Section 3

Integrating Mathematics

Acceleration

Reading Preview

Key Concepts

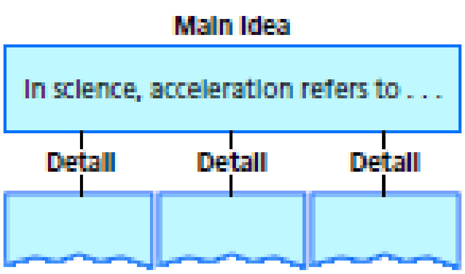
- What kind of motion does acceleration refer to?
- How is acceleration calculated?
- What graphs can be used to analyze the motion of an accelerating object?

Key Term

- acceleration

Target Reading Skill

Identifying Main Ideas As you read the What Is Acceleration? section, write the main idea in a graphic organizer like the one below. Then write three supporting details that give examples of the main idea.



Lab zone Discover Activity

Will You Hurry Up?

1. Measure 10 meters in an open area. Mark the distance with masking tape.
2. Walk the 10 meters in such a way that you keep moving faster throughout the entire distance. Have a partner time you.
3. Repeat Step 2, walking the 10 meters in less time than you did before. Then try it again, this time walking the distance in twice the time as the first. Remember to keep speeding up throughout the entire 10 meters.

Think It Over

Inferring How is the change in your speed related to the time in which you walk the 10-meter course?

The pitcher throws. The ball speeds toward the batter. Off the bat it goes. It's going, going, gone! A home run!

Before landing, the ball went through several changes in motion. It sped up in the pitcher's hand, and lost speed as it traveled toward the batter. The ball stopped when it hit the bat, changed direction, sped up again, and eventually slowed down. Most examples of motion involve similar changes. In fact, rarely does any object's motion stay the same for very long.

What Is Acceleration?

Suppose you are a passenger in a car stopped at a red light. When the light changes to green, the driver steps on the accelerator. As a result, the car speeds up, or accelerates. In everyday language, *acceleration* means "the process of speeding up."

Acceleration has a more precise definition in science. Scientists define **acceleration** as the rate at which velocity changes. Recall that velocity describes both the speed and direction of an object. A change in velocity can involve a change in either speed or direction—or both. **In science, acceleration refers to increasing speed, decreasing speed, or changing direction.**

