KEY CONCEPT

1.2 Speed measures how fast position changes.

BEFORE, you learned

- An object's position is measured from a reference point
- To describe the position of an object, you can use distance and direction
- An object in motion changes position with time

NOW, you will learn

- How to calculate an object's speed
- How to describe an object's velocity

VOCABULARY

speed p. 16
velocity p. 22
vector p. 22

EXPLORE Speed

How can you measure speed?

PROCEDURE

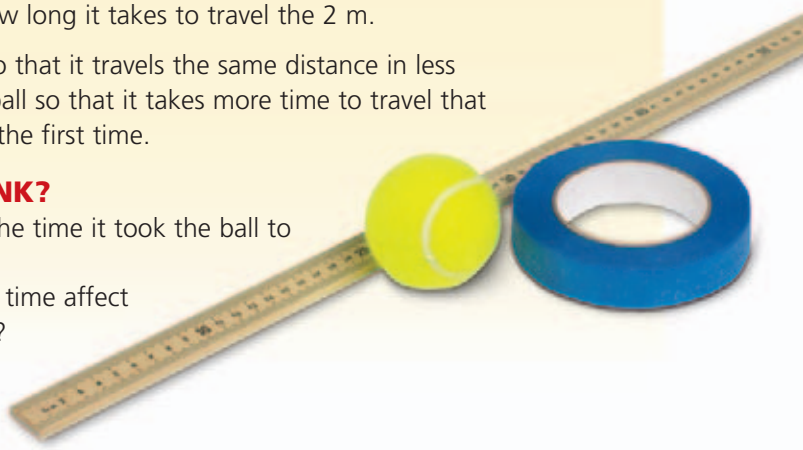
1. Place a piece of tape on the floor. Measure a distance on the floor 2 m away from the tape. Mark this distance with a second piece of tape.
2. Roll a tennis ball from one piece of tape to the other, timing how long it takes to travel the 2 m.
3. Roll the ball again so that it travels the same distance in less time. Then roll the ball so that it takes more time to travel that distance than it did the first time.

MATERIALS

- tape
- meter stick
- tennis ball
- stopwatch

WHAT DO YOU THINK?

- How did you change the time it took the ball to travel 2 m?
- How did changing the time affect the motion of the ball?



Position can change at different rates.

VOCABULARY
Make a description wheel in your notebook for *speed*.

When someone asks you how far it is to the library you can answer in terms of distance or time. You can say it is several blocks, or you can say it is a five-minute walk. When you give a time instead of a distance, you are basing your time estimate on the distance to the library and the person's speed. **Speed** is a measure of how fast something moves or the distance it moves, in a given amount of time. The greater the speed an object has, the faster it changes position.

CHECK YOUR READING How are speed and position related?

The way in which one quantity changes compared to another quantity is called a rate. Speed is the rate at which the distance an object moves changes compared to time. If you are riding a bike to a movie, and you think you might be late, you increase the rate at which your distance changes by pedaling harder. In other words, you increase your speed.

