Section 1

Describing and Measuring Motion

Reading Preview

Key Concepts

- When is an object in motion?
- How do you know an object's speed and velocity?
- How can you graph motion?

Key Terms

- motion • reference point
- International System of Units
- meter • speed • average speed
- instantaneous speed
- velocity • slope

Target Reading Skill

Using Prior Knowledge Before you read, write what you know about motion in a graphic organizer like the one below. As you read, write what you learn.

What You Know
1. A moving object changes position.
2.

What You Learned
1.
2.

Lab zone Discover Activity

How Fast and How Far?

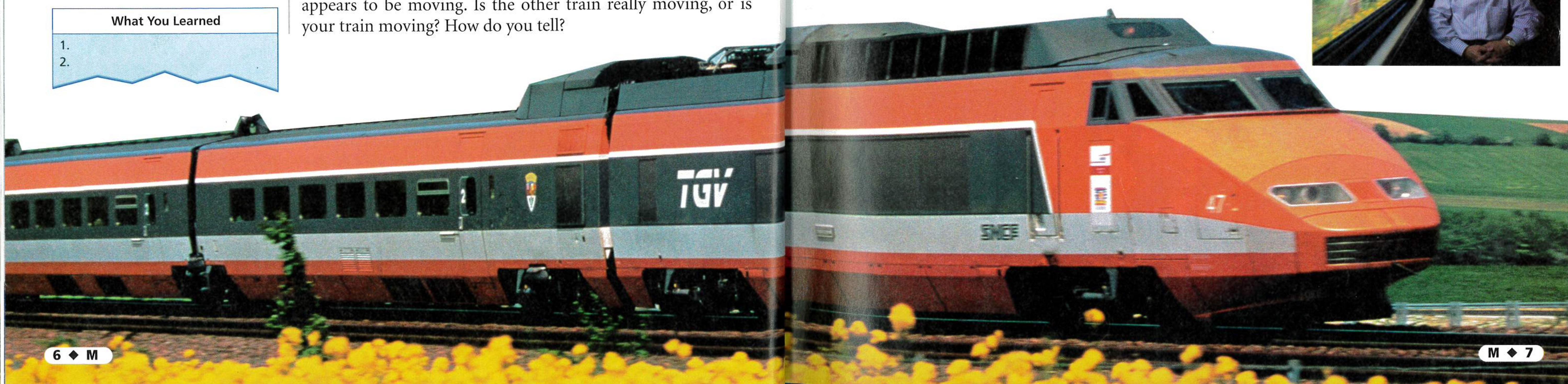
1. Using a stopwatch, find out how long it takes you to walk 5 meters at a normal pace. Record your time.
2. Now find out how far you can walk in 5 seconds if you walk at a normal pace. Record your distance.
3. Repeat Steps 1 and 2, walking slower than your normal pace. Then repeat Steps 1 and 2 walking faster than your normal pace.

Think It Over

Inferring What is the relationship between the distance you walk, the time it takes you to walk, and your walking speed?

How do you know if you are moving? If you've ever traveled on a train, you know you cannot always tell if you are in motion. Looking at a building outside the window helps you decide. Although the building seems to move past the train, it's you and the train that are moving.

However, sometimes you may see another train that appears to be moving. Is the other train really moving, or is your train moving? How do you tell?



Describing Motion

Deciding if an object is moving isn't as easy as you might think. For example, you are probably sitting in a chair as you read this book. Are you moving? Well, parts of you may be. Your eyes blink and your chest moves up and down. But you would probably say that you are not moving. An object is in **motion** if its distance from another object is changing. Because your distance from your chair is not changing, you could say you are not in motion.

Reference Points To decide if you are moving, you use your chair as a reference point. A **reference point** is a place or object used for comparison to determine if something is in motion. **An object is in motion if it changes position relative to a reference point.**

Objects that we call stationary—such as a tree, a sign, or a building—make good reference points. From the point of view of the train passenger in Figure 1, such objects are not in motion. If the passenger is moving relative to a tree, he can conclude that the train is in motion.

