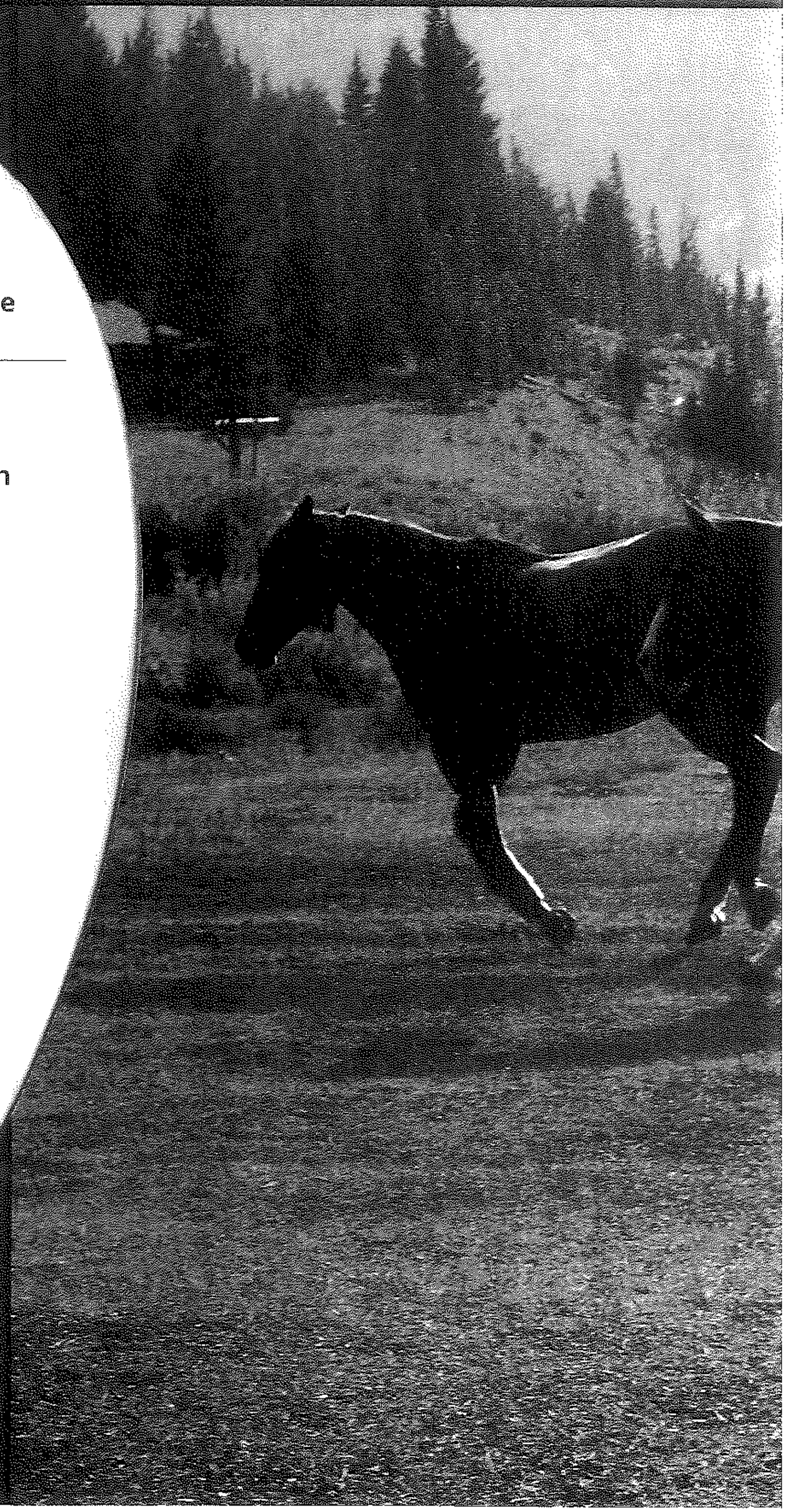
Chapter 9 Motion

The BIG Idea
Motion and Forces

How can an object's motion be described?

Chapter Preview



The wild horses are in motion. ▶

Lab zone™ **Chapter Project**

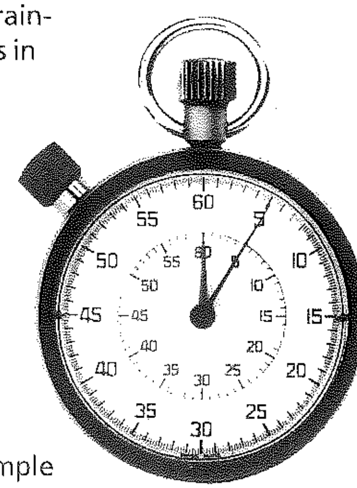
Show Some Motion

Your Goal To identify the motion of several common objects and calculate how fast each one moves

To complete this project, you must

- measure distance and time carefully
- calculate the speed of each object using your data
- prepare display cards of your data, diagrams, and calculations
- follow the safety guidelines in Appendix A

Plan It! With your classmates, brainstorm several examples of objects in motion, such as a feather falling, your friend riding a bicycle, or the minute hand moving on a clock. Choose your examples and have your teacher approve them. Create a data table for each example and record your measurements. For accuracy, repeat your measurements. Then calculate the speed of each object. Make display cards for each example that show data, diagrams, and calculations.



Section 1

Describing and Measuring Motion

Reading Preview

Key Concepts

- When is an object in motion?
- How do scientists measure distance?

Key Terms

- motion
- reference point
- International System of Units
- meter

Target Reading Skill

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

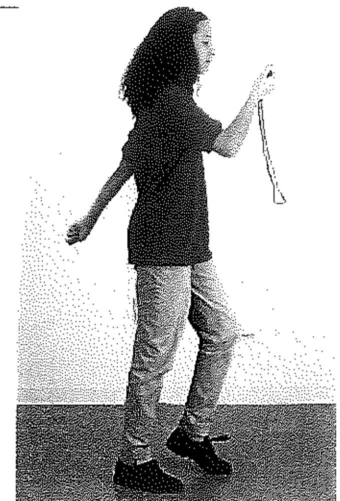
What You Know
1. A moving object changes position. 2.

What You Learned
1. 2.

Lab zone Discover Activity

How Fast and How Far?

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

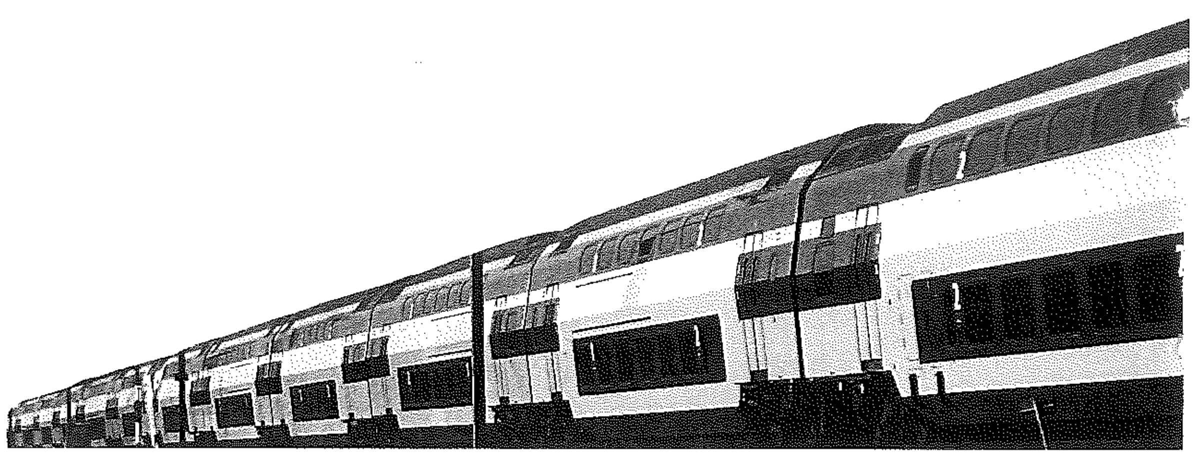


Think It Over

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

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

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



Describing Motion

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

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

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

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

Reading Checkpoint **What is a reference point?**

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

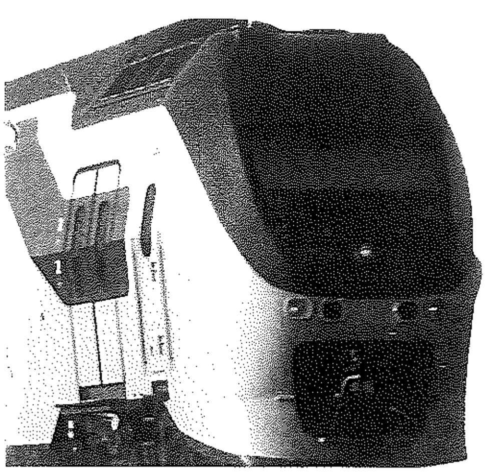


FIGURE 2 Relative Motion
Whether or not an object is in motion depends on the reference point.
Comparing and Contrasting *Are the skydivers moving relative to the airplane from which they jumped? Are they moving relative to the ground?*

