Section 11.3

1 FOCUS

Objectives

11.3.1 **Identify** changes in motion that produce acceleration.
11.3.2 **Describe** examples of constant acceleration.
11.3.3 **Calculate** the acceleration of an object.
11.3.4 **Interpret** speed-time and distance-time graphs.
11.3.5 **Classify** acceleration as positive or negative.
11.3.6 **Describe** instantaneous acceleration.

Reading Focus

Build Vocabulary

L2

Word Forms Point out other forms of the terms or parts of the terms. For example, in this section, explain that *linear* contains the word *line* and means, "in a straight line," or more generally, "having to do with lines." Then have students predict what *nonlinear* might mean. *(It means not in a straight line or having to do with lines that are not straight.)*

Reading Strategy

L2

a. Speed (or direction)
b. Direction (or speed)
c. m/s^2

2 INSTRUCT

What is Acceleration?

Use Visuals

L1

Figure 11 Use the example of a bouncing basketball to introduce acceleration. Ask, **As the ball falls from the girl's hand, how does its speed change?** *(Its speed increases.)* **What happens to the speed of the ball as the ball rises from the ground back to her hand?** *(The speed decreases.)* **At what points does the ball have zero velocity?** *(When it touches the girl's hand and when it touches the floor)* **How does the velocity of the ball change when it bounces on the floor?** *(The speed quickly drops to zero, then quickly increases again. The ball also changes direction.)*
Visual, Logical

11.3 Acceleration

Reading Focus

Key Concepts

- How are changes in velocity described?
- How can you calculate acceleration?
- How does a speed-time graph indicate acceleration?
- What is instantaneous acceleration?

Vocabulary

- acceleration
- free fall
- constant acceleration
- linear graph
- nonlinear graph

Reading Strategy

Summarizing Read the section on acceleration. Then copy and complete the concept map below to organize what you know about acceleration.

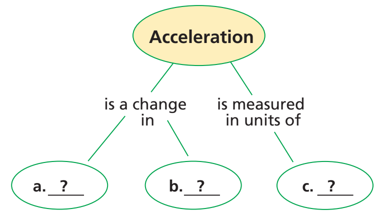
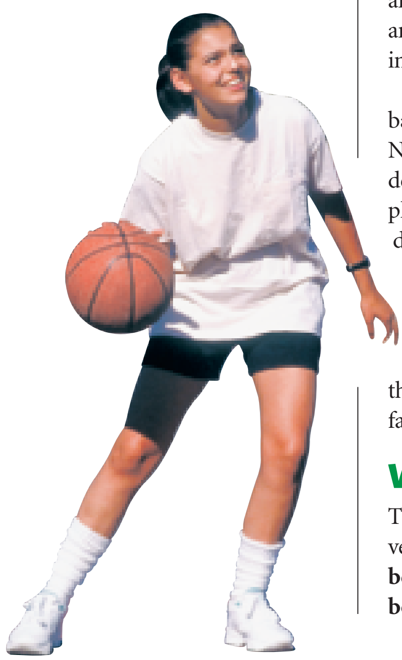


Figure 11 The basketball constantly changes velocity as it rises and falls.



A basketball constantly changes velocity during a game. The player in Figure 11 dribbles the ball down the court, and the ball speeds up as it falls and slows down as it rises. As she passes the ball, it flies through the air and suddenly stops when a teammate catches it. The velocity of the ball increases again as it is thrown toward the basket.

But the rate at which velocity changes is also important. Imagine a basketball player running down the court and slowly coming to a stop. Now imagine the player running down the court and stopping suddenly. If the player stops slowly, his or her velocity changes slowly. If the player stops suddenly, his or her velocity changes quickly. The ball handler's teammates must position themselves to assist the drive or to take a pass. Opposing team members want to prevent the ball handler from reaching the basket. Each player must anticipate the ball handler's motion.

