UNIT

3

Motion

A roller coaster is designed to provide the rider with thrills—sensations that do not normally occur while riding on a bus to school. Although a school bus and a roller coaster both change speed and direction while travelling to their destination, there is a difference in the experience of the passengers. The roller coaster changes its speed and direction much more rapidly than a school bus does.

Key Ideas

8 **Average velocity is the rate of change in position.**

8.1 The Language of Motion

8.2 Average Velocity

9 **Acceleration is the rate of change in velocity.**

9.1 Describing Acceleration

9.2 Calculating Acceleration

Getting Started

A fraction of a second is the difference between a hit and a miss when the ball is travelling at over 150 km/h.

Goalkeepers need to be able to react quickly.

A warm summer breeze gently blows across the newly cut grass. The umpire's call of "batter up" signals the beginning of the game. When people think of a sport such as baseball, they might not think of science. However, during a baseball game, the ball and the players will change speed and direction as they travel to different positions on the playing field. All of these factors involve motion.

Consider the motion involved in a single pitch during a baseball game. The ball starts at rest in the pitcher's hand, approximately 20 m from the batter. A professional league pitcher can release the ball at a speed of over 150 km/h. At this speed, it takes the ball less than half a second to travel to the batter. During this short trip, the batter has about 0.2 s to decide how to react to the pitch. It will take the batter about 0.15 s to swing the bat. If the batter swings the bat one-hundredth of a second too early or too late, the result will be a foul ball instead of a home run.

Soccer goalkeepers, like batters in baseball, must analyze a ball's motion. If the ball is moving quickly or is kicked to a corner of the net, goalkeepers must change their motion in a much shorter period of time. Both the speed of the ball and the direction it is kicked will determine how quickly a goalkeeper will have to react to make the save.

All sports are a combination of athletic skill and science. Skill in many sports is the ability to make judgements about speed and direction as well as angles. Athletes and coaches study the science of motion to increase their skill and improve their performance.

In physics, the study of an object's motion in terms of its change in position, velocity, and rate of change in velocity is called kinematics. "Kinematics" is derived from the Greek word *kinema*, which means motion. Kinesiology is the study of human body movement.

internet connect

To find out more about the science of sports, go to **www.bcscience10.ca**.

Think Fast

Find Out ACTIVITY

What makes locating the position of a fast-moving object so difficult? In this activity, you will analyze the motion of a falling object.

Materials

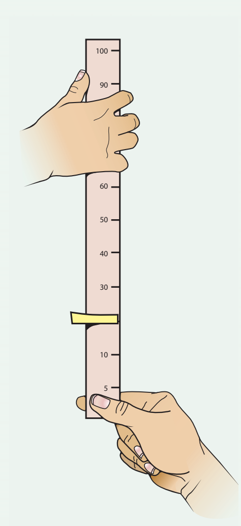
- class chart
- self-adhesive removable notes or masking tape
- metre stick

What to Do

1. Create a class chart with three columns labelled 20 cm, 50 cm, and 80 cm.
2. Attach a self-adhesive removable note or piece of masking tape at the 20 cm mark on a metre stick.
3. Have your partner hold the metre stick vertically between your thumb and index finger. Your own thumb and finger should be at the 0 cm mark and not be touching the metre stick.
4. When your partner releases the metre stick, try to stop the metre stick at exactly the 20 cm mark by squeezing your thumb and finger together. Then, without moving your fingers, measure and record the distance from the centre of your thumb to the marked 20 cm location. For example, whether you stopped the metre stick at 15 cm or 25 cm, you would record your distance as 5 cm. Then switch roles with your partner and repeat.
5. Record the results on the class chart in the 20 cm column.
6. Move the self-adhesive removable note or masking tape to the 50 cm mark on your metre stick. Repeat steps 3 and 4, trying to stop the metre stick at exactly 50 cm. Record the results.
7. Move the self-adhesive removable note or masking tape to the 80 cm mark on your metre stick. Repeat steps 3 and 4, trying to stop the metre stick at exactly 80 cm. Record the results.
8. For each of the three locations, calculate the average distance that the class "missed the mark."

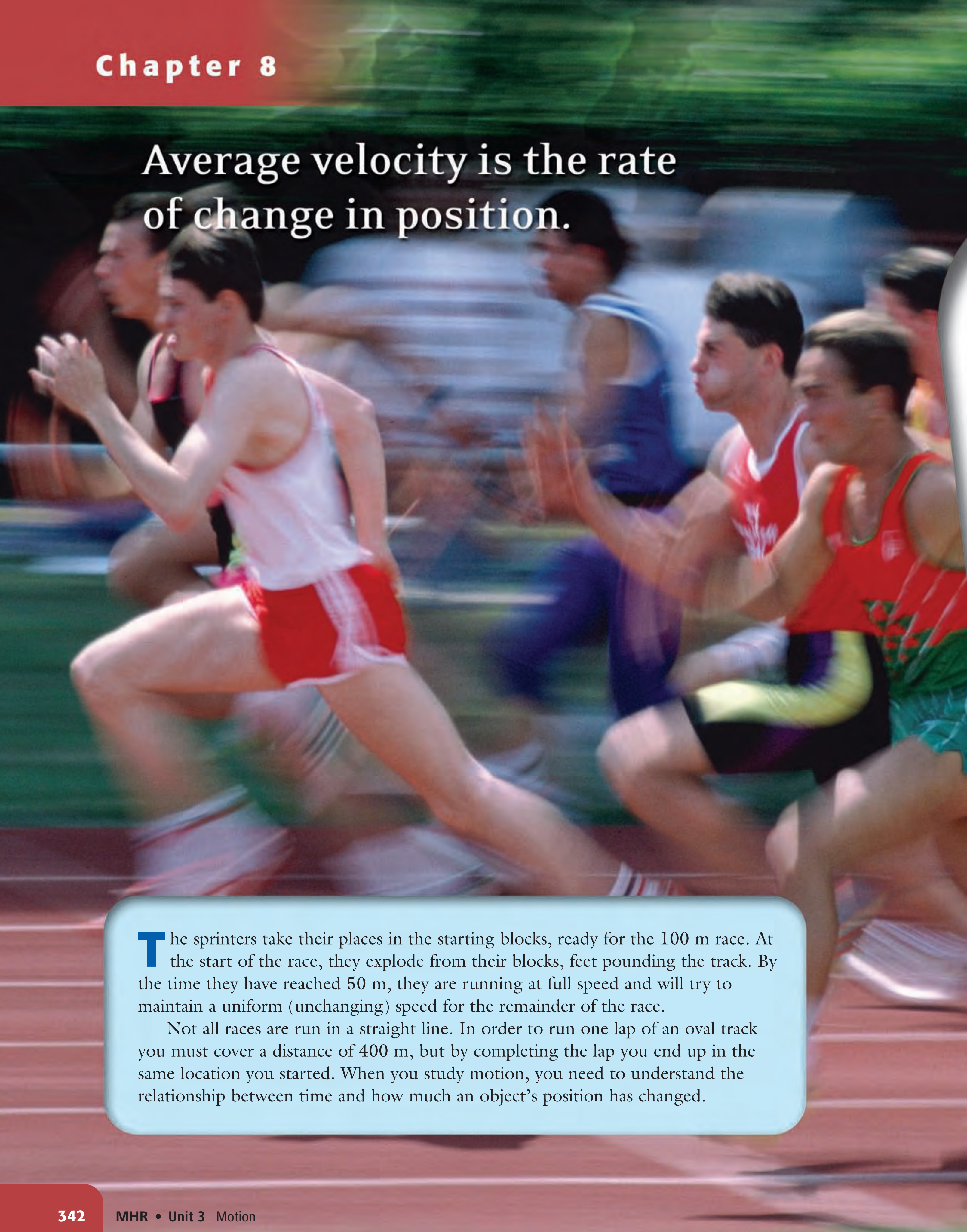
What Did You Find Out?

