CHAPTER 12

Displacement, Time, and Velocity

Chapter Preview

"How much longer until we get there?" You have probably asked that question at least once while travelling to a place. People have always been interested in knowing how long it takes to get from one place to another. Sometimes, if we are in a train or a plane, we arrive at our destination fairly quickly. Other times, because we do not always travel at the same speed, it takes a long time to reach our destination. Speed plays a big role in determining how long a journey will take.

Look at the series of photos of the long jumper. He is moving very fast so that he can jump a great distance. How can we describe his motion? What is the best way to display information about moving objects?

In this chapter, you will learn how to describe an object's motion. You will use this information to learn more about the motion. You will also learn several different methods of describing the motion of an object and apply these methods in different situations.

KEY IDEAS

- **The motion of an object can be described by displacement, time, and velocity.**
- **Distance–time graphs and position–time graphs can visually display information about an object's motion.**
- **Quantities can be either scalar or vector.**
- **An object's speed and velocity can be described in different ways.**

TRY THIS: Motion of a Table Tennis Ball

Skills Focus: observing, recording, communicating

In this activity, you will describe the motion of a table tennis ball.

Materials: table tennis table or rectangular table with masking tape across the middle, table tennis ball, two racquets

1. Position two people to play table tennis and position yourself in the middle beside the net.
2. The person on your right will serve the table tennis ball and the person on your left will receive the ball.
3. The server makes an easy serve with the table tennis ball. The receiver hits the ball to return it to the server. The server catches the ball and does not hit it.

A. Describe the position of the ball relative to you during the serve and return.

B. Describe the speed of the ball relative to you during the serve and return.

C. How did you indicate the direction that the ball was travelling relative to you in parts A and B?

12.1 Distance and Time

The concepts of distance and time are so commonplace that we take them for granted. We know the distances to different places (Figure 1) and we know the time that class begins and ends. We have units for distance and we have units for time. In addition, we have different needs for accuracy. A game of basketball with a bunch of friends ends when everyone wants to stop, while a championship game ends exactly when the buzzer goes!

LEARNING TIP

Skim (read quickly) to get a general sense of Chapter 12. Consider information gathered from the title, headings, figures, words in bold, and sample problems. What do you expect to learn in this chapter?

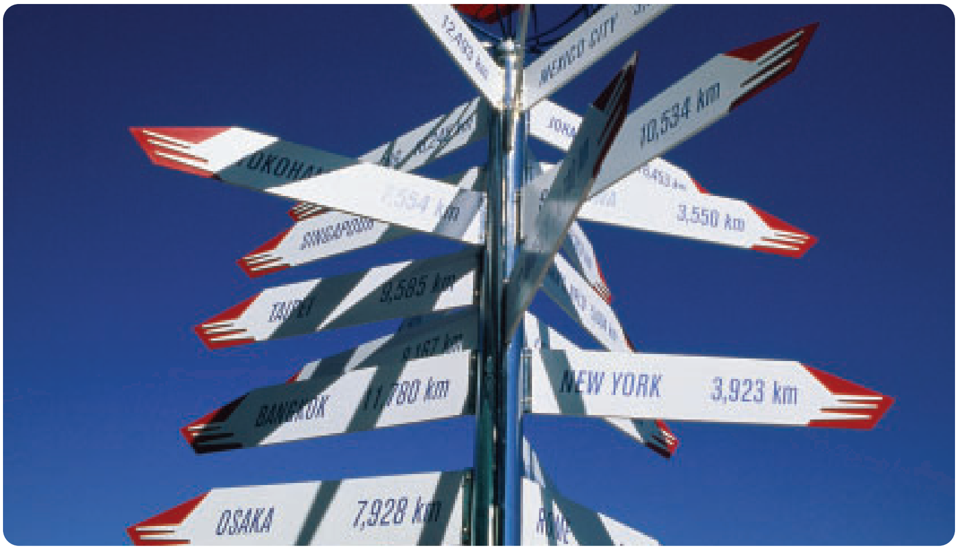


Figure 1 This signpost marks the distance from Canada Place in Vancouver to places all around the world.

Distance

The space between two points is the distance. Distances are commonly measured in units of metres. Historically, the metre was defined as one ten-millionth of the distance from the North Pole to the equator through Paris. Today, it is defined as the distance travelled by light in empty space during a time of 0.000 000 003 s. We use the metre to indicate not only the size of an object but also how far the object travelled. For example, consider the situation shown in Figure 2. John wants to visit his grandmother who lives on the opposite side of the lake. He can either cross the lake using a boat, or he can walk along the shore.

Distances can vary greatly in size. For example, the distance between tracks on a CD is 1.6×10^{-6} m, or 1.6 μm. Although this seems small, the diameter of a hydrogen atom is about ten thousand times smaller: about 10^{-10} m. On the other extreme, the distance to the Sun is 1.5×10^{9} m. The distance to Proxima Centauri, the nearest star to our solar system, is 4.0×10^{16} m. The distances in space are so large that astronomers use units of light-years to measure them. A light-year is the distance that light travels in one year and is equal to 9.46×10^{15} m. This means that Proxima Centauri is 4.22 light-years away from Earth.

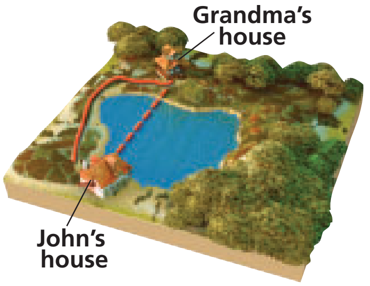


Figure 2 The distance to Grandma's house depends on the path that John takes.

TRY THIS: *Standards of Measurement*

Skills Focus: observing, predicting, analyzing, communicating

In this activity, you will measure lengths using commonplace objects.

