its circular path. At the instant shown, the direction of the moon’s velocity is straight down toward the bottom of the page.)

Visual, Logical

Answer to . . .
Mass and distance

Section 12.4 Assessment

**Reviewing Concepts**
1. Which universal force can repel as well as attract?
2. Which universal force acts to hold the nucleus together?
3. State in your own words what is meant by Newton's law of universal gravitation.
4. How does friction with the atmosphere affect the speed of an artificial satellite?

**Critical Thinking**
5. Using Models The moon in its orbit around Earth behaves like a ball at the end of a string being swung above your head. Explain the forces involved.

6. Predicting If the speed of an orbiting satellite decreases, how might you expect its orbit to change?
7. Inferring Explain how Newton's third law and his law of universal gravitation are connected.

**Writing in Science**

Paragraph

Writing a short paragraph comparing the similarities and differences of the universal forces. Discuss the distances over which the forces act and whether each force attracts, repels, or can do either.

Satellites in Orbit Artificial satellites are launched into orbit by a rocket or space shuttle. Why doesn’t a satellite in a high orbit need to fire rocket engines continuously to remain in orbit? Much like the moon, the satellite needs only the centripetal force provided by gravity and its inertia to maintain its orbit. Satellites in a low orbit, however, are slowed by friction with Earth’s atmosphere. As a satellite loses speed, it loses altitude. Eventually the satellite reenters Earth’s atmosphere and burns up.

Uses of Satellites Currently, there are hundreds of artificial satellites orbiting Earth. These satellites perform many functions. They monitor Earth’s weather, create detailed radar maps of Earth’s surface, use telescopes to gaze deep into space, and study Earth’s climate. Some satellites, like the one shown in Figure 23, receive and transmit radio and microwave signals. Numerous communication satellites are used to receive and transmit cell phone and satellite television signals.

The next time you watch an event on television transmitted by satellite from another part of the world, you should thank Isaac Newton. His work to discover the laws of motion and universal gravitation have led to the development of countless modern technologies.

Section 12.4 Assessment

1. Electromagnetic force is the only force that can both attract and repel.
2. The strong nuclear force acts within the nucleus to hold it together.
3. According to Newton’s law of universal gravitation, every object in the universe attracts every other object.
4. Friction with the atmosphere slows artificial satellites in low orbit.

5. Earth’s gravitational attraction acts as a centripetal force on the moon.
6. It would gradually be pulled closer to Earth and eventually fall out of orbit.
7. According to Newton’s third law, whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first object. Newton’s law of gravitation is a special case of this in which the force is gravity.
Chapter 12
Forces and Motion

How do science concepts apply to your world? Here are some questions you’ll be able to answer after you read this chapter.

- Why doesn’t the pulling by each team in a tug of war always result in motion? (Section 12.1)
- Why do flying squirrels spread their arms and legs when they jump through the air? (Section 12.1)
- What happens to the forward motion of a passenger in a head-on auto accident? (Section 12.2)
- What factors affect the fall of a sky diver? (page 370)
- What brings the head of a hammer to a stop when you drive a nail into a board? (Section 12.3)
- What causes tides? (Section 12.4)

Chapter Pretest

1. What is relative motion? (Relative motion is movement in relation to a frame of reference.)
2. What is the difference between distance and displacement? (Distance is the length of a path between two points. Displacement is the direction from the starting point and the length of a straight line from the starting point to the ending point.)
3. How is average speed calculated? (Total distance is divided by total time.)
4. On a distance-time graph, what does the slope represent? (The slope represents the speed.)
5. What is velocity? (Velocity is speed with direction.)
6. How is acceleration related to velocity? (Acceleration is change in velocity, that is, any change in speed, direction, or both.)
7. A backpack falls out of an open window. The backpack starts from rest and hits the ground 1.0 second later with a velocity of 9.8 m/s. What is the average acceleration of the backpack? (c)
   a. 9.8 m/s
   b. 9.8 m
   c. 9.8 m/s²
   d. All of the above
8. How are mass and weight different? (Mass is a measure of inertia. Weight is the measure of the force of gravity acting on an object.)
Chapter Preview

12.1 Forces
12.2 Newton’s First and Second Laws of Motion
12.3 Newton’s Third Law of Motion and Momentum
12.4 Universal Forces

ENGAGE/EXPLORE

What Starts an Object Moving?