1. For which location on the metre stick was the class able to stop the metre stick closest to the mark? Farthest from the mark?
2. Speed describes how far an object moves in a given time. In question 1, how does the speed of the metre stick at the two locations compare?
3. Explain how your accuracy at stopping the metre stick at an exact location might be related to the speed that the metre stick is travelling.



Chapter 8

Average velocity is the rate of change in position.



The sprinters take their places in the starting blocks, ready for the 100 m race. At the start of the race, they explode from their blocks, feet pounding the track. By the time they have reached 50 m, they are running at full speed and will try to maintain a uniform (unchanging) speed for the remainder of the race.

Not all races are run in a straight line. In order to run one lap of an oval track you must cover a distance of 400 m, but by completing the lap you end up in the same location you started. When you study motion, you need to understand the relationship between time and how much an object's position has changed.

FOLDABLES™
Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 8.

What You Will Learn

In this chapter, you will
- **define** displacement, time interval, and average velocity
- **analyze** graphically the relationship between displacement and time interval for an object displaying characteristics of uniform motion
- **explain** the relationship of displacement and time interval to average velocity for objects displaying characteristics of uniform motion

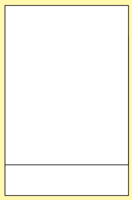
Why It Is Important

Describing and analyzing motion allow us to predict the motion of objects. Understanding velocity and time allows us to understand the parts of our world that display characteristics of uniform motion, such as estimating how long it takes to go somewhere.

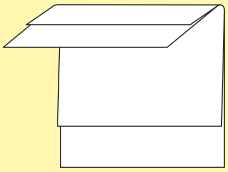
Skills You Will Use

In this chapter, you will
- **observe** and **measure** displacement and time
- **graph** the relationship between position and time for objects displaying characteristics of uniform motion
- **calculate** using $\vec{v}_{av} = \frac{\Delta \vec{d}}{\Delta t}$
- **design** an experiment to determine the average velocity of an object displaying characteristics of uniform motion

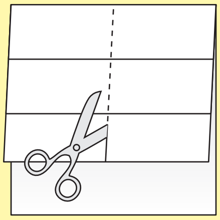
STEP 1 **Stack** two sheets of paper (22 cm by 28 cm) so that the back sheet is about 2.5 cm lower than the front sheet.



STEP 2 **Bring** the top of both sheets downward, and **align** the edges so that all of the layers or tabs are the same distance apart.



STEP 3 When all tabs are an equal distance apart, **fold** the papers and **crease** well. **Cut** the top three layers in half, without cutting the bottom layer.



STEP 4 **Open** the papers and **glue** them together along the inner centre fold (or staple them along the mountain). **Label** each tab as shown. **Record** information, take notes, and define lesson terms under the appropriate tab.

Scalars (magnitude with no direction)	Vectors (magnitude with direction)
Speed	Velocity
Time	Displacement
Distance	Position

8.1 The Language of Motion

A vector quantity has both a magnitude and a direction. A scalar quantity has magnitude only. Position and displacement are vector quantities. Distance and time are scalar quantities. The magnitude of an object's displacement will be the same as the distance an object travels only if it travels in a straight line in one direction. An object in uniform motion travels equal displacements in equal time intervals. Uniform motion is represented as a straight line on a position-time graph.

Words to Know

displacement
distance
position
position-time graph
scalars
slope
uniform motion
vectors

Did You Know?

In 1999, NASA's *Mars Climate Orbiter* space probe, which cost more than $300 million, disappeared in the Martian atmosphere. An investigation later found that one group working with the probe had used SI units, such as metres and kilograms. Another group of researchers had used feet and pounds. As a result, the computers on the probe made errors in the calculations for putting it into orbit.

Participants in the biennial Victoria to Maui international yacht race take part in a 4274 km journey across the Pacific Ocean (Figure 8.1A). Starting from Victoria harbour, competitors face waves that can reach as high as 3 m before the boats arrive at their destination on the Hawaiian island of Maui (Figure 8.1B). Relying on the wind, boats can obtain speeds as high as 40 km/h or spend days travelling at less than 10 km/h. Along the way, distance, time, and speed of the boats are recorded and their position is carefully monitored by both the race officials and the well-wishers back home.

Figure 8.1A Sailors must be aware of their changes in position and speed.

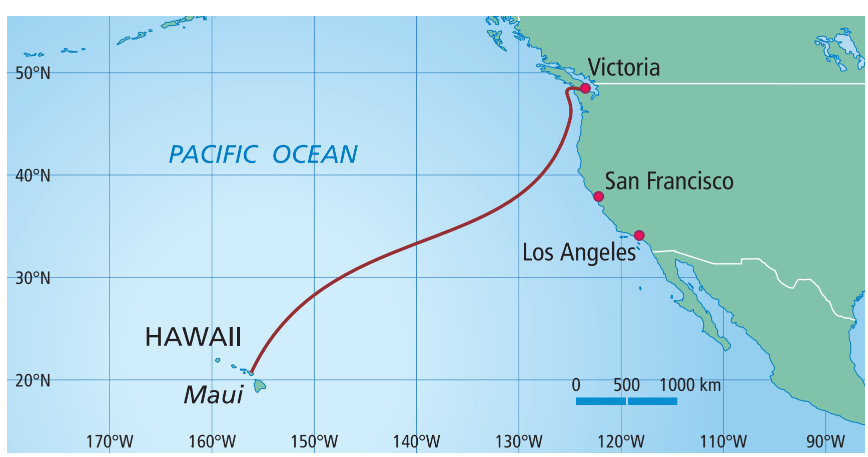


Figure 8.1B Sailors rely on the wind to propel the boats along the race course.

The first official Victoria to Maui international yacht race occurred in 1968. Using boats that were far less efficient than today's modern craft, the first race was completed in a time of 17 days, 6 hours, and 50 minutes. Since then, the fastest time reported was during the 2000 race, when the winning boat finished in only 9 days, 2 hours, and 8 minutes.