Velocity changes frequently, not only in a basketball game, but throughout our physical world. Describing changes in velocity, and how fast they occur, is a necessary part of describing motion.

What Is Acceleration?

The rate at which velocity changes is called **acceleration.** Recall that velocity is a combination of speed and direction. **Acceleration can be described as changes in speed, changes in direction, or changes in both. Acceleration is a vector.**

Section Resources

Print
- ***Reading and Study Workbook With Math Support,*** Section 11.3
- ***Math Skills and Problem Solving Workbook,*** Section 11.3
- ***Transparencies,*** Section 11.3

Technology
- ***Interactive Textbook,*** Section 11.3
- ***Presentation Pro CD-ROM,*** Section 11.3
- ***Go Online,*** NSTA SciLinks, Acceleration

Changes in Speed We often use the word *acceleration* to describe situations in which the speed of an object is increasing. A television newscaster describing the liftoff of a rocket-launched space shuttle, for example, might exclaim, "That shuttle is really accelerating!" We understand that the newscaster is describing the spacecraft's quickly increasing speed as it clears its launch pad and rises through the atmosphere. Scientifically, however, acceleration applies to any change in an object's velocity. This change may be either an increase or a decrease in speed. Acceleration can be caused by positive (increasing) change in speed or by negative (decreasing) change in speed.

For example, suppose that you are sitting on a bus waiting at a stoplight. The light turns green and the bus moves forward. You feel the acceleration as you are pushed back against your seat. The acceleration is the result of an increase in the speed of the bus. As the bus moves down the street at a constant speed, its acceleration is zero. You no longer feel pushed toward your seat. When the bus approaches another stoplight, it begins to slow down. Again, its speed is changing, so the bus is accelerating. You feel pulled away from your seat. Acceleration results from increases or decreases in speed. As the bus slows to a stop, it experiences negative acceleration, also known as deceleration. Deceleration is an acceleration that slows an object's speed.

An example of acceleration due to change in speed is **free fall,** the movement of an object toward Earth solely because of gravity. Recall that the unit for velocity is meters per second. The unit for acceleration, then, is meters per second per second. This unit is typically written as meters per second squared (m/s^2). Objects falling near Earth's surface accelerate downward at a rate of 9.8 m/s^2. Each second an object is in free fall, its velocity increases downward by 9.8 meters per second. Imagine the stone in Figure 12 falling from the mouth of the well. After 1 second, the stone will be falling at about 9.8 m/s. After 2 seconds, the stone will be going faster by 9.8 m/s. Its speed will now be downward at 19.6 m/s. The change in the stone's speed is 9.8 m/s^2, the acceleration due to gravity.

