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.

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.

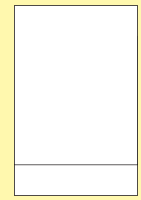
Skills You Will Use

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

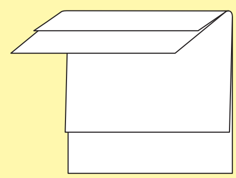
FOLDABLES™
Reading & Study Skills

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

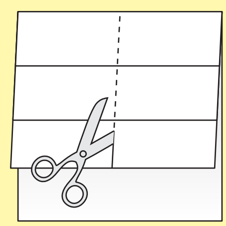
STEP 1 **Stack** two sheets of paper (22 cm by 28 cm) so that the back sheet is about 2.5 cm lower than the front sheet.



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

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.

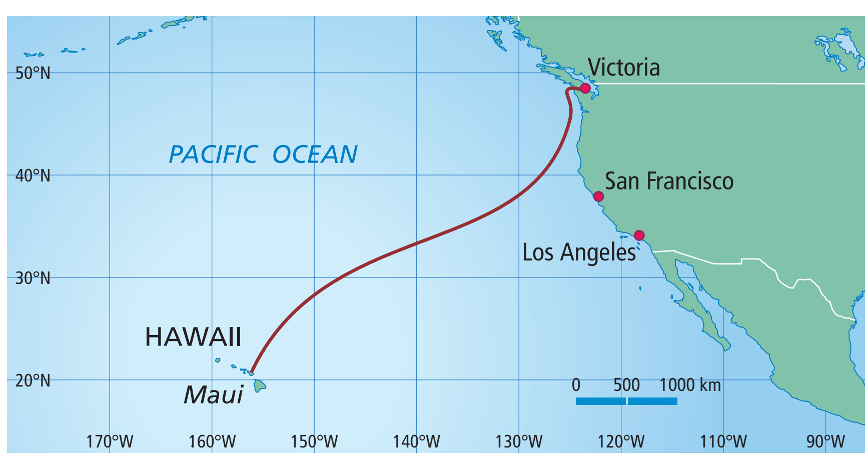


Figure 8.1B Sailors rely on the wind to propel the boats along the race course.

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.

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.

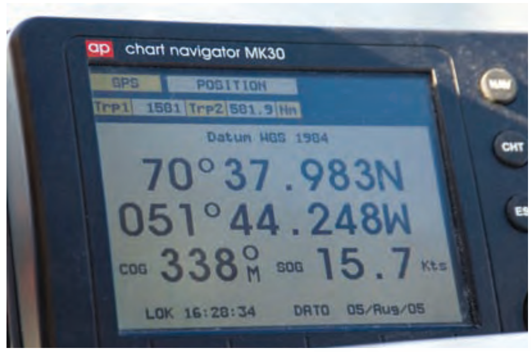


Figure 8.2 A Global Positioning System (GPS) receiver onboard the boat calculates its position by measuring the distance between itself and three or more GPS satellites.

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.

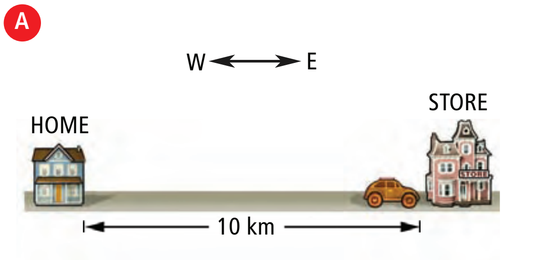


Figure 8.5A The car's position is 10 km east of home. The distance it has driven is 10 km.

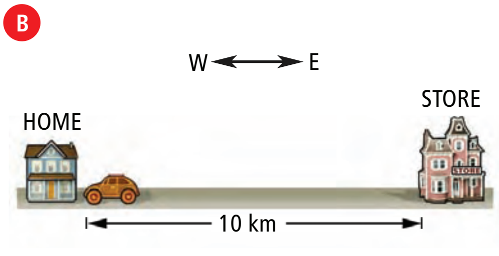


Figure 8.5B The car's position is 0 km from home. The distance it has driven is 20 km.

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.

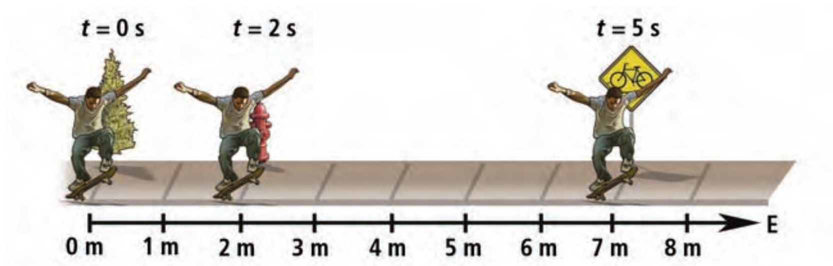


Figure 8.6 The sign is 7 m east of the tree in a straight line.

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.

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

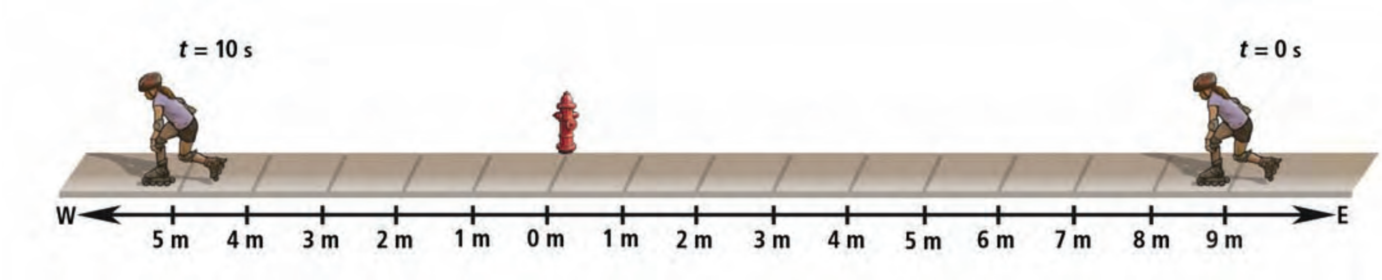


Figure 8.7 The skater's initial position is 9 m [E] of the fire hydrant. Her final position is 5 m [W] of the fire hydrant.

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].

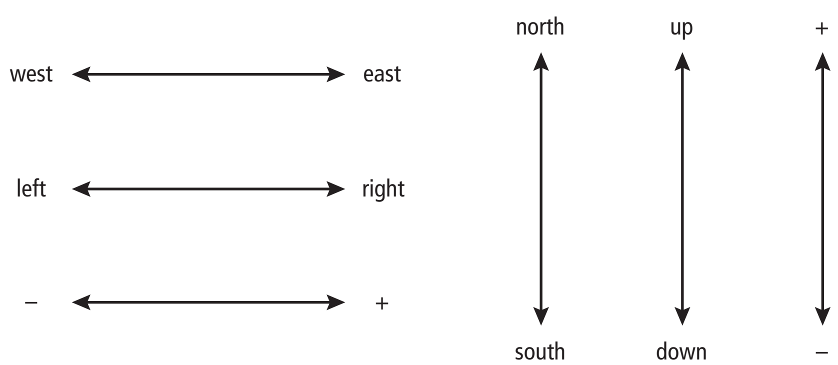


Figure 8.8 North, east, up, and right are called positive (+). South, west, down, and left are called negative (−).

