section 1

* Annotated *

Describing Motion

Reading Guide

What **You'll Learn**

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

Why **It's Important**

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

Review Vocabulary

instantaneous: occurring at a particular instant of time

New Vocabulary

- distance
- displacement
- speed
- average speed
- instantaneous speed
- velocity

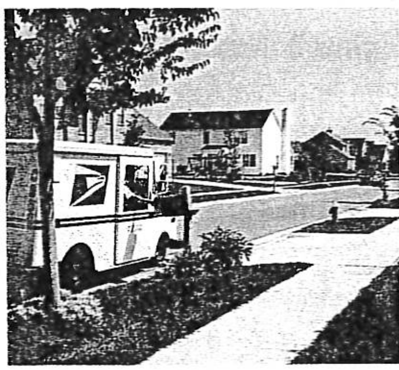


Figure 1 This mail truck is in motion. #3

Infer *How do you know the mail truck has moved?* #4

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?

#1 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. #2

A reference point is needed to determine the position of an object. In **Figure 1,** the reference point might be a tree or a mailbox. Motion occurs when an object changes its position relative to a reference point. The motion of an object depends on the reference point that is chosen. For example, the motion of the mail truck in **Figure 1** would be different if the reference point were a car moving along the street, instead of a mailbox.

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.

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.

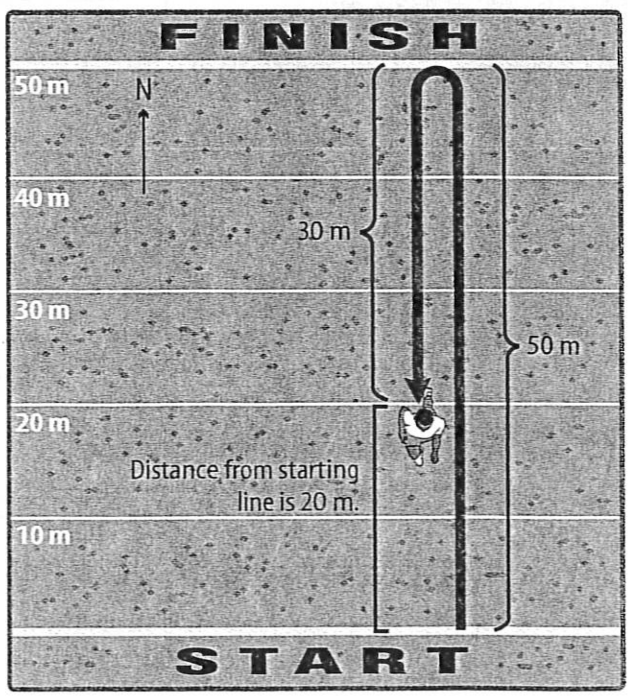
INTEGRATE Astronomy

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?

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 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.

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

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.

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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.

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Speed Equation

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

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

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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 → means → $d = 750$ m

in 25 s → means → $t = 25$ s

Identify the unknown value:

What is the car's speed? → means → $s = ?$ 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.

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. #13

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?

Science Online

Topic: Running Speeds

Visit 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.

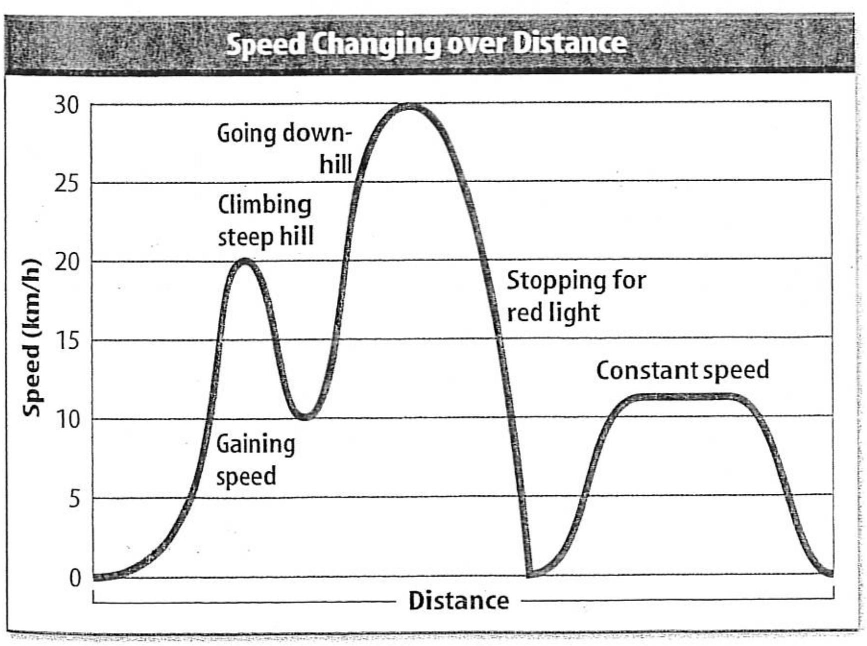


Figure 3 The graph shows how the speed of a cyclist changes during a trip.
Explain *how you describe the speed of an object when the speed is changing.*

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 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.

Science Online

Topic: Olympic Swimming Speeds

Visit 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?

