KEY CONCEPT

1.3 Acceleration measures how fast velocity changes.

BEFORE, you learned

- Speed describes how far an object travels in a given time
- Velocity is a measure of the speed and direction of motion

NOW, you will learn

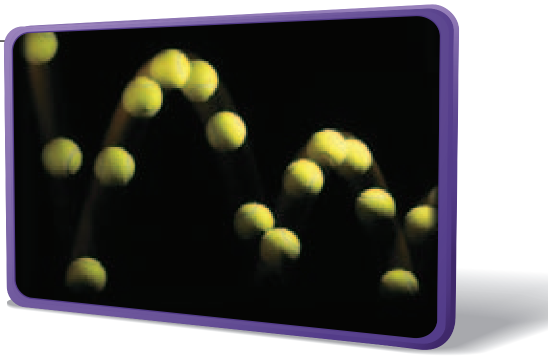
- How acceleration is related to velocity
- How to calculate acceleration

VOCABULARY

acceleration p. 25

THINK ABOUT

How does velocity change?



The photograph at right shows the path that a bouncing ball takes. The time between each image of the ball is the same during the entire bounce. Is the ball moving the same distance in each time interval? Is the ball moving the same direction in each time interval?

OUTLINE
Remember to use the blue and red headings in this chapter to help you make notes on acceleration.

I. Main idea
  A. Supporting idea
    1. Detail
    2. Detail
  B. Supporting idea

Speed and direction can change with time.

When you throw a ball into the air, it leaves your hand at a certain speed. As the ball rises, it slows down. Then, as the ball falls back toward the ground, it speeds up again. When the ball hits the ground, its direction of motion changes and it bounces back up into the air. The speed and direction of the ball do not stay the same as the ball moves. The ball's velocity keeps changing.

You can find out how much an object's position changes during a certain amount of time if you know its velocity. In a similar way, you can measure how an object's velocity changes with time. The rate at which velocity changes with time is called **acceleration.** Acceleration is a measure of how quickly the velocity is changing. If velocity does not change, there is no acceleration.

CHECK YOUR READING What is the relationship between velocity and acceleration?

The word *acceleration* is commonly used to mean "speeding up." In physics, however, acceleration refers to any change in velocity. A driver slowing down to stop at a light is accelerating. A runner turning a corner at a constant speed is also accelerating because the direction of her velocity is changing as she turns.

Like velocity, acceleration is a vector, which means it has both size and direction. The direction of the acceleration determines whether an object will slow down, speed up, or turn.

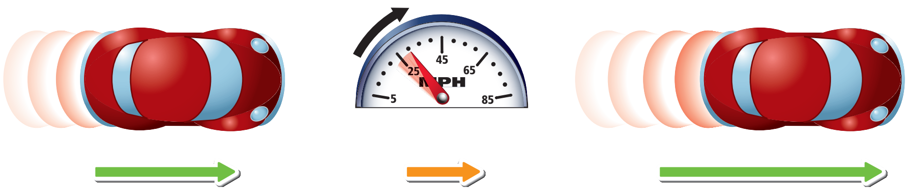
READING TIP

Orange arrows are used to show acceleration.

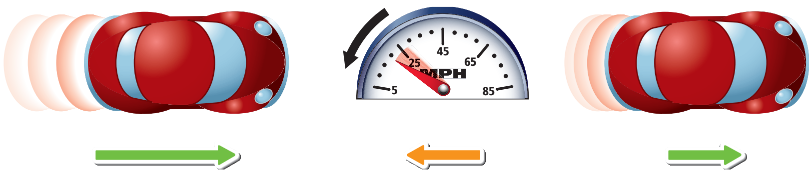
Remember that green arrows show velocity.

A longer arrow means greater acceleration or velocity.

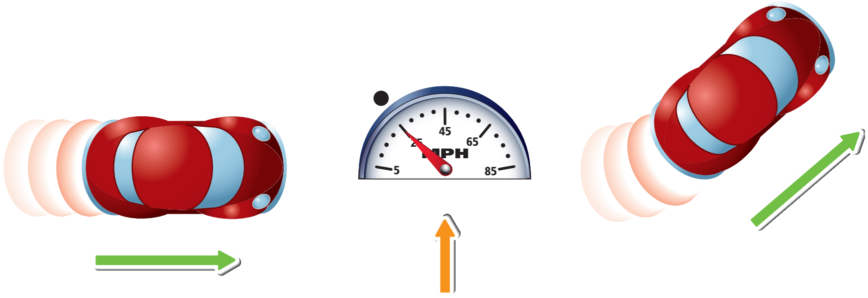
1 **Acceleration in the Same Direction as Motion** When the acceleration is in the same direction as the object is moving, the speed of the object increases. The car speeds up.