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.

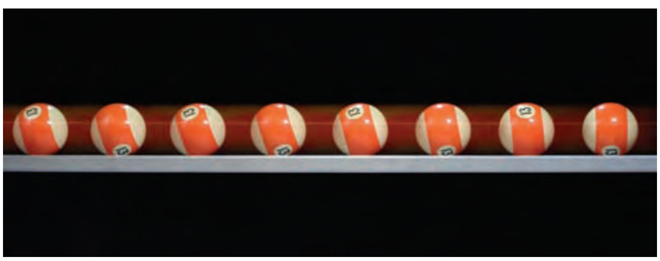


Figure 8.9 The displacement of the ball is very nearly uniform for each time interval.

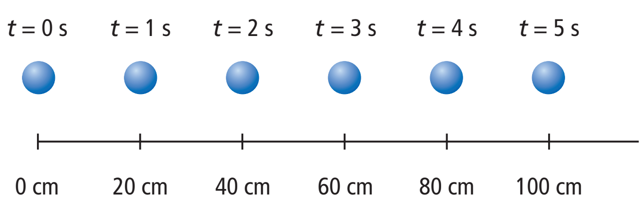


Figure 8.10 A motion diagram can show the position of an object at a given time.

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

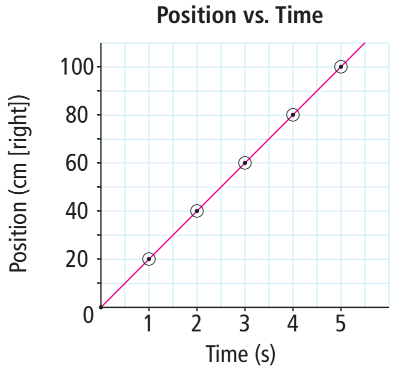


Figure 8.11 The uniform motion of the ball is shown as a straight line on a position-time graph.

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.

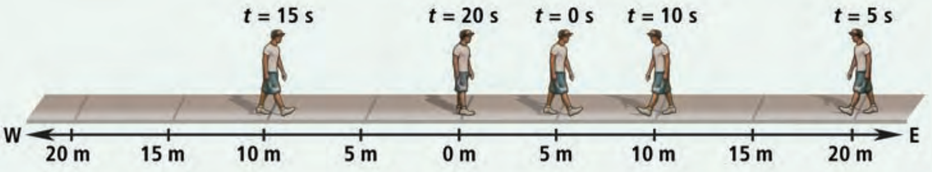
What to Do

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.

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

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.

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.

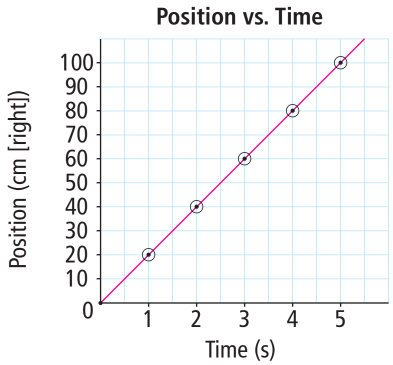


Figure 8.12 A positive slope

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.

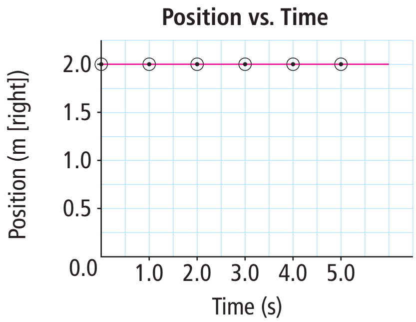


Figure 8.13B An object at rest is represented as a horizontal straight line on a position-time graph.

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.

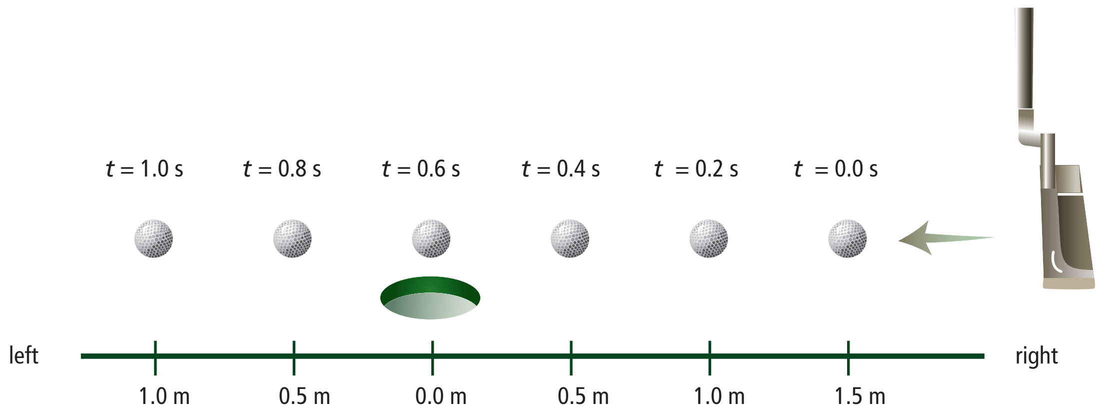


Figure 8.14 Picture the golf ball travelling uniformly past the hole.

Suggested Activity

Think About It 8-1D on page 355

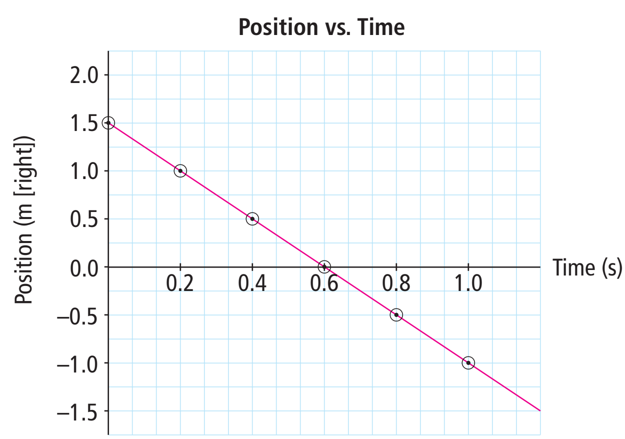


Figure 8.15 If *right* is given a positive value, then a negative slope indicates the object is travelling to the *left*.

