

**Frame of Reference** After a reference point is chosen, a frame of reference can be created. A frame of reference is a coordinate system in which the position of the objects is measured. The  $x$ -axis and  $y$ -axis of the reference frame are drawn so that they intersect the reference point.



### Moving Through Space

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

**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.

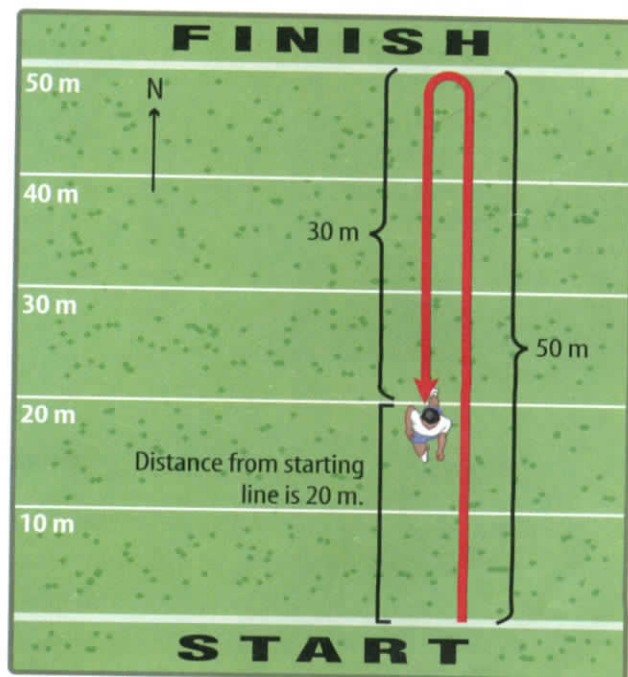
**Figure 2** Distance and displacement are not the same. The runner's displacement is 20 m north of the starting line. However, the total distance traveled is 80 m.

The length 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**. You 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.



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

**Calculating Speed** Any change over time is called a rate. 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.

### Speed Equation

$$\text{speed (in meters/second)} = \frac{\text{distance (in meters)}}{\text{time (in seconds)}}$$

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

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). Sometimes it is more convenient to express speed in other units, such as kilometers per hour (km/h). **Table 1** shows some convenient units for certain types of motion.

## Applying Math

### Solve a One-Step Equation

**CALCULATING SPEED** A car traveling at a constant speed covers a distance of 750 m in 25 s. What is the car's speed?

**IDENTIFY** known values and the unknown value

Identify the known values:

covers a distance of 750 m  $\xrightarrow{\text{means}}$   $d = 750 \text{ m}$

in 25 s  $\xrightarrow{\text{means}}$   $t = 25 \text{ s}$

Identify the unknown value:

What is the car's speed?  $\xrightarrow{\text{means}}$   $s = ? \text{ m/s}$

**SOLVE** the problem

Substitute the given values of distance and time into the speed equation:

$$s = \frac{d}{t} = \frac{750 \text{ m}}{25 \text{ s}} = 30 \text{ m/s}$$

**CHECK** the answer

Does your answer seem reasonable? Check your answer by multiplying the time by the speed. The result should be the distance given in the problem.

### 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 practice problems go to page 834, and visit [gpscience.com/extra\\_problems](http://gpscience.com/extra_problems).

**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	2cm/yr–17 cm/yr

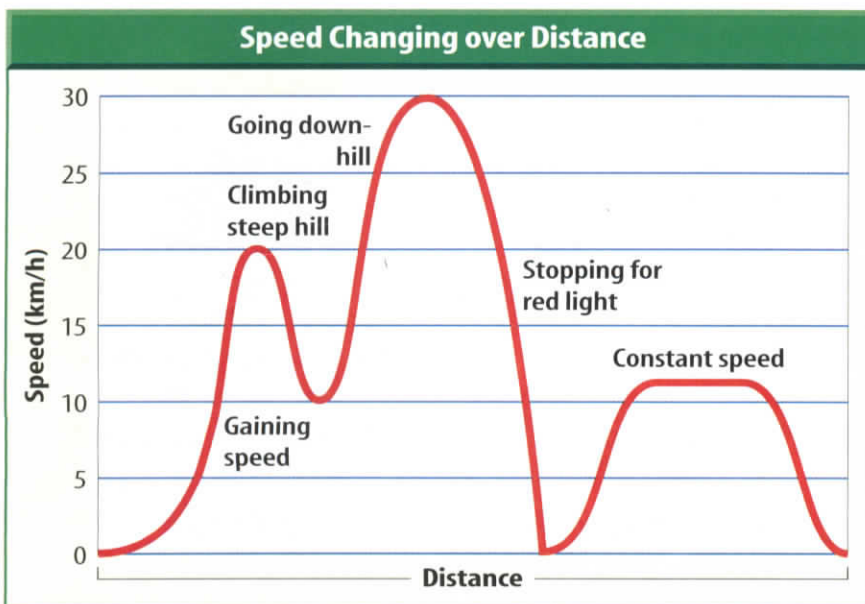
**Motion with Constant Speed** Suppose you are in a car traveling on a nearly empty freeway. You look at the speedometer and see that the car's speed hardly changes. If the car neither slows down nor speeds up, the car is traveling at a constant speed. If you are traveling at a constant speed, you can measure your speed over any distance interval.

**Changing Speed** Usually speed is 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 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. Finally, you slow down and then stop. Checking your watch, you find that the trip took 15 min. 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?

**Topic: Running Speeds**

Visit [gpscience.com](http://gpscience.com) for Web links to information about the running speeds of various animals.

**Activity** In your Science Journal, describe how running fast benefits the survival of animals in the wild.



**Figure 3** The graph shows how the speed of a cyclist changes during a trip.

**Explain** how you describe the speed of an object when the speed is changing.



**Figure 4** The speed shown on the speedometer gives the instantaneous speed—the speed at one instant in time.

## 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 on the floor at the front of the car with a **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?

**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 relationships among speed, distance, and time. For the bicycle trip just described, the total distance traveled was 5 km and the total time was  $\frac{1}{4}$  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.

**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?*

## Graphing Motion

The motion of an object over a period of time can be shown on a distance-time graph. Time is plotted along the horizontal axis of the graph and the distance traveled is plotted along the vertical axis of the graph. If the object moves with constant speed, the increase in distance over equal time intervals is the same. As a result, the line representing the object's motion is a straight line.

For example, the graph shown in **Figure 5** represents the motion of three swimmers during a 30-min workout. The straight red line represents the motion of Mary, who swam with a constant speed of 80 m/min over the 30-min workout. The straight blue line represents the motion of Kathy, who swam with a constant speed of 60 m/min during the workout.