You probably know what happens if your reference point is moving. Have you ever been in a school bus parked next to another bus? Suddenly, you think your bus is moving backward. But, when you look out a window on the other side, you find that your bus isn't moving at all—the other bus is moving forward! Your bus seems to be moving backward because you used the other bus as a reference point.

FIGURE 1
Reference Points
The passenger can use a tree as a reference point to decide if the train is moving. A tree makes a good reference point because it is stationary from the passenger's point of view.
Applying Concepts *Why is it important to choose a stationary object as a reference point?*

Relative Motion Are you moving as you read this book? The answer to that question depends on your reference point. When your chair is your reference point, you are not moving. But if you choose another reference point, you may be moving.

Suppose you choose the sun as a reference point instead of your chair. If you compare yourself to the sun, you are moving quite rapidly. This is because you and your chair are on Earth, which moves around the sun. Earth moves about 30 kilometers every second. So you, your chair, this book, and everything else on Earth move that quickly as well. Going that fast, you could travel from New York City to Los Angeles in about 2 minutes! Relative to the sun, both you and your chair are in motion. But because you are moving with Earth, you do not seem to be moving.

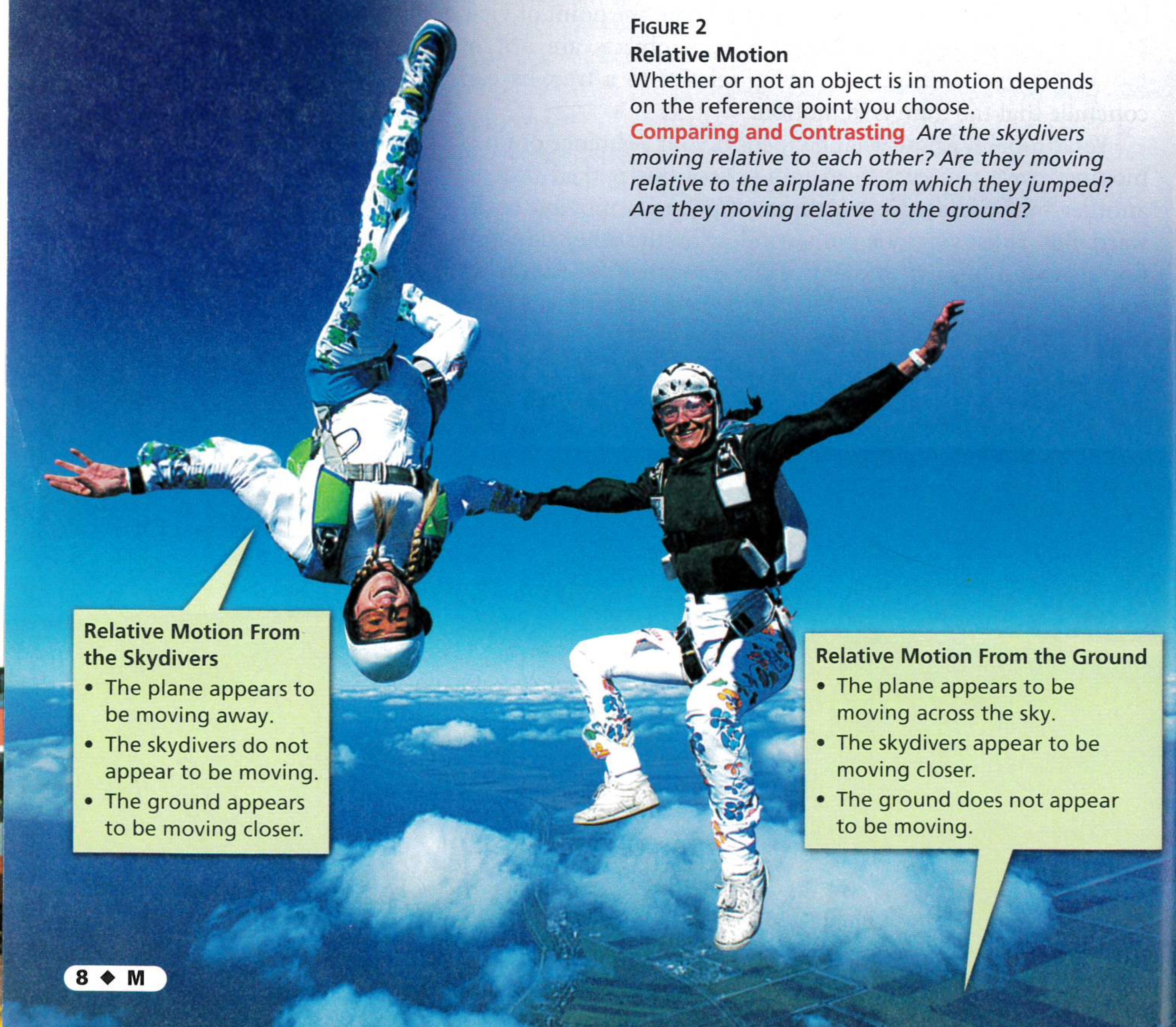


FIGURE 2
Relative Motion
Whether or not an object is in motion depends on the reference point you choose.
Comparing and Contrasting *Are the skydivers moving relative to each other? Are they moving relative to the airplane from which they jumped? Are they moving relative to the ground?*

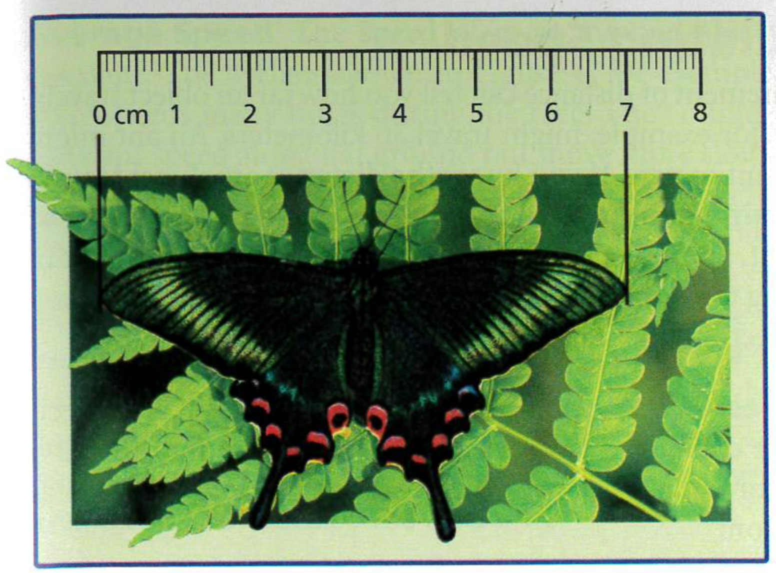


FIGURE 3
Measuring Distance
You can measure distances shorter than 1 meter in centimeters. The wingspan of the butterfly is 7 cm.

Measuring Distance You can use units of measurement to describe motion precisely. You measure in units, or standard quantities of measurement, all the time. For example, you might measure 1 cup of milk for a recipe, run 2 miles after school, or buy 3 pounds of fruit at the store. Cups, miles, and pounds are all units of measurement.

Scientists all over the world use the same system of measurement so that they can communicate clearly. This system of measurement is called the **International System of Units** or, in French, *Système International* (SI).

When describing motion, scientists use SI units to describe the distance an object moves. When you measure distance, you measure length. The SI unit of length is the **meter** (m). A meter is a little longer than a yard. An Olympic-size swimming pool is 50 meters long. A football field is about 91 meters long.