Sailors must know their position and speed at all times during the race (Figure 8.2). Each day, new conditions require the crews to make adjustments to their heading. Since the speed and direction of the wind as well as the speed and direction of the ocean currents can change very quickly, an understanding of motion is crucial for the crews of these sailboats.

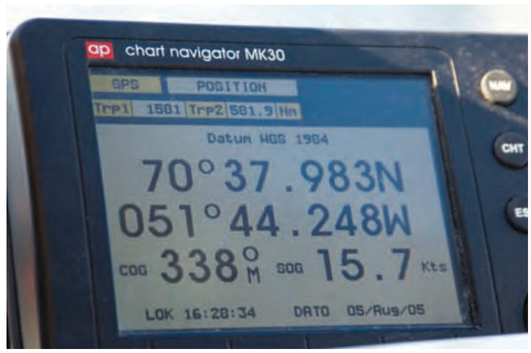


Figure 8.2 A Global Positioning System (GPS) receiver onboard the boat calculates its position by measuring the distance between itself and three or more GPS satellites.

8-1A Describing Motion

Think About It

The English language has many terms that express the motion of an object. It is important in science that we understand the exact meaning of each of these terms so that we can communicate with precision and accuracy. In this activity, you will identify the key words used to describe motion.

Photo A

Photo B

Photo C

What to Do

1. Study the three photos above.
2. Using short sentences, write down your descriptions of the motion that occurred immediately before, during, and after the actions shown in the photographs.
3. Underline what you think are the key words you used to describe motion.
4. Compare your key words with those of a partner. Share your key words with the class.

What Did You Find Out?

1. (a) Did you and your partner have the same key words?
   (b) If not, which key word(s) were different?
2. (a) Which of the key words have similar meaning?
   (b) What do they mean?

Figure 8.3 Every time you use a map or give directions, you are using vectors.

Direction Makes a Difference

Imagine the following scene. A classmate invites a few friends over after school to study for an exam. He tells the group, "I live 1 km from school. If you walk at 4 km/h, it will take you only about 15 minutes to get there." Could you find the way to your classmate's house? He told you how far (distance) he lives from school and how long (time) it will take to get there if you walk at a certain pace (speed). However, you still do not know the *direction* in which to walk to his house.

The quantities that your classmate used to give instructions—distance, time, and speed—have magnitude but no direction. *Magnitude* refers to the size of a measurement or the amount (number) you are counting. Quantities that describe magnitude but do not include direction are called scalar quantities or **scalars**.

Now suppose your classmate told you to walk east from the school at 4 km/h. Quantities that describe magnitude and also include direction are called vector quantities or **vectors** (Figure 8.3).

Did You Know?

Pilots use vector quantities when flying and landing a plane. These vectors are instructions about which direction to head as well as speed and altitude.

Representing Vectors

To distinguish between scalars and vectors, symbols for vectors in this book are bolded and written with arrows above them, whereas symbols for scalars are not. When a direction is written in a vector description, it is usually abbreviated and put into square brackets. For example, if your car's position is 10 km east of your home, you would write the position as 10 km [E].

Figure 8.4 The odometer displays the distance the car has travelled. A speedometer indicates the car's speed.

Distance

The dashboard of a car contains displays that indicate the motion of the vehicle (Figure 8.4). The speedometer measures how fast you are driving. The odometer keeps track of the distance the car has travelled. Suppose you wish to drive in a straight line to a store that is 10 km east of where you live. When you drive to the store, the reading on the odometer will increase by 10 km, which is the distance the car travelled. **Distance** (d) is a scalar quantity that describes the length of a path between two points or locations. The SI unit for distance is metres, m.

Position

The odometer does not show which direction you drove to get to the store. To indicate the location of your car, you would say that the car's position is now 10 km east of your home (Figure 8.5A). **Position** ($\vec{d}$) is a vector quantity that describes a specific point relative to a reference point. In other words, position describes an object's location as seen by an observer from a particular viewpoint. You can choose any point as a reference. For example, suppose after shopping at the store you drive home in a straight line along the same route. The odometer will show that you have driven a *distance* of 20 km since you left home, yet your *position* upon returning is 0 km because you are back at the place where you started (Figure 8.5B). The SI unit for position is metres, m.

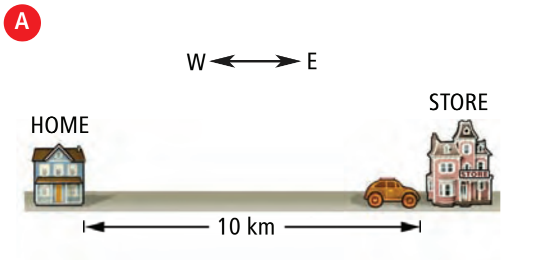


Figure 8.5A The car's position is 10 km east of home. The distance it has driven is 10 km.

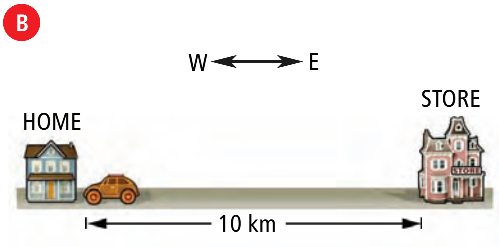


Figure 8.5B The car's position is 0 km from home. The distance it has driven is 20 km.

Time and Time Interval

You are already familiar with using the concept of **time** (t) to describe when an event occurs. The difference between the initial time (when the event begins) and the final time (when the event ends) is called the **time interval**. The symbol for a change in time or time interval is Δt. The symbol Δ is the Greek letter delta. Physicists and mathematicians often use the delta symbol to mean a difference or change. The time interval (Δt) describes the duration of an event. Both time and time interval are scalar quantities. The SI unit for time and time interval is seconds, s.

Word Connect

The international science community has an agreed set of units for all measurements in science. The SI abbreviation for the International System of Units comes from the French "Le Système international d'unités."

Reading Check

1. What is the quantity that describes the length of a path between two points or locations?
2. What is the quantity that describes a specific point relative to a reference point?
3. What is the term used for the difference between the final and initial time?

Calculating the Time Interval

The skateboarder in Figure 8.6 is travelling along a bike path at 1 m per second. Suppose you need to know how long it takes for him to travel in a straight line from the fire hydrant to the sign. The time he starts is called his initial time. Use the symbol t for time and assign a subscript letter "i" for "initial time" to the time he is at the fire hydrant (t_i). Assign t_f (final time) to the time when he is at the sign.

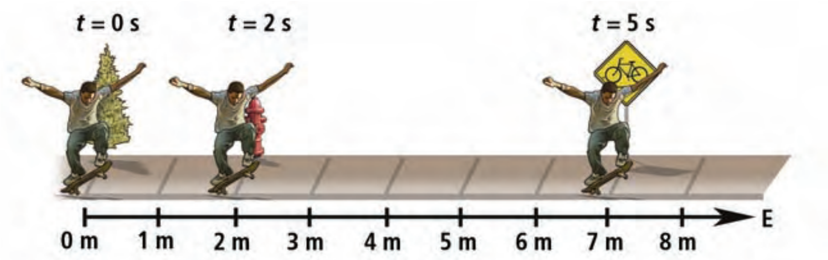


Figure 8.6 The sign is 7 m east of the tree in a straight line.