Purpose
In this activity, students begin to use the concept of force to explain movement.

Address Misconceptions
Students may hold the misconception that only a moving object can exert force. To help dispel this misconception, after completing this activity ask students what caused the penny on the end of the row to move. Each penny exerts a force on the next, although only the last penny in the row moves.

Skills Focus
Observing, Formulating Hypotheses

Prep Time 5 minutes

Materials
5 pennies

Advance Prep
Checkers or game chips can be substituted for pennies.

Class Time 10 minutes

Safety
Students should wear safety goggles. Caution students not to observe from a position in which the pennies move toward them.

Teaching Tips
• If students are having difficulty striking the row of coins head-on, they can tape a pair of rulers to the table on either side of the row of coins to create a linear track for the coins to travel along.

Expected Outcome
As the row of coins is struck, the moving coin will stop at the head of the row while the coin at the far end of the row will move away.

Think About It
1. Only the coin at the far end of the row moved away.
2. During the collision, a force was transferred from one coin to the next in the row. Because no horizontal force was acting on the coins before the collision, they did not move at that time. Students may not articulate the abstract concept of a force well at this stage. Although students can reasonably be expected to start developing this concept, they may not express it in formally correct scientific language at this stage.

Visual

Encourage students to view the Video Field Trip “Air Forces.”
Investigating a Balloon Jet

In this lab, you will examine the relationships among force, mass, and motion.

**Problem** How does a jet-powered device move?

**Materials**
- string, 3 m in length
- drinking straw
- 4 long balloons
- masking tape
- stopwatch
- meter stick
- 2 threaded nuts
- 2 chairs

**Skills** Applying Concepts

**Procedure**
1. On a separate sheet of paper, make a copy of the data table shown.
2. Insert the string through the straw and tie each end of the string to the back of a separate chair. Pull the chairs apart until the string is tight and horizontal.
3. Blow up the balloon and then hold the balloon’s opening closed. Record the length of the balloon. Have a classmate attach the balloon lengthwise to the straw using tape.
4. While continuing to hold the balloon’s opening closed, slide the balloon jet to the end of the string as shown.
5. Release the balloon. Measure the time during which the balloon jet moves. Measure the distance that the balloon jet travels along the string. Record the distance and time values in the data table for 0 Nuts Used, Trial 1.
6. Repeat Steps 3 through 5 with a new balloon. Make sure to inflate the balloon to the same size as in Step 3. Record your results in the data table for 0 Nuts Used, Trial 2.
7. Repeat Steps 3 through 6 twice more with a new balloon. This time, tape two nuts to the balloon before releasing it. Record your results in the data table for 2 Nuts Used, Trials 1 and 2.
8. Calculate and record the average speed for each trial. The average speed is equal to the distance divided by the time.

**Analyze and Conclude**

1. **Applying Concepts** Use Newton’s second and third laws to explain the motion of the balloon jet.
2. **Analyzing Data** How did adding mass (nuts) to the balloon jet affect its motion?

<table>
<thead>
<tr>
<th>Number of Nuts Used</th>
<th>Trial Number</th>
<th>Time (seconds)</th>
<th>Distance (centimeters)</th>
<th>Average Velocity (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Length of Inflated Balloon (centimeters)**

**Proeware Lab Manual** Versions of this lab for use with proeware available from Pasco, Texas Instruments, and Vernier are in the Proeware Lab Manual.

**Investigating a Balloon Jet**

**Objective**
After completing this activity, students will be able to:
- use Newton’s second and third laws of motion to explain the movement of a jet-powered device.
- use Newton’s second and third laws of motion to describe how the mass of an object affects its acceleration in response to a force.

**Address Misconceptions**

Many students hold the misconception that a jet functions by pushing against the surrounding air. Point out that rockets work in the vacuum of outer space. Then, ask students to explain how they think the balloon jet moves. As the air in the balloon jet is pushed out the end, it produces an equal and opposite reaction in the balloon, which accelerates the balloon forward.

**Skills Focus** Measuring, Calculating, Applying Concepts

**Prep Time** 5 minutes

**Class Time** 45 minutes

**Expected Outcome** As the balloon is released it will accelerate along the length of the string. Adding the nuts to the mass of the balloon will reduce the time and distance that the balloon travels.

