

# Motion and Speed

When you think of amusement parks, do you automatically think about roller coasters? Do you remember your last roller coaster ride? Do you recall the fast speeds, sharp turns, and plunging hills that cause your senses and balance to be in a state of total confusion. At this moment, it is doubtful that you are thinking about motion, the laws of gravity, or how to describe motion. In this chapter, you will learn about motion and speed—what they are and how to describe them.

## What do you think?

**Science Journal** Look at the picture below with a classmate. Discuss what you think this is or what is happening. Here's a hint: *Without these on your car, it would slide on a dry road.* Write your answer or best guess in your Science Journal.



## EXPLORE ACTIVITY

A cheetah can run at a speed of almost 120 km/h and is the fastest runner in the world. A horse can reach a speed of 64 km/h; an elephant's top speed is about 40 km/h, and the fastest snake slithers at a speed of about 3 km/h. The speed of an object is calculated by dividing the distance the object travels by the time it takes it to move that distance. How does the speed of a human compare to these animals?

### Calculate your speed

1. Use a meterstick to mark off a 10-m distance.
2. Have your partner use a stopwatch to determine how fast you run 10 m.
3. Divide 10 m by your time in seconds to calculate your speed in m/s.
4. Multiply your answer by 3.6 to determine your speed in km/h.



### Observe

Compare your speed with the maximum speed of a cheetah, horse, elephant, and snake. Could you win a race with any of them?

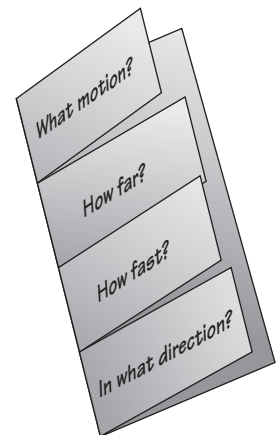
## FOLDABLES Reading & Study Skills



## Before You Read

**Making a Question Study Fold** Asking yourself questions helps you stay focused and better understand motion and speed when you are reading the chapter.

1. Place a sheet of paper in front of you so the short side is at the top. Fold the paper in half from the left side to the right side.
2. Now fold the paper in half from top to bottom. Then fold it in half again top to bottom. Unfold the last two folds that you did.
3. Label the four sections *What motion?*, *How far?*, *How fast?*, and *In what direction?* as shown.
4. Through one thickness of paper, cut along each of the fold lines to form four tabs as shown.
5. Before you read the chapter, select a motion you can observe and write it on the front of the top tab. As you read the chapter, write answers to the other questions under the correct tab.





# Describing Motion

## As You Read

### What You'll Learn

- **Distinguish** between distance and displacement.
- **Explain** the difference between speed and velocity.
- **Interpret** motion graphs.

### Vocabulary

distance	average speed
displacement	instantaneous speed
speed	velocity

### Why It's Important

Understanding the nature of motion and how to describe it helps you understand why motion occurs.

### Figure 1

This mail truck is in motion.

How do you know the mail truck has moved?



## Motion

Are distance and time important in describing running events at the track and field meets in the Olympics? Would the winners of the 5-km race and the 10-km race complete the run in the same length of time?

Distance and time are important. In order to win a race, you must cover the distance in the shortest amount of time. The time required to run the 10-km race should be longer than the time needed to complete the 5-km race because the first distance is longer. How would you describe the motion of the runners in the two races?

**Motion and Position** You don't always need to see something move to know that motion has taken place. For example, suppose you look out a window and see a mail truck stopped next to a mailbox. One minute later, you look out again and see the same truck stopped farther down the street. Although you didn't see the truck move, you know it moved because its position relative to the mailbox changed.

Motion occurs when an object changes its position. To know whether the position of something has changed, you need a reference point such as the mailbox in **Figure 1**. A reference point also helps you determine how far the truck moved.

**Relative Motion** Not all motion is as obvious as that of a truck that has changed its position. Even if you are sitting in a chair reading this book, you are moving. You are not moving relative to your desk or your school building, but you are moving relative to the other planets in the solar system and the Sun.

**Distance** In track and field events, have you ever run a 50-m dash? A distance of 50 m was marked on the track or athletic field to show you how far to run. An important part of describing the motion of an object is to describe how far it has moved, which is **distance**. The SI unit of length or distance is the meter (m). Longer distances are measured in kilometers (km). One kilometer is equal to 1,000 m. Shorter distances are measured in centimeters (cm). One meter is equal to 100 centimeters.

**Displacement** Suppose a runner jogs to the 50-m mark and then turns around and runs back to the 20-m mark, as shown in **Figure 2**. The runner travels 50 m in the original direction (north) plus 30 m in the opposite direction (south), so the total distance she ran is 80 m. How far is she from the starting line? The answer is 20 m. Sometimes you may want to know not only your distance but also your direction from a reference point, such as from the starting point. **Displacement** is the distance and direction of an object's change in position from the starting point. The runner's displacement in **Figure 2** is 20 m north.

The size of the runner's displacement and the distance traveled would be the same if the runner's motion was in a single direction. If the runner ran from the starting point to the finish line in a straight line, then the distance traveled would be 50 m and the displacement would be 50 m north.

 **Reading Check** *How do distance and displacement differ?*

## Speed

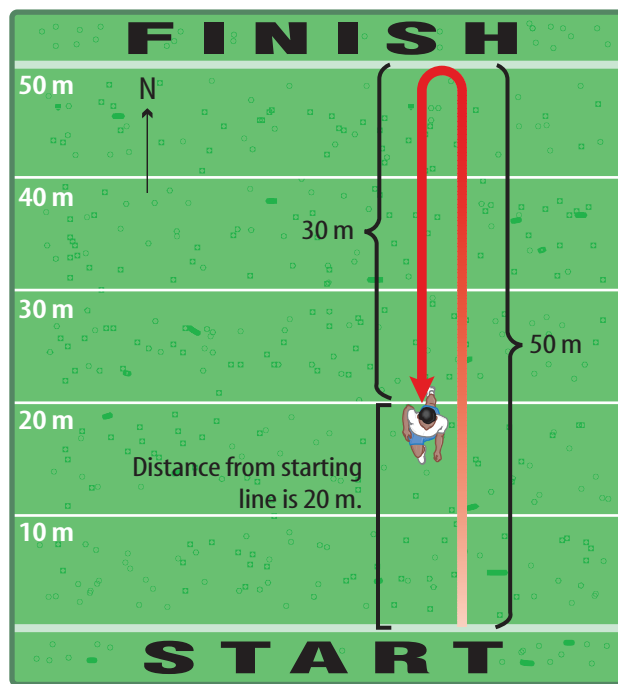
Think back to the example of the mail truck's motion in **Figure 1**. We now could describe the movement by the distance traveled and by the displacement from the starting point. You also might want to describe how fast it is moving. To do this, you need to know how far it travels in a given amount of time. **Speed** is the distance an object travels per unit of time.



## Astronomy INTEGRATION

Using the Sun as your reference point, you are moving about 30 km through space every second. How many meters are in 30 km? What is this speed in meters per second? Record your answers in your Science Journal.

**Figure 2**  
Distance and displacement are not the same. The runner's displacement is 20 m north of the starting line. However, the total distance traveled is 80 m.



Displacement = 20 m north of starting line  
Distance traveled = 50 m + 30 m = 80 m

## Mini LAB

### Describing the Motion of a Car

#### Procedure

1. Mark your starting point on the floor with **tape**.
2. At the starting line, give your **toy car** a gentle push forward. At the same time, start your **stopwatch**.
3. Stop timing when the car comes to a complete stop. Mark the spot at the front of the car with another **pencil**. Record the time for the entire trip.
4. Use a **meterstick** to measure the distance to the nearest tenth of a centimeter and convert it to meters.

#### Analysis

Calculate the speed. How would the speed differ if you repeated your experiment in exactly the same way but the car traveled in the opposite direction?

**Rate** Any change over time is called a rate. For example, your rate of growth is how much your height changes over a certain period of time, such as a year. If you think of distance as the change in position, then speed is the rate at which distance is traveled or the rate of change in position.