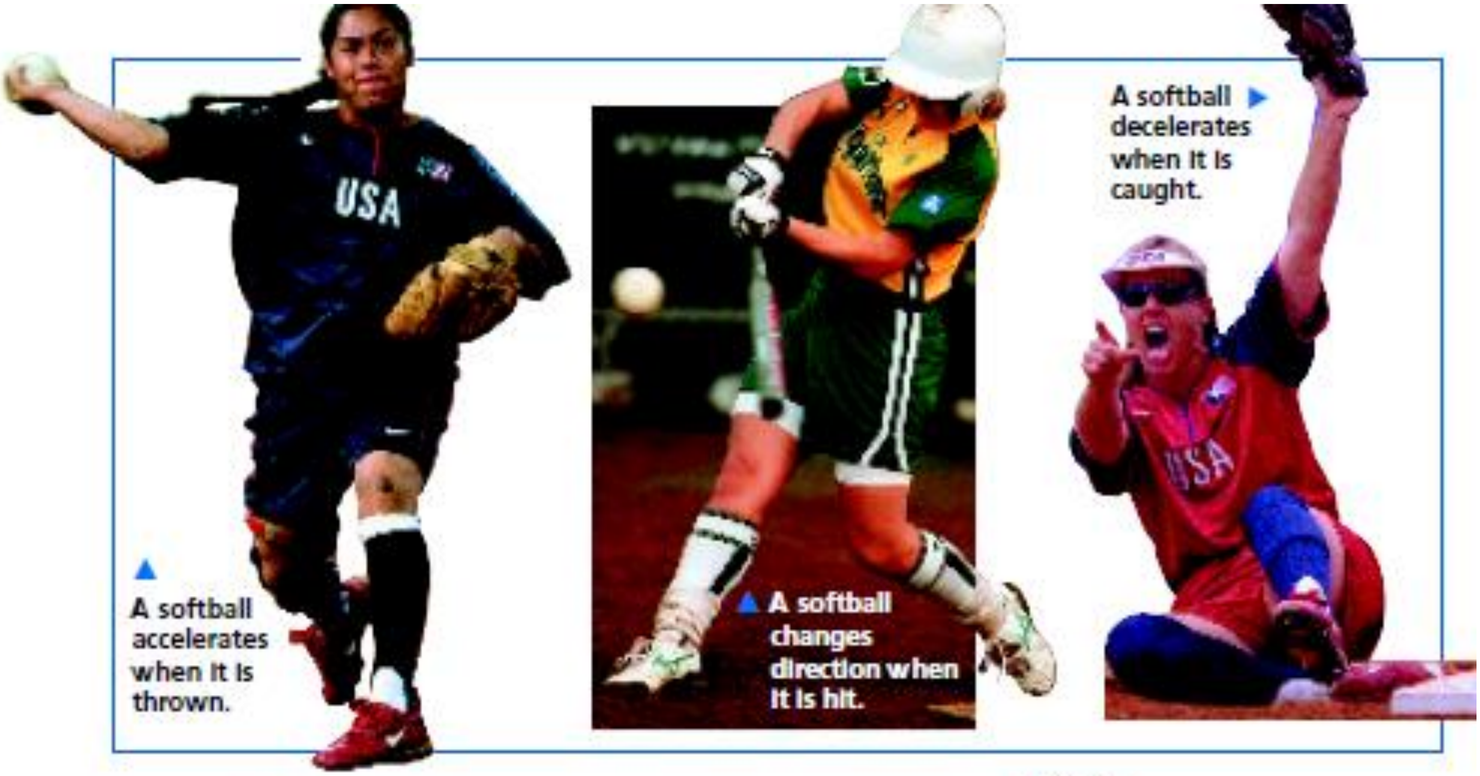


Figure 6
Acceleration
A softball experiences acceleration when it is thrown, caught, and hit. **Classifying** *What change in motion occurs in each example?*

Increasing Speed Whenever an object's speed increases, the object accelerates. A softball accelerates when the pitcher throws it, and again when a bat hits it. A car that begins to move from a stopped position or speeds up to pass another car is accelerating. People can accelerate too. For example, you accelerate when you coast down a hill on your bike.

Decreasing Speed Just as objects can speed up, they can also slow down. This change in speed is sometimes called deceleration, or negative acceleration. For example, a softball decelerates when it lands in a fielder's mitt. A car decelerates when it stops at a red light. A water skier decelerates when the boat stops pulling.

Changing Direction Even an object that is traveling at a constant speed can be accelerating. Recall that acceleration can be a change in direction as well as a change in speed. Therefore, a car accelerates as it follows a gentle curve in the road or changes lanes. Runners accelerate as they round the curve in a track. A softball accelerates when it changes direction as it is hit.

Many objects continuously change direction without changing speed. The simplest example of this type of motion is circular motion, or motion along a circular path. For example, the seats on a Ferris wheel accelerate because they move in a circle.

Reading Checkpoint **How can a car be accelerating if its speed is constant at 65 km/h?**