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

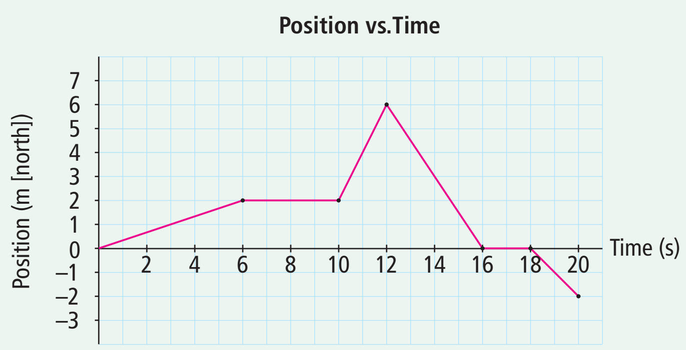
Think About It

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

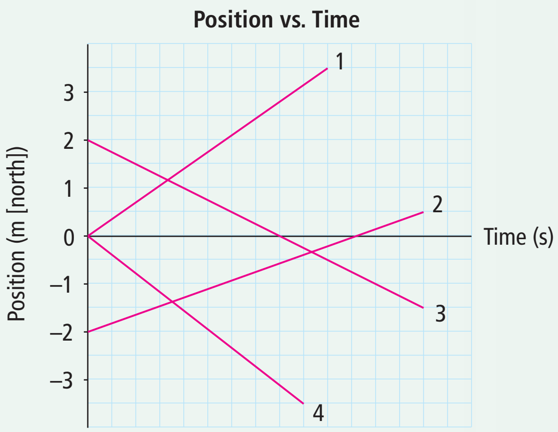
1. Sketch position-time graph A in your notebook.
2. For each of the following time intervals, describe the motion of the object represented by the position-time graph. Be sure to include directions when needed.
   (a) 0 s–6 s
   (b) 6 s–10 s
   (c) 10 s–12 s
   (d) 12 s–16 s
   (e) 16 s–18 s
   (f) 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

Skill Check

- Observing
- Measuring
- Controlling variables
- Evaluating information

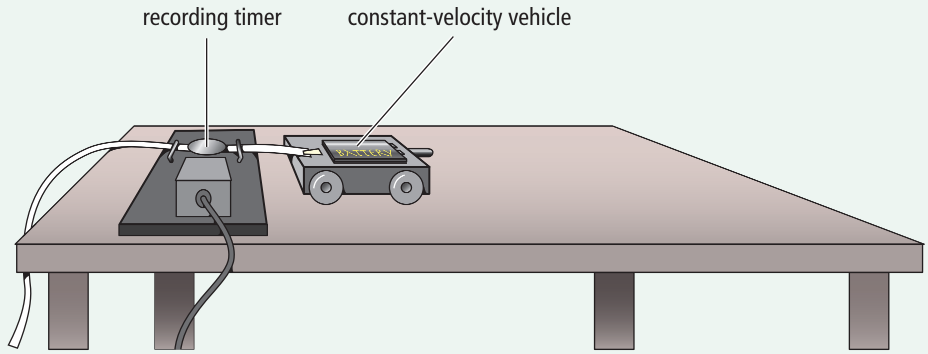
Materials

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

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?



Step 3

Procedure

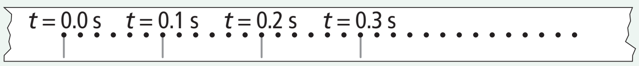
Part 1 Collecting Data

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

Skill Check

- 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	

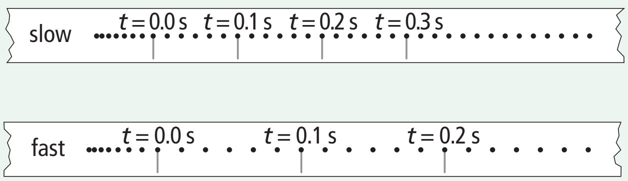
Fast Motion Trial	
Time (s)	**Position (m [forward])**
0.0	
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1.0	

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.

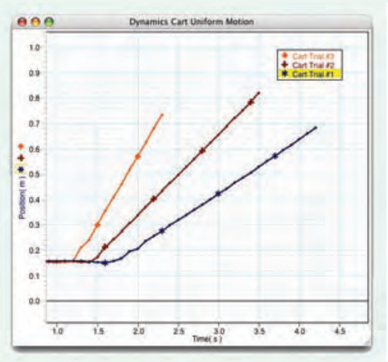
Analyze

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?

Career Connect

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?

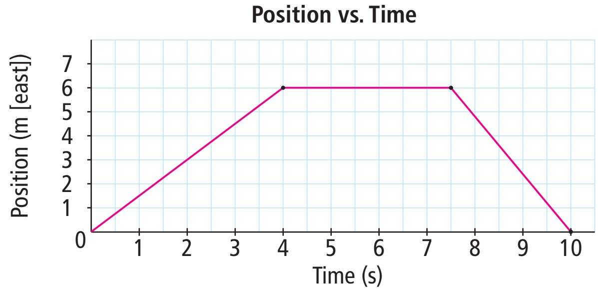
Check Your Understanding

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.

8.2 Average Velocity

Average velocity is the rate of change in position. Speed is the magnitude of the velocity. The slope of the best-fit line on a position-time graph is average velocity. The relationship between average velocity, displacement, and time interval is given by $\vec{v}_{av} = \frac{\Delta \vec{d}}{\Delta t}$.

Words to Know

average velocity
speed
velocity

It is a beautiful, sunny, winter morning. Last night, 15 cm of fresh powder snow fell on your favourite ski hill. You stand happily at the base of the hill, waiting to be the first to carve your mark in the new snow.

British Columbia has some of the best skiing and snowboarding in the world. Our ski hills offer various methods to transport people safely and efficiently up and down the mountains. Gondolas, like those in Figure 8.16, are connected to one continuous loop of cable. Each gondola on that cable travels the same amount of distance in the same time interval.

Did You Know?

Police instruments for detecting speeding vehicles include lasers, handheld radar devices, instruments mounted on police cars, and speed cameras. Some machines are able to track vehicles both approaching and receding and can track the fastest vehicle among a group of vehicles.

Figure 8.16 These two gondolas have the same rate of change in distance but in different directions.

The Peak to Peak gondola at Whistler Blackcomb has the longest uninterrupted span in the world at 3024 m between supports. The gondola ride takes skiers 4.4 km from the peak of Whistler Mountain to the peak of Blackcomb in just over 11 min. The Skyride gondola ride at Grouse Mountain in North Vancouver takes 8 min for its passengers to go 3 km up or down the mountain.

Suppose you were asked which of the two gondola rides travels faster. You probably already understand that it takes less time to get to your destination when you travel faster. The slower you travel, the longer it takes to arrive. But how do we compare objects that travel different distances, in different directions, all with various time intervals? In this section, you will learn how to use displacement and time intervals to calculate the rate and direction of motion.

8-2A The Faster Car Wins

Find Out ACTIVITY

In order to compare motion, we usually consider how fast the objects move and the direction in which the objects travel. In this activity, you will observe which toy car is faster.