**Calculating Speed** Speed is related to the distance traveled and the time needed to travel the distance as follows:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

If  $s$  = speed,  $d$  = distance, and  $t$  = time, this relationship can be written as follows:

$$s = \frac{d}{t}$$

Suppose you ran 2 km in 10 min. Your speed, or rate of change of position, would be found using the following equation:

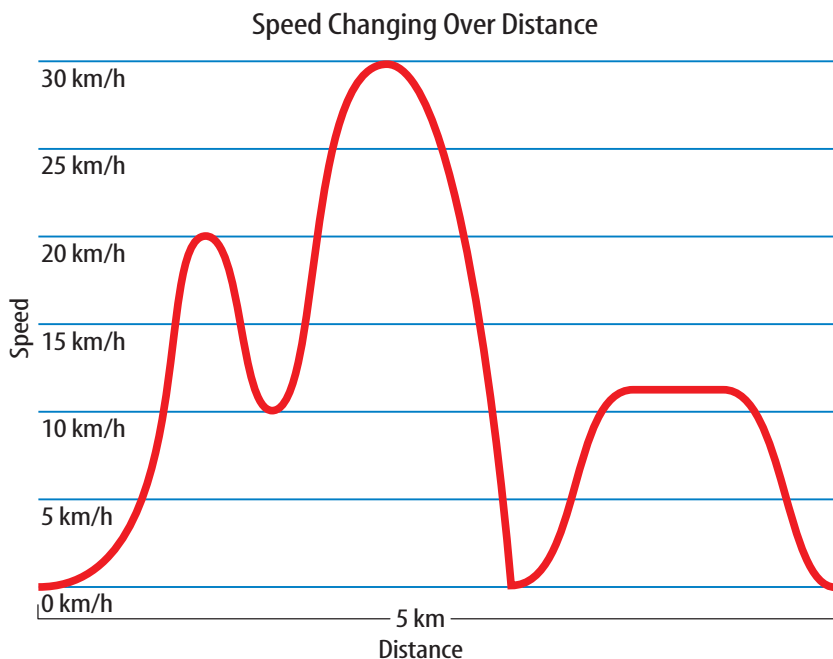
$$s = \frac{d}{t} = \frac{2 \text{ km}}{10 \text{ min}} = 0.2 \text{ km/min}$$

Because speed is calculated as distance divided by time, the units in which speed is measured always include a distance unit over a time unit. The SI unit for distance is the meter and the SI unit of time is the second (s), so in SI, units of speed are measured in meters per second (m/s). Speed also can be expressed in other units of distance and time, such as kilometers per hour (km/h) or centimeters per second (cm/s). **Table 1** shows some rates that show the range in which motion can occur. What units would you use to describe your rate of growth?

**Motion with Constant Speed** Suppose you are in a car traveling on a nearly empty freeway. You look at the speedometer and see that the car's speed hardly changes. If the car neither slows down nor speeds up, the car is traveling at a constant speed. Can you think of other examples of something moving at constant speed? If you are traveling at a constant speed, you can measure your speed over any distance interval from millimeters to light years.

**Table 1** Examples of Units of Speed

Unit of Speed	Examples of Uses	Approximate Speed
km/s	rocket escaping Earth's atmosphere	11.2 km/s
km/h	car traveling at highway speed	100 km/h
cm/yr	geological plate movements	2 cm/yr–17 cm/yr



**Figure 3**

The cyclist is undergoing speed changes.

How do you describe the speed of an object when the speed is changing?

**Changing Speed** Much of the time, the speeds you experience are not constant. Think about riding a bicycle for a distance of 5 km as in **Figure 3**. As you start out, your speed increases from 0 km/h to, say, 20 km/h. You slow down to 10 km/h as you pedal up a steep hill and speed up to 30 km/h going down the other side of the hill. You stop for a red light, speed up again, and move at a constant speed for a while. As you near the end of the trip, you slow down and then stop. Checking your watch, you find that the trip took 15 min, or one-quarter of an hour. How would you express your speed on such a trip? Would you use your fastest speed, your slowest speed, or some speed between the two?

**Average Speed** Average speed describes speed of motion when speed is changing. **Average speed** is the total distance traveled divided by the total time of travel. It can be calculated using the relationship among speed, distance, and time. For the bicycle trip just described, the total distance traveled was 5 km and the total time was 1/4 h, or 0.25 h. The average speed was:

$$s = \frac{d}{t} = \frac{5 \text{ km}}{0.25 \text{ h}} = 20 \text{ km/h}$$

**Instantaneous Speed** Suppose you watch a car's speedometer, like the one in **Figure 4**, go from 0 km/h to 60 km/h. A speedometer shows how fast a car is going at one point in time or at one instant. The speed shown on a speedometer is the instantaneous speed. **Instantaneous speed** is the speed at a given point in time.

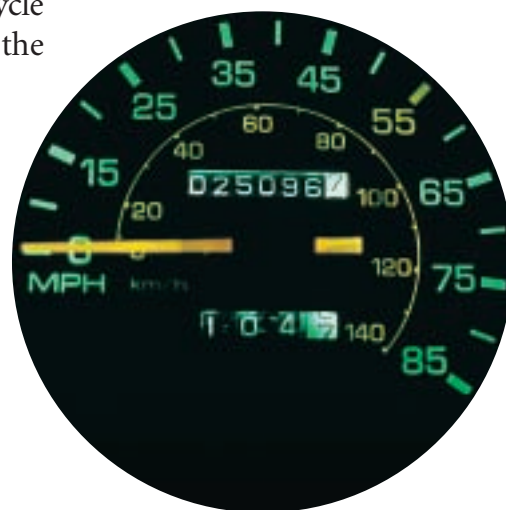
**SCIENCE Online** 

**Research** Visit the Glencoe Science Web site at [science.glencoe.com](http://science.glencoe.com) for interesting facts about running speeds. In your Science Journal describe how running fast benefits the survival of animals in the wild.



**Figure 4**

The speed shown on the speedometer gives the instantaneous speed—the speed at one instant in time.





**Changing Instantaneous Speed** When something is speeding up or slowing down, its instantaneous speed is changing. The speed is different at every point in time. If an object is moving with constant speed, the instantaneous speed doesn't change. The speed is the same at every point in time.



**Reading Check**

What are two examples of motion in which the instantaneous speed changes?

## Math Skills Activity

### Calculating Time from Speed

#### Example Problem

Sound travels at a speed of 330 m/s. If a lightning bolt strikes the ground 1 km away from you, how long will it take for the sound to reach you?

#### Solution

1 This is what you know:

distance:  $d = 1 \text{ km}$  or  $1,000 \text{ m}$

speed:  $s = 330 \text{ m/s}$

2 This is the equation you need to use to find time,  $t$ :

$$s = \frac{d}{t}$$

3 To find  $t$ , multiply both sides of this equation by  $t$  and divide both sides by  $s$ :

$$t = \frac{d}{s}$$

4 Substitute the known values, and then solve the equation for  $t$ :

$$t = \frac{1 \text{ km}}{330 \text{ m/s}} = \frac{1,000 \text{ m}}{330 \text{ m/s}} = 3.03 \text{ s}$$



#### Practice Problems

1. A passenger elevator operates at an average speed of 8 m/s. If the 60th floor is 219 m above the first floor, how long does it take the elevator to go from the first floor to the 60th floor?
2. A motorcyclist travels an average speed of 20 km/h. If the cyclist is going to a friend's house 5 km away, how long does it take the cyclist to make the trip?


For more help, refer to the **Math Skill Handbook**.

## Graphing Motion

A distance-time graph makes it possible to display the motion of an object over a period of time. For example, the graph in **Figure 5** shows the motion of three swimmers during a 30-min workout. The straight, red line represents the motion of a swimmer who swam 800 m during each 10-min period. Her speed was constant at 80 m/min.

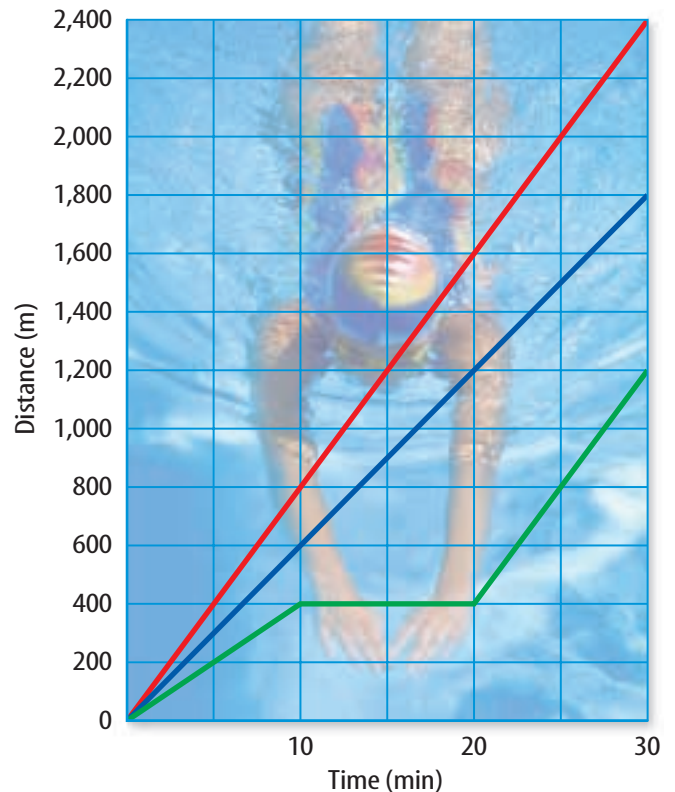
The straight blue line represents the motion of a swimmer who swam with a constant speed of 60 m/min. Notice that the line representing the motion of the faster swimmer is steeper. The steepness of a line on a graph is called the slope. On a distance-time graph, the slope of the line representing the motion of an object is the speed. Because the first swimmer has a greater speed, her line has a larger slope.