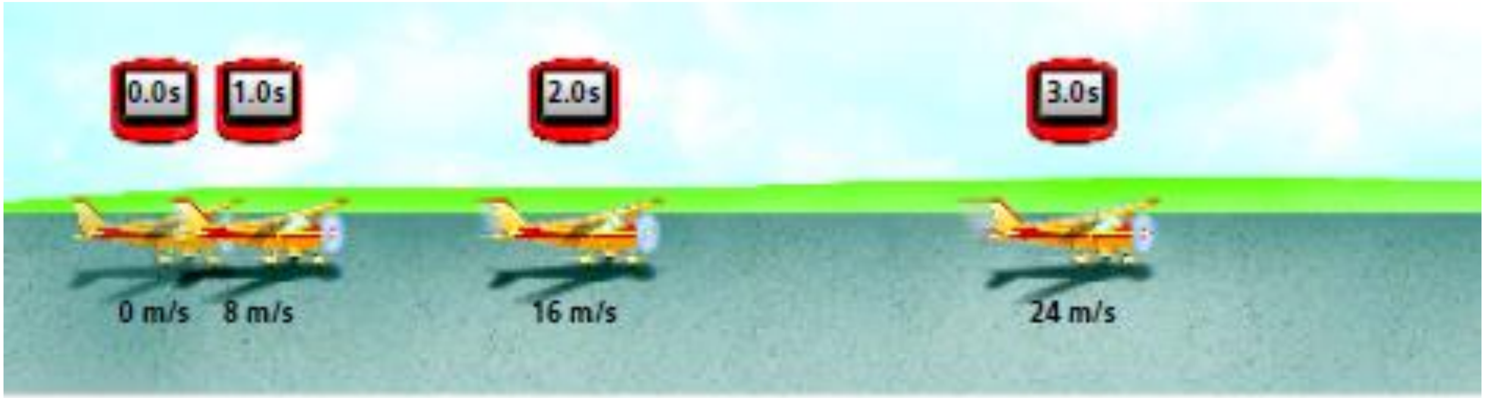


FIGURE 7
Analyzing Acceleration
The speed of the airplane increases by the same amount each second.
Interpreting Diagrams *How does the distance change in each second for an accelerating object?*

Calculating Acceleration

Acceleration describes the rate at which velocity changes. If an object is not changing direction, you can describe its acceleration as the rate at which its speed changes. **To determine the acceleration of an object moving in a straight line, you must calculate the change in speed per unit of time.** This is summarized by the following formula.

$$\text{Acceleration} = \frac{\text{Final speed} - \text{Initial speed}}{\text{Time}}$$

If speed is measured in meters per second (m/s) and time is measured in seconds, the SI unit of acceleration is meters per second per second, or m/s^2. Suppose speed is measured in kilometers per hour and time is measured in hours. Then the unit for acceleration is kilometers per hour per hour, or km/h^2.

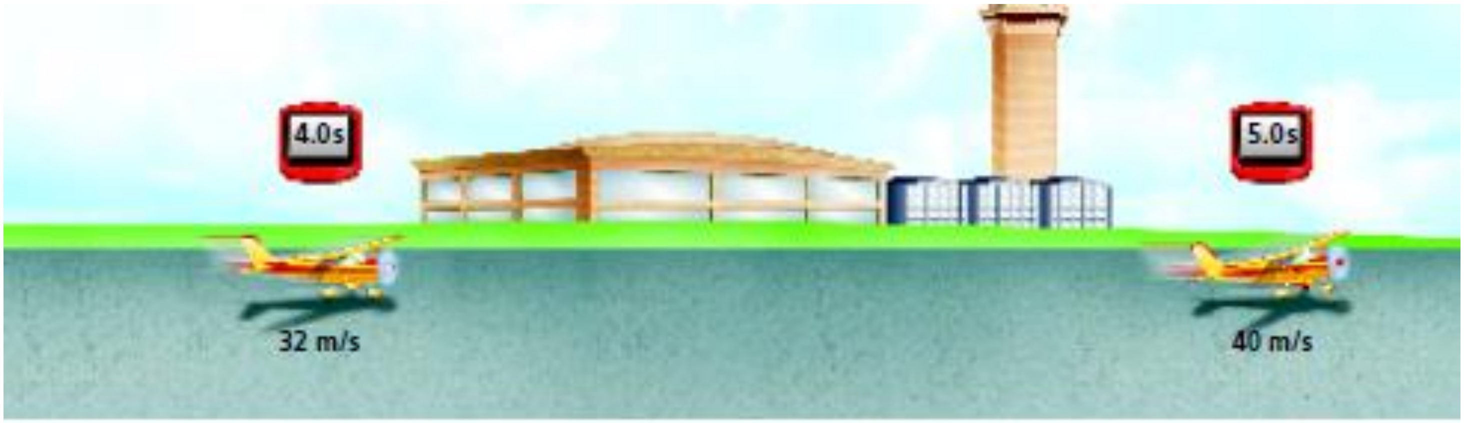
To understand acceleration, imagine a small airplane moving down a runway. Figure 7 shows the airplane's motion after each of the first five seconds of its acceleration. To calculate the average acceleration of the airplane, you must first subtract the initial speed of 0 m/s from the final speed of 40 m/s. Then divide the change in speed by the time, 5 seconds.

$$\text{Acceleration} = \frac{40\text{ m/s} - 0\text{ m/s}}{5\text{ s}}$$

$$\text{Acceleration} = 8\text{ m/s}^2$$

The airplane accelerates at a rate of 8 m/s^2. This means that the airplane's speed increases by 8 m/s every second. Notice in Figure 7 that, after each second of travel, the airplane's speed is 8 m/s greater than it was the previous second.