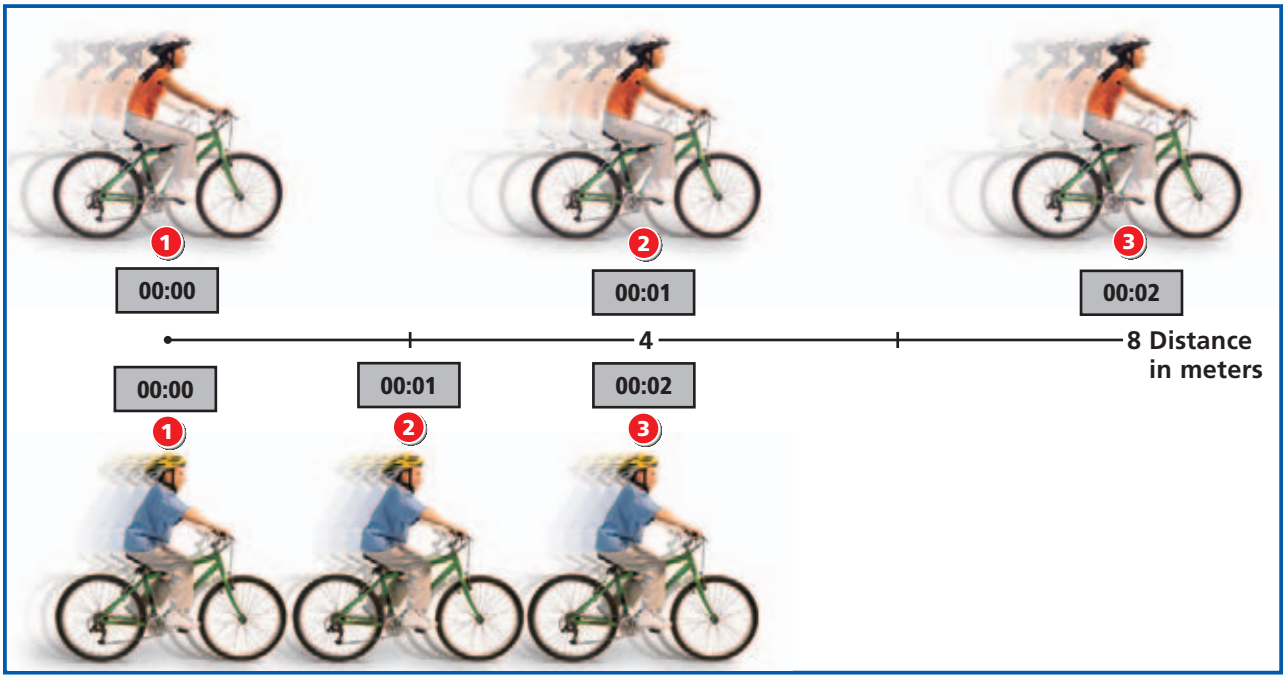
Calculating Speed

To calculate speed, you need to know both distance and time measurements. Consider the two bike riders below.

1. The two bikes pass the same point at the same time.
2. After one second, the first bike has traveled four meters, while the second has traveled only two meters. Because the first bike has traveled four meters in one second, it has a speed of four meters per second. The second bike has a speed of two meters per second.
3. If each bike continues moving at the same speed as before, then after two seconds the first rider will have traveled eight meters, while the second one will have traveled only four meters.

Comparing Speed

Objects that travel at different speeds move different distances in the same amount of time.



READING VISUALS How far will each rider travel in five seconds?

Racing wheelchairs are specially designed to reach higher speeds than regular wheelchairs.

Speed can be calculated by dividing the distance an object travels by the time it takes to cover the distance. The formula for finding speed is

$$\text{Speed} = \frac{\text{distance}}{\text{time}} \qquad S = \frac{d}{t}$$

Speed is shown in the formula as the letter *S*, distance as the letter *d*, and time as the letter *t*. The formula shows how distance, time, and speed are related. If two objects travel the same distance, the object that took a shorter amount of time will have the greater speed. Similarly, an object with a greater speed will travel a longer distance in the same amount of time than an object with a lower speed will.

The standard unit for speed is meters per second (m/s). Speed is also given in kilometers per hour (km/h). In the United States, where the English system of measurement is still used, speeds are often given in miles per hour (mi/h or mph). One mile per hour is equal to 0.45 m/s.

The man participating in the wheelchair race, at left, will win if his speed is greater than the speed of the other racers. You can use the formula to calculate his speed.

CHECK YOUR READING If two runners cover the same distance in different amounts of time, how do their speeds compare?

Calculating Speed

Sample Problem

A wheelchair racer completes a 100-meter course in 20 seconds. What is his speed?

What do you know?	distance = 100 m, time = 20 s
What do you want to find out?	speed
Write the formula:	$S = \frac{d}{t}$
Substitute into the formula:	$S = \frac{100\text{ m}}{20\text{ s}}$
Calculate and simplify:	$S = 5$ m/s
Check that your units agree:	Unit is m/s. Unit of speed is m/s. Units agree.
Answer:	$S = 5$ m/s

Practice the Math

1. A man runs 200 m in 25 s. What is his speed?
2. If you travel 100 m in 50 s, what is your speed?

Average Speed

Speed is not constant. When you run, you might slow down to pace yourself, or speed up to win a race. At each point as you are running, you have a specific speed. This moment-to-moment speed is called your instantaneous speed. Your instantaneous speed can be difficult to measure; however, it is easier to calculate your average speed over a distance.