2 **Acceleration in the Opposite Direction of Motion** When the acceleration is opposite to the motion, the speed of the object decreases. The car slows down. Slowing down is also called negative acceleration.



3 **Acceleration at a Right Angle to Motion** When the acceleration is at a right angle to the motion, the direction of motion changes. The car changes the direction in which it is moving by some angle, but its speed does not change.



CHECK YOUR READING How does acceleration affect velocity? Give examples.

INVESTIGATE Acceleration

When does an object accelerate?

PROCEDURE

1. Use the template and materials to construct an acceleration measuring tool.
2. Hold the tool in your right hand so that the string falls over the 0 m/s^2 mark. Move the tool in the direction of the arrow. Try to produce both positive and negative acceleration without changing the direction of motion.
3. With the arrow pointing ahead of you, start to walk. Observe the motion of the string while you increase your speed.
4. Repeat step 3, but this time observe the string while slowing down.
5. Repeat step 3 again, but observe the string while walking at a steady speed.

WHAT DO YOU THINK?

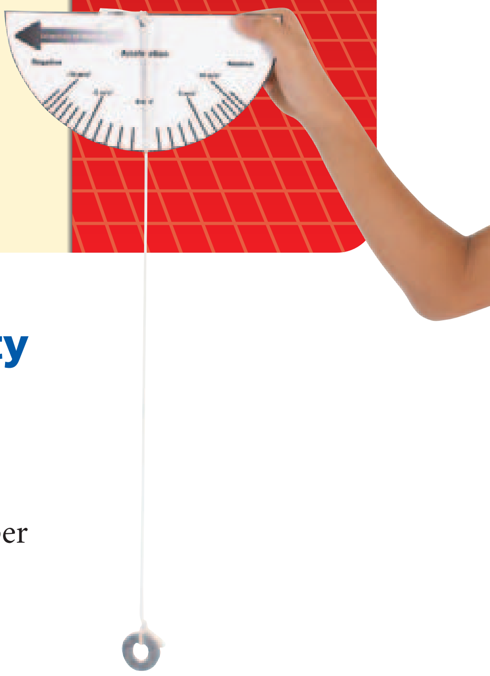
- When could you measure an acceleration?
- What was the largest acceleration (positive or negative) that you measured?

CHALLENGE If you moved the acceleration measuring tool backward, how would the measuring scale change?

SKILL FOCUS
Measuring

MATERIALS
- template for tool
- cardboard
- scissors
- glue
- piece of string
- weight

TIME
30 minutes



Acceleration can be calculated from velocity and time.

Suppose you are racing a classmate. In one second, you go from standing still to running at six meters per second. In the same time, your classmate goes from standing still to running at three meters per second. How does your acceleration compare with your classmate's acceleration? To measure acceleration, you need to know how velocity changes with time.

- The change in velocity can be found by comparing the initial velocity and the final velocity of the moving object.
- The time interval over which the velocity changed can be measured.

In one second, you increase your velocity by six meters per second, and your friend increases her velocity by three meters per second. Because your velocity changes more, you have a greater acceleration during that second of time than your friend does. Remember that acceleration measures the change in velocity, not velocity itself. As long as your classmate increases her current velocity by three meters per second, her acceleration will be the same whether she is going from zero to three meters per second or from three to six meters per second.

Calculating Acceleration

If you know the starting velocity of an object, the final velocity, and the time interval during which the object changed velocity, you can calculate the acceleration of the object. The formula for acceleration is shown below.

$$\text{acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time}}$$

$$a = \frac{v_{final} - v_{initial}}{t}$$

Remember that velocity is expressed in units of meters per second. The standard units for acceleration, therefore, are meters per second over time, or meters per second per second. This is simplified to meters per second squared, which is written as m/s^2.

As the girl in the photograph at left sleds down the sandy hill, what happens to her velocity? At the bottom of the hill, her velocity will be greater than it was at the top. You can calculate her average acceleration down the hill if you know her starting and ending velocities and how long it took her to get to the bottom. This calculation is shown in the sample problem below.

REMINDER

Remember that velocity is the speed of the object in a particular direction.

Calculating Acceleration

Sample Problem

Ama starts sliding with a velocity of 1 m/s. After 3 s, her velocity is 7 m/s. What is Ama's acceleration?