Reading Checkpoint **What must you know about an object that is moving in a straight line to calculate its acceleration?**



Math Sample Problem

Calculating Acceleration

As a roller coaster car starts down a slope, its speed is 4 m/s. But 3 seconds later, at the bottom, its speed is 22 m/s. What is its average acceleration?

1 Read and Understand

What information are you given?

Initial speed = 4 m/s

Final speed = 22 m/s

Time = 3 s

2 Plan and Solve

What quantity are you trying to calculate?

The average acceleration of the roller coaster car = ■

What formula contains the given quantities and the unknown quantity?

$$\text{Acceleration} = \frac{\text{Final speed} - \text{Initial speed}}{\text{Time}}$$

Perform the calculation.

$$\text{Acceleration} = \frac{22\text{ m/s} - 4\text{ m/s}}{3\text{ s}}$$

$$\text{Acceleration} = \frac{18\text{ m/s}}{3\text{ s}}$$

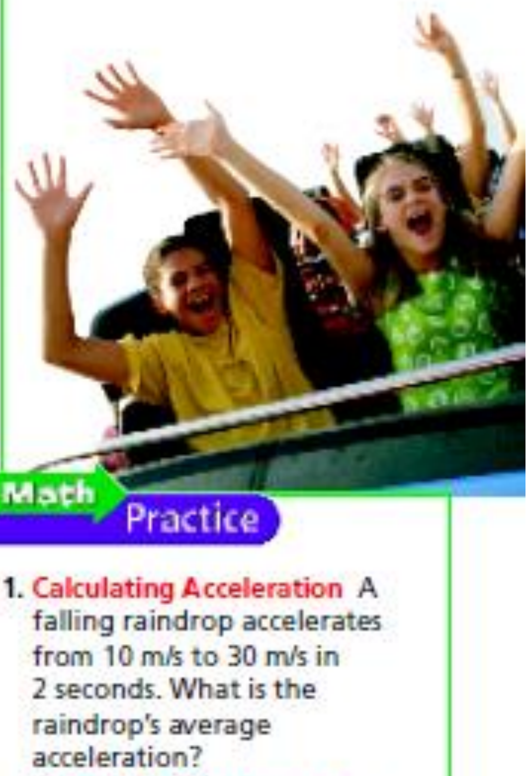
$$\text{Acceleration} = 6\text{ m/s}^2$$

The roller coaster car's average acceleration is 6 m/s^2.

3 Look Back and Check

Does your answer make sense?

The answer is reasonable. If the car's speed increases by 6 m/s each second, its speed will be 10 m/s after 1 second, 16 m/s after 2 seconds, and 22 m/s after 3 seconds.



Math Practice

1. **Calculating Acceleration** A falling raindrop accelerates from 10 m/s to 30 m/s in 2 seconds. What is the raindrop's average acceleration?
2. **Calculating Acceleration** A certain car can accelerate from rest to 27 m/s in 9 seconds. Find the car's average acceleration.

Figure 8
Speed-Versus-Time Graph
The slanted, straight line on this speed-versus-time graph tells you that the cyclist is accelerating at a constant rate. The slope of a speed-versus-time graph tells you the object's acceleration.
Predicting *How would the slope of the graph change if the cyclist were accelerating at a greater rate? At a lesser rate?*

Graphing Acceleration

Suppose you ride your bicycle down a long, steep hill. At the top of the hill your speed is 0 m/s. As you start down the hill, your speed increases. Each second, you move at a greater speed and travel a greater distance than the second before. During the five seconds it takes you to reach the bottom of the hill, you are an accelerating object. **You can use both a speed-versus-time graph and a distance-versus-time graph to analyze the motion of an accelerating object.**