The time interval to travel from the fire hydrant to the sign is

$$\begin{aligned}\Delta t &= t_f - t_i\\ &= 5\text{ s} - 2\text{ s}\\ &= 3\text{ s}\end{aligned}$$

During the 3 s time interval, the skateboarder's position has changed. The position of an object is measured from a reference location or *origin*. In this example, the origin is the tree. The position of the skateboarder at $t = 5$ s is 7 m east of the tree. The position of the skateboarder at $t = 2$ s is 2 m east of the tree.

Did You Know?

In 1999, Michael Johnson set the world record for running a distance of 400 m in a time of 43.18 s. Since the track is an oval, this 400 m race has a displacement of zero.

Displacement and Distance

When you know the direction, you can describe the displacement. **Displacement** describes the straight-line distance and direction from one point to another. In other words, displacement describes how much an object's position has changed. If the object ends up back where it started, its displacement is zero. Since it includes direction, displacement is a vector quantity. The symbol for displacement is $\Delta\vec{d}$. The SI unit for displacement is metres, m.

Displacement is equal to the final position minus the initial position.

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

For the skateboarder, in the time interval from 2 s to 5 s, the displacement is

$$\begin{aligned}\Delta\vec{d} &= \vec{d}_f - \vec{d}_i\\ &= 7\text{ m [E]} - 2\text{ m [E]}\\ &= 5\text{ m [E]}\end{aligned}$$

Between $t = 2$ s and $t = 5$ s, the displacement of the skateboarder is 5 m [E]. The distance that the skateboarder travelled in this time interval is 5 m.

Watch for Signs

Consider the motion of the in-line skater in Figure 8.7. She travelled from 9 m east of the fire hydrant to 5 m west of the fire hydrant. How would you calculate the distance she travelled? You would add the magnitudes of the positions 9 m and 5 m for a total of 14 m. How would you calculate the displacement? You would subtract the initial position from the final position.

$$\Delta\vec{d} = \vec{d}_f - \vec{d}_i$$
$$\Delta\vec{d} = 5\text{ m [W]} - 9\text{ m [E]}$$

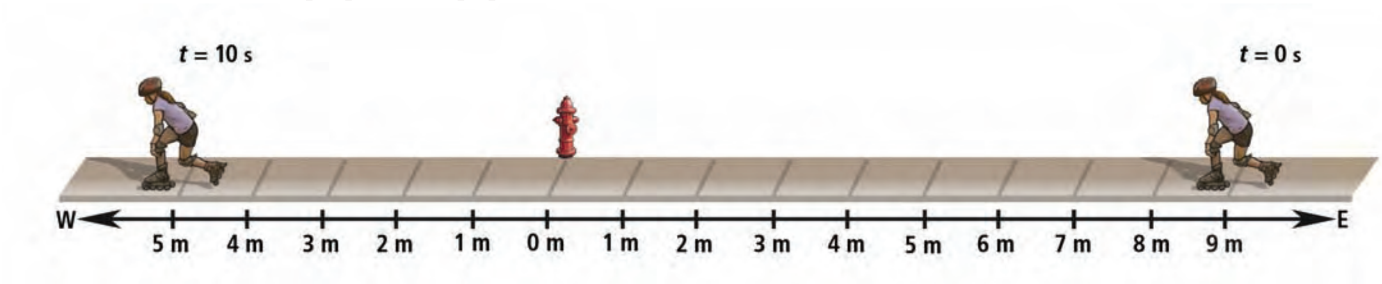


Figure 8.7 The skater's initial position is 9 m [E] of the fire hydrant. Her final position is 5 m [W] of the fire hydrant.

When we use vectors that are opposite in direction, for example east and west, it is convenient to designate these directions as either positive or negative (Figure 8.8). It is common to call east positive (+) and to call west negative (−).

9 m [E] becomes +9 m.
5 m [W] becomes −5 m.

Now you can calculate the displacement:

$$\Delta\vec{d} = \vec{d}_f - \vec{d}_i$$
$$\Delta\vec{d} = -5\text{ m} - (+9\text{ m})$$
$$= -14\text{ m}$$

Since the negative sign (−) represents west, the answer is 14 m [W].

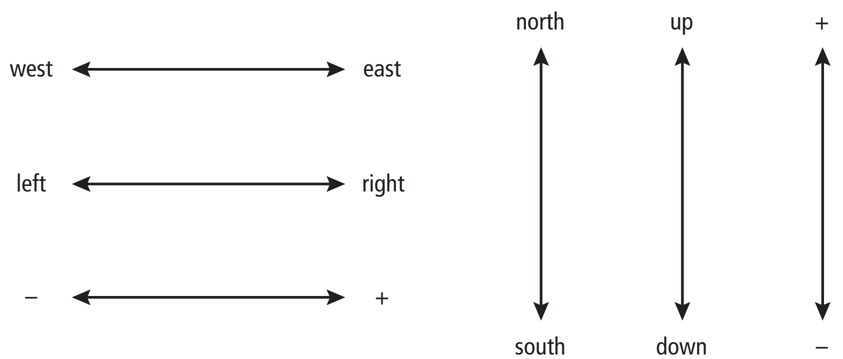


Figure 8.8 North, east, up, and right are called positive (+). South, west, down, and left are called negative (−).

Suggested Activity

Conduct an Investigation 8-1E on page 356

Uniform Motion

Suppose you went ice skating at a skating rink and you stood on the ice wearing skates. If you gave yourself a push off the boards, you would glide across the ice, but eventually you would slow down and stop. This is because there is friction, especially between the ice and your skates. Now imagine what would happen if there were no friction of any kind. When you pushed off the boards, you would never stop. You would be in *uniform* (unchanging) motion. We describe this motion scientifically by saying that objects in **uniform motion** travel equal displacements in equal time intervals. In other words, objects in uniform motion would not speed up or slow down and they would not change direction. In the physical world around you, there is no such thing as true uniform motion, but many examples of motion are close to being uniform. Applying a uniform motion model to these situations helps us understand motion in the real world.

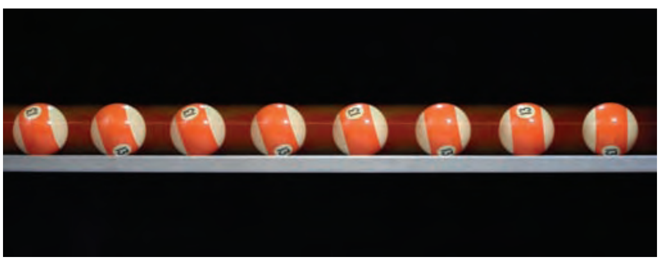


Figure 8.9 The displacement of the ball is very nearly uniform for each time interval.