The graph shows that the line representing the motion of the faster swimmer is steeper. The steepness of a line on a graph is the slope of the line. The slope of a line on a distance-time graph equals the speed. A horizontal line on a distance-time graph has zero slope, and represents an object at rest. Because Mary has a larger speed than Kathy, the line representing her motion has a larger slope.

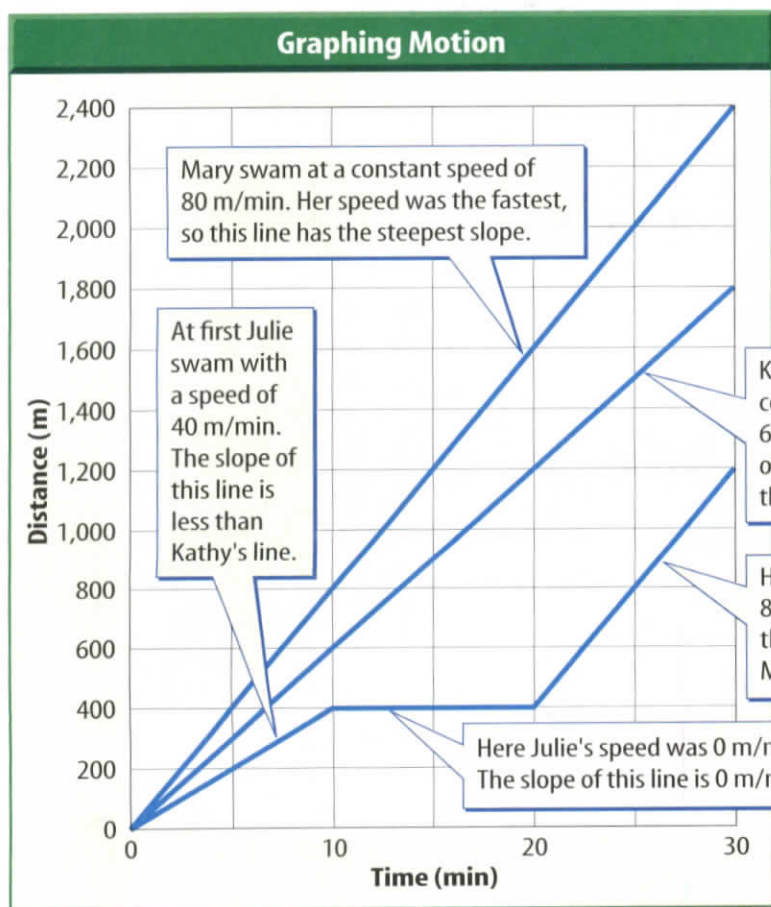
**Changing Speed** The green line represents the motion of Julie, who did not swim at a constant speed. She covered 400 m at a constant speed during the first 10 min, rested for the next 10 min, and then covered 800 m during the final 10 min. During the first 10 min, her speed was less than Mary's or Kathy's, 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 Mary, so that part of her line has the same slope.

**Plotting a Distance-Time Graph** On a distance-time graph, 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 to be plotted. In **Figure 5** the distance scale must range from 0 to 2,400 m and the time scale must range from 0 to 30 min. Then, each axis can be divided into equal time intervals to represent the data. 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.

**Topic: Olympic Swimming Speeds**

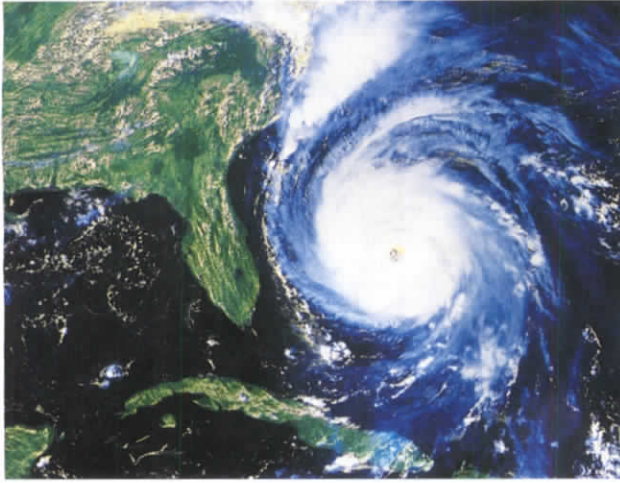
Visit [gpscience.com](http://gpscience.com) for Web links to information about the speeds of Olympic swimmers over the past 60 years.

**Activity** Make a speed-year graph showing the swimming speeds over time. Are there any trends in the speed data?



**Figure 5** The slope of a line on a distance-time graph gives the speed of an object in motion.

**Identify** the part of the graph that shows one of the swimmers resting for 10 min.



**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.

## 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 answer that question. 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

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

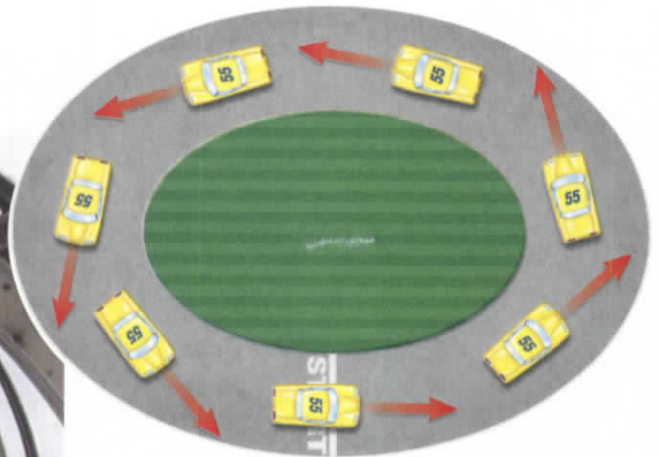
Escalators like the one shown in **Figure 7** are found in shopping malls and airports. The two sets of passengers pictured are moving at constant speed, but in opposite directions. The speeds of the passengers are the same, but their velocities are different because the passengers are moving in different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

 **Reading Check** How are velocity and speed different?

The people on these two escalators have the same speed. However, their velocities are different because they are traveling in opposite directions.