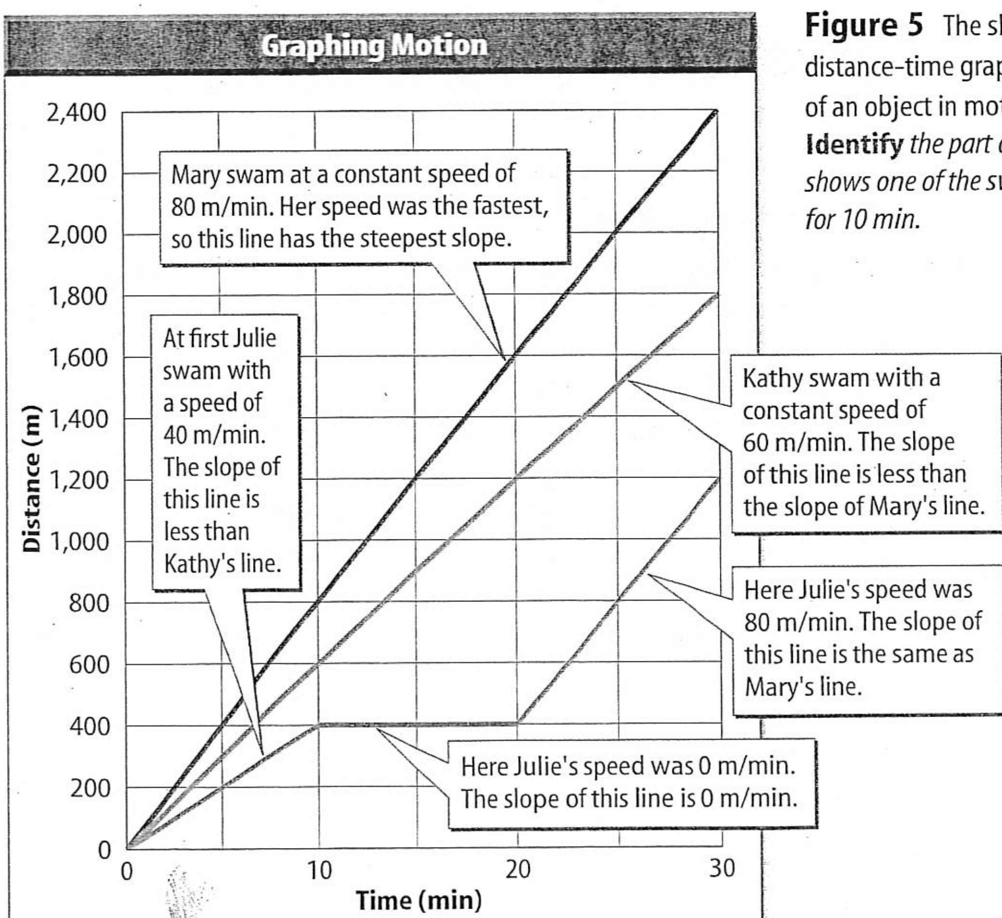
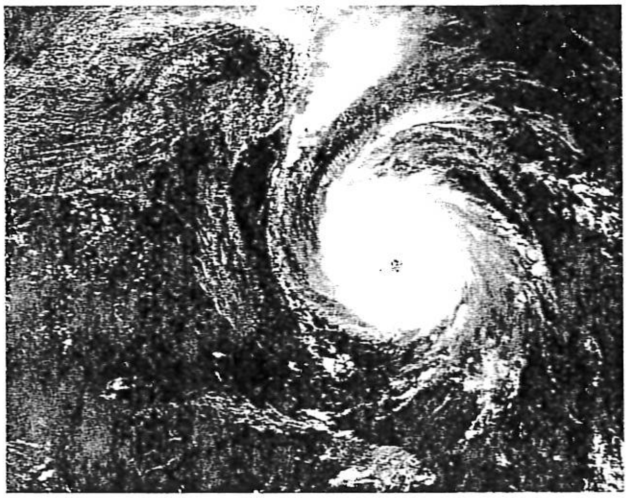


Figure 5 The slope of a line on a distance-time graph gives the speed of an object in motion.
Identify *the part of the graph that shows one of the swimmers resting for 10 min.*



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.

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.

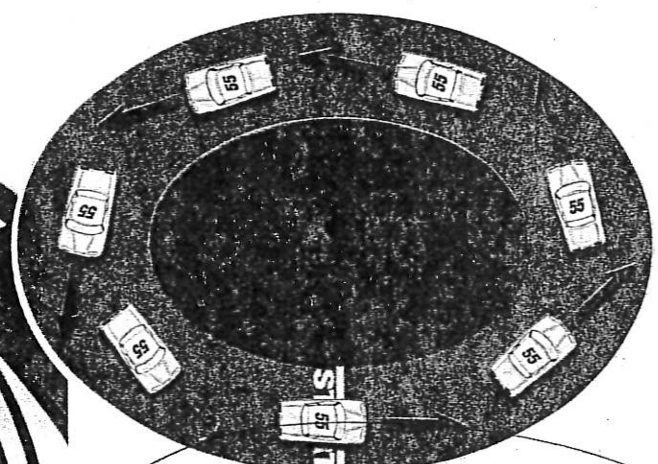
Escalators like the one shown in **Figure 7** are found in shopping malls and airports. The two sets of passengers pictured are moving at constant speed, but in opposite directions. The speeds of the passengers are the same, but their velocities are different because the passengers are moving in different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