**Changing Speed** The green line represents the motion of a third swimmer, who did not swim at a constant speed. She covered 400 m during the first 10 min at a constant speed, rested for the next 10 min, and covered 800 m during the final 10 min. During the first 10 min, she swam a shorter distance than the other two swimmers, so her line has a smaller slope. During the middle period her speed is zero, so her line over this interval is horizontal and has zero slope. During the last time interval, she swam as fast as the first swimmer so that part of her line has the same slope.

 **Reading Check** *What was the average speed of each swimmer over the 30-min period?*

**Plotting a Distance-Time Graph** Plotting a distance-time graph is simple. The distance is plotted on the vertical axis and the time on the horizontal axis. Each axis must have a scale that covers the range of numbers you are working with. For instance, the total distance that the swimmers traveled was 2,400 m. The scale for distance must range from 0 to 2,400 m. The total time the swimmers worked out was 30 min. Therefore, the time scale must range from 0 to 30 min. Then each axis must be divided into equal intervals to represent the data correctly. Once the scales for each axis are in place, the data points can be plotted. After plotting the data points, draw a line connecting the points.

## Graphing Motion



**Figure 5**  
The slope of a distance-time graph gives the velocity of the object in motion.

**CLICK HERE**

**SCIENCE**  
*Online*



**Research** Visit the Glencoe Science Web site at [science.glencoe.com](http://science.glencoe.com) for information about the speed of Olympic swimmers for the past 60 years. Communicate to your class what you learn.





## Velocity

You turn on the radio and hear the tail end of a news story about a hurricane, like the one in **Figure 6**, that is approaching land. The storm, traveling at a speed of 20 km/h, is located 100 km east of your location. Should you be worried?

Unfortunately, you don't have enough information to figure out the answer. Knowing only the speed of the storm isn't much help. Speed describes only how fast something is moving. To decide whether you need to move to a safer area, you also need to know the direction that the storm is moving. In other words, you need to

**Figure 6**

The speed of a storm is not enough information to plot the path. The direction the storm is moving must be known, too.

know the velocity of the storm. **Velocity** includes the speed of an object and the direction of its motion.

Escalators like the one shown in **Figure 7A** are found in shopping malls and airports. The two sets of passengers are moving at constant speed, but in opposite directions. The speeds of the passengers are the same, but their velocities are different because the passengers are moving in different directions.

Because velocity depends on direction as well as speed, the velocity of an object can change even if the speed of the object remains constant. For example, look at **Figure 7B**. A race car has a constant speed of 100 km/h and is going around an oval track. Even though the speed remains constant, the velocity changes because the direction of the car's motion is changing constantly.

**Figure 7**

For an object to have constant velocity, speed and direction must not be changing.

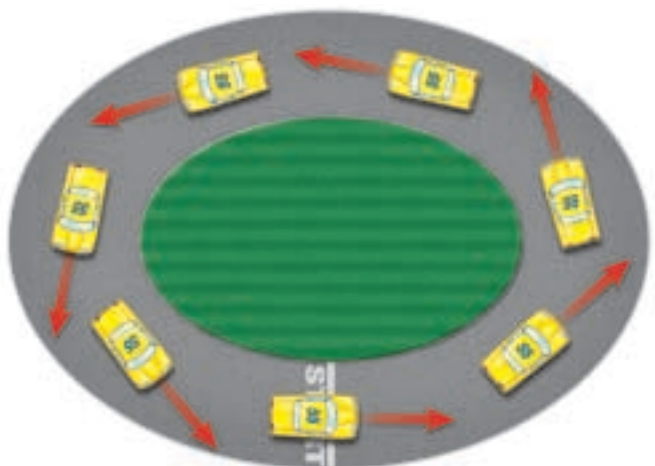
**A** These two escalators have the same speed. However, their velocities are different because they are traveling in opposite directions.



### Reading Check

*How are velocity and speed different?*

**B** The speed of this car might be constant, but its velocity is not constant because the direction of motion is always changing.



