Representing Motion

What You'll Learn

- You will represent motion through the use of words, motion diagrams, and graphs.
- You will use the terms *position, distance, displacement,* and *time interval* in a scientific manner to describe motion.

Why It's Important

Without ways to describe and analyze motion, travel by plane, train, or bus would be chaotic at best. Times and speeds determine the winners of races as well as transportation schedules.

Running a Marathon As one runner passes another, the speed of the overtaking runner is greater than the speed of the other runner.

Think About This ▶

How can you represent the motion of two runners?

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LAUNCH Lab
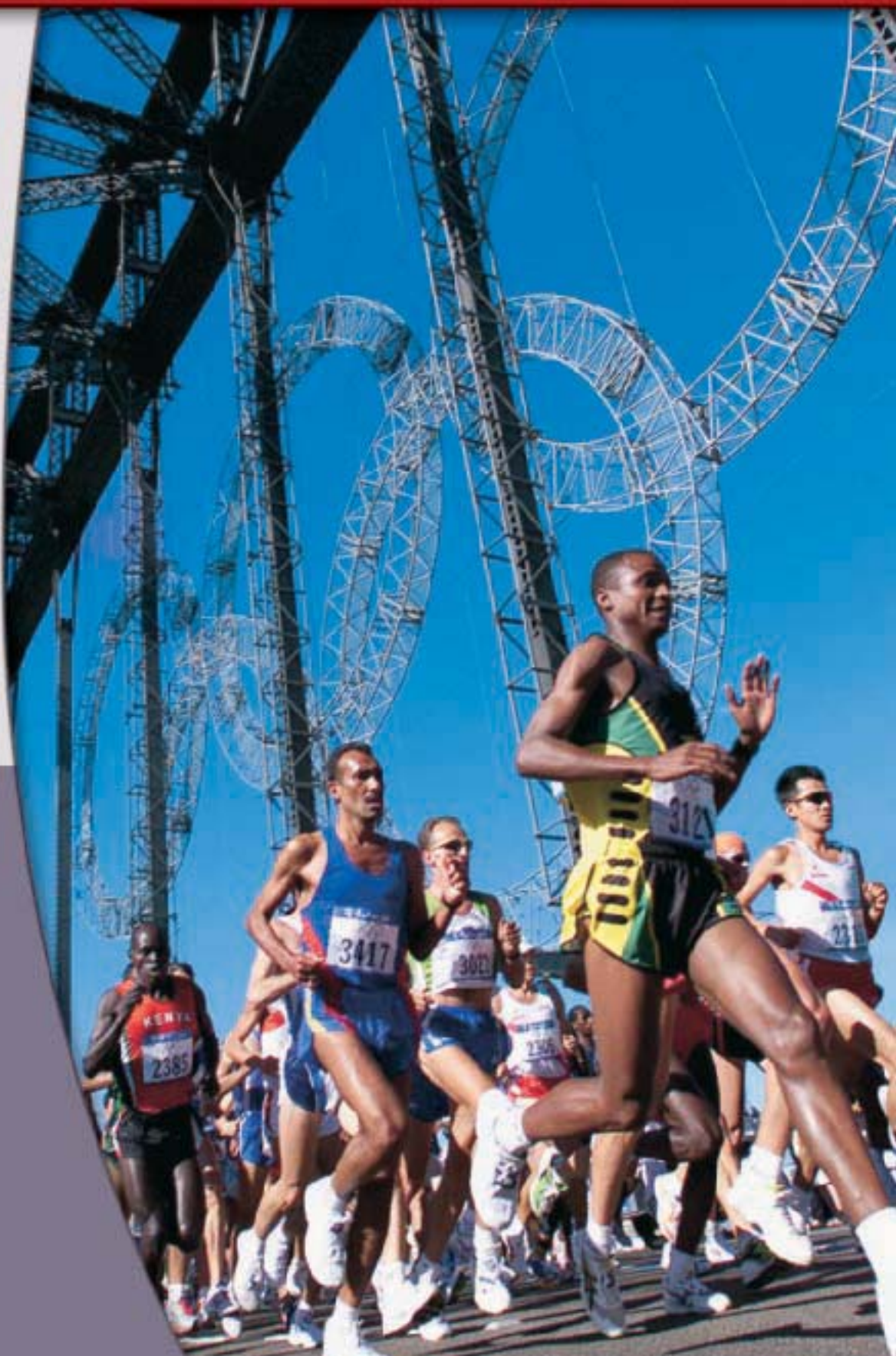
Which car is faster?

Question

In a race between two toy cars, can you explain which car is faster?

Procedure

1. Obtain two toy cars, either friction cars or windup cars. Place the cars on your lab table or other surface recommended by your teacher.
2. Decide on a starting line for the race.
3. Release both cars from the same starting line at the same time. Note that if you are using windup cars, you will need to wind them up before you release them. Be sure to pull the cars back before release if they are friction cars.
4. **Observe** Watch the two cars closely as they move and determine which car is moving faster.
5. Repeat steps 1–3, but this time collect one type of data to support your conclusion about which car is faster.

Analysis

What data did you collect to show which car was moving faster? What other data could you collect to determine which car is faster?

Critical Thinking Write an operational definition of average speed.

2.1 Picturing Motion

In the previous chapter, you learned about the scientific processes that will be useful in your study of physics. In this chapter, you will begin to use these tools to analyze motion. In subsequent chapters, you will apply them to all kinds of movement using sketches, diagrams, graphs, and equations. These concepts will help you to determine how fast and how far an object will move, whether the object is speeding up or slowing down, and whether it is standing still or moving at a constant speed. Perceiving motion is instinctive—your eyes naturally pay more attention to moving objects than to stationary ones. Movement is all around you—from fast trains and speedy skiers to slow breezes and lazy clouds. Movements travel in many directions, such as the straight-line path of a bowling ball in a lane's gutter, the curved path of a tether ball, the spiral of a falling kite, and the swirls of water circling a drain.

▶ **Objectives**
- **Draw** motion diagrams to describe motion.
- **Develop** a particle model to represent a moving object.

▶ **Vocabulary**

motion diagram
particle model

All Kinds of Motion

What comes to your mind when you hear the word *motion?* A speeding automobile? A spinning ride at an amusement park? A baseball soaring over a fence for a home run? Or a child swinging back and forth in a regular rhythm? When an object is in motion, as shown in **Figure 2-1,** its position changes. Its position can change along the path of a straight line, a circle, an arc, or a back-and-forth vibration.

Some of the types of motion described above appear to be more complicated than others. When beginning a new area of study, it is generally a good idea to begin with what appears to be the least complicated situation, learn as much as possible about it, and then gradually add more complexity to that simple model. In the case of motion, you will begin your study with movement along a straight line.

Movement along a straight line Suppose that you are reading this textbook at home. At the beginning of Chapter 2, you glance over at your pet hamster and see that he is sitting in a corner of his cage. Sometime later, you look over again, and you see that he now is sitting by the food dish in the opposite corner of the cage. You can infer that he has moved from one place to another in the time in between your observations. Thus, a description of motion relates to place and time. You must be able to answer the questions of where and when an object is positioned to describe its motion. Next, you will look at some tools that are useful in determining when an object is at a particular place.

■ **Figure 2-1** An object in motion changes its position as it moves. In this photo, the camera was focused on the rider, so the blurry background indicates that the rider's position has changed.

Motion Diagrams

Consider an example of straight-line motion: a runner is jogging along a straight path. One way of representing the motion of the runner is to create a series of images showing the positions of the runner at equal time intervals. This can be done by photographing the runner in motion to obtain a series of images.

Suppose you point a camera in a direction perpendicular to the direction of motion, and hold it still while the motion is occurring. Then you take a series of photographs of the runner at equal time intervals. **Figure 2-2** shows what a series of consecutive images for a runner might look like. Notice that the runner is in a different position in each image, but everything in the background remains in the same position. This indicates that, relative to the ground, only the runner is in motion. What is another way of representing the runner's motion?

CLICK HERE

Concepts In Motion

Interactive Figure To see an animation on motion diagrams versus particle motion, visit **physicspp.com**.

■ **Figure 2-2** If you relate the position of the runner to the background in each image over equal time intervals, you will conclude that she is in motion.

Suppose that you stacked the images from Figure 2-2, one on top of the other. **Figure 2-3** shows what such a stacked image might look like. You will see more than one image of the moving runner, but only a single image of the motionless objects in the background. A series of images showing the positions of a moving object at equal time intervals is called a **motion diagram.**

The Particle Model

Keeping track of the motion of the runner is easier if you disregard the movement of the arms and legs, and instead concentrate on a single point at the center of her body. In effect, you can disregard the fact that she has some size and imagine that she is a very small object located precisely at that central point. A **particle model** is a simplified version of a motion diagram in which the object in motion is replaced by a series of single points. To use the particle model, the size of the object must be much less than the distance it moves. The internal motions of the object, such as the waving of the runner's arms are ignored in the particle model. In the photographic motion diagram, you could identify one central point on the runner, such as a dot centered at her waistline, and take measurements of the position of the dot. The bottom part of Figure 2-3 shows the particle model for the runner's motion. You can see that applying the particle model produces a simplified version of the motion diagram. In the next section, you will learn how to create and use a motion diagram that shows how far an object moved and how much time it took to move that far.

■ **Figure 2-3** Stacking a series of images taken at regular time intervals and combining them into one image creates a motion diagram for the runner for one portion of her run. Reducing the runner's motion to a series of single points results in a particle model of her motion.

2.1 Section Review

1. **Motion Diagram of a Runner** Use the particle model to draw a motion diagram for a bike rider riding at a constant pace.

2. **Motion Diagram of a Bird** Use the particle model to draw a simplified motion diagram corresponding to the motion diagram in **Figure 2-4** for a flying bird. What point on the bird did you choose to represent it?

