SECTION 1

Measuring Motion

Look around you—you are likely to see something in motion. Your teacher may be walking across the room, or perhaps your friend is writing with a pencil.

Even if you don't see anything moving, motion is still occurring all around you. Air particles are moving, the Earth is circling the sun, and blood is traveling through your blood vessels!

READING WARM-UP

Objectives

- Describe the motion of an object by the position of the object in relation to a reference point.
- Identify the two factors that determine speed.
- Explain the difference between speed and velocity.
- Analyze the relationship between velocity and acceleration.
- Demonstrate that changes in motion can be measured and represented on a graph.

Terms to Learn

motion
speed
velocity
acceleration

READING STRATEGY

Discussion Read this section silently. Write down questions that you have about this section. Discuss your questions in a small group.

Observing Motion by Using a Reference Point

You might think that the motion of an object is easy to detect—you just watch the object. But you are actually 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 describe the direction of the object's motion with a reference direction, such as north, south, east, west, up, or down.

Reading Check **What is a reference point?** (*See the Appendix for answers to Reading Checks.*)

Common Reference Points

The Earth's surface is a common reference point for determining motion, as shown in **Figure 1.** Nonmoving objects, such as trees and buildings, are also useful reference points.

A moving object can also be used as a reference point. For example, if you were on the hot-air balloon shown in **Figure 1,** you could watch a bird fly by and see that the bird was changing position in relation to your 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.*

Speed Depends on Distance and Time

speed is the distance traveled by an object divided by the time taken to travel that distance. Look again at **Figure 1.** Suppose the time interval between the pictures was 10 s and that the balloon traveled 50 m in that time. The speed of the balloon is (50 m)/(10 s), or 5 m/s.

The SI unit for speed is meters per second (m/s). Kilometers per hour (km/h), feet per second (ft/s), and miles per hour (mi/h) are other units commonly used to express speed.

motion an object's change in position relative to a reference point

speed the distance traveled divided by the time interval during which the motion occurred

Determining Average Speed

Most of the time, objects do not travel at a constant speed. For example, you probably do not walk at a constant speed from one class to the next. So, it is very useful to calculate *average speed* using the following equation:

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

Recognizing Speed on a Graph

Suppose a person drives from one city to another. The blue line in the graph in **Figure 2** shows the total distance traveled during a 4 h period. Notice that the distance traveled during each hour is different. The distance varies because the speed is not constant. The driver may change speed because of weather, traffic, or varying speed limits. The average speed for the entire trip can be calculated as follows:

$$\textit{average speed} = \frac{360 \text{ km}}{4 \text{ h}} = 90 \text{ km/h}$$

The red line on the graph shows how far the driver must travel each hour to reach the same city if he or she moved at a constant speed. The slope of this line is the average speed.

SCHOOL to HOME

What's Your Speed?

Measure a distance of 5 m or a distance of 25 ft inside or outside. Ask an adult at home to use a stopwatch or a watch with a second hand to time you as you travel the distance you measured. Then, find your average speed. Find the average speed of other members of your family in the same way.