Materials: a variety of objects (for example, desk, pencil, beaker, and classroom door), tickertape or string

1. Choose a commonplace object to be the basis for measuring distances. The width of the thumb at the base of the nail has already been chosen for the inch. However, you could use another part of your body (e.g., finger width/length, arm length, etc.) or another object (this textbook, your pen, a dime, a hockey stick, etc.).
2. Create a name for the base unit of your measuring system. For example, the thumb width is called the inch. However, the name of the base and the unit could be the same. For example, the Swedish word "tum" and the French word "pouce" both mean inch and thumb.
3. Use your measuring object to measure the lengths of other objects. For convenience, you may transfer the length of your base unit to tickertape or string for measuring. If the object is smaller than your base unit, you will have to devise a means to measure or estimate fractional units.

A. Which length was the easiest to measure? Why?

B. Which length was the most difficult to measure? Why?

C. Compare your measurements for the length of each object on the list with your classmates. For each object, decide which base unit created by the class was most suitable.

D. What was the basis for choosing the most suitable unit?

E. How could you measure the width of a page of this text using your unit?

Figure 3 The Gastown Steam Clock in Vancouver was built in 1977, and is the world's only steam powered clock.

Time

Most people have an intuitive understanding of time. We speak of how soon an event will take place compared with the present time or how much time has passed since an event occurred. Time can also mean the reading on a clock (Figure 3) or the difference between two clock readings. Time is measured in different units including years, days, hours, minutes, and seconds. In general, time is the duration of an event.

To emphasize that time is a duration, it is often referred to as a **time interval** and given the symbol Δt. The symbol Δ is the Greek letter *delta*, and represents change. Therefore, the symbol Δt combines the symbols for change (Δ) and time (t) together to mean "change in time."

Time and Distance

Time and distance are fundamental to our understanding of the natural world around us. These quantities can be used by themselves, for example, in using distance measurements to determine area or volume. By combining time and distance we can determine speed. Often we combine them with other quantities, such as mass, to describe quantities such as density, force, or energy.

Period and Frequency

One of the early proposals for defining distance was to make the base unit equal to the length of a pendulum that had a period of one second. A period (T) is the time interval between two repeating events. For example, the period of a pendulum is the time interval needed for a complete swing (both back-and-forth swings, or one cycle). The period of a pendulum does not depend on the mass of the bob or on the amplitude (the amount the pendulum is pulled to the side) if the amplitude is small. A period is measured in units of time.

Frequency is related to period. Frequency (f) is the number of cycles that occur in a specific time interval. For example, the frequency of a pendulum might be 15 cycles per minute. The SI unit for frequency is the hertz (Hz), which is equal to one cycle per second.

Since frequency is the number of occurrences per second, and period is the time per occurrence, they are reciprocals of each other, which can be written as

$$T = \frac{1}{f} \quad \text{or} \quad f = \frac{1}{T}$$

where T is the period (in s) and f is the frequency (in Hz). The occurrence or event that is repeating is often circular so frequency is often referred to as revolutions per second or cycles per second. Therefore, three cycles per second is equal to 3 Hz and 45 revolutions per second is 45 Hz. GO

Did You KNOW?

The Father of Standard Time

Can you imagine what life would be like if every city followed its own time—for example, if Vancouver was about ten minutes later than Victoria? This is what it would be like if Canadian engineer Sir Sandford Fleming (1827–1915) had not invented the system of standard time. His idea divided the world into 24 time zones measured against the time set in Greenwich, England. Fleming's standard time revolutionized travel and is still used today.

To learn more about period and frequency, go to **www.science.nelson.com** GO

SAMPLE PROBLEM 1

Determine Period and Frequency

Ann counted 7 pulses in her wrist in 6.0 s. What are the period and frequency of her heart beat?

Solution

Determine the period.

$$T = \frac{6.0 \text{ s}}{7 \text{ pulses}} = 0.86 \text{ s}$$

There are two possible methods to determine the frequency.

Method A

$$f = \frac{7 \text{ pulses}}{6.0 \text{ s}}$$

$$f = 1.2 \text{ Hz}$$

Method B

$$T = \frac{1}{f}$$

$$f = \frac{1}{T} = \frac{1}{0.86 \text{ s}}$$

$$f = 1.2 \text{ Hz}$$

The period is 0.86 s and the frequency is 1.2 Hz.

Practice

Five waves wash up on shore in 60 s. Determine their period and frequency.

STUDY TIP

There are many ways to improve your chances of remembering new material. One way is to plan an immediate review after each class and to build a review into each study session.

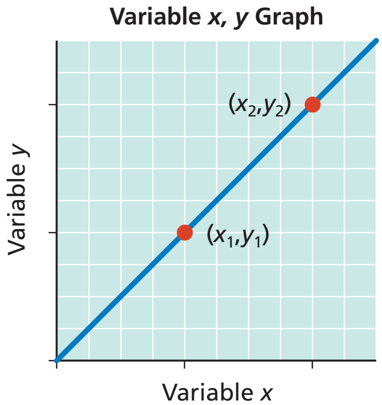


Figure 4 Graphing two variables that are directly related produces a straight line, which can then be used to calculate the slope.

Graphs and the Slope of a Line

Many quantities, including distance and time, and period and frequency, have mathematical relationships. If we graph two quantities that are directly related, such as x and y, we will get a straight line (Figure 4). The angle, or steepness, of the line is known as the **slope** of the line. In science, the x-axis is very often time. Therefore, the slope tells us what happens to the y variable as a function of time.

To calculate the slope, we divide the rise (along the y-axis) by the run (along the x-axis) using any two points on the line (x_1, y_1) and (x_2, y_2).

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{y_2 - y_1}{x_2 - x_1}$$

In the following activity, you will use a graph and the slope of the line to see how the period of a pendulum is related to its length. In section 12.3, we will look at how graphs can help us understand the relationship between distance and time.

TRY THIS: *Length of a Pendulum with a Period of One Second*

Skills Focus: observing, conducting, recording, analyzing, communicating

In this activity, you will determine the length of a pendulum with a period of one second.

Materials: pendulum (string, bob, retort stand, and clamp), stopwatch or clock with a second hand

1. Make a pendulum with a length of 1 m. Using a small amplitude swing, measure the time interval needed for 10 cycles (complete swings) of the pendulum (Figure 5).