■ **Figure 2-4**

3. **Motion Diagram of a Car** Use the particle model to draw a simplified motion diagram corresponding to the motion diagram in **Figure 2-5** for a car coming to a stop at a stop sign. What point on the car did you use to represent it?

■ **Figure 2-5**

4. **Critical Thinking** Use the particle model to draw motion diagrams for two runners in a race, when the first runner crosses the finish line as the other runner is three-fourths of the way to the finish line.

Hutchings Photography

2.2 Where and When?

Would it be possible to take measurements of distance and time from a motion diagram, such as the motion diagram of the runner? Before taking the photographs, you could place a meterstick or a measuring tape on the ground along the path of the runner. The measuring tape would tell you where the runner was in each image. A stopwatch or clock within the view of the camera could tell the time. But where should you place the end of the measuring tape? When should you start the stopwatch?
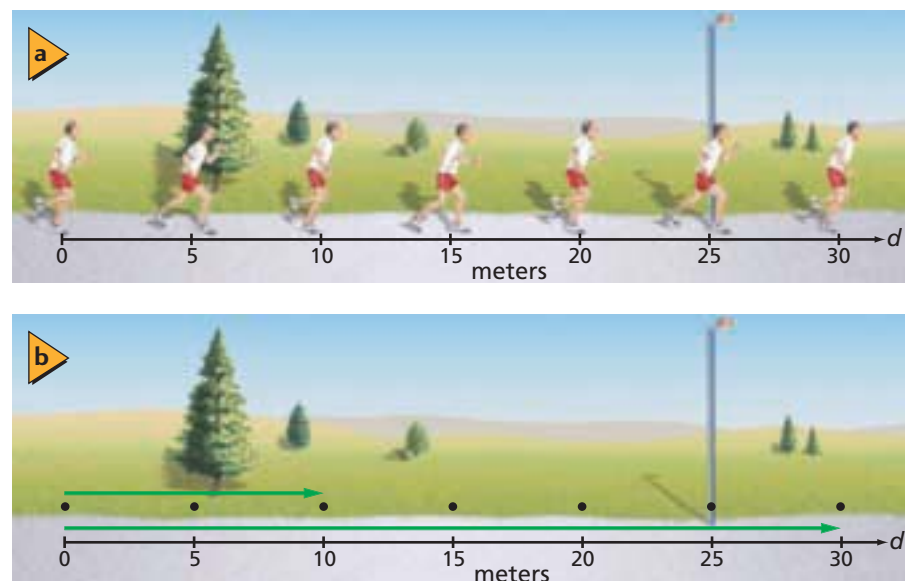
Coordinate Systems

When you decide where to place the measuring tape and when to start the stopwatch, you are defining a **coordinate system,** which tells you the location of the zero point of the variable you are studying and the direction in which the values of the variable increase. The **origin** is the point at which both variables have the value zero. In the example of the runner, the origin, represented by the zero end of the measuring tape, could be placed 6 m to the left of the tree. The motion is in a straight line; thus, your measuring tape should lie along that straight line. The straight line is an axis of the coordinate system. You probably would place the tape so that the meter scale increases to the right of the zero, but putting it in the opposite direction is equally correct. In **Figure 2-6a,** the origin of the coordinate system is on the left.

You can indicate how far away the runner is from the origin at a particular time on the simplified motion diagram by drawing an arrow from the origin to the point representing the runner, as shown in **Figure 2-6b.** This arrow represents the runner's **position,** the separation between an object and the origin. The length of the arrow indicates how far the object is from the origin, or the object's **distance** from the origin. The arrow points from the origin to the location of the moving object at a particular time.


■ **Figure 2-6** In these motion diagrams, the origin is at the left **(a),** and the positive values of distance extend horizontally to the right. The two arrows, drawn from the origin to points representing the runner, locate his position at two different times **(b).**

Is there such a thing as a negative position? Suppose you chose the coordinate system just described, placing the origin 4 m left of the tree with the d-axis extending in a positive direction to the right. A position 9 m to the left of the tree, 5 m left of the origin, would be a negative position, as shown in **Figure 2-7.** In the same way, you could discuss a time before the stopwatch was started.
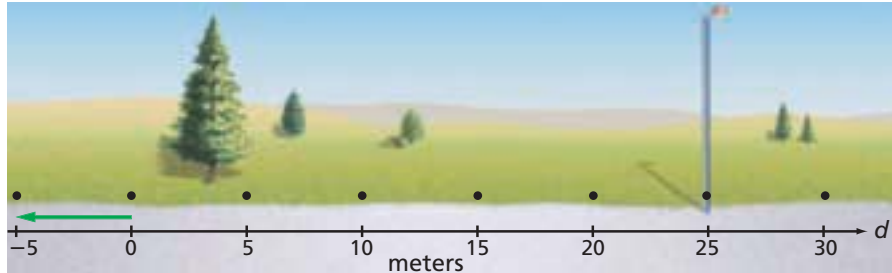

■ **Figure 2-7** The arrow drawn on this motion diagram indicates a negative position.

Vectors and scalars Quantities that have both size, also called **magnitude,** and direction, are called **vectors,** and can be represented by arrows. Quantities that are just numbers without any direction, such as distance, time, or temperature, are called **scalars.** This textbook will use boldface letters to represent vector quantities and regular letters to represent scalars.

You already know how to add scalars; for example, $0.6 + 0.2 = 0.8$. How do you add vectors? Think about how you would solve the following problem. Your aunt asks you to get her some cold medicine at the store nearby. You walk 0.5 km east from your house to the store, buy the cold medicine, and then walk another 0.2 km east to your aunt's house. How far from the origin are you at the end of your trip? The answer, of course, is 0.5 km east + 0.2 km east = 0.7 km east. You also could solve this problem graphically, using the following method.

Using a ruler, measure and draw each vector. The length of a vector should be proportional to the magnitude of the quantity being represented, so you must decide on a scale for your drawing. For example, you might let 1 cm on paper represent 0.1 km. The important thing is to choose a scale that produces a diagram of reasonable size with a vector that is about 5–10 cm long. The vectors representing the two segments that made up your trip to your aunt's house are shown in **Figure 2-8,** drawn to a scale of 1 cm, which represents 0.1 km. The vector that represents the total of these two, shown here with a dotted line, is 7 cm long. According to the established scale, you were 0.7 km from the origin at the end of your trip. The vector that represents the sum of the other two vectors is called the **resultant.** The resultant always points from the tail of the first vector to the tip of the last vector.
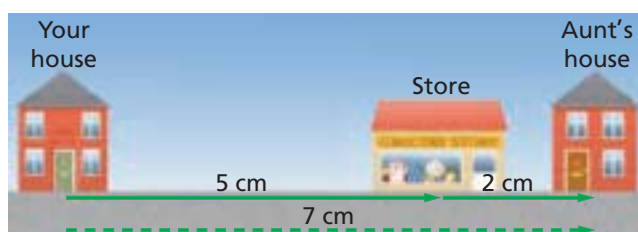
■ **Figure 2-8** Add two vectors by placing them tip to tail. The resultant points from the tail of the first vector to the tip of the last vector.

■ **Figure 2-9** You can see that it took the runner 4.0 s to run from the tree to the lamppost. The initial position of the runner is used as a reference point. The vector from position 1 to position 2 indicates both the direction and amount of displacement during this time interval.
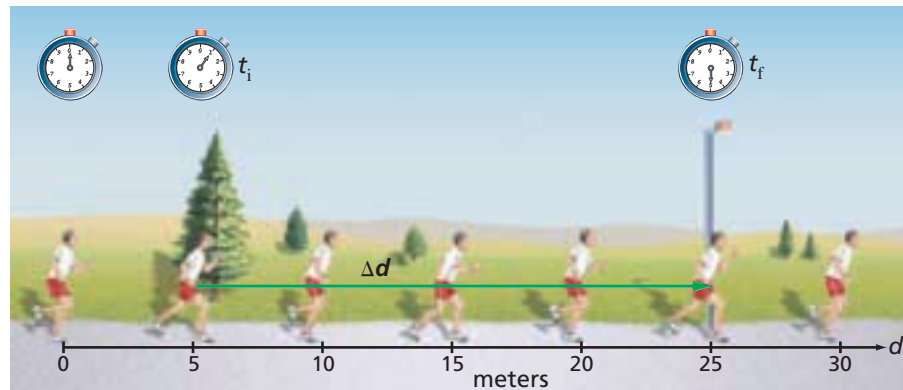
Time Intervals and Displacements

When analyzing the runner's motion, you might want to know how long it took the runner to travel from the tree to the lamppost. This value is obtained by finding the difference in the stopwatch readings at each position. Assign the symbol t_i to the time when the runner was at the tree and the symbol t_f to the time when he was at the lamppost. The difference between two times is called a **time interval.** A common symbol for a time interval is Δt, where the Greek letter delta, Δ, is used to represent a change in a quantity. The time interval is defined mathematically as follows.

> **Time Interval** $\Delta t = t_f - t_i$
>
> The time interval is equal to the final time minus the initial time.

Although i and f are used to represent the initial and final times, they can be the initial and final times of any time interval you choose. In the example of the runner, the time it takes for him to go from the tree to the lamppost is $t_f - t_i = 5.0 \text{ s} - 1.0 \text{ s} = 4.0 \text{ s}$. How did the runner's position change when he ran from the tree to the lamppost, as shown in **Figure 2-9?** The symbol **d** may be used to represent position. In common speech, a position refers to a place; but in physics, a position is a vector with its tail at the origin of a coordinate system and its tip at the place.

