**The basketball constantly changes velocity as it rises and falls.** Describing changes in velocity, and how fast they occur, is a part of describing motion.

# What Is Acceleration?

**How are changes in velocity described?**

The rate at which velocity changes is called **acceleration.**

# What Is Acceleration?

## Changes in Speed

- In science, acceleration applies to any change in an object's velocity.
- Acceleration can be caused by positive (increasing) change in speed or by negative (decreasing) change in speed.
- Deceleration is an acceleration that slows an object's speed.

# What Is Acceleration?

**Free fall** is the movement of an object toward Earth solely because of gravity.

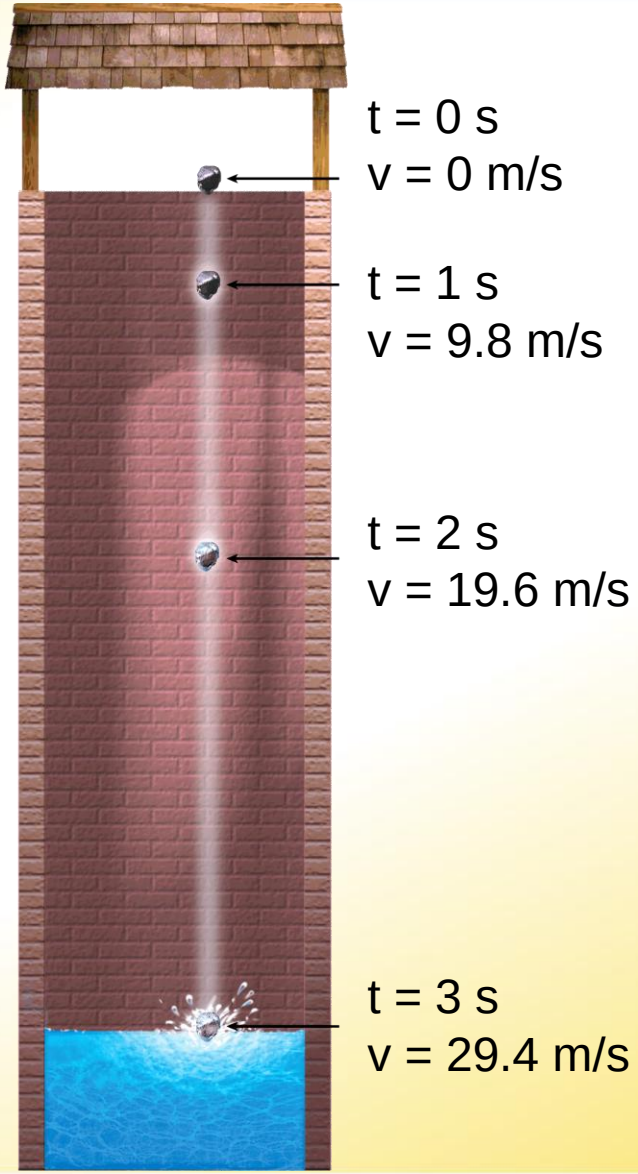
The unit for velocity is meters per second. The unit for acceleration, then, is meters per second per second. This unit is typically written as meters per second squared ($m/s^2$).

Objects falling near Earth's surface accelerate downward at a rate of 9.8 $m/s^2$.

# What Is Acceleration?

Each second an object is in free fall, its velocity increases downward by 9.8 meters per second.

The change in the stone's speed is 9.8 $m/s^2$, the acceleration due to gravity.



# What Is Acceleration?

## Changes in Direction

Acceleration can be the result of a change in direction at constant speed, for example, riding a bicycle around a curve.

# What Is Acceleration?

A horse on the carousel is traveling at a constant speed, but it is accelerating because its direction is constantly changing.

# What Is Acceleration?

## Changes in Speed and Direction

Sometimes motion is characterized by changes in both speed and direction at the same time.

Passengers in a car moving along a winding road experience rapidly changing acceleration.