In a long race, runners often want to know their times for each lap so that they can pace themselves. For example, an excellent middle school runner might have the following times for the four laps of a 1600-meter race: 83 seconds, 81 seconds, 79 seconds, 77 seconds. The lap times show the runner is gradually increasing her speed throughout the race.

The total time for the four laps can be used to calculate the runner's average speed for the entire race. The total time is 320 seconds (5 min 20 s) for the entire distance of 1600 meters. The runner's average speed is 1600 meters divided by 320 seconds, or 5.0 meters per second.

READING TiP
The root of *instantaneous* is *instant,* meaning "moment."

INVESTIGATE Speed and Distance

How does design affect speed?

DESIGN YOUR OWN EXPERIMENT

Cars are built in different shapes. How does the shape of the car affect the way it moves? Design your own car, and see how fast it can go.

SKILL FOCUS
Designing experiments

MATERIALS
- clay
- film container lids
- toothpicks
- beam balance
- board
- books
- string
- straw
- scissors
- stopwatch

TIME
20 minutes

PROCEDURE

1. Use the clay, film container lids, and toothpicks to design a car that rolls when it is pushed. The car should have a total mass of 150 g or less.
2. Using any or all of the other materials, design an experiment to measure and compare the speed of your car with the speed of someone else's car. Your experiment should be designed so that the design of the car is the only variable being tested. Write up your procedure.
3. Perform the experiment using your car and another student's car. Record the data you need to calculate the speed of both cars.
4. Calculate the speed of each car, and record which car went faster.

WHAT DO YOU THINK?
- What were the constants in your experiment?
- How would you improve your design if you were to repeat the experiment?

Distance-Time Graphs

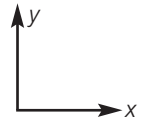
A convenient way to show the motion of an object is by using a graph that plots the distance the object has traveled against time. This type of graph, called a distance-time graph, shows how speed relates to distance and time. You can use a distance-time graph to see how both distance and speed change with time.

The distance-time graph on page 21 tracks the changing motion of a zebra. At first the zebra looks for a spot to graze. Its meal is interrupted by a lion, and the zebra starts running to escape.

In a distance-time graph, time is on the horizontal axis, or *x*-axis, and distance is on the vertical axis, or *y*-axis.

REMINDER

The *x*-axis and *y*-axis are arranged as shown:



1. As an object moves, the distance it travels increases with time. This can be seen as a climbing, or rising, line on the graph.
2. A flat, or horizontal, line shows an interval of time where the speed is zero meters per second.
3. Steeper lines show intervals where the speed is greater than intervals with less steep lines.

You can use a distance-time graph to determine the speed of an object. The steepness, or slope, of the line is calculated by dividing the change in distance by the change in time for that time interval.

Calculating Speed from a Graph

Sample Problem

How fast is the zebra walking during the first 20 seconds?