Figure 2-9 shows $\Delta \boldsymbol{d}$, an arrow drawn from the runner's position at the tree to his position at the lamppost. This vector represents his change in position, or **displacement,** during the time interval between t_i and t_f. The length of the arrow represents the distance the runner moved, while the direction the arrow points indicates the direction of the displacement. Displacement is mathematically defined as follows.
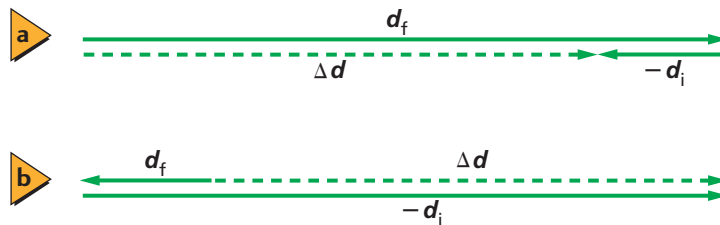
> **Displacement** $\Delta \boldsymbol{d} = \boldsymbol{d}_f - \boldsymbol{d}_i$
>
> Displacement is equal to the final position minus the initial position.

Again, the initial and final positions are the beginning and end of any interval you choose. Also, while position can be considered a vector, it is common practice when doing calculations to drop the boldface, and use signs and magnitudes. This is because position usually is measured from the origin, and direction typically is included with the position indication.

Color Convention

- Displacement vectors are shown in **green.**

■ **Figure 2-10** Start with two vectors, **A** and **B (a).** To subtract vector **B** from vector **A,** first reverse vector **B,** then add them together to obtain the resultant, **R (b).**
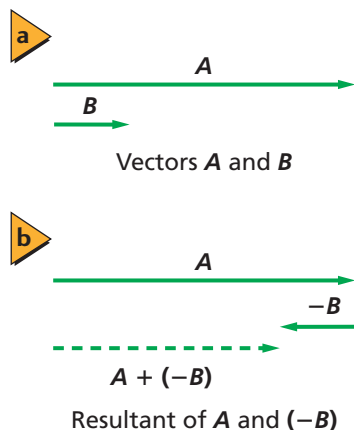
a

A

B

Vectors **A** and **B**

b

A

−B

A + (−B)

Resultant of **A** and **(−B)**

How do you subtract vectors? Reverse the subtracted vector and add. This is because $A - B = A + (-B)$. **Figure 2-10a** shows two vectors, A, 4 cm long pointing east, and B, 1 cm long also pointing east. **Figure 2-10b** shows $-B$, which is 1 cm long pointing west. Figure 2-10b shows the resultant of A and $-B$. It is 3 cm long pointing east.

To determine the length and direction of the displacement vector, $\Delta d = d_f - d_i$, draw $-d_i$, which is d_i reversed. Then draw d_f and copy $-d_i$ with its tail at d_f's tip. Add d_f and $-d_i$. In the example of the runner, his displacement is $d_f - d_i = 25.0 \text{ m} - 5.0 \text{ m} = 20.0 \text{ m}$. He moved to the right of the tree. To completely describe an object's displacement, you must indicate the distance it traveled and the direction it moved. Thus, displacement, a vector, is not identical to distance, a scalar; it is distance and direction.

What would happen if you chose a different coordinate system; that is, if you measured the position of the runner from another location? Look at Figure 2-9, and suppose you change the right side of the d-axis to be zero. While the vectors drawn to represent each position change, the length and direction of the displacement vector does not, as shown in **Figures 2-11a** and **b.** The displacement, Δd, in the time interval from 1.0 s to 5.0 s does not change. Because displacement is the same in any coordinate system, you frequently will use displacement when studying the motion of an object. The displacement vector is always drawn with its flat end, or tail, at the earlier position, and its point, or tip, at the later position.

2.2 Section Review

5. Displacement The particle model for a car traveling on an interstate highway is shown below. The starting point is shown.

Here ● ● ● ● ● ● There

Make a copy of the particle model, and draw a vector to represent the displacement of the car from the starting time to the end of the third time interval.

6. Displacement The particle model for a boy walking to school is shown below.

Home ● ● ● ● ● ● ● ● ● ● School

Make a copy of the particle model, and draw vectors to represent the displacement between each pair of dots.

7. Position Two students compared the position vectors they each had drawn on a motion diagram to show the position of a moving object at the same time. They found that their vectors did not point in the same direction. Explain.

8. Critical Thinking A car travels straight along the street from the grocery store to the post office. To represent its motion you use a coordinate system with its origin at the grocery store and the direction the car is moving in as the positive direction. Your friend uses a coordinate system with its origin at the post office and the opposite direction as the positive direction. Would the two of you agree on the car's position? Displacement? Distance? The time interval the trip took? Explain.

2.3 Position-Time Graphs

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Interactive Figure To see an animation on position-time graphs, visit **physicspp.com**.

When analyzing motion, particularly when it is more complex than the examples considered so far, it often is useful to represent the motion of an object in a variety of ways. As you have seen, a motion diagram contains useful information about an object's position at various times and can be helpful in determining the displacement of an object during time intervals. Graphs of the object's position and time also contain this information.

Review Figure 2-9, the motion diagram for the runner with a location to the left of the tree chosen as the origin. From this motion diagram, you can organize the times and corresponding positions of the runner, as in **Table 2-1.**

Using a Graph to Find Out Where and When

The data from **Table 2-1** can be presented by plotting the time data on a horizontal axis and the position data on a vertical axis, which is called a **position-time graph.** The graph of the runner's motion is shown in **Figure 2-12.** To draw this graph, first plot the runner's recorded positions. Then, draw a line that best fits the recorded points. Notice that this graph is not a picture of the path taken by the runner as he was moving—the graphed line is sloped, but the path that he ran was flat. The line represents the most likely positions of the runner at the times between the recorded data points. (Recall from Chapter 1 that this line often is referred to as a best-fit line.) This means that even though there is no data point to tell you exactly when the runner was 30.0 m beyond his starting point or where he was at $t = 4.5$ s, you can use the graph to estimate his position. The following example problem shows how. Note that before estimating the runner's position, the questions first are restated in the language of physics in terms of positions and times.

■ **Figure 2-12** A position-time graph for the runner can be created by plotting his known position at each of several times. After these points are plotted, the line that best fits them is drawn. The best-fit line indicates the runner's most likely positions at the times between the data points.

Table 2–1	
Position v. Time	
Time t **(s)**	**Position** d **(m)**
0.0	0.0
1.0	5.0
2.0	10.0
3.0	15.0
4.0	20.0
5.0	25.0
6.0	30.0
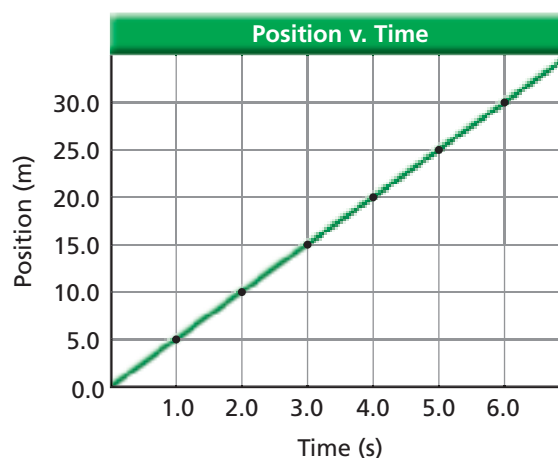
▶ EXAMPLE **Problem 1**

When did the runner whose motion is described in Figure 2-12 reach 30.0 m beyond the starting point? Where was he after 4.5 s?

1 Analyze the Problem

- Restate the questions.

  Question 1: At what time was the position of the object equal to 30.0 m?

  Question 2: What was the position of the object at 4.5 s?

2 Solve for the Unknown

Question 1

Examine the graph to find the intersection of the best-fit line with a horizontal line at the 30.0-m mark. Next, find where a vertical line from that point crosses the time axis. The value of t there is 6.0 s.

Position v. Time

Question 2

Find the intersection of the graph with a vertical line at 4.5 s (halfway between 4.0 s and 5.0 s on this graph). Next, find where a horizontal line from that point crosses the position axis. The value of d is approximately 22.5 m.

The two intersections are shown on the graph above.
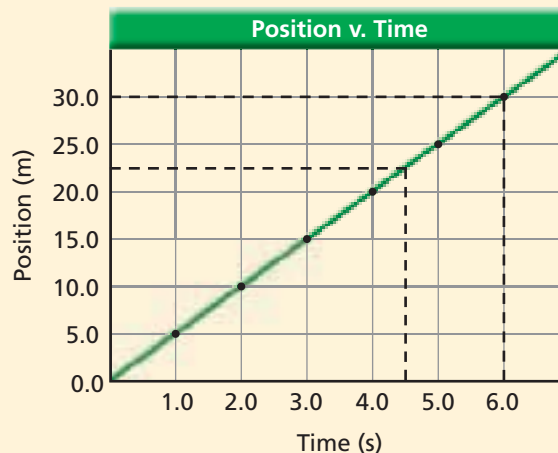
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▶ PRACTICE **Problems**

- Additional Problems, Appendix B
- Solutions to Selected Problems, Appendix C

For problems 9–11, refer to **Figure 2-13.**

9. Describe the motion of the car shown by the graph.

10. Draw a motion diagram that corresponds to the graph.

11. Answer the following questions about the car's motion. Assume that the positive d-direction is east and the negative d-direction is west.

  a. When was the car 25.0 m east of the origin?

  b. Where was the car at 1.0 s?

12. Describe, in words, the motion of the two pedestrians shown by the lines in **Figure 2-14.** Assume that the positive direction is east on Broad Street and the origin is the intersection of Broad and High Streets.

13. Odina walked down the hall at school from the cafeteria to the band room, a distance of 100.0 m. A class of physics students recorded and graphed her position every 2.0 s, noting that she moved 2.6 m every 2.0 s. When was Odina in the following positions?

  a. 25.0 m from the cafeteria

  b. 25.0 m from the band room

  c. Create a graph showing Odina's motion.