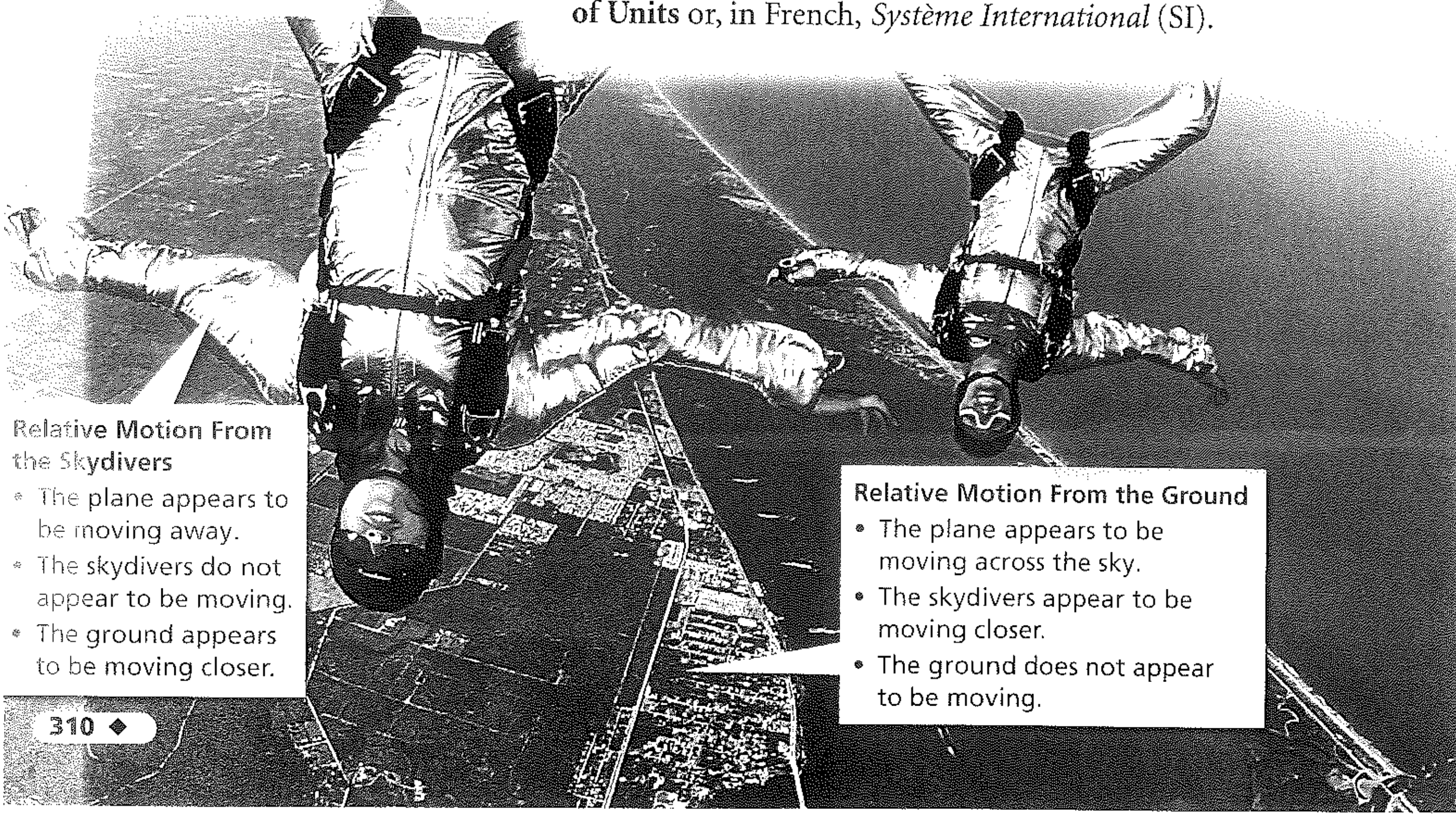
Relative Motion Are you moving as you read this book? The answer to that question depends on your reference point. When your chair is your reference point, you are not moving. But if you choose another reference point, you may be moving.

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

Measuring Distance

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

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



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

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

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

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

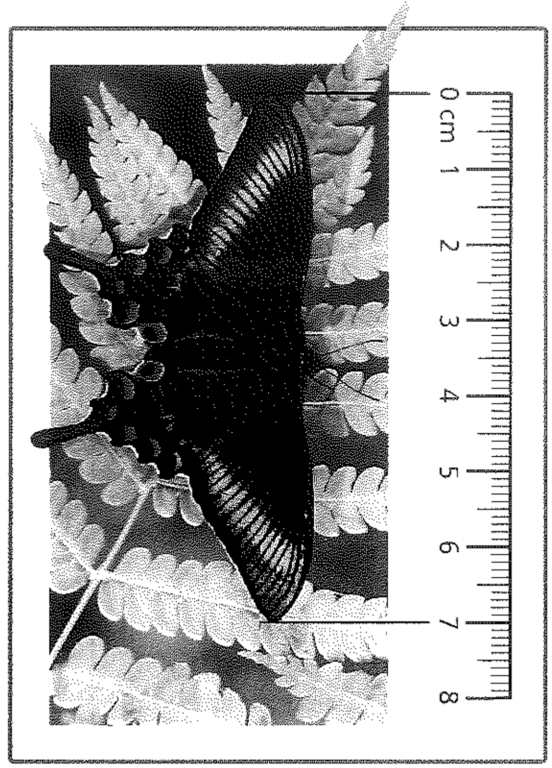


FIGURE 3
Measuring Distance
You can measure distances shorter than 1 meter in centimeters. The wingspan of the butterfly is 7 cm.

Section 1 Assessment

Target Reading Skill

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

Reviewing Key Concepts

1. a. Reviewing How do you know if an object is moving?
   b. Explaining Why is it important to know if your reference point is moving?
   c. Applying Concepts Suppose you are riding in a car. Describe your motion relative to the car, the road, and the sun.
2. a. Identifying What is the SI unit for length?
   b. Defining How many centimeters are there in a meter? How many meters are there in a kilometer?
   c. Calculating This week at swim practice, Jamie swam a total of 1,500 m, while Ellie swam 1.6 km. Convert Ellie's distance to meters. Which swimmer swam the greater distance?

Lab zone At-Home Activity

Roomy Size With the help of a family member, use a ruler to measure the length and width of a room at home to the nearest centimeter. Convert these measurements into meters and then into millimeters.

Section 2

Speed and Velocity

Reading Preview

Key Concepts

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

Key Terms

- speed
- average speed
- instantaneous speed
- velocity
- slope

Target Reading Skill

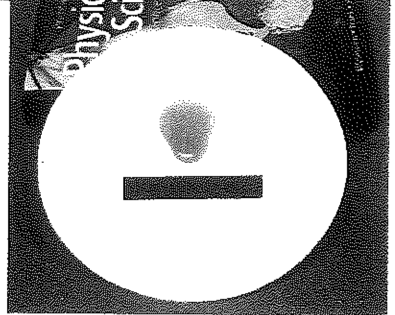
Previewing Visuals Before you read, preview Figure 5. Then write two questions that you have about the diagram in a graphic organizer like the one below. As you read, answer your questions.

Graphing Motion

Q.	How can you determine the slope of a graph?
A.	
Q.	

Lab zone Discover Activity

How Slow Can It Flow?



1. Put a spoonful of honey on a plate.
2. Place a piece of tape 4 cm from the bottom edge of the honey.
3. Lift one side of the plate just high enough that the honey starts to flow.
4. Reduce the plate's angle until the honey barely moves. Prop up the plate at this angle.
5. Time how long the honey takes to reach the tape. Calculate the speed of the honey.

Think It Over

Forming Operational Definitions When an object doesn't appear to be moving at first glance, how can you tell if it is?