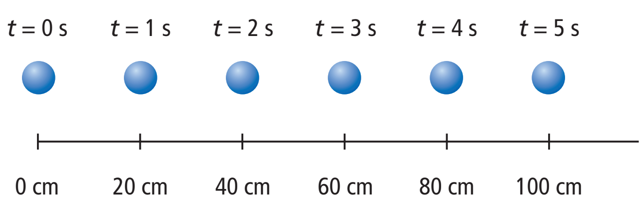


Figure 8.10 A motion diagram can show the position of an object at a given time.

Graphing Uniform Motion

You can represent the motion of an object in a variety of ways. The motion of the ball in Figure 8.9 can be represented in a motion diagram, such as Figure 8.10. A **motion diagram** shows the object's position at given times and allows us to *picture* or *visualize* motion.

From the motion diagram, you can identify the position of the ball at corresponding time intervals. Then you can use the data to make a graph. A graph of the object's position during corresponding time intervals allows us to *analyze* the motion. When you plot the time data on the horizontal axis (called the *x*-axis) and the position data on the vertical axis (called the *y*-axis), this type of graph is called a **position-time graph**. The position-time graph for the ball rolling with uniform motion is shown in Figure 8.11 on the next page. Notice that uniform motion is represented by a *straight line* on a position-time graph.

Table 8.1 Position of Rolling Ball

Time (s)	Position (cm [right])
0	0
1	20
2	40
3	60
4	80
5	100

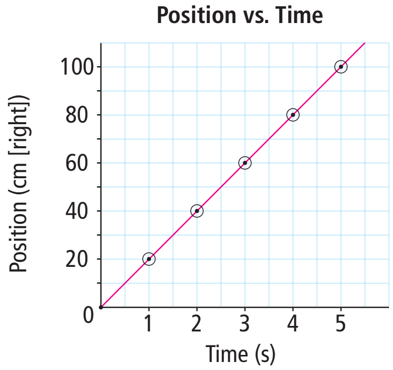


Figure 8.11 The uniform motion of the ball is shown as a straight line on a position-time graph.

Using a best-fit line

Scientific investigations often involve quantities that do not change in equal intervals. Real motion is not perfectly uniform. There may be measuring errors as well as bumps and dents on surfaces that we need to account for. When you graph motion data, it is useful to use a best-fit line that passes through as many of the points as possible. A **best-fit line** is a smooth curve or straight line that most closely fits the general shape outlined by the points. Notice that in Figure 8.11 the best-fit line passes through all the plotted points because the motion is very nearly uniform.

Position-time graphs can be used to estimate positions and times that are not given as data. The straight best-fit line in Figure 8.11 represents the position of the ball at all times, unlike the motion diagram in Figure 8.10, which only gives the position of the ball at five separate times. By using the best-fit line on the position-time graph, you could estimate the ball's position at any given time. For example, to find the position of the ball at 3.5 s, you would find the location on the best-fit line that corresponds to a time of 3.5 s. The value of the position when time equals 3.5 s is 70 cm [right]. A best-fit line can also be extended beyond the first and last points to indicate what might happen beyond the measured data.

Word Connect

The plural of axis is axes.

Reading Check

1. Describe the displacement, during equal time intervals, of an object moving with uniform motion.
2. What kind of a line is used to represent uniform motion on a position-time graph?
3. What is a best-fit line?

8-1B Distance and Displacement

Think About It

In this activity, you will determine the position, distance, and displacement of a person walking.

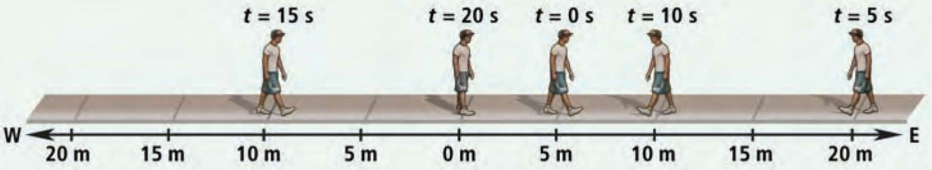
What to Do

1. Copy the following tables into your notebook. Give each table a title.

Time (s)	Position (m)
0	5 m [E]
5	
10	
15	
20	

Time Interval (s)	Distance Travelled (m)	Displacement (m)
0 s–5 s	15 m	15 m [E]
0 s–10 s		
0 s–15 s		
0 s–20 s		

2. The illustration below shows a person walking toward the east, then toward the west, and then toward the east again. Use the illustration to help you complete the tables. The person walks east, then west, and then east again.



The person starts walking at $t = 0$ s and finishes walking at $t = 20$ s.

What Did You Find Out?

1. (a) Is the magnitude of the displacement always the same as the distance?
   (b) Explain why or why not.
2. Under what conditions would the magnitude of the displacement be the same as the distance?

8-1C Graphing Motion Data

Think About It

Imagine you recorded the position of the lawnmower at 5 s time intervals as the groundskeeper cut the grass on your school's football field. In this activity, you will sketch a position-time graph and draw a best-fit line that represents the given data.

Materials

- ruler
- graph paper

What to Do

1. With a ruler, draw an *x*-axis and a *y*-axis on a piece of graph paper. Label the *y*-axis Position. Be sure to include the units (m) and the direction [N]. Label the *x*-axis Time. Be sure to include the unit (s). Scale the axes so that the graph takes up at least half the page.
2. Plot the data from the table on your graph.
3. Draw a best-fit straight line through your plotted data points. Give your graph a title.

Time (s)	Position (m [N])
0	0
5	14
10	27
15	34
20	50
25	64
30	73
35	88
40	100

What Did You Find Out?

1. (a) Did your best-fit straight line go through all your plotted points?
   (b) What does your answer to (a) indicate about the motion of the lawnmower?

Slope

Even though a ball might be travelling on a level surface, the graph of its motion has a slope. The **slope** of a graph refers to whether a line is horizontal or goes up or down at an angle. A slope may be positive, zero, or negative. On a position-time graph, objects whose data produce a negative slope are moving opposite in direction to objects that produce a positive slope.

Positive slope

A positive slope on a position-time graph slants up to the right. The positive slope in Figure 8.12 indicates that the ball's position, from the origin, is increasing with respect to time. Since the slope of the line in Figure 8.12 is constant, the displacement of the object is the same for equal time intervals.

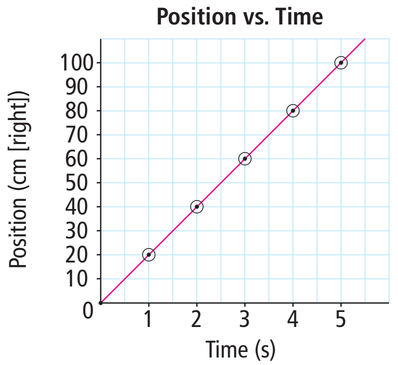


Figure 8.12 A positive slope

Zero slope

On a position-time graph, an object at rest is represented by a line that has zero slope. For example, the golf ball shown in Figure 8.13A is remaining stationary 2.0 m to the right of the hole. Its position-time graph for a 5.0 s time interval would be a horizontal straight line (Figure 8.13B). An object at rest is an example of uniform motion since the displacement of the ball during any time interval is constant ($\Delta\vec{d} = 0$ m).