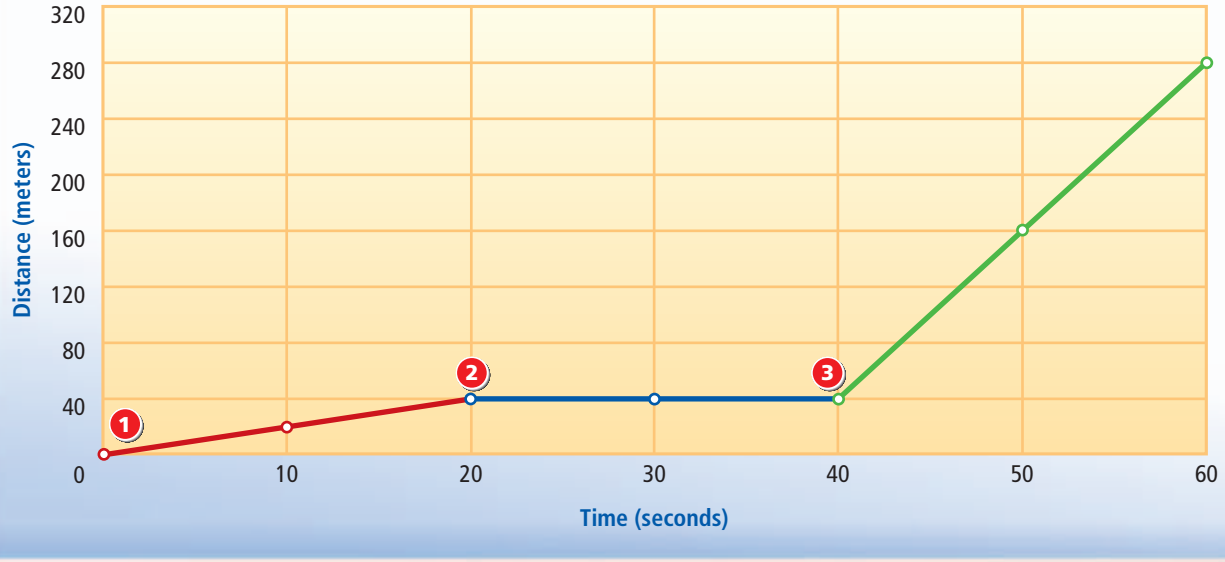
What do you know?	Reading from the graph: At time = 0 s, distance = 0 m. At time = 20 s, distance = 40 m.
What do you want to find out?	speed
Write the formula:	$S = \frac{d}{t}$
Substitute into the formula:	$S = \frac{40\text{ m} - 0\text{ m}}{20\text{ s} - 0\text{ s}}$
Calculate and simplify:	$S = \frac{40\text{ m}}{20\text{ s}} = 2\text{ m/s}$
Check that your units agree:	Unit is m/s. Unit of speed is m/s. Units agree.
Answer:	$S = 2\text{ m/s}$

Practice the Math

1. What is the speed of the zebra during the 20 s to 40 s time interval?
2. What is the speed of the zebra during the 40 s to 60 s interval?