Materials

- masking tape
- 2 different toy cars (wind-up or friction)

What to Do

1. On your lab table or other flat surface, stick two strips of masking tape approximately 2 m apart to indicate the start and finish line of the race.
2. Place one car on each of the lines so that when released they will head opposite directions to complete the race.
3. Release both cars at the same time. Note that if you are using wind-up cars, you will need to wind them before you release them. Friction cars will need to be pulled back before they are released.
4. Watch the two cars closely after they are released and determine which car is moving faster.

What Did You Find Out?

1. How did you determine which car was travelling faster?
2. If you wanted to calculate how fast the cars were travelling, what data would you need to collect?
3. Both of these cars travelled the same distance, but did they have the same displacement? Explain.
4. What words could you use to describe how fast something is moving?

Speed and Velocity

You probably use the term *speed* to describe how fast an object moves. In the study of motion, **speed** (v) is the distance an object travels during a given time interval divided by the time interval. Speed is a scalar quantity. The SI unit for speed is metres per second (m/s).

If you want to describe both the speed and the direction of motion, you would use the term *velocity*. **Velocity** ($\vec{v}$) is the displacement of an object during a time interval divided by the time interval. In other words, velocity describes how fast an object's position is changing. The direction of the velocity is the same as the direction of the displacement. Because it includes direction, velocity is a vector quantity. The SI unit for velocity is metres per second (m/s).

Figure 8.17 These two escalators have the same speed but different velocities since they are travelling in opposite directions.

Same speed, different velocities

Objects travelling the same speed can have different velocities. The reason for the difference lies in the definitions of distance and displacement. Distance is measured along the actual path taken. Displacement, however, is always measured along a straight line joining the initial and final positions. For example, the people on the two escalators in Figure 8.17 are travelling the same speed, but they are travelling opposite directions. One of these directions must be given a negative sign, and therefore they have different velocities. Velocities change when magnitude or direction or both change.

Calculating the Slope of the Position-Time Graph

The motion of two joggers is shown in Figure 8.18A below as a motion diagram and in Figure 8.18B on the next page as a position-time graph. A position-time graph represents the motion of objects, and we can determine the velocity of the objects from the graph.

Suppose each jogger moves at a constant velocity. During equal time intervals, the position of the female jogger changes more than the position of the male jogger. Since her displacement for equal time intervals is greater than his, we can conclude that she is jogging faster than he is. In order to calculate how fast each jogger is moving, you need to know both the displacement and the time interval.

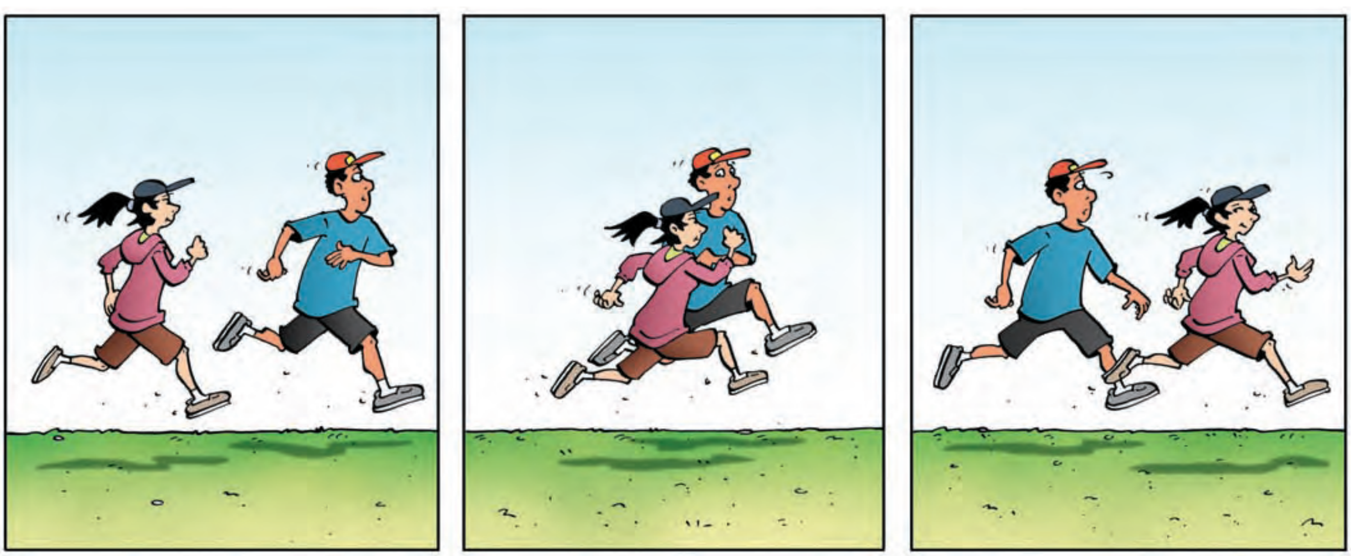


Figure 8.18A A motion diagram of two joggers. The female jogger is travelling faster than the male jogger.

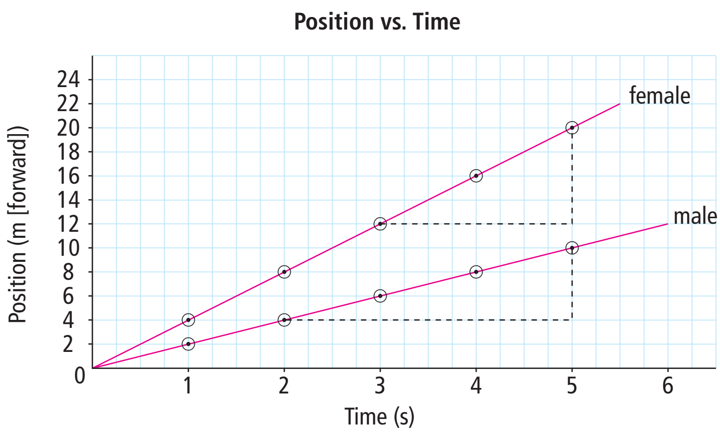


Figure 8.18B A position-time graph for two joggers. The female jogger is travelling faster than the male jogger.

Notice in Figure 8.18B that the slope of the female jogger's line is steeper than the slope of the male jogger's line. This is because she has a greater change in position (displacement) than he does during the same time interval. We can calculate and compare the slopes of each of these lines as follows.

Female jogger

$$\begin{aligned} \text{Slope} &= \frac{\Delta \vec{d}}{\Delta t} \\ &= \frac{(\vec{d}_f - \vec{d}_i)}{(t_f - t_i)} \\ &= \frac{(20\text{ m} - 12\text{ m})}{(5.0\text{ s} - 3.0\text{ s})} \\ &= \frac{8.0\text{ m}}{2.0\text{ s}} \\ &= 4.0\text{ m/s} \end{aligned}$$

Male jogger

$$\begin{aligned} \text{Slope} &= \frac{\Delta \vec{d}}{\Delta t} \\ &= \frac{(\vec{d}_f - \vec{d}_i)}{(t_f - t_i)} \\ &= \frac{(10\text{ m} - 4\text{ m})}{(5.0\text{ s} - 2.0\text{ s})} \\ &= \frac{6.0\text{ m}}{3.0\text{ s}} \\ &= 2.0\text{ m/s} \end{aligned}$$

Average Velocity

If we compare the two slopes in Figure 8.18B, the value of the female jogger's slope is greater than the value of the male jogger's slope. Since she was running faster than he was, we could assume that the slope might be related to the runner's speed. If we analyze the units of the slope calculation, metres per second (m/s), the slope shows on average how many metres the runner moved in one second. In other words, the slope of a position-time graph for an object is the object's average velocity.