Figure 8.13A A stationary object, such as the golf ball, is an example of uniform motion since its displacement is not changing.

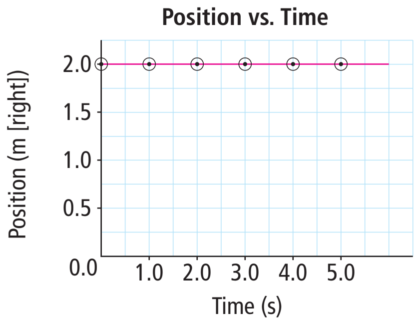


Figure 8.13B An object at rest is represented as a horizontal straight line on a position-time graph.

Suggested Activity

Conduct an Investigation 8-1F on page 358

Negative slope

A negative slope on a position-time graph slants down to the right. Suppose the golfer hits the ball too hard and it travels with uniform motion past the hole (Figure 8.14). If you give the position of the ball to the right of the hole a positive value and the position of the ball to the left of the hole a negative value, your position-time graph would look something like Figure 8.15. Since the motion of the ball is uniform, the best-fit line is straight. However, the ball is initially travelling toward the origin, which is the hole. This produces a line with a negative slope.

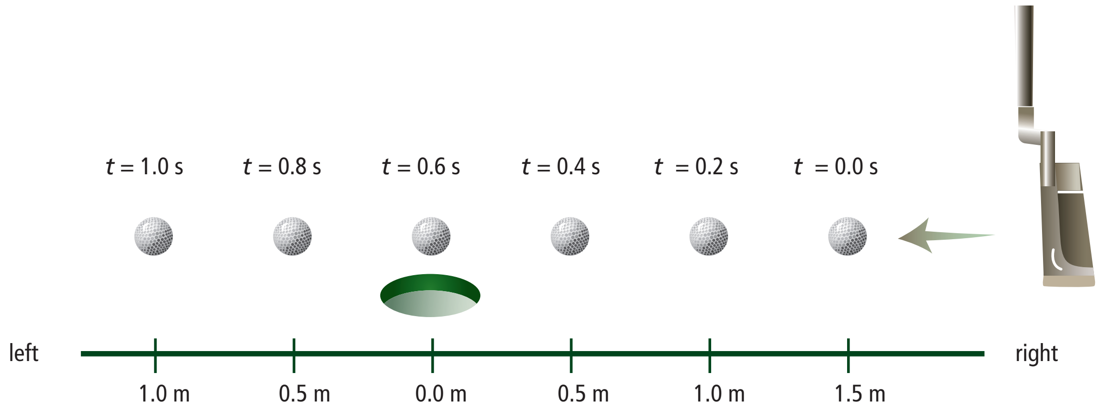


Figure 8.14 Picture the golf ball travelling uniformly past the hole.

Suggested Activity

Think About It 8-1D on page 355

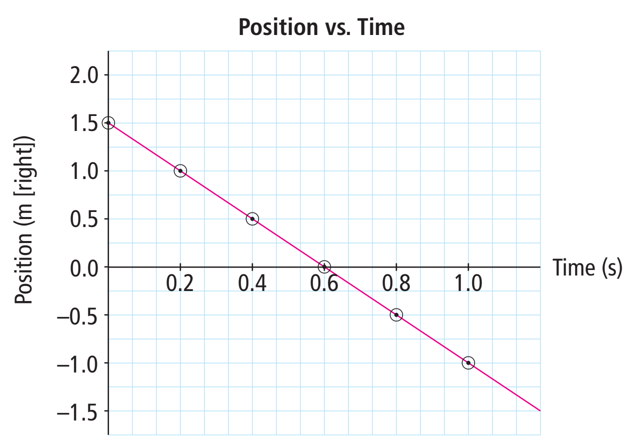


Figure 8.15 If *right* is given a positive value, then a negative slope indicates the object is travelling to the *left*.

Explore More

In an athletic race such as the 100 m sprint, time intervals of less than a thousandth of a second can separate first place from second place. Digital cameras and photogate timers are used to verify the positions of the racers. To learn more about photo finishes and how races are timed, go to **www.bcscience10.ca**.

8-1D Analyzing a Position-Time Graph

Think About It

In this activity, you will analyze position-time graphs to describe the motion of an object.

What to Do

Part 1 Analyzing Position-Time Graph A

1. Sketch position-time graph A in your notebook.

2. For each of the following time intervals, describe the motion of the object represented by the position-time graph. Be sure to include directions when needed.

(a) 0 s–6 s

(b) 6 s–10 s

(c) 10 s–12 s

(d) 12 s–16 s

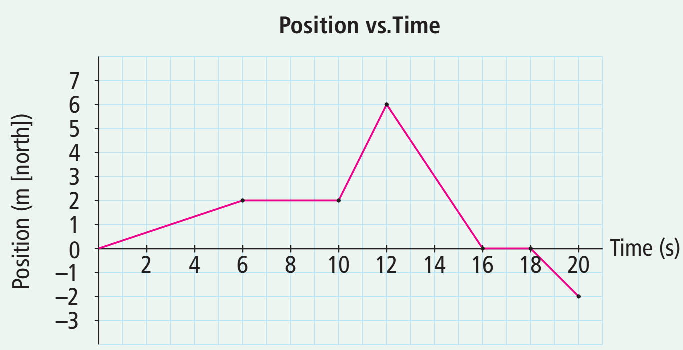
(e) 16 s–18 s

(f) 18 s–20 s

3. Calculate the displacement for each of the time intervals in question 2.

4. For each of the time intervals in question 2, identify the slope of the line as positive, negative, or zero.

5. What total distance did this object travel in 20 s?



Graph A

Part 2 Analyzing Position-Time Graph B

6. Sketch position-time graph 2 in your notebook.

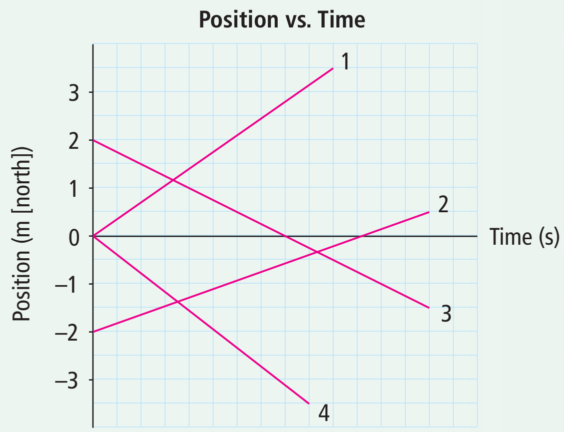
7. Match each of the following descriptions to the appropriate line.