The car may enter a long curve at the same time that it slows. The car is accelerating both because it is changing direction and because its speed is decreasing.

# What Is Acceleration?

A roller coaster produces acceleration due to changes in both speed and direction.

# What Is Acceleration?

## 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.
- An airplane's acceleration may be constant during a portion of its takeoff.

# What Is Acceleration?

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

# Calculating Acceleration

**How can you calculate acceleration?**

**You calculate acceleration for straight-line motion by dividing the change in velocity by the total time.**

# Calculating Acceleration

Acceleration is the rate at which velocity changes. *Vi* is the initial velocity, *vf* is the final velocity, and *t* is total time.

**Acceleration**

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

# Calculating Acceleration

If the velocity increases, the acceleration is positive. If the velocity decreases, the acceleration is negative.

- If you are coasting downhill on a bicycle, your velocity increases, and your acceleration is positive.
- If you continue coasting on level ground, your velocity decreases, and your acceleration is negative.

# Calculating Acceleration

Acceleration and velocity are both vector quantities.

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

# Calculating Acceleration

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?

## Calculating Acceleration

Math Skills

### 1 Read and Understand

*What information are you given?*

## Calculating Acceleration

Math Skills

### 1 Read and Understand

*What information are you given?*

$$\text{Time} = 2\ \text{s}$$

$$\text{Starting velocity} = 0\ \text{m/s}$$

$$\text{Ending velocity} = 6\ \text{m/s}$$

## Calculating Acceleration

Math Skills

### 2 Plan and Solve

*What unknown are you trying to calculate?*

*What formula contains the given quantities and the unknown?*

## Calculating Acceleration

Math Skills

### 2 Plan and Solve

*What unknown are you trying to calculate?*

$$\text{Acceleration} = ?$$

*What formula contains the given quantities and the unknown?*

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

## Calculating Acceleration

Math Skills

### 2 Plan and Solve

*Replace each variable with its known value.*

## Calculating Acceleration

Math Skills

### 2 Plan and Solve

*Replace each variable with its known value.*

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

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

## Calculating Acceleration

Math Skills

### 3 Look Back and Check

*Is your answer reasonable?*

## Calculating Acceleration

Math Skills

### 3 Look Back and Check

*Is your answer reasonable?*

Objects in free fall accelerate at a rate of 9.8 $m/s^2$. The ramp is not very steep. An acceleration of 3 $m/s^2$ seems reasonable.

# Describing Ionic Compounds

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?

## Calculating Acceleration

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?

Answer:

$A = V / t = 10 / 20 = - .5 \text{ m/s}^2$

## Calculating Acceleration

Math Practice

**2.** An airplane travels down a runway for 4.0 seconds with an acceleration of 9.0 $m/s^2$. What is its change in velocity during this time?

## Calculating Acceleration

Math Practice

**2.** An airplane travels down a runway for 4.0 seconds with an acceleration of 9.0 m/s$^2$. What is its change in velocity during this time?

Answer:

($vf$ – $vi$) = $at$ = (9.0 m/s2)(4.0 s) = 36 m/s

## Calculating Acceleration

Math Practice

**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?

## Calculating Acceleration

Math Practice

**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?

Answer:

$v_i = 0$; $v_f = at = (9.8\ m/s2)(2.0\ s) = 20\ m/s$

## Calculating Acceleration

Math Practice

**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?

## Calculating Acceleration

Math Practice

**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?

Answer:

$v_f = 0$; $v_i = -at = -(9.8\ m/s^2)(2.5\ s) = -25\ m/s$

(The minus sign indicates that the velocity is in the direction opposite the acceleration.)

# Graphs of Accelerated Motion

- How does a speed-time graph indicate acceleration?
- The slope of a speed-time graph is acceleration.