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

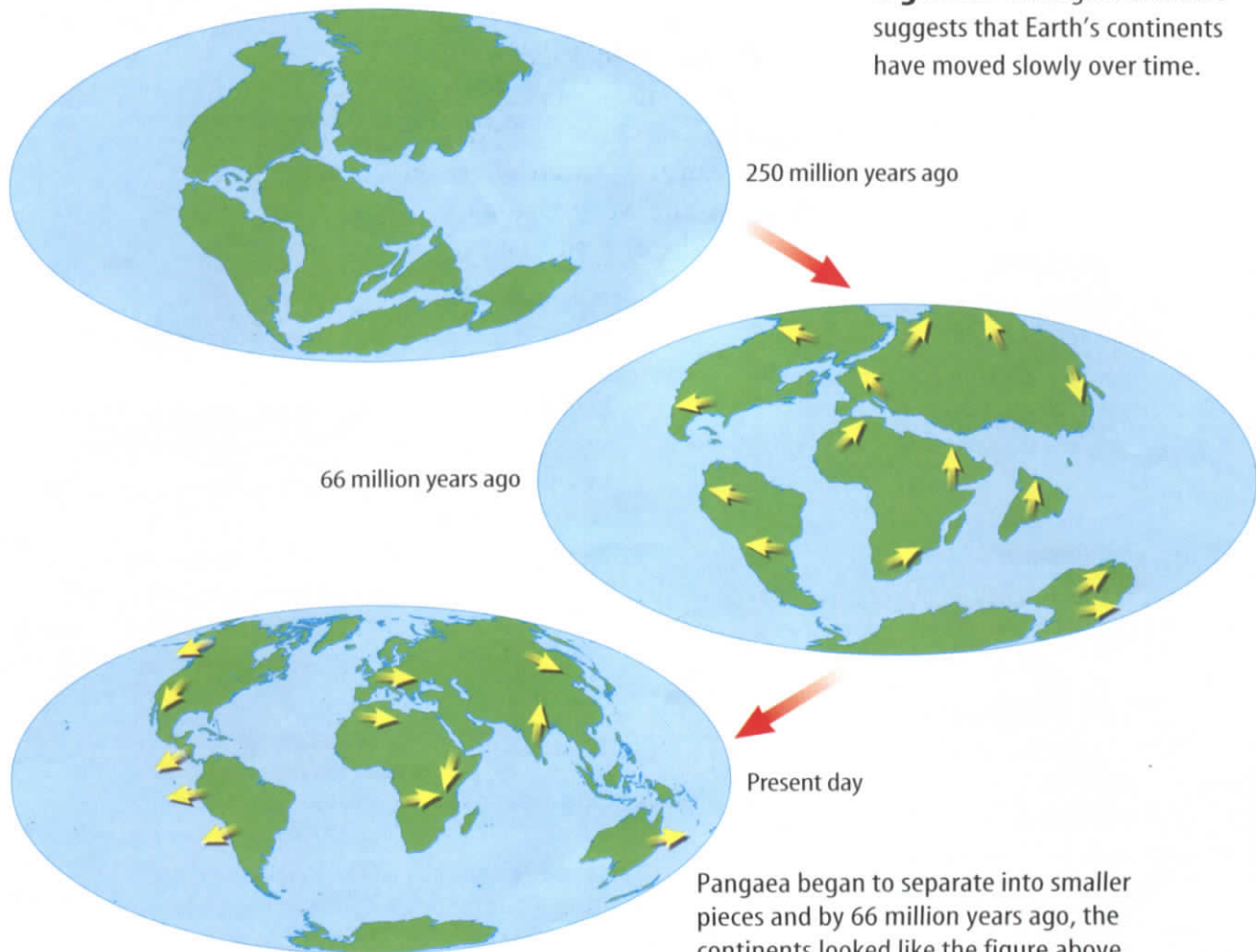


## Motion of Earth's Crust



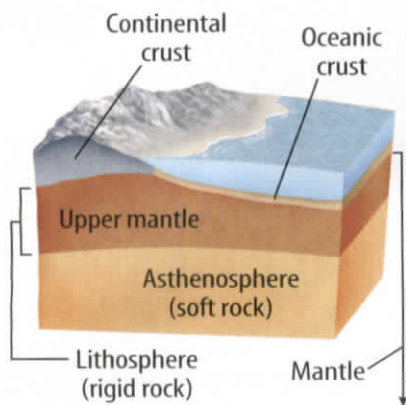
Can you think of something that is moving so slowly you cannot detect its motion, yet you can see evidence of its motion over long periods of time? As you look around the surface of Earth from year to year, the basic structure of the planet seems the same. Mountains, plains, lakes, and oceans seem to 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.

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



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

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.

The movement of the plates also is changing the size of the oceans and the shapes of the continents. The Pacific Ocean is getting smaller while the Atlantic Ocean is getting larger. The movement of the plates also changes the shape of the continents as they collide and spread apart.

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.

## section 1 review

### Summary

#### Position and Motion

- The position of an object is determined relative to a reference point.
- Motion occurs when an object changes its position relative to a reference point.
- Distance is the length of the path an object has traveled. Displacement is the distance and direction of a change in position.

#### Speed and Velocity

- Speed is the distance an object travels per unit time and is given by this equation:

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

- The velocity of an object includes the object's speed and its direction of motion relative to a reference point.

#### Graphing Motion

- On a distance-time graph, time is the horizontal axis and distance is the vertical axis.
- The slope of a line plotted on a distance-time graph is the speed.

### Self Check

1. **Infer** whether the size of an object's displacement could be greater than the distance the object travels.
2. **Describe** the motion represented by a horizontal line on a distance-time graph.
3. **Explain** whether, during a trip, a car's instantaneous speed can ever be greater than its average speed.
4. **Describe** the difference between average speed and constant speed.
5. **Think Critically** You are walking toward the back of a bus that is moving forward with a constant velocity. Describe your motion relative to the bus and relative to a point on the ground.

### Applying Math

6. **Calculate Speed** Michiko walked a distance of 1.60 km in 30 min. Find her average speed in m/s.
7. **Calculate Distance** A car travels at a constant speed of 30.0 m/s for 0.8 h. Find the total distance traveled in km.



# Acceleration

## Reading Guide

### 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.

### Why It's Important

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

### Review Vocabulary

**speed:** rate of change of position; can be calculated by dividing the distance traveled by the time taken to travel the distance

### New Vocabulary

- 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.

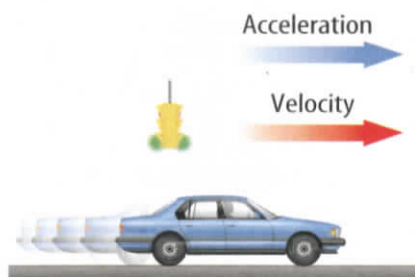
Remember that velocity includes the speed and direction of an object. Therefore, a change in velocity can be either a change in how fast something is moving or a change in the direction it is moving. Acceleration occurs when an object changes its speed, its direction, or both.

**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.

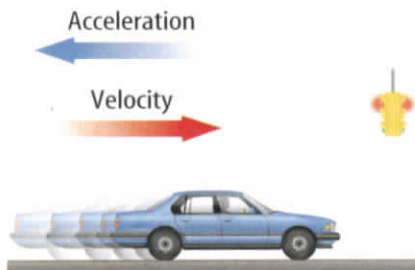
Imagine a car traveling through a city. If the speed is increasing, the car has positive acceleration. When the car slows down its speed is decreasing and the car has negative acceleration. In both cases the car is accelerating because its speed is changing.