Average velocity is the rate of change in position for a time interval. It would be almost impossible for a person to walk or run at a perfectly uniform rate. This is because many factors, such as wind or an uneven surface, may cause the person to slightly speed up or slow down. The concept of average velocity "smooths out" these changes.

It is a common error to consider average velocity to be the same as average speed. However, average velocity is a vector and includes a direction. Average speed is a scalar and does not include direction. The symbol $\vec{v}$ usually means the average velocity over a particular time interval. For clarity, $\vec{v}_{av}$ is used as a symbol for the average velocity.

Position-time graphs and average velocity

A position-time graph can contain positive, zero, and negative slopes, (Figure 8.19). If we designate moving away from the origin as positive, then a positive slope represents the average velocity of the object moving away from the origin. A horizontal line, which has zero slope, represents the object not moving. A negative slope represents the average velocity of the object moving back toward the origin. Table 8.2 summarizes this motion.

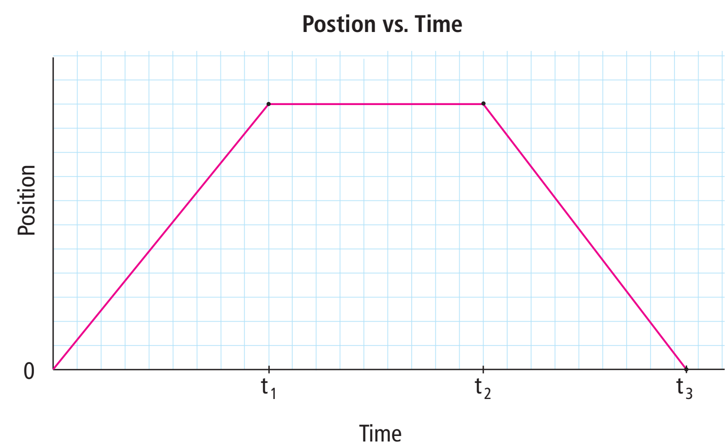


Figure 8.19 The slope of a position-time graph represents the object's average velocity.

Table 8.2 Average velocity of an object

Time interval	$t_1 - 0$	$t_2 - t_1$	$t_3 - t_2$
Velocity	Positive	Zero	Negative
Motion	Moving away from the origin at a uniform speed	Remaining stationary	Returning to the origin at a uniform speed

Reading Check

1. How is speed different from velocity?
2. How is the motion of an object with a positive velocity different from the motion of an object with a negative velocity?
3. What concept does the slope of a position-time graph represent?
4. On a position-time graph, line A has a greater slope than line B. What does this indicate about the average velocity of the two objects represented by line A and line B?
5. What does a zero slope on a position-time graph indicate about the object's average velocity?

8-2B Slope and the Position-Time Graph

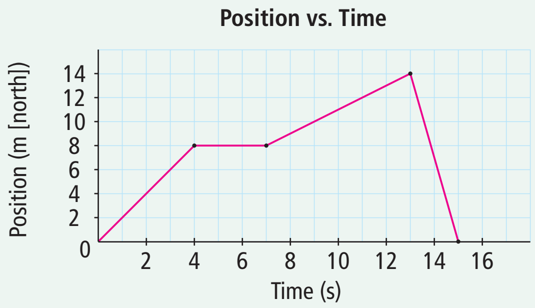
Think About It

In this activity, you will use an object's position-time graph to make inferences about the object's motion and calculate the object's average velocity.

What to Do

1. Copy the following table into your notebook. Give the table a title. Then use the table and graph to help you answer the questions that follow.

Time interval (s)	0 s to 4 s	4 s to 7 s	7 s to 13 s	13 s to 15 s
Velocity (positive, negative, or zero)				
Motion of the object				



2. For each of the time intervals indicated in your table, record whether the velocity of the object is positive, negative, or zero.
3. For each of the time intervals indicated in your table, what can you infer about the motion of the object? Record your inferences in the table.
4. Calculate the average velocity of the object for each of the following time intervals.
   (a) 0 s–4 s
   (b) 4 s–7 s
   (c) 7 s–13 s
   (d) 13 s–15 s

What Did You Find Out?

1. During what time interval was the object moving the fastest?
2. What direction was the object travelling when it was moving the fastest?

Converting between m/s and km/h

It is sometimes necessary to change from one unit of measurement into another. For example, the SI unit of measurement for both speed and velocity is metres per second (m/s). In daily life, kilometres per hour (km/h) is a common unit when representing both speed and velocity (Figure 8.20).

To convert a velocity given in km/h to m/s, you must first change kilometres to metres, then hours to seconds. Given that 1000 m = 1 km and 3600 s = 1 h, multiply by an appropriate distance conversion factor and then by a time conversion factor. For example, 55 km/h [W] becomes

$$\frac{55\ \cancel{\text{km}}}{1\ \cancel{\text{h}}} \times \frac{(1000\ \text{m})}{(1\ \cancel{\text{km}})} \times \frac{(1\ \cancel{\text{h}})}{(3600\ \text{s})} = 15\ \text{m/s [W]}$$

Notice that the units have been converted from km/h to m/s.

Figure 8.20 Speed zone limits are stated in kilometres per hour.

Calculating Average Velocity

In mathematics, we calculate the slope of a line as: slope = rise/run (Figure 8.21). On a graph, this would mean slope $= \frac{\triangle y}{\triangle x}$, where $\triangle y$ represents the change in the y-axis value and $\triangle x$ represents the change in the x-axis value. In other words, the slope of the line on a position-time graph is the displacement ($\triangle \vec{d}$) divided by the time interval ($\triangle t$).

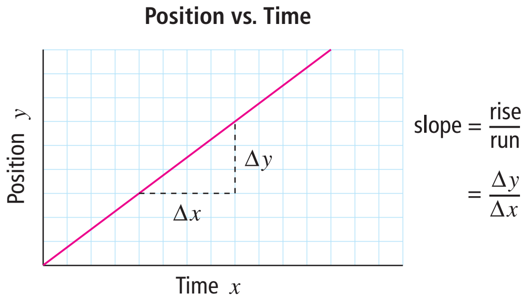


Figure 8.21 The slope of a straight line is the ratio of rise to run.

$$\text{Slope} = \frac{\text{rise}}{\text{run}}$$
$$= \frac{\triangle \vec{d}}{\triangle t}$$

Since the slope of a position-time graph is the average velocity ($\vec{v}_{av}$), the relationship between the average velocity, displacement, and time shown in Figure 8.22 is given as:

$$\vec{v}_{av} = \frac{\triangle \vec{d}}{\triangle t}$$

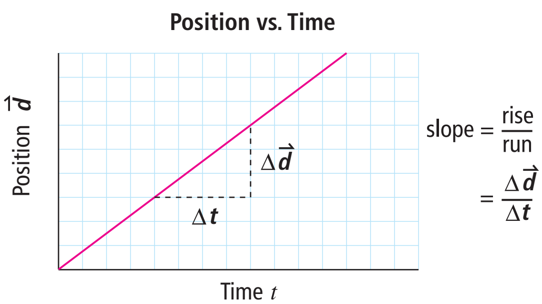


Figure 8.22 The slope of a straight line on a position-time graph is the ratio of displacement to time interval. The slope represents the average velocity.