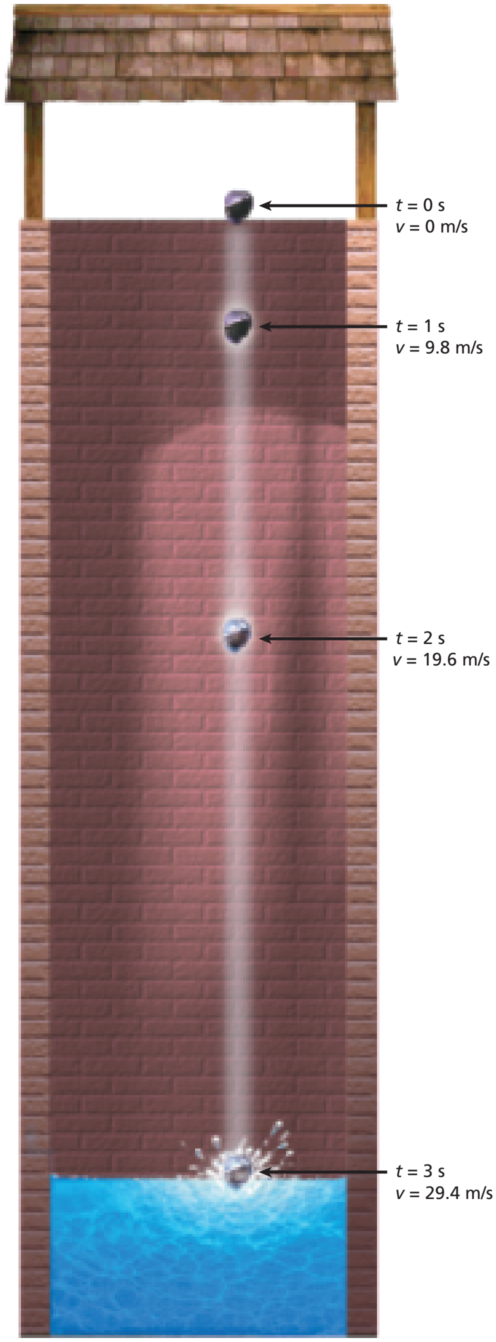


Figure 12 The velocity of an object in free fall increases 9.8 m/s each second.

Build Reading Literacy L1

Outline Refer to page **156D** in **Chapter 6,** which provides the guidelines for an outline.

Have students create an outline of Section 11.3 (pp. 342–348). Outlines should follow the head structure used in the section. Major headings are shown in green, and subheadings are shown in blue. Ask students, **Based on your outline, what are two types of changes associated with acceleration?** *(Changes in speed and changes in direction)* **Name two types of graphs that can be used to represent acceleration.** *(Speed-time graphs and distance-time graphs)*
Verbal, Logical

Address Misconceptions L2

Students may think that if an object is accelerating then the object is speeding up. Explain to students that this is true in common, everyday usage. But in scientific terms, acceleration refers to any change in velocity. Velocity is a vector including both speed and direction, so acceleration can be speeding up, slowing down, or even just changing direction.
Verbal

Use Visuals L1

Figure 12 Have students examine Figure 12. Ask, **How much time passes between each image of the falling rock?** *(1 s)* **How does the distance traveled change between successive time intervals?** *(The distance traveled increases.)* **How does the average speed change between successive time intervals?** *(The average speed increases.)*
Visual, Logical

Customize for Inclusion Students

Visually Impaired
Students who are visually impaired may grasp the concept of acceleration by considering the following scenario. When traveling in a closed car with your eyes closed, it is hard to tell how far you have traveled or how fast you are going. But you can feel accelerations. Ask, **How do you know when you are speeding up or slowing down?** *(When speeding up, it feels as if you are pressed against the back of the seat. When you are slowing down, it feels as if you are pulled forward against the seat belt.)* **How can you tell if you are changing direction?** *(You can feel yourself pulled to one side, away from the direction the car is turning.)*

Teacher Demo

Pendulum Accelerometer L2

Purpose Students observe how the displacement of a pendulum can be used as evidence of acceleration, and how a pendulum can show that acceleration is taking place during uniform circular motion.

Materials short pendulum (25 cm), turntable, lab stand, tape

Advance Prep Place the lab stand on the outer edge of the turntable. The stand should be tall enough to hold the pendulum so that it doesn't touch the turntable. Tape the base of the stand to the turntable.

Procedure Tell students that a pendulum can be used to provide evidence of acceleration. Acceleration causes displacement of the pendulum. Demonstrate this by walking forward and backward while holding a pendulum in one hand held in front of you. You will have to accelerate slightly as you walk; otherwise, the pendulum will start swinging. Ask students to describe the position of the pendulum when you stand still, walk forward, change direction, and walk backward. Show students the turntable, and tie the pendulum to the lab stand. Ask students to predict how the pendulum will be displaced when the turntable is spinning. Start the turntable spinning, and have students compare the observed displacement of the pendulum to their predictions.

