You can use displacement and velocity to describe an object’s motion.

SECTIONS
1 Picturing Motion
2 Where and When?
3 Position-Time Graphs
4 How Fast?

MEASURING SPEED
Have you ever been passed by another car on the freeway? If you know a few important details, it’s possible to determine how fast that car is going. It’s physics in action on the freeway.
MAIN IDEA
You can use motion diagrams to show how an object’s position changes over time.

Essential Questions
• How do motion diagrams represent motion?
• How can you use a particle model to represent a moving object?

Review Vocabulary
model  a representation of an idea, event, structure, or object to help people better understand it

New Vocabulary
motion diagram
particle model

All Kinds of Motion
You have learned about scientific processes that will be useful in your study of physics. You will now begin to use these tools to analyze motion. In subsequent chapters, you will apply these processes to many kinds of motion. You will use words, sketches, diagrams, graphs, and equations. These concepts will help you determine how fast and how far an object moves, in which direction that object is moving, whether that object is speeding up or slowing down, and whether that object is standing still or moving at a constant speed.

Changes in position What comes to your mind when you hear the word motion? A spinning ride at an amusement park? A baseball soaring over a fence for a home run? Motion is all around you—from fast trains and speedy skiers to slow breezes and lazy clouds. Objects move in many different ways, such as the straight-line path of a bowling ball in a bowling lane’s gutter, the curved path of a car rounding a turn, the spiral of a falling kite, and swirls of water circling a drain. When an object is in motion, such as the subway train in Figure 1, its position changes.

Some types of motion are more complicated than others. When beginning a new area of study, it is generally a good idea to begin with 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.

Figure 1 The subway train appears blurry in the photograph because its position changed during the time the camera shutter was open.

Describe how the picture would be different if the train were sitting still.
**Movement along a straight line** In general, an object can move along many different kinds of paths, but straight-line motion follows a path directly between two points without turning left or right. For example, you might describe an object’s motion as forward and backward, up and down, or north and south. In each of these cases, the object moves along a straight line.

Suppose you are reading this textbook at home. As you start to read, you glance over at your pet hamster and see that it is sitting in a corner of the cage. Sometime later you look over again, and you see that it now is sitting next to the food dish in the opposite corner of the cage. You can infer that your hamster has moved from one place to another in the time between your observations. What factors helped you make this inference about the hamster’s movement?

The description of motion is a description of place and time. You must answer the questions of where an object is located and when it is at that position in order to clearly describe its motion. Next, you will look at some tools that help determine when an object is at a particular place.

**READING CHECK** Identify two factors you must know in order to describe the motion of an object along a straight line.

**Motion Diagrams**

Consider the following example of straight-line motion: a runner jogs along a straight path. One way of representing the runner’s motion is to create a series of images showing the runner’s position at equal time intervals. You can do this by photographing the runner in motion to obtain a sequence of pictures. Each photograph will show the runner at a point that is farther along the straight path.

**Consecutive images** Suppose you point a camera in a direction and a runner crosses the camera’s field of view. Then you take a series of photographs of the runner at equal time intervals, without moving the camera. Figure 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 camera and the ground, only the runner is in motion.

**READING CHECK** Decide whether the spaces between a moving object’s position must be equal if photographs are taken of the object at equal time intervals. Explain.

**Figure 2** You can tell that the jogger is in motion because her position changes relative to the tree and the ground.
Combining images Suppose that you layered the four images of the runner from Figure 2 one on top of the other. Figure 3 shows what such a layered image might look like. You see more than one image of the moving runner, but you see only a single image of the tree and other 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.

Particle Models

Keeping track of the runner’s motion is easier if you disregard the movement of her arms and her legs and instead concentrate on a single point at the center of her body. In effect, you can disregard the fact that the runner has size and imagine that she is a very small object located precisely at that central point. In a particle model, you replace the object or objects of interest with single points. Use of the particle model is common throughout the study of physics.

To use the particle model, the object’s size must be much less than the distance it moves. The object’s internal motions, such as the waving of the runner’s arms or the movement of her legs, are ignored in the particle model. In the photographic motion diagram, you could identify one central point on the runner, such as a point centered at her waistline, and draw a dot at its position at different times. The bottom of Figure 3 shows the particle model for the runner’s motion. 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.

PhysicsLAB

MOTION DIAGRAMS

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

1. MAIN IDEA How does a motion diagram represent an object’s motion?

2. Motion Diagram of a Bike Rider Draw a particle model motion diagram for a bike rider moving at a constant pace along a straight path.

3. Motion Diagram of a Car Draw a particle model motion diagram corresponding to the motion diagram in Figure 4 for a car coming to a stop at a stop sign. What point on the car did you use to represent the car?

4. Motion Diagram of a Bird Draw a particle model motion diagram corresponding to the motion diagram in Figure 5 for a flying bird. What point on the bird did you choose to represent the bird?

5. Critical Thinking Draw particle model motion diagrams for two runners during a race in which the first runner crosses the finish line as the other runner is three-fourths of the way to the finish line.

Figure 3 Combining the images from Figure 2 produces this motion diagram of the jogger’s movement. The series of dots at the bottom of the figure is a particle model that corresponds to the motion diagram. Explain how the particle model shows that the jogger’s speed is not changing.

View an animation of motion diagrams v. particle motion.

Concepts In Motion

SECTION 1 REVIEW

Check your understanding.
A coordinate system is helpful when you are describing motion.

**Essential Questions**
- What is a coordinate system?
- How does the chosen coordinate system affect the sign of objects' positions?
- How are time intervals measured?
- What is displacement?
- How are motion diagrams helpful in answering questions about an object's position or displacement?