■ Figure 2-13
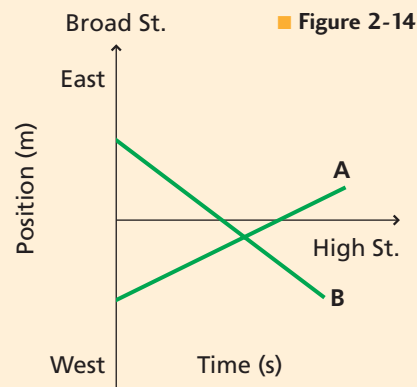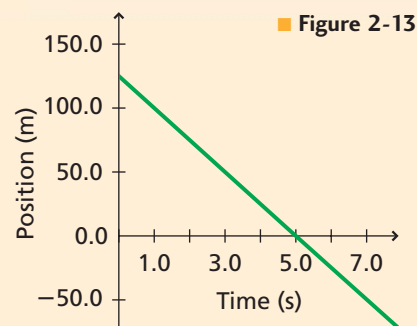
■ Figure 2-14

Table 2-1	
Position v. Time	
Time t (s)	Position d (m)
0.0	0.0
1.0	5.0
2.0	10.0
3.0	15.0
4.0	20.0
5.0	25.0
6.0	30.0

b
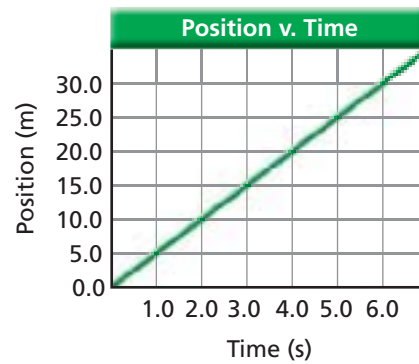
Position v. Time

c   Begin • • • • • • • End

■ **Figure 2-15** The data table **(a),** position-time graph **(b),** and particle model **(c)** all represent the same moving object.

How long did the runner spend at any location? Each position has been linked to a time, but how long did that time last? You could say "an instant," but how long is that? If an instant lasts for any finite amount of time, then the runner would have stayed at the same position during that time, and he would not have been moving. However, as he was moving, an instant is not a finite period of time. This means that an instant of time lasts zero seconds. The symbol **d** represents the **instantaneous position** of the runner—the position at a particular instant.

Equivalent representations As shown in **Figure 2-15,** you now have several different ways to describe motion: words, pictures (or pictorial representations), motion diagrams, data tables, and position-time graphs. All of these representations are equivalent. That is, they can all contain the same information about the runner's motion. However, depending on what you want to find out about an object's motion, some of the representations will be more useful than others. In the pages that follow, you will get some practice constructing these equivalent representations and learning which ones are the easiest to use in solving different kinds of problems.

Considering the motion of multiple objects A position-time graph for two different runners in a race is shown in Example Problem 2. When and where does one runner pass the other? First, you need to restate this question in physics terms: At what time do the two objects have the same position? You can evaluate this question by identifying the point on the position-time graph at which the lines representing the two objects intersect.

● CHALLENGE **PROBLEM**

Niram, Oliver, and Phil all enjoy exercising and often go to a path along the river for this purpose. Niram bicycles at a very consistent 40.25 km/h, Oliver runs south at a constant speed of 16.0 km/h, and Phil walks south at a brisk 6.5 km/h. Niram starts biking north at noon from the waterfalls. Oliver and Phil both start at 11:30 A.M. at the canoe dock, 20.0 km north of the falls.

1. Draw position-time graphs for each person.
2. At what time will the three exercise enthusiasts be within the smallest distance interval?
3. What is the length of that distance interval?

When and where does runner B pass runner A?

1 Analyze the Problem

- Restate the question.
  At what time do A and B have the
  same position?

2 Solve for the Unknown

In the figure at right, examine the graph to find
the intersection of the line representing the
motion of A with the line representing
the motion of B.

These lines intersect at 45 s and at about
190 m.

B passes A about 190 m beyond the origin,
45 s after A has passed the origin.
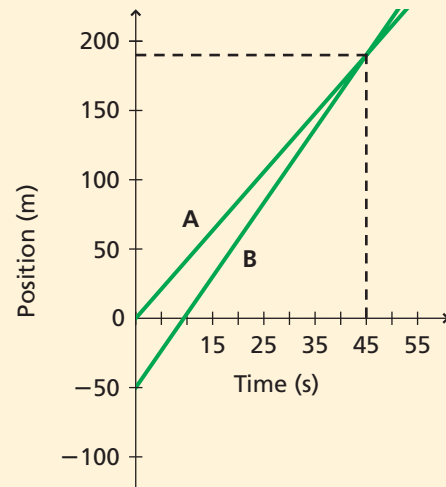
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▶ PRACTICE **Problems**   • Additional Problems, Appendix B
• Solutions to Selected Problems, Appendix C

For problems 14–17, refer to the figure in Example Problem 2.

14. What event occurred at $t = 0.0$ s?

15. Which runner was ahead at $t = 48.0$ s?

16. When runner A was at 0.0 m, where was runner B?

17. How far apart were runners A and B at $t = 20.0$ s?

18. Juanita goes for a walk. Sometime later, her friend Heather starts to
walk after her. Their motions are represented by the position-time
graphs in **Figure 2-16.**

  a. How long had Juanita been walking when Heather started
  her walk?

 **b.** Will Heather catch up to Juanita? How can you tell?
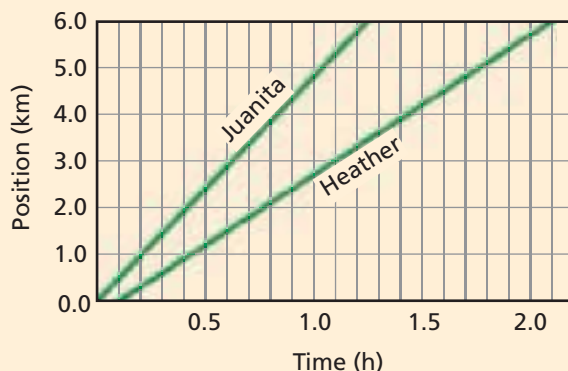
■ **Figure 2-16**

As you have seen, you can represent the motion of more than one object on a position-time graph. The intersection of two lines tells you when the two objects have the same position. Does this mean that they will collide? Not necessarily. For example, if the two objects are runners and if they are in different lanes, they will not collide. Later in this textbook, you will learn to represent motion in two dimensions.

Is there anything else that you can learn from a position-time graph? Do you know what the slope of a line means? In the next section, you will use the slope of a line on a position-time graph to determine the velocity of an object. What about the area under a plotted line? In Chapter 3, you will draw other graphs and learn to interpret the areas under the plotted lines. In later chapters you will continue to refine your skills with creating and interpreting graphs.
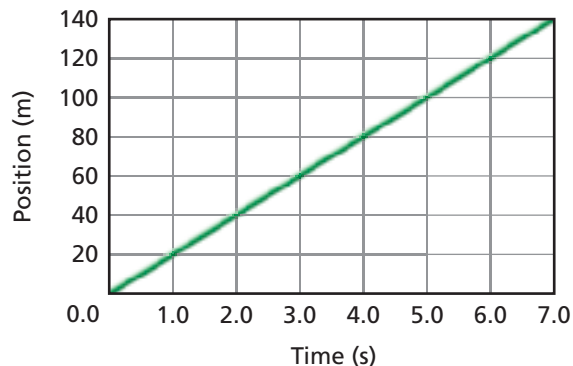
2.3 Section Review

19. Position-Time Graph From the particle model in **Figure 2-17** of a baby crawling across a kitchen floor, plot a position-time graph to represent his motion. The time interval between successive dots is 1 s.
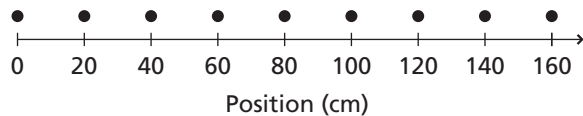
■ **Figure 2-17**

20. Motion Diagram Create a particle model from the position-time graph of a hockey puck gliding across a frozen pond in **Figure 2-18.**
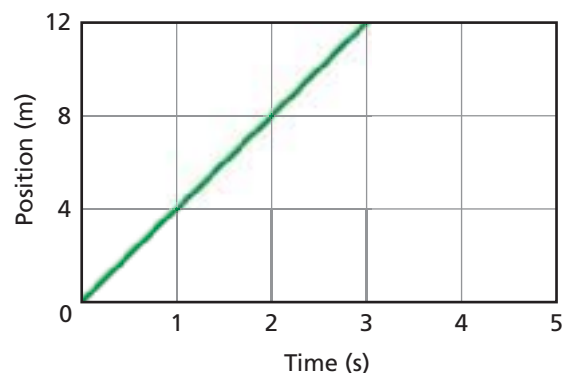

■ **Figure 2-18**

For problems 21–23, refer to Figure 2-18.

21. Time Use the position-time graph of the hockey puck to determine when it was 10.0 m beyond the origin.

22. Distance Use the position-time graph of the hockey puck to determine how far it moved between 0.0 s and 5.0 s.

23. Time Interval Use the position-time graph for the hockey puck to determine how much time it took for the puck to go from 40 m beyond the origin to 80 m beyond the origin.

24. Critical Thinking Look at the particle model and position-time graph shown in **Figure 2-19.** Do they describe the same motion? How do you know? Do not confuse the position coordinate system in the particle model with the horizontal axis in the position-time graph. The time intervals in the particle model are 2 s.

■ **Figure 2-19**

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2.4 How Fast?