Expected Outcome When you are holding the pendulum, the pendulum will be displaced toward you when you are walking forward and away from you when you are walking backward. When the turntable is spinning, the pendulum will be displaced away from the center of the turntable. This demonstrates that acceleration is taking place during uniform circular motion. The acceleration in this case is purely a change in direction.
Kinesthetic, Visual

Figure 13 When you ride on a carousel, you accelerate because of the changing direction.

Changes in Direction Acceleration isn't always the result of changes in speed. You can accelerate even if your speed is constant. You experience this type of acceleration if you ride a bicycle around a curve. Although you may have a constant speed, your change in direction means you are accelerating. You also may have experienced this type of acceleration if you have ridden on a carousel like the one in Figure 13. A horse on the carousel is traveling at a constant speed, but it is accelerating because its direction is constantly changing.

Changes in Speed and Direction Sometimes motion is characterized by changes in both speed and direction at the same time. You experience this type of motion if you ride on a roller coaster like the one in Figure 14. The roller coaster ride starts out slowly as the cars travel up the steeply inclined rails. The cars reach the top of the incline. Suddenly they plummet toward the ground and then whip around a curve. You are thrown backward, forward, and sideways as your velocity increases, decreases, and changes direction. Your acceleration is constantly changing because of changes in the speed and direction of the cars of the roller coaster.

Similarly, passengers in a car moving at the posted speed limit along a winding road experience rapidly changing acceleration. The car may enter a long curve at the same time that it slows to maintain a safe interval behind another car. The car is accelerating both because it is changing direction and because its speed is decreasing.

Figure 14 A roller coaster produces acceleration due to changes in both speed and direction. **Applying Concepts** ***Describe the acceleration occuring at this instant on the rollercoaster ride.***

Constant Acceleration The velocity of an object moving in a straight line changes at a constant rate when the object is experiencing constant acceleration. **Constant acceleration** is a steady change in velocity. That is, the velocity of the object changes by the same amount each second. An example of constant acceleration is illustrated by the jet airplane shown in Figure 15. The airplane's acceleration may be constant during a portion of its takeoff.

Figure 15 Constant acceleration during takeoff results in changes to an aircraft's velocity that are in a constant direction.

Reading Checkpoint *What is constant acceleration?*

Calculating Acceleration

Acceleration is the rate at which velocity changes. **You calculate acceleration for straight-line motion by dividing the change in velocity by the total time.** If a is the acceleration, v_i is the initial velocity, v_f is the final velocity, and t is total time, then this equation can be written as follows.

Acceleration

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Total time}} = \frac{(v_f - v_i)}{t}$$

Notice in this formula that velocity is in the numerator and time is in the denominator. If the velocity increases, the numerator is positive and thus the acceleration is also positive. For example, if you are coasting downhill on a bicycle, your velocity increases and your acceleration is positive. If the velocity decreases, then the numerator is negative and the acceleration is also negative. For example, if you continue coasting after you reach the bottom of the hill, your velocity decreases and your acceleration is negative.

Remember that acceleration and velocity are both vector quantities. Thus, if an object moving at constant speed changes its direction of travel, there is still acceleration. In other words, the acceleration can occur even if the speed is constant. Think about a car moving at a constant speed as it rounds a curve. Because its direction is changing, the car is accelerating.

To determine a change in velocity, subtract one velocity vector from another. If the motion is in a straight line, however, the velocity can be treated as speed. You can then find acceleration from the change in speed divided by the time.

Go Online NSTA SCILINKS

For: Links on acceleration
Visit: www.SciLinks.org
Web Code: ccn-2113

Calculating Acceleration

Build Science Skills L2

Calculating Once students have learned the equation for acceleration, return to Figure 12 on p. 343. Apply the equation for acceleration to calculate the magnitude of the stone's acceleration in the first time interval:

$$a = (v_f - v_i)/t$$
$$= (9.8\ m/s - 0\ m/s)/(1\ s) = 9.8\ m/s^2$$

Then, have the students use the equation to calculate the acceleration of the stone for other time intervals. They should find that for every time interval, the magnitude of the acceleration is 9.8 m/s^2.
Logical