# Motion of Earth's Crust

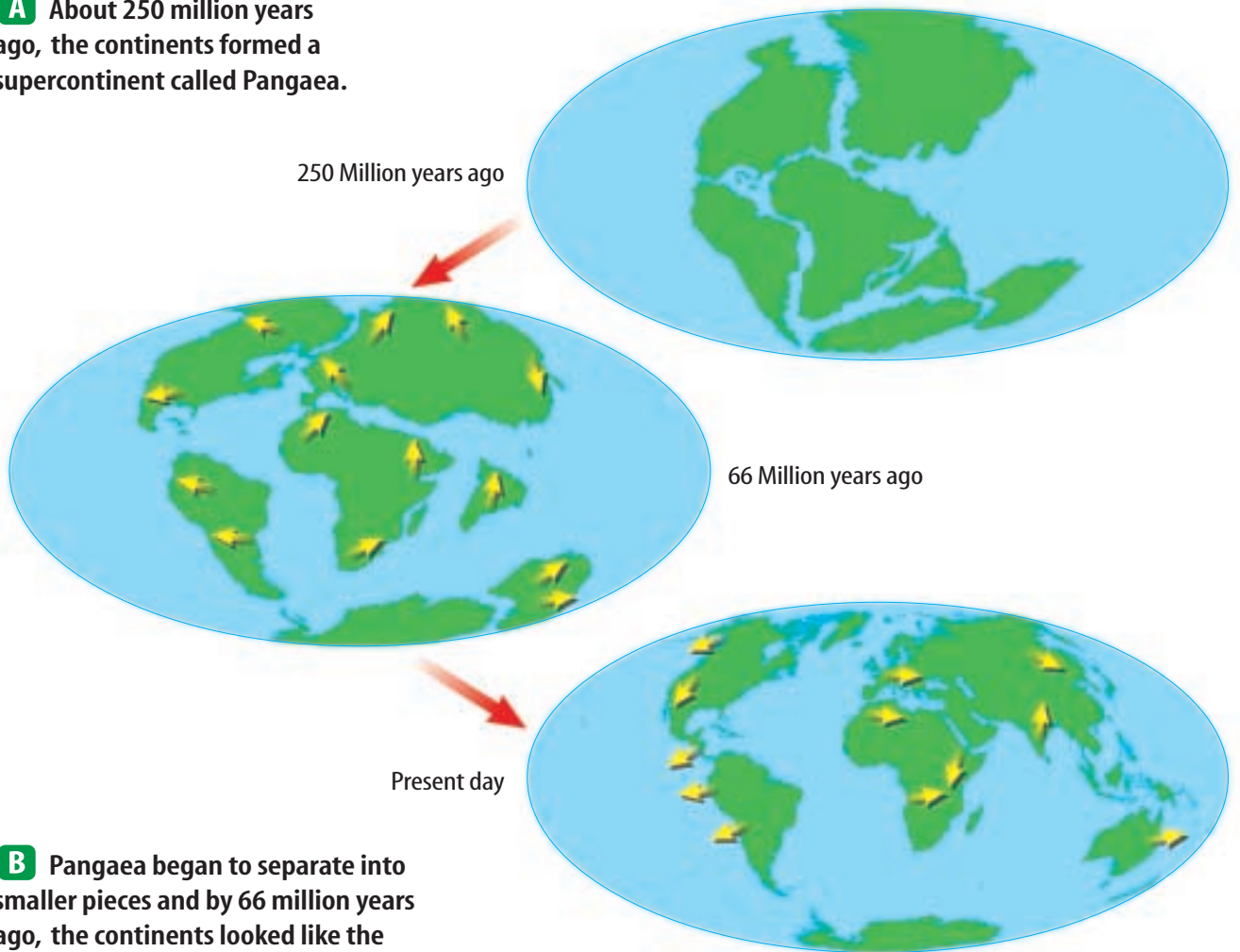


## Earth Science INTEGRATION

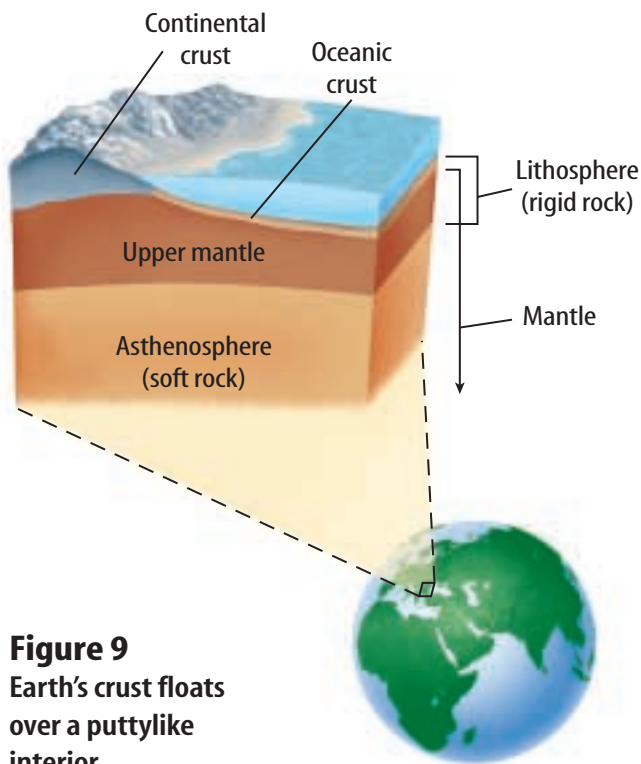
Can you think of something that is moving so slowly you cannot detect its motion, yet you can see evidence of its motion over long periods of time? As you look around the surface of Earth from year to year, the basic structure of the planet seems the same. Mountains, plains, lakes, and oceans seem to remain unchanged over hundreds of years. Yet if you examined geological evidence of what Earth's surface looked like over the past 250 million years, you would see that large changes have occurred. **Figure 8** shows how, according to the theory of plate tectonics, the positions of landmasses have changed during this time. Changes in the landscape occur constantly as continents drift slowly over Earth's surface. However, these changes are so gradual that you do not notice them.

**Figure 8**  
Geological evidence suggests that continents have moved slowly over time.

**A** About 250 million years ago, the continents formed a supercontinent called Pangaea.



**B** Pangaea began to separate into smaller pieces and by 66 million years ago, the continents looked like the figure above. The continents are still moving today.



**Figure 9**  
Earth's crust floats over a puttylike interior.

**Moving Continents** How can continents move around on the surface of Earth? Earth is made of layers, as shown in **Figure 9**. The outer layer is the crust, and the layer just below the crust is called the upper mantle. Together the crust and the top part of the upper mantle are called the lithosphere. The lithosphere is broken into huge sections called plates that slide slowly on the puttylike layers just below. If you compare Earth to an egg, these plates are about as thick as the eggshell. These moving plates cause geological changes such as the formation of mountain ranges, earthquakes, and volcanic eruptions.

Plates move so slowly that their speeds are given in units of centimeters per year. In California, two plates slide past each other along the San Andreas Fault with an average relative speed of about 1 cm per year. The

Australian Plate's movement is one of the fastest, pushing Australia north at an average speed of about 17 cm per year.

**Reading Check** How do the continents drift?

## Section 1 Assessment

1. How does displacement differ from distance? Give an example of displacement and distance.
2. You bike from your house to school, covering a distance of 3 km in 15 min. What is your average speed? Give your answer in kilometers per hour.
3. What do speed and velocity have in common? How do they differ?
4. What information does the slope of the line in a distance-time graph give?
5. **Think Critically** What units would you use to describe the speed of a car? Would you use different units for the speeds of runners in a school race? Explain.

### Skill Builder Activities

6. **Making and Using Graphs** Make a distance-time graph for a 2-h car trip. The car covered 50 km in the first 30 min, stopped for 30 min, and covered 60 km in the final 60 min. Which graph segment has the greatest slope? What was the car's average speed? **For more help, refer to the Science Skill Handbook.**
7. **Using an Electronic Spreadsheet** Use a computer to construct a data table. Using the data in problem 6, list the distance and time measurements at 5-min intervals. Use a spreadsheet program to make a data table and, if possible, re-create the graphs. **For more help, refer to the Technology Skill Handbook.**



# Acceleration

## Acceleration, Speed, and Velocity

You're sitting in a car at a stoplight when the light turns green. The driver steps on the gas pedal and the car starts moving faster and faster. Just as speed is the rate of change of position, **acceleration** is the rate of change of velocity. When the velocity of an object changes, the object is accelerating.

Remember that velocity includes the speed and direction of an object. Therefore, a change in velocity can be either a change in how fast something is moving or a change in the direction it is moving. Acceleration occurs when an object changes its speed, its direction, or both.

**Speeding Up and Slowing Down** When you think of acceleration, you probably think of something speeding up. However, an object that is slowing down also is accelerating.

Imagine a car traveling through a city. If the speed is increasing, the car has positive acceleration. When the car slows down its speed is decreasing and the car has negative acceleration. In both cases the car is accelerating because its speed is changing.

An acceleration has a direction, just as a velocity does. If the acceleration is in the same direction as the velocity, as in **Figure 10A**, the speed increases and the acceleration is positive. If the speed decreases, the acceleration is in the opposite direction from the velocity, and the acceleration is negative for the car shown in **Figure 10B**.



**A** The speed of this car is increasing. The car has positive acceleration.



**B** The speed of this car is decreasing. The car has negative acceleration.

### As You Read

#### What You'll Learn

- **Identify** how acceleration, time, and velocity are related.
- **Explain** how positive and negative acceleration affect motion.
- **Describe** how to calculate the acceleration of an object.

#### Vocabulary

acceleration

#### Why It's Important

Acceleration occurs all around you as objects speed up, slow down, or change direction.

#### Figure 10

These cars are accelerating because their speed is changing.



**Figure 11**  
The speed of the horses in this carousel is constant, but the horses are accelerating because their direction is changing constantly.



### Life Science

#### INTEGRATION

Your body is sensitive to acceleration. Much of the thrill of riding a roller coaster is due to the way your body feels while accelerating in different ways. Write a paragraph describing three situations in which you can feel accelerations while riding in a car.

**Changing Direction** A change in velocity can be either a change in how fast something is moving or a change in the direction of movement. Any time a moving object changes direction, its velocity changes and it is accelerating. Think about a horse on a carousel. Although the horse's speed remains constant, the horse is accelerating because it is changing direction constantly as it travels in a circular path, as shown in **Figure 11**. In the same way, Earth is accelerating constantly as it orbits the Sun in a nearly circular path.

Graphs of speed versus time can provide information about accelerated motion. The shape of the plotted curve shows when an object is speeding up or slowing down. **Figure 12** describes how motion graphs are constructed.

## Calculating Acceleration

Remember that acceleration is the rate of change in velocity. To calculate the acceleration of an object, the change in velocity or speed is divided by the length of the time interval over which the change occurred. Another way to write this relationship is as follows:

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time}}$$

How is the change in velocity calculated? Always subtract the initial velocity—the velocity at the beginning of the time interval—from the final velocity—the velocity at the end of the time interval. Let  $v_i$  stand for the initial velocity and  $v_f$  stand for the final velocity. The change in velocity is as follows:

$$\begin{aligned} \text{Change in velocity} &= \text{final velocity} - \text{initial velocity} \\ &= v_f - v_i \end{aligned}$$

Then the relationship between acceleration, velocity, and time is as follows:

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

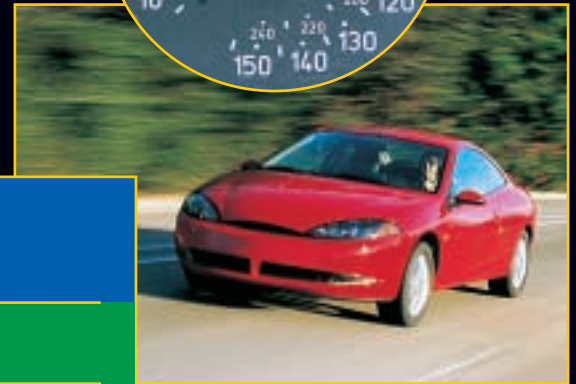
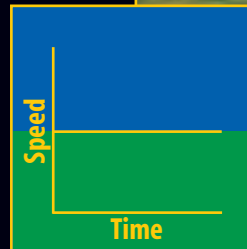
If the motion is in a single direction or a straight line, the change in speed can be used to calculate the change in velocity. The change in speed is the final speed minus the initial speed.

In the equation above, the unit of acceleration is a unit of velocity divided by a unit of time. The SI unit for velocity is meters/second (m/s), and the SI unit for time is seconds (s). So, the unit for acceleration is meters/second/second. This unit is written as  $\text{m/s}^2$  and is read “meters per second squared.”