**Analyze and Conclude**

1. The jet’s movement depends on Newton’s third law of motion. The pressurized air inside the sealed balloon pushes outward in all directions, but as long as the air can’t go anywhere, neither can the balloon. As soon as the air inside the balloon is allowed to escape, the force of the air on the opened end of the balloon no longer balances the force of air on the opposite end. The reaction to this action is the movement of the balloon in the opposite direction. Newton’s second law of motion predicts that the balloon will accelerate at a rate that is directly proportional to the force of the compressed air, and inversely proportional to the balloon’s mass.
2. Adding nuts increased the mass of the balloon jet, which reduced its acceleration.

**Logical**
# Planning Guide

## Section Objectives

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<th>Section</th>
<th>Objectives</th>
<th>Standards</th>
<th>Activities and Labs</th>
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</table>
| **12.1 Forces**, pp. 356–362 | - Describe examples of force and identify appropriate SI units used to measure force.  
- Explain how the motion of an object is affected when balanced and unbalanced forces act on it.  
- Compare and contrast the four kinds of friction.  
- Describe how Earth’s gravity and air resistance affect falling objects.  
- Describe the path of a projectile and identify the forces that produce projectile motion. | A-1, A-2, B-4, G-1 |  
SE Quick Lab: Observing the Effects of Friction, p. 360  
TE Build Science Skills: Measuring, p. 357 |
- Describe Newton’s second law of motion and use it to calculate acceleration, force, and mass values.  
- Relate the mass of an object to its weight. | A-1, A-2, B-4, F-1, G-1, G-2, G-3 |  
SE Quick Lab: Investigating Inertia, p. 365  
TE Teacher Demo: Force and Acceleration, p. 365  
TE Teacher Demo: Newton’s Second Law of Motion, p. 367  
LM Investigation 12A: Investigating Gravitational Acceleration and Fluid Resistance  
LM Investigation 12B: Testing Galileo’s Hypothesis |
| **12.3 Newton’s Third Law of Motion and Momentum**, pp. 372–377 | - Explain how action and reaction forces are related according to Newton’s third law of motion.  
- Calculate the momentum of an object and describe what happens when momentum is conserved during a collision. | B-4, G-1, G-2, G-3 |  
SE Exploration Lab: Investigating a Balloon Jet, p. 383  
TE Build Science Skills: Predicting, p. 373  
TE Teacher Demo: Momentum, p. 374 |
| **12.4 Universal Forces**, pp. 378–382 | - Identify the forms of electromagnetic force that can both attract and repel.  
- Identify and describe the universal forces acting within the nucleus.  
- Define Newton’s law of universal gravitation and describe the factors affecting gravitational force.  
- Describe centripetal force and the type of motion it produces. | A-1, A-2, B-1, B-4, E-2, G-1, G-2, G-3 |  
SE Quick Lab: Investigating Force and Distance, p. 380  
TE Teacher Demo: Nuclear Forces, p. 379 |
### Materials for Activities and Labs

**Quantities for each group**

**STUDENT EDITION**

- **Inquiry Activity, p. 355**  
  5 pennies
- **Quick Lab, p. 360**  
  2 rubber erasers, sticky notes, scissors, metric ruler
- **Quick Lab, p. 364**  
  index card, coin
- **Quick Lab, p. 380**  
  balloon, bubble solution, bubble wand
- **Exploration Lab, p. 383**  
  string (3 m in length), drinking straw, 4 long balloons, masking tape, stopwatch, meter stick, 2 threaded nuts, 2 chairs

**TEACHER’S EDITION**

- **Teacher Demo, p. 365**  
  2 identical toy cars (or dynamics carts), 2 student volunteers, identical floor surface for each car
- **Teacher Demo, p. 367**  
  wind-up toy car, 3 metal washers, tape
- **Build Science Skills, p. 370**  
  sheet of paper, stopwatch, auditorium stage
- **Build Science Skills, p. 373**  
  soccer ball, several heavy books
- **Teacher Demo, p. 374**  
  water-filled balloons, pillow
- **Teacher Demo, p. 379**  
  2 magnetic toy train cars or any 2 magnets, wide adhesive tape on a roll (or rubber band)

### Chapter Assessment

<table>
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<tr>
<th>CHAPTER ASSESSMENT</th>
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<td><strong>SE</strong> Chapter Assessment, pp. 385–386</td>
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<table>
<thead>
<tr>
<th>STANDARDIZED TEST PREP</th>
</tr>
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<tbody>
<tr>
<td><strong>SE</strong> Chapter 12, p. 387</td>
</tr>
<tr>
<td><strong>TP</strong> Diagnose and Prescribe</td>
</tr>
</tbody>
</table>

Interactive Textbook with assessment at PHSchool.com
Forces 12.1

A force, which can be simply defined as any push or pull, is the cause of acceleration (change in velocity). Force is a vector, that is, it has magnitude and direction. The SI unit of force is the newton (N), the amount of force that produces an acceleration of $1 \text{ m/s}^2$ on a $1 \text{ kg}$ mass.

