## Section 1
# Measuring Motion

**Key Concept** Motion can be measured and described in many ways.

### What You Will Learn
- Properties used to describe the motion of an object include a reference point, direction, speed, velocity, and acceleration.
- Average speed can be calculated by dividing total distance by total time.
- A change in velocity is due to a change in speed, direction, or both.
- Speed and acceleration can be represented on graphs.

### Why It Matters
Learning about motion will help you give directions, plan trips, and predict the future locations of objects.

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If you look around, you will likely see something in motion. Your teacher may be walking across the room. Perhaps your friend is writing with a pencil. Even if you do not see anything moving, things are in motion all around you. Air particles are moving. Earth is circling the sun. And blood is flowing through your blood vessels!

## Motion and Reference Points
You may think that you only have to watch an object to tell that it is moving. But often, you are watching the object in relation to another object that appears to stay in place. The object that appears to stay in place is a *reference point.* When an object changes position over time relative to a reference point, the object is in **motion.** You can use a reference direction—such as north, south, east, west, up, or down—to describe the direction of an object's motion.

### Standard Reference Points
As **Figure 1** shows, features on Earth's surface are often used as standard reference points for determining motion. Nonmoving objects, such as trees and buildings, are also useful reference points. A moving object can be used as a reference point, too. For example, suppose that a bird flies by the hot-air balloon shown in **Figure 1.** Anyone in the balloon will see that the bird is changing position in relation to the moving balloon.

**Figure 1** During the interval between the times that these pictures were taken, the hot-air balloon changed position relative to a reference point–the mountain.

## Motion in a Two-Dimensional System

**Figure 2** shows a two-dimensional system in which a sheet of paper is passed around a room. A grid can be used to describe motion in such a system. The reference point Owen's desk is at the origin, where the *x*-axis meets the *y*-axis. Four reference directions are represented by the positive and negative directions on the axes. As the paper in **Figure 2** moves toward the front of the room, the paper moves in the positive direction on the *y*-axis. As the paper moves to the right side of the room, it moves in the positive direction on the *x*-axis. As it moves toward the back of the room, the paper moves in the negative direction on the *y*-axis. Finally, as the paper moves to the left side of the room, it moves in the negative direction on the *x*-axis.

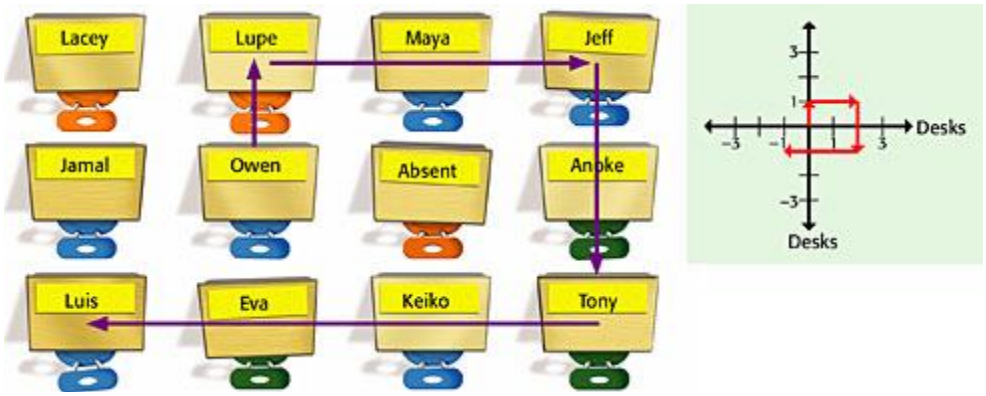


**Figure 2** Owen started passing around a sign-up sheet for choir auditions. The sheet ended up one desk to the left of and one desk behind the origin of the paper's movement.

**Standards Check** If an object moves to the right, in which direction and along which axis of a grid does the object move?

## Average Speed

The speed of an object is the rate at which the object moves. The speed of an object is rarely constant. For example, the speed of each racer in **Figure 3** varies during the race. So, it is useful to find the average speed of an object. **Average speed** is the total distance traveled divided by the total time taken. The following equation can be used to find average speed:

$$average\ speed = \frac{total\ distance}{total\ time}$$

**Figure 3** A racer's average speed can be determined by timing the racer on a set course. **What is a racer's average speed if the racer finishes a 200 m race in 25 s?**

Suppose that it takes you 2 s to walk 4 m down a hallway. You can use the equation above to find your average speed: (4 m)/(2 s), or 2 m/s. The SI unit for speed is meters per second (m/s). Other units for speed include kilometers per hour (km/h), feet per second (ft/s), and miles per hour (mi/h).

