1 FOCUS

Objectives

11.2.1 **Identify** appropriate SI units for measuring speed.
11.2.2 **Compare** and **contrast** average speed and instantaneous speed.
11.2.3 **Interpret** distance-time graphs.
11.2.4 **Calculate** the speed of an object using slopes.
11.2.5 **Describe** how velocities combine.

Reading Focus

Build Vocabulary L2

Venn Diagram Have students draw a Venn diagram to show how the key terms of the section are related to each other. Student diagrams should show circles labeled Speed and Direction. The area in which the circles overlap should be labeled Velocity.

Reading Strategy L2

Answers may vary. Sample answers are shown below.
a. Average speed is distance divided by time. **b.** I could use this to calculate various speeds, like the average speed at which I travel getting to school. **c.** Instantaneous speed is different from average speed **d.** You can't use a single speedometer reading to determine how long a trip will take. **e.** Velocity is not the same as speed. **f.** This could be useful in giving directions or in describing the path that you take on a walk.

2 INSTRUCT

Speed

Build Science Skills L2

Forming Operational Definitions An operational definition limits the meaning of a term to what is observed or measured in a particular situation. Ask, **What is an operational definition of speed for a skater on a circular track?** *(Sample answer: The amount of time it takes to circle the track one time, the number of times the skater could circle the track one time)* **What is an operational definition for a person walking down a street?** *(Sample answer: The number of meters traveled each second)*
Verbal, Logical

11.2 Speed and Velocity

Reading Focus

Key Concepts

- How are instantaneous speed and average speed different?
- How can you find the speed from a distance-time graph?
- How are speed and velocity different?
- How do velocities add?

Vocabulary

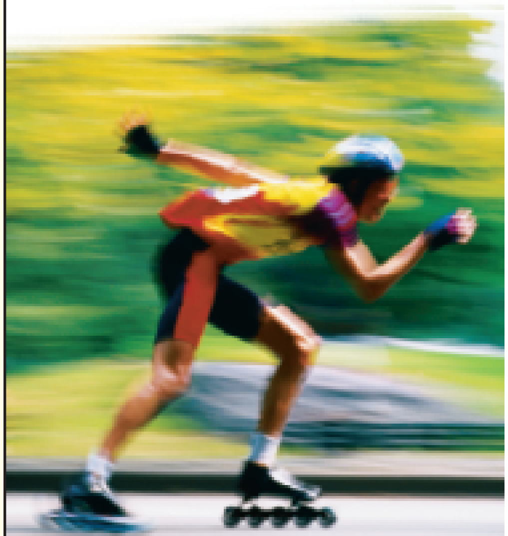
- speed
- average speed
- instantaneous speed
- velocity

Reading Strategy

Monitoring Your Understanding After you have finished reading this section, copy the table below. Identify several things you have learned that are relevant to your life. Explain why they are relevant to you.

What Is Relevant	Why It Is Relevant
a. ?	b. ?
c. ?	d. ?
e. ?	f. ?

Figure 5 The speed of an in-line skater is usually described in meters per second. The speed of a car is usually described in kilometers per hour.



Look out a window for a few minutes, and you will see things in motion. Some things are moving slowly. Perhaps you see a leaf floating through the air. Other things, such as a car or a bird, are moving fast. The growth rate of trees and grass is so slow that their motion cannot be detected with the unaided eye. The differences among these types of motion can be described in terms of speed.

Speed

To describe the speed of a car, you might say it is moving at 45 kilometers per hour. **Speed** is the ratio of the distance an object moves to the amount of time the object moves. The SI unit of speed is meters per second (m/s). However, just as with distances, you need to choose units that make the most sense for the motion you are describing. The in-line skater in Figure 5 may travel 2 meters in one second. The speed would be expressed as 2 m/s. A car might travel 80 kilometers in one hour. Its speed would be expressed as 80 km/h.