Ⓨou have learned how to use a motion diagram to show an object's movement. How can you measure how fast it is moving? With devices such as a meterstick and a stopwatch, you can measure position and time. Can this information be used to describe the rate of motion?

Velocity

Suppose you recorded two joggers on one motion diagram, as shown in **Figure 2-20a.** From one frame to the next you can see that the position of the jogger in red shorts changes more than that of the one wearing blue. In other words, for a fixed time interval, the displacement, Δd, is greater for the jogger in red because she is moving faster. She covers a larger distance than the jogger in blue does in the same amount of time. Now, suppose that each jogger travels 100.0 m. The time interval, Δt, would be smaller for the jogger in red than for the one in blue.

Average velocity From the example of the joggers, you can see that both the displacement, Δd, and time interval, Δt, might be needed to create the quantity that tells how fast an object is moving. How might they be combined? Compare the lines representing the red and blue joggers in the position-time graphs in **Figure 2-20b.** The slope of the red jogger's line is steeper than the slope of the blue jogger's line. A steeper slope indicates a greater change in displacement during each time interval.

Recall from Chapter 1 that to find the slope, you first choose two points on the line. Next, you subtract the vertical coordinate (d in this case) of the first point from the vertical coordinate of the second point to obtain the rise of the line. After that, you subtract the horizontal coordinate (t in this case) of the first point from the horizontal coordinate of the second point to obtain the run. Finally, you divide the rise by the run to obtain the slope. The slopes of the two lines shown in Figure 2-20b are found as follows:

$$\text{Red slope} = \frac{d_f - d_i}{t_f - t_i} \qquad\qquad \text{Blue slope} = \frac{d_f - d_i}{t_f - t_i}$$

$$= \frac{6.0\text{ m} - 2.0\text{ m}}{3.0\text{ s} - 1.0\text{ s}} \qquad\qquad = \frac{3.0\text{ m} - 2.0\text{ m}}{3.0\text{ s} - 2.0\text{ s}}$$

$$= 2.0\text{ m/s} \qquad\qquad\qquad = 1.0\text{ m/s}$$

▶ **Objectives**
- **Define** velocity.
- **Differentiate** between speed and velocity.
- **Create** pictorial, physical, and mathematical models of motion problems.

▶ **Vocabulary**
average velocity
average speed
instantaneous velocity

CLICK HERE

■ **Figure 2-20** The red jogger's displacement is greater than the displacement of the blue jogger in each time interval because the jogger in red is moving faster than the jogger in blue **(a).** The position-time graph represents the motion of the red and blue joggers. The points used to calculate the slope of each line are shown **(b).**
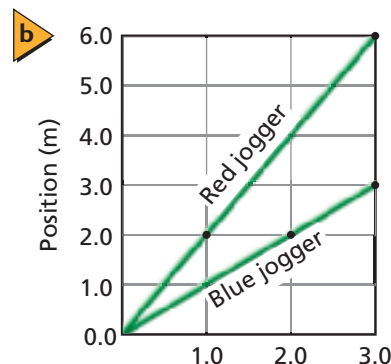
Hutchings Photography

There are some important things to notice about this comparison. First, the slope of the faster runner is a greater number, so it is reasonable to assume that this number might be connected with the runner's speed. Second, look at the units of the slope, meters per second. In other words, the slope tells how many meters the runner moved in 1 s. These units are similar to miles per hour, which also measure speed. Looking at how the slope is calculated, you can see that slope is the change in position, divided by the time interval during which that change took place, or $(d_f - d_i) / (t_f - t_i)$, or $\Delta d / \Delta t$. When Δd gets larger, the slope gets larger; when Δt gets larger, the slope gets smaller. This agrees with the interpretation above of the movements of the red and blue joggers. The slope of a position-time graph for an object is the object's **average velocity** and is represented by the ratio of the change of position to the time interval during which the change occurred.

Average Velocity $\overline{v} \equiv \dfrac{\Delta d}{\Delta t} = \dfrac{d_f - d_i}{t_f - t_i}$

Average velocity is defined as the change in position, divided by the time during which the change occurred.

Color Convention

- Velocity vectors are **red.**
- Displacement vectors are **green.**

The symbol $\equiv$ means that the left-hand side of the equation is defined by the right-hand side.

It is a common misconception to say that the slope of a position-time graph gives the speed of the object. Consider the slope of the position-time graph shown in **Figure 2-21.** The slope of this position-time graph is -5.0 m/s. As you can see the slope indicates both the magnitude and direction. Recall that average velocity is a quantity that has both magnitude and direction. The slope of a position-time graph indicates the average velocity of the object and not its speed. Take another look at Figure 2-21. The slope of the graph is -5.0 m/s and thus, the object has a velocity of -5.0 m/s. The object starts out at a positive position and moves toward the origin. It moves in the negative direction at a rate of 5.0 m/s.

Average speed The absolute value of the slope of a position-time graph tells you the **average speed** of the object; that is, how fast the object is moving. The sign of the slope tells you in what direction the object is moving. The combination of an object's average speed, $\overline{v}$, and the direction in which it is moving is the average velocity, $\overline{v}$. Thus, for the object represented in Figure 2-21, the average velocity is -5.0 m/s, or 5.0 m/s in the negative direction. Its average speed is 5.0 m/s. Remember that if an object moves in the negative direction, then its displacement is negative. This means that the object's velocity always will have the same sign as the object's displacement.

As you consider other types of motion to analyze in future chapters, sometimes the velocity will be the important quantity to consider, while at other times, the speed will be the important quantity. Therefore, it is a good idea to make sure that you understand the differences between velocity and speed so that you will be sure to use the right one later.

■ **Figure 2-21** The object whose motion is represented here is moving in the negative direction at a rate of 5.0 m/s.
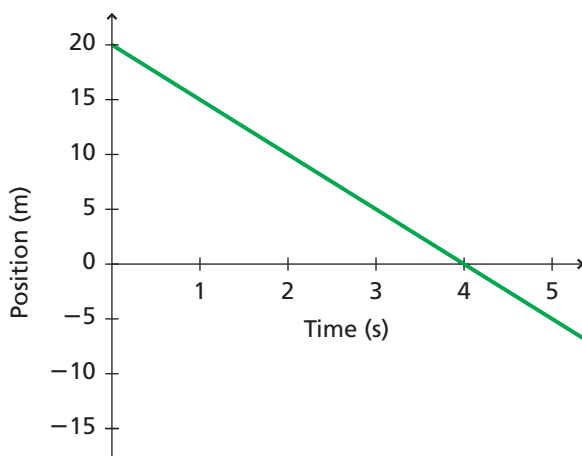
The graph at the right describes the motion of a student riding his skateboard along a smooth, pedestrian-free sidewalk. What is his average velocity? What is his average speed?

1 Analyze and Sketch the Problem

• Identify the coordinate system of the graph.

2 Solve for the Unknown

Unknown:

$\bar{v} = ?$ $\bar{v} = ?$

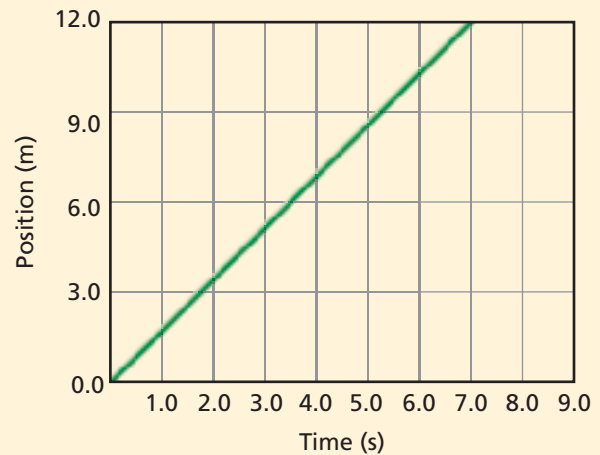Find the average velocity using two points on the line.

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

Use magnitudes with signs indicating directions.

$$= \frac{d_2 - d_1}{t_2 - t_1}$$

$$= \frac{12.0 \text{ m} - 6.0 \text{ m}}{8.0 \text{ s} - 4.0 \text{ s}}$$

Substitute $d_2 = 12.0$ m, $d_1 = 6.0$ m, $t_2 = 8.0$ s, $t_1 = 4.0$ s.

$\bar{v} = 1.5$ m/s in the positive direction

The average speed, $\bar{v}$, is the absolute value of the average velocity, or 1.5 m/s.

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Personal Tutor For an online tutorial on average velocity and average speed, visit physicspp.com.

3 Evaluate the Answer

• **Are the units correct?** m/s are the units for both velocity and speed.
• **Do the signs make sense?** The positive sign for the velocity agrees with the coordinate system. No direction is associated with speed.

▶ PRACTICE **Problems**

• Additional Problems, Appendix B
• Solutions to Selected Problems, Appendix C

25. The graph in **Figure 2-22** describes the motion of a cruise ship during its voyage through calm waters. The positive d-direction is defined to be south.

  a. What is the ship's average speed?

  b. What is its average velocity?

26. Describe, in words, the motion of the cruise ship in the previous problem.

27. The graph in **Figure 2-23** represents the motion of a bicycle. Determine the bicycle's average speed and average velocity, and describe its motion in words.