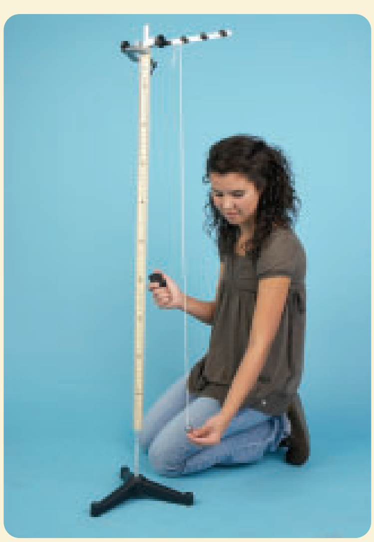


Figure 5

2. Copy Table 1 into your notebook and record the time. Divide the time by 10 to determine the period of the pendulum and record it in the table.

Table 1 Data Table

Length (cm)	Time (s)	Period (s)	Square root of length ($\sqrt{cm}$)
100	10		
80			
60			

3. Repeat step 2 for different pendulum lengths.
4. Although the period of a pendulum increases with the length of the pendulum, it is not a direct relationship. The period is related to the square root of the length of the pendulum. The last column of your table is for the square root of the length of the pendulum ($\sqrt{cm}$).

A. Estimate what pendulum length would have a period of 1 s.

B. Plot the data on a graph with period as a function of length. Draw a line through the data. Use the graph to estimate the length of a pendulum with a period of 1 s.

C. Plot a graph with period as a function of the square root of the length. Draw a line of best fit. Use the graph to estimate the length of a pendulum with a period of 1 s.

D. Why would this last estimate of length be more accurate than either of the first two estimates?

E. Calculate the slope of the line of the graph made in part C.

12.1 CHECK YOUR Understanding

1. There are different units used to measure time. Which unit would most commonly be used to measure the following?
   (a) your age
   (b) the duration of a Grade 10 Science class
   (c) the time an Olympic athlete needs to run 100 m
   (d) the time needed to fly from Vancouver to Paris
   (e) the duration of the summer holiday from school
2. Write a definition of distance in your own words.
3. The metre was originally defined as a fraction of the distance from the North Pole to the equator. What problems would this definition of the metre create for people?
4. A rectangular field is 1.5 km long and 700 m wide (Figure 6). An asphalt road goes around the outside of the field and a dirt path cuts across the field. A student wants to go from A to B on the field. Path *x* goes along the road and is shown in red; path *y* is shown in blue. Which path has the shorter distance? By how much is this path shorter?

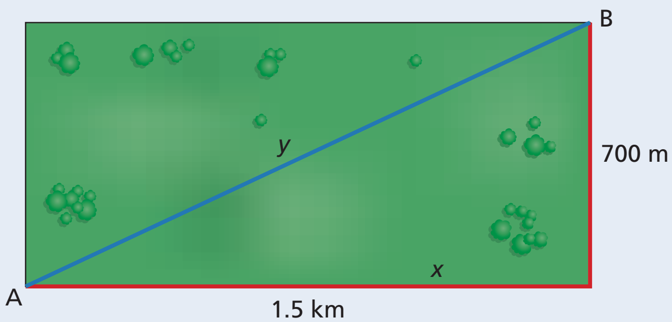


Figure 6

5. Why is time often referred to as a time interval in science?
6. Grandpa Adams took a nap from 2:32 p.m. until 3:19 p.m. How many seconds was Grandpa asleep?
7. Two points or locations are needed to measure distance. What two things are needed to measure a time interval?
8. A woodpecker taps 8 times on a tree in 2 s. What are the period and the frequency of the tapping?
9. Two children are playing on a teeter-totter (seesaw) in a park. They each move up and down 9 times in 25 s. Determine the period and frequency of their movement on the teeter-totter.
10. A bee's wings beat with a frequency of 200 Hz (Figure 7). What is the period of a beat of the bee's wings?

Figure 7

12.2 Speed

Everyone has seen the road signs "Maximum 90 km/h" (Figure 1). The **speed** of an object is equal to the distance an object travels divided by the time interval. In other words, speed is the rate at which the object is travelling. The equation that we use to calculate speed is

$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{\Delta d}{\Delta t}$$

where Δd is the change in distance, and Δt is the change in time.

Figure 1 Road signs tell us the maximum speed at which we are allowed to drive.

LEARNING TIP

Note that in an equation where the variables have a delta symbol in both the numerator and the denominator, the symbols cannot be cancelled. Recall that the delta symbol (Δ) represents "change in."

For example, if a bus takes 10 min to travel from the bus stop to a beach that is 6 km away, we could say the bus is travelling at 0.6 km/min. However, this is not a typical unit for measuring the speed of motor vehicles. Instead we could say that, at that rate, in 1 h the bus would have gone 36 km. Therefore, the speed of the bus was 36 km/h.

It is not likely that a bus would travel all the time at 36 km/h. In other words, the speed of 36 km/h would be an average speed for the trip to the beach.

Average Speed

The speed of an object is calculated by dividing the distance travelled by the time taken. The **average speed** of an object is the total distance the object travelled divided by the total time taken. The equation for calculating average speed is

$$v_{av} = \frac{\Delta d}{\Delta t} = \frac{d_f - d_i}{t_f - t_i}$$

where v_{av} is the average speed, d_f is the final position, d_i is the initial position, t_f is the final time, and t_i is the initial time. In this equation, the motion started at time t_i at a position of d_i and ended at time t_f at a position of d_f. This way of writing the equation for average speed is useful when the initial location or time is not considered to be zero.

Did You KNOW?

Mach Speed

The speed of aircraft is given in Mach number, which measures the speed of an object relative to the speed of sound (332 m/s or 1195 km/h). Mach 1 equals the speed of sound. The fastest airplane, the Lockheed SR-71 Blackbird, can travel at Mach 3.

SAMPLE PROBLEM 1

Determine Average Speed

A student saw a spider walking along a metre stick. When the spider crossed the 15 cm mark, the student started a stopwatch. When the spider reached the 60 cm mark, the student stopped the stopwatch. It took the spider 84 s. Calculate the average speed of the spider in cm/s.