Two ways to express the speed of an object are average speed and instantaneous speed. **Average speed is computed for the entire duration of a trip, and instantaneous speed is measured at a particular instant.** In different situations, either one or both of these measurements may be a useful way to describe speed.

Section Resources

Print
- ***Laboratory Manual,*** Investigation 11B
- ***Reading and Study Workbook With Math Support,*** Section 11.2 and **Math Skill:** Interpreting a Distance-Time Graph
- ***Math Skills and Problem Solving Workbook,*** Section 11.2
- ***Transparencies,*** Section 11.2

Technology
- ***Interactive Textbook,*** Section 11.2
- ***Presentation Pro CD-ROM,*** Section 11.2
- ***Go Online,*** NSTA SciLinks, Motion; PHSchool.com, Data sharing

Average Speed Describing the speed of a hiker isn't as easy as describing constant speed along a straight line. A hiker may travel slowly along rocky areas but then travel quickly when going downhill. Sometimes it is useful to know how fast something moves for an entire trip. **Average speed,** $\bar{v}$, is the total distance traveled, *d*, divided by the time, *t*, it takes to travel that distance. This can be written as an equation:

Average Speed

$$\text{Average speed} = \frac{\text{Total distance}}{\text{Total time}}, \text{ or } \bar{v} = \frac{d}{t}$$

During the time an object is moving, its speed may change, but this equation tells you the average speed over the entire trip.

Go Online NSTA SCILINKS

For: Links on motion
Visit: www.SciLinks.org
Web Code: ccn-2112

Math Skills

Calculating Average Speed

While traveling on vacation, you measure the times and distances traveled. You travel 35 kilometers in 0.4 hour, followed by 53 kilometers in 0.6 hour. What is your average speed?

1 Read and Understand

What information are you given?

Total Distance $(d) = 35 \text{ km} + 53 \text{ km} = 88 \text{ km}$

Total Time $(t) = 0.4 \text{ h} + 0.6 \text{ h} = 1.0 \text{ h}$

2 Plan and Solve

What unknown are you trying to calculate?

Average Speed $(\bar{v}) = ?$

What formula contains the given quantities and the unknown?

$$\bar{v} = \frac{d}{t}$$

Replace each variable with its known value.

$$\bar{v} = \frac{88 \text{ km}}{1 \text{ h}} = 88 \text{ km/h}$$

3 Look Back and Check

Is your answer reasonable?

Yes, 88 km/h is a typical highway speed.

Math Practice

1. A person jogs 4.0 kilometers in 32 minutes, then 2.0 kilometers in 22 minutes, and finally 1.0 kilometer in 16 minutes. What is the jogger's average speed in kilometers per minute?
2. A train travels 190 kilometers in 3.0 hours, and then 120 kilometers in 2.0 hours. What is its average speed?

Go Online PLANETDIARY

For: Activity on the movement of Earth's plates
Visit: PHSchool.com
Web Code: ccc-2112

Math Practice

Solutions L2

1. $\bar{v}$ = (4.0 km + 2.0 km + 1.0 km)/(32 min + 22 min + 16 min) = (7.0 km)/(70 min) = 0.10 km/min
2. $\bar{v}$ = (190 km + 120 km)/(3.0 h + 2.0 h) = (310 km)/(5.0 h) = 62 km/h
Logical

For Extra Help L1

Remind students that all the values they plug into the equation must have appropriate units. They may have to convert some of the given units. Also remind students that the equation can be rearranged to solve for other variables. Show them how to rearrange to solve for *d* or *t*. **Logical**`

Direct students to the **Math Skills** in the **Skills and Reference Handbook** at the end of the student text for additional help.