If all forces on an object are combined and the net force is zero, the object does not accelerate. If the net force is not zero, velocity remains constant.

Friction 12.1

Friction is the opposing force that touching objects experience as they move past one another. Static friction is the force of resistance to motion when two contacting surfaces are stationary. Kinetic friction (which includes sliding, rolling, and fluid friction) is the force of resistance that opposes the relative motion of two contacting surfaces moving past one another.

Laws of Motion 12.2 and 12.3

Newton’s first law of motion says that an object at rest will remain at rest, and an object in motion will continue in motion with constant velocity unless it experiences a net force.

Newton’s second law of motion says that an object’s acceleration is directly proportional to the net force acting on it and

Address Misconceptions

Some students may incorrectly think that only animate objects can exert a force. However, gravity is inanimate, as are many other forces. For a strategy to overcome this misconception, see Address Misconceptions on page 358.
inversely proportional to its mass \((a = F/m, F = ma)\). One application is the measurement of weight. Weight, \(W\), is a force, while the gravity, \(g\), is the acceleration \((W = mg)\). On Earth’s surface, \(g\) is approximately 9.8 m/s\(^2\).

In the 1680s, Newton related the laws in his book *Philosophiae Naturalis Principia Mathematica*. He stated that force is proportional to change in momentum. Mathematically, this law is \(F = m \times \Delta v\). A change in velocity is the same as acceleration, so this equation became \(F = ma\).

Newton’s third law of motion says that, when object A exerts a force on object B, object B exerts a force on object A that is equal in magnitude and opposite in direction.

**Universal Forces** 12.4

Three of the four universal forces are electromagnetic, strong nuclear, and weak nuclear. The range and relative strengths of the universal forces are summarized in the table below.

<table>
<thead>
<tr>
<th>Force</th>
<th>Relative Strength</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong nuclear</td>
<td>1</td>
<td>(-10^{-15} \text{ m})</td>
</tr>
<tr>
<td>Electromagnetic</td>
<td>(10^{-2})</td>
<td>(\frac{1}{r})</td>
</tr>
<tr>
<td>Weak nuclear</td>
<td>(10^{-13})</td>
<td>(&lt; 10^{-18} \text{ m})</td>
</tr>
<tr>
<td>Gravitational</td>
<td>(10^{-38})</td>
<td>(\frac{1}{r^2})</td>
</tr>
</tbody>
</table>

The electromagnetic force consists of both the electric force and the magnetic force. These forces are found in regions in which there are electric and magnetic fields. Michael Faraday discovered that a changing magnetic field produces an electric field, and James Clerk Maxwell illustrated that a changing electric field produces a magnetic field.

The nucleus of an atom is held together by attractions among protons and neutrons called the strong nuclear force and the weak nuclear force. The strong nuclear force is greater than the electric repulsion of the protons’ positive forces and therefore overcomes that repulsion, holding them together. The attraction due to the strong force, however, occurs over a very short distance, less than \(3 \times 10^{-15} \text{ m}\), or about three protons’ width. The weak nuclear force is stronger than gravitational force.

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**Build Reading Literacy**

**Visualize**

**Forming Mental Pictures**

**Strategy** Help students understand and recall complex text by forming mental pictures as they read. In some cases, visual elements of the text can aid students in visualizing; in other cases students must rely solely on text descriptions. Choose several paragraphs from Chapter 12, such as the four on p. 358. If possible, include at least one paragraph that has an accompanying figure and at least one other paragraph that refers to concepts or events that are not illustrated in visual elements, such as diagrams, charts, graphs, or photographs.