Solution

Substitute the values into the average speed equation. In this case, the initial time was 0 s.

$$\begin{aligned} v_{av} &= \frac{d_f - d_i}{t_f - t_i} \\ &= \frac{60\text{ cm} - 15\text{ cm}}{84\text{ s} - 0\text{ s}} \\ v_{av} &= 0.54\text{ cm/s} \end{aligned}$$

The average speed of the spider was 0.54 cm/s.

Practice

A dog was seen walking down a marked track by a student with a stopwatch. The student started the stopwatch when the dog was at the 20 m line. The stopwatch read 37 s when the dog crossed the 45 m line. Determine the average speed of the dog in m/s.

The average speed equation can be used to solve motion problems. In addition to solving for average speed, we can rearrange the equation to solve for time or distance. Note that all distances need to be in the same units, and all time measurements must also be in the same units. For example, if the distance is in metres (m) and the speed is in km/h, then one of the units must be changed to reflect the same distance unit (m and m/h, or km and km/h). GO

To learn more about different units for measuring speed and how they are related, go to **www.science.nelson.com** GO

SAMPLE PROBLEM 2

Determine Average Speed

A person walks 8.5 km in 2.2 h. What was the person's average speed?

Solution

Substitute the values into the average speed equation.

$$\begin{aligned} v_{av} &= \frac{\Delta d}{\Delta t} \\ &= \frac{8.5\text{ km}}{2.2\text{ h}} \\ v_{av} &= 3.9\text{ km/h} \end{aligned}$$

The person's average speed was 3.9 km/h.

Practice

A racing pigeon flew a distance of 52 km in 1.7 h. What was the average speed of the racing pigeon?

Did You KNOW?

Breaking the Sound Barrier

Although American pilot Chuck Yeager experienced queasiness the first time he ever flew an airplane, he was the first pilot to fly faster than the speed of sound. On October 14, 1947, days after cracking several ribs in a horseback riding accident, he broke the sound barrier flying the rocket-powered Bell X-1 at Mach 1.06.

SAMPLE PROBLEM 3

Determine the Time

A small plane flies 84 km from Nanaimo to Victoria. The average speed of the plane when flying is 280 km/h. Determine the plane's flying time.

Solution

Change the form of the average speed equation to solve for Δt. Then, substitute the values into the equation and solve.

$$v_{av} = \frac{\Delta d}{\Delta t}$$

$$\Delta t = \frac{\Delta d}{v_{av}}$$

$$= \frac{84 \text{ km}}{280 \text{ km/h}}$$

$$\Delta t = 0.30 \text{ h}$$

The plane's flying time will be about 0.30 h.

Practice

A bowler rolls a bowling ball at 7 m/s down a bowling alley. The pin is 18.5 m away. How long will it take for the ball to reach the pin?

SAMPLE PROBLEM 4

Determine Distance

Sunlight takes about 500. s to reach Earth. Light travels at 3.0×10^8 m/s. How far is the Sun from Earth? (Refer to Appendix B2 for tips on the appropriate use of scientific calculators with scientific notation.)

Solution

Change the form of the average speed equation to solve for Δd. Then, substitute the values into the equation and solve.

$$v_{av} = \frac{\Delta d}{\Delta t}$$

$$\Delta d = v_{av} \Delta t$$

$$= (3.0 \times 10^8 \text{ m/s})(500. \text{ s})$$

$$\Delta d = 1.5 \times 10^{11} \text{ m}$$

The Sun is 1.5×10^{11} m from Earth.

Practice

A speed skater is skating at 13.2 m/s. How far will he skate in 37.9 s?

STUDY TIP

Don't delay! As soon as you have read the sample problem, do the practice problem right away. The experience of solving a problem will increase your chances of remembering the new material.

SAMPLE PROBLEM 5

Determine the Distance

The driver of a car travelling at 50.0 km/h sees a deer crossing the road ahead. It takes the driver 1.2 s to react and start to apply the brakes. How far did the car travel before the driver hit the brakes?

Solution

In this case, the answer will be most useful in metres. Therefore, the speed will have to be changed from km/h to m/s.

$$\left(\frac{50.0\ \cancel{\text{km}}}{\cancel{\text{h}}}\right)\left(\frac{1000\ \text{m}}{1\ \cancel{\text{km}}}\right)\left(\frac{1\ \cancel{\text{h}}}{3600\ \text{s}}\right) = 13.9\ \text{m/s}$$

Rearrange the average speed equation, and then substitute the values into the equation.

$$\begin{aligned} v_{\text{av}} &= \frac{\Delta d}{\Delta t} \\ \Delta d &= v_{\text{av}}\,\Delta t \\ &= (13.9\ \text{m/s})(1.2\ \text{s}) \\ \Delta d &= 17\ \text{m} \end{aligned}$$

The car travelled 17 m.

Practice

A person is riding a bicycle at 9.2 m/s. How far, in kilometres, will the person travel in 2.6 h?

Instantaneous Speed

Often we want to know how fast an object is going at a particular instant in time. The speedometer of the car indicates the current speed at which the car is moving (Figure 2). **Instantaneous speed** is the speed of an object at a particular instant in time. When a driver gets a speeding ticket, it is because the instantaneous speed of the car, as indicated by the police officer's speed detector, exceeds the maximum speed limit. GO

Figure 2 A speedometer tells you how fast you are travelling at a particular instant in time.

To learn about the world's fastest airplane, boat, and car, go to
www.science.nelson.com GO

Constant Speed

Vehicles, such as buses and cars, often change speeds to pass other cars, to slow down for pedestrians, or to obey traffic signals. However, some objects, such as light travelling from a star, travel at a constant speed. If the speed of an object is constant (does not change), then its average speed will be the same as its instantaneous speed. Therefore, an object has constant speed if its instantaneous speed is not changing.