Additional Problems

1. A car travels 85 km from Town A to Town B, then 45 km from Town B to Town C. The total trip took 1.5 hours. What was the average speed of the car? *(87 km/h)*
2. A bicyclist travels for 1.5 hours at an average speed of 32 km/h. How far does the bicyclist travel in that time? *(48 km)*
Logical, Portfolio

Use Community Resources L2

Have students contact their local or state department of transportation to find out about laws or guidelines for the assignments of speed limits. They may ask, "Are there specific maximum speed limits for residential areas?" or "What is the maximum speed limit for highways outside of city limits?" They may also ask the department representative what other factors are used in determining speed limits.
Interpersonal, Portfolio

Customize for English Language Learners

Create a Word Wall
Students can relate the concepts in this section to the vocabulary words by creating a word wall. Write the words *speed, average speed, instantaneous speed,* and *velocity* on the board. Then, as students work through the section, ask them to define each word in their own terms. Discuss their definitions and write acceptable definitions on the board next to each word. Students may also draw a graph or paste a magazine picture next to the corresponding word.

Go Online NSTA SCILINKS

Download a worksheet on motion for students to complete, and find additional teacher support from NSTA SciLinks.

Section 11.2 (continued)

Graphing Motion

Teacher Demo

Ticker Tape Car L2

Purpose Students observe a technique that visually records motion.

Materials toy car, ticker tape, ticker timer (acceleration timer), masking tape

Procedure Place the car and the ticker on the ground in an open area. Thread the ticker tape through the ticker, then attach the ticker tape to the car with masking tape. Before you perform the demonstration, show the setup to the students and explain how the ticker works (the ticker marks the ticker tape at regular time intervals). Ask, **How will the marks appear on the tape when the car is moving at a constant speed?** *(The marks will be evenly spaced.)* Start the ticker and give the car a quick push. Turn off the ticker and cut off the used portion of the ticker tape. Have the students gather around the ticker tape and relate the marks on the ticker tape to the motion of the car that they observed.

Expected Outcome At first, the marks on the tape will be unevenly spaced (getting farther apart) because the car is accelerating. As the car slows down, the marks will get closer together again. When the car is at rest, many marks will be superimposed. If possible, demonstrate the car moving at a constant speed. When the car is moving at constant speed, the marks will be evenly spaced on the ticker tape. As an alternative, you can use probeware to plot the car's motion on a computer or graphing calculator, and then relate the graphs to the motion of the car.
Kinesthetic, Logical

Build Science Skills L2

Analyzing Data Use Figures 7A and 7B to demonstrate that speed is shown by the slope of the line on a distance-time graph. For Figure 7A, calculate the slope of the line on the board:

slope = rise/run = $(y_2 - y_1)/(x_2 - x_1)$
= (350 m − 100 m)/(14 s − 4 s)
= (250 m)/(10 s)
= 25 m/s

Then, have students calculate the speed represented by the three distinct portions on the graph in Figure 7C. *(25 m/s, 0 m/s, 37.5 m/s)*
Visual, Logical

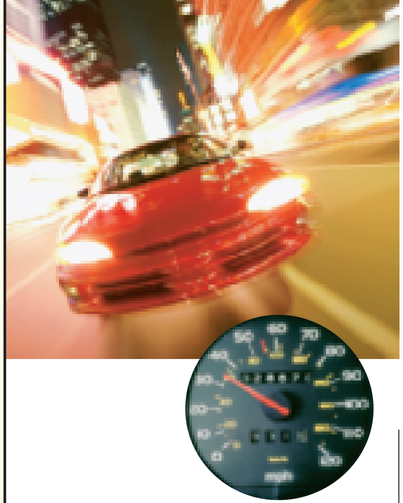


Figure 6 The speedometer in a car measures the car's instantaneous speed. Note the scale markings are given both in km/h and miles per hour, mph.

Instantaneous Speed Average speed is useful because it lets you know how long a trip will take. Sometimes however, such as when driving on the highway, you need to know how fast you are going at a particular moment. The car's speedometer gives your instantaneous speed. **Instantaneous speed,** *v*, is the rate at which an object is moving at a given moment in time. For example, you could describe the instantaneous speed of the car in Figure 6 as 55 km/h.