**Standards Check** What is average speed? What is the equation for average speed?

## Making a Graph Showing Speed

Speed can be shown on a graph of position versus time. On this kind of graph, position is a measure of the distance of an object from a reference point. The object's distance from the reference point in either the positive or negative direction is plotted on the *y*-axis. So, the *y*-axis expresses distance in units such as meters, centimeters, or kilometers. Time is plotted on the *x*-axis. Thus, the *x*-axis displays units such as seconds, minutes, or hours. On a graph of position versus time, the slope of the line is equal to the speed of the object.

### Recognizing Speed on a Graph

Suppose that you watched a dog walk beside a fence. The orange line in the graph in **Figure 4** shows the total distance that the dog walked in 10 s. Notice that the dog did not walk the same distance each second. The distance varies because the speed is not constant. The dog walked slowly at first. Then, it moved quickly for 1 s. The dog did not move for the next 3 s. During the last 4 s, the dog walked with a moderate speed.

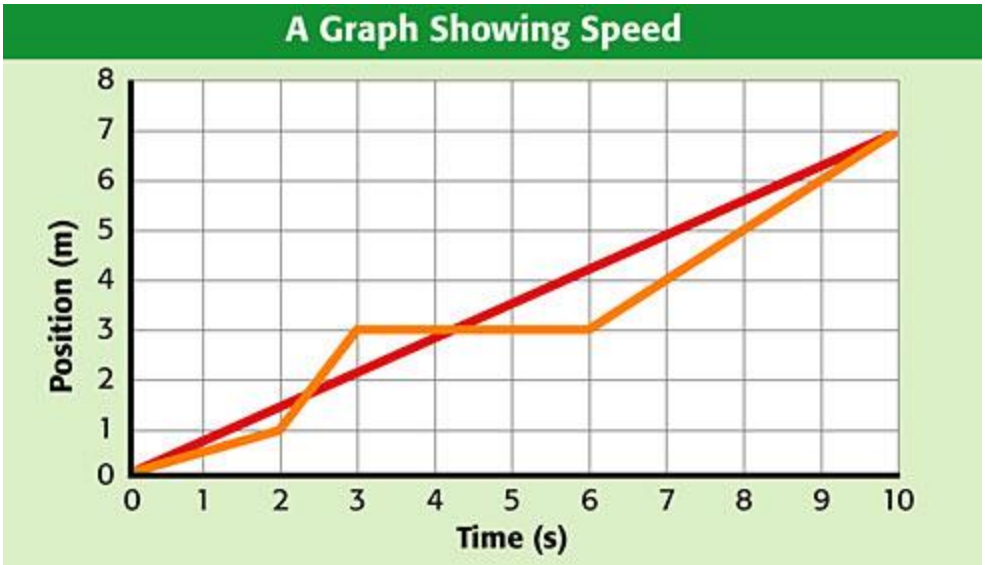


**Figure 4** A graph of position versus time can show an object's speed and average speed.

The dog's average speed can be calculated as follows:

$$average\ speed = \frac{7\ \text{m}}{10\ \text{s}} = 0.7\ \text{m/s}$$

Suppose that the dog walked at a constant speed. The red line on the graph shows how far the dog must walk each second at that speed to cover the same distance covered earlier.

The slope of this line is the average speed.

## Velocity: Direction Matters

*Suppose that two birds leave the same tree at the same time. They both fly at 10 km/h for 5 min, 12 km/h for 8 min, and 5 km/h for 10 min. Why don't they end up at the same place?*

Have you figured out the answer? The birds went in different directions. Their speeds were the same, but they had different velocities. **Velocity** is the speed of an object as well as the direction in which the object is moving.

### Speed Versus Velocity

The terms *speed* and *velocity* do not have the same meaning. Velocity must include a direction. If you say that an airplane's velocity is 600 km/h, you are not correct. But you can say that the airplane's velocity is 600 km/h south. **Figure 5** shows an example of the difference between speed and velocity.

**Figure 5** The speeds of these cars may be similar, but the velocities of the cars differ because the cars are going in different directions.

### Changing Velocity

The velocity of an object is constant only if the speed and direction of the object do not change. So, constant velocity is always motion along a straight line. The velocity of an object changes if the object's speed, direction, or both change.

For example, as a bus driving at 15 m/s south speeds up to 20 m/s south, its velocity changes. If the bus keeps moving at the same speed but changes direction to travel east, its velocity changes again. And if the bus slows down at the same time that it

swerves north to avoid a cat, the velocity of the bus changes yet again. **Table 1** shows other examples of velocity changes.