12.2

CHECK YOUR Understanding

1. A freestyle swimmer was timed every 10 m as she swam a 50 m race. The times and distances are shown in Table 1.

Table 1 Motion of a Swimmer

Distance (m)	0	10	20	30	40	50
Time (s)	0	5.9	17.9	28.2	43.0	61.2

   (a) What is the average speed of the swimmer for the first 10 m?
   (b) What is the average speed of the swimmer for the last 10 m?
   (c) What was her average speed for the entire race?

2. A driver travelled 22 km in 15 min, then stopped for lunch for 25 min, and then drove another 34 km in 20 min. What was the average speed for the trip? What was the average speed while the car was moving?

3. Greyhounds can race faster than any other breed of dog (Figure 3). A greyhound ran 250 m in a time of 13.1 s. What was its average speed?

Figure 3

4. A large clock has a second hand that is 18 cm long.
   (a) What distance does the tip of the second hand travel in 1 min?
   (b) What is the speed of the tip of the second hand?
   (c) Is the speed constant? Explain your answer.

5. A golf ball landed 75 m away from the tee. The golf ball travelled with an average speed of 43 m/s. How long was the golf ball in the air?

6. The speed of sound is 343 m/s at 20 °C. A baseball fan is sitting 150 m from home plate. How much longer will it take for the sound of the batter hitting the ball to be heard by the fan than the umpire?

7. A nerve impulse travels with a speed of 90 m/s. How long would it take for an impulse to go a distance of 55 cm?

8. A wheelchair athlete can travel at 6.1 m/s. How far can the athlete travel in 65 s?

9. A family travels from Squamish to Kelowna in 4 h 38 min, not including rest stops, at an average speed of 82 km/h. What is the distance between the two cities?

10. A river is flowing at 2.5 m/s. How long will it take a log floating in the river to travel 1 km?

11. A motorcycle is being designed to be the fastest in the world. The target speed on a trial ride was 540 km/h. How far would the motorcycle travel in 15 s?

12. The space shuttle travels at 7800 m/s in an orbit with a radius of 6700 km about Earth.
   (a) What is the distance the shuttle travels in one complete orbit?
   (b) How long does it take to complete an orbit?

13. One object had an average speed of 36 km/h while another object had a constant speed of 36 km/h. Explain how these two speeds could be different.

14. A train had a constant speed of 65 km/h travelling beside a highway for 10 min. What was the instantaneous speed of the train at the 5 min mark?

THE TORTOISE, THE HARE, AND THE HUMAN

If a hare and tortoise were to race, the hare would easily beat the tortoise. But how would the hare do against a human or a horse? Different animals travel at different speeds.

Everyone knows that in the story of the hare and the tortoise, the tortoise won the race because it ran at a steady speed, while the hare ran fast, but took many rest stops (Figure 1). In truth, the desert tortoise has been clocked at speeds of 0.21 to 0.48 km/h while the snowshoe hare races past at speeds of 45 km/h. While the tortoise would not actually win a race against a hare, what would the outcome be if people and other animals joined in?

Many people run for fun, for exercise, or competitively. However, the running speed of humans depends on the length of the race. The fastest time recorded for a 100 m sprint is 9.74 s, which means that the current record holder ran at 37 km/h. The fastest time recorded for a marathon (42 km) is currently 2:04:26, which means that the person ran at 20 km/h (or about half the speed of the sprint runner). While the hare can run past the fastest sprinter, it would have a hard time maintaining a speed of 45 km/h for 42 km to stay ahead of the marathon runner.

The cheetah, recognized as the world's fastest land animal, can hit a top speed of over 110 km/h (Figure 2). However, a cheetah would not be able to maintain that speed for more than 1500 m because it would overheat. The fastest land animal in North America has much more stamina for speed than the cheetah. The pronghorn antelope travels at an average speed of 55 km/h for distances as great as 43 km.

How would animals, such as racehorses and greyhounds that are bred to race, fare in the race against the hare? The famous racing horse, Secretariat, has held the record for the Kentucky Derby since 1973 when he raced the 2 km track at an average speed of 60 km/h. In 2000, the world's fastest greyhound, Be My Bubba, ran a 500 m track at an average speed of 61 km/h. Both the racehorse and the greyhound can go faster than the hare, but the horse can hold the speed for much longer than the greyhound.

What would the outcome of the race be if flying and swimming competitors were allowed to participate? The ruby-throated hummingbird darts from flower to flower at speeds of 97 km/h. The peregrine falcon flies at average speeds of 105 km/h, but has been measured at diving speeds of 282 km/h. Swimming competitors are equally fast. The sailfish is the fastest fish swimming at 110 km/h. Dolphins are the fastest swimming mammals reaching speeds of 60 km/h. The fastest human swimmers reach speeds of 8 km/h.

Clearly, different animals have adaptations that allow them to run at speeds that ensure their survival. Herbivores, such as hares, antelopes, and horses, are able to run at speeds that allow them to escape predators. Carnivores, such as cheetahs, run at speeds to help them catch their prey. Fast swimmers have a streamlined shape to allow them to move quickly through the water. And the slow and steady tortoise, which may not be able to win any races, can always retreat into its shell.

Figure 1 Would the tortoise really win a race against a hare?

Figure 2 The cheetah is the fastest land animal.

12.3 Graphing Distance and Time

If you were walking down the sidewalk and a passing motorist stopped and asked for directions to the nearest gas station, you could give the directions in a variety of ways. You could give the directions including distances or, if you had a map of the area, you could highlight the path the motorist should follow to get to the gas station.

There are different ways that we can analyze an object's motion. For example, we can record the motion with a video camera, write a description of the object's motion, look at the position and time data for the object in a data table, or look at the data organized into a graph. No method is appropriate for all uses and each method has its advantages. In this section, we will explore these methods. Think about how you could redo the Try This Activity at the start of the chapter investigating the motion of a table tennis ball and describe the motion differently.

TRY THIS: *Graphing the Motion of a Trotting Cat*

Skills Focus: recording, analyzing, communicating

In this activity, you will use a graph to communicate the motion of a trotting cat. Before motion pictures and video cameras existed, British photographer Eadweard Muybridge developed a machine that was able to take pictures in rapid succession. Your handout shows Muybridge's photos, taken in 1887, showing the motion of a trotting cat. Lines were added every 0.5 m in the background to help study the motion. There are 20 pictures in the sequence. However, the time between pictures is not known.