ACTIVITY

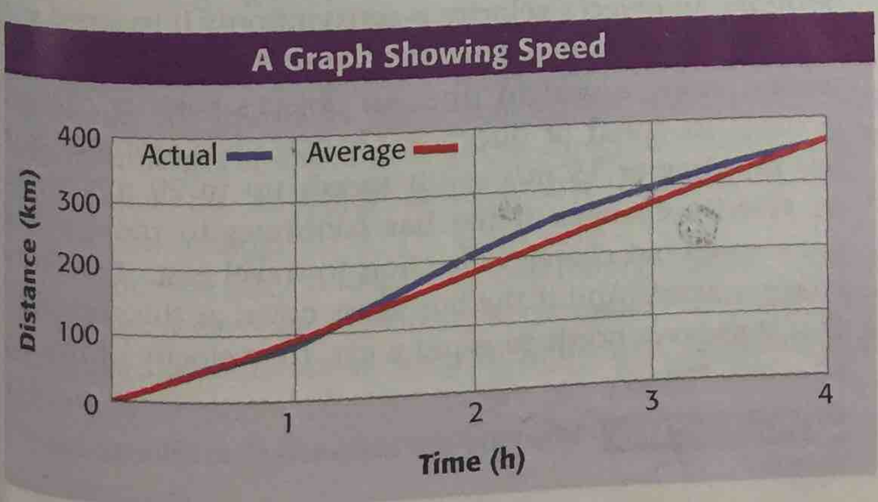


Figure 2 *Speed can be shown on a graph of distance versus time.*

MATH FOCUS

Calculating Average Speed An athlete swims a distance from one end of a 50 m pool to the other end in a time of 25 s. What is the athlete's average speed?

Step 1: Write the equation for average speed.

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

Step 2: Replace the total distance and total time with the values given, and solve.

$$\text{average speed} = \frac{50 \text{ m}}{25 \text{ s}} = 2 \text{ m/s}$$

Now It's Your Turn

1. Kira jogs to a store 72 m away in a time of 36 s. What is Kira's average speed?
2. If you travel 7.5 km and walk for 1.5 h, what is your average speed?
3. An airplane traveling from San Francisco to Chicago travels 1,260 km in 3.5 h. What is the airplane's average speed?

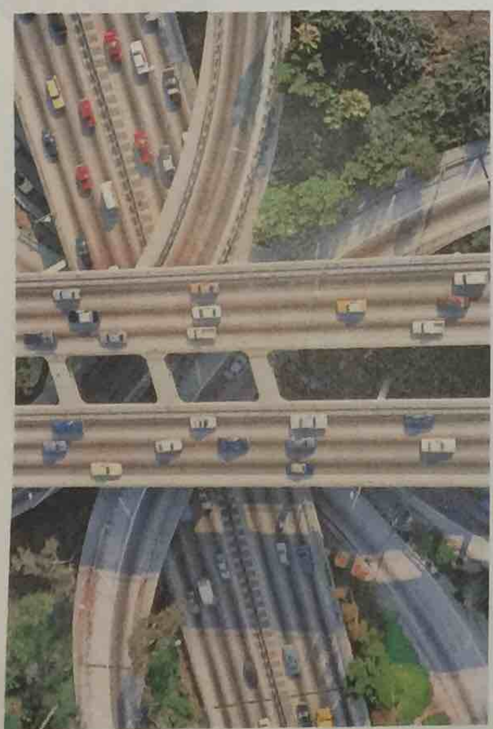
Velocity: Direction Matters

Imagine 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** (vuh LAHS uh tee) is the speed of an object in a particular direction.

Be careful not to confuse the terms *speed* and *velocity.* They do not have the same meaning. Velocity must include a reference direction. If you say that an airplane's velocity is 600 km/h, you would not be correct. But you could say the plane's velocity is 600 km/h south. **Figure 3** shows an example of the difference between speed and velocity.

Figure 3 *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

You can think of velocity as the rate of change of an object's position. An object's velocity is constant only if its speed and direction don't change. Therefore, constant velocity is always motion along a straight line. An object's velocity changes if either its speed or direction changes. For example, as a bus traveling at 15 m/s south speeds up to 20 m/s south, its velocity changes. If the bus continues to travel 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, too.

Reading Check What are the two ways that velocity can change?

Figure 4 Finding Resultant Velocity

When you combine two velocities that are **in the same direction,** add them together to find the resultant velocity.

Person's resultant velocity
15 m/s east + 1 m/s east = 16 m/s east

When you combine two velocities that are **in opposite directions,** subtract the smaller velocity from the larger velocity to find the resultant velocity. The resultant velocity is in the direction of the larger velocity.