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

Calculating Speed

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

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

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

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

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

$$\text{Total distance} = 32 \text{ km} + 13 \text{ km} = 45 \text{ km}$$

$$\text{Total time} = 2 \text{ h} + 1 \text{ h} = 3 \text{ h}$$

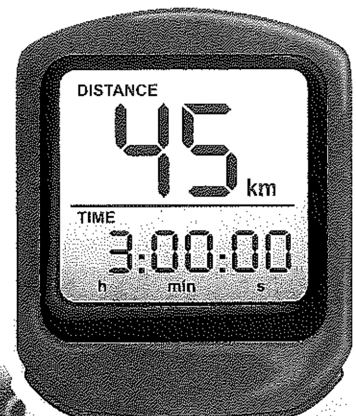
$$\text{Average speed} = \frac{45 \text{ km}}{3 \text{ h}} = 15 \text{ km/h}$$

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

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

✔ Reading Checkpoint **How do you calculate average speed?**

FIGURE 4
Measuring Speed
Cyclists use an electronic device known as a cyclometer to track the distance and time that they travel. A cyclometer can calculate both average and instantaneous speed.
Comparing and Contrasting
Explain why the instantaneous speed and the average speed shown below are different.



Describing Velocity

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

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

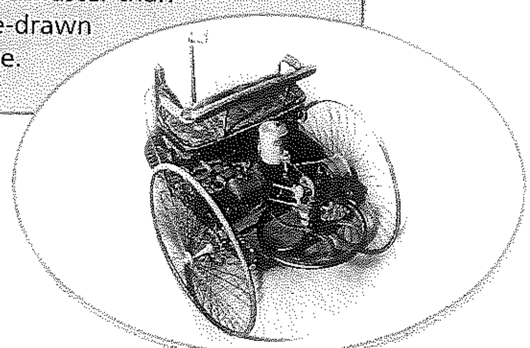
• Tech & Design in History •

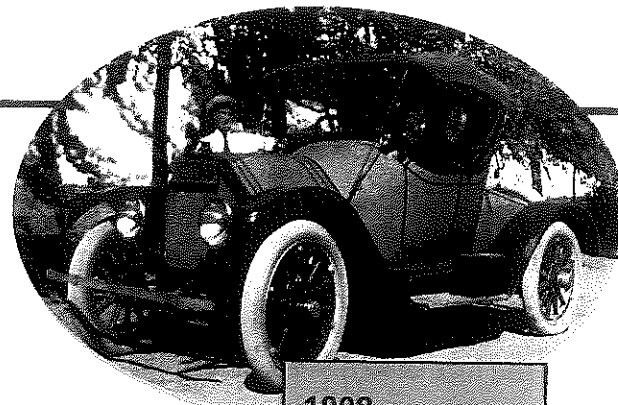
The Speed of Transportation

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

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

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





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

1800 **1850** **1900**

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

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

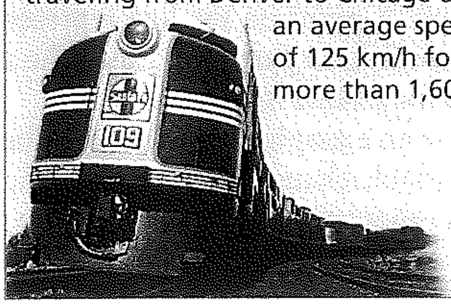
Reading Checkpoint What is velocity?

Writing in Science

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

1943 Diesel Freight Train

This diesel train traveled along the Atchison, Topeka, and Santa Fe Railroad in Arizona. Perhaps the most famous diesel train, the *Zephyr*, set a long-distance record in 1934, traveling from Denver to Chicago at an average speed of 125 km/h for more than 1,600 km.



1956 Interstate Highway System Established

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

2003 Maglev in Motion

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

1950 2000 2050

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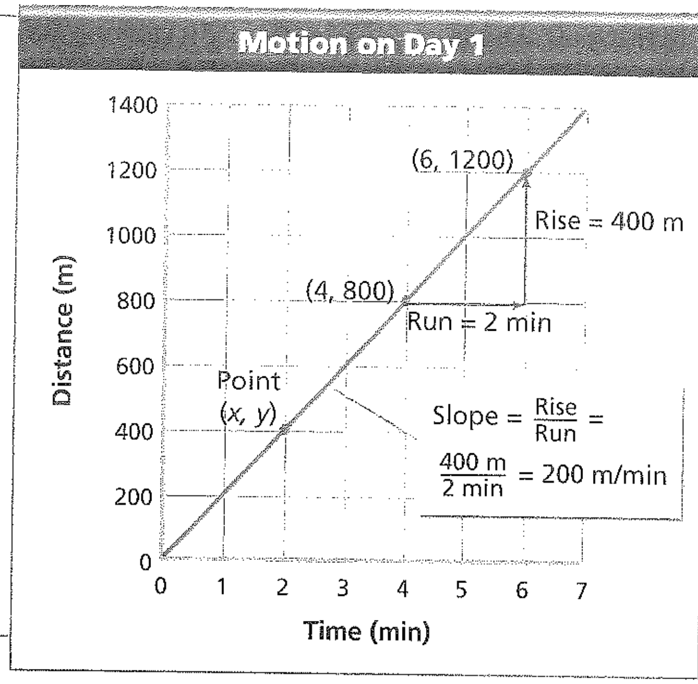
FIGURE 5
Graphing Motion
Distance-versus-time graphs can be used to analyze motion. On the jogger's first day of training, her speed is the same at every point. On the second day of training, her speed varies. Reading Graphs *On the first day, how far does the jogger run in 5 minutes?*



Graphing Motion

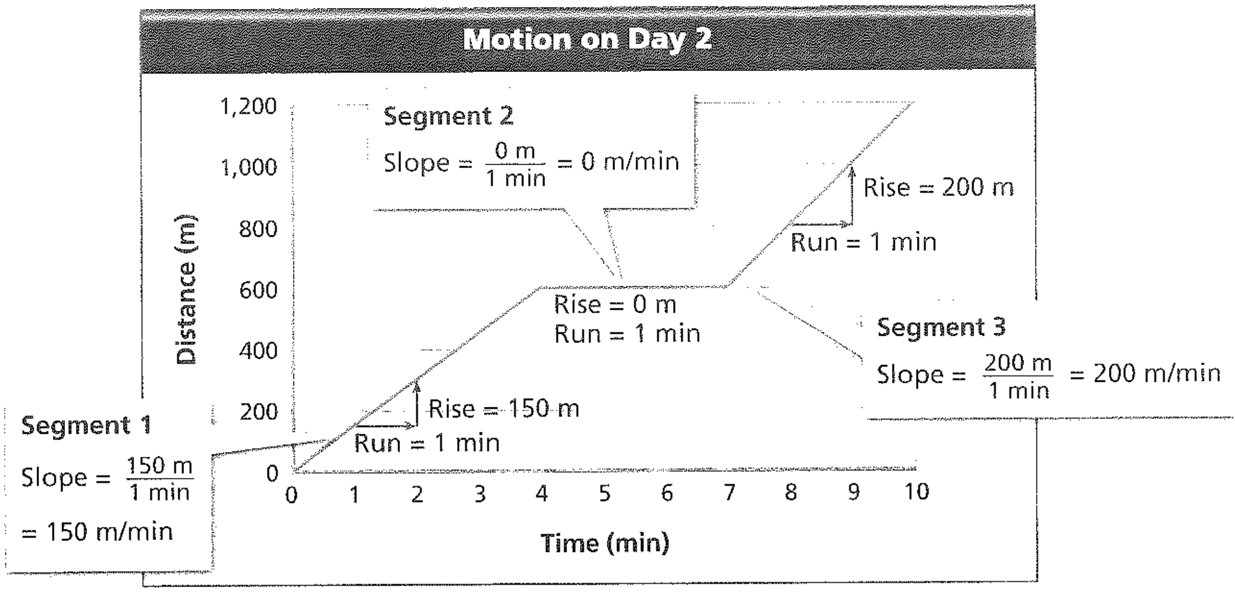
You can show the motion of an object on a line graph in which you plot distance versus time. The graphs you see in Figure 5 are distance-versus-time motion graphs. Time is shown on the horizontal axis, or x-axis. Distance is shown on the vertical axis, or y-axis. A point on the line represents the distance an object has traveled at a particular time. The x value of the point is time, and the y value is distance.

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

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

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

In *Figure 5*, using the points shown, the rise is 400 meters and the run is 2 minutes. To find the slope, you divide 400 meters by 2 minutes. The slope is 200 meters per minute.



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

Reading Checkpoint **What is the slope of a graph?**

Section 2 Assessment

Target Reading Skill Previewing Visuals Refer to your questions and answers about Figure 5 to help you answer Question 2 below.