## Graphs of Accelerated Motion

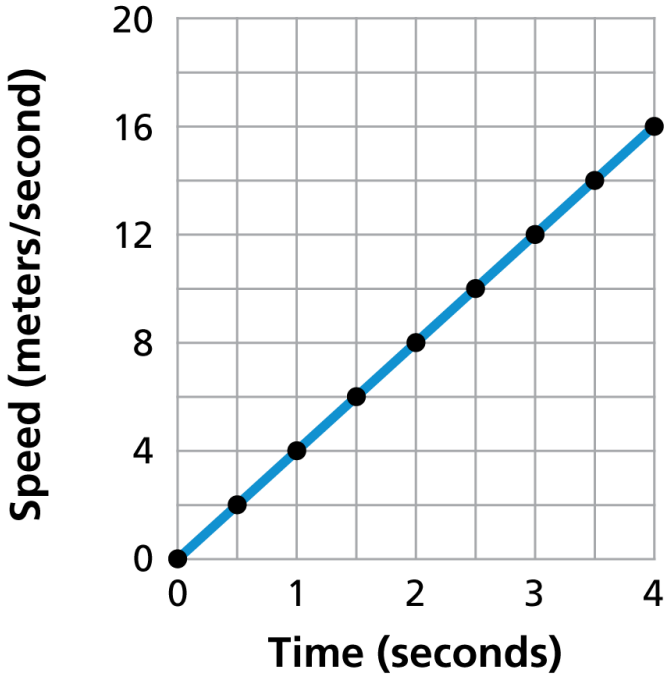
You can use a graph to calculate acceleration. Graph speed on the vertical axis and time on the horizontal axis.

The slope is change in speed divided by change in time, which is equal to the acceleration.

# Graphs of Accelerated Motion

The skier's acceleration is positive. The acceleration is 4 $m/s^2$.

**Positive Acceleration**



# Graphs of Accelerated Motion

## Speed-Time Graphs

Constant acceleration is represented on a speed–time graph by a straight line. The slope of the line is the acceleration.

The graph is an example of a linear graph, in which the displayed data form straight-line parts.