Go Online NSTA SCILINKS

Download a worksheet on acceleration for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Figure 14 *The roller coaster is accelerating; its speed is increasing (because it is falling) and its direction is changing (because the track is curved).*

Reading Checkpoint *Constant acceleration is a steady change in velocity.*

Math Practice

Solutions

1. $a = (v_f - v_i)/t = (0 \text{ m/s} - 10 \text{ m/s})/20 \text{ s} = -0.5 \text{ m/s}^2$

2. $(v_f - v_i) = at = (9.0 \text{ m/s}^2)(4.0 \text{ s}) = 36 \text{ m/s}$

3. $v_i = 0$; $v_f = at = (9.8 \text{ m/s}^2)(2.0 \text{ s}) = 2.0 \times 10^1 \text{m/s}$

4. $v_f = 0$; $v_i = -at = -(9.8 \text{ m/s}^2)(2.5 \text{ s}) = -25 \text{ m/s}$ (the minus sign indicates that the velocity is in the direction opposite the acceleration)

Logical

For Extra Help **L1**

Students may have difficulty rearranging the equation to solve for other variables, especially for v_i or v_f. Write the procedure clearly on the board and describe each step. For example, to solve for v_f, 1) multiply both sides of the equation by t, then 2) cancel the t/t on the right side of the equation, then 3) add v_i to both sides of the equation. Afterwards, have students work in pairs and demonstrate the procedure for each other for the different variables. When you feel they understand the process, they can begin to solve problems that include numbers. **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 sprinter accelerates from the starting block to a speed of 8.0 m/s in 4.0 s. What is the magnitude of the sprinter's acceleration? *(2.0 m/s²)*

2. A car is traveling at 14 m/s. Stepping on the gas pedal causes the car to accelerate at 2.0 m/s². How long does the driver have to step on the pedal to reach a speed of 18 m/s? *(2.0 s)*

Logical, Portfolio

Math Skills

Calculating Acceleration

A ball rolls down a ramp, starting from rest. After 2 seconds, its velocity is 6 meters per second. What is the acceleration of the ball?

1 Read and Understand

What information are you given?

Time = **2 s**

Starting velocity = **0 m/s**

Ending velocity = **6 m/s**

2 Plan and Solve

What unknown are you trying to calculate?

Acceleration = **?**

What formula contains the given quantities and the unknown?

$$a = \frac{(v_f - v_i)}{t}$$

Replace each variable with its known value.

$$\text{Acceleration} = \frac{(6 \text{ m/s} - 0 \text{ m/s})}{2 \text{ s}}$$

$$= 3 \text{ m/s}^2 \text{ down the ramp}$$

3 Look Back and Check

Is your answer reasonable?

Objects in free fall accelerate at a rate of 9.8 m/s². The ramp is not very steep. An acceleration of 3 m/s² seems reasonable.

Math Practice

1. A car traveling at 10 m/s starts to decelerate steadily. It comes to a complete stop in 20 seconds. What is its acceleration?
2. An airplane travels down a runway for 4.0 seconds with an acceleration of 9.0 m/s². What is its change in velocity during this time?
3. A child drops a ball from a bridge. The ball strikes the water under the bridge 2.0 seconds later. What is the velocity of the ball when it strikes the water?
4. A boy throws a rock straight up into the air. It reaches the highest point of its flight after 2.5 seconds. How fast was the rock going when it left the boy's hand?

Graphs of Accelerated Motion

You can use a graph to calculate acceleration. For example, consider a downhill skier who is moving in a straight line. After traveling down the hill for 1 second, the skier's speed is 4 meters per second. In the next second the speed increases by an additional 4 meters per second, so the skier's acceleration is 4 m/s². Figure 16 is a graph of the skier's speed. **The slope of a speed-time graph is acceleration.** This slope is change in speed divided by change in time.