Distance-Time Graph

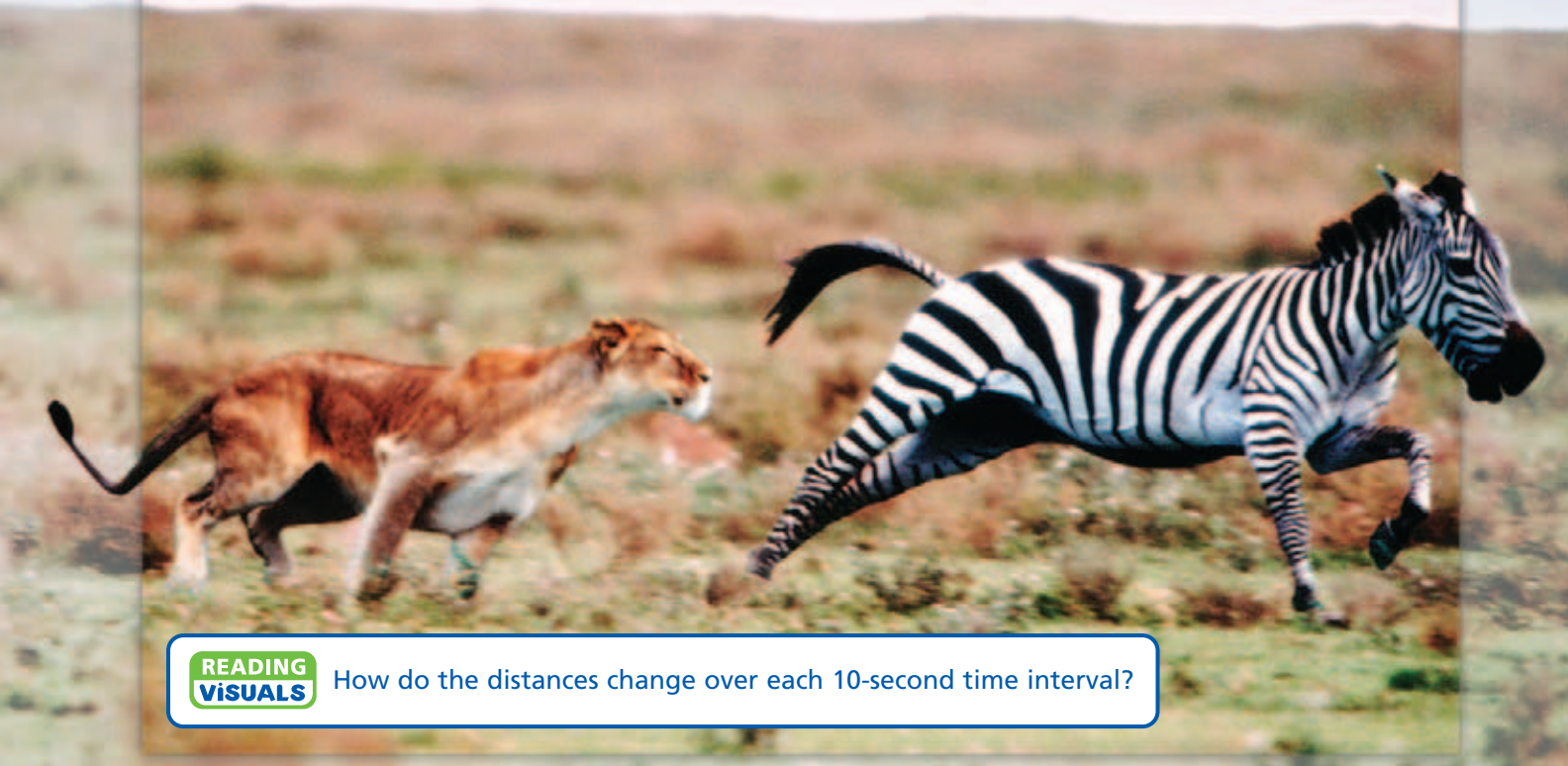
A zebra's speed will change throughout the day, especially if a hungry lion is nearby. You can use a distance-time graph to compare the zebra's speed over different time intervals.



1. When the zebra is walking, its distance from its starting point increases. You can see this motion on the graph as a climbing line.

2. When the zebra stops to graze, it no longer changes its distance from the starting point. Time, however, continues to pass. Therefore, the graph shows a flat, or horizontal, line.

3. As soon as the zebra notices the lion, it stops grazing and starts to run for its life. The zebra is covering a greater distance in each time interval than it was before the chase started, so the line is steeper.



READING VISUALS How do the distances change over each 10-second time interval?

Velocity includes speed and direction.

Sometimes the direction of motion is as important as its speed. In large crowds, for example, you probably always try to walk in the same direction the crowd is moving and at the same speed. If you walk in even a slightly different direction, you can bump into other people. In a crowd, in other words, you try to walk with the same velocity as the people around you. **Velocity** is a speed in a specific direction. If you say you are walking east at a speed of three meters per second, you are describing your velocity. A person walking north with a speed of three meters per second would have the same speed as you do, but not the same velocity.

CHECK YOUR READING What is velocity? Give an example of a velocity.