**Example**

1. Have students keep their books closed. Tell them to listen while you read and to visualize, or form mental pictures of, each object or action you read about.
2. Then, read a paragraph or so aloud, pausing frequently to demonstrate, by thinking aloud, how to visualize each thing described. When reading complex or technical text, pausing after each phrase will often be appropriate.
3. Tell students to continue visualizing. Slowly and clearly, read on. Then, select a logical stopping point and discuss with students the images they visualized.
4. If there is an accompanying figure, have students open to it and see how it compares with their visualizing. Point out that visuals in the text help readers picture what they are reading.
5. Have students work with partners to practice by taking turns reading and visualizing aloud. Tell them to expand on visuals that appear in the text and to describe their own mental images of ideas or events that are not shown in visuals.

See p. 368 for a script on how to use the visualize strategy with students. For additional Build Reading Literacy strategies, see pp. 357, 372, and 378.

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Some students may think that objects become positively charged because they have gained protons. What takes place is electron (not proton) transfer. Electrons have a negative charge. For a strategy to overcome this misconception, see Address Misconceptions on page 379.
### 12.1 Forces

**Key Concepts**
- A force can cause a resting object to move, or it can accelerate a moving object by changing the object’s speed or direction.
- When the forces on an object are balanced, there is no change in the object’s motion. When an unbalanced force acts on an object, the object accelerates.
- There are four main types of friction: static friction, sliding friction, rolling friction, and fluid friction.
- Earth’s gravity acts downward toward the center of Earth. Gravity causes objects to accelerate downward, whereas air resistance acts in the direction opposite to the motion and reduces acceleration.
- The combination of initial forward velocity and downward vertical force of gravity cause a projectile to follow a curved path.

**Vocabulary**
- force, p. 356; newton, p. 357; net force, p. 357; friction, p. 359; static friction, p. 359; sliding friction, p. 359; rolling friction, p. 360; fluid friction, p. 360; air resistance, p. 360; gravity, p. 361; terminal velocity, p. 361; projectile motion, p. 362

### 12.2 Newton’s First and Second Laws of Motion

**Key Concepts**
- According to Newton’s first law of motion, the state of motion of an object does not change as long as the net force acting on the object is zero.
- According to Newton’s second law of motion, the acceleration of an object is equal to the net force acting on it divided by the object’s mass.
- Acceleration = \( \frac{\text{net force}}{\text{mass}} \)
- Weight = Mass \( \times \) Acceleration due to gravity
- Mass is a measure of the inertia of an object; weight is a measure of the force of gravity acting on an object.

**Vocabulary**
- inertia, p. 364; mass, p. 365; weight, p. 368

### 12.3 Newton’s Third Law of Motion and Momentum

**Key Concepts**
- According to Newton’s third law of motion, forces exist as equal and opposite force pairs.
- Momentum = Mass \( \times \) Velocity
- An object has a large momentum if the product of its mass and velocity is large.
- Momentum is conserved in a closed system.

**Vocabulary**
- momentum, p. 374; law of conservation of momentum, p. 376

### 12.4 Universal Forces

**Key Concepts**
- Electric and magnetic forces are the only forces that can both attract and repel.
- The strong and weak nuclear forces hold the nucleus together.
- Newton’s law of universal gravitation states that every object in the universe attracts every other object.

**Vocabulary**
- electromagnetic force, p. 378; strong nuclear force, p. 379; weak nuclear force, p. 380; gravitational force, p. 380; centripetal force, p. 381

### Thinking Visually

**Concept Map** Use the information on forces from the chapter to complete the concept map below.
Assessment

CHAPTER 12

Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. Which is not a force?
   a. friction  
   b. gravity  
   c. momentum  
   d. weight

2. You push on a box and are unable to move it. What force opposes your push?
   a. static friction  
   b. rolling friction  
   c. sliding friction  
   d. air resistance

3. Air resistance depends on
   a. the velocity of a moving object.  
   b. the weight of a moving object.  
   c. the mass of a moving object.  
   d. the inertia of a moving object.

4. What force besides gravity acts on a projectile?
   a. weak nuclear  
   b. electrical  
   c. magnetic  
   d. air resistance

5. Newton’s first law of motion is sometimes called the law of
   a. inertia  
   b. conservation  
   c. momentum  
   d. resistance.

6. A change in which of the following affects the weight of an object?
   a. momentum  
   b. velocity  
   c. acceleration due to gravity  
   d. friction

7. Which represents Newton’s second law?
   a. \( v = \frac{1}{t} \)  
   b. \( a = \frac{1}{t} \)  
   c. \( F = ma \)  
   d. \( f = 0 \)

8. For every action force there is a
   a. reaction force  
   b. net force  
   c. friction force  
   d. unbalanced force.