**Review Vocabulary**
- **dimension**: extension in a given direction; one dimension is along a straight line; three dimensions are height, width, and length

**New Vocabulary**
- **coordinate system**
- **origin**
- **position**
- **distance**
- **magnitude**
- **vector**
- **scalar**
- **time interval**
- **displacement**
- **resultant**

**Coordinate Systems**

Is it possible to measure distance and time on a motion diagram? Before photographing a runner, you could place a long measuring tape on the ground to show where the runner is in each image. A stopwatch within the camera's view could show the time. But where should you place the end of the measuring tape? When should you start the stopwatch?

**Position and distance** It is useful to identify a system in which you have chosen where to place the zero point of the measuring tape and when to start the stopwatch. A **coordinate system** gives 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 all variables in a coordinate system have the value zero. In the example of the runner, the origin, which is the zero point of the measuring tape, could be 6 m to the left of the tree. Because the motion is in a straight line, your measuring tape should lie along this line. The straight line is an axis of the coordinate system.

You can indicate how far the runner in Figure 6 is from the origin at a certain time on the motion diagram by drawing an arrow from the origin to the point that represents the runner, shown at the bottom of the figure. This arrow represents the runner's **position**, the distance and direction from the origin to the object. In general, **distance** is the entire length of an object's path, even if the object moves in many directions. Because the motion in Figure 6 is in one direction, the arrow lengths represent distance.
Negative position  Is there such a thing as a negative position? Suppose you chose the coordinate system just described but this time placed the origin 4 m left of the tree with the x-axis extending in a positive direction to the right. A position 9 m left of the tree, or 5 m left of the origin, would be a negative position, as shown in Figure 7.

Vectors and Scalars

Many quantities in physics have both size, also called magnitude, and direction. A quantity that has both magnitude and direction is called a vector. You can represent a vector with an arrow. The length of the arrow represents the magnitude of the vector, and the direction of the arrow represents the direction of the vector. A quantity that is just a number without any direction, such as distance, time, or temperature, is called a scalar. In this textbook, we will use boldface letters to represent vector quantities and regular letters to represent scalars.

Time intervals are scalars. When analyzing the runner’s motion, you might want to know how long it took her to travel from the tree to the lamppost. You can obtain this value by finding the difference between the stopwatch reading at the tree and the stopwatch reading at the lamppost. Figure 8 shows these stopwatch readings. The difference between two times is called a time interval.

A common symbol for a time interval is \( \Delta t \), where the Greek letter delta (\( \Delta \)) is used to represent a change in a quantity. Let \( t_i \) represent the initial (starting) time, when the runner was at the tree. Let \( t_f \) represent the final (ending) time of the interval, when the runner was at the lamppost. We define a time interval mathematically as follows.

**TIME INTERVAL**

The time interval is equal to the change in time from the initial time to the final time.

\[
\Delta t = t_f - t_i
\]

The subscripts i and f represent the initial and final times, but 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 her to go from the tree to the lamppost is \( t_f - t_i = 5.0 \text{ s} - 1.0 \text{ s} = 4.0 \text{ s} \). You could instead describe the time interval for the runner to go from the origin to the lamppost. In this case the time interval would be \( t_f - t_i = 5.0 \text{ s} - 0.0 \text{ s} = 5.0 \text{ s} \). The time interval is a scalar because it has no direction. What about the runner’s position? Is it also a scalar?

---

**Figure 7** The green arrow indicates a negative position of –5 m if the direction right of the origin is chosen as positive.

**Infer** What position would the arrow indicate if you chose the direction left of the origin as positive?

**Figure 8** You can use the clocks in the figure to calculate the time interval (\( \Delta t \)) for the runner’s movement from one position to another.

---

**VOCABULARY**

**Magnitude**
- Science usage: a measure of size
- **•** When drawing vectors, the magnitude of a vector is proportional to that vector’s length.
- **•** Common usage: great size or extent

The magnitude of the Grand Canyon is difficult to capture in photographs.
**Positions and displacements are vectors.** You have already seen how a position can be described as negative or positive in order to indicate whether that position is to the left or the right of a coordinate system’s origin. This suggests that position is a vector because position has direction—either right or left in this case.

**Figure 9** shows the position of the runner at both the tree and the lamppost. Notice that you can draw an arrow from the origin to the location of the runner in each case. These arrows have magnitude and direction. In common speech, a position refers to a certain place, but in physics, the definition of a position is more precise. A position is a vector with the arrow’s tail at the origin of a coordinate system and the arrow’s tip at the place.

You can use the symbol \( \mathbf{x} \) to represent position vectors mathematically. In **Figure 9**, the symbol \( \mathbf{x}_i \) represents the position at the tree, and the symbol \( \mathbf{x}_f \) represents the position at the lamppost. The symbol \( \Delta \mathbf{x} \) represents the change in position from the tree to the lamppost. Because a change in position is described and analyzed so often in physics, it has a special name. In physics, a change in position is called a **displacement**. Because displacement has direction, it is a vector.

**READING CHECK** Contrast the distance an object moves and the object’s displacement for straight-line motion.

What was the runner’s displacement when she ran from the tree to the lamppost? By looking at **Figure 9**, you can see that this displacement is 20 m to the right. Notice also, that the displacement from the tree to the lamppost (\( \Delta \mathbf{x} \)) equals the position at the lamppost (\( \mathbf{x}_f \)) minus the position at the tree (\( \mathbf{x}_i \)). This is true in general; displacement equals final position minus initial position.

**DISPLACEMENT**

Displacement is the change in position from initial position to final position.

\[
\Delta \mathbf{x} = \mathbf{x}_f - \mathbf{x}_i
\]

Remember that the initial and final positions are the start and the end of any interval you choose. Although position is a vector, sometimes the magnitude of a position is described without the boldface. In this case, a plus or minus sign might be used to indicate direction.