(a) The object starts at the origin and travels south with uniform motion.

(b) The object starts 2 m [S] and travels north with uniform motion.

(c) The object starts at the origin and travels north with uniform motion.

(d) The object starts 2 m [N] and travels south with uniform motion.



Graph B

8-1E Toy Car Time Trials

SkillCheck
- Observing
- Measuring
- Controlling variables
- Evaluating information

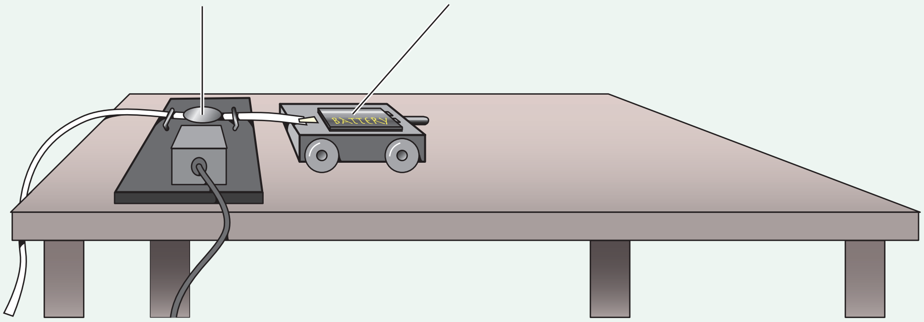
A recording timer is a device that vibrates at a uniform rate. Most recording timers have a frequency of 60 Hz. This means that if you pull a ticker tape (a narrow paper strip) through the recording timer it will create 60 dots in one second. You can use the ticker tape to analyze the motion of an object. In this activity, you will use a recording timer to analyze the motion of a toy car.

Question

How closely does a toy car's motion approximate uniform motion?

Materials

- 1.5 m of ticker tape
- battery-powered toy car
- masking tape
- recording timer
- carbon disk
- ruler



Step 3

Procedure

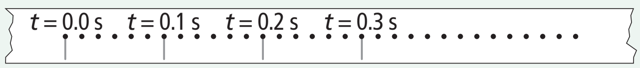
Part 1 Collecting Data

1. Copy the following table into your notebook. Give your table a title.

Time Interval (s)	Displacement (cm [forward])
0.0–0.1	
0.1–0.2	
0.2–0.3	
0.3–0.4	
0.4–0.5	

2. On a flat surface such as the floor or a lab bench, attach the ticker tape to the back of the car using masking tape.
3. Thread the ticker tape through the recording timer so that the carbon disk will produce a mark on the tape.
4. Turn the car on.
5. Once the car has travelled about 10 cm, turn on the recording timer. Allow the car to pull all of the ticker tape through the timer.
6. Clean up and put away the equipment you have used.

Part 2 Marking the Ticker Tape



An example of how to mark the ticker tape

7. Draw a line though the first dot on the ticker tape and label it $t = 0.0$ s.
8. From the $t = 0.0$ s line, count six dots and draw a line through the sixth dot. Since the recording timer produces 60 dots per second, these six dots would represent a time interval of 0.1 s. Label the line you just drew $t = 0.1$ s.
9. Count another six dots from the $t = 0.1$ s line, mark this dot with a line, and label it $t = 0.2$ s.
10. Continue marking your tape in this manner until you mark $t = 0.5$ s.
11. Measure the displacement from
    $t = 0.0$ s to $t = 0.1$ s
    $t = 0.1$ s to $t = 0.2$ s
    $t = 0.2$ s to $t = 0.3$ s
    $t = 0.3$ s to $t = 0.4$ s
    $t = 0.4$ s to $t = 0.5$ s
12. Record the data in your table. Since your car travelled only forward, each of these displacements is given a positive value.

Analyze

1. Compare the displacements for each of your time intervals.
   (a) Were all of the displacements exactly the same?
   (b) If not, what does this indicate?
   (c) What could have caused these variations?

Conclude and Apply

1. State the relationship between equal time intervals and the actual displacements for the car's motion.
2. If you repeated this experiment with a faster car, how would the ticker tape from that experiment compare to this ticker tape?

When all cars travel with uniform motion, their spacing remains constant.

8-1F Slow Motion and Fast Motion Trials

SkillCheck

- Observing
- Measuring
- Controlling variables
- Graphing

In order to analyze motion, you need both position and time data. There are various methods you can use to obtain the data. In this activity, you will use a recording timer or a motion sensor connected to a computer.

Question

How can you represent slow motion and fast motion on a position-time graph?

Materials

Option A

- ruler
- ticker tape
- recording timer (60 Hz)
- carbon disk

Option B

- motion sensor
- dynamics cart
- data collection device, such as a computer or graphing calculator

Procedure

Option A Using a Recording Timer

Part 1 Collecting Data

1. Copy the following tables into your notebook.

Slow Motion Trial	
Time (s)	**Position (m [forward])**
0.0	
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1.0	

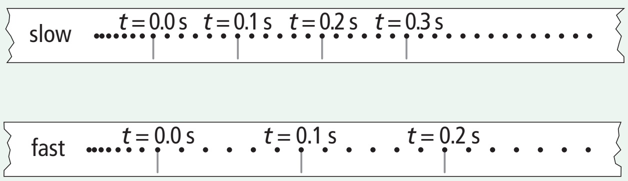
Fast Motion Trial	
Time (s)	**Position (m [forward])**
0.0	
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1.0	

2. Cut a piece of ticker tape approximately 1.5 m long. Insert the ticker tape into the recording timer.
3. Have your partner hold the recording timer securely against the table top and turn the timer on.
4. Pull the tape slowly with as steady a motion as you can until all the tape has been pulled through the timer. (Check the dots on your tape. If they are so close together that you cannot see individual dots, repeat this procedure pulling a little faster.) Label this tape "slow."
5. Repeat steps 2 to 4, this time pulling the tape steadily but approximately twice as fast as the first tape. Label this tape "fast."
6. Clean up and put away the equipment you have used.

Science Skills

Go to Science Skill 5 for information about how to organize and communicate scientific results with graphs.

Part 2 Graphing the Data



Marking the ticker tape

7. The dots on the very beginning of your tapes may not be evenly spaced. Locate the section of your tape where the dots become evenly spaced. Draw a line through the first dot that represents the even spacing and label it $t = 0.0$ s.
8. Since your recording timer has a frequency of 60 Hz, every six dots represent a time interval of 0.1 s. Starting from the $t = 0.0$ s line, count six dots and draw a line through the sixth dot and label it $t = 0.1$ s.
9. Now from the $t = 0.1$ s line, count six dots and draw a line through the sixth dot and label it $t = 0.2$ s. Continue marking your tape into six dot intervals until you label $t = 1.0$ s.
10. Measure the distance from $t = 0.0$ to $t = 0.1$ s, $t = 0.0$ to $t = 0.2$ s, $t = 0.0$ to $t = 0.3$ s, etc., for each tape. Record the data in the appropriate position-time table.
11. On a single graph, draw a best-fit line for each set of data. Be sure to indicate which line represents the slow motion trial and which line represents the fast motion trial.