Acceleration also has direction, just as velocity does. If the acceleration is in the same direction as the velocity, as in **Figure 10**, 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 10**.

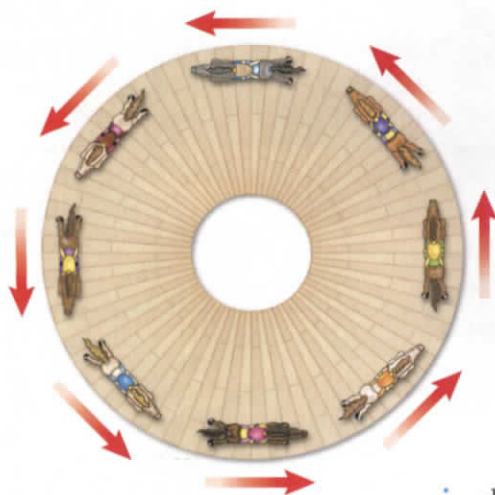
**Figure 10** These cars are both accelerating because their speed is changing.



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



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



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



### INTEGRATE History

**Aircraft Carriers** An aircraft carrier provides a landing strip for airplanes to land and take off at sea. The carrier must be equipped to provide enough negative acceleration to stop a moving plane. The carrier also must be equipped to quickly accelerate planes to allow them to take off on a short runway. In 1911, American pilot Eugene Ely landed on a specially equipped deck on the battleship *Pennsylvania*. The experiment was successful, and today aircraft carriers are an important part of navies worldwide.

**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** shows how motion graphs are constructed.

## Calculating Acceleration

Acceleration is the rate of change in velocity. To calculate the acceleration of an object, the change in velocity is divided by the length of the time interval over which the change occurred.

To calculate the change in velocity, 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. Then the change in velocity is:

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

Using this expression for the change in velocity, the acceleration can be calculated from the following equation:

**Acceleration Equation**

$$\text{acceleration (in meters/second}^2\text{)} = \frac{\text{change in velocity (in meters/second)}}{\text{time (in seconds)}}$$

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

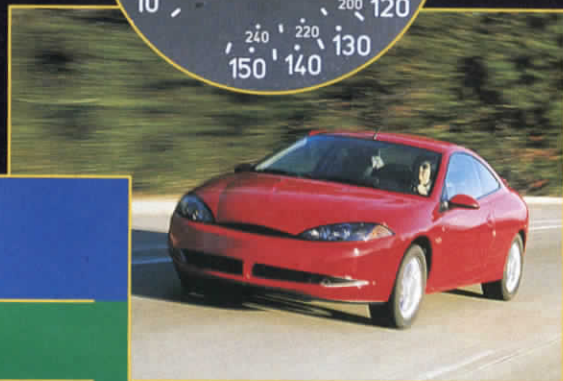
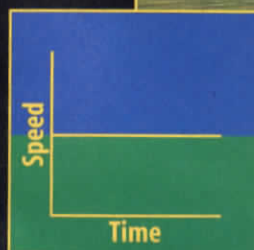
Recall that velocity includes both speed and direction. However, if the direction of motion doesn't change and the object moves in a straight line, the change in velocity is the same as the change in speed. The change in velocity then is the final speed minus the initial speed.

The unit for acceleration is a unit for velocity divided by a unit for time. In SI units, velocity has units of m/s, and time has units of s, so acceleration has units of  $\text{m/s}^2$ .

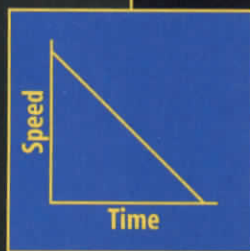
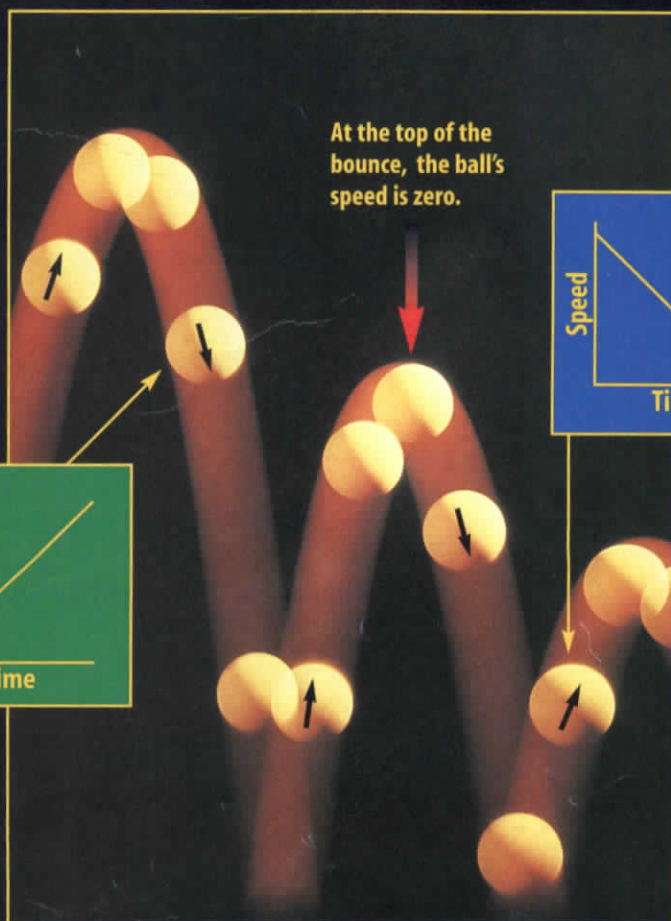
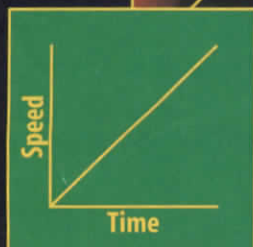
**Figure 12**

**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.



**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 13** 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.

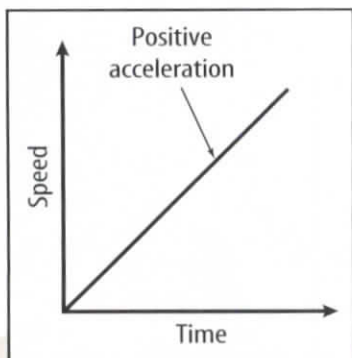
**Calculating Negative Acceleration** Now imagine that the skateboarder in **Figure 13** is moving in a straight line at a constant speed of 3 m/s and comes to a stop in 2 s. The final speed is zero and the initial speed was 3 m/s. The skateboarder's acceleration is calculated as follows:

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

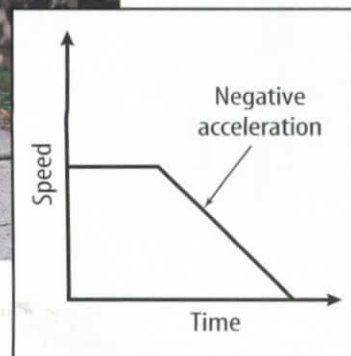
The skateboarder is slowing down, so the final speed is less than the initial speed and the acceleration is negative. The acceleration always will be positive if an object is speeding up and negative if the object is slowing down.