**READING CHECK** Describe what the direction and length of a displacement arrow indicate.

---

**Figure 9** The vectors \( \mathbf{x}_i \) and \( \mathbf{x}_f \) represent positions. The vector \( \Delta \mathbf{x} \) represents displacement from \( \mathbf{x}_i \) to \( \mathbf{x}_f \).

**Describe** the displacement from the lamppost to the tree.

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**MiniLAB**

**VECTOR MODELS**

How can you model vector addition using construction toys?

**iLab Station**
**Vector addition and subtraction** You will learn about many different types of vectors in physics, including velocity, acceleration, and momentum. Often, you will need to find the sum of two vectors or the difference between two vectors. A vector that represents the sum of two other vectors is called a **resultant**. Figure 10 shows how to add and subtract vectors in one dimension. In a later chapter, you will learn how to add and subtract vectors in two dimensions.

---

**Example of Vector Addition**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 km east</td>
<td>2 km east</td>
</tr>
</tbody>
</table>

Resultant \( R \)

7 km east

\[ R = A + B \]
\[ = 5 \text{ km} + 2 \text{ km} \]
\[ = 7 \text{ km} \]

---

**Examples of Vector Subtraction**

<table>
<thead>
<tr>
<th>A</th>
<th>(-B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 km east</td>
<td>6 km west</td>
</tr>
</tbody>
</table>

Resultant \( R \)

2 km west

\[ R = A - B \]
\[ = 4 \text{ km} - 6 \text{ km} \]
\[ = -2 \text{ km} \]

---

<table>
<thead>
<tr>
<th>A</th>
<th>(-B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 km east</td>
<td>4 km west</td>
</tr>
</tbody>
</table>

Resultant \( R \)

3 km east

\[ R = A - B \]
\[ = 7 \text{ km} - 4 \text{ km} \]
\[ = 3 \text{ km} \]

---

**SECTION 2 REVIEW**

6. **MAIN IDEA** Identify a coordinate system you could use to describe the motion of a girl swimming across a rectangular pool.

7. **Displacement** The motion diagram for a car traveling on an interstate highway is shown below. The starting and ending points are indicated.

   **Start** • • • • • • • • • • **End**

   Make a copy of the diagram. Draw a vector to represent the car’s displacement from the starting time to the end of the third time interval.

8. **Position** Two students added a vector for a moving object’s position at \( t = 2 \text{ s} \) to a motion diagram. When they compared their diagrams, they found that their vectors did not point in the same direction. Explain.

9. **Displacement** The motion diagram for a boy walking to school is shown below.

   **Home** • • • • • • • • • • • • **School**

   Make a copy of this motion diagram, and draw vectors to represent the displacement between each pair of dots.

10. **Critical Thinking** A car travels straight along a street from a grocery store to a 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 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.
Position-Time Graphs

Main Idea
You can use position-time graphs to determine an object’s position at a certain time.

Essential Questions
- What information do position-time graphs provide?
- How can you use a position-time graph to interpret an object’s position or displacement?
- What are the purposes of equivalent representations of an object’s motion?

Review Vocabulary
intersection: a point where lines meet and cross

New Vocabulary
position-time graph
instantaneous position

Finding Positions
When analyzing complex motion, it often is useful to represent the motion in a variety of ways. A motion diagram contains information about an object’s position at various times. Tables and graphs can also show this same information. Review the motion diagrams in Figure 8 and Figure 9. You can use these diagrams to organize the times and corresponding positions of the runner, as in Table 1.

Plotting data
The data listed in Table 1 can be presented on a position-time graph, in which the time data is plotted on a horizontal axis and the position data is plotted on a vertical axis. The graph of the runner’s motion is shown in Figure 11. To draw this graph, first plot the runner’s positions. Then, draw a line that best fits the points.

Estimating time and position
Notice that the graph is not a picture of the runner’s path—the graphed line is sloped, but the runner’s path was horizontal. Instead, the line represents the most likely positions of the runner at the times between the recorded data points. Even though there is no data point exactly when the runner was 12.0 m beyond her starting point or where she was at $t = 4.5$ s, you can use the graph to estimate the time or her position. The example problem on the next page shows how.

Table 1 Position v. Time

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Position (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1.0</td>
<td>5.0</td>
</tr>
<tr>
<td>2.0</td>
<td>10.0</td>
</tr>
<tr>
<td>3.0</td>
<td>15.0</td>
</tr>
<tr>
<td>4.0</td>
<td>20.0</td>
</tr>
<tr>
<td>5.0</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Figure 11
You can create a position-time graph by plotting the positions and times from the table. By drawing a best-fit line, you can estimate other times and positions.

Explain Why is the line on the graph sloped even though it describes motion along a flat path?

View an animation of position-time graphs.
### EXAMPLE PROBLEM 1

**ANALYZE A POSITION-TIME GRAPH**  When did the runner whose motion is described in Figure 11 reach 12.0 m beyond the starting point? Where was she after 4.5 s?

1. **ANALYZE THE PROBLEM**
   - Restate the questions.
     - Question 1: At what time was the magnitude of the runner’s position \( r \) equal to 12.0 m?
     - Question 2: What was the runner’s position at time \( t = 4.5 \) 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 12.0 m mark. Next, find where a vertical line from that point crosses the time axis. The value of \( t \) there is 2.4 s.
   - **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 \( r \) is approximately 22.5 m.

### PRACTICE PROBLEMS

- **For problems 11–13, refer to Figure 12.**

11. The graph in Figure 12 represents the motion of a car moving along a straight highway. Describe in words the car’s motion.

12. Draw a particle model motion diagram that corresponds to the graph.

13. Answer the following questions about the car’s motion. Assume that the positive \( x \)-direction is east of the origin and the negative \( x \)-direction is west of the origin.
   - a. At what time was the car’s position 25.0 m east of the origin?
   - b. Where was the car at time \( t = 1.0 \) s?
   - c. What was the displacement of the car between times \( t = 1.0 \) s and \( t = 3.0 \) s?