28. When Marilyn takes her pet dog for a walk, the dog walks at a very consistent pace of 0.55 m/s. Draw a motion diagram and position-time graph to represent Marilyn's dog walking the 19.8-m distance from in front of her house to the nearest fire hydrant.
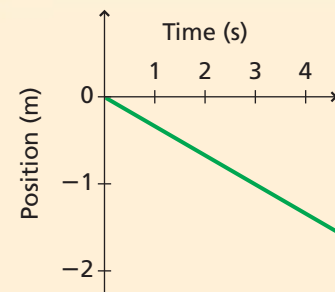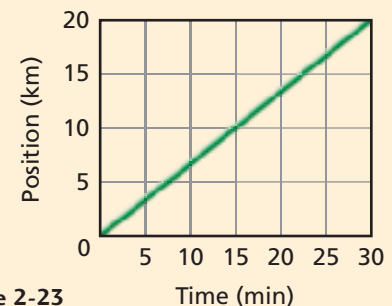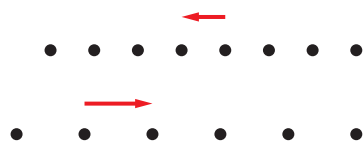
■ Figure 2-22

■ Figure 2-23

■ Figure 2-24 Average velocity vectors have the same direction as their corresponding displacement vectors. Their lengths are different, but proportional, and they have different units because they are obtained by dividing the displacement by the time interval.

Instantaneous Velocity

Why is the quantity $\Delta d/\Delta t$ called average velocity? Why isn't it called velocity? Think about how a motion diagram is constructed. A motion diagram shows the position of a moving object at the beginning and end of a time interval. It does not, however, indicate what happened within that time interval. During the time interval, the speed of the object could have remained the same, increased, or decreased. The object may have stopped or even changed direction. All that can be determined from the motion diagram is an average velocity, which is found by dividing the total displacement by the time interval in which it took place. The speed and direction of an object at a particular instant is called the **instantaneous velocity.** In this textbook, the term *velocity* will refer to instantaneous velocity, represented by the symbol v.

Average Velocity on Motion Diagrams

How can you show average velocity on a motion diagram? Although the average velocity is in the same direction as displacement, the two quantities are not measured using the same units. Nevertheless, they are proportional—when displacement is greater during a given time interval, so is average velocity. A motion diagram is not a precise graph of average velocity, but you can indicate the direction and magnitude of the average velocity on it. Imagine two cars driving down the road at different speeds. A video camera records their motions at the rate of one frame every second. Imagine that each car has a paintbrush attached to it that automatically descends and paints a line on the ground for half a second every second. The faster car would paint a longer line on the ground. The vectors you draw on a motion diagram to represent the velocity are like the lines made by the paintbrushes on the ground below the cars. Red is used to indicate velocity vectors on motion diagrams. **Figure 2-24** shows the particle models, complete with velocity vectors, for two cars: one moving to the right and the other moving more slowly to the left.

Using equations Any time you graph a straight line, you can find an equation to describe it. There will be many cases for which it will be more efficient to use such an equation instead of a graph to solve problems. Take another look at the graph in Figure 2-21 on page 44 for the object moving with a constant velocity of −5.0 m/s. Recall from Chapter 1 that any straight line can be represented by the formula: $y = mx + b$ where y is the quantity plotted on the vertical axis, m is the slope of the line, x is the quantity plotted on the horizontal axis, and b is the y-intercept of the line.

For the graph in Figure 2-21, the quantity plotted on the vertical axis is position, and the variable used to represent position is d. The slope of the line is −5.0 m/s, which is the object's average velocity, $\bar{v}$. The quantity plotted on the horizontal axis is time, t. The y-intercept is 20.0 m. What does this 20.0 m represent? By inspecting the graph and thinking about how the object moves, you can figure out that the object was at a position of 20.0 m when $t = 0.0$ s. This is called the initial position of the object, and is designated d_i. **Table 2-2** summarizes how the general variables in the straight-line formula are changed to the specific variables you have been using to describe motion. It also shows the numerical values for the two constants in this equation.

Based on the information shown in Table 2-2, the equation $y = mx + b$ becomes $d = \bar{v}t + d_i$, or, by inserting the values of the constants, $d = (-5.0 \text{ m/s})t + 20.0 \text{ m}$. This equation describes the motion that is represented in Figure 2-21. You can check this by plugging a value of t into the equation and seeing that you obtain the same value of d as when you read it directly from the graph. To conduct an extra check to be sure the equation makes sense, take a look at the units. You cannot set two items with different units equal to each other in an equation. In this equation, the left-hand side is a position, so its units are meters. The first term on the right-hand side multiplies meters per second times seconds, so its units are also meters. The last term is in meters, too, so the units on this equation are valid.

Table 2-2		
Comparison of Straight Lines with Position-Time Graphs		
General Variable	Specific Motion Variable	Value in Figure 2-21
y	d	
m	$\bar{v}$	-5.0 m/s
x	t	
b	d_i	20.0 m

> **Equation of Motion for Average Velocity** $\quad d = \bar{v}t + d_i$
>
> An object's position is equal to the average velocity multiplied by time plus the initial position.

This equation gives you another way to represent the motion of an object. Note that once a coordinate system is chosen, the direction of d is specified by positive and negative values, and the boldface notation can be dispensed with, as in "d-axis." However, the boldface notation for velocity will be retained to avoid confusing it with speed.

Your toolbox of representations now includes words, motion diagrams, pictures, data tables, position-time graphs, and an equation. You should be able to use any one of these representations to generate at least the characteristics of the others. You will get more practice with this in the rest of this chapter and also in Chapter 3 as you apply these representations to help you solve problems.
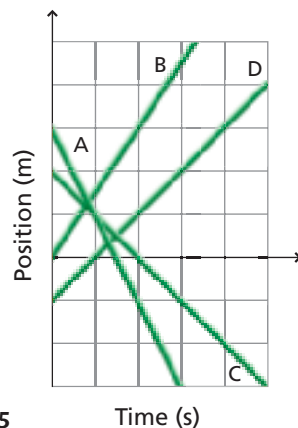
2.4 Section Review

For problems 29–31, refer to **Figure 2-25.**

29. Average Speed Rank the position-time graphs according to the average speed of the object, from greatest average speed to least average speed. Specifically indicate any ties.

■ **Figure 2-25**

30. Average Velocity Rank the graphs according to average velocity, from greatest average velocity to least average velocity. Specifically indicate any ties.

31. Initial Position Rank the graphs according to the object's initial position, from most positive position to most negative position. Specifically indicate any ties. Would your ranking be different if you had been asked to do the ranking according to initial distance from the origin?

32. Average Speed and Average Velocity Explain how average speed and average velocity are related to each other.

33. Critical Thinking In solving a physics problem, why is it important to create pictorial and physical models before trying to solve an equation?

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Creating Motion Diagrams

In this activity you will construct motion diagrams for two toy cars. A motion diagram consists of a series of images showing the positions of a moving object at equal time intervals. Motion diagrams help describe the motion of an object. By looking at a motion diagram you can determine whether an object is speeding up, slowing down, or moving at constant speed.

QUESTION

How do the motion diagrams of a fast toy car and a slow toy car differ?

Objectives

- **Measure in SI** the location of a moving object.
- **Recognize spatial relationships** of moving objects.
- **Describe** the motion of a fast and slow object.

Safety Precautions

Materials

video camera
two toy windup cars
meterstick
foam board

Procedure

1. Mark a starting line on the lab table or the surface recommended by your teacher.
2. Place both toy cars at the starting line and release them at the same time. Be sure to wind them up before releasing them.
3. Observe both toy cars and determine which one is faster.
4. Place the slower toy car at the starting line.
5. Place a meterstick parallel to the path the toy car will take.
6. Have one of the members of your group get ready to operate the video camera.
7. Release the slower toy car from the starting line. Be sure to wind up the toy car before releasing it.
8. Use the video camera to record the slower toy car's motion parallel to the meterstick.
9. Set the recorder to play the tape frame by frame. Replay the video tape for 0.5 s, pressing the pause button every 0.1 s (3 frames).
10. Determine the toy car's position for each time interval by reading the meterstick on the video tape and record it in the data table.
11. Repeat steps 5–10 with the faster car.
12. Place a piece of foam board at an angle of approximately 30° to form a ramp.
13. Place the meterstick on the ramp so that it is parallel to the path the toy car will take.
14. Place the slower toy car at the top of the ramp and repeat steps 6–10.

Data Table 1	
Time (s)	Position of the Slower Toy Car (cm)
0.0	
0.1	
0.2	
0.3	
0.4	
0.5	

Data Table 2	
Time (s)	Position of the Faster Toy Car (cm)
0.0	
0.1	
0.2	
0.3	
0.4	
0.5	

Data Table 3	
Time (s)	Position of the Slower Toy Car on the Ramp (cm)
0.0	
0.1	
0.2	
0.3	
0.4	
0.5	

Analyze

1. Draw a motion diagram for the slower toy car using the data you collected.

2. Draw a motion diagram for the faster toy car using the data you collected.

3. Using the data you collected, draw a motion diagram for the slower toy car rolling down the ramp.

Conclude and Apply

How is the motion diagram of the faster toy car different from the motion diagram of the slower toy car?

Going Further

1. Draw a motion diagram for a car moving at a constant speed.

2. What appears to be the relationship between the distances between points in the motion diagram of a car moving at a constant speed?

3. Draw a motion diagram for a car that starts moving fast and then begins to slow down.

4. What happens to the distance between points in the motion diagram in the previous question as the car slows down?

5. Draw a motion diagram for a car that starts moving slowly and then begins to speed up.

6. What happens to the distance between points in the motion diagram in the previous question as the car speeds up?

Real-World Physics

Suppose a car screeches to a halt to avoid an accident. If that car has antilock brakes that pump on and off automatically every fraction of a second, what might the tread marks on the road look like? Include a drawing along with your explanation of what the pattern of tread marks on the road might look like.

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Accurate Time

What time is it really?
You might use a clock to find out what time it is at any moment. A clock is a device that counts regularly recurring events in order to measure time. Suppose the clock in your classroom reads 9:00. Your watch, however, reads 8:55, and your friend's watch reads 9:02. So what time is it, really? Which clock or watch is accurate?