Materials: handout of Muybridge's moving cat photos, ruler, graph paper

1. Look at the pictures of the cat on your handout. Write a brief description of the cat's motion.
2. Copy Table 1 in your notebook. Although the time between pictures is not known, we will assume that the pictures were taken every 0.1 s.
3. The picture is not life-sized. Distances, as measured on the picture, need to be scaled to know the actual distances. To determine the scale of the photograph, measure the distance (in mm) between the 0 m line and the 0.5 m line. Then, divide the 0.5 by the distance (in mm). This is the scale factor, which will be used to convert distances measured on the picture (in mm) into the real distances of the cat (in m).

Table 1

Picture (cm)	Time (s)	Picture distance (mm)	Real distance (m)
1	0		
2	0.1		
3	0.2		

4. Choose a point on the cat to represent the position of the cat. The tip of the nose is a good choice. That means that the distance of the cat in the first picture can be read from the picture and is 0.5 m.
5. Determine the distance of the cat in the second picture by measuring the distance (in mm), from the 0.5 m line to the tip of the cat's nose. This is the picture distance. Multiply the picture distance by the scale factor. This is the real distance.
6. Repeat step 5 for the remaining pictures.

A. Draw a graph of the real distance of the cat's nose as a function of time.

B. What happens to the slope of the graph over the time of the motion? How does this relate to the motion of the cat?

C. What does the slope of the line of a distance–time graph indicate about motion?

When you look at a distance–time graph, you can see how the distance of an object varies with time by the steepness of the slope. Recall from page 344 that we can calculate the slope of a line by dividing the rise (change in distance) by the run (change in time). Therefore, the equation is

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{\Delta d}{\Delta t}$$

This is the same equation that we use to calculate speed. This means that the slope of a line on a distance–time graph is equal to speed. You saw this when you observed the slope of the line you drew in the Try This activity. Note that if the distances were measured in metres and the time in seconds, then the units for the slope would be metres/second (m/s), which is a unit of speed. If the distances were measured in kilometres and the time in hours, the units for the slope would be kilometres/hour (km/h), which is also a unit for speed. GO

To learn more about graphing and slopes, go to **www.science.nelson.com** GO

Graphing Constant Speed

What does the distance–time graph of an object moving at a constant speed look like? Suppose that a jogger is moving toward the start of a 100 m track. If she was moving at a constant speed of 3 m/s when she crossed the start line, in 1 s her distance on the track would be 3 m, at 2 s her distance would be 6 m, at 3 s her distance would be 9 m, and so on. The information for the first 10 s is shown in Table 2. Figure 1 shows the graph of the time and distance.

LEARNING TIP
When graphing distance and time, time is always on the *x*-axis (horizontal). You may remember this from your Grades 9 and 10 math classes.

Table 2 Distance of a Jogger

Time (s)	Distance (m)
0	0
1	3
2	6
3	9
4	12
5	15
6	18
7	21
8	24
9	27
10	30

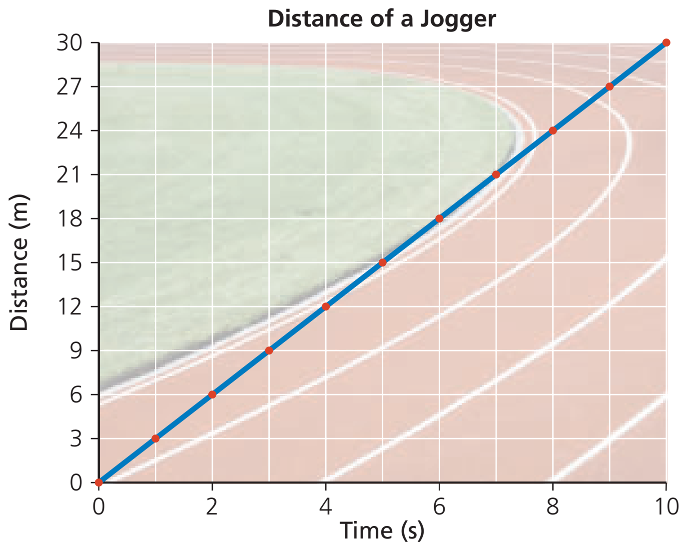


Figure 1 Distance–time graph for a jogger

How can we determine the average speed of the jogger using the graph? We can calculate the slope of the line for the graph using the following equation:

$$\text{slope} = \frac{d_f - d_i}{t_f - t_i} = \frac{\Delta d}{\Delta t}$$

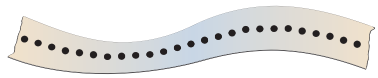


Figure 2 The spacing of the dots on the tickertape indicates the rate of motion.

We can conclude that the slope of a line on a distance–time graph is equal to average speed. We can calculate the slope of the line in Figure 1 to determine the average speed of the jogger as follows:

$$\text{slope} = v_{\text{av}} = \frac{\Delta d}{\Delta t} = \frac{30\ \text{m} - 0\ \text{m}}{10\ \text{s} - 0\ \text{s}} = 3\ \text{m/s}$$

Therefore, for a distance–time graph of constant speed, the slope of the line is equal to the average speed.

Scientists use different techniques to investigate motion. One technique involves using a recording timer. As the paper tape is pulled through the timer, dots are recorded on tickertape paper. Figure 2 shows an illustration of tickertape that has been pulled through a timer. For example, Table 3 shows how far a student pulled tickertape through the timer in 1.2 s at a constant speed. Figure 3 shows the graph of the data with a line of best fit. (See Appendix B5 for information on a line of best fit.)