By using this relationship, you can calculate the average velocity without analyzing a position-time graph. For example, suppose that it takes a sprinter 8.2 s to run forward 75.0 m. What is the sprinter's average velocity?

Given: $\triangle \vec{d} = +75.0 \text{ m}$, $\triangle t = 8.2 \text{ s}$

$$\vec{v}_{av} = \frac{\triangle \vec{d}}{\triangle t}$$
$$= \frac{+75.0 \text{ m}}{8.2 \text{ s}}$$
$$= +9.1 \text{ m/s}$$

The sprinter ran 9.1 m/s forward.

Did You Know?

A golf ball leaves the tee at over 250 km/h. The change in velocity from 0 km/h to 250 km/h occurs in 450 microseconds (0.00045 s), which is less time than it takes to blink your eye.

Calculating Displacement

The relationship $\vec{v}_{av} = \frac{\Delta\vec{d}}{\Delta t}$ can also be used to calculate the displacement or the time. For example, what is the displacement of a skateboarder who travels 3.5 m/s [W] for 12 s?

We will use a negative sign (−) to indicate west [W].

Given: $\vec{v}_{av} = -3.5 \text{ m/s}, \Delta t = 12 \text{ s}$

$$\vec{v}_{av} = \frac{\Delta\vec{d}}{\Delta t}$$

$$\Delta\vec{d} = (\vec{v}_{av})(\Delta t)$$

$$= (-3.5 \text{ m/s})(12 \text{ s})$$

$$= -42 \text{ m}$$

Since the negative sign (−) was used to indicate west, the skateboarder's displacement is 42 m [W].

Calculating Time

To find time, the equation can be rewritten as follows:

$$\vec{v}_{av} = \frac{\Delta\vec{d}}{\Delta t}$$

$$\Delta t = \frac{\Delta\vec{d}}{\vec{v}_{av}}$$

For example, if a cyclist travels south at 12 m/s, how long would it take the cyclist to travel 600 m [S]?

We will use a negative sign (−) to indicate south.
Given: $\Delta\vec{d} = -600 \text{ m}$ and $\vec{v}_{av} = -12 \text{ m/s}$

$$\Delta t = \frac{\Delta\vec{d}}{\vec{v}_{av}}$$

$$= \frac{(-600 \text{ m})}{(-12 \text{ m/s})}$$

$$= 50 \text{ s}$$

It takes the cyclist 50 s to travel 600 m.

Suggested Activity

Conduct an Investigation 8-2D on page 371
Conduct an Investigation 8-2E on page 372

Practice Problems

Try the following average velocity problems yourself.

1. What is the average velocity of a dog that runs 35 m [S] in 4.5 s?

2. If a baseball is thrown at 25 m/s toward home plate, what would be the ball's displacement after 0.65 s?

3. Two friends want to paddle their canoe 450 m across a lake. If they head across the lake at 2.5 m/s, how long does it take them to cross?

Answers

1. 7.8 m/s south
2. 16 m toward home plate
3. 180 s

Explore More

To find out more about shortcuts for converting units, go to **www.bcscience10.ca**.

Answers

1. 9.7 m/s
2. 56 km/h, 16 m/s
3. 520 m
4. (a) 6.0 km/h [W]
   (b) 1.7 m/s [W]
5. 67 m [E]
6. 11 s

Practice Problems

Try the following unit conversion problems yourself.

1. Convert 35 km/h to m/s.
2. A car's displacement is 42 km [S] after driving for 0.75 hours. What is the car's average velocity in km/h and m/s?
3. A car is travelling forward at 75 km/h. How far does the car travel in 25 s?
4. A person paddles a canoe 1.2 km [W] in 0.20 hours.
   (a) What is the average velocity of the canoe in km/h?
   (b) What is the average velocity of the canoe in m/s?
5. What is the displacement of a car travelling 48 km/h [E] during a 5.0 s time interval?
6. How many seconds would it take a cyclist, travelling at 25 km/h, to travel 75 m forward?

8-2C Determining Average Velocity

Think About It

In this activity, you will determine the average velocity by finding the slope of the best-fit line on a position-time graph.

Materials

- graph paper
- ruler
- calculator

What to Do

1. The following data was recorded for a student jogging. Copy this data table into your notebook. Give the data table a title.

Position (m [E])	0	7	15	20	26	35	42	49	56
Time (s)	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0

2. Draw and label a position-time graph.
3. Calculate the slope of your best-fit line.

What Did You Find Out?

1. Did the student jog with motion at a constant rate? Explain your answer.
2. Calculate the average velocity of the jogger.
3. (a) Write the equation for the best-fit line.
   (b) Use your equation to calculate the jogger's position after running for 25 s.

Science Skills

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

8-2D What Is Its Velocity?

Design an INVESTIGATION

SkillCheck

- Observing
- Measuring
- Graphing
- Evaluating information

In this activity, you will design and conduct an experiment to find the average velocity of an object of your choice.

Problem

Design and conduct an experiment to measure the average velocity of an object with nearly uniform motion.

Criteria

- Create a procedure that will allow you to determine the average velocity of your chosen object.
- Your analysis must include a data table, position-time graph, and calculations.

Materials

Any of:

- measuring tapes
- metre sticks
- stopwatches
- recording timers
- ticker tape
- motion sensors

Design and Conduct

1. Choose an object that displays relatively uniform motion.
2. Write down your procedure for determining the object's average velocity. Have your teacher confirm that your procedure is safe and accurate before performing your experiment.
3. Collect all data and record in a titled data table.
4. Use a position-time graph to interpret your data.

Evaluate

1. What is the average velocity of your object? Show how you obtained your answer.
2. Was the object's motion perfectly uniform? Use your graph to justify your answer.
3. Describe any changes you would make to your procedure in order to improve your accuracy.

A volcanologist is using a radar gun to measure the speed of flowing lava. A similar type of radar gun is used to measure the speed of pitches in baseball.

8-2E Walk This Way

SkillCheck

- Measuring
- Controlling variables
- Graphing
- Working co-operatively

Materials

- 50 m tape measure
- 10 stopwatches
- 11 students

In order to find the average velocity of an object's motion, measurements of displacements during time intervals are required. The velocity of an object travelling in one direction must be opposite in sign to an object travelling in the other direction. On a position-time graph, this is represented as positive and negative slopes. In this activity, you will determine the average velocity of a person walking both forward and backward.