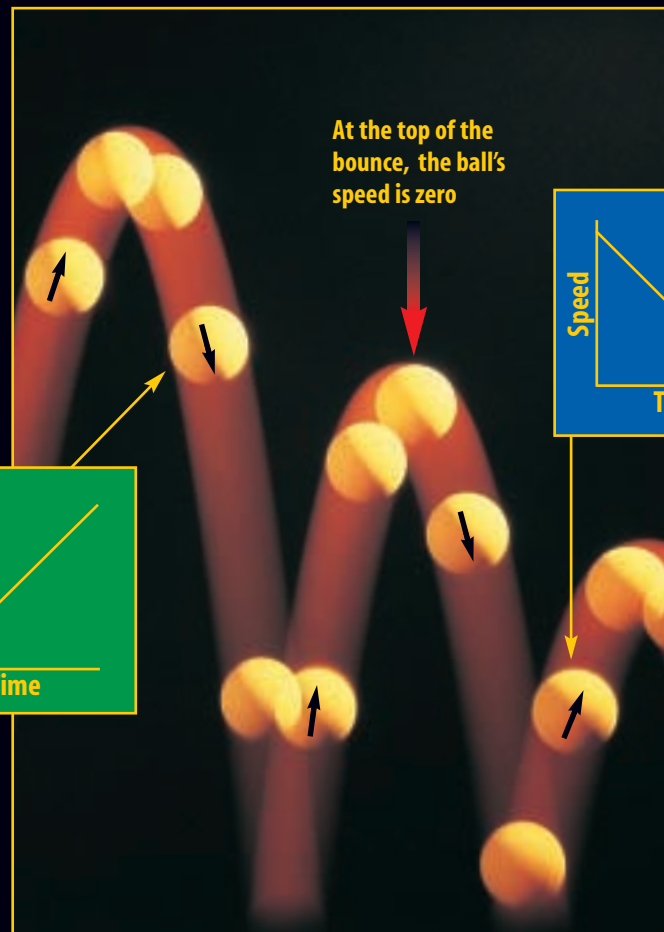
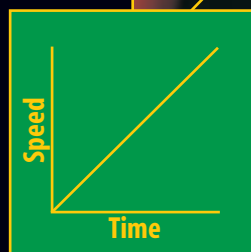
**Figure 12**

**A** cceleration can be positive, negative, or zero depending on whether an object is speeding up, slowing down, or moving at a constant speed. If the speed of an object is plotted on a graph, with time along the horizontal axis, the slope of the line is related to the acceleration.

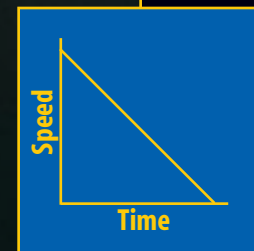
**A** The car in the photograph on the right is maintaining a constant speed of about 90 km/h. Because the speed is constant, the car's acceleration is zero. A graph of the car's speed with time is a horizontal line.



**B** The green graph shows how the speed of a bouncing ball changes with time as it falls from the top of a bounce. The ball speeds up as gravity pulls the ball downward, so the acceleration is positive. For positive acceleration, the plotted line slopes upward to the right.



At the top of the bounce, the ball's speed is zero



**C** The blue graph shows the change with time in the speed of a ball after it hits the ground and bounces upward. The climbing ball slows as gravity pulls it downward, so the acceleration is negative. For negative acceleration, the plotted line slopes downward to the right.



**Calculating Positive Acceleration** How is the acceleration for an object that is speeding up different from that of an object that is slowing down? Suppose the jet airliner in **Figure 13A** starts at rest at the end of a runway and reaches a speed of 80 m/s in 20 s. The airliner is traveling in a straight line down the runway, so its speed and velocity are the same. Because it started from rest, its initial speed was zero. Its acceleration can be calculated as follows:

$$a = \frac{(v_f - v_i)}{t} = \frac{(80 \text{ m/s} - 0 \text{ m/s})}{20 \text{ s}} = 4 \text{ m/s}^2$$

The airliner is speeding up, so the final speed is greater than the initial speed and the acceleration is positive.

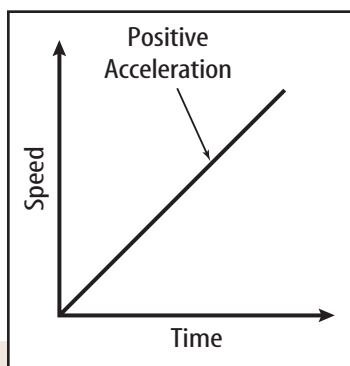
**Calculating Negative Acceleration** Now imagine that the skateboarder in **Figure 13B** is moving in a straight line at a speed of 3 m/s and comes to a stop in 2 s. The final speed is zero and the initial speed was 3 m/s. The skateboarder's acceleration is calculated as follows:

$$a = \frac{(v_f - v_i)}{t} = \frac{(0 \text{ m/s} - 3 \text{ m/s})}{2 \text{ s}} = -1.5 \text{ m/s}^2$$

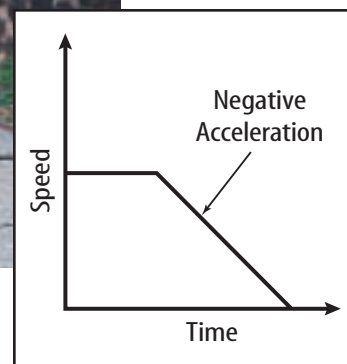
The skateboarder is slowing down, so the final speed is less than the initial speed and the acceleration is negative. The acceleration always will be positive if an object is speeding up and negative if the object is slowing down. What is the acceleration if an object moves with constant velocity?

**Figure 13**  
A speed-time graph tells you if acceleration is a positive or negative number.

**A** If acceleration is a positive number, the line slopes upward to the right.



**B** If acceleration is a negative number, the line slopes downward to the right.



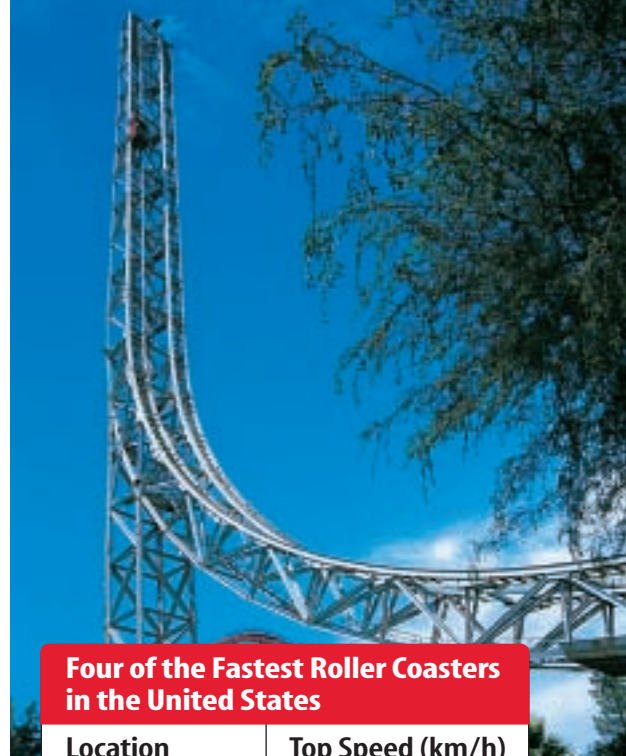
## Amusement Park Acceleration

Riding roller coasters in amusement parks can give you the feeling of danger—but these rides are designed to be safe. Engineers use the laws of physics to provide a thrilling but harmless ride. Roller coasters are constructed of wood or steel. Wooden roller coasters do not have the high velocities and accelerations that steel roller coasters do. Wood is not as rigid as steel. Therefore, these roller coasters do not have steep hills or inversion loops that propel the rider at high speeds. However, wooden roller coasters can have a swaying movement that steel roller coasters do not have. This swaying motion can give the rider a different type of thrill.

Steel roller coasters can offer multiple steep drops and inversion loops, which give the rider large accelerations. As the rider moves down a steep hill or an inversion loop, he or she will accelerate toward the ground at  $9.8 \text{ m/s}^2$  due to gravity. When riders go around a sharp turn, they also are accelerated. This acceleration makes them feel as if a force is pushing them toward the side of the car. The table in **Figure 14** shows the four fastest roller coasters in the United States. The fastest roller coaster goes from 0 to 160.9 km/h in 7 s.

### ✓ Reading Check

*What material are roller coasters with the steepest hills made from?*



**Four of the Fastest Roller Coasters in the United States**

Location	Top Speed (km/h)
Valencia, CA	160.9
Sandusky, OH	148
Valencia, CA	136.8
Primm, NV	128.7

**Figure 14**  
This roller coaster is the fastest roller coaster in the world. Riders reach a speed of 160.9 km/h.

## Section 2 Assessment

1. How are velocity, time, and acceleration related mathematically?
2. A swimmer speeds up from 1.1 m/s to 1.3 m/s during the last 20 s of a workout. What is the swimmer's acceleration during this time interval?
3. While walking to school, you approach an intersection and slow down from 2 m/s to a stop in 3 s. What was your acceleration during this time interval?
4. Explain the term *negative acceleration*.
5. **Think Critically** Describe three ways to change your velocity while riding a bicycle.