The length of an object smaller than a meter often is measured in a unit called the centimeter (cm). The prefix *centi-* means "one hundredth." A centimeter is one hundredth of a meter, so there are 100 centimeters in a meter. The wingspan of the butterfly shown in Figure 3 can be measured in centimeters. For lengths smaller than a centimeter, the millimeter (mm) is used. The prefix *milli-* means "one thousandth," so there are 1,000 millimeters in a meter. Distances too long to be measured in meters often are measured in kilometers (km). The prefix *kilo-* means "one thousand." There are 1,000 meters in a kilometer.

Scientists also use SI units to describe quantities other than length. You can find more information about SI units in the Skills Handbook at the end of this book.

Reading Checkpoint **What system of measurement do scientists use?**

Math Skills

Converting Units

Use a conversion factor to convert one metric unit to another. A conversion factor is a fraction in which the numerator and denominator represent equal amounts in different units. Multiply the number you want to convert by the conversion factor.

Suppose you want to know how many millimeters (mm) are in 14.5 meters (m). Since there are 1,000 millimeters in 1 meter, the conversion factor is

$$\frac{1{,}000 \text{ mm}}{1 \text{ m}}$$

Multiply 14.5 meters by the conversion factor to find millimeters.

$$14.5 \text{ m} \times \frac{1{,}000 \text{ mm}}{1 \text{ m}}$$

$$= 14.5 \times 1{,}000 \text{ mm}$$

$$= 14{,}500 \text{ mm}$$

Practice Problem How many centimeters are in 22.5 meters?

Lab zone **Skills Activity**

Calculating

Two families meet at the City Museum at 10:00 A.M. Each family uses a different means of transportation to get there. The Gonzalez family leaves at 9:00 A.M. and drives 90 km on a highway. The Browns leave at 9:30 A.M. and ride the train 30 km. What is the average speed for each family's trip? Which family travels at the faster speed?

Calculating Speed

A measurement of distance can tell you how far an object travels. A cyclist, for example, might travel 30 kilometers. An ant might travel 2 centimeters. **If you know the distance an object travels in a certain amount of time, you can calculate the speed of the object.** Speed is a type of rate. A rate tells you the amount of something that occurs or changes in one unit of time. The **speed** of an object is the distance the object travels per unit of time.

The Speed Equation To calculate the speed of an object, divide the distance the object travels by the amount of time it takes to travel that distance. This relationship can be written as an equation.

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

The speed equation consists of a unit of distance divided by a unit of time. If you measure distance in meters and time in seconds, you express speed in meters per second, or m/s. (The slash is read as "per.") If you measure distance in kilometers and time in hours, you express speed in kilometers per hour, or km/h. For example, a cyclist who travels 30 kilometers in 1 hour has a speed of 30 km/h. An ant that moves 2 centimeters in 1 second is moving at a speed of 2 centimeters per second, or 2 cm/s.

FIGURE 4
Speed
The cyclists' speeds will vary throughout the cross-country race. However, the cyclist with the greatest average speed will win.

Average Speed The speed of most moving objects is not constant. The cyclists shown in Figure 4, for example, change their speeds many times during the race. They might ride at a constant speed along flat ground but move more slowly as they climb hills. Then they might move more quickly as they come down hills. Occasionally, they may stop to fix their bikes.

Although a cyclist does not have a constant speed, the cyclist does have an average speed throughout a race. To calculate **average speed,** divide the total distance traveled by the total time. For example, suppose a cyclist travels 32 kilometers during the first 2 hours. Then the cyclist travels 13 kilometers during the next hour. The average speed of the cyclist is the total distance divided by the total time.

$$\text{Total distance} = 32\text{ km} + 13\text{ km} = 45\text{ km}$$
$$\text{Total time} = 2\text{ h} + 1\text{ h} = 3\text{ h}$$
$$\text{Average speed} = \frac{45\text{ km}}{3\text{ h}} = 15\text{ km/h}$$

The cyclist's average speed is 15 kilometers per hour.