9. Momentum depends upon
   a. force only.  
   b. velocity and friction.  
   c. weight and mass.  
   d. mass and velocity.

10. What force holds the nucleus together?
    a. magnetic  
    b. strong nuclear  
    c. gravitational  
    d. centripetal

Understanding Concepts

11. Three forces act on a wooden crate that is initially at rest as shown below. Determine the net force acting on the crate and describe the resulting motion of the crate.

   \[ \begin{align*}
   3 \text{ N} & \quad 8 \text{ N} \\
   5 \text{ N} & \quad 8 \text{ N}
   \end{align*} \]

12. Suppose two 4-newton forces act on an object in the same direction. What is the net force on the object?

13. Five different forces act on an object. Is it possible for the net force on the object to be zero? Explain.

14. What happens to an object when an unbalanced force acts on it?

15. You push harder and harder on a box until it begins sliding across the floor. Which was the stronger of the forces acting on the box, static friction or sliding friction?

16. How do ball bearings reduce friction in machinery?

17. Explain why a falling object subjected to Earth’s gravity does not continue to accelerate forever.

18. What is the difference between mass and weight?

19. What is an action-reaction pair?

20. What must you know to determine which of two vehicles traveling at the same velocity, has the greater momentum?

21. What force is responsible for your socks sticking together after they have been in a clothes dryer?

22. What particles do the strong and weak nuclear forces act on?

23. What force is responsible for the orbits of the planets in the solar system?

Assessment (continued)

Understanding Concepts

11. The net force is zero and the crate does not move.
12. 8 N
13. Yes, all of the forces can cancel one another.
15. Static friction
16. A machine part rubs against a rolling surface rather than a flat surface, thus reducing the size of the surfaces in contact and the amount of friction.
17. As the velocity of the falling object increases, the air resistance acting on it also increases. Eventually the opposing force of air resistance equals the object’s weight, and the object reaches its terminal velocity.
18. Weight is a measure of the force of gravity acting on an object. Mass is the amount of matter an object contains as measured by its inertia.
19. When a force is exerted on an object, the object responds with an equal and opposite force. The forces generated in this way are called action-reaction pairs.
20. The mass of each vehicle
21. Electric force
22. Strong: protons and neutrons; weak: all particles
23. Gravitational force
Chapter 12

Critical Thinking
24. The arrow follows a projectile path. It begins to fall as soon as it leaves the bow. Thus, if the arrow is aimed directly at the target, it will hit the target below the bull's-eye.

25. Newton's third law of motion describes the action and reaction forces that occur when the ball is struck by the racquet and when the ball strikes the wall. Newton's second law of motion describes the acceleration of the tennis ball when a force from the racquet or the wall is applied to it.

26. An object's weight is six times greater on Earth, however, its mass is the same in both locations.

27. 0.6 m/s²; 5 kg

28. The inertia, mass, and weight of the 10-kg rock are 10 times greater than that of the 1-kg rock.

29. The air resistance is greatly increased when the top is down resulting in fewer miles per gallon.

30. Increasing the force applied to the object or decreasing the mass of the object will increase the acceleration of the object.

Math Skills
31. 0.25 m/s²

32. 200 kg•m/s

33. 290 N

Concepts in Action
34. The fluid friction from the hovercraft's contact with the air is less than an ordinary boat's fluid friction from contact with the water.

35. The racer could be tested in a wind tunnel or out on a road. If the clothing is effective, the force on the racer in the wind tunnel will decrease. The racer's maximum speed on the road will increase.

36. Attach a spring scale to the box. Gradually increase the force applied by pulling on the spring scale. The smallest measured force on the spring scale that moves the box equals the force of static friction.

37. All of the force acting on the object are equal to the force applied at the drive wheels (supplied by the engine).

38. Applying Concepts: What are the two ways in which the acceleration of an object can be increased?

Critical Thinking
24. Applying Concepts: When shooting an arrow at a target, why is it advisable to aim above the bull's-eye rather than directly at it?

25. Inferring: When a tennis player practices by hitting a ball against a wall, which of Newton's laws of motion is the player making use of?

26. Comparing and Contrasting: The moon's gravity is only one sixth that of Earth's. Explain how the weight and mass of an object differ between the two locations.