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

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



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 design amusement park rides that are thrilling, but harmless. Roller coasters are constructed of steel or wood. Because wood is not as rigid as steel, wooden roller coasters do not have hills that are as high and steep as some steel roller coasters have. As a result, the highest speeds and accelerations usually are produced on steel roller coasters.

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 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. **Figure 14** shows the fastest roller coaster in the United States.



**Figure 14** This roller coaster can reach a speed of about 150 km/h in 4 s.

### Reading Check

*What happens when riders on a roller coaster go around a sharp turn?*

## section 2 review

### Summary

#### Acceleration, Speed, and Velocity

- Acceleration is the rate of change of velocity.
- A change in velocity occurs when the speed of an object changes, or its direction of motion changes, or both occur.
- The speed of an object increases if the acceleration is in the same direction as the velocity.
- The speed of an object decreases if the acceleration and the velocity of the object are in opposite directions.

#### Calculating Acceleration

- Acceleration can be calculated by dividing the change in velocity by the time according to the following equation:

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

- The SI unit for acceleration is  $\text{m/s}^2$ .
- If an object is moving in a straight line, the change in velocity equals the final speed minus the initial speed.

### Self Check

1. **Describe** three ways to change the velocity of a moving car.
2. **Determine** the change in velocity of a car that starts at rest and has a final velocity of 20 m/s north.
3. **Explain** why streets and highways have speed limits rather than velocity limits.
4. **Describe** the motion of an object that has an acceleration of  $0 \text{ m/s}^2$ .
5. **Think Critically** Suppose a car is accelerating so that its speed is increasing. Describe the plotted line on a distance–time graph of the motion of the car.

### Applying Math

6. **Calculate Time** A ball is dropped from a cliff and has an acceleration of  $9.8 \text{ m/s}^2$ . How long will it take the ball to reach a speed of 24.5 m/s?
7. **Calculate Speed** A sprinter leaves the starting blocks with an acceleration of  $4.5 \text{ m/s}^2$ . What is the sprinter's speed 2 s later?

# Motion and Forces

## Reading Guide

### What You'll Learn

- **Explain** how force and motion 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.

### Why It's Important

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

### Review Vocabulary

**scientific law:** statement about something that happens in nature that seems to be true all the time

### New Vocabulary

- force
- net force
- balanced force
- inertia

**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.



## 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. In both examples, the applied force changes 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 16** Forces can be balanced and unbalanced.



**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.



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



**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.

**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. 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** Give another example of an unbalanced force.

  
**Science online**

**Topic: Forces and Fault Lines**

Visit [gpscience.com](http://gpscience.com) for Web links to information about the unbalanced forces that occur along Earth's fault lines.

**Activity** Use inexpensive materials such as bars of soap to model the forces and movements along the fault lines. Share your models and demonstrations with your class.

## Mini LAB

### 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 Science Journal.
3. Secure the object in the cart with **rubber bands** (safety 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 safety belts in a car.



## Inertia and Mass

The dirt bike in **Figure 17** is sliding on the track. This sliding bike demonstrates the property of inertia. **Inertia** (ih NUR shuh) is the tendency of an object to resist any change in its motion. If an object is moving, it will have uniform motion. It will keep moving at the same speed and in the same direction unless an unbalanced force acts on it. 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.

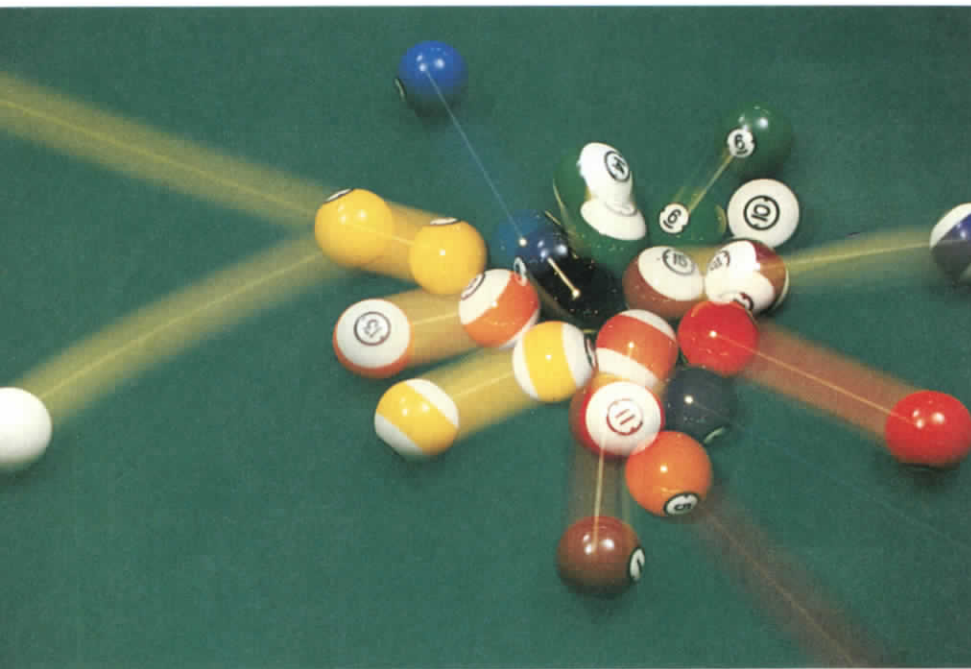
Does a bowling ball have the same inertia as a table-tennis ball? Why is there a difference? You couldn't change the motion of a bowling ball much by swatting it with a table-tennis paddle. However, you easily could change the motion of the table-tennis ball. A greater force would be needed to change 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 Laws 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** This racer is skidding because of inertia. The bike tends to move in a straight line with constant speed despite the efforts of the rider to steer the bike around the curve.








**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.

**Newton's First Law of Motion** Newton's first law of motion states that an object moving at a constant velocity keeps moving at that velocity unless an unbalanced net force acts on it. If an object is at rest, it stays at rest unless an unbalanced 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?