Instantaneous Speed Calculating the average speed of a cyclist during a race is important. However, it is also useful to know the cyclist's instantaneous speed. **Instantaneous speed** is the rate at which an object is moving at a given instant in time.

Reading Checkpoint How do you calculate average speed?

FIGURE 5
Measuring Speed
Cyclists use an electronic device known as a cyclometer to track the distance and time that they travel. A cyclometer can calculate both average and instantaneous speed.
Comparing and Contrasting *Explain why the instantaneous speed and the average speed shown below are different.*

Discovery Channel School

Motion

Video Preview
▶ Video Field Trip
Video Assessment

Describing Velocity

Knowing the speed at which something travels does not tell you everything about its motion. To describe an object's motion completely, you need to know the direction of its motion. For example, suppose you hear that a thunderstorm is traveling at a speed of 25 km/h. Should you prepare for the storm? That depends on the direction of the storm's motion. Because storms usually travel from west to east in the United States, you need not worry if you live to the west of the storm. But if you live to the east of the storm, take cover.

When you know both the speed and direction of an object's motion, you know the velocity of the object. Speed in a given direction is called **velocity.** You know the velocity of the storm when you know that it is moving 25 km/h eastward.

At times, describing the velocity of moving objects can be very important. For example, air traffic controllers must keep close track of the velocities of the aircraft under their control. These velocities continually change as airplanes move overhead and on the runways. An error in determining a velocity, either in speed or in direction, could lead to a collision.

Velocity is also important to airplane pilots. For example, stunt pilots make spectacular use of their control over the velocity of their aircrafts. To avoid colliding with other aircraft, these skilled pilots must have precise control of both their speed and direction. Stunt pilots use this control to stay in close formation while flying graceful maneuvers at high speed.

Reading Checkpoint **What is velocity?**

Writing in Science

Research and Write What styles of automobile were most popular during the 1950s, 1960s, and 1970s? Were sedans, convertibles, station wagons, or sports cars the bestsellers? Choose an era and research automobiles of that time. Then write an advertisement for one particular style of car. Be sure to include information from your research.

• Tech & Design in History •

The Speed of Transportation

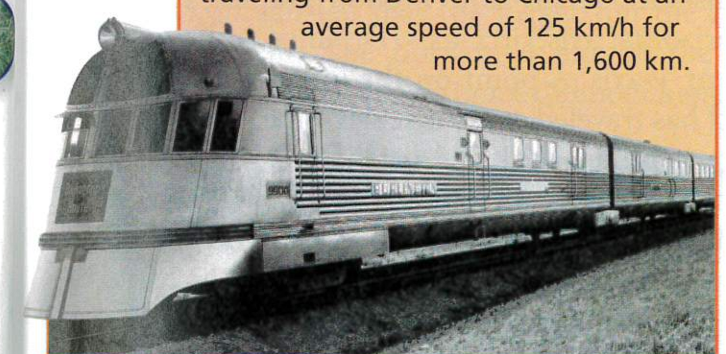
The speed with which people can travel from one place to another has increased over the years.

1818 National Road Constructed
The speed of transportation has been limited largely by the quality of roadways. The U.S. government paid for the construction of a highway named the Cumberland Road. It ran from Cumberland, Maryland, to Wheeling, in present-day West Virginia. Travel by horse and carriage on the roadway was at a speed of about 11 km/h.

1885 Benz Tricycle Car Introduced
This odd-looking vehicle was the first internal combustion (gasoline-powered) automobile sold to the public. Although it is an ancestor of the modern automobile, its top speed was only about 15 km/h—not much faster than a horse-drawn carriage.

1908 Ford Model T Mass-Produced
Between 1908 and 1927, over 15 million of these automobiles were sold. The Model T had a top speed of 65 km/h.