Person's resultant velocity
15 m/s east − 1 m/s west = 14 m/s east

Combining Velocities

Imagine that you are riding in a bus that is traveling east at 15 m/s. You and the other passengers are also traveling at a velocity of 15 m/s east. But suppose you stand up and walk down the bus's aisle while the bus is moving. Are you still moving at the same velocity as the bus? No! **Figure 4** shows how you can combine velocities to find the *resultant velocity.*

Acceleration

Although the word *accelerate* is commonly used to mean "speed up," the word means something else in science. **Acceleration** (ak SEL uhr AY shuhn) is the rate at which velocity changes. Velocity changes if speed changes, if direction changes, or if both change. So, an object accelerates if its speed, its direction, or both change.

An increase in velocity is commonly called *positive acceleration.* A decrease in velocity is commonly called *negative acceleration,* or *deceleration.* Keep in mind that acceleration is not only how much velocity changes but also how fast velocity changes. The faster the velocity changes, the greater the acceleration is.

velocity the speed of an object in a particular direction

acceleration the rate at which velocity changes over time; an object accelerates if its speed, direction, or both change

Figure 5 *This cyclist is accelerating at 1 m/s^2 south.*

Calculating Average Acceleration

You can find average acceleration by using the equation:

$$\text{average acceleration} = \frac{\text{final velocity} - \text{starting velocity}}{\text{time it takes to change velocity}}$$

Velocity is expressed in meters per second (m/s), and time is expressed in seconds (s). So acceleration is expressed in meters per second per second, or (m/s)/s, which equals m/s^2. For example, look at **Figure 5.** Every second, the cyclist's southward velocity increases by 1 m/s. His average acceleration can be calculated as follows:

$$\text{average acceleration} = \frac{5\ \text{m/s} - 1\ \text{m/s}}{4\ \text{s}} = 1\ \text{m/s}^2\ \text{south}$$

Reading Check What are the units of acceleration?

MATH PRACTICE

Calculating Acceleration

Use the equation for average acceleration to do the following problem.

A plane passes over point A at a velocity of 240 m/s north. Forty seconds later, it passes over point B at a velocity of 260 m/s north. What is the plane's average acceleration?

Recognizing Acceleration on a Graph

Suppose that you are riding a roller coaster. The roller-coaster car moves up a hill until it stops at the top. Then, you are off! The graph in **Figure 6** shows your acceleration for the next 10 s. During the first 8 s, you move down the hill. You can tell from the graph that your acceleration is positive for the first 8 s because your velocity increases as time passes. During the last 2 s, your car starts climbing the next hill. Your acceleration is negative because your velocity decreases as time passes.