Speed-Versus-Time Graph Figure 8 shows a speed-versus-time graph for your bicycle ride down the hill. What can you learn about your motion by analyzing this graph? First, since the line slants upward, the graph shows you that your speed was increasing. Next, since the line is straight, you can tell that your acceleration was constant. A slanted, straight line on a speed-versus-time graph means that the object is accelerating at a constant rate. You can find your acceleration by calculating the slope of the line. To calculate the slope, choose any two points on the line. Then, divide the rise by the run.

$$\text{Slope} = \frac{\text{Rise}}{\text{Run}} = \frac{8\text{ m/s} - 4\text{ m/s}}{4\text{ s} - 2\text{ s}} = \frac{4\text{ m/s}}{2\text{ s}}$$

$$\text{Slope} = 2\text{ m/s}^2$$

During your bike ride, you accelerated down the hill at a constant rate of 2 m/s^2.

Distance-Versus-Time Graph You can represent the motion of an accelerating object with a distance-versus-time graph. Figure 9 shows a distance-versus-time graph for your bike ride. On this type of graph, a curved line means that the object is accelerating. The curved line in Figure 9 tells you that during each second, you traveled a greater distance than the second before. For example, you traveled a greater distance during the third second than you did during the first second.

The curved line in Figure 9 also tells you that during each second your speed is greater than the second before. Recall that the slope of a distance-versus-time graph is the speed of an object. From second to second, the slope of the line in Figure 9 gets steeper and steeper. Since the slope is increasing, you can conclude that the speed is also increasing. You are accelerating.

Reading Checkpoint What does a curved line on a distance-versus-time graph tell you?

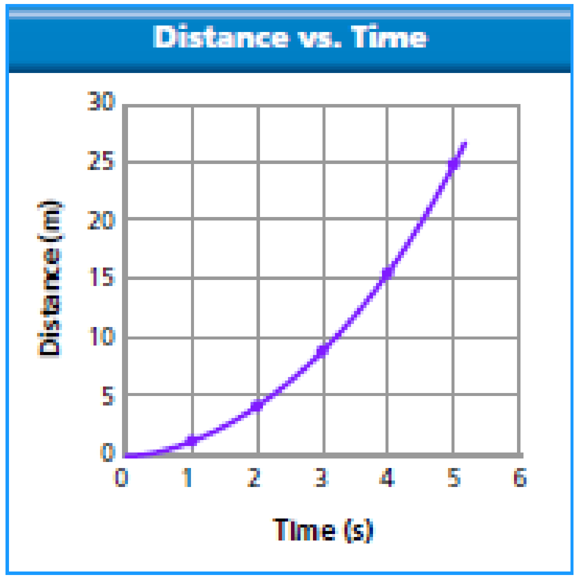


FIGURE 9
Distance-Versus-Time Graph
The curved line on this distance-versus-time graph tells you that the cyclist is accelerating.

Section 3 Assessment

Target Reading Skill **Identifying Main Ideas** Use information in your graphic organizer to answer Question 1 below.

Reviewing Key Concepts

1. a. **Describing** What are the three ways that an object can accelerate?
   b. **Summarizing** Describe how a baseball player accelerates as he runs around the bases after hitting a home run.
   c. **Applying Concepts** An ice skater glides around a rink at a constant speed of 2 m/s. Is the skater accelerating? Explain your answer.
2. a. **Identifying** What is the formula used to calculate the acceleration of an object moving in a straight line?
   b. **Calculating** A cyclist's speed changes from 0 m/s to 15 m/s in 10 seconds. What is the cyclist's average acceleration?
3. a. **Naming** What types of graphs can you use to analyze the acceleration of an object?
   b. **Explaining** How is an object moving if a slanted, straight line on a speed-versus-time graph represents its motion?
   c. **Predicting** What would a distance-versus-time graph look like for the moving object in part (b)?

Math Practice

4. **Calculating Acceleration** A downhill skier reaches the steepest part of a trail. Her speed increases from 9 m/s to 18 m/s in 3 seconds. What is her average acceleration?
5. **Calculating Acceleration** What is a race car's average acceleration if its speed changes from 0 m/s to 40 m/s in 4 seconds?