Table 3 Motion of Tickertape

Time (s)	Distance (cm)
0	0
0.10	3.1
0.20	5.8
0.30	7.7
0.40	9.2
0.50	13.3
0.60	15.7
0.70	17.3
0.80	18.8
0.90	21.1
1.00	23.7
1.10	26.0
1.20	28.2

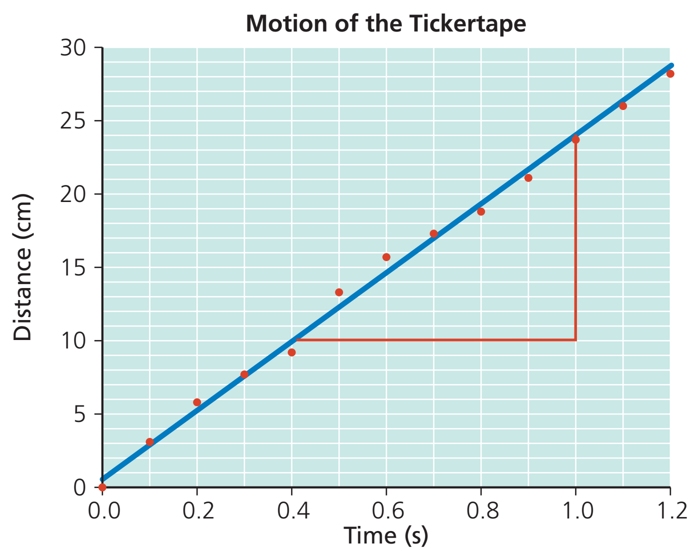


Figure 3 Distance–time graph showing line of best fit

We can calculate the slope of the line as

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{24\ \text{cm} - 1.00\ \text{cm}}{1.00\ \text{s} - 0.40\ \text{s}} = 23\ \text{cm/s}$$

Therefore, we can conclude that the tickertape was pulled at an average speed of 23 cm/s.

We can also use the average speed equation to calculate average speed:

$$v_{\text{av}} = \frac{\Delta d}{\Delta t} = \frac{28.2\ \text{cm} - 0\ \text{cm}}{1.20\ \text{s} - 0\ \text{s}} = 23.5\ \text{cm/s}$$

There is a slight difference between the two calculations of average speed. Can you think of an explanation for this difference?

LEARNING TIP

When working through calculations such as the ones found here, it helps to work with a partner. Can you think of a reason for the slight difference between the two calculations of average speed?

Let's look at another example. Table 4 shows the time and distance for a bicycle. Figure 4 shows the graph of the bicycle's motion.

Table 4 Motion of a Bicycle

Time (s)	Distance (m)
0	0
2	5
4	26
6	62
8	106
10	141
12	185
14	225

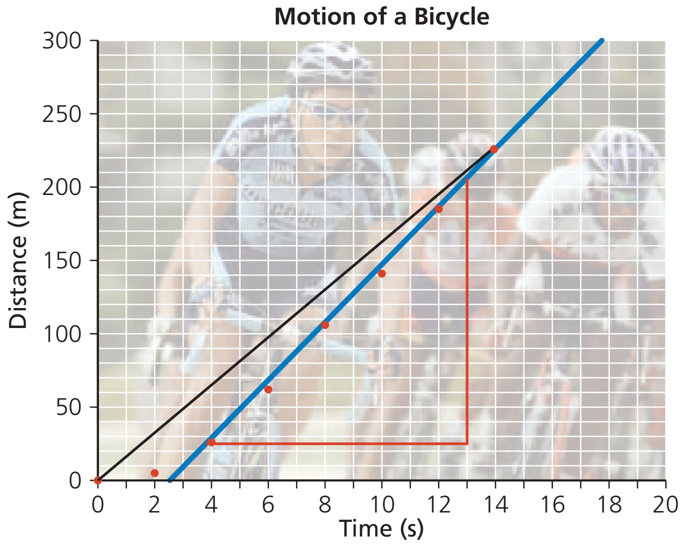


Figure 4 Distance–time graph. The black line is the average speed. The blue line is the line of best fit after 3 s.

From the graph, we can see that the bicycle started slowly and then travelled at a constant speed. The blue line shows that the speed is almost constant after 3 s. We can determine the average speed for the entire trip:

$$v_{av} = \frac{\Delta d}{\Delta t} = \frac{225\text{ m} - 0\text{ m}}{14\text{ s} - 0\text{ s}} = 16\text{ m/s}$$

The average speed is shown as the black line on the distance–time graph.

We can calculate the slope of the blue line to determine the average constant speed. To do this, we pick two points, shown here as two red lines, which form a triangle with the line of best fit. The advantage of the triangle is that it makes it easy to see the points on the graph. The larger the triangle, the easier it is to read the values, thereby reducing the error. The triangle is attached to the line of best fit and not to observed data points.

$$\text{slope} = v_{av} = \frac{\Delta d}{\Delta t} = \frac{205\text{ m} - 25\text{ m}}{13\text{ s} - 4\text{ s}} = 20\text{ m/s}$$

This shows us that, once the bicycle was travelling at a constant speed (after 3 s), the average speed was 20 m/s. What do we do if we only want to know the speed at a particular instant in time on a graph?

Sometimes objects travel at a constant slow speed and then at a constant faster speed. For example, a car could travel at 50 km/h on city streets and then increase speed to 80 km/h on a highway. What do you think this type of motion would look like on a graph? You will investigate this type of motion in Investigation 12A. 12A *Investigation*

12A *Investigation*

Motion with Two Speeds

To perform this investigation, turn to page 366.

In this investigation, you will investigate the motion of an object.

Did You KNOW?

Sonic Booms

An airplane travelling faster than the speed of sound (supersonic speed) produces a sonic boom. This is because, as the airplane increases its speed, it pushes air molecules out of its way. At supersonic speeds, the airplane causes the air pressure waves to build up and compress, producing shock waves. When the shock waves reach your ears, you hear a sonic boom.

Determining Instantaneous Speed

How could you graph the motion of a car that does not travel at a constant speed: for example, a car that travels at 36 km/h (10 m/s) and then increases its speed to 108 km/h (30 m/s)? Note that such a change would not happen instantly. If the change in speed took 5 s, we can graph the motion as shown in Figure 5.