Reviewing Key Concepts

1. a. Defining What is speed?
   b. Describing What do you know about the motion of an object that has an average speed of 1 m/s?
   c. Comparing and Contrasting What is the difference between speed and velocity?
2. a. Identifying What does the slope of a distance-versus-time graph show you about the motion of an object?
   b. Calculating The rise of a line on a distance-versus-time graph is 600 m and the run is 3 minutes. What is the slope of the line?

Writing in Science

Explanation Think about a recent trip that you have taken. What was the approximate total distance that you traveled and the total time it took? Calculate your average speed from this information. Then explain how your instantaneous speed varied over the course of the trip.

Lab zone **Skills Lab**

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Problem

How does the steepness of a ramp affect how fast an object rolling off it moves across the floor?

Skills Focus

measuring, calculating, graphing

Materials

- skateboard • meter stick • protractor
- masking tape • flat board, about 1.5 m long
- small piece of sturdy cardboard
- supports to prop up the board (books, boxes)
- two stopwatches

Procedure

1. In your notebook, make a data table like the one below. Include space for five angles.
2. Lay the board flat on the floor. Using masking tape, mark a starting line in the middle of the board. Mark a finish line on the floor 1.5 m beyond one end of the board. Place a barrier after the finish line.
3. Prop up the other end of the board to make a slight incline. Use a protractor to measure the angle that the board makes with the ground. Record the angle in your data table.
4. Working in groups of three, have one person hold the skateboard so that its front wheels are even with the starting line. As the holder releases the skateboard, the other two students should start their stopwatches.
5. One timer should stop his or her stopwatch when the front wheels of the skateboard reach the end of the incline.
6. The second timer should stop his or her stopwatch when the front wheels reach the finish line. Record the times in your data table in the columns labeled Time 1 and Time 2.
7. Repeat Steps 4–6 two more times. If your results for the three times aren't within 0.2 second of one another, carry out more trials.

Data Table

Angle (degrees)	Trial Number	Time 1 (to bottom) (s)	Time 2 (to finish) (s)	Avg Time 1 (s)	Avg Time 2 (s)	Avg Time 2 – Avg Time 1 (s)	Avg Speed (m/s)
	1						
	2						
	3						
	1						
	2						
	3						
	1						
	2						

8. Repeat Steps 3–7 four more times, making the ramp gradually steeper each time.
9. For each angle of the incline, complete the following calculations and record them in your data table.
   a. Find the average time the skateboard takes to get to the bottom of the ramp (Time 1).
   b. Find the average time the skateboard takes to get to the finish line (Time 2).
   c. Subtract the average of Time 1 from the average of Time 2.

Analyze and Conclude

1. Calculating How can you find the average speed of the skateboard across the floor for each angle of the incline? Determine the average speed for each angle and record it in your data table.
2. Classifying Which is your manipulated variable and which is your responding variable in this experiment? Explain. (For a discussion of manipulated and responding variables, see the Skills Handbook.)
3. Graphing On a graph, plot the average speed of the skateboard (on the *y*-axis) against the angle of the ramp (on the *x*-axis).
4. Drawing Conclusions What does your graph show about the relationship between the skateboard's speed and the angle of the ramp?
5. Measuring If your measurements for distance, time, or angle were inaccurate, how would your results have been affected?
6. Communicating Do you think your method of timing was accurate? Did the timers start and stop their stopwatches exactly at the appropriate points? How could the accuracy of the timing be improved? Write a brief procedure for your method.

Design an Experiment

A truck driver transporting new cars needs to roll the cars off the truck. You offer to design a ramp to help with the task. What measurements would you make that might be useful? Design an experiment to test your ideas. *Obtain your teacher's permission before carrying out your investigation.*

Section 3

Integrating Mathematics

Acceleration

Reading Preview

Key Concepts

- What kind of motion does acceleration refer to?
- How is acceleration calculated?
- What graphs can be used to analyze the motion of an accelerating object?

Key Term

- acceleration

Target Reading Skill

Identifying Main Ideas As you read the What Is Acceleration? section, write the main idea in a graphic organizer like the one below. Then write three supporting details that give examples of the main idea.

Main Idea

In science, acceleration refers to . . .

Detail | Detail | Detail

Lab zone Discover Activity

Will You Hurry Up?

1. Measure 10 meters in an open area. Mark the distance with masking tape.
2. Walk the 10 meters in such a way that you keep moving faster throughout the entire distance. Have a partner time you.
3. Repeat Step 2, walking the 10 meters in less time than you did before. Then try it again, this time walking the distance in twice the time as the first. Remember to keep speeding up throughout the entire 10 meters.

Think It Over

Inferring How is the change in your speed related to the time in which you walk the 10-meter course?

The pitcher throws. The ball speeds toward the batter. Off the bat it goes. It's going, going, gone! A home run!

Before landing, the ball went through several changes in motion. It sped up in the pitcher's hand, and lost speed as it traveled toward the batter. The ball stopped when it hit the bat, changed direction, sped up again, and eventually slowed down. Most examples of motion involve similar changes. In fact, rarely does any object's motion stay the same for very long.

What Is Acceleration?

Suppose you are a passenger in a car stopped at a red light. When the light changes to green, the driver steps on the accelerator. As a result, the car speeds up, or accelerates. In everyday language, *acceleration* means "the process of speeding up."

Acceleration has a more precise definition in science. Scientists define **acceleration** as the rate at which velocity changes. Recall that velocity describes both the speed and direction of an object. A change in velocity can involve a change in either speed or direction—or both. **In science, acceleration refers to increasing speed, decreasing speed, or changing direction.**

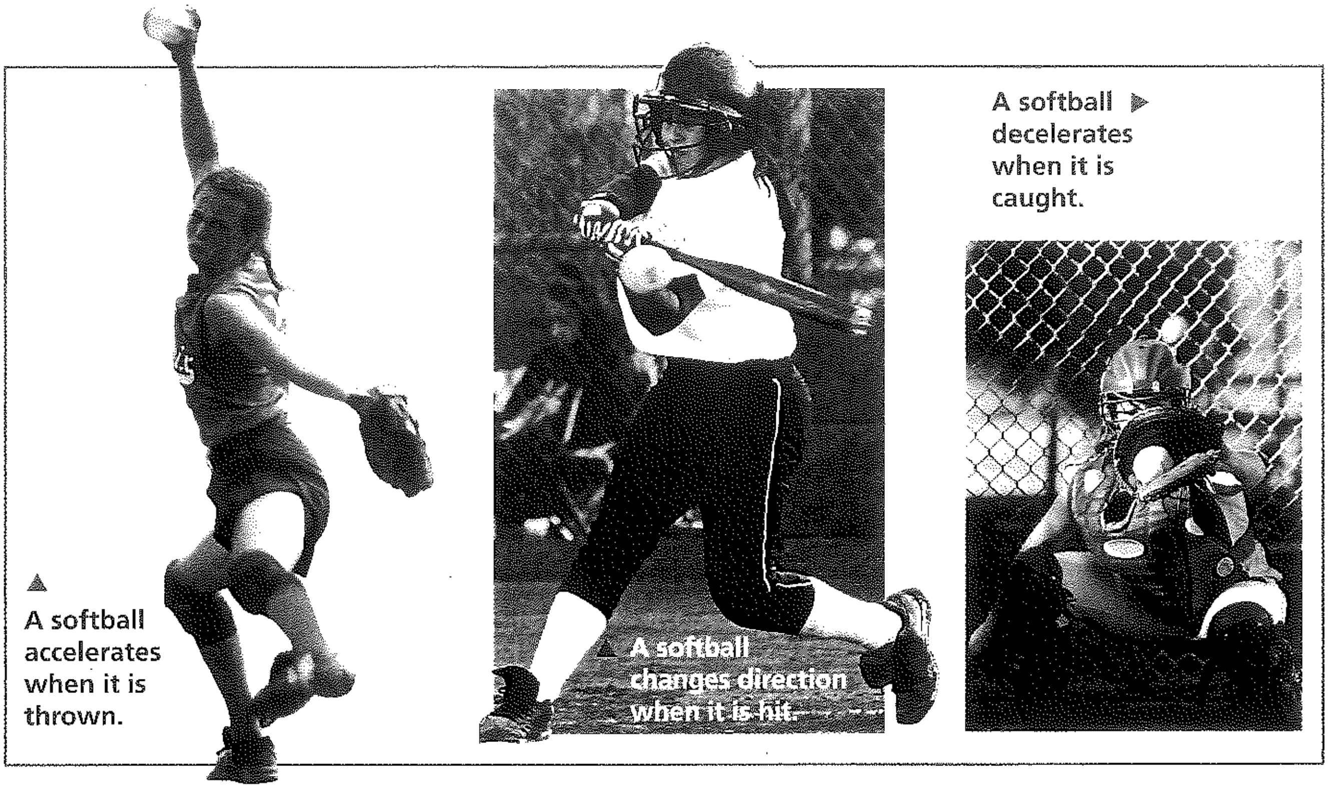


FIGURE 6
Acceleration
A softball experiences acceleration when it is thrown, caught, and hit. Classifying *What change in motion occurs in each example?*

Increasing Speed Whenever an object's speed increases, the object accelerates. A softball accelerates when the pitcher throws it, and again when a bat hits it. A car that begins to move from a stopped position or speeds up to pass another car is accelerating. People can accelerate too. For example, you accelerate when you coast down a hill on your bike.