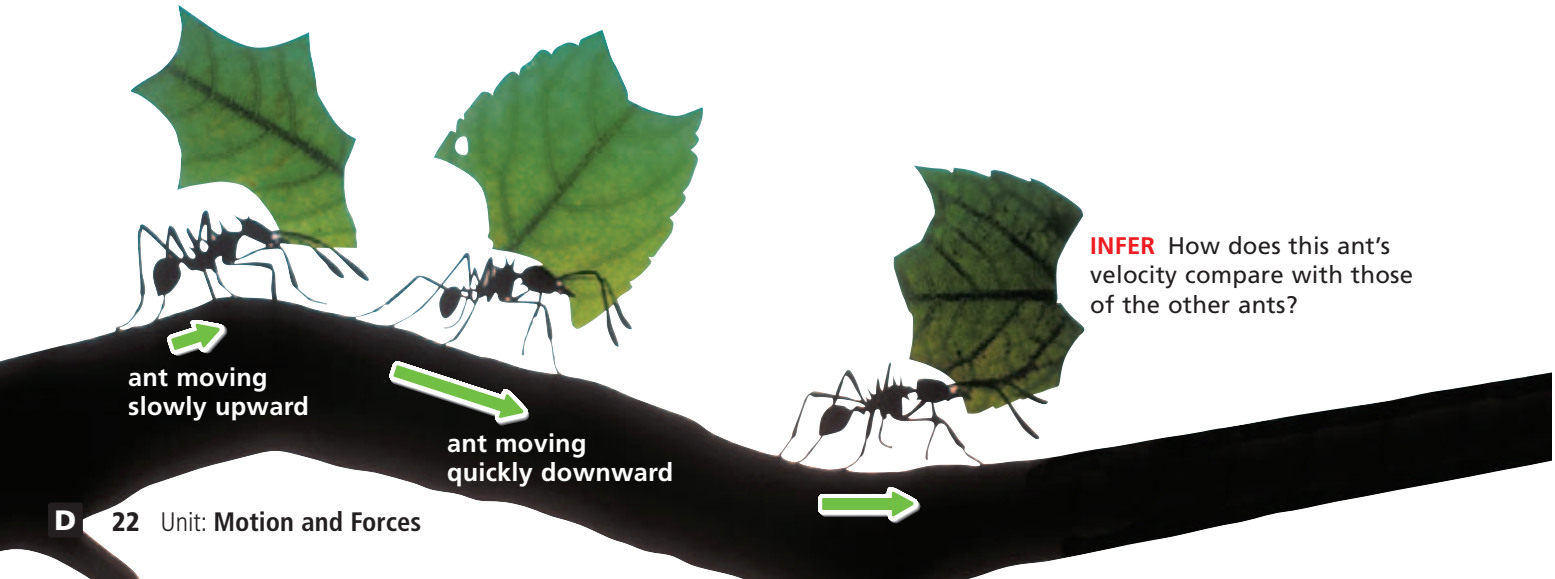
Velocity

The picture below shows several ants as they carry leaves along a branch. Each ant's direction of motion changes as it walks along the bends of the branch. As the arrows indicate, each ant is moving in a specific direction. Each ant's velocity is shown by the length and direction of the arrow. A longer arrow means a greater speed in the direction the arrow is pointing. In this picture, for example, the ant moving up the branch is traveling more slowly than the ant moving down the branch.

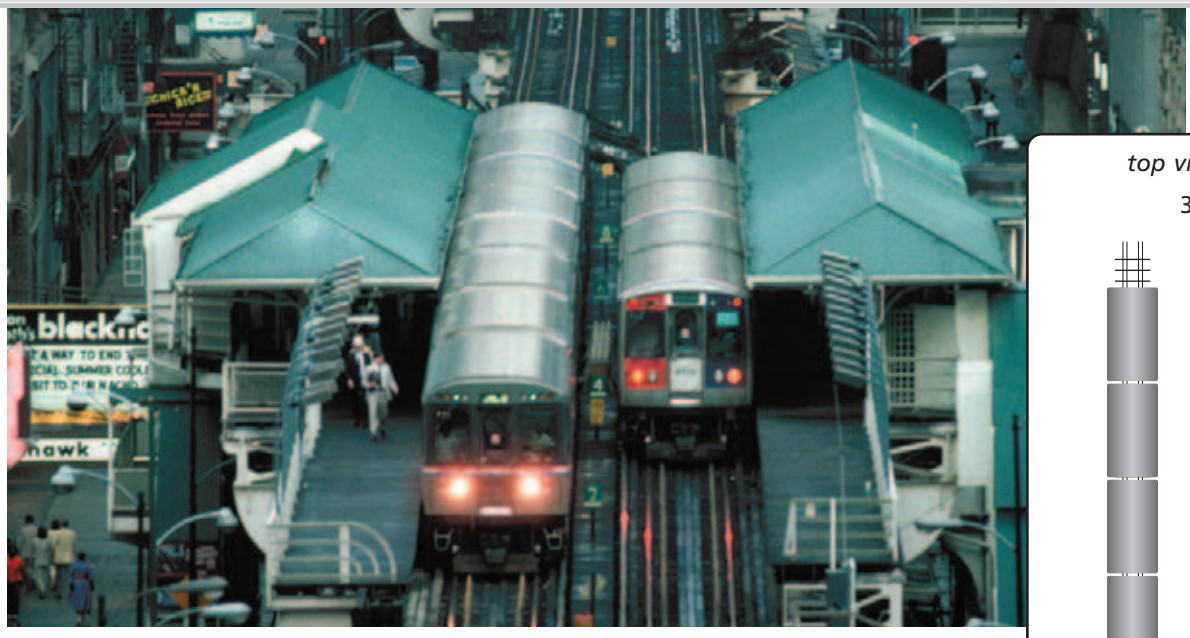
To determine the velocity of an ant as it carries a leaf, you need to know both its speed and its direction. A change in either speed or direction results in a change in velocity. For example, the velocity of an ant changes if it slows down but continues moving in the same direction. Velocity also changes if the ant continues moving at the same speed but changes direction.