What do you know? initial velocity = 1 m/s, final velocity = 7 m/s, time = 3 s

What do you want to find out? acceleration

Write the formula: $a = \frac{v_{final} - v_{initial}}{t}$

Substitute into the formula: $a = \frac{7\ m/s - 1\ m/s}{3\ s}$

Calculate and simplify: $a = \frac{6\ m/s}{3\ s} = 2\ \frac{m/s}{s} = 2\ m/s^2$

Check that your units agree: $\frac{m/s}{s} = \frac{m}{s} \cdot \frac{1}{s} = \frac{m}{s^2}$

Unit of acceleration is m/s^2. Units agree.

Answer: $a = 2\ m/s^2$

Practice the Math

1. A man walking at 0.5 m/s accelerates to a velocity of 0.6 m/s in 1 s. What is his acceleration?
2. A train traveling at 10 m/s slows down to a complete stop in 20 s. What is the acceleration of the train?

The sledder's final velocity was greater than her initial velocity. If an object is slowing down, on the other hand, the final velocity is less than the initial velocity. Suppose a car going 10 meters per second takes 2 seconds to stop for a red light. In this case, the initial velocity is 10 m/s and the final velocity is 0 m/s. The formula for acceleration gives a negative answer, $-5\ m/s^2$. The negative sign indicates a negative acceleration—that is, an acceleration that decreases the velocity.

RESOURCE CENTER
CLASSZONE.COM
Learn more about acceleration.

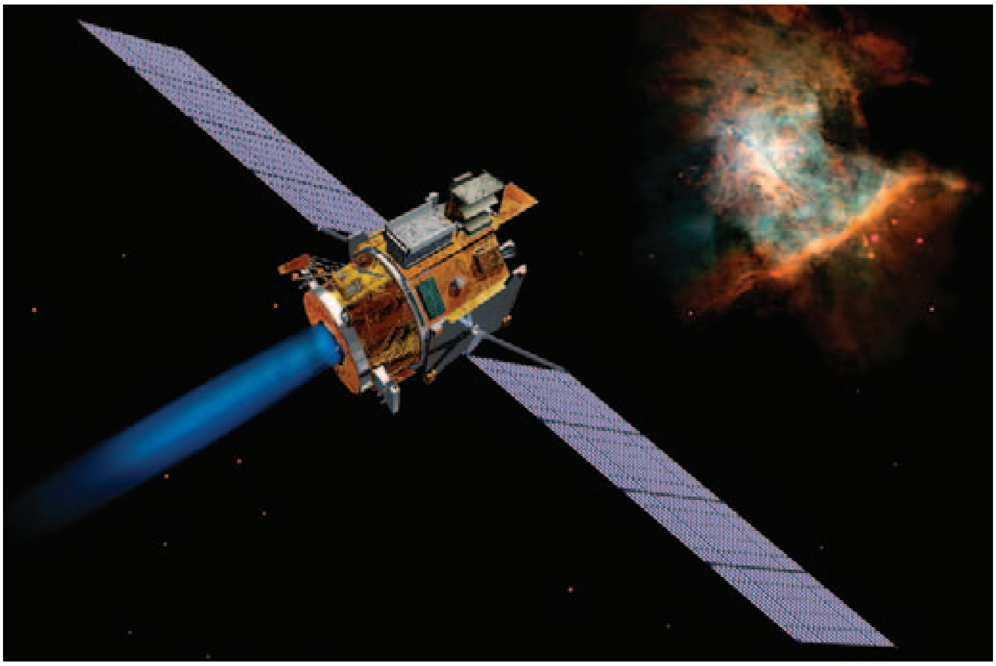
CHECK YOUR READING What would be true of the values for initial velocity and final velocity if the acceleration were zero?

Acceleration over Time

Even a very small positive acceleration can lead to great speeds if an object accelerates for a long enough period. In 1998, NASA launched the *Deep Space 1* spacecraft. This spacecraft tested a new type of engine—one that gave the spacecraft an extremely small acceleration. The new engine required less fuel than previous spacecraft engines. However, the spacecraft needed a great deal of time to reach its target velocity.

The acceleration of the *Deep Space 1* spacecraft is less than 2/10,000 of a meter per second per second ($0.0002\ m/s^2$). That may not seem like much, but over 20 months, the spacecraft could increase its speed by 4500 meters per second (10,000 mi/h).

By carefully adjusting both the amount and the direction of the acceleration of *Deep Space 1*, scientists were able to control its flight path. In 2001, the spacecraft successfully flew by a comet, sending back images from about 230 million kilometers (140 million mi) away.