14. The graph in Figure 13 represents the motion of two pedestrians who are walking along a straight sidewalk in a city. Describe in words the motion of the pedestrians. Assume that the positive direction is east of the origin.

15. **CHALLENGE**  Ari 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 his position every 2.0 s, noting that he moved 2.6 m every 2.0 s. When was Ari at the following positions?
   - a. 25.0 m from the cafeteria
   - b. 25.0 m from the band room
   - c. Create a graph showing Ari’s motion.
Instantaneous position 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 she would not have been moving. An instant is not a finite period of time, however. It lasts zero seconds. The symbol \( x \) represents the runner’s instantaneous position—the position at a particular instant. Instantaneous position is usually simply called position.

**READING CHECK** Explain what is meant by the instantaneous position of a runner.

Equivalent representations As shown in Figure 14, you now have several different ways to describe motion. You might describe motion using words, pictures (or pictorial representations), motion diagrams, data tables, or position-time graphs. All of these representations contain the same information about the runner’s motion. However, depending on what you want to learn about an object’s motion, some types of representations will be more useful than others. In the pages that follow, you will practice constructing these equivalent representations and learn which ones are most useful for solving different kinds of problems.

**PHYSICS CHALLENGE**

**POSITION-TIME GRAPHS** Natana, Olivia, and Phil all enjoy exercising and often go to a path along the river for this purpose. Natana bicycles at a very consistent 40.25 km/h, Olivia runs south at a constant speed of 16.0 km/h, and Phil walks south at a brisk 6.5 km/h. Natana starts biking north at noon from the waterfalls. Olivia 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 located within the smallest distance interval from each other?
3. What is the length of that distance interval?
Multiple Objects on a Position-Time Graph

A position-time graph for two different runners is shown in Example Problem 2 below. Notice that runner A is ahead of runner B at time \( t = 0 \), but the motion of each runner is different. When and where does one runner pass the other? First, you should restate this question in physics terms: At what time are the two runners at the same position? What is their position at this time? You can evaluate these questions by identifying the point on the position-time graph at which the lines representing the two runners’ motions intersect.

The intersection of two lines on a position-time graph tells you when objects have the same position, but 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, even though they might be the same distance from the starting point.

READING CHECK Explain what the intersection of two lines on a position-time graph means.

What else can you learn from a position-time graph? Notice in Example Problem 2 that the lines on the graph have different slopes. What does the slope of the line on a position-time graph tell you? In the next section, you will use the slope of a line on a position-time graph to determine the velocity of an object. When you study accelerated motion, you will draw other motion graphs and learn to interpret the areas under the plotted lines. In later studies, you will continue to refine your skills with creating and interpreting different types of motion graphs.

EXAMPLE PROBLEM 2

INTERPRETING A GRAPH The graph to the right describes the motion of two runners moving along a straight path. The lines representing their motion are labeled A and B. When and where does runner B pass runner A?

1 ANALYZE THE PROBLEM
Restate the questions.
Question 1: At what time are runner A and runner B at the same position?
Question 2: What is the position of runner A and runner B at this time?

2 SOLVE FOR THE UNKNOWN

Question 1
Examine the graph to find the intersection of the line representing the motion of runner A with the line representing the motion of runner B. These lines intersect at time 45 s.

Question 2
Examine the graph to determine the position when the lines representing the motion of the runners intersect. The position of both runners is about 190 m from the origin.
Runner B passes runner A about 190 m beyond the origin, 45 s after A has passed the origin.
PRACTICE PROBLEMS

For problems 16–19, refer to the figure in Example Problem 2 on the previous page.

16. Where was runner A located at $t = 0$ s?
17. Which runner was ahead at $t = 48.0$ s?
18. When runner A was at 0.0 m, where was runner B?
19. How far apart were runners A and B at $t = 20.0$ s?
20. CHALLENGE Juanita goes for a walk. Later her friend Heather starts to walk after her. Their motions are represented by the position-time graph in Figure 15.
   a. How long had Juanita been walking when Heather started her walk?
   b. Will Heather catch up to Juanita? How can you tell?
   c. What was Juanita’s position at $t = 0.2$ h?
   d. At what time was Heather 5.0 km from the start?

SECTION 3 REVIEW

21. MAIN IDEA Using the particle model motion diagram in Figure 16 of a baby crawling across a kitchen floor, plot a position-time graph to represent the baby’s motion. The time interval between successive dots on the diagram is 1 s.

![Figure 16](image)

For problems 22–25, refer to Figure 17.

22. Particle Model Create a particle model motion diagram from the position-time graph in Figure 17 of a hockey puck gliding across a frozen pond.

23. Time Use the hockey puck’s position-time graph to determine the time when the puck was 10.0 m beyond the origin.

![Figure 17](image)

24. Distance Use the position-time graph in Figure 17 to determine how far the hockey puck moved between times 0.0 s and 5.0 s.

25. 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.

26. Critical Thinking Look at the particle model diagram and the position-time graph shown in Figure 18. 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 diagram are 2 s.

![Figure 18](image)
Snails move much slower than cheetahs. You can see this by observing how far the animals travel during a given time period. For example, a cheetah can travel 30 m in a second, but a snail might move only 1 cm in that time interval.

**Velocity and Speed**

Suppose you recorded the motion of two joggers on one diagram, as shown by the graph in Figure 19. The position of the jogger wearing red changes more than that of the jogger wearing blue. For a fixed time interval, the magnitude of the displacement (\(\Delta x\)) is greater for the jogger in red because she is moving faster. Now, suppose that each jogger travels 100 m. The time interval (\(\Delta t\)) for the 100 m would be smaller for the jogger in red than for the one in blue.