1934 Zephyr Introduced
The first diesel passenger train in the United States was the *Zephyr*. The *Zephyr* set a long-distance record, traveling from Denver to Chicago at an average speed of 125 km/h for more than 1,600 km.



1956 Interstate Highway System Established
The passage of the Federal-Aid Highway Act established the Highway Trust Fund. This act allowed the construction of the Interstate and Defense Highways. Nonstop transcontinental auto travel became possible. Speed limits in many parts of the system were more than 100 km/h.

2003 Maglev in Motion
The first commercial application of high-speed maglev (magnetic levitation) was unveiled in Shanghai, China. During the 30-km trip from Pudong International Airport to Shanghai's financial district, the train operates at a top speed of 430 km/h, reducing commuting time from 45 minutes to just 8 minutes.

1800 | 1850 | 1900 | 1950 | 2000 | 2050

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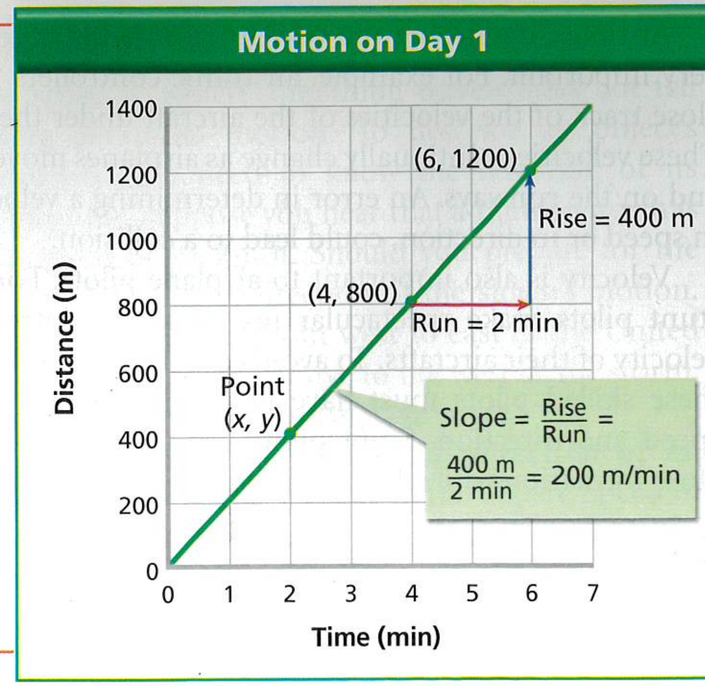
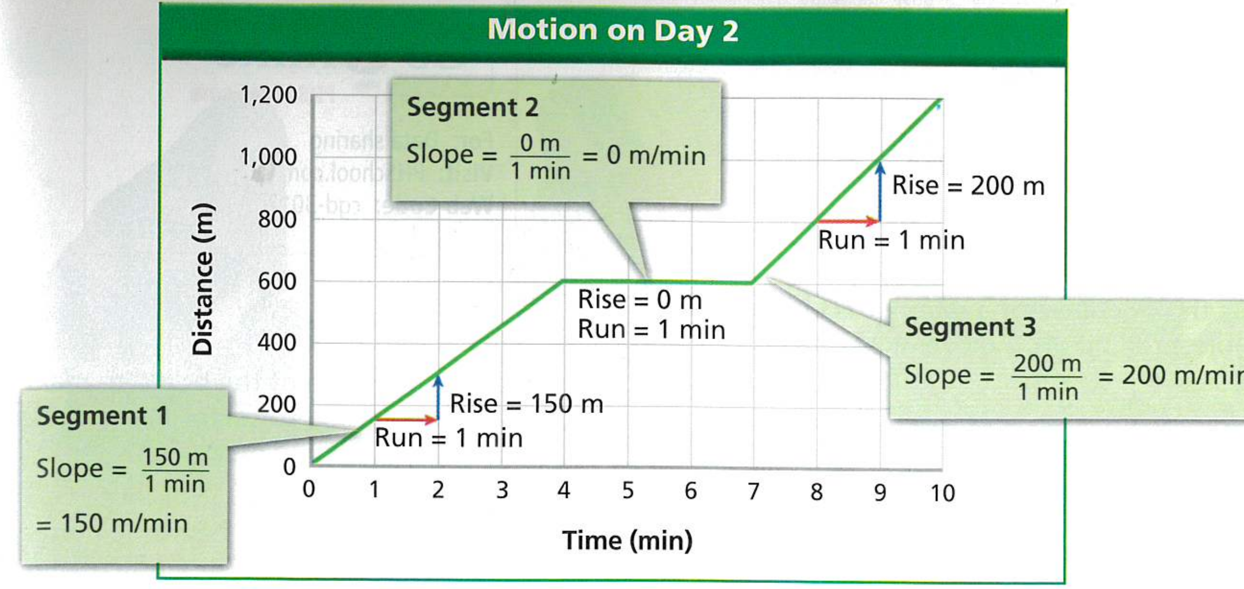