### Skill Builder Activities

6. **Making and Using Graphs** In the graph shown in **Figure 13A**, is the speed increasing or decreasing? Explain. Is the speed increasing or decreasing in **Figure 13B**? Explain. Describe how the graph would look for a jet airplane cruising at a constant speed. **For more help, refer to the Science Skill Handbook.**
7. **Communicating** In your Science Journal, explain why streets and highways have speed limits rather than velocity limits. Where might a velocity limit be used? **For more help, refer to the Science Skill Handbook.**

# Motion and Forces

## As You Read

### What You'll Learn

- **Explain** how force and velocity are related.
- **Describe** what inertia is and how it is related to Newton's first law of motion.
- **Identify** the forces and motion that are present during a car crash.

### Vocabulary

force  
net force  
balanced force  
inertia

### Why It's Important

Force and motion are directly linked—without force, you cannot have motion.

## What is force?

Passing a basketball to a team member or kicking a soccer ball into the goal are examples of applying force to an object. A **force** is a push or pull that one body exerts on another. In both examples, the applied force results in the movement of the ball. Sometimes it is obvious that a force has been applied. But other forces aren't as noticeable. For instance, are you conscious of the force the floor exerts on your feet? Can you feel the force of the atmosphere pushing against your body or gravity pulling on your body?

Think about all the forces you exert in a day. Every push, pull, stretch, or bend results in a force being applied to an object.

**Changing Motion** What happens to the motion of an object when you exert a force on it? A force can cause the motion of an object to change. Think of hitting a ball with a racket, as in **Figure 15**. The racket strikes the ball with a force that causes the ball to stop and then move in the opposite direction. If you have played billiards, you know that you can force a ball at rest to roll into a pocket by striking it with another ball. The force of the moving ball causes the ball at rest to move in the direction of the force. In these cases, the velocities of the ball and the billiard ball were changed by a force.

**Figure 15**

This ball is hit with a force. The racket strikes the ball with a force in the opposite direction of its motion. As a result, the ball changes the direction it is moving.





**Figure 16**  
Forces can be balanced  
and unbalanced.



$$\begin{array}{c} \longrightarrow + \longleftarrow = 0 \\ \text{Net Force} = 0 \end{array}$$

**A** These students are pushing on the box with an equal force but in opposite directions. Because the forces are balanced, the box does not move.



$$\begin{array}{c} \longrightarrow + \longleftarrow = \longrightarrow \\ \text{Net Force} = \longrightarrow \end{array}$$

**B** These students are pushing on the box with unequal forces in opposite directions. The box will be moved in the direction of the larger force.



$$\begin{array}{c} \longrightarrow + \longrightarrow = \longrightarrow \\ \text{Net Force} = \longrightarrow \end{array}$$

**C** These students are pushing on the box in the same direction. The combined forces will cause the box to move.

**Balanced Forces** Force does not always change velocity. In **Figure 16A**, two students are pushing on opposite sides of a box. Both students are pushing with an equal force but in opposite directions. When two or more forces act on an object at the same time, the forces combine to form the **net force**. The net force on the box in **Figure 16A** is zero because the two forces cancel each other. Forces on an object that are equal in size and opposite in direction are called **balanced forces**.

**Unbalanced Forces** Another example of how forces combine is shown in **Figure 16B**. When two students are pushing with unequal forces in opposite directions, a net force occurs in the direction of the larger force. In other words, the student who pushes with a greater force will cause the box to move in the direction of the force. The net force that moves the box will be the difference between the two forces because they are in opposite directions or they are considered to be unbalanced forces.

In **Figure 16C**, the students are pushing on the box in the same direction. These forces are combined or added together because they are exerted on the box in the same direction. The net force that acts on this box is found by adding the two forces together.

**Reading Check** *What is an unbalanced force?*

**SCIENCE** *Online*

**Research** Visit the Glencoe Science Web site at [science.glencoe.com](http://science.glencoe.com) for information about unbalanced forces along fault lines in the Earth's crust. In your Science Journal describe the significant activity that occurs along these fault lines.

**CLICK HERE**

**Observing Inertia****Procedure**

1. Create an inclined plane between  $25^\circ$  and  $50^\circ$  using a **board** and **textbooks**. Place a **stop block** (brick or other heavy object) at the end of the plane.
2. Place a **small object** in a **cart** and allow both to roll down the plane. Record the results in your journal.
3. Secure the object in the cart with **rubber bands** (seat belts). Allow both to roll down the plane again. Record the results.

**Analysis**

1. Identify the forces acting on the object in both runs.
2. Explain why it is important to wear seat belts in a car.

**Inertia and Mass**

The car in **Figure 17** is sliding on an icy road. This sliding car demonstrates the property of inertia. **Inertia** (ihn UR shuh) is the tendency of an object to resist any change in its motion. If an object is moving, it will keep moving at the same speed and in the same direction unless an unbalanced force acts on it. In other words, the velocity of the object remains constant unless a force changes it. If an object is at rest, it tends to remain at rest. Its velocity is zero unless a force makes it move.

Does a bowling ball have the same inertia as a table-tennis ball? Why is there a difference? You couldn't change the motion of a bowling ball much by swatting it with a table-tennis paddle. However, you easily could change the motion of the table-tennis ball. A greater force would be needed to change the motion of the bowling ball because it has greater inertia. Why is this? Recall that mass is the amount of matter in an object, and a bowling ball has more mass than a table-tennis ball does. The inertia of an object is related to its mass. The greater the mass of an object is, the greater its inertia.

**Newton's First Law of Motion** Forces change the motion of an object in specific ways. The British scientist Sir Isaac Newton (1642–1727) was able to state rules that describe the effects of forces on the motion of objects. These rules are known as Newton's laws of motion. They apply to the motion of all objects you encounter every day such as cars and bicycles, as well as the motion of planets around the Sun.

**Figure 17**

On an icy road, it is hard to turn or stop a car because the car has no traction. Because of its inertia, the car tends to move in a straight line with constant speed.





**Figure 18**  
The inertia of the billiard balls causes them to remain at rest until a force is exerted on them by the cue ball.

**The Law of Inertia** According to Newton’s first law of motion, an object moving at a constant velocity keeps moving at that velocity unless a net force acts on it. If an object is at rest, it stays at rest unless a net force acts on it. Does this sound familiar? It is the same as the earlier discussion of inertia. This law is sometimes called the law of inertia. You probably have seen and felt this law at work without even knowing it. **Figure 18** shows a billiard ball striking the other balls in the opening shot. What are the forces involved when the cue ball strikes the other balls? Are the forces balanced or unbalanced? How does this demonstrate the law of inertia?

 **Reading Check** *What is Newton’s first law?*

## What happens in a crash?

The law of inertia can explain what happens in a car crash. When a car traveling about 50 km/h collides head-on with something solid, the car crumples, slows down, and stops within approximately 0.1 s. Any passenger not wearing a seat belt continues to move forward at the same speed the car was traveling. Within about 0.02 s (1/50 of a second) after the car stops, unbelted passengers slam into the dashboard, steering wheel, windshield, or the backs of the front seats, as in **Figure 19**. They are traveling at the car’s original speed of 50 km/h—about the same speed they would reach falling from a three-story building.



**Figure 19**  
The crash dummy is not restrained in this low-speed crash. Inertia causes the dummy to slam into the steering wheel.



**Figure 20**

These crash dummies were restrained safely with seat belts in this low-speed crash. Usually humans would have fewer injuries if they were restrained safely during an accident.



**Seat belts** The crash dummy wearing a seat belt in **Figure 20** will be attached to the car and will slow down as the car slows down. The force needed to slow a person from 50 km/h to zero in 0.1 s is equal to 14 times the force that gravity exerts on the person. The belt loosens a little as it restrains the person, increasing the time it takes to slow the person down. This reduces the force exerted on the person. The seat belt also prevents the person from being thrown out of the car. Car-safety experts say that about half the people who die in car crashes would survive if they wore seat belts. Thousands of others would suffer fewer serious injuries.

## Section 3 Assessment

1. When a soccer player kicks a ball, the ball accelerates. Explain what causes this acceleration in terms of forces.
2. Explain which has greater inertia—a speeding car or a jet airplane sitting on a runway.
3. Do forces always cause motion? Explain.
4. While trying to explain a physics concept, a student said, “Stuff keeps doing what it’s doing unless something messes with it.” What law was this student summarizing? Explain your answer.
5. **Think Critically** Describe three examples from sports in which a force changes the velocity of an object or a person.

### Skill Builder Activities

6. **Researching Information** Many states have passed seat belt laws requiring all passengers in cars to wear seat belts. Research whether your state has such a law and when it became a law. Record your answer in your Science Journal. **For more help, refer to the Science Skill Handbook.**
7. **Communicating** Inertia plays an important role in most sports. In your Science Journal, write a paragraph describing the role of inertia in your favorite sport. Write another paragraph describing how the sport would be different without inertia. **For more help, refer to the Science Skill Handbook.**

# Activity

## Force and Acceleration

If you stand at a stoplight, you will see cars stopping for red lights and then taking off when the light turns green. What makes the cars slow down? What makes them speed up? The cars accelerate because an unbalanced force is acting on them.