27. Interpreting Graphs: The graph below shows the relationship between the force acting on an object and the acceleration of the object. What is the acceleration of the object when a 3-newton force acts on it? What is the object's mass?

![Graph](image)

Math Skills
31. Using Formulas: A 100-kg crate, sliding on a floor, is brought to a stop by 25-N force. What is the deceleration of the crate?

32. Calculating: What is the momentum of an 80-kg runner moving at the speed of 2.5 m/s?

33. Using Formulas: What is the weight on Earth of a girl with a mass of 30 kg? The acceleration due to gravity on Earth is 9.8 m/s².

Concepts in Action
34. Hovercraft, which move over water, are propelled by a water jet. Explain why this is possible.

35. Making Judgments: Imagine that you have designed clothing for professional bicycle racers. How could you judge the effectiveness of the clothing at improving a racer's speed?

36. Designing an Experiment: Explain how you could determine the force of static friction acting on a box that is resting on a rough floor.

37. Writing in Science: Consider an automobile cruising at a constant speed on the highway. Write a paragraph summarizing the forces acting on the car. Be sure to include the force supplied by the engine and at least two types of friction acting on the car.

Performance-Based Assessment
Communicating Results: Draw a cartoon that illustrates one of Newton's laws in an amusing way. You and your classmates might display your cartoons for the whole school to enjoy.

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Performance-Based Assessment
Drawings will vary but must properly illustrate one of Newton's laws.

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Forces and Motion

Standardized Test Prep

1. Which of the following correctly lists friction types (excluding fluid friction) from weakest to strongest?
   (A) sliding, static, magnetic
   (B) static, rolling, sliding
   (C) weak, strong, nuclear
   (D) rolling, sliding, static
   (E) static, sliding, rolling

2. Which statement about an object falling at terminal velocity is TRUE?
   (A) Unbalanced forces act on the object.
   (B) The net force acting on the object is zero.
   (C) The object is accelerating.
   (D) The object is traveling in a circular path.
   (E) No fluid friction acts on the object.

3. An object changes direction as it moves. Which of the following is FALSE?
   (A) The acting net force is not zero.
   (B) An unbalanced force acts on the object.
   (C) The object is accelerating.
   (D) A centripetal force must act on the object.
   (E) The object's inertia remains unchanged.

4. Which has the greatest momentum?
   (A) a huge boulder at rest
   (B) a small pebble that is tossed into the air
   (C) a baseball after it is hit with a bat
   (D) a small pebble at rest
   (E) a car traveling on a highway

5. If \( A = 60 \text{ N}, B = 20 \text{ N}, C = 30 \text{ N}, D = 30 \text{ N}, \) and \( E = 30 \text{ N}, \) which of the following statements is FALSE?
   (A) A net force of 50 N acts on the crate and the crate moves to the right.
   (B) The crate accelerates to the right.
   (C) The net force in the vertical direction is zero.
   (D) Force C represents the weight of the crate.
   (E) Forces C and E represent balanced forces acting in the vertical direction.

6. Which force represents the sliding friction force?
   (A) A
   (B) B
   (C) C
   (D) D
   (E) E

Choose the letter that best answers the question or completes the statement.

What is the acceleration of a 1200-kg car acted on by a net force of 250 N?
   (A) 0.21 m/s\(^2\)
   (B) 2.4 m/s\(^2\)
   (C) 4.8 m/s\(^2\)
   (D) 950 m/s\(^2\)
   (E) 300,000 m/s\(^2\)

(A) Answer: A

Test-Taking Tip

Using a Calculator

Keep the following tips in mind when solving problems that require a calculator. Write down the equation that you will be solving before using the calculator. Next, substitute the known values for each term in the equation. Then, enter the numbers into your calculator and calculate the answer. It is also important to become familiar with the order in which your calculator performs operations. Most calculators operate using an algebra-based operating system. If time permits, double-check your answer by performing the calculations a second time.

What is the acceleration of a 1200-kg car acted on by a net force of 250 N?
   (A) 0.21 m/s\(^2\)
   (B) 2.4 m/s\(^2\)
   (C) 4.8 m/s\(^2\)
   (D) 950 m/s\(^2\)
   (E) 300,000 m/s\(^2\)

(A) Answer: A

Use the diagram below to answer Questions 5 and 6. The diagram shows how five forces act on a wooden crate as it slides across the floor.