Reading Checkpoint ***What does a car's speedometer measure?***

Graphing Motion

A distance-time graph is a good way to describe motion. Figure 7 shows distance-time graphs for the motion of three cars. Recall that slope is the change in the vertical axis value divided by the change in the horizontal axis value. On these graphs, the slope is the change in the distance divided by the change in time. **The slope of a line on a distance-time graph is speed.** In Figure 7A, the car travels 500.0 meters in 20.0 seconds, or 25.0 meters per second. In Figure 7B, another car travels 250.0 meters in 20.0 seconds at a constant speed. The slope of the line is 250.0 meters divided by 20.0 seconds, or 12.5 meters per second. Notice that the line for the car traveling at a higher speed is steeper. A steeper slope on a distance-time graph indicates a higher speed.

Figure 7C shows the motion of a car that is not traveling at a constant speed. This car travels 200.0 meters in the first 8.0 seconds. It then stops for 4.0 seconds, as indicated by the horizontal part of the line. Next the car travels 300.0 meters in 8.0 seconds. The times when the car is gradually increasing or decreasing its speed are shown by the curved parts of the line. The slope of the straight portions of the line represent periods of constant speed. Note that the car's speed is 25 meters per second during the first part of its trip and 38 meters per second during the last part of its trip.

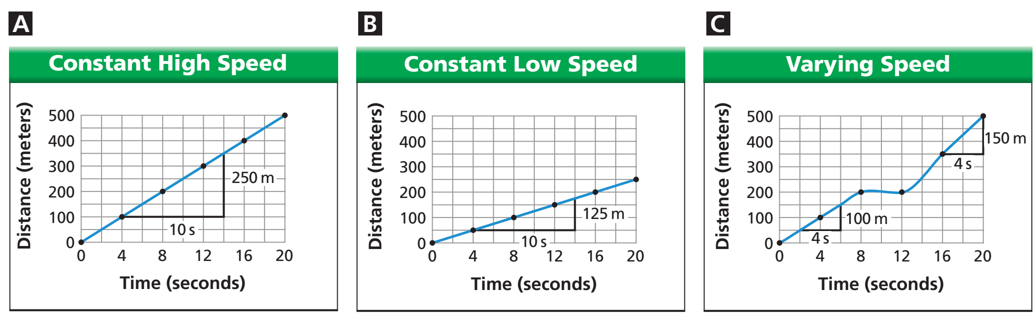


Figure 7 The slope of the line on a distance–time graph indicates the speed of the object. Using Graphs ***If the car in Figure 7A required less time to travel a given distance, how would the slope change?***

Facts and Figures

Speed Records According to the Guinness World Records, the fastest human sprinter is Tim Montgomery, who set a record of 100 m in 9.78 s in 2002. Fred Rompelberg set a record for the fastest speed on a bicycle when he rode 268.831 km/h (167.043 mph) in 1995. In 1972, the fastest recorded wind speed was clocked at 333 km/h (207 mph) in Thule, Greenland. The fastest speed in the universe is the speed of light. Light travels in a vacuum at 3.00×10^8 m/s (186,000 miles/second).