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

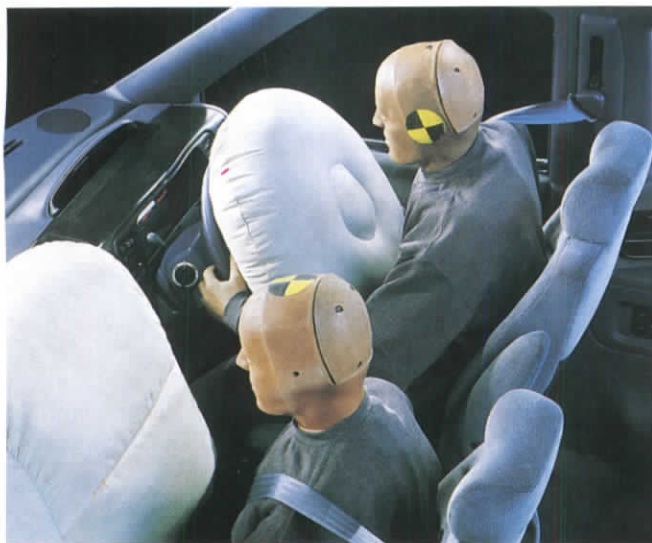
**Explain** how safety belts can help keep passengers from being seriously injured.

 **Reading Check** What is Newton's first law of motion?

## 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 safety 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 20** These crash dummies were restrained safely with safety belts in this low-speed crash. Usually humans would have fewer injuries if they were restrained safely during an accident.

**Safety Belts** The crash dummy wearing a safety belt in **Figure 20** is attached to the car and slows 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 safety 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 safety belts. Thousands of others would suffer fewer serious injuries.

Air bags also reduce injuries in car crashes by providing a cushion that reduces the force on the car's occupants. When impact occurs, a chemical reaction occurs in the air bag that produces nitrogen gas. The air bag expands rapidly and then deflates just as quickly as the nitrogen gas escapes out of tiny holes in the bag. The entire process is completed in about 0.04 s.

## section 3 review

### Summary

#### What is Force?

- A force is a push or a pull on an object.
- The net force on an object is the combination of all the forces acting on the object.
- When the forces on an object are balanced, the net force on the object is zero.
- Unbalanced forces cause the motion of objects to change.

#### Inertia and Newton's First Law of Motion

- The inertia of an object is the tendency of an object to resist a change in motion.
- The larger the mass of an object, the greater its inertia.
- Newton's first law of motion states that the motion of an object at rest or moving with constant velocity will not change unless an unbalanced net force acts on the object.
- In a car crash, inertia causes an unrestrained passenger to continue moving at the speed of the car before the crash.

### Self Check

1. **Infer** whether the inertia of an object changes as the object's velocity changes.
2. **Explain** whether or not there must be an unbalanced net force acting on any moving object.
3. **Explain** Can there be forces acting on an object if the object is at rest?
4. **Infer** the net force on a refrigerator if you push on the refrigerator and it doesn't move.
5. **Think Critically** Describe three situations in which a force changes the velocity of an object.

### Applying Math

6. **Calculate Net Force** Two students push on a box in the same direction, and one pushes in the opposite direction. What is the net force on the box if each pushes with a force of 50 N?
7. **Calculate Acceleration** The downward force of gravity and the upward force of air resistance on a ball are both 5 N. What is the ball's acceleration?

## 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? Can a study of unbalanced forces lead to a better understanding of these everyday activities?

### Real-World Question

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

#### Goals

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

#### Materials

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

#### 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. **Explain** how adding the second book changed the results.

### Communicating Your Data

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

## Comparing Motion from Different Forces

### 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.

### 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



### Real-World Question

Think 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?

### 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.

### Test Your Hypothesis

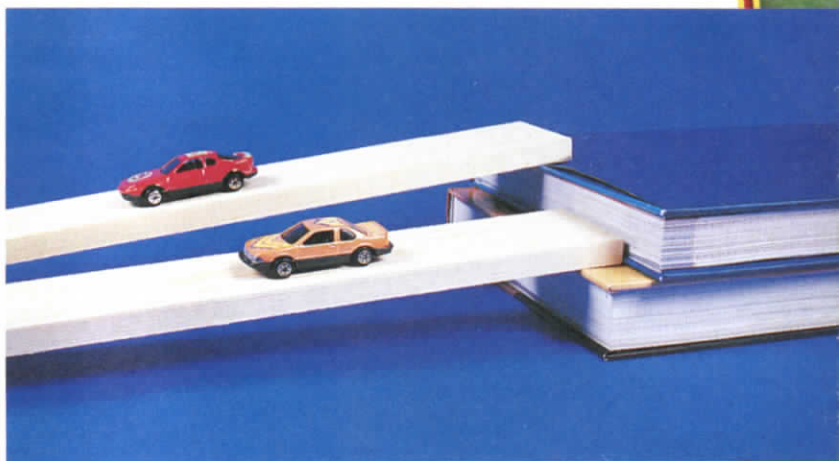
#### Make a Plan

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.



## Using Scientific Methods

- 4. Read** the entire experiment to make sure all steps are in logical order and will lead to a useful 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.



### Follow Your Plan

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?

### ► Conclude and Apply

1. **Evaluate** Did the speed of the toy car vary depending upon the force applied to it?
2. **Determine** 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. **Draw Conclusions** Did your results support your hypothesis? Why or why not?

### Communicating Your Data

**Compare** your data with 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

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 ...  
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.



### Understanding Literature

**Descriptive Writing** The poet names some special places on Earth. These places, although marvelous, fall short of being really wonderful. How does Angelou contrast Earth's position within the universe to emphasize the importance of people?

### Respond to the Reading

1. What adjectives does the poet use to describe Earth?
2. What does the poet believe are the true wonders of the world?
3. **Linking Science and Writing** Write a six-line poem that describes Earth's movement from the point of view of the Moon.



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 relative to a reference point such as the Sun. If the Sun is the reference point, Earth moves because the Sun appears to change its position in the sky. The poem describes Earth's movement from a reference point outside of Earth, somewhere in space.

- 1 to be without friends or neighbors
- 2 small particle
- 3 wanting one's own way in spite of the advice or wishes of another
- 4 a self-important show of being religious

## Reviewing Main Ideas

### Section 1 Describing Motion

- 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.



- A reference point must be specified in order to determine an object's position.
- The speed of an object can be calculated from this equation:
 
$$s = \frac{d}{t}$$
- The slope of a line on a distance-time graph is equal to the speed.
- Velocity describes the speed and direction of a moving object.

### Section 2 Acceleration

- Acceleration occurs when an object changes speed or changes direction.
- An object speeds up if its acceleration is in the direction of its motion.