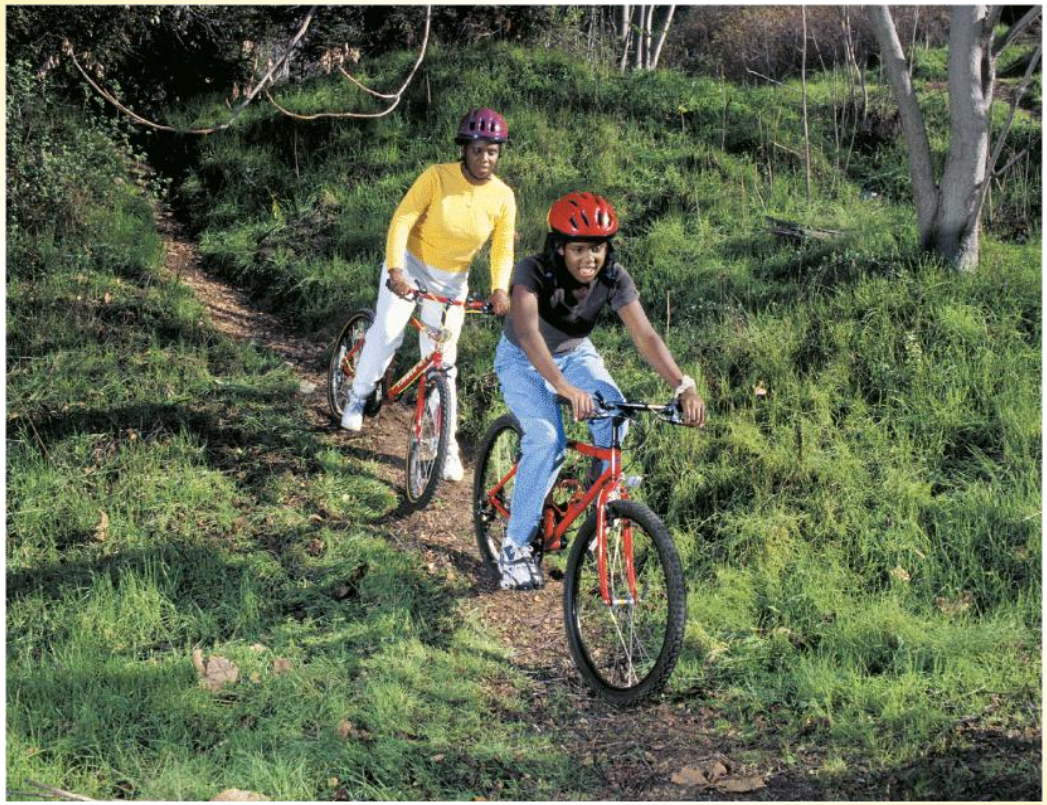
## Graphs of Accelerated Motion

Constant negative acceleration decreases speed.

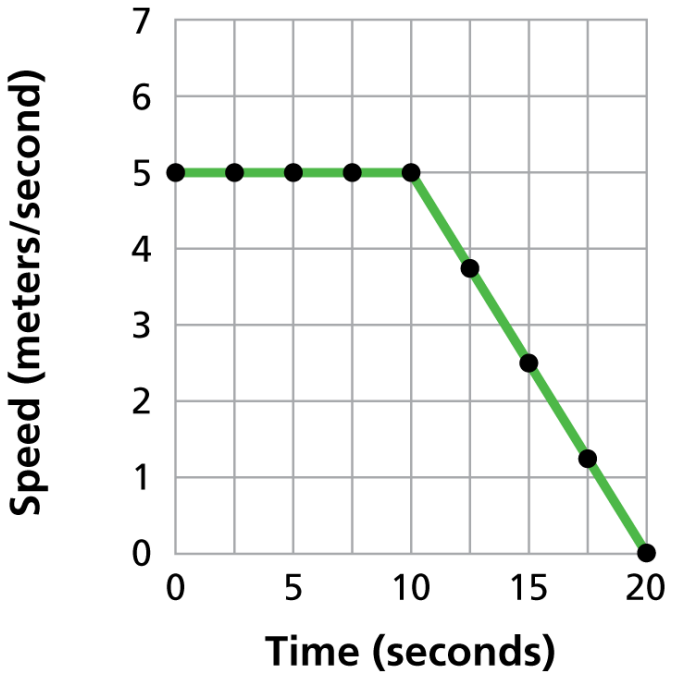
- On a speed-time graph of a bicycle slowing to a stop, a line sloping downward represents the bicycle decelerating.
- The change in speed is negative, so the slope of the line is negative.

# Graphs of Accelerated Motion

The biker moves at a constant speed and then slows to a stop.