**Slope on a position-time graph** Compare the lines representing the joggers in the graph in Figure 19. The slope of the red jogger’s line is steeper, indicating a greater change in position during each time interval. Recall that you find the slope of a line by first choosing two points on the line. Next, you subtract the vertical coordinate (\(x\) 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. The rise divided by the run is the slope.

**Analyze** How much farther did the red jogger travel than the blue jogger in the 3 s interval described by the graph?

\[
\text{Slope} = \frac{x_f - x_i}{t_f - t_i}
\]

For the red jogger:

\[
= \frac{6.0 \text{ m} - 2.0 \text{ m}}{3.0 \text{ s} - 1.0 \text{ s}}
= 2.0 \text{ m/s}
\]

For the blue jogger:

\[
= \frac{3.0 \text{ m} - 2.0 \text{ m}}{3.0 \text{ s} - 2.0 \text{ s}}
= 1.0 \text{ m/s}
\]
**Average velocity** Notice that the slope of the faster runner’s line in Figure 19 is a greater number. A greater slope indicates a faster speed. Also notice that the slope’s units are meters per second. Looking at how the slope is calculated, you can see that slope is the change in the magnitude of the position divided by the time interval during which that change took place: \( \frac{x_f - x_i}{t_f - t_i} \), or \( \frac{\Delta x}{\Delta t} \). When \( \Delta x \) gets larger, the slope gets larger; when \( \Delta t \) gets larger, the slope gets smaller. This agrees with the interpretation given on the previous page of the speeds of the red and blue joggers. **Average velocity** is the ratio of an object’s change in position to the time interval during which the change occurred. If the object is in uniform motion, so that its speed does not change, then its average velocity is the slope of its position-time graph.

![Average Velocity Equation](equation)

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

**Interpreting slope** The position-time graph’s slope in Figure 20 is \(-5.0 \text{ m/s}\). Notice that the slope of the graph indicates both magnitude and direction. By calculating the slope from the rise divided by the run between two points, you find that the object whose motion is represented by the graph has an average velocity of \(-5.0 \text{ m/s}\). The object started out at a positive position and moves toward the origin. After 4 s, it passes the origin and continues moving in the negative direction at a rate of 5.0 m/s.

**READING CHECK** Explain the meaning of a position-time graph slope that is upward or downward, and above or below the \( x \)-axis.

**Average speed** The slope’s absolute value is the object’s **average speed**, 5.0 m/s, which is the distance traveled divided by the time taken to travel that distance. For uniform motion, average speed is the absolute value of the slope of the object’s position-time graph. The combination of an object’s average speed (\( \bar{v} \)) and the direction in which it is moving is the average velocity (\( \bar{v} \)). Remember that if an object moves in the negative direction, its change in position is negative. This means that an object’s displacement and velocity are both always in the same direction.
EXAMPLE PROBLEM 3

AVERAGE VELOCITY  The graph at the right describes the straight-line motion of a student riding her skateboard along a smooth, pedestrian-free sidewalk. What is her average velocity? What is her average speed?

1 ANALYZE AND SKETCH THE PROBLEM
Identify the graph's coordinate system.

UNKNOWN

\[ v = ? \quad \Delta v = ? \]

2 SOLVE FOR THE UNKNOWN
Find the average velocity using two points on the line.

\[ \Delta v = \frac{\Delta x}{\Delta t} \]

\[ = \frac{x_2 - x_1}{t_2 - t_1} \]

\[ = \frac{12.0 \text{ m} - 0.0 \text{ m}}{7.0 \text{ s} - 0.0 \text{ s}} \]

\[ \Delta v = 1.7 \text{ m/s} \] in the positive direction

The average speed \( |\Delta v| \) is the absolute value of the average velocity, or 1.7 m/s.

3 EVALUATE THE ANSWER
• Are the units correct? The units for both velocity and speed are meters per second.
• Do the signs make sense? The positive sign for the velocity agrees with the coordinate system. No direction is associated with speed.

PRACTICE PROBLEMS

27. The graph in Figure 21 describes the motion of a cruise ship drifting slowly through calm waters. The positive x-direction (along the vertical axis) is defined to be south.

a. What is the ship’s average speed?
b. What is its average velocity?

28. Describe, in words, the cruise ship’s motion in the previous problem.

29. What is the average velocity of an object that moves from 6.5 cm to 3.7 cm relative to the origin in 2.3 s?

30. The graph in Figure 22 represents the motion of a bicycle.

a. What is the bicycle’s average speed?
b. What is its average velocity?

31. Describe, in words, the bicycle’s motion in the previous problem.

32. CHALLENGE When Marshall takes his pet dog for a walk, the dog walks at a very consistent pace of 0.55 m/s. Draw a motion diagram and a position-time graph to represent Marshall’s dog walking the 19.8-m distance from in front of his house to the nearest stop sign.
**Instantaneous velocity** Why do we call the quantity $\frac{\Delta x}{\Delta t}$ average velocity? Why don't we just call it velocity? 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 object's speed could have remained the same, increased, or decreased. The object may have stopped or even changed direction. You can find the average velocity for each time interval in the motion diagram, but you cannot find the speed and the direction of the object at any specific instant. The speed and the 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 $v$.

**READING CHECK** Explain how average velocity is different from velocity.

**Average velocity on motion diagrams** When an object moves between two points, its average velocity is in the same direction as its displacement. The two quantities are also proportional—when displacement is greater during a given time interval, so is average velocity. A motion diagram indicates the average velocity's direction and magnitude.