Question

How can a position-time graph be used to analyze the magnitude and direction of a person's average velocity?

Procedure

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

Table 1

Walking Forward											
Position (m)	0	5	10	15	20	25	30	35	40	45	50
Time (s)	0										

Table 2

Walking Backward											
Position (m)	50	45	40	35	30	25	20	15	10	5	0
Time (s)	0										

2. On an open field, or in a long hallway, extend the 50 m tape measure in a straight line.
3. Place a student with a stopwatch at each of the positions indicated in Table 1, from 5 m to 50 m. There does not need to be a student with a stopwatch at the origin (0 m).
4. Place the student who is going to walk the 50 m at the origin (0 m).
5. On the command "Go," all students will start their stopwatches and the student who is going to walk will begin walking with as uniform a velocity as possible for the complete 50 m.
6. Students will stop their stopwatches when the walking student passes their position.

7. The time on each student's stopwatch will be shared with the group and recorded in Table 1.
8. Place a student, with a stopwatch, at each of the positions indicated in Table 2, from 45 m to 0 m. There does not need to be a student with a stopwatch at the 50 m position.
9. Place the student who is going to walk backward at the 50 m position.
10. On the command "Go," all students will start their stopwatches and the student who is going to walk will begin walking backward with as uniform a velocity as possible for the complete 50 m.
11. Students will stop their stopwatches when the walking student passes their position.
12. The time on each student's stopwatch will be shared with the group and recorded in Table 2.
13. Clean up and put away the equipment you have used.

Analyze

1. On the same set of axes, plot a position-time graph for both sets of recorded data. Draw a best-fit line for each of your sets of data. Calculate the slope of each of your best-fit lines.
2. What is the average velocity of the student
   (a) walking forward?
   (b) walking backward?
3. Was the student's average speed faster when walking forward or when walking backward?

Conclude and Apply

1. What can you infer about whether the student's motion was perfectly uniform while walking forward or backward? Use your graph to justify your answer.

The Snowbirds Demonstration Team features more than 50 different formations and manoeuvres requiring precise changes in velocity. The head-on cross manoeuvre has a combined closing speed of approximately 1100 km/h.

Science Skills

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

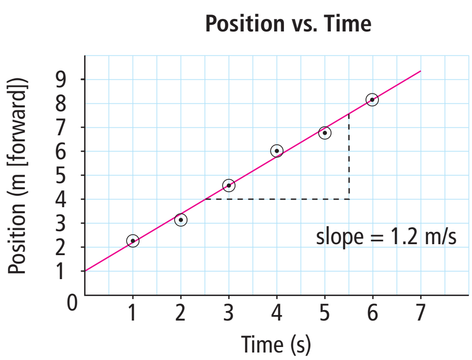
Science Math connect

Finding Relationships from Straight Line Graphs

A volcanologist tracks the position of the front of a lava flow at specific times as it travels forward in a straight line.

Time (s)	1.0	2.0	3.0	4.0	5.0	6.0
Position (m [forward])	2.2	3.3	4.6	5.9	6.9	8.2

When the data are plotted in a position-time graph, the slope shows that the lava's average velocity is 1.2 m/s forward. What other information does the graph show?



The *y*-intercept

The *y*-intercept is the location on the vertical axis where the graph line touches the *y*-axis. Not all graph lines must pass through the origin (0,0). On any graph, the *y*-intercept is the value on the *y*-axis when the value on the *x*-axis is zero. For the position-time graph shown above, the *y*-intercept is 1.0 m. This means that the lava front was located 1.0 m forward of the origin when timing began. This is information about the experiment that the graph shows but that the data table does not easily display.

The equation of the line

When the data are represented by a best-fit straight line, the two variables on the *x*-axis and the *y*-axis are directly proportional to each other. Directly proportional means, for example, as the value of one variable on the axis doubles, the value of the other axis doubles as well.

The equation of a straight line is given as $y = mx + b$, where y is the variable on the vertical axis, x is the variable on the horizontal axis, m is the slope, and b is the *y*-intercept. Using this general equation, we can write the equation for the directly proportional relationship between any two variables. The equation of the line for our position-time graph could be written as follows:

$$y = mx + b$$

$$\vec{d} = (1.2\ \text{m/s})t + 1.0\ \text{m}$$

where $\vec{d}$ represents the lava's position forward and t represents the time.

Using the equation of the line

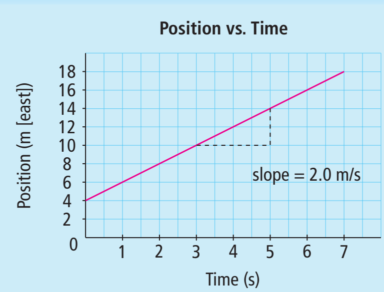
Interpolation is the process of estimating a value that is between two directly measured data points. Extrapolation is the process of estimating values that are beyond the measured data points. Interpolation and extrapolation are easily done from a equation of the line. For example, suppose we wanted to know the position of the lava front at 2.5 s. Rather than approximating from our graph, we can use the equation:

At $t = 2.5$ s

$$\begin{aligned}\vec{d} &= (1.2\ \text{m/s})t + 1.0\ \text{m}\\ &= (1.2\ \text{m/s})(2.5\ \text{s}) + 1.0\ \text{m}\\ &= 4.0\ \text{m}\end{aligned}$$

At 2.5 s, the lava front position is 4.0 m forward.

Questions



Use this graph to answer the questions.

1. What is the value of the *y*-intercept in this graph?
2. What equation represents the lava flow's motion?
3. Use your equation to determine the position of the front of the lava flow at 6.5 s.

Check Your Understanding

Checking Concepts

1. Two lines on a position-time graph represent the motion of two world-class sprinters. Line 1 has a steeper slope than line 2. How does the average velocity of the sprinter represented by line 1 compare to the average velocity of the sprinter represented by line 2?

2. What does the slope of the line on a position-time graph represent?

3. What are two common units for velocity?

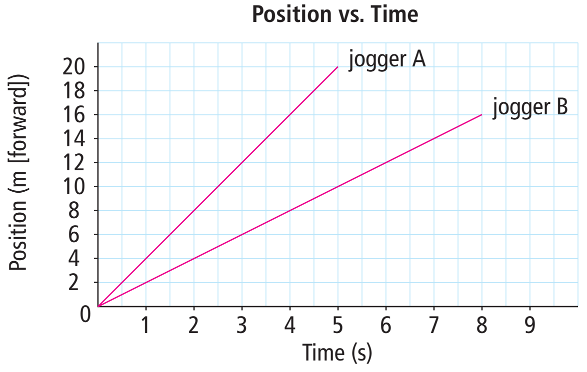
4. Explain the difference between average speed and average velocity.

5. What is the mathematical relationship between average velocity ($\vec{v}_{av}$), displacement ($\Delta\vec{d}$), and time interval (Δt)?