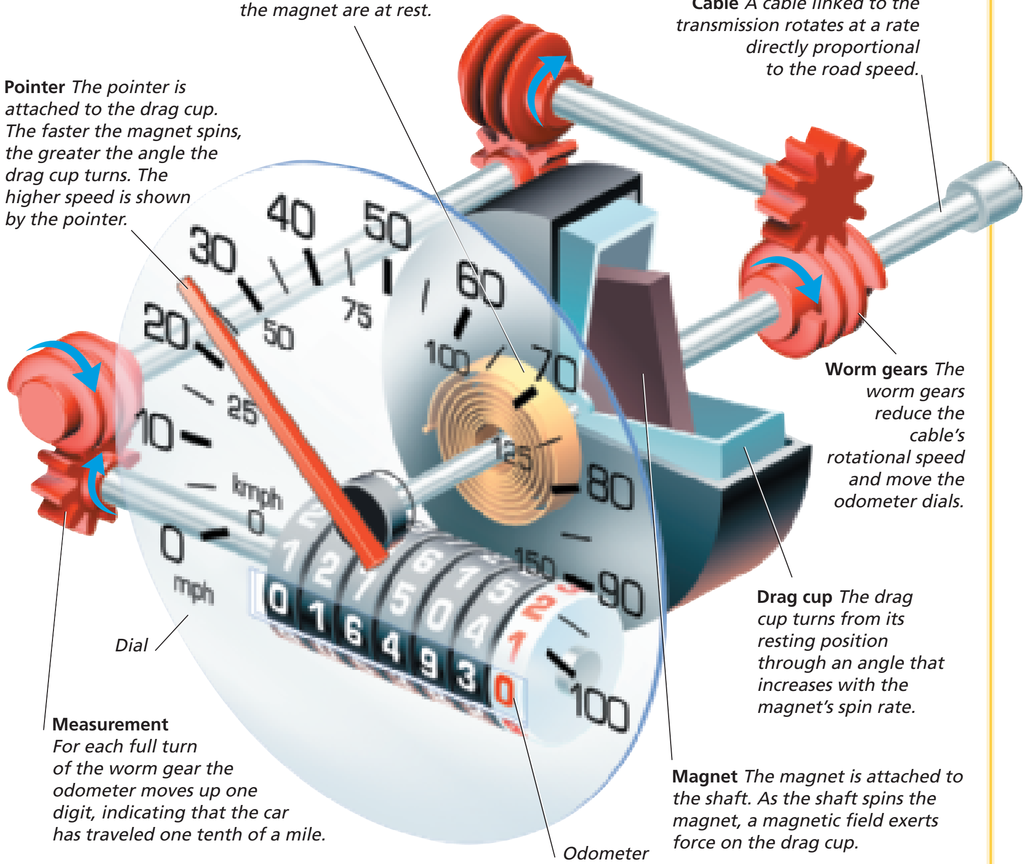
HOW It Works

Measuring Distance and Speed

Every car has a speedometer, which measures the car's speed, and an odometer, which measures the distance it has traveled. These devices work by counting the number of times the car's wheels turn (to give distance) and their rate of turning (speed).

Interpreting Diagrams ***What is the purpose of the worm gears?***

Digital Odometer
Some cars have a magnetic sensor that detects turns of the transmission shaft. The signal is transmitted to a computer, which calculates and displays the car's distance traveled.



HOW It Works

Measuring Distance and Speed **L2**

The speedometer is an important part of any car. Knowing the speed of the car is important for following safety cautions on road signs.

By law, all cars must have a working odometer. It is against the law to change odometer readings or to operate a car in which the odometer is not working. The law prevents people from "rolling back" the odometers in order to increase the resale value of the car.

Interpreting Diagrams The worm gears convert the rotation of the cable into a much slower rotation that turns the odometer. The worm gears also change the direction of rotation so the shafts can be positioned to align with the odometer.
Logical, Visual

For Enrichment **L3**

Have students use a library or the Internet to research how speeds are measured on ships, airplanes, or spacecraft. Have them write a paragraph explaining their findings.
Verbal, Portfolio

Answer to . . .

Figure 7 *The slope of the line would increase.*

Reading Checkpoint *Instantaneous speed*

Velocity

Build Reading Literacy

L1

Compare and Contrast Refer to page **226D** in **Chapter 8,** which provides guidelines for comparing and contrasting.