Decreasing Speed Just as objects can speed up, they can also slow down. This change in speed is sometimes called deceleration, or negative acceleration. For example, a softball decelerates when it lands in a fielder's mitt. A car decelerates when it stops at a red light. A water skier decelerates when the boat stops pulling.

Changing Direction Even an object that is traveling at a constant speed can be accelerating. Recall that acceleration can be a change in direction as well as a change in speed. Therefore, a car accelerates as it follows a gentle curve in the road or changes lanes. Runners accelerate as they round the curve in a track. A softball accelerates when it changes direction as it is hit.

Many objects continuously change direction without changing speed. The simplest example of this type of motion is circular motion, or motion along a circular path. For example, the seats on a Ferris wheel accelerate because they move in a circle.

Reading Checkpoint **How can a car be accelerating if its speed is constant at 65 km/h?**

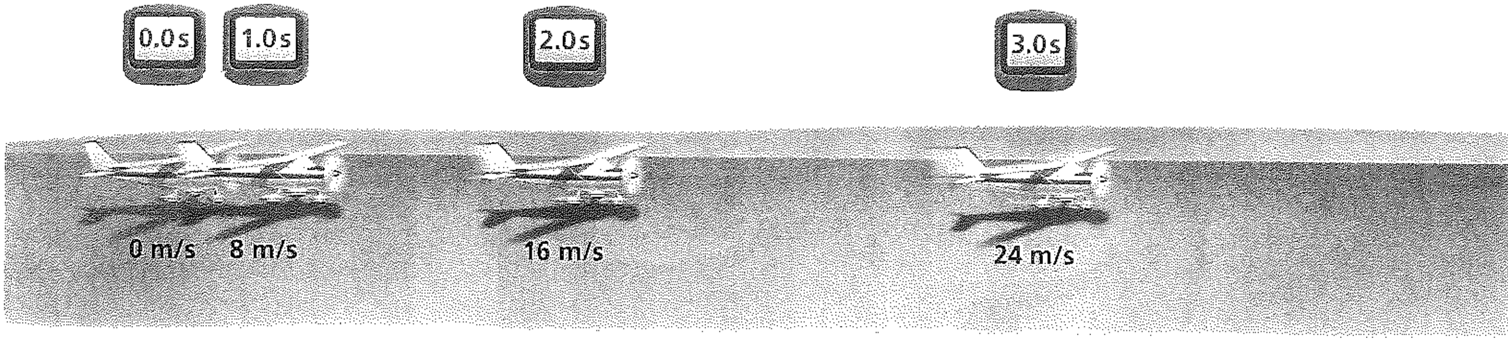


FIGURE 7
Analyzing Acceleration
The speed of the airplane above increases by the same amount each second. **Interpreting Diagrams** *How does the distance change in each second?*

Calculating Acceleration

Acceleration describes the rate at which velocity changes. If an object is not changing direction, you can describe its acceleration as the rate at which its speed changes. **To determine the acceleration of an object moving in a straight line, you must calculate the change in speed per unit of time.** This is summarized by the following formula.

$$\text{Acceleration} = \frac{\text{Final speed} - \text{Initial speed}}{\text{Time}}$$

If speed is measured in meters per second (m/s) and time is measured in seconds, the SI unit of acceleration is meters per second per second, or m/s^2. Suppose speed is measured in kilometers per hour and time is measured in hours. Then the unit for acceleration is kilometers per hour per hour, or km/h^2.

To understand acceleration, imagine a small airplane moving down a runway. Figure 7 shows the airplane's motion after each of the first five seconds of its acceleration. To calculate the average acceleration of the airplane, you must first subtract the initial speed of 0 m/s from the final speed of 40 m/s. Then divide the change in speed by the time, 5 seconds.

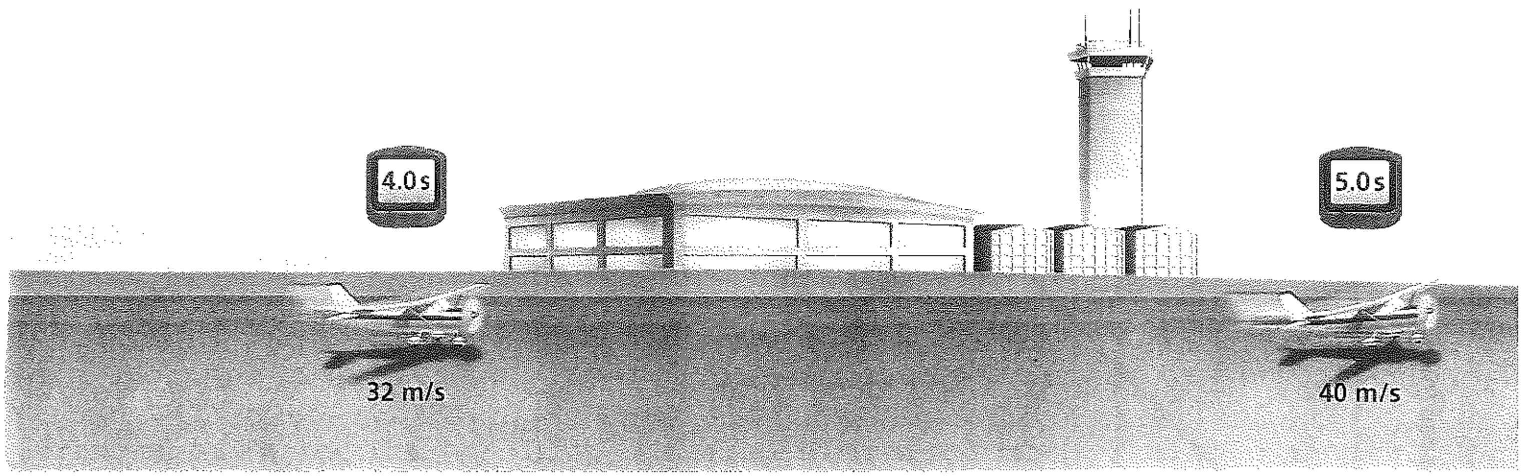
$$\text{Acceleration} = \frac{40\text{ m/s} - 0\text{ m/s}}{5\text{ s}}$$

$$\text{Acceleration} = 8\text{ m/s}^2$$

The airplane accelerates at a rate of 8 m/s^2. This means that the airplane's speed increases by 8 m/s every second. Notice in Figure 7 that, after each second of travel, the airplane's speed is 8 m/s greater than it was the previous second.

Reading Checkpoint **What must you know about an object that is moving in a straight line to calculate its acceleration?**

Go Online SCI LINKS NSTA
For: Links on acceleration
Visit: www.SciLinks.org
Web Code: scn-1313



Math Sample Problem

Calculating Acceleration

As a roller coaster car starts down a slope, its speed is 4 m/s. But 3 seconds later, at the bottom, its speed is 22 m/s. What is its average acceleration?

1 Read and Understand

What information are you given?

Initial speed = 4 m/s

Final speed = 22 m/s

Time = 3 s

2 Plan and Solve

What quantity are you trying to calculate?

The average acceleration of the roller coaster car = ?

What formula contains the given quantities and the unknown quantity?

$$\text{Acceleration} = \frac{\text{Final speed} - \text{Initial speed}}{\text{Time}}$$

Perform the calculation.

$$\text{Acceleration} = \frac{22 \text{ m/s} - 4 \text{ m/s}}{3 \text{ s}}$$

$$\text{Acceleration} = \frac{18 \text{ m/s}}{3 \text{ s}}$$

$$\text{Acceleration} = 6 \text{ m/s}^2$$

The roller coaster car's average acceleration is 6 m/s^2.

3 Look Back and Check

Does your answer make sense?