- An object slows down if its acceleration is opposite to the direction of its motion.
- Acceleration is the rate of change of velocity, and is calculated from this equation:

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

### Section 3 Motion and Forces

- A force is a push or a pull.
- The net force acting on an object is the combination of all the forces acting on the object.
- The forces on an object are balanced if the net force is zero.
- Inertia is the resistance of an object to a change in motion.
- According to Newton's first law of motion, the motion of an object does not change unless an unbalanced net force acts on the object.



**FOLDABLES™** Use the Foldable that you made at the beginning of this chapter to help you review motion.

## Using Vocabulary

- |                     |                          |
|---------------------|--------------------------|
| acceleration p.47   | inertia p.54             |
| average speed p.42  | instantaneous speed p.42 |
| balanced force p.53 | net force p.53           |
| displacement p.39   | speed p.39               |
| distance p.39       | velocity p.44            |
| force p.52          |                          |

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

## 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
- Which term below best describes the forces on an object with a net force of zero?
  - inertia
  - balanced forces
  - acceleration
  - unbalanced forces

- Which of the following is a proper unit of acceleration?
  - $\text{s/km}^2$
  - $\text{km/h}$
  - $\text{m/s}^2$
  - $\text{cm/s}$
- 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.
- What is the tendency for an object to resist any change in its motion called?
  - net force
  - acceleration
  - balanced force
  - inertia
- How can speed be defined?
  - acceleration/time
  - change in velocity/time
  - distance/time
  - displacement/time

## Interpreting Graphics

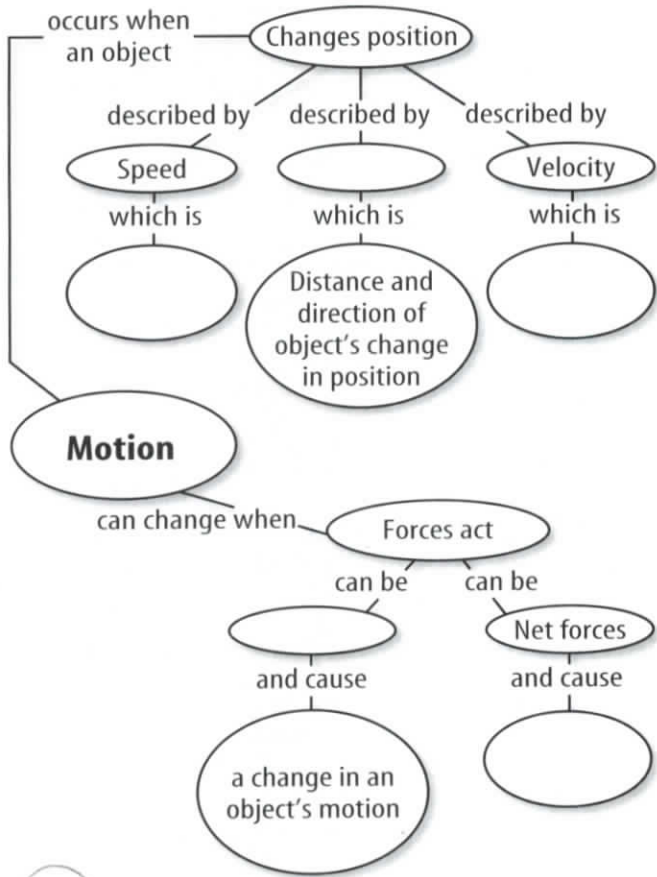
Use the table below to answer question 17.

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

- Make a distance-time graph that shows the motion of both runners. What is the average speed of each runner? Which runner stops briefly? Over what time interval do they both have the same speed?



18. Copy and complete this concept map on motion.



**Thinking Critically**

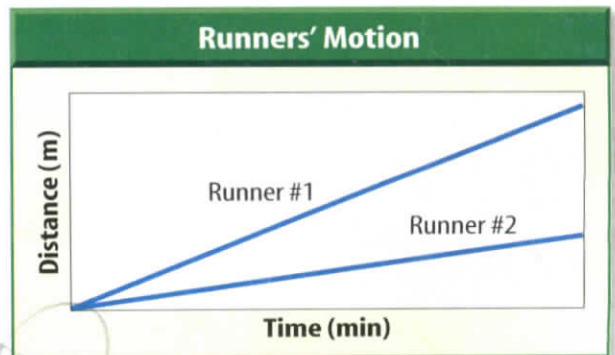
- 19. **Evaluate** Which of the following represents the greatest speed: 20 m/s, 200 cm/s, or 0.2 km/s?
- 20. **Recognize Cause and Effect** Acceleration can occur when a car is moving at constant speed. What must cause this acceleration?
- 21. **Explain** why a passenger who is not wearing a safety belt will likely hit the windshield in a head-on collision.
- 22. **Determine** If you walked 20 m, took a book from a library table, turned around and walked back to your seat, what are the distance traveled and displacement?

23. **Explain** When you are describing the rate that a race car goes around a track, should you use the term *speed* or *velocity* to describe the motion?

**Applying Math**

- 24. **Calculate Speed** 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?
- 25. **Calculate Acceleration** A satellite's speed is 10,000 m/s. After 1 min, it is 5,000 m/s. What is the satellite's acceleration?
- 26. **Calculate Displacement** 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?
- 27. **Calculate Velocity** 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?

Use the graph below to answer question 28.



28. **Interpret a Graph** Use the graph to determine which runner had the greatest speed.

## Part 1 Multiple Choice

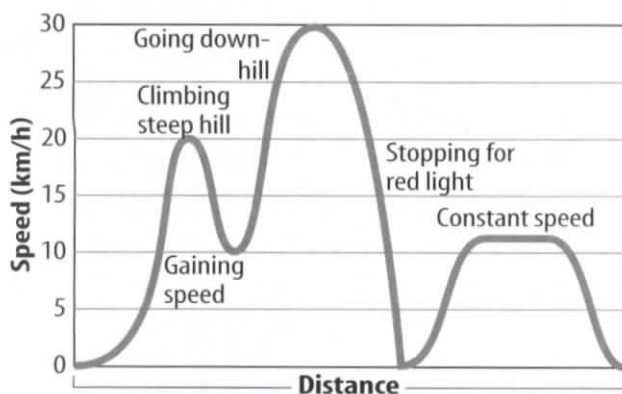
Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

1. Sound travels at a speed of 330 m/s. How long does it take for the sound of thunder to travel 1485 m?

A. 45 s  
B. 4.5 s  
C. 4,900 s  
D. 0.22 s

Use the graph below to answer questions 2–4.