Have students compare and contrast speed and velocity. Ask students, **How are speed and velocity similar?** *(They both measure how fast something is moving.)* **How are speed and velocity different?** *(Velocity includes the direction of motion, while speed does not.)* **Is velocity more like distance or displacement? Why?** *(Velocity is more like displacement. Both velocity and displacement are vectors, including magnitude and direction.)*
Logical

Address Misconceptions

L2

Students may think that an object's speed and its velocity are the same thing. On the board, draw a picture of an oval racetrack. Have students imagine a racecar traveling at a constant speed of 120 km/h around the track. Point to a place on the track where the car would be moving to the right. Ask students, **What is the speed of the racecar at this point?** *(120 km/h)* **In what direction is the racecar traveling at this point?** *(To the right)* **What is the velocity of the racecar at this point?** *(120 km/h to the right)* Now point to a point on the track where the car would be moving to the left. Ask students, **What is the speed of the racecar at this point?** *(120 km/h)* **In what direction is the racecar traveling at this point?** *(To the left)* **What is the velocity of the racecar at this point?** *(120 km/h to the left)* The speeds are the same at each point, but the velocities are different because the racecar is traveling in different directions.
Verbal, Visual

Figure 8 A cheetah's speed may be as fast as 90 km/h. To describe the cheetah's velocity, you must also know the direction in which it is moving.

Velocity

The cheetah is the fastest land animal in the world. Suppose a cheetah, running at 90 kilometers per hour, is 30 meters from an antelope that is standing still. How long will it be before the cheetah reaches the antelope? Do you have enough information to answer the question? The answer is no. Sometimes knowing only the speed of an object isn't enough. You also need to know the direction of the object's motion. Together, the speed and direction in which an object is moving are called **velocity.** To determine how long it will be before the cheetah reaches the antelope, you need to know the cheetah's velocity, not just its speed. **Velocity is a description of both speed and direction of motion. Velocity is a vector.**

Figure 8 shows a cheetah in motion. If you have ever seen a video of a cheetah chasing its prey, you know that a cheetah can change speed and direction very quickly. To represent the cheetah's motion, you could use velocity vectors. You would need vectors of varying lengths, each vector corresponding to the cheetah's velocity at a particular instant. A longer vector would represent a faster speed, and a shorter one would show a slower speed. The vectors would also point in different directions to represent the cheetah's direction at any moment.

A change in velocity can be the result of a change in speed, a change in direction, or both. The sailboat in Figure 9 moves in a straight line (constant direction) at a constant speed. The sailboat can be described as moving with uniform motion, which is another way of saying it has constant velocity. The sailboat may change its velocity simply by speeding up or slowing down. However, the sailboat's velocity also changes if it changes its direction. It may continue to move at a constant speed, but the change of direction is a change in velocity.

Figure 9 As the sailboat's direction changes, its velocity also changes, even if its speed stays the same. **Inferring** ***If the sailboat slows down at the same time that it changes direction, how will its velocity be changed?***

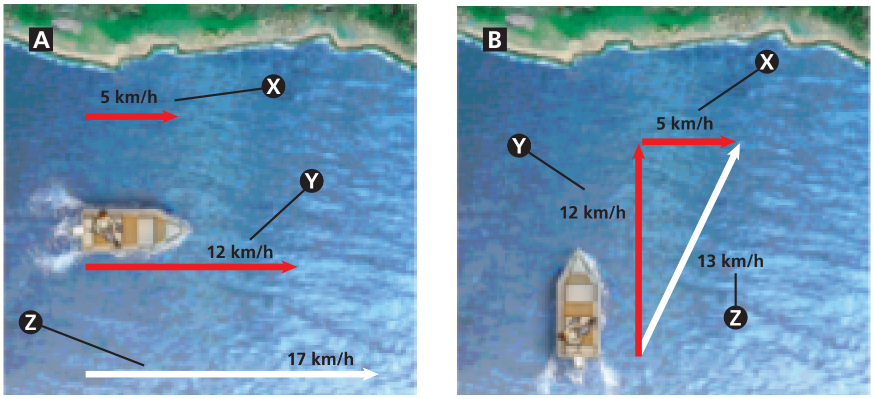


Figure 10 Vector addition is used when motion involves more than one velocity. **A** The velocity of the boat in the reference frame of the riverbank (17 km/h) is a combination of the relative velocities of the boat and the river. **B** You can determine the resultant velocity of the boat relative to the riverbank (13 km/h) by measuring from the tail of one vector to the head of the other.