The answer is reasonable. If the car's speed increases by 6 m/s each second, its speed will be 10 m/s after 1 second, 16 m/s after 2 seconds, and 22 m/s after 3 seconds.

Math Practice

1. **Calculating Acceleration** A falling raindrop accelerates from 10 m/s to 30 m/s in 2 seconds. What is the raindrop's average acceleration?
2. **Calculating Acceleration** A certain car can accelerate from rest to 27 m/s in 9 seconds. Find the car's average acceleration.

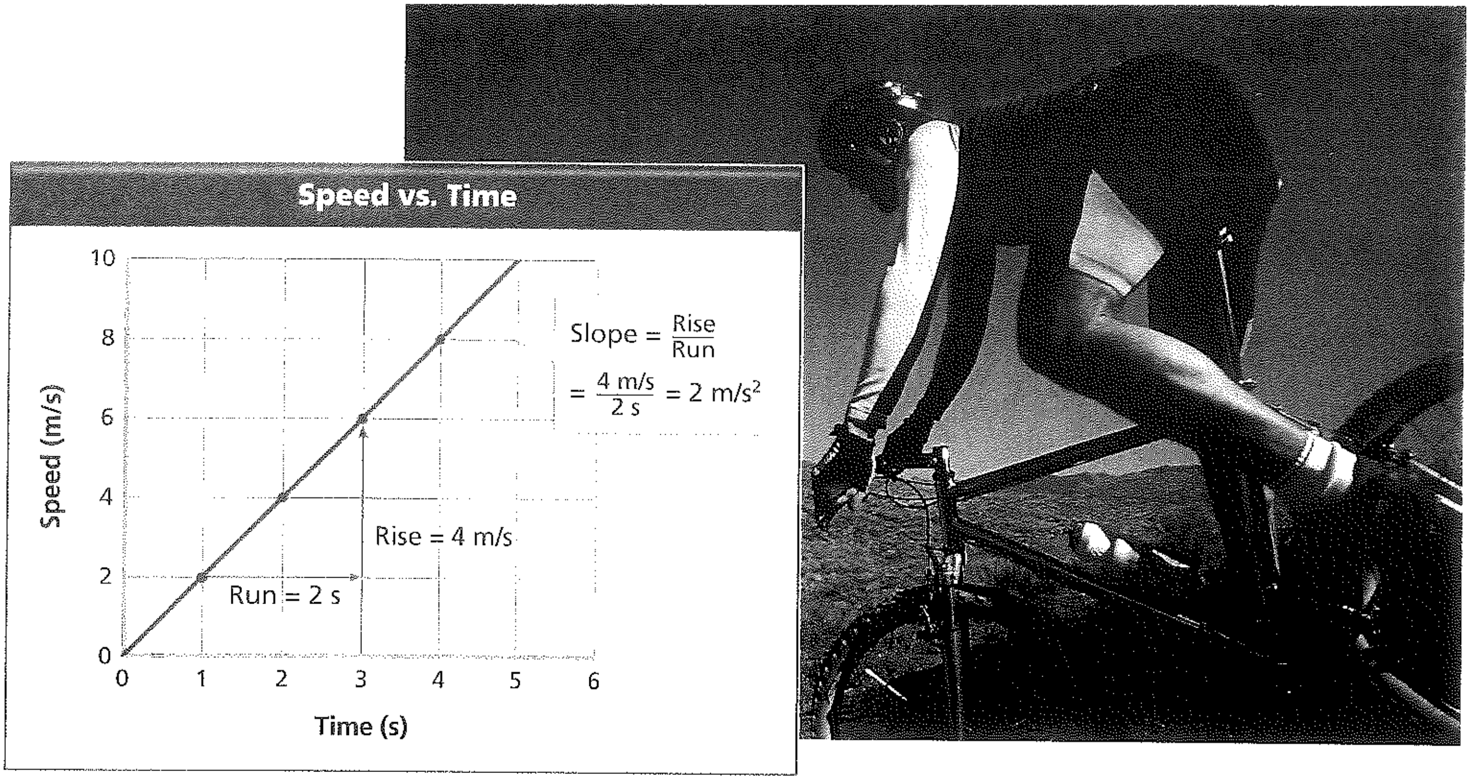


FIGURE 8
Speed-Versus-Time Graph
The slanted, straight line on this speed-versus-time graph tells you that the cyclist is accelerating at a constant rate. The slope of a speed-versus-time graph tells you the object's acceleration.
Predicting *How would the slope of the graph change if the cyclist were accelerating at a greater rate? At a lesser rate?*

Graphing Acceleration

Suppose you ride your bicycle down a long, steep hill. At the top of the hill your speed is 0 m/s. As you start down the hill, your speed increases. Each second, you move at a greater speed and travel a greater distance than the second before. During the five seconds it takes you to reach the bottom of the hill, you are an accelerating object. **You can use both a speed-versus-time graph and a distance-versus-time graph to analyze the motion of an accelerating object.**

Speed-Versus-Time Graph Figure 8 shows a speed-versus-time graph for your bicycle ride down the hill. What can you learn about your motion by analyzing this graph? First, since the line slants upward, the graph shows you that your speed was increasing. Next, since the line is straight, you can tell that your acceleration was constant. A slanted, straight line on a speed-versus-time graph means that the object is accelerating at a constant rate. You can find your acceleration by calculating the slope of the line. To calculate the slope, choose any two points on the line. Then, divide the rise by the run.

$$\text{Slope} = \frac{\text{Rise}}{\text{Run}} = \frac{8\text{ m/s} - 4\text{ m/s}}{4\text{ s} - 2\text{ s}} = \frac{4\text{ m/s}}{2\text{ s}}$$

$$\text{Slope} = 2\text{ m/s}^2$$

During your bike ride, you accelerated down the hill at a constant rate of 2 m/s^2.

Distance-Versus-Time Graph You can represent the motion of an accelerating object with a distance-versus-time graph. Figure 9 shows a distance-versus-time graph for your bike ride. On this type of graph, a curved line means that the object is accelerating. The curved line in Figure 9 tells you that during each second, you traveled a greater distance than the second before. For example, you traveled a greater distance during the third second than you did during the first second.

The curved line in Figure 9 also tells you that during each second your speed is greater than the second before. Recall that the slope of a distance-versus-time graph is the speed of an object. From second to second, the slope of the line in Figure 9 gets steeper and steeper. Since the slope is increasing, you can conclude that the speed is also increasing. You are accelerating.

Reading Checkpoint **What does a curved line on a distance-versus-time graph tell you?**

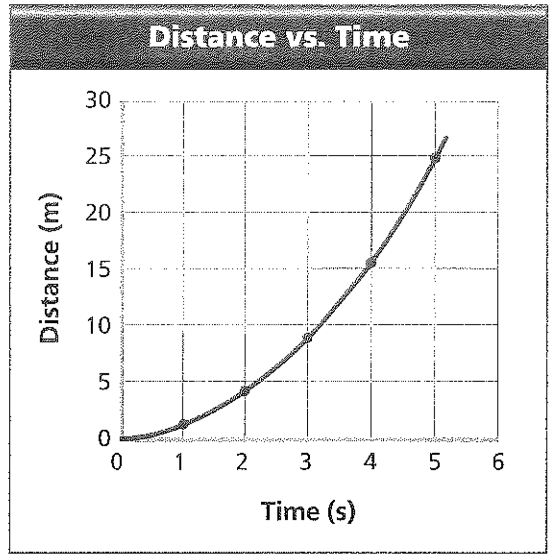


FIGURE 9
Distance-Versus-Time Graph
The curved line on this distance-versus-time graph tells you that the cyclist is accelerating.

Section 3 Assessment

Target Reading Skill Identifying Main Ideas
Use information in your graphic organizer to answer Question 1 below.

Reviewing Key Concepts

1. a. Describing What are the three ways that an object can accelerate?
   b. Summarizing Describe how a baseball player accelerates as he runs around the bases after hitting a home run.
   c. Applying Concepts An ice skater glides around a rink at a constant speed of 2 m/s. Is the skater accelerating? Explain your answer.
2. a. Identifying What is the formula used to calculate the acceleration of an object moving in a straight line?
   b. Calculating A cyclist's speed changes from 0 m/s to 15 m/s in 10 seconds. What is the cyclist's average acceleration?
3. a. Naming What types of graphs can you use to analyze the acceleration of an object?
   b. Explaining How is an object moving if a slanted, straight line on a speed-versus-time graph represents its motion?
   c. Predicting What would a distance-versus-time graph look like for the moving object in part (b)?