Speed Changing Over Distance



2. The graph shows how a cyclist's speed changed over distance of 5 km. What is the cyclist's average speed if the trip took 0.25 h?
- A. 2 km/h  
B. 30 km/h  
C. 20 km/h  
D. 8 km/h
3. Once the trip was started, how many times did the cyclist stop?
- A. 0  
B. 4  
C. 2  
D. 5
4. What was the fastest speed the cyclist traveled?
- A. 20 km/h  
B. 30 km/h  
C. 12 km/h  
D. 10 km/h

**Test-Taking Tip**

**Read Carefully** Read each question carefully for full understanding.

5. A skier is going down a hill at a speed of 9 km/s. The hill gets steeper and her speed increases to 18 m/s in 3 s. What is her acceleration?
- A.  $9 \text{ m/s}^2$   
B.  $3 \text{ m/s}^2$   
C.  $27 \text{ m/s}^2$   
D.  $6 \text{ m/s}^2$
6. Which of the following best describes an object with constant velocity?
- A. It is changing direction.  
B. Its acceleration is increasing.  
C. Its acceleration is zero.  
D. Its acceleration is negative.
7. Which of the following is a force?
- A. friction  
B. acceleration  
C. inertia  
D. velocity

Use the table below to answer questions 8 and 9.

Runner	Distance covered (km)	Time (min)
Daisy	12.5	42
Jane	7.8	38
Bill	10.5	32
Joe	8.9	30

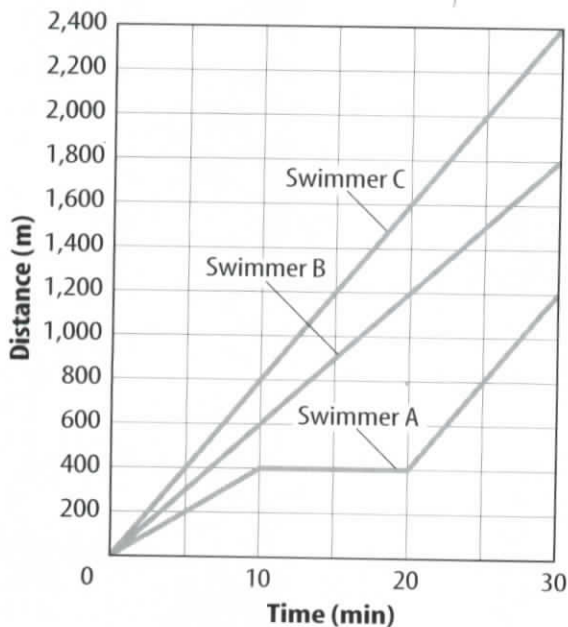
8. What is Daisy's average speed?
- A. 0.29 km/min  
B. 530 km/min  
C. 2.9 km/min  
D. 3.4 km/min
9. Which runner has the fastest average speed?
- A. Daisy  
B. Jane  
C. Bill  
D. Joe
10. The movement of the Australian plate pushes Australia north at an average speed of about 17 cm per year. What will Australia's displacement be in meters in 1,000 years?
- A. 170 m north  
B. 170 m south  
C. 1,700 m north  
D. 1,700 m south

## Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

Use the graph below to answer questions 11 and 12.

**Graphing Motion**



- The graph shows the motion of three swimmers during a 30-min workout. Which swimmer had the highest average speed over the 30-min time interval?
- Did all the swimmers swim at a constant speed? Explain how you know.
- Why is knowing just the speed at which a hurricane is traveling toward land not enough information to be able to warn people to evacuate?
- If the speedometer on a car indicates a constant speed, can you be sure the car is not accelerating? Explain.
- If a car is traveling at a speed of 40 km/h and then comes to a stop in 5 s, what is its acceleration in  $m/s^2$ ?

## Part 3 Open Ended

Record your answers on a sheet of paper.

- Describe three ways that your acceleration could change as you jog along a path through a park.
- An object in motion slows down and comes to a stop. Use Newton's first law of motion to explain why this happens.
- Give an example of a force applied to an object that does not change the object's velocity.
- In an airplane flying at a constant speed, the force exerted by the engine pushing the airplane forward is equal to the opposite force of air resistance. Describe how these forces compare when the plane speeds up and slows down. In which direction is the net force on the airplane in each case?
- Where would you place the location of a reference point in order to describe the motion of a space probe traveling from Earth to Jupiter? Explain your choice.

Use the table below to answer question 21.

Car	Mass (kg)	Stopping distance(m)
A	1000	80
B	1250	100
C	1500	120
D	2000	160

- What is the relationship between a car's mass and its stopping distance? How can you explain this relationship?
- Two cars approach each other. How does the speed of one car relative to the other compare with speed of the car relative to the ground?

# Forces



## chapter preview

### sections

1 Newton's Second Law

2 Gravity

3 The Third Law of Motion

*Lab* Measuring the Effects of Air Resistance

*Lab* The Momentum of Colliding Objects



*Virtual Lab* How is momentum conserved in a vehicle collision?

## Who's a dummy?



Crunch! This test dummy would have some explaining to do if this were a traffic accident. But in a test crash, the dummy plays an important role. The forces acting on it during a crash are measured and analyzed in order to learn how to make cars safer.

**Science Journal** Explain which would be a safer car—a car with a front that crumples in a crash, or one with a front that doesn't crumple.

# Start-Up Activities



## The Force of Gravity

The force of Earth's gravity pulls all objects downward. However, objects such as rocks seem to fall faster than feathers or leaves. Do objects with more mass fall faster?  

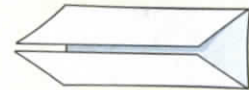
1. Measure the mass of a softball, a tennis ball, and a flat sheet of paper. Copy the data table below and record the masses.
2. Drop the softball from a height of 2.5 m and use a stopwatch to measure the time it takes for the softball to hit the floor. Record the time in your data table.
3. Repeat step 2 using the tennis ball and the flat sheet of paper. Record the times in your data table.
4. Crumple the flat sheet of paper into a ball, and measure the time for the crumpled paper to fall 2.5 m. Record the time in your data table.
5. **Think Critically** Write a paragraph comparing the times it took each item to fall 2.5 m. From your data, infer if the speed of a falling object depends on the object's mass.

Falling Object Data		
Object	Mass	Time
Softball		
Tennis ball		
Flat paper		
Crumpled paper		

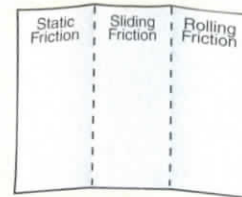
## FOLDABLES™ Study Organizer

**The Force of Friction** One of the forces you encounter every day is friction. Make the following Foldable to help you compare the three types of friction—static friction, sliding friction, and rolling friction.

- STEP 1** Fold the top of a vertical piece of paper down and the bottom up to divide the paper into thirds.



- STEP 2** Unfold and label the rows *Static Friction*, *Sliding Friction*, and *Rolling Friction*.



**Read and Write** As you read, write the definition and give examples of each type of friction.



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