### What You'll Investigate

How does an unbalanced force on a book affect its motion?

### Materials

tape	this science book
paper clip	triple beam balance
10-N spring scale	* <i>electronic balance</i>
large book	* <i>Alternate materials</i>

### Goals

- **Observe** the effect of force on the acceleration of an object.
- **Interpret** the data collected for each trial.

### Safety Precautions



Proper eye protection should be worn at all times while performing this lab.

### Procedure

1. With a piece of tape, attach the paper clip to your textbook so that the paper clip is just over the edge of the book.
2. Prepare a data table with the following headings: Force, Mass.
3. If available, use a large balance to find the mass of this science book.
4. Place the book on the floor or on the surface of a long table. Use the paper clip to hook the spring scale to the book.



5. Pull the book across the floor or table at a slow but constant velocity. While pulling, read the force you are pulling with on the spring scale and record it in your table.
6. Repeat step 5 two more times, once accelerating slowly and once accelerating quickly. Be careful not to pull too hard. Your spring scale will read only up to 10 N.
7. Place a second book on top of the first book and repeat steps 3 through 6.

### Conclude and Apply

1. **Organize** the pulling forces from greatest to least for each set of trials. Do you see a relationship between force and acceleration? Explain your answer.
2. How did adding the second book change the results? Explain your answer.

### Communicating Your Data

Compare your conclusions with those of other students in your class. For more help, refer to the **Science Skill Handbook**.

# Activity

## Design Your Own Experiment

### Comparing Motion from Different Forces

**T**hink about a small ball. How many ways could you exert a force on the ball to make it move? You could throw it, kick it, roll it down a ramp, blow it with a large fan, etc. Do you think the distance and speed of the ball's motion will be the same for all of these forces? Do you think the acceleration of the ball would be the same for all of these types of forces?

#### Recognize the Problem

How will the motion of a small toy car vary when different forces are applied to it?

#### Form a Hypothesis

Based on your reading and observations, state a hypothesis about how a force can be applied that will cause the toy car to go fastest.

#### Possible Materials

small toy car  
ramps or boards of different lengths  
springs or rubber bands  
string  
stopwatch  
meterstick or tape measure  
graph paper

#### Safety Precautions

#### Goals

- **Identify** several forces that you can use to propel a small toy car across the floor.
- **Demonstrate** the motion of the toy car using each of the forces.
- **Graph** the position versus time for each force.
- **Compare** the motion of the toy car resulting from each force.





## Test Your Hypothesis

### Plan

1. As a group, agree upon the hypothesis and decide how you will test it. Identify which results will confirm the hypothesis that you have written.
2. **List** the steps you will need to test your hypothesis. Be sure to include a control run. Be specific. Describe exactly what you will do in each step. List your materials.
3. Prepare a data table in your Science Journal to record your observations.
4. **Read** the entire experiment to make sure all steps are in logical order and will lead to a conclusion.
5. **Identify** all constants, variables, and controls of the experiment. Keep in mind that you will need to have measurements at multiple points.

These points are needed to graph your results. You should make sure to have several data points taken after you stop applying the force and before the car starts to slow down. It might be useful to have several students taking measurements, making each responsible for one or two points.



### Do

1. Make sure your teacher approves your plan before you start.
2. Carry out the experiment as planned.
3. While doing the experiment, record your observations and complete the data tables in your Science Journal.

## Analyze Your Data

1. **Graph** the position of the car versus time for each of the forces you applied. How can you use the graphs to compare the speeds of the toy car?
2. **Calculate** the speed of the toy car over the same time interval for each of the forces that you applied. How do the speeds compare?

## Draw Conclusions

1. Did the speed of the toy car vary depending upon the force applied to it?
2. For any particular force, did the speed of the toy car change over time? If so, how did the speed change? Describe how you can use your graphs to answer these questions.
3. Did your results support your hypothesis? Why or why not?

### Communicating Your Data

**Compare** your data to those of other students. **Discuss** how the forces you applied might be different from those others applied and how that affected your results.

## A Brave and Startling Truth

by Maya Angelou

### Respond to the Reading

1. What adjectives does the poet use to describe Earth?
2. What wonders of the world does the poet name?
3. What does the poet believe are the true wonders of the world?

We, this people, on a small and lonely planet  
Traveling through casual space  
Past aloof stars, across the way of indifferent suns  
To a destination where all signs tell us  
It is possible and imperative that we learn  
A brave and startling truth...

When we come to it  
Then we will confess that not the Pyramids  
With their stones set in mysterious perfection  
Nor the Gardens of Babylon  
Hanging as eternal beauty  
In our collective memory  
Not the Grand Canyon  
Kindled into delicious color  
By Western sunsets  
These are not the only wonders of the world...

When we come to it  
We, this people, on this minuscule and kithless<sup>1</sup> globe...  
We this people on this mote<sup>2</sup> of matter

When we come to it  
We, this people, on this wayward<sup>3</sup>, floating body  
Created on this earth, of this earth  
Have the power to fashion for this earth  
A climate where every man and every woman  
Can live freely without sanctimonious piety<sup>4</sup>  
Without crippling fear

When we come to it  
We must confess that we are the possible  
We are the miraculous, the true wonder of the world  
That is when, and only when  
We come to it.

<sup>1</sup> to be without friends or neighbors

<sup>2</sup> small particle

<sup>3</sup> wanting one's own way in spite of the advice or wishes of another

<sup>4</sup> a self-important show of being religious



## Understanding Literature

**Descriptive Writing** This poem is full of images of Earth moving through space. But the adjectives the author uses to describe Earth are from the perspective of the universe. This description from the point of view of the universe gives the impression that Earth is small and insignificant.

The poet also names some special places on Earth. These places, although marvelous, fall short of being really wonderful. Angelou contrasts Earth's position within the universe to emphasize the importance of people. The power that people have to make changes for better lives is more significant than the universe and the special places people have built on Earth.

**Science Connection** Sometimes a person doesn't need to see movement to know that something has moved. Even though we don't necessarily see Earth's movement, we know Earth moves because of reference points such as the Sun. We know Earth moves because the Sun appears to change its position in the sky. The poem describes Earth's movement from the point of view of the universe. The universe serves as a reference point for detecting Earth's movement.

## Linking Science and Writing

**Write a Poem** In the poem you just read, Maya Angelou describes Earth's movement from the point of view of the universe. Write a six-line poem that describes Earth's movement from the point of view of the Moon. How might the Moon's point of view toward Earth be different from that of remote stars and suns?

## Career Connection



### Roller Coaster Designer and Engineer

**Ancient engineers** designed the pyramids. Today, engineers design everything from can openers to cars. Werner Stengel and his team have designed and engineered more than 200 roller coasters. They compute the forces that react on roller coaster passengers. They also analyze the kind and amount of stress the roller-coaster structure will have to bear. Stengel has worked with safety committees and research groups to make sure that amusement park rides are safe for their riders.

**SCIENCE Online** To learn more about careers in engineering, visit the Glencoe Science Web site at [science.glencoe.com](http://science.glencoe.com).

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CONTENTS



## Reviewing Main Ideas

### Section 1 Describing Motion

1. Motion is a change of position of a body. Distance is the measure of how far an object moved. Displacement is the distance and direction of an object's change in position from the starting point. *In the figure above, how can the motion of this shot put be described correctly?*



2. Average speed is the total distance traveled divided by the total time of travel.
3. Instantaneous speed is the speed at a given instant of time.
4. Velocity describes the speed and direction of a moving object.