FIGURE 6
Graphing Motion
Distance-versus-time graphs can be used to analyze motion. On the jogger's first day of training, her speed is the same at every point. On the second day of training, her speed varies. **Reading Graphs** *On the first day, how far does the jogger run in 5 minutes?*



Graphing Motion

You can show the motion of an object on a line graph in which you plot distance versus time. The graphs you see in Figure 6 are distance-versus-time motion graphs. Time is shown on the horizontal axis, or *x*-axis. Distance is shown on the vertical axis, or *y*-axis. A point on the line represents the distance an object has traveled at a particular time. The *x* value of the point is time, and the *y* value is distance.

The steepness of a line on a graph is called **slope.** The slope tells you how fast one variable changes in relation to the other variable in the graph. In other words, slope tells you the rate of change. Since speed is the rate that distance changes in relation to time, the slope of a distance-versus-time graph represents speed. The steeper the slope is, the greater the speed. A constant slope represents motion at constant speed.

Calculating Slope You can calculate the slope of a line by dividing the rise by the run. The rise is the vertical difference between any two points on the line. The run is the horizontal difference between the same two points.

$$\text{Slope} = \frac{\text{Rise}}{\text{Run}}$$

In Figure 6, using the points shown, the rise is 400 meters and the run is 2 minutes. To find the slope, you divide 400 meters by 2 minutes. The slope is 200 meters per minute.

Reading Checkpoint What is the slope of a graph?

Different Slopes Most moving objects do not travel at a constant speed. The graph above shows a jogger's motion on her second day. The line is divided into three segments. The slope of each segment is different. From the steepness of the slopes you can tell that the jogger ran the fastest during the third segment. The horizontal line in the second segment shows that the jogger's distance did not change at all.

Section 1 Assessment

Target Reading Skill

Using Prior Knowledge Review your graphic organizer and revise it based on what you just learned about motion.

Reviewing Key Concepts

1. a. **Reviewing** How do you know if an object is moving?
   b. **Explaining** Why is it important to know if your reference point is moving?
   c. **Applying Concepts** Suppose you are riding in a car. Describe your motion relative to the car, the road, and the sun.
2. a. **Defining** What is speed?
   b. **Describing** What do you know about the motion of an object that has an average speed of 1 m/s?
   c. **Comparing and Contrasting** What is the difference between speed and velocity?
3. a. **Identifying** What does the slope of a distance-versus-time graph show you about the motion of an object?
   b. **Calculating** The rise of a line on a distance-versus-time graph is 600 m and the run is 3 minutes. What is the slope of the line?

Math Practice

This week at swim practice, Jamie swam a total of 1,500 m, while Ellie swam 1.6 km.

4. **Converting Units** Convert Ellie's distance to meters. Who swam the greater distance: Jamie or Ellie?
5. **Converting Units** How many kilometers did Jamie swim?