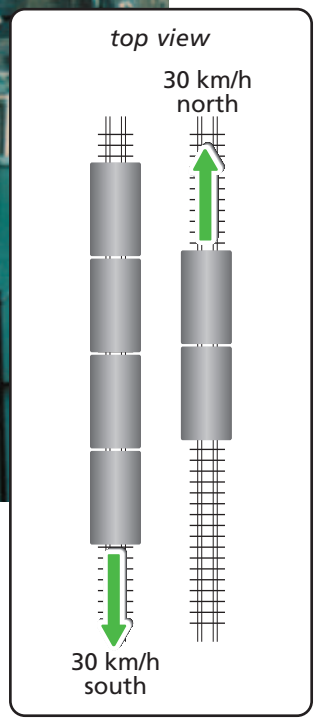
Velocity is an example of a vector. A **vector** is a quantity that has both size and direction. Speed is not a vector because speed is a measure of how fast or slow an object moves, not which direction it moves in. Velocity, however, has a size—the speed—and a direction, so it is a vector quantity.

READING TiP
Green arrows show velocity.
A longer arrow indicates a faster speed than a shorter arrow. The direction of the arrow indicates the direction of motion.



INFER How does this ant's velocity compare with those of the other ants?





INFER How do the speeds and velocities of these trains compare?

Velocity Versus Speed

Because velocity includes direction, it is possible for two objects to have the same speed but different velocities. If you traveled by train to visit a friend, you might go 30 kilometers per hour (km/h) north on the way there and 30 km/h south on the way back. Your speed is the same both going and coming back, but your velocity is different because your direction of motion has changed.

Another difference between speed and velocity is the way the average is calculated. Your average speed depends on the total distance you have traveled. The average velocity depends on the total distance you are from where you started. Going north, your average speed would be 30 km/h, and your average velocity would be 30 km/h north. After the round-trip ride, your average traveling speed would still be 30 km/h. Your average velocity, however, would be 0 km/h because you ended up exactly where you started.

CHECK YOUR READING Use a Venn diagram to compare and contrast speed and velocity.

1.2 Review

KEY CONCEPTS

1. How is speed related to distance and time?
2. How would decreasing the time it takes you to run a certain distance affect your speed?
3. What two things do you need to know to describe the velocity of an object?

CRITICAL THINKING

4. **Compare** Amy and Ellie left school at the same time. Amy lives farther away than Ellie, but she and Ellie arrived at their homes at the same time. Compare the girls' speeds.
5. **Calculate** Carlos lives 100 m away from his friend's home. What is his average speed if he reaches his friend's home in 50 s?

CHALLENGE

6. **Synthesize** If you watch a train go by at 20 m/s, at what speed will the people sitting on the train be moving relative to you? Would someone walking toward the back of the train have a greater or lesser speed relative to you? Explain.