Understanding Key Ideas

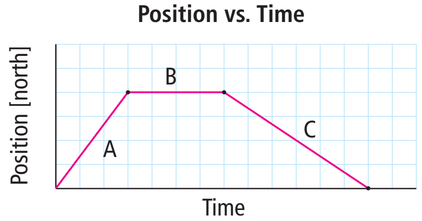
6. The motion of two joggers is recorded in the position-time graph below. Calculate the average velocity of jogger A and jogger B.

Position vs. Time



7. Given the position-time graph below, determine which segment of the graph represents each of the following.
(a) zero velocity
(b) positive slope
(c) moving north with a uniform velocity
(d) zero slope
(e) moving south with a uniform velocity
(f) negative slope

Position vs. Time



8. What is the average velocity of an arrow that travels 12 m [E] in 0.15 s?

9. What is the average velocity of a snail that crawls 0.25 m forward in 150 s?

10. If a canoe has an average velocity of 4.2 m/s [W], what is its displacement after 25 s?

11. A ball rolls across the floor with an average velocity of 6.0 m/s [S]. What is the ball's displacement after 12 s?

12. How long does it take to run forward 420 m if the runner's forward velocity is 6.0 m/s?

13. If sound travels at 350 m/s, how long does it take the sound to travel 110 m across a field?

14. Convert 45 km/h to m/s.

15. A car travels 45 km [N] in 0.70 h.
(a) What is the car's average velocity in km/h?
(b) What is the car's average velocity in m/s?

16. A horse is running forward at 42 km/h. What is the horse's displacement during a 3.0 s time interval?

17. The position of an object is recorded in the following data table.

Time	0.0 s	2.0 s	4.0 s
Position	3.0 m [N]	7.0 m [S]	3.0 m [S]

Calculate the average velocity for each of the following time intervals.
(a) 0.0 s–2.0 s
(b) 2.0 s–4.0 s
(c) 0.0 s–4.0 s

Pause and Reflect

Most major harbours have a 10 km/h speed limit for boats travelling in the harbour. Suppose you are sitting by the harbour and watching the motion of the boats. Describe a simple experiment you could perform to determine if a boat is exceeding the speed limit.

Chapter Review

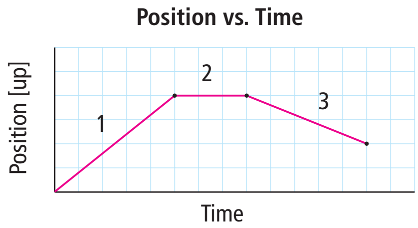
Prepare Your Own Summary

In this chapter, you investigated the relationship between average velocity, displacement, and time interval. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 11 for help with using graphic organizers.) Use the following headings to organize your notes:

1. Terms Used to Describe Motion
2. Scalars and Vectors
3. Uniform Motion
4. Position-Time Graph
5. Calculating Average Velocity

Checking Concepts

1. How is a vector quantity different from a scalar quantity?
2. (a) Give an example of a scalar quantity.
   (b) Give an example of a vector quantity.
3. Explain which would be more useful to you if you needed to locate a buried treasure: the distance to the treasure or the position of the treasure.
4. Explain how it is possible to run a distance of 1.0 km and have zero displacement.
5. How do we determine a time interval?
6. What Greek letter represents the change in a quantity?
7. If a negative sign (−) is used to describe a soccer ball's direction of motion, what sign would you use if the ball were kicked in the opposite direction?
8. A ball travelling with uniform motion has a displacement of 6 m [E] during the first 2 s time interval. What would be the ball's displacement during the next 2 s time interval?
9. How is uniform motion represented on a position-time graph?
10. The following position-time graph represents the motion of an elevator. State which section of the graph describes:
    (a) the elevator at rest
    (b) the elevator moving downward
    (c) the elevator moving upward



11. Describe how you could use a position-time graph to determine average velocity.
12. The traffic sign at the beginning of a school zone reads "30 km/h." Is this sign a "speed zone" sign or a "velocity zone" sign? Explain your answer.
13. Suppose forward is assigned a positive sign (+). Describe the motion of an object whose velocity is:
    (a) positive
    (b) negative
14. State the mathematical relationship between average velocity, displacement, and time interval.
15. Copy and complete the following table in your notebook.

Concept	Symbol	Unit	Scalar or Vector?
Time interval			Scalar
Distance	*d*		
Displacement			
Speed		m/s	
Velocity			

16. The SI unit for average speed or average velocity is m/s. What is another common unit used for these two concepts?
17. Explain how you would convert 85 km/h to m/s.

Understanding Key Ideas

18. The motion of a canoe, leaving the dock, is recorded in the data table below. Use the data to draw a properly labelled position-time graph. Draw a best-fit line through the plotted points, and use your graph to answer the following questions.

(a) What is the average velocity of the canoe?

(b) What was the position of the canoe when the timer was started (t = 0 s)?

Time (s)	5	10	15	20	25	30	35	40	45	50
Position (m[E])	12	20	25	31	40	49	56	60	67	75

19. A boy rides his bicycle north with a uniform velocity of 5 m/s for 10 s. Then he stops for 15 s to adjust his helmet. Next, he pushes his bicycle south with a uniform velocity of 2 m/s for 20 s.

(a) Sketch a position-time graph that represents the bicycle's motion for the 45 s time interval.

(b) What is the displacement of the bike after the 45 s time interval?

20. A girl rides her bicycle 420 m south in a time of 47 s. What is her average velocity?

21. What is the average velocity of a sprinter who takes 8.8 s to run forward 75 m?

22. If you paddled a boat with an average velocity of 2.1 m/s south, what would be your displacement if you paddled for 120 s?

23. What would be the height of a hot-air balloon after 5.0 min if the balloon lifted off the ground with an average velocity of 0.75 m/s?

Applying Your Understanding

24. On April 12, 1980, Terry Fox dipped his artificial right leg into the Atlantic Ocean off the coast of St. John's, Newfoundland. This was the beginning of the Marathon of Hope. Terry Fox's goal was to run across Canada to raise money for cancer research. It was a journey that Canadians would never forget.

Terry Fox tried to run a minimum of 42 km each day. He set a goal of 42 km since that is the distance run during a marathon. Some days, when the weather was good and the road was flat, Fox would run up to 50 km. But other days, when the hills were steep or the weather was stormy, he was not able to complete his 42 km goal. On September 1, 1980, outside Thunder Bay, Ontario, Terry Fox was forced to stop. The cancer that had taken his leg had moved to his lungs. His shortest daily distance, 28 km, occurred on this final day.

In 143 days, Terry Fox ran 5373 km, more than halfway across Canada. Terry Fox died on June 28, 1981, but his legacy lives on.

(a) Was it likely that Terry Fox's average velocity was the same every day? Use evidence from the above reading to support your answer.

(b) On average, how far did Terry Fox run each day of his 143 day journey?

(c) If the average forward velocity of a runner is about 10 km/h, how many hours would it take to run the distance Terry Fox ran?

Pause and Reflect

In science, a model is anything that helps you better understand a scientific concept. How can uniform motion be a useful model for real motion if real motion is never quite uniform? In other words, if real motion is not uniform, why study uniform motion?