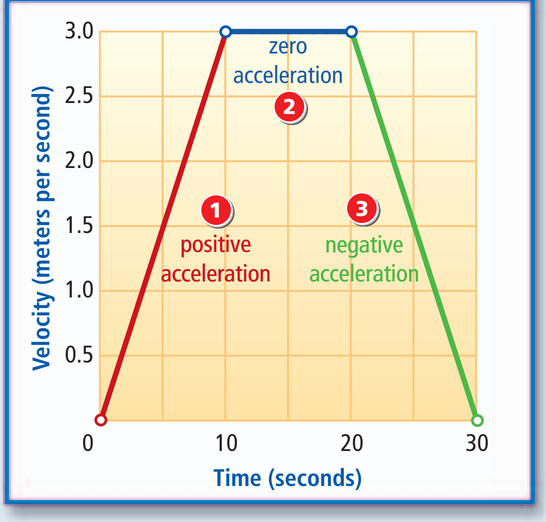


APPLY What makes the new engine technology used by *Deep Space 1* more useful for long-term missions than for short-term ones?

Velocity-Time Graphs

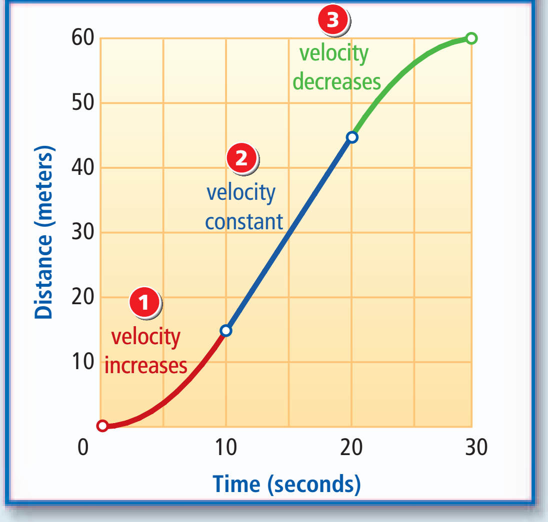
Velocity-time graphs and distance-time graphs are related. This is because the distance an object travels depends on its velocity. Compare the velocity-time graph on the right with the distance-time graph below it.

Velocity-Time Graph



1. As the student starts to push the scooter, his velocity increases. His acceleration is positive, so he moves forward a greater distance with each second that passes.
2. He coasts at a constant velocity. Because his velocity does not change, he has no acceleration, and he continues to move forward the same distance each second.
3. As he slows down, his velocity decreases. His acceleration is negative, and he moves forward a smaller distance with each passing second until he finally stops.

Distance-Time Graph



READING VISUALS What velocity does the student have after five seconds? About how far has he moved in that time?

Velocity-Time Graphs

Acceleration, like position and velocity, can change with time. Just as you can use a distance-time graph to understand velocity, you can use a velocity-time graph to understand acceleration. Both graphs tell you how something is changing over time. In a velocity-time graph, time is on the horizontal axis, or *x*-axis, and velocity is on the vertical axis, or *y*-axis.

SIMULATION
CLASSZONE.COM
Explore how changing the acceleration of an object changes its motion.

The two graphs on page 30 show a velocity-time graph and a distance-time graph of a student riding on a scooter. He first starts moving and speeds up. He coasts, and then he slows down to a stop.

1. The rising line on the velocity-time graph shows where the acceleration is positive. The steeper the line, the greater the acceleration. The distance-time graph for the same interval is curving upward more and more steeply as the velocity increases.
2. The flat line on the velocity-time graph shows an interval of no acceleration. The distance-time graph has a straight line during this time, since the velocity is not changing.
3. The falling line on the velocity-time graph shows where the acceleration is negative. The same interval on the distance-time graph shows a curve that becomes less and less steep as the velocity decreases. Notice that the overall distance still increases.

Velocity-time graphs and distance-time graphs can provide useful information. For example, scientists who study earthquakes create these graphs in order to study the up-and-down and side-to-side movement of the ground during an earthquake. They produce the graphs from instruments that measure the acceleration of the ground.

CHECK YOUR READING What does a flat line on a velocity-time graph represent?

1.3 Review

KEY CONCEPTS

1. What measurements or observations tell you that a car is accelerating?
2. If an object accelerates in the same direction in which it is moving, how is its speed affected?
3. What measurements do you need in order to calculate acceleration?

CRITICAL THINKING

4. **Calculate** A car goes from 20 m/s to 30 m/s in 10 seconds. What is its acceleration?
5. **Infer** Two runners start a race. After 2 seconds, they both have the same velocity. If they both started at the same time, how do their average accelerations compare?

CHALLENGE

6. **Analyze** Is it possible for an object that has a constant negative acceleration to change the direction in which it is moving? Explain why or why not.