## Negative Acceleration



# Graphs of Accelerated Motion

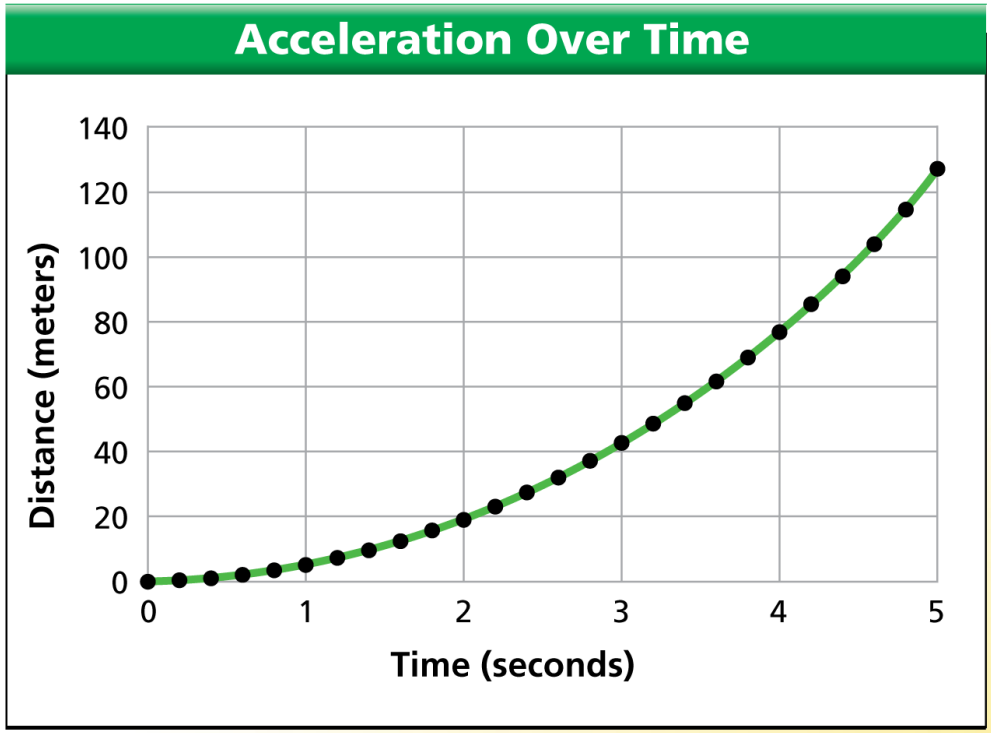
## Distance-Time Graphs

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.

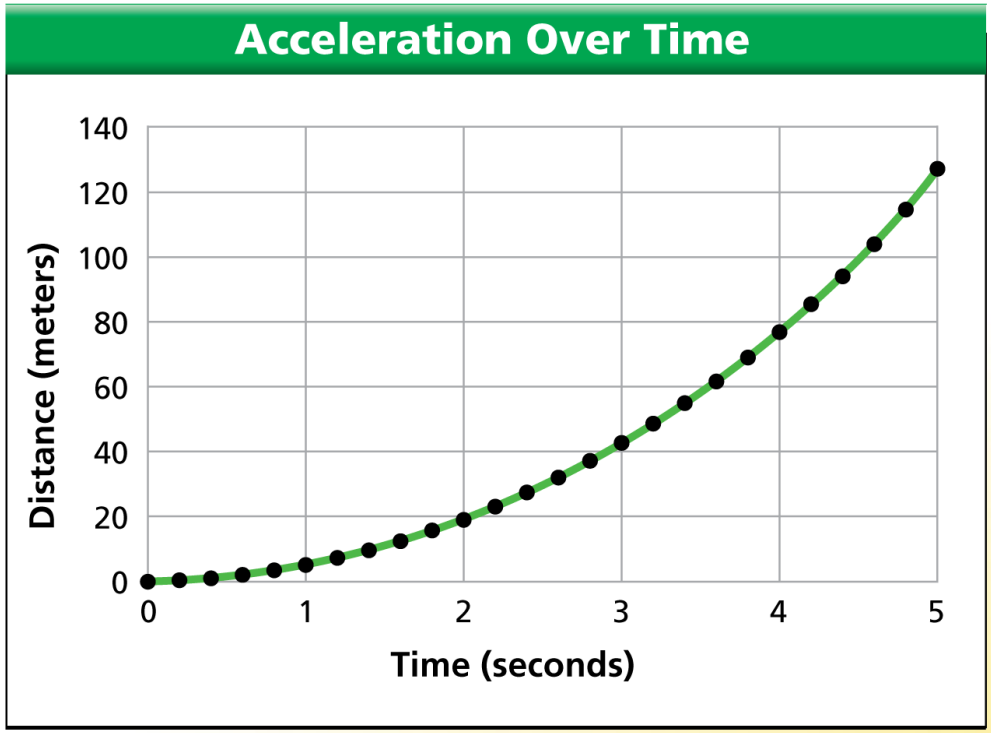
# Graphs of Accelerated Motion

**A distance-time graph of accelerated motion is a curve.** The data in this graph are for a ball dropped from rest toward the ground.