Imagine two cars driving down the road at different speeds. A video camera records the motion of the cars at the rate of one frame every second. Imagine that each car has a paintbrush attached to it that automatically descends and paints a red 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 that the paintbrushes make on the ground below the cars. In this book, we use red to indicate velocity vectors on motion diagrams. Figure 23 shows motion diagrams with velocity vectors for two cars. One is moving to the right, and the other is moving to the left.

**READING CHECK** Identify what the lengths of velocity vectors mean.

**Equation of Motion**

Often it is more efficient to use an equation, rather than a graph, to solve problems. Any time you graph a straight line, you can find an equation to describe it. Take another look at the graph in Figure 20 for the object moving with a constant velocity of $-5.0\ \text{m/s}$. Recall that you can represent any straight line with the equation $y = mx + b$, where $y$ is the quantity plotted on the vertical axis, $m$ is the line's slope, $x$ is the quantity plotted on the horizontal axis, and $b$ is the line's $y$-intercept.

For the graph in Figure 20, the quantity plotted on the vertical axis is position, represented by the variable $x$. The line's slope is $-5.0\ \text{m/s}$, which is the object's average velocity ($\vec{v}$). The quantity plotted on the horizontal axis is time ($t$). The $y$-intercept is $20.0\ \text{m}$. What does this $20.0\ \text{m}$ represent? This shows that the object was at a position of $20.0\ \text{m}$ when $t = 0.0\ \text{s}$. This is called the initial position of the object and it is designated $x_i$.

**REAL-WORLD PHYSICS**

**SPEED RECORDS** The world record for the men's 100-m dash is 9.58 s, established in 2009 by Usain Bolt. The world record for the women's 100-m dash is 10.49 s, established in 1988 by Florence Griffith-Joyner.

**MiniLAB**

**VELOCITY VECTORS** How can velocity vectors represent the motion of a mass on a string?

**Figure 23** The length of each velocity vector is proportional to the magnitude of the velocity that it represents.
EXAMPLE PROBLEM 4

The figure shows a motorcyclist traveling east along a straight road. After passing point B, the cyclist continues to travel at an average velocity of 12 m/s east and arrives at point C 3.0 s later. What is the position of point C?

1. ANALYZE THE PROBLEM
   Choose a coordinate system with the origin at A.
   KNOWN
   $\vec{v} = 12 \text{ m/s east}$
   $x_i = 46 \text{ m east}$
   $t = 3.0 \text{ s}$
   UNKNOWN
   $x = ?$

2. SOLVE FOR THE UNKNOWN
   
   $x = \vec{v}t + x_i$
   $= (12 \text{ m/s})(3.0 \text{ s}) + 46 \text{ m}$
   $= 82 \text{ m}$
   
   $x = 82 \text{ m east}$

3. EVALUATE THE ANSWER
   • Are the units correct? Position is measured in meters.
   • Does the direction make sense? The motorcyclist is traveling east the entire time.

A summary is given to the left of how the general variables in the straight-line formula are changed to the specific variables you have been using to describe motion. The table also shows the numerical values for the average velocity and initial position. Consider the graph shown in Figure 20. The mathematical equation for the line graphed is as follows:

$$y = (-5.0 \text{ m/s})x + 20.0 \text{ m}$$

You can rewrite this equation, using $x$ for position and $t$ for time.

$$x = (-5.0 \text{ m/s})t + 20.0 \text{ m}$$

It might be confusing to use $y$ and $x$ in math but use $x$ and $t$ in physics. You do this because there are many types of graphs in physics, including position v. time graphs, velocity v. time graphs, and force v. position graphs. For a position v. time graph, the math equation $y = mx + b$ can be rewritten as follows:

$$x = \vec{v}t + x_i$$

This equation gives you another way to represent motion. Note that a graph of $x$ v. $t$ would be a straight line.
PRACTICE PROBLEMS
For problems 33–36, refer to Figure 24.

33. The diagram at the right shows the path of a ship that sails at a constant velocity of 42 km/h east. What is the ship’s position when it reaches point C, relative to the starting point, A, if it sails from point B to point C in exactly 1.5 h?

34. Another ship starts at the same time from point B, but its average velocity is 58 km/h east. What is its position, relative to A, after 1.5 h?

35. What would a ship’s position be if that ship started at point B and traveled at an average velocity of 35 km/h west to point D in a time period of 1.2 h?

36. CHALLENGE Suppose two ships start from point B and travel west. One ship travels at an average velocity of 35 km/h for 2.2 h. Another ship travels at an average velocity of 26 km/h for 2.5 h. What is the final position of each ship?

SECTION 4 REVIEW

37. MAIN IDEA How is an object’s velocity related to its position?

For problems 38–40, refer to Figure 25.

38. Ranking Task Rank the position-time graphs according to the average speed, from greatest average speed to least average speed. Specifically indicate any ties.

39. Contrast Average Velocities Describe differences in the average velocities shown on the graph for objects A and B. Describe differences in the average velocities shown on the graph for objects C and D.

40. Ranking Task Rank the graphs in Figure 25 according to each object’s initial position, from most positive position to most negative position. Specifically indicate any ties. Would your ranking be different if you ranked according to initial distance from the origin?

41. Average Speed and Average Velocity Explain how average speed and average velocity are related to each other for an object in uniform motion.

42. Position Two cars are traveling along a straight road, as shown in Figure 26. They pass each other at point B and then continue in opposite directions. The red car travels for 0.25 h from point B to point C at a constant velocity of 32 km/h east. The blue car travels for 0.25 h from point B to point D at a constant velocity of 48 km/h west. How far has each car traveled from point B? What is the position of each car relative to the origin, point A?

43. Position A car travels north along a straight highway at an average speed of 85 km/h. After driving 2.0 km, the car passes a gas station and continues along the highway. What is the car’s position relative to the start of its trip 0.25 h after it passes the gas station?