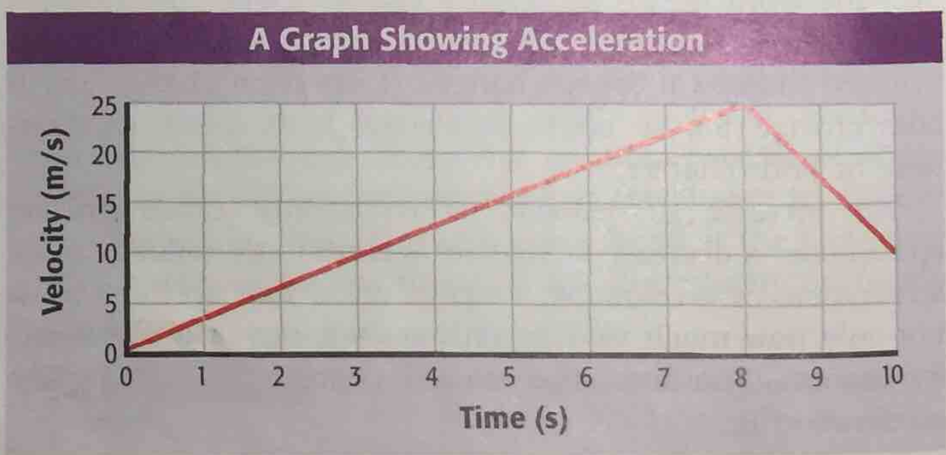


Figure 6 *Acceleration can be shown on a graph of velocity versus time.*

Circular Motion: Continuous Acceleration

You may be surprised to know that even when you are completely still, you are experiencing acceleration. You may not seem to be changing speed or direction, but you are! You are traveling in a circle as the Earth rotates. An object traveling in a circular motion is always changing its direction. Therefore, its velocity is always changing, so it is accelerating. The acceleration that occurs in circular motion is known as *centripetal acceleration* (sen TRIP uht uhl ak SEL uhr AY shuhn). Centripetal acceleration occurs on a Ferris wheel at an amusement park or as the moon orbits Earth. Another example of centripetal acceleration is shown in **Figure 7.**

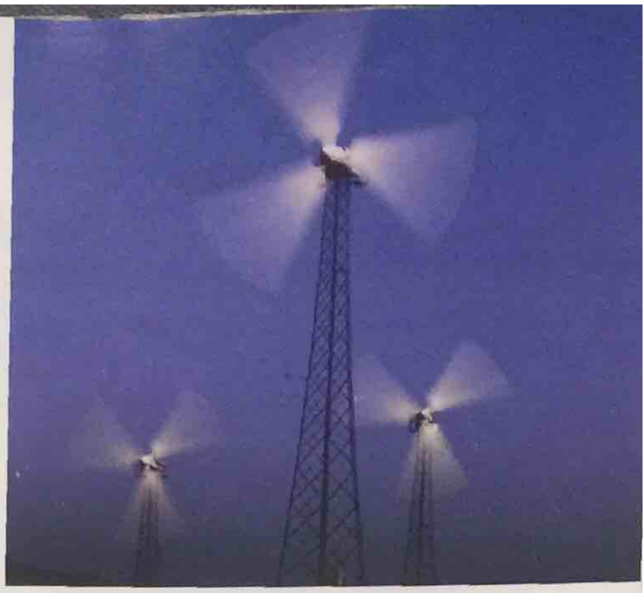


Figure 7 *The blades of these windmills are constantly changing direction. Thus, centripetal acceleration is occurring.*

SECTION Review

Summary

- An object is in motion if it changes position over time in relation to a reference point.
- Speed is the distance traveled by an object divided by the time the object takes to travel that distance.
- Velocity is speed in a given direction.
- Acceleration is the rate at which velocity changes.
- An object can accelerate by changing speed, direction, or both.
- Speed can be represented on a graph of distance versus time.
- Acceleration can be represented by graphing velocity versus time.

Using Key Terms

1. In your own words, write definitions for each of the following terms: *motion* and *acceleration*.
2. Use each of the following terms in a separate sentence: *speed* and *velocity*.

Understanding Key Ideas

3. Which of the following is NOT an example of acceleration?
   - **a.** a person jogging at 3 m/s along a winding path
   - **b.** a car stopping at a stop sign
   - **c.** a cheetah running 27 m/s east
   - **d.** a plane taking off
4. Which of the following would be a good reference point to describe the motion of a dog?
   - **a.** the ground
   - **b.** another dog running
   - **c.** a tree
   - **d.** All of the above
5. Explain the difference between speed and velocity.
6. What two things must you know to determine speed?
7. How are velocity and acceleration related?

Math Skills

8. Find the average speed of a person who swims 105 m in 70 s.
9. What is the average acceleration of a subway train that speeds up from 9.6 m/s to 12 m/s in 0.8 s on a straight section of track?

Critical Thinking

10. **Applying Concepts** Why is it more helpful to know a tornado's velocity rather than its speed?
11. **Evaluating Data** A wolf is chasing a rabbit. Graph the wolf's motion using the following data: 15 m/s at 0 s, 10 m/s at 1 s, 5 m/s at 2 s, 2.5 m/s at 3 s, 1 m/s at 4 s, and 0 m/s at 5 s. What does the graph tell you?

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