Math Practice

4. Calculating Acceleration A downhill skier reaches the steepest part of a trail. Her speed increases from 9 m/s to 18 m/s in 3 seconds. What is her average acceleration?
5. Calculating Acceleration What is a race car's average acceleration if its speed changes from 0 m/s to 40 m/s in 4 seconds?

Lab zone **Skills Lab**

Stopping on a Dime

Problem

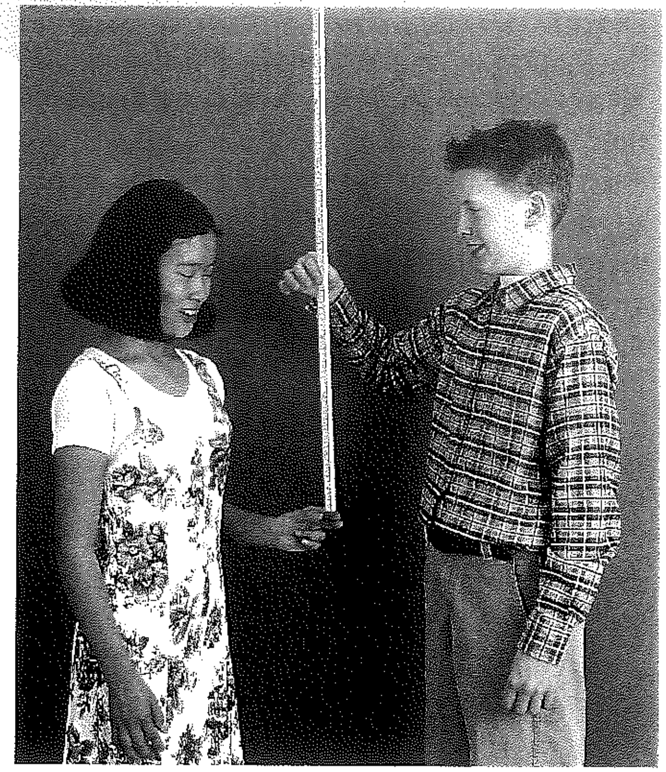
The school will put in a new basketball court in a small area between two buildings. Safety is an important consideration in the design of the court. What is the distance needed between an out-of-bounds line and a wall so that a player can stop before hitting the wall?

Skills Focus

calculating, interpreting data

Materials

- wooden meter stick
- tape measure
- 2 stopwatches or watches with second hands



Procedure

PART 1 Reaction Time

1. Have your partner suspend a wooden meter stick, zero end down, between your thumb and index finger, as shown. Your thumb and index finger should be about 3 cm apart.
2. Your partner will drop the meter stick without giving you any warning. Try to grab it with your thumb and index finger.

Reaction Time

Distance (cm)	Time (s)	Distance (cm)	Time (s)
15	0.175	25	0.226
16	0.181	26	0.230
17	0.186	27	0.235
18	0.192	28	0.239
19	0.197	29	0.243
20	0.202	30	0.247
21	0.207	31	0.252
22	0.212	32	0.256
23	0.217	33	0.260
24	0.221	34	0.263

3. Note the level at which you grabbed the meter stick and use the chart shown to determine your reaction time. Record the time in the class data table.
4. Reverse roles with your partner and repeat Steps 1–3.

PART 2 Stopping Distance

5. On the school field or in the gymnasium, mark off a distance of 25 m. **CAUTION:** *Be sure to remove any obstacles from the course.*
6. Have your partner time how long it takes you to run the course at full speed. After you pass the 25-m mark, come to a stop as quickly as possible and remain standing. You must not slow down before the mark.
7. Have your partner measure the distance from the 25-m mark to your final position. This is the distance you need to come to a complete stop. Enter your time and distance into the class data table.
8. Reverse roles with your partner. Enter your partner's time and distance into the class data table.

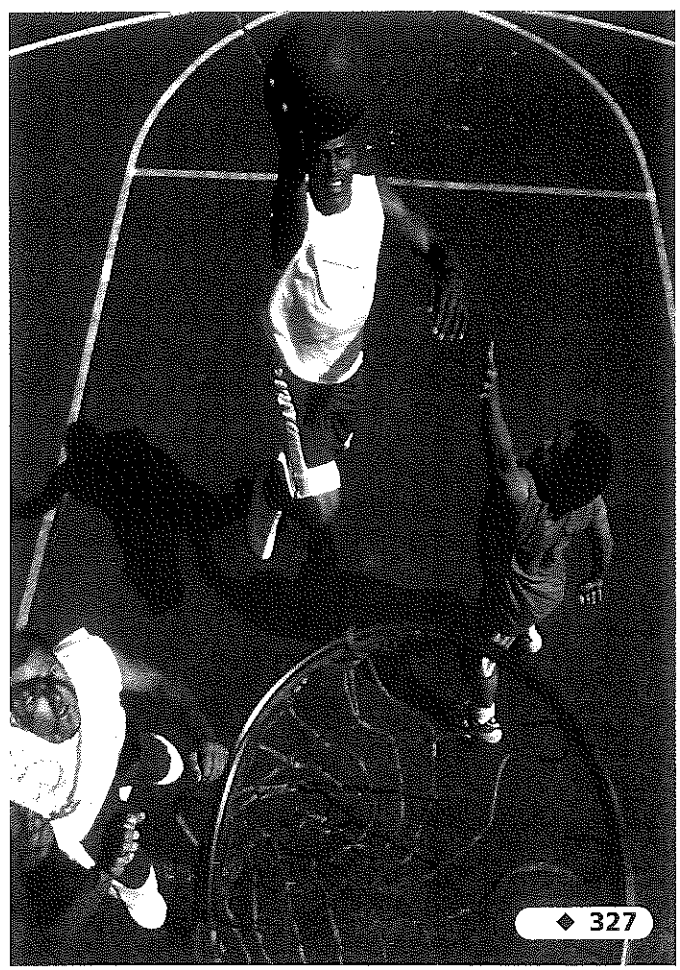
Class Data Table			
Student Name	Reaction Time (s)	Running Time (s)	Stopping Distance (m)

Analyze and Conclude

1. Calculating Calculate the average speed of the student who ran the 25-m course the fastest.
2. Interpreting Data Multiply the speed of the fastest student (calculated in Question 1) by the slowest reaction time listed in the class data table. Why would you be interested in this product?
3. Interpreting Data Add the distance calculated in Question 2 to the longest stopping distance in the class data table. What does this total distance represent?
4. Drawing Conclusions Explain why it is important to use the fastest speed, the slowest reaction time, and the longest stopping distance in your calculations.
5. Controlling Variables What other factors should you take into account to get results that apply to a real basketball court?
6. Communicating Suppose you calculate that the distance from the out-of-bounds line to the wall of the basketball court is too short for safety. Write a proposal to the school that describes the problem. In your proposal, suggest a strategy for making the court safer.

More to Explore

Visit a local playground and examine it from the viewpoint of safety. Use what you learned about stopping distance as one of your guidelines, but also try to identify other potentially unsafe conditions. Write a letter to the Department of Parks or to the officials of your town informing them of your findings.



Chapter 9 Study Guide

The BIG Idea **Motion and Forces** The motion of an object can be described by its position, speed, direction, and acceleration.

1 Describing and Measuring Motion

Key Concepts

- An object is in motion if it changes position relative to a reference point.
- Scientists use SI units to describe the distance an object moves.

Key Terms

- motion • reference point
- International System of Units • meter

2 Speed and Velocity

Key Concepts

- If you know the distance an object travels in a certain amount of time, you can calculate the speed of the object.
- $\text{Speed} = \frac{\text{Distance}}{\text{Time}}$
- When you know both the speed and direction of an object's motion, you know the velocity of the object.
- You can show the motion of an object on a line graph in which you plot distance versus time.
- $\text{Slope} = \frac{\text{Rise}}{\text{Run}}$

Key Terms

- speed • average speed • instantaneous speed
- velocity • slope

3 Acceleration

Key Concepts

- In science, acceleration refers to increasing speed, decreasing speed, or changing direction.
- To determine the acceleration of an object moving in a straight line, you must calculate the change in speed per unit of time.
- $\text{Acceleration} = \frac{\text{Final speed} - \text{Initial speed}}{\text{Time}}$
- You can use both a speed-versus-time graph and a distance-versus-time graph to analyze the motion of an accelerating object.