**Table 1 Examples of Velocity Changes**

| Situation | What changes |
|---|---|
| Raindrop falling faster and faster | speed |
| Runner going around a turn on a track | direction |
| Taking an exit off a highway | speed and direction |
| Train arriving at a station | speed |
| Baseball caught by a catcher | speed |
| Baseball hit by a batter | speed and direction |
| Cyclist riding a bike around a corner | speed and direction |

Standards Check How does velocity differ from speed? What changes in motion can result in a change in velocity?

## Acceleration

The word *accelerate* is often used to mean "speed up," but the word means something else in science. **Acceleration** is the rate at which velocity changes over time. The units for acceleration are the units for velocity divided by a unit for time. A common unit for acceleration is meters per second per second, or (m/s)/s, which is also written as $m/s^2$.

Velocity changes if speed, direction, or both change. So, an object accelerates if its speed, direction, or both change. **Figure 6** shows the acceleration of a person on a bicycle. The person is accelerating because his speed is increasing. An increase in speed is sometimes called *positive acceleration.* A decrease in speed is sometimes called *negative*

*acceleration,* or *deceleration.*


**Figure 6** This cyclist is accelerating at 1 $m/s^2$ south.

### Circular Motion: Continuous Acceleration

You may be surprised to know that even when you are sitting still, you are accelerating. You may not seem to be changing speed or direction, but you are! You are moving in a circle as Earth rotates. An object moving in a circular motion is always changing direction. Therefore, the object's velocity is always changing. So, the object is accelerating.

The acceleration that happens when an object moves at a constant speed in circular motion is known as *centripetal acceleration* (sen TRIP uht uhl ak SEL uhr AY shuhn). Centripetal acceleration happens as a Ferris wheel turns at an amusement park and as the moon orbits Earth. **Figure 7** shows another example of centripetal acceleration.

**Figure 7** As the blades of these windmills turn, the blades are constantly changing direction. Thus, the blades are undergoing

centripetal acceleration.

## Recognizing Acceleration on a Graph

Acceleration can be shown on a graph of speed versus time. Suppose you are playing with a remote-control car. You push the lever on the remote to drive the car forward. The graph in **Figure 8** shows the car's acceleration as the car moves east. For the first 5 s, the car moves faster and faster. You know that the car's acceleration is positive because the car's speed increases as time passes. You also know that the acceleration is changing because the line between 0 s and 5 s is not straight.

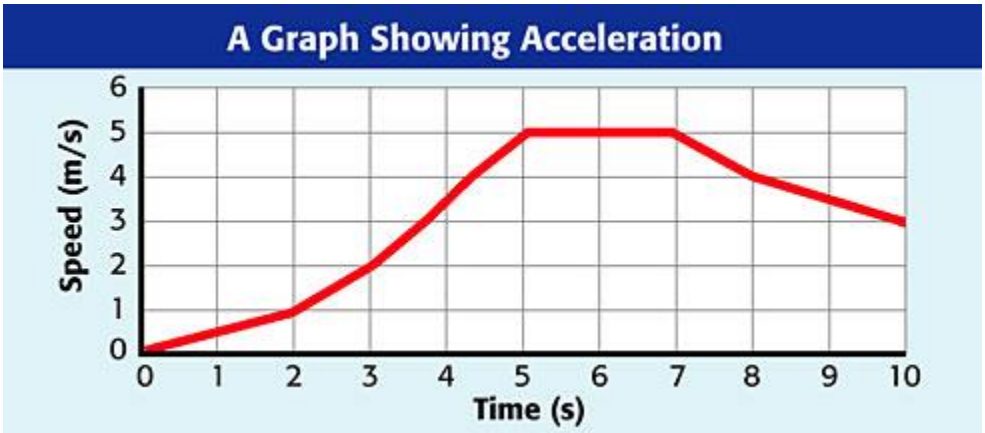


**Figure 8** A graph of speed versus time can show positive acceleration, no acceleration, and negative acceleration.

For the next 2 s, the speed of the car is constant. So, the slope of the graph is 0, which means that the car is not accelerating (0 m/s2). During the last 3 s, you let go of the lever, and the car slows down. The car's acceleration is negative because the speed of the car decreases as time passes.

**Standards Check** What does negative acceleration look like on a graph of speed versus time?

## Section Summary

- An object is in motion if it changes position over time in relation to a reference point.
- Average speed is the total distance that an object travels divided by the total time that the object takes to travel that distance.
- Speed can be shown on a graph of position versus time.
- Velocity is speed as well as the direction of motion. The velocity of an object changes if the object's speed, direction, or both change.
- Acceleration is the rate at which velocity changes.
- An object can accelerate by changing speed, direction, or both.
- Acceleration can be shown on a graph of speed versus time.