44. Critical Thinking In solving a physics problem, why is it important to create pictorial and physical models before trying to solve an equation?
What is time? If one hour of time passes for you, does one hour of time also pass for your friend? You might think that the answer is yes, but it is actually no. Time passes at different rates depending on your point of view.

**Speed and time** Think about how wrong that last sentence seems. For example, suppose that you tell your friend to meet you at the mall in one hour. You both assume that when one hour passes for you, one hour also passes for your friend.

This is because you and your friend move very slowly relative to each other. At slow speeds, one hour for you is almost exactly the same as one hour for your friend. As you move faster relative to your friend, however, the difference between your time and your friend’s time increases.

**How fast?** You would need to travel very fast relative to your friend in order for any difference to be noticeable. If you travel at 100,000 km/s, then only 57 minutes pass for you when one hour passes for your friend. At 200,000 km/s, only 45 minutes pass for you during your friend’s hour. Figure 1 shows how your time compares to one hour of your friend’s time as you travel faster and faster relative to your friend.

**Real–World Application** All of this might seem rather pointless. After all, even the fastest spacecraft travel at less than 100 km/s. Have you ever used a GPS receiver, such as the one shown in Figure 2? At 4 km/s, a GPS satellite travels fast enough for time differences to affect the accuracy of the GPS receiver. The effect is small—approximately 10 μs in one day. It is enough, however, that the GPS would become completely useless within one month if engineers did not account for it.

**FIGURE 1** In this graph, 60 minutes always passes for your friend, but other amounts of time pass for you.

**FIGURE 2** This GPS receiver would be completely inaccurate if the designers of the Global Positioning System did not understand the relativity of time.

**Research** Gravity also affects time. Research how gravity affects time on Earth and on a GPS satellite.
You can use displacement and velocity to describe an object’s motion.

**VOCABULARY**
- motion diagram (p. 36)
- particle model (p. 36)

**SECTION 1 Picturing Motion**

**MAIN IDEA** You can use motion diagrams to show how an object’s position changes over time.
- A motion diagram shows the position of an object at successive equal time intervals.
- In a particle model motion diagram, an object’s position at successive times is represented by a series of dots. The spacing between dots indicates whether the object is moving faster or slower.

**VOCABULARY**
- coordinate system (p. 37)
- origin (p. 37)
- position (p. 37)
- distance (p. 37)
- magnitude (p. 38)
- vector (p. 38)
- scalar (p. 38)
- time interval (p. 38)
- displacement (p. 39)
- resultant (p. 40)

**SECTION 2 Where and When?**

**MAIN IDEA** A coordinate system is helpful when you are describing motion.
- A coordinate system gives the location of the zero point of the variable you are studying and the direction in which the values of the variable increase.
- A vector drawn from the origin of a coordinate system to an object indicates the object’s position in that coordinate system. The directions chosen as positive and negative on the coordinate system determine whether the objects’ positions are positive or negative in the coordinate system.
- A time interval is the difference between two times.
  \[ \Delta t = t_f - t_i \]
- Change in position is displacement, which has both magnitude and direction.
  \[ \Delta x = x_f - x_i \]
- On a motion diagram, the displacement vector’s length represents how far the object was displaced. The vector points in the direction of the displacement, from \( x_i \) to \( x_f \).

**VOCABULARY**
- position-time graph (p. 41)
- instantaneous position (p. 43)

**SECTION 3 Position-Time Graphs**

**MAIN IDEA** You can use a position-time graph to determine an object’s position at a certain time.
- Position-time graphs provide information about the motion of objects. They also might indicate where and when two objects meet.
- The line on a position-time graph describes an object’s position at each time.
- Motion can be described using words, motion diagrams, data tables, or graphs.

**VOCABULARY**
- average velocity (p. 47)
- average speed (p. 47)
- instantaneous velocity (p. 49)

**SECTION 4 How Fast?**

**MAIN IDEA** An object’s velocity is the rate of change in its position.
- An object’s velocity tells how fast it is moving and in what direction it is moving.
- Speed is the magnitude of velocity.
- Slope on a position-time graph describes the average velocity of the object.
  \[ \mathbf{v} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i} \]
- You can represent motion with pictures and physical models. A simple equation relates an object’s initial position \( (x_i) \), its constant average velocity \( (\mathbf{v}) \), its position \( (x) \), and the time \( (t) \) since the object was at its initial position.
  \[ x = \mathbf{v} t + x_i \]
SECTION 1  Picturing Motion
Mastering Concepts
45. What is the purpose of drawing a motion diagram?
46. Under what circumstances is it legitimate to treat an object as a particle when solving motion problems?

SECTION 2  Where and When?
Mastering Concepts
47. The following quantities describe location or its change: position, distance, and displacement. Briefly describe the differences among them.
48. How can you use a clock to find a time interval?

SECTION 3  Position-Time Graphs
Mastering Concepts
49. 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?
50. BIGIDEA  Which equation describes how the average velocity of a moving object relates to its displacement?
51. 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.
52. What does the slope of a position-time graph measure?
53. If you know the time it took an object to travel between two points and the positions of the object at the points, can you determine the object’s instantaneous velocity? Its average velocity? Explain.

Mastering Problems
54. You ride a bike at a constant speed of 4.0 m/s for 5.0 s. How far do you travel?
55. Astronomy  Light from the Sun reaches Earth in about 8.3 min. The speed of light is 3.00×10^8 m/s. What is the distance from the Sun to Earth?
56. Problem Posing  Complete this problem so that someone must solve it using the concept of average speed: “A butterfly travels 15 m from one flower to another ....”

57. 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 is a way she can still have some idea of her time. As she passes a particular bank building, 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?

58. 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 much sooner will your friend finish the trip?

Applying Concepts
59. Ranking Task  The position-time graph in Figure 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.