Combining Velocities

Sometimes the motion of an object involves more than one velocity. **Two or more velocities add by vector addition.** The velocity of the river relative to the riverbank (X) and the velocity of the boat relative to the river (Y) in Figure 10A combine. They yield the velocity of the boat relative to the riverbank (Z). This velocity is 17 kilometers per hour downstream.

In Figure 10B, the relative velocities of the current (X) and the boat (Y) are at right angles to each other. Adding these velocity vectors yields a resultant velocity of the boat relative to the riverbank of 13 km/h (Z). Note that this velocity is at an angle to the riverbank.

Section 11.2 Assessment

Reviewing Concepts

1. What does velocity describe?
2. What shows the speed on a distance-time graph?
3. What is the difference between average speed and instantaneous speed?
4. How can two or more velocities be combined?

Critical Thinking

5. **Applying Concepts** Does a car's speedometer show instantaneous speed, average speed, or velocity? Explain.
6. **Designing Experiments** Describe an experiment you could perform to determine the average speed of a toy car rolling down an incline.
7. **Applying Concepts** Explain why the slope on a distance-time graph is speed. (*Hint:* Use the definition of *speed* on page 332 and the graphs in Figure 7.)

Math Practice

8. An Olympic swimmer swims 50.0 meters in 23.1 seconds. What is his average speed?
9. A plane's average speed between two cities is 600 km/h. If the trip takes 2.5 hours, how far does the plane fly? (*Hint:* Use the average speed formula in the form $d = \bar{v}t$.)

Combining Velocities

Use Visuals L1

Figure 10 Figure 10B shows two velocity vectors at right angles combining to form a single vector. You can use this opportunity to show students how to find the magnitude of resultant vectors.

Start by reminding students of the Pythagorean theorem:

$$a^2 + b^2 = c^2$$

for right triangles in which *a* and *b* are the legs and *c* is the hypotenuse. In this case, *a* is the speed of the boat, *b* is the speed of the river, and *c* is the resulting combined speed.
Do the following calculation on the board:

$$c = \sqrt{a^2 + b^2}$$
$$= \sqrt{(12\ km/h)^2 + (5\ km/h)^2}$$
$$= \sqrt{144\ km^2/h^2 + 25\ km^2/h^2}$$
$$= \sqrt{169\ km^2/h^2}$$
$$= 13\ km/h$$

When you have finished the calculation, point out that the result agrees with the speed shown in Figure 10B.
Visual, Logical

3 ASSESS

Evaluate Understanding L2

Ask students to write a paragraph describing how they could measure the average speed of a racecar on a racetrack. Also have them draw the velocity vectors at several locations for a racecar traveling at a constant speed around a circular track.

Reteach L1

Use the graphs in Figure 7 to reteach the concepts in the section.

Math Practice

Solutions L2
8. $\bar{v}$ = (50.0 m)/(23.1 s) = 2.16 m/s
9. $d = \bar{v}t$ = (600 km/h)(2.5 h) = 1500 km

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 11.2.

Answer to . . .

Figure 9 *Both the magnitude and direction of the velocity will change.*

Section 11.2 Assessment

1. Velocity describes both speed and direction of motion.
2. The slope of a line on a distance-time graph is equal to speed.
3. Average speed is calculated for the entire duration of a trip, whereas instantaneous speed is determined at a single moment.
4. Two or more velocities can be combined by vector addition.
5. A speedometer measures speed at the current moment, so it shows instantaneous speed, not average speed. Because a speedometer does not show direction it does not show velocity.
6. Students may describe how they could use a stopwatch to measure the time for the car to travel down the incline. The average speed would be calculated by dividing the distance traveled by the total time.
7. Slope is equal to the change in vertical value divided by the change in horizontal value. On a distance-time graph, the change in vertical value is a distance and the change in horizontal value is a time. Therefore, the slope is distance divided by time, which equals average speed.