Many automated processes are controlled by clocks. For example, an automated bell that signals the end of a class period is controlled by a clock. Thus, if you wanted to be on time for a class you would have to synchronize your watch to the one controlling the bell. Other processes, such as GPS navigation, space travel, internet synchronization, transportation, and communication, rely on clocks with extreme precision and accuracy. A reliable standard clock that can measure when exactly one second has elapsed is needed.

The Standard Cesium Clock
Atomic clocks, such as cesium clocks, address this need. Atomic clocks measure the number of times the atom used in the clock switches its energy state. Such oscillations in an atom's energy occur very quickly and regularly. The National Institute of Standards and Technology (NIST) currently uses the oscillations of the cesium atom to determine the standard 1-s interval. One second is defined as the duration of 9,192,631,770 oscillations of the cesium atom.

The cesium atom has a single electron in its outermost energy level. This outer electron spins and behaves like a miniature magnet. The cesium nucleus also spins and acts like a miniature magnet. The nucleus and electron may spin in such a manner that their north magnetic poles are aligned. The nucleus and electron also may spin in a way that causes opposite poles to be aligned. If the poles are aligned, the cesium atom is in one energy state. If they are oppositely aligned, the atom is in another energy state. A microwave with a particular frequency can strike a cesium atom and cause the outside spinning electron to switch its magnetic pole orientation and change the atom's energy state. As a result, the atom emits light. This occurs at cesium's natural frequency of 9,192,631,770 cycles/s. This principle was used to design the cesium clock.

The cesium clock, *NIST-F1*, located at the NIST laboratories in Boulder, Colorado is among the most accurate clocks in the world.

How Does the Cesium Clock Work?
The cesium clock consists of cesium atoms and a quartz crystal oscillator, which produces microwaves. When the oscillator's microwave signal precisely equals cesium's natural frequency, a large number of cesium atoms will change their energy state. Cesium's natural frequency is equal to 9,192,631,770 microwave cycles. Thus, there are 9,192,631,770 cesium energy level changes in 1 s. Cesium clocks are so accurate that a modern cesium clock is off by less than 1 s in 20 million years.

Going Further

1. **Research** What processes require the precise measurement of time?
2. **Analyze and Conclude** Why is the precise measurement of time essential to space navigation?

2.1 Picturing Motion

Vocabulary
- motion diagram (p. 33)
- particle model (p. 33)

Key Concepts
- A motion diagram shows the position of an object at successive times.
- In the particle model, the object in the motion diagram is replaced by a series of single points.

2.2 Where and When?

Vocabulary
- coordinate system (p. 34)
- origin (p. 34)
- position (p. 34)
- distance (p. 34)
- magnitude (p. 35)
- vectors (p. 35)
- scalars (p. 35)
- resultant (p. 35)
- time interval (p. 36)
- displacement (p. 36)

Key Concepts
- You can define any coordinate system you wish in describing motion, but some are more useful than others.
- A time interval is the difference between two times.

$$\Delta t = t_f - t_i$$

- A vector drawn from the origin of the coordinate system to the object indicates the object's position.
- Change in position is displacement, which has both magnitude and direction.

$$\Delta \boldsymbol{d} = \boldsymbol{d}_f - \boldsymbol{d}_i$$

- The length of the displacement vector represents how far the object was displaced, and the vector points in the direction of the displacement.

2.3 Position-Time Graphs

Vocabulary
- position-time graph (p. 38)
- instantaneous position (p. 40)

Key Concepts
- Position-time graphs can be used to find the velocity and position of an object, as well as where and when two objects meet.
- Any motion can be described using words, motion diagrams, data tables, and graphs.

2.4 How Fast?

Vocabulary
- average velocity (p. 44)
- average speed (p. 44)
- instantaneous velocity (p. 46)

Key Concepts
- The slope of an object's position-time graph is the average velocity of the object's motion.

$$\bar{\boldsymbol{v}} = \frac{\Delta \boldsymbol{d}}{\Delta t} = \frac{\boldsymbol{d}_f - \boldsymbol{d}_i}{t_f - t_i}$$

- The average speed is the absolute value of the average velocity.
- An object's velocity is how fast it is moving and in what direction it is moving.
- An object's initial position, $\boldsymbol{d}_i$, its constant average velocity, $\bar{\boldsymbol{v}}$, its position, $\boldsymbol{d}$, and the time, t, since the object was at its initial position are related by a simple equation.

$$\boldsymbol{d} = \bar{\boldsymbol{v}}t + \boldsymbol{d}_i$$

Concept Mapping

34. Complete the concept map below using the following terms: *words, equivalent representations, position-time graph.*
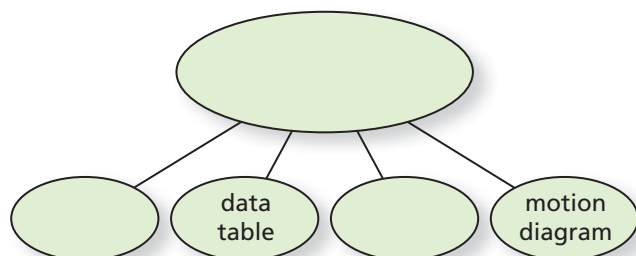
Mastering Concepts

35. What is the purpose of drawing a motion diagram? (2.1)

36. Under what circumstances is it legitimate to treat an object as a point particle? (2.1)

37. The following quantities describe location or its change: position, distance, and displacement. Briefly describe the differences among them. (2.2)

38. How can you use a clock to find a time interval? (2.2)

39. In-line Skating How can you use the position-time graphs for two in-line skaters to determine if and when one in-line skater will pass the other one? (2.3)

40. Walking Versus Running A walker and a runner leave your front door at the same time. They move in the same direction at different constant velocities. Describe the position-time graphs of each. (2.4)

41. What does the slope of a position-time graph measure? (2.4)

42. If you know the positions of a moving object at two points along its path, and you also know the time it took for the object to get from one point to the other, can you determine the particle's instantaneous velocity? Its average velocity? Explain. (2.4)

Applying Concepts

43. Test the following combinations and explain why each does not have the properties needed to describe the concept of velocity: $\Delta d + \Delta t$, $\Delta d - \Delta t$, $\Delta d \times \Delta t$, $\Delta t/\Delta d$.

44. Football When can a football be considered a point particle?

45. When can a football player be treated as a point particle?

46. Figure 2-26 is a graph of two people running.
   a. Describe the position of runner A relative to runner B at the *y*-intercept.
   b. Which runner is faster?
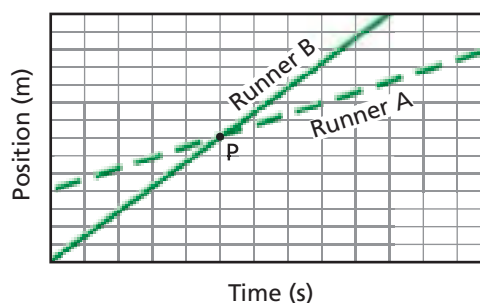   **c.** What occurs at point P and beyond?

■ **Figure 2-26**

47. The position-time graph in **Figure 2-27** shows the motion of four cows walking from the pasture back to the barn. Rank the cows according to their average velocity, from slowest to fastest.
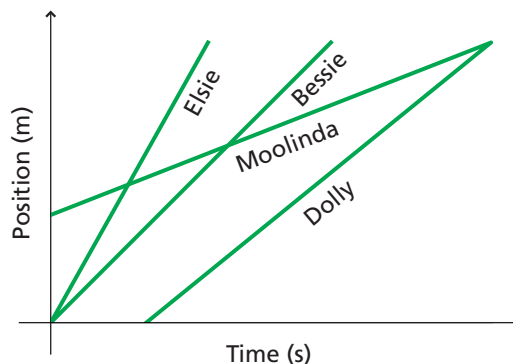

■ **Figure 2-27**

48. Figure 2-28 is a position-time graph for a rabbit running away from a dog.
   a. Describe how this graph would be different if the rabbit ran twice as fast.
   b. Describe how this graph would be different if the rabbit ran in the opposite direction.
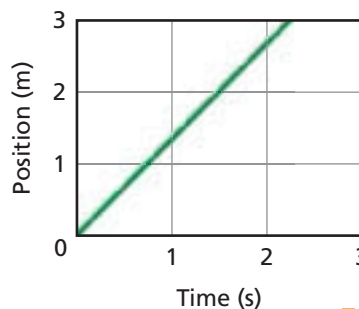

■ **Figure 2-28**

Mastering Problems

2.4 How Fast?

49. A bike travels at a constant speed of 4.0 m/s for 5.0 s. How far does it go?

50. **Astronomy** Light from the Sun reaches Earth in 8.3 min. The speed of light is 3.00×10^8 m/s. How far is Earth from the Sun?

51. A car is moving down a street at 55 km/h. A child suddenly runs into the street. If it takes the driver 0.75 s to react and apply the brakes, how many meters will the car have moved before it begins to slow down?

52. Nora jogs several times a week and always keeps track of how much time she runs each time she goes out. One day she forgets to take her stopwatch with her and wonders if there's a way she can still have some idea of her time. As she passes a particular bank, she remembers that it is 4.3 km from her house. She knows from her previous training that she has a consistent pace of 4.0 m/s. How long has Nora been jogging when she reaches the bank?

53. **Driving** You and a friend each drive 50.0 km. You travel at 90.0 km/h; your friend travels at 95.0 km/h. How long will your friend have to wait for you at the end of the trip?

Mixed Review

54. **Cycling** A cyclist maintains a constant velocity of $+5.0$ m/s. At time $t = 0.0$ s, the cyclist is $+250$ m from point A.

a. Plot a position-time graph of the cyclist's location from point A at 10.0-s intervals for 60.0 s.

b. What is the cyclist's position from point A at 60.0 s?

c. What is the displacement from the starting position at 60.0 s?