Speed-Time Graphs The skier's speed increased at a constant rate because the skier was moving down the hill with constant acceleration. Constant acceleration is represented on a speed–time graph by a straight line. The graph in Figure 16 is an example of a **linear graph,** in which the displayed data form straight-line parts. The slope of the line is the acceleration.

Constant negative acceleration decreases speed. A speed-time graph of the motion of a bicycle slowing to a stop is shown in Figure 17. The horizontal line segment represents constant speed. The line segment sloping downward represents the bicycle slowing down. The change in speed is negative, so the slope of the line is negative.

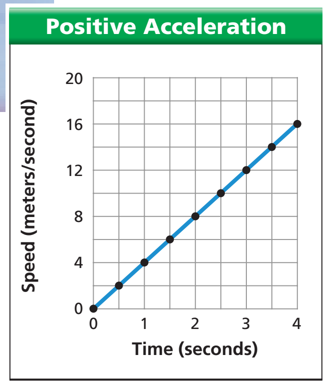


Figure 16 The slope of a speed-time graph indicates acceleration. A positive slope shows that the skier's acceleration is positive.

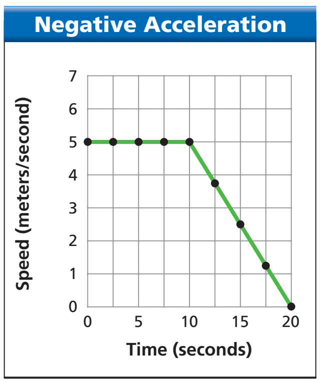


Figure 17 The horizontal part of the graph shows a biker's constant speed. The part of the graph with negative slope shows negative acceleration as the mountain biker slows to a stop.

Graphs of Accelerated Motion

Build Math Skills L1

Finding Slope on a Graph Remind students that the slope of a line on a graph is found by dividing the difference of two points on the vertical axis by the corresponding points on the horizontal axis. The two points used to find the slope should be chosen as far apart on the line as possible.

Have students calculate the slope of the line on the graph in Figure 16. Tell them also to include the units in their calculation. *(4 m/s^2)* Now have them calculate the slope of the line between 10 and 20 seconds on the graph in Figure 17. *(0.5 m/s^2)*
Logical

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

Use Visuals L1

Figure 17 Ask students the following questions about the speed-time graph in Figure 17. **What are the units on the vertical axis?** *(m/s)* **What are the units on the horizontal axis?** *(s)* **What would be the units of the slope of a line on this graph?** *(m/s/s, or m/s^2)* Remind students that the bike represents the motion of a mountain biker in the photograph. Ask students, **Is the bike moving at time zero?** *(Yes)* **How fast is it moving at that time?** *(5 m/s)* **What happens to the bike after 10 seconds?** *(It starts to slow down.)* **How would you describe the acceleration of the bike from that point on?** *(The acceleration is constant and negative.)*
Visual, Logical

Section 11.3 (continued)

Instantaneous Acceleration

Integrate Math

L2

Differential calculus is the branch of mathematics that physicists use when considering instantaneous quantities, such as instantaneous speed or instantaneous acceleration. When you use calculus to determine acceleration, you can take the difference in velocities over smaller and smaller time intervals until the time interval becomes, in effect, infinitely small. The slope of a curved line is equal to the slope of a line drawn tangent to a point on the plotted curve. Graphically, this is like finding the slope of a line connecting two points on a speed-time graph, but then moving the points closer and closer together until you have the slope of a line tangent to the curve at a single point on the graph. In this case, the slope of the line represents the instantaneous acceleration at that point.

Logical, Visual

3 ASSESS

Evaluate Understanding

L2

Ask students to sketch a speed-time graph of a car starting from rest, accelerating up to the speed limit, maintaining that speed, then slowing again to a stop.