### Section 2 Acceleration

1. Acceleration is the rate of change of velocity for any object.
2. Any time the velocity of an object changes, the object must be accelerated. *In the figure below, describe the type of acceleration that occurs when the car stops for the red light and when it moves again for a green light.*



3. Acceleration occurs if an object speeds up, slows down, or changes direction.

### Section 3 Motion and Forces

1. A force is a push or a pull one body exerts on another.
2. Balanced forces acting on a body do not change the motion of the body. Unbalanced forces result in a net force, which always changes the motion of a body.
3. Inertia is the resistance of an object to a change in its motion.
4. Newton's first law says an object's motion will not change unless a net force acts on it. *In the figure below, describe the forces that are acting on the car.*



### After You Read

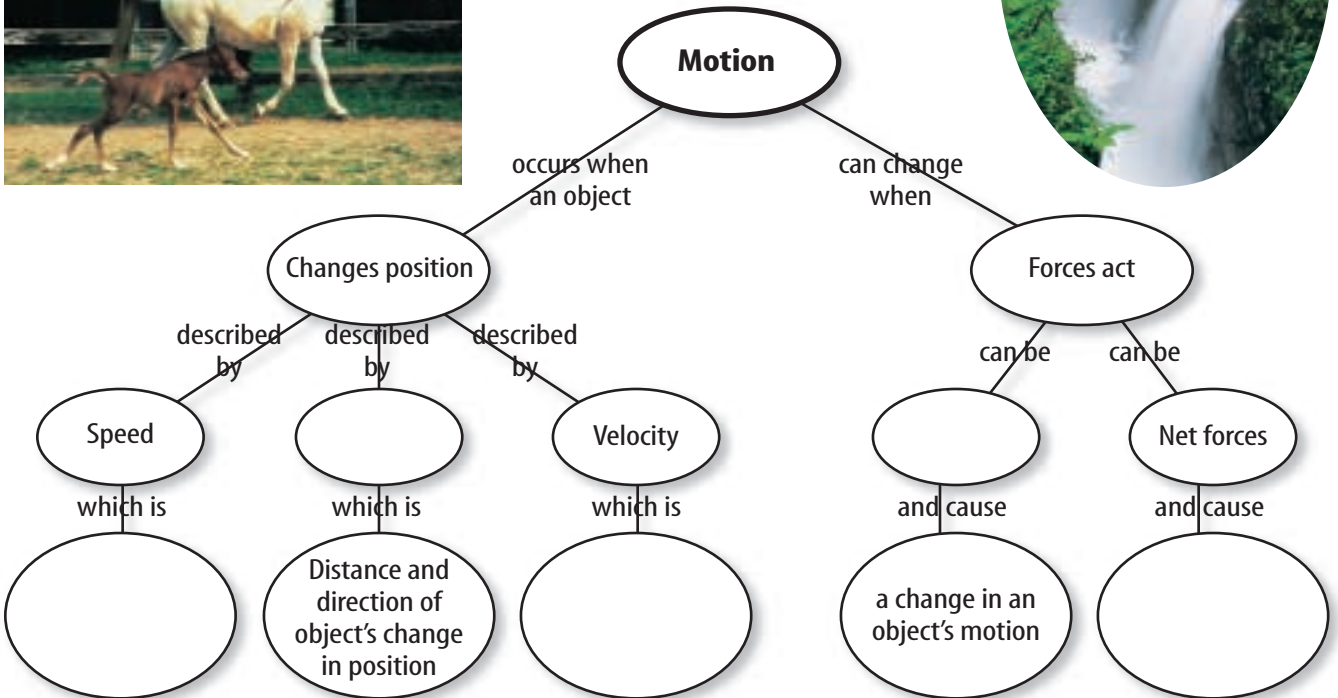
#### FOLDABLES Reading & Study Skills



To help you review the characteristics of motion, use the Foldable you made at the beginning of this chapter. Use the Foldable to review for quizzes, chapter tests, and semester exams.

## Visualizing Main Ideas

Complete the following concept map about motion.



## Vocabulary Review

### Vocabulary Words

- |                   |                        |
|-------------------|------------------------|
| a. acceleration   | g. inertia             |
| b. average speed  | h. instantaneous speed |
| c. balanced force | i. net force           |
| d. displacement   | j. speed               |
| e. distance       | k. velocity            |
| f. force          |                        |

### Using Vocabulary

Compare and contrast the following pairs of vocabulary words.

- speed, velocity
- distance, displacement
- average speed, instantaneous speed
- balanced force, net force
- force, inertia
- acceleration, velocity
- velocity, instantaneous speed
- force, net force
- force, acceleration



### Study Tip

To understand the information on a graph, write a sentence about the relationship between the x-axis and y-axis in the graph.

## Checking Concepts

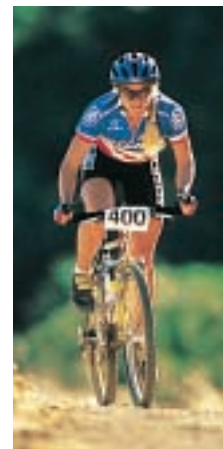
Choose the word or phrase that best answers the question.

- Which of the following do you calculate when you divide the total distance traveled by the total travel time?
  - average speed
  - constant speed
  - variable speed
  - instantaneous speed
- What is the tendency for an object to resist any change in its motion called?
  - net force
  - acceleration
  - balanced force
  - inertia
- Which of the following is a proper unit of acceleration?
  - $\text{s}/\text{km}^2$
  - $\text{km}/\text{h}$
  - $\text{m}/\text{s}^2$
  - $\text{cm}/\text{s}$
- Which of the following is not used in calculating acceleration?
  - initial velocity
  - average speed
  - time interval
  - final velocity
- In which of the following conditions does the car NOT accelerate?
  - A car moves at 80 km/h on a flat, straight highway.
  - The car slows from 80 km/h to 35 km/h.
  - The car turns a corner.
  - The car speeds up from 35 km/h to 80 km/h.
- Which term below best describes the forces on an object with a net force of zero?
  - inertia
  - balanced forces
  - acceleration
  - unbalanced forces
- How can speed be defined?
  - acceleration/time
  - change in velocity/time
  - distance/time
  - displacement/time

- Which of the following objects has the greatest inertia?
  - a car parked on the side of the road
  - a baseball during a pop fly
  - a computer sitting on a desk
  - a woman running on a track
- A man drives 3 km east from home to the store and then 2 km west to a friend's house. What is his displacement from his starting point at home?
  - 1 km west
  - 1 km east
  - 5 km west
  - 5 km east
- Which answer best describes why a passenger who is not wearing a seat belt will likely hit the windshield in a head-on collision?
  - forces acting on the windshield
  - inertia of the unbelted person
  - acceleration of the car
  - gravity taking over

## Thinking Critically

- A cyclist must travel 800 km. How many days will the trip take if the cyclist travels 8 h/day at an average speed of 16 km/h?
- A satellite's speed is 10,000 m/s. After 1 min, it is 5,000 m/s. What is the satellite's acceleration?
- A cyclist leaves home and rides due east for a distance of 45 km. She returns home on the same bike path. If the entire trip takes 4 h, what is her average speed? What is her displacement?
- The return trip of the cyclist in question 13 took 30 min longer than her trip east, although her total time was still 4 h. What was her velocity in each direction?





## Developing Skills

- 15. Measuring in SI** Which of the following represents the greatest speed: 20 m/s, 200 cm/s, or 0.2 km/s? Here's a hint:  
*Express all three in m/s and then compare.*
- 16. Recognizing Cause and Effect** Acceleration can occur when a car is moving at constant speed. What must cause this acceleration?
- 17. Making and Using Graphs** The following data were obtained for two runners. Make a distance-time graph that shows the motion of both runners. What is the average speed of each runner? Which runner stops briefly? During what time interval do Sally and Alonzo run at the same speed?

Distance-Time for Runners				
Time (s)	1	2	3	4
Sally's Distance (m)	2	4	6	8
Alonzo's Distance (m)	1	2	2	4

## Performance Assessment

- 18. Poster** Research the current safety features available in cars, including seat belts, improved door locks, collapsible steering columns, and air bags. Use this information, along with the statistics you found in the Science Online Feature regarding safety in cars, to make a poster on the benefits of using seat belts.

### TECHNOLOGY

Go to the Glencoe Science Web site at [science.glencoe.com](http://science.glencoe.com) or use the Glencoe Science CD-ROM for additional chapter assessment.

**CLICK HERE**



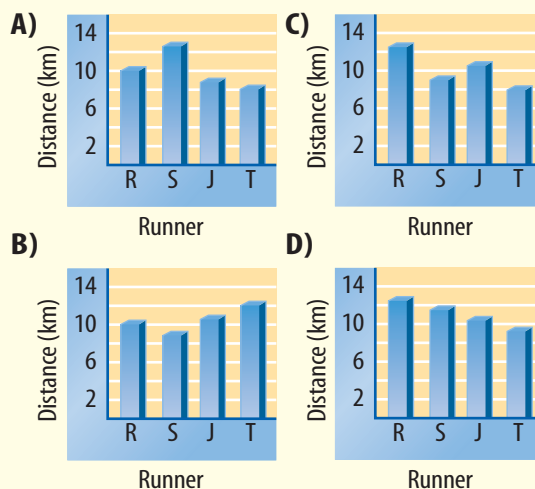
## Test Practice

Four runners ran for 40 min. The following table represents the distance each runner covered in that time:

Runners' Distances	
Runner Name	Distance Covered (km)
Rosemarie (R)	12.5
Sam (S)	8.9
Jake (J)	10.5
Theresa (T)	7.8

Study the table and answer the following questions.

1. Which of these graphs best represents these data?



2. The average speed of each runner can be determined by dividing the total distance by the total travel time. Which runner has the fastest average speed?
- F) Rosemarie      H) Jake  
G) Sam              J) Theresa