# Graphs of Accelerated Motion

Compare the slope of the curve during the first second to the slope during the fourth second. An increasing slope means that the speed is increasing.



# Instantaneous Acceleration

- **What is instantaneous acceleration?**
- **Instantaneous acceleration is how fast a velocity is changing at a specific instant.**

# Instantaneous Acceleration

Acceleration is rarely constant, and motion is rarely in a straight line.

- Acceleration involves a change in velocity or direction or both, so the vector of acceleration can point in any direction.
- The vector's length depends on how fast  velocity is changing.
- For an object that is standing still, the acceleration vector is zero.

# Assessment Questions

1. What is acceleration?
   a. the rate at which speed increases
   b. the time an object's velocity increases
   c. the rate at which displacement changes
   d. the rate at which velocity changes

## Assessment Questions

1. What is acceleration?
   a. the rate at which speed increases
   b. the time an object's velocity increases
   c. the rate at which displacement changes
   d. the rate at which velocity changes

   ANS: D

## Assessment Questions

2. A sports car can accelerate from 0 m/s to 28 m/s in four seconds. What is the acceleration of the car?
   a. 24 s
   b. 7 $m/s^2$
   c. 27 $m/s^2$
   d. 27 m/s

## Assessment Questions

2. A sports car can accelerate from 0 m/s to 28 m/s in four seconds. What is the acceleration of the car?

   a. 24 s
   b. 7 $m/s^2$
   c. 27 $m/s^2$
   d. 27 m/s

   ANS: b

# Assessment Questions

3. If you were to sketch a displacement-time graph and a speed-time graph for an object experiencing constant acceleration, what would they look like?
   a. Both graphs would be linear, with the displacement-time graph being steeper.
   b. Both graphs would be linear, with the speed-time graph being steeper.
   c. Both graphs would be nonlinear.
   d. The speed-time graph would be linear; the displacement-time graph would be nonlinear.

# Assessment Questions

3. If you were to sketch a displacement-time graph and a speed-time graph for an object experiencing constant acceleration, what would they look like?

   a. Both graphs would be linear, with the displacement-time graph being steeper.

   b. Both graphs would be linear, with the speed-time graph being steeper.

   c. Both graphs would be nonlinear.

   d. The speed-time graph would be linear; the displacement-time graph would be nonlinear.

   ANS: D

## Assessment Questions

4. Which of the following is an example of negative acceleration?
   a. Mike starts riding his bike and uses the pedals to go from 0 km/h to 20 km/h.
   b. Mike pedals up a hill and gradually slows from 20 km/h to 5 km/h.
   c. Mike sits on his bike at the top of the hill and rests.
   d. Mike coasts downhill without pedalling, going from 0 km/h to 15 km/h.

## Assessment Questions

4. Which of the following is an example of negative acceleration?

   a. Mike starts riding his bike and uses the pedals to go from 0 km/h to 20 km/h.

   b. Mike pedals up a hill and gradually slows from 20 km/h to 5 km/h.

   c. Mike sits on his bike at the top of the hill and rests.

   d. Mike coasts downhill without pedalling, going from 0 km/h to 15 km/h.

   ANS: B

## Assessment Questions

5. The acceleration at a specific point on a distance-time graph is the
   a. instantaneous acceleration.
   b. momentary acceleration.
   c. positive acceleration.
   d. numerical acceleration.

## Assessment Questions

5. The acceleration at a specific point on a distance-time graph is the
   a. instantaneous acceleration.
   b. momentary acceleration.
   c. positive acceleration.
   d. numerical acceleration.

   ANS: A

## Assessment Questions

1. If an object experiences a steady velocity change in a straight line, it is undergoing constant acceleration.

   True
   False

## Assessment Questions

1. If an object experiences a steady velocity change in a straight line, it is undergoing constant acceleration.

   True
   False

   ANS: T