Reteach

L1

Use the graphs on page 347 to reteach the concepts in the section. Ask students to identify which kind of acceleration cannot be shown on the graphs.
(A change in direction)

Math Practice

Solutions

L2

8. $a = (v_f - v_i)/t =$
$(25\ m/s - 0\ m/s)/(30.0\ s) =$
$0.83\ m/s^2$
9. $a = (v_f - v_i)/t =$
$(30.0\ m/s - 25\ m/s)/(10.0\ s) =$
$0.50\ m/s^2$

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 11.3.

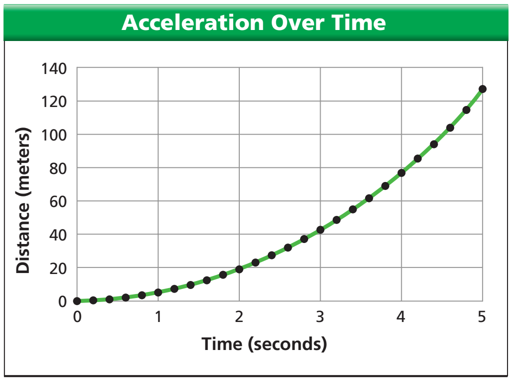


Figure 18 A distance-time graph of accelerated motion is a curve.

Distance-Time Graphs Accelerated motion is represented by a curved line on a distance-time graph. In a **nonlinear graph,** a curve connects the data points that are plotted. Figure 18 is a distance-time graph. The data in this graph are for a ball dropped from rest toward the ground.

Compare the slope of the curve during the first second to the slope of the curve during the fourth second. Notice that the slope is much greater during the fourth second than it is during the first second. Because the slope represents the speed of the ball, an increasing slope means that the speed is increasing. An increasing speed means that the ball is accelerating.

Instantaneous Acceleration

Acceleration is rarely constant, and motion is rarely in a straight line. A skateboarder moving along a half-pipe changes speed and direction. As a result, her acceleration changes. At each moment she is accelerating, but her instantaneous acceleration is always changing. **Instantaneous acceleration is how fast a velocity is changing at a specific instant.**

Acceleration involves a change in velocity or direction or both, so the vector of the skateboarder's acceleration can point in any direction. The vector's length depends on how fast she is changing her velocity. At every moment she has an instantaneous acceleration, even if she is standing still and the acceleration vector is zero.

Section 11.3 Assessment

Reviewing Concepts

1. Describe three types of changes in velocity.
2. What is the equation for acceleration?
3. What shows acceleration on a speed-time graph?
4. Define instantaneous acceleration.

Critical Thinking

5. **Comparing and Contrasting** How are deceleration and acceleration related?
6. **Applying Concepts** Two trains leave a station at the same time. Train A travels at a constant speed of 16 m/s. Train B starts at 8.0 m/s but accelerates constantly at $1.0\ m/s^2$. After 10.0 seconds, which train has the greater speed?
7. **Inferring** Suppose you plot the distance traveled by an object at various times and you discover that the graph is not a straight line. What does this indicate about the object's acceleration?

Math Practice

8. A train moves from rest to a speed of 25 m/s in 30.0 seconds. What is the magnitude of its acceleration?
9. A car traveling at a speed of 25 m/s increases its speed to 30.0 m/s in 10.0 seconds. What is the magnitude of its acceleration?

Section 11.3 Assessment

1. Changes in velocity can be described as changes in speed, changes in direction, or changes in both (or, an increase in speed, a decrease in speed, or a change in direction).
2. $a = (v_f - v_i)/t$
3. The slope of the line on a speed-time graph gives the acceleration.
4. Instantaneous acceleration is how fast the velocity is changing at a specific instant.
5. Deceleration is a special case of acceleration in which the speed of an object is decreasing.
6. Train B ($v = v_o + at = 8.0\ m/s +$ $(1.0\ m/s^2)(10.0\ s) = 8.0\ m/s +$ $10.0\ m/s = 18\ m/s$)
7. The graph indicates that the object is accelerating.