50
51
52
53
54
55
56
57
58
59
60
61. Test the following combinations and explain why each does not have the properties needed to describe the concept of velocity: \( \Delta x + \Delta t, \Delta x - \Delta t, \Delta x \times \Delta t, \frac{\Delta t}{\Delta x} \).

62. Football When solving physics problems, what must be true about the motion of a football in order for you to treat the football as if it were a particle?

63. Figure 29 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?

![Position v. Time](Figure 29)

**Mixed Review**

64. Cycling A cyclist traveling along a straight path maintains a constant velocity of 5.0 m/s west. At time \( t = 0.0 \) s, the cyclist is 250 m west of point A.
   a. Plot a position-time graph of the cyclist’s location from point A at 10.0-s intervals for a total time of 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?

65. Figure 30 is a particle model diagram for a chicken casually walking across a road. Draw the corresponding position-time graph, and write an equation to describe the chicken’s motion.

![Figure 30](This side The other side)

Time intervals are 0.1 s.

66. Figure 31 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 long does Joszi paddle before passing Heike?
   c. Where on the river does it appear that there might be a swift current?

![Position v. Time](Figure 31)

67. 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 over 3 hours. 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.

68. Draw a position-time graph for two cars traveling to a beach that 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?

69. Two cars travel along a straight road. When a stopwatch reads \( t = 0.00 \) h, car A is at \( x_A = 48.0 \) km moving at a constant speed of 36.0 km/h. Later, when the watch reads \( t = 0.50 \) h, car B is at \( x_B = 0.00 \) km moving at 48.0 km/h. Answer the following questions, first graphically by creating a position-time graph and then algebraically by writing equations for the positions \( x_A \) and \( x_B \) 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?
70. The graph in Figure 32 depicts Jim’s movement along a straight path. The origin is at one end of the path.

![Position v. Time Graph](image)

Figure 32

a. **Reverse Problem** Write a story describing Jim’s movements along the path that would correspond to the motion represented by the graph.

b. When is Jim 6.0 m from the origin?

c. How much time passes between when Jim starts moving and when he is 12.0 m from the origin?

d. What is Jim’s average velocity between 37.0 s and 46.0 s?

**Thinking Critically**

71. **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. Table 2 shows their data.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Position (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1.3</td>
<td>25.0</td>
</tr>
<tr>
<td>2.7</td>
<td>50.0</td>
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<tr>
<td>8.6</td>
<td>175.0</td>
</tr>
<tr>
<td>10.3</td>
<td>200.0</td>
</tr>
</tbody>
</table>

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 line’s slope. What was the car’s speed?

72. **Apply Concepts** You want to average 90 km/h on a car trip. You cover the first half of the distance at an average speed of 48 km/h. What average speed must you have for 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.

73. **Design an Experiment** Every time someone drives a particular red motorcycle past your friend’s home, his father becomes angry. 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 the motorcycle is speeding the next time it passes your friend’s house.

74. **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**

75. Physicists have determined that the speed of light is \(3.00 \times 10^8\) m/s. How did they arrive at this number? Read about some of the experiments scientists have performed to determine light’s speed. Describe how the experimental techniques improved to make the experiments’ results more accurate.

76. Some species of animals have good endurance, while others have the ability to move very quickly, but only for 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**

77. Convert each of the following time measurements to its equivalent in seconds:

a. 58 ns  
c. 9270 ms

b. 0.046 Gs  
d. 12.3 ks

78. State the number of significant figures in the following measurements:

a. 3218 kg  
c. 801 kg

b. 60.080 kg  
d. 0.000534 kg

79. Using a calculator, Chris obtained the following results. Rewrite each answer using the correct number of significant figures.

a. \(5.32 \text{ mm} + 2.1 \text{ mm} = 7.4200000 \text{ mm}\)

b. \(13.597 \text{ m} \times 3.65 \text{ m} = 49.62905 \text{ m}^2\)

(continued...)

---

**Figure 32**

Position v. Time

0.0 10.0 20.0 30.0 40.0 50.0 60.0

0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0

Time (s)

Position (m)

---

**Table 2** Position v. Time

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Position (m)</th>
</tr>
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<tbody>
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<td>10.3</td>
<td>200.0</td>
</tr>
</tbody>
</table>
MULTIPLE CHOICE

1. Which statement would be true about the particle model motion diagram for an airplane flying at a constant speed of 850 km/h?
   A. The dots would start close together and get farther apart as the plane moved away from the airport.
   B. The dots would be far apart at the beginning and get closer together as the plane moved away from the airport.
   C. The dots would form an evenly spaced pattern.
   D. The dots would start close together, get farther apart, and then get close together again as the airplane traveled away from the airport.

2. Which statement about drawing vectors is true?
   A. The vector's length should be proportional to its magnitude.
   B. You need a vector diagram to solve all physics problems properly.
   C. A vector is a quantity that has a magnitude but no direction.
   D. All quantities in physics are vectors.

3. The figure below shows a simplified graph of a bicyclist’s motion. (Speeding up and slowing down motion is ignored.) When is the person’s velocity greatest?
   A. section I C. point D
   B. section III D. point B

4. What is the average velocity of a train moving along a straight track if its displacement is 192 m east during a time period of 8.0 s?
   A. 12 m/s east C. 48 m/s east
   B. 24 m/s east D. 96 m/s east

5. 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. A loud noise then causes the squirrel to scamper back up the tree in 0.1 min to the exact position on the branch from which it started. Ignoring speeding up and slowing down motion, which graph most closely represents the squirrel’s vertical displacement from the base of the tree?

FREE RESPONSE

6. A rat is moving along a straight path. Find the rat’s position relative to its starting point if it moves 12.8 cm/s north for 3.10 s.

NEED EXTRA HELP?

<table>
<thead>
<tr>
<th>If You Missed Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
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