Key Term

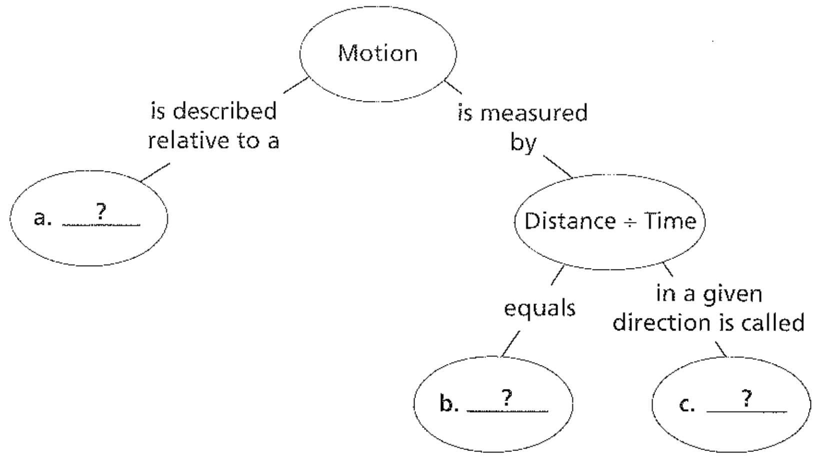
acceleration

Review and Assessment

Go Online
PHSchool.com
For: Self-Assessment
Visit: PHSchool.com
Web Code: cka-2090

Organizing Information

Concept Mapping Copy the concept map about motion onto a separate sheet of paper. Then complete it and add a title. (For more information on Concept Mapping, see the Skills Handbook.)



Reviewing Key Terms

Choose the letter of the best answer.

1. A change in position with respect to a reference point is
   a. acceleration.
   b. velocity.
   c. direction.
   d. motion.
2. You do not know an object's velocity until you know its
   a. speed and distance.
   b. reference point.
   c. speed and direction.
   d. acceleration.
3. If you know a car travels 30 km in 20 minutes, you can find its
   a. acceleration.
   b. average speed.
   c. direction.
   d. instantaneous speed.
4. Acceleration is a change in speed or
   a. time.
   b. slope.
   c. direction.
   d. distance.
5. The rate at which velocity changes is called
   a. acceleration. b. constant speed.
   c. average speed. d. velocity.

If the statement is true, write *true*. If it is false, change the underlined word or words to make the statement true.

6. The distance an object travels per unit of time is called acceleration.
7. The basic SI unit of length is the meter.
8. The SI unit of velocity is m/s^2.
9. The slope of a speed-versus-time graph represents acceleration.
10. Both speed and acceleration include the direction of an object's motion.

Writing in Science

News Report Two trucks have competed in a race. Write an article describing the race and who won. Explain the role the average speed of the trucks played. Tell how average speed can be calculated.

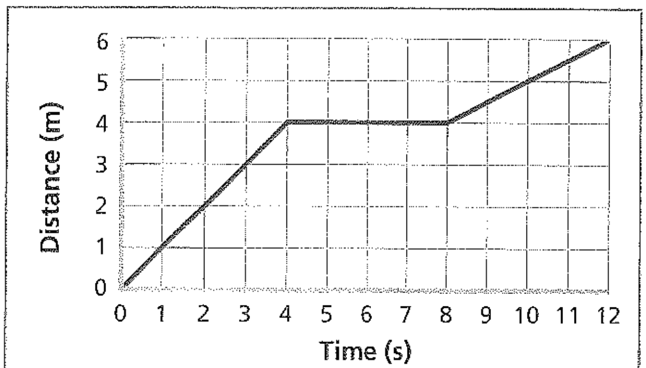
Review and Assessment

Checking Concepts

11. A passenger walks toward the rear of a moving train. Describe her motion as seen from a reference point on the train. Then describe it from a reference point on the ground.
12. Which has a greater speed, a heron that travels 600 m in 60 seconds or a duck that travels 60 m in 5 seconds? Explain.
13. You have a motion graph for an object that shows distance and time. How does the slope of the graph relate to the object's speed?
14. An insect lands on a compact disc that is put into a player. If the insect spins with the disc, is the insect accelerating? Why or why not?

Thinking Critically

15. Interpreting Graphs The graph below shows the motion of a remote-control car. During which segment is the car moving the fastest? The slowest? How do you know?



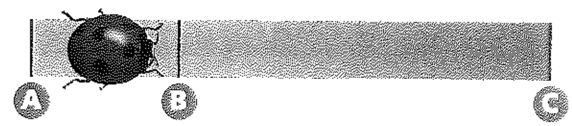
16. Inferring How can you tell if an object is moving when its motion is too slow to see?
17. Problem Solving Two drivers make a 100-km trip. Driver 1 completes the trip in 2 hours. Driver 2 takes 3 hours but stops for an hour halfway. Which driver had a greater average speed? Explain.
18. Applying Concepts A family takes a car trip. They travel for an hour at 80 km/h and then for 2 hours at 40 km/h. Find their average speed during the trip.

Math Practice

19. Converting Units Convert 119 cm to meters.
20. Converting Units Convert 22.4 km to meters.
21. Calculating Acceleration During a slap shot, a hockey puck takes 0.5 second to reach the goal. It started from rest and reached a final speed of 35 m/s. What is the puck's average acceleration?

Applying Skills

Use the illustration of the motion of a ladybug to answer Questions 22–24.



22. Measuring Measure the distance from the starting line to line B, and from line B to the finish line. Measure to the nearest tenth of a centimeter.
23. Calculating Starting at rest, the ladybug accelerated to line B and then moved at a constant speed until it reached the finish line. If the ladybug took 2.5 seconds to move from line B to the finish line, calculate its constant speed during that time.
24. Interpreting Data The speed you calculated in Question 21 is also the speed the ladybug had at the end of its acceleration at line B. If it took 2 seconds for the ladybug to accelerate from the start line to line B, what is its average acceleration during that time?

Lab zone Chapter Project

Performance Assessment Organize your display cards so that they are easy to follow. Remember to put a title on each card stating the speed that you measured. Place the cards in order from the slowest speed to the fastest. Then display them to your class. Compare your results with those of other students.

Standardized Test Prep

Test-Taking Tip

Converting Units

A test question may ask you to change one unit of measurement to another. You do this by using a conversion factor, a fraction that represents the relationship between the units. For example, to convert meters to centimeters, you need to remember that 1 meter equals 100 centimeters: 1 m = 100 cm. To figure out the answer, you would multiply by the conversion factor $\frac{100 \text{ cm}}{1 \text{ m}}$.

Sample Question

A garden measures 3.12 meters wide. How many centimeters wide is the garden?

A 0.312 cm
B 31.2 cm
C 312 cm
D 3,120 cm

Answer

The correct answer is C. When you multiply 3.12 m by 100 cm, you get 312 cm.

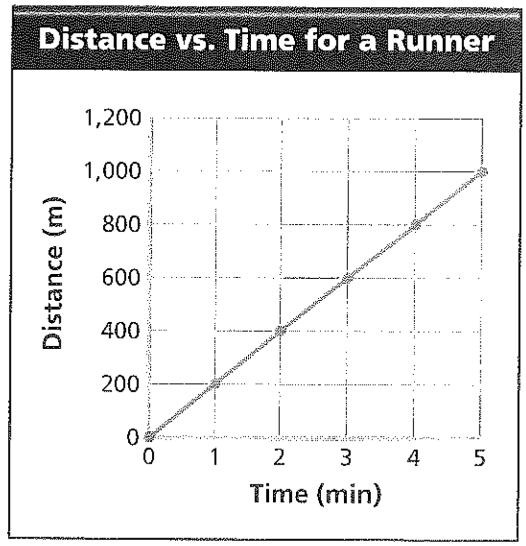
Choose the letter of the best answer.

1. Members of the Fairview Track Club are running a 1.5-km race. What is the distance of the race in meters?
   A 0.15 m
   B 15 m
   C 150 m
   D 1,500 m

2. Your father is driving to the beach. He drives at one speed for two hours. He drives at a different speed for another two hours and a third speed for the final hour. How would you find his average speed for all five hours?
   F Divide the total driving time by the total distance.
   G Multiply the total driving time by the total distance.
   H Divide the total distance by the total driving time.
   J Subtract the total driving time from the total distance.

3. Two objects traveling at the same speed have different velocities if they
   A start at different times.
   B travel different distances.
   C have different masses.
   D move in different directions.

4. The graph below shows the distance versus time for a runner moving at a constant 200 m/min. What could the runner do to make the slope of the line rise?



   F stop running
   G decrease speed
   H maintain the same speed
   J increase speed

5. An object used as a reference point to determine motion should be
   A accelerating.
   B stationary.
   C decelerating.
   D changing direction.

Constructed Response

6. Explain how speed, velocity, and acceleration are related.