55. **Figure 2-29** is a particle model for a chicken casually walking across the road. Time intervals are every 0.1 s. Draw the corresponding position-time graph and write the equation to describe the chicken's motion.

This side   The other side

● ●

Time intervals are 0.1 s.

■ **Figure 2-29**

56. Figure 2-30 shows position-time graphs for Joszi and Heike paddling canoes in a local river.

a. At what time(s) are Joszi and Heike in the same place?

b. How much time does Joszi spend on the river before he passes Heike?

c. Where on the river does it appear that there might be a swift current?
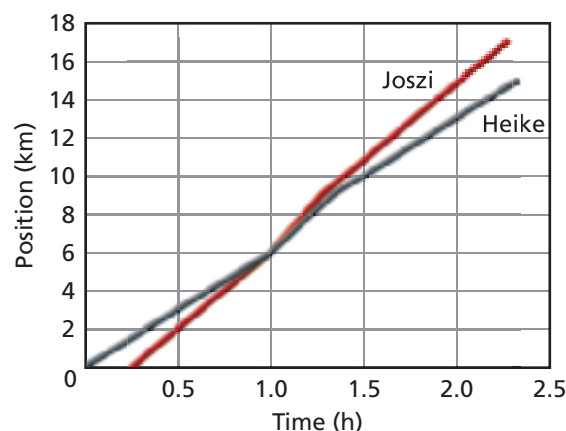
■ **Figure 2-30**

57. **Driving** Both car A and car B leave school when a stopwatch reads zero. Car A travels at a constant 75 km/h, and car B travels at a constant 85 km/h.

a. Draw a position-time graph showing the motion of both cars. How far are the two cars from school when the stopwatch reads 2.0 h? Calculate the distances and show them on your graph.

b. Both cars passed a gas station 120 km from the school. When did each car pass the gas station? Calculate the times and show them on your graph.

58. Draw a position-time graph for two cars traveling to the beach, which is 50 km from school. At noon, Car A leaves a store that is 10 km closer to the beach than the school is and moves at 40 km/h. Car B starts from school at 12:30 P.M. and moves at 100 km/h. When does each car get to the beach?

59. Two cars travel along a straight road. When a stopwatch reads $t = 0.00$ h, car A is at $d_A = 48.0$ km moving at a constant 36.0 km/h. Later, when the watch reads $t = 0.50$ h, car B is at $d_B = 0.00$ km moving at 48.0 km/h. Answer the following questions, first, graphically by creating a position-time graph, and second, algebraically by writing equations for the positions d_A and d_B as a function of the stopwatch time, t.

a. What will the watch read when car B passes car A?

b. At what position will car B pass car A?

c. When the cars pass, how long will it have been since car A was at the reference point?

60. Figure 2-31 shows the position-time graph depicting Jim's movement up and down the aisle at a store. The origin is at one end of the aisle.
  a. Write a story describing Jim's movements at the store that would correspond to the motion represented by the graph.
  b. When does Jim have a position of 6.0 m?
  c. How much time passes between when Jim enters the aisle and when he gets to a position of 12.0 m? What is Jim's average velocity between 37.0 s and 46.0 s?
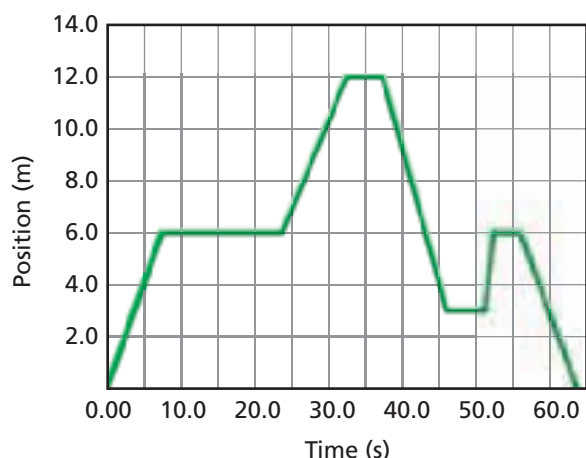

■ **Figure 2-31**

Thinking Critically

61. Apply Calculators Members of a physics class stood 25 m apart and used stopwatches to measure the time at which a car traveling on the highway passed each person. Their data are shown in **Table 2-3.**

Table 2-3	
Position v. Time	
Time (s)	**Position (m)**
0.0	0.0
1.3	25.0
2.7	50.0
3.6	75.0
5.1	100.0
5.9	125.0
7.0	150.0
8.6	175.0
10.3	200.0

Use a graphing calculator to fit a line to a position-time graph of the data and to plot this line. Be sure to set the display range of the graph so that all the data fit on it. Find the slope of the line. What was the speed of the car?

62. Apply Concepts You plan a car trip for which you want to average 90 km/h. You cover the first half of the distance at an average speed of only 48 km/h. What must your average speed be in the second half of the trip to meet your goal? Is this reasonable? Note that the velocities are based on half the distance, not half the time.

63. Design an Experiment Every time a particular red motorcycle is driven past your friend's home, his father becomes angry because he thinks the motorcycle is going too fast for the posted 25 mph (40 km/h) speed limit. Describe a simple experiment you could do to determine whether or not the motorcycle is speeding the next time it is driven past your friend's house.

64. Interpret Graphs Is it possible for an object's position-time graph to be a horizontal line? A vertical line? If you answer yes to either situation, describe the associated motion in words.

Writing in Physics

65. Physicists have determined that the speed of light is 3.00×10^8 m/s. How did they arrive at this number? Read about some of the series of experiments that were done to determine light's speed. Describe how the experimental techniques improved to make the results of the experiments more accurate.

66. Some species of animals have good endurance, while others have the ability to move very quickly, but for only a short amount of time. Use reference sources to find two examples of each quality and describe how it is helpful to that animal.

Cumulative Review

67. Convert each of the following time measurements to its equivalent in seconds. (Chapter 1)
  a. 58 ns   **c.** 9270 ms
  b. 0.046 Gs   **d.** 12.3 ks

68. State the number of significant digits in the following measurements. (Chapter 1)
  a. 3218 kg   **c.** 801 kg
  b. 60.080 kg   **d.** 0.000534 kg

69. Using a calculator, Chris obtained the following results. Rewrite the answer to each operation using the correct number of significant digits. (Chapter 1)
  a. 5.32 mm + 2.1 mm = 7.4200000 mm
  b. 13.597 m × 3.65 m = 49.62905 m^2
 **c.** 83.2 kg − 12.804 kg = 70.3960000 kg

Standardized Test Practice

Multiple Choice

1. Which of the following statements would be true about the particle model motion diagram for an airplane taking off from an airport?

- Ⓐ The dots would form an evenly spaced pattern.
- Ⓑ The dots would be far apart at the beginning, but get closer together as the plane accelerated.
- Ⓒ The dots would be close together to start with, and get farther apart as the plane accelerated.
- Ⓓ The dots would be close together to start, get farther apart, and become close together again as the airplane leveled off at cruising speed.

2. Which of the following statements about drawing vectors is false?

- Ⓐ A vector diagram is needed to solve all physics problems properly.
- Ⓑ The length of the vector should be proportional to the data.
- Ⓒ Vectors can be added by measuring the length of each vector and then adding them together.
- Ⓓ Vectors can be added in straight lines or in triangle formations.

Use this graph for problems 3–5.

Time
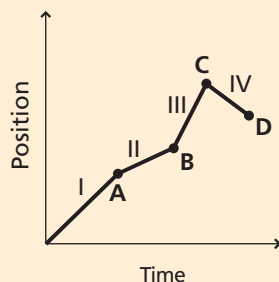
3. The graph shows the motion of a person on a bicycle. When does the person have the greatest velocity?

- Ⓐ section I
- Ⓒ point D
- Ⓑ section III
- Ⓓ point B

4. When is the person on the bicycle farthest away from the starting point?

- Ⓐ point A
- Ⓒ point C
- Ⓑ point B
- Ⓓ point D

5. Over what interval does the person on the bicycle travel the greatest distance?

- Ⓐ section I
- Ⓒ section III
- Ⓑ section II
- Ⓓ point IV

6. A squirrel descends an 8-m tree at a constant speed in 1.5 min. It remains still at the base of the tree for 2.3 min, and then walks toward an acorn on the ground for 0.7 min. A loud noise causes the squirrel to scamper back up the tree in 0.1 min to the exact position on the branch from which it started. Which of the following graphs would accurately represent the squirrel's vertical displacement from the base of the tree?
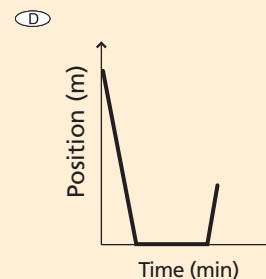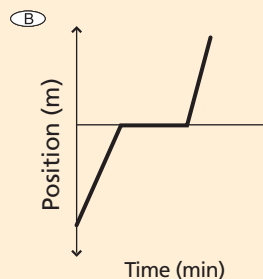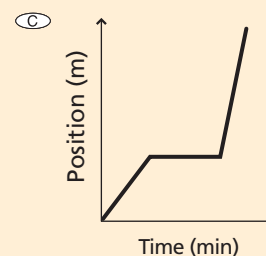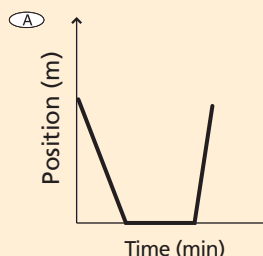
Extended Answer

7. Find a rat's total displacement at the exit if it takes the following path in a maze: start, 1.0 m north, 0.3 m east, 0.8 m south, 0.4 m east, finish.