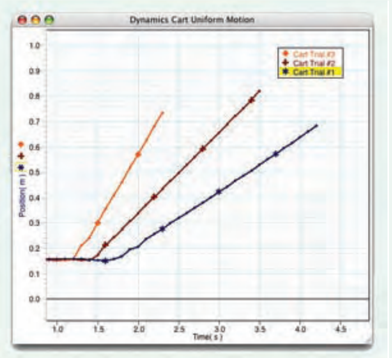
Analyze

1. (a) For which of the two motions, slow or fast, does the best-fit line most resemble the plotted data?
   (b) Explain what this indicates.

Conclude and Apply

1. The two trials produced graph lines with different slopes. What is the relationship between the steepness of the graph line and how fast you pulled the tape?

Option B Using a Motion Sensor



Sample motion sensor graph

1. Connect your motion sensor to your data collection device. Configure your data collection device to display a position-time graph.
2. Place the dynamics cart on a smooth surface, about 10 cm in front of the motion sensor. Make sure the cart will travel directly away from the motion sensor when given a push. Use your finger to propel the dynamics cart away from the motion sensor, and then begin recording data. Allow the cart to move about a metre away from the motion sensor, and then stop recording data. If you did not collect sufficient data, adjust the aim of the motion sensor and repeat the trial.
3. Repeat step 2 twice, each time propelling the dynamics cart at a slightly greater rate.
4. Observe the graphed data that was produced by the motion sensor (if possible, print the graph).

Analyze

1. How nearly did the carts travel with uniform motion? Use your graph to explain your answer.
2. If the carts were to travel with uniform motion, what would your graph look like?

Conclude and Apply

1. The three trials produced graph lines with different slopes. What is the relationship between the steepness of the graph line and how fast you pushed the cart?

Rapattack Helicopter Pilot

A helicopter hovers near the smouldering fire caused by a lightning strike in the middle of thousands of hectares of forest in northern British Columbia. The firefighters carefully exit the side of the helicopter and rappel down a rope to an area next to the blaze. The firefighters are part of Rapattack, British Columbia's initial response team, which uses specialized equipment and skills to reach hard-to-access areas where fires can quickly take hold. Rockie Saliken is a Rapattack helicopter pilot. Each summer, he works with specialized firefighters out of Salmon Arm, to keep lightning strikes from starting forest fires.

Rockie Saliken

Rappelling out of a helicopter

Q. What training do you need to become a helicopter pilot?

A. To become a helicopter pilot, you go to school for about four months. You learn about aerodynamics, weather, radio communication, navigation, and air regulations. Then you write an exam and take a flight test. This is your basic helicopter licence. You are constantly learning new concepts. To become a Rapattack pilot, you need 10 to 15 years of experience plus a lot of other training along the way.

Q. Are you a Rapattack pilot all year long?

A. No, it is one of many jobs that a helicopter pilot does depending on the season. Rapattack happens in the summer. At other times of year, I have piloted for heliskiing, helilogging, mining exploration, oil exploration, patient transfers, mountain rescues, and search and rescue.

Q. What type of helicopters do you fly?

A. I have flown almost every type of helicopter. We match the aircraft to the job, so what helicopter I will fly depends on what I am doing that day. For the Rapattack work, I fly a Bell 212 twin-engine, which can hold about 15 people. We usually have five people on board: the pilot, the helicopter operations technician, and three firefighters.

Q. What is a typical day in the summer like for you?

A. We get the call and fly out to where the fire is. Usually, we respond to lightning strikes that conventional crews cannot get to because the locations are too remote. My job as the pilot is to keep the platform as stable as possible while the firefighters rappel down to the ground with help from the operations technician. I am constantly adjusting controls to keep the helicopter stable so they can land or be picked up safely.

Q. Why are vectors important to a helicopter pilot?

A. We use vectors for everything from aerodynamics to navigation. We use thrust vectors, drop patterns, and power. It is important for us to be able to work with whatever conditions we are in.

Q. Why are position and direction important to a helicopter pilot?

A. When hovering, you need to be positioned into the wind to keep the helicopter stable. In forward flight, direction and position help you navigate the aircraft. You need to know how much power to give a certain job depending on the conditions, including wind and internal weight.

Q. What affects the acceleration of a helicopter?

A. A helicopter is a high performance machine, but how it is internally loaded affects how fast it can go up or move forward. The more weight (whether people, gear, or fuel), the slower it goes. You have to balance performance with the internal weight.

Questions

1. List five things you learn about when studying to be a pilot.
2. What is a Rapattack pilot's job?
3. What affects the acceleration of a helicopter?

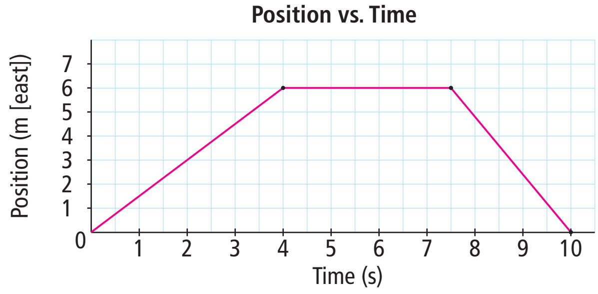
Check Your Understanding

Checking Concepts

1. Define "scalar quantity."
2. Define "vector quantity."
3. What does "magnitude" mean?
4. Explain the difference between position and distance.
5. Classify each of the following as either vectors or scalars.
   (a) distance
   (b) time interval
   (c) position
   (d) displacement
6. Give the symbol used to represent each of the following.
   (a) distance
   (b) time interval
   (c) position
   (d) displacement
7. What is the mathematical difference between final and initial time called?
8. What Greek letter is used to represent the change in a quantity?
9. Define "displacement."
10. In terms of the final and initial position of an object, how would you calculate displacement?
11. An object has a displacement of 2 m forward during a 5 s time interval. If the object's motion were uniform, what would be its displacement during the next 5 s time interval?
12. When drawing a position-time graph, which data would you plot on
    (a) the horizontal (x) axis?
    (b) the vertical (y) axis?
13. What kind of a line represents uniform motion on a position-time graph?

Understanding Key Ideas

Use the graph below to answer questions 14 to 16.



14. For each of the time intervals below, describe the motion of the object. Be sure to include direction when necessary.
    (a) 0 s–4 s
    (b) 4 s–8 s
    (c) 8 s–10 s
15. Calculate the displacement for each of the following time intervals.
    (a) 0 s–4 s
    (b) 4 s–8 s
    (c) 8 s–10 s
    (d) 0 s–10 s
16. What total distance did the object travel in the time interval 0 s to 10 s?
17. Under what conditions will the magnitude of the displacement be equal to the distance?

Pause and Reflect

A horizontal line (zero slope) on a position-time graph indicates that the object is remaining stationary for that time interval. What type of graph line would represent impossible motion? Explain your answer.