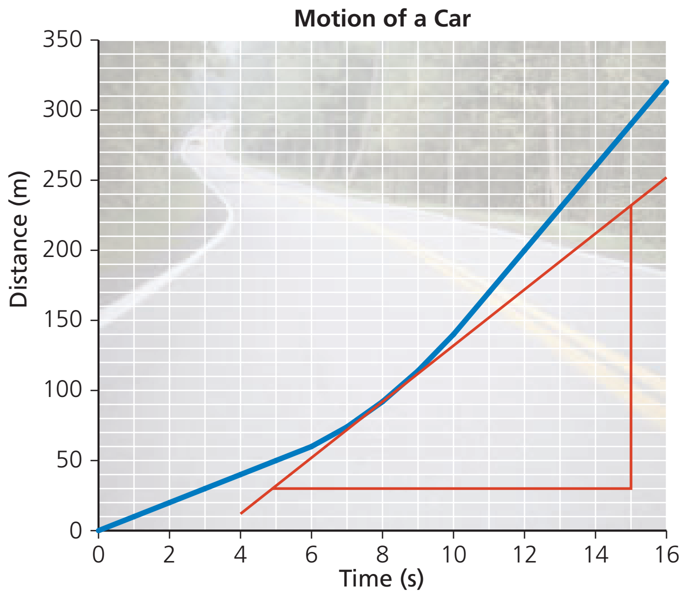


Figure 5 Distance–time graph. The red line is the tangent at 8 s.

We can see from the graph that the car had a constant speed of 10 m/s for the first 6 s and that it had a constant speed of 30 m/s for the last 6 s. However, between 6 s and 10 s, the car was changing speed. We can determine the speed of the car at any particular time using the slope of the line on the graph. For example, if we want to know the speed of the car at exactly 8 s, we would find the slope of the line at 8 s. To do this, we draw a tangent to the line at 8 s. The tangent to the line is the direction that the line is pointing at that time, and can be drawn by aligning a ruler with the line at that point on the curve. Note that drawing a tangent to the line requires a little practice and different people will draw slightly different lines. However, if all the students in your class drew tangents to the same line, their slopes would all be very similar.

We can calculate the slope of the tangent to determine the instantaneous speed at 8 s:

$$\text{slope} = v = \frac{230\text{ m} - 30\text{ m}}{15\text{ s} - 5\text{ s}} = 20\text{ m/s}$$

The instantaneous speed of the car at 8 s was 20 m/s. We can calculate the instantaneous speed of an object (that does not have constant speed) at a particular time by calculating the slope of the tangent to the line of the distance–time graph of the object's motion.

Using Distance–Time Graphs

So far, we have used distance–time data to construct a graph. However, it is possible to start with a graph and derive information from it. For example, look at the graph in Figure 6.

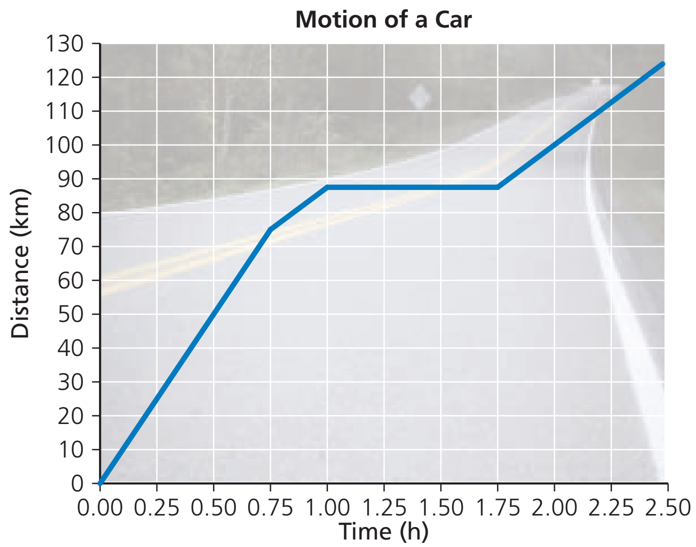


Figure 6 The distance–time graph of the motion of a car

LEARNING TIP

Adopt a questioning attitude when you are interpreting a graph such as Figure 6. What type of graph is it? What does the title tell you? What is represented on the vertical and horizontal axes? What does the plotted line tell you?

We can see that the car was travelling at a constant speed for the first 45 min (0.75 h) since the slope of the graph is constant. We can calculate the speed the car was travelling during this time by noticing that the car travelled 50 km in the first 30 min (0.50 h) and would, therefore, travel 100 km in 1 h. This is an informal way of calculating the slope. The car then slowed down for 15 min (0.25 h) and travelled 12 km. Its speed was therefore 48 km/h. The car then stopped for 45 min before travelling for 45 min at a constant speed. We can determine the speed at which the car was travelling during this time by calculating the slope:

$$\text{slope} = v = \frac{125 \text{ km} - 87 \text{ km}}{2.5 \text{ h} - 1.75 \text{ h}} = 51 \text{ km/h}$$

Therefore, the car travelled at 100 km/h for 45 min and 48 km/h for 15 min, stopped for 45 min, and then travelled at 51 km/h for 45 min. We can see, from the graph, the distance the car travelled at different times. For example, at 30 min, the car travelled 50 km. At 45 min, the distance is about 75 km. The total distance the car travelled is about 125 km. Although it looks as though the speed of the car changed instantly from one constant speed to a different constant speed, we can assume that the change of speed was more gradual. However, the graph does not show enough detail.

12.3 CHECK YOUR Understanding

1. The position of a dog running down a soccer field for 7 s is given in Table 1.

Table 1 The Motion of a Dog

Time (s)	0	1	2	3	4	5	6	7
Distance (m)	0	2	5	9	18	22	25	31

   (a) Draw a distance–time graph for the dog.
   (b) What was the average speed for the dog?
   (c) What was the speed of the dog when $t = 6$ s?
   (d) During which second was the dog running the slowest?
   (e) During which second was the dog running the fastest?

2. A bowling ball is rolling down the alley with a constant speed. What would the distance–time graph look like? Sketch the graph.

3. The distance a car travelled was recorded every 6 min (0.1 h) and plotted on a graph (Figure 6). The car started the journey in town for 30 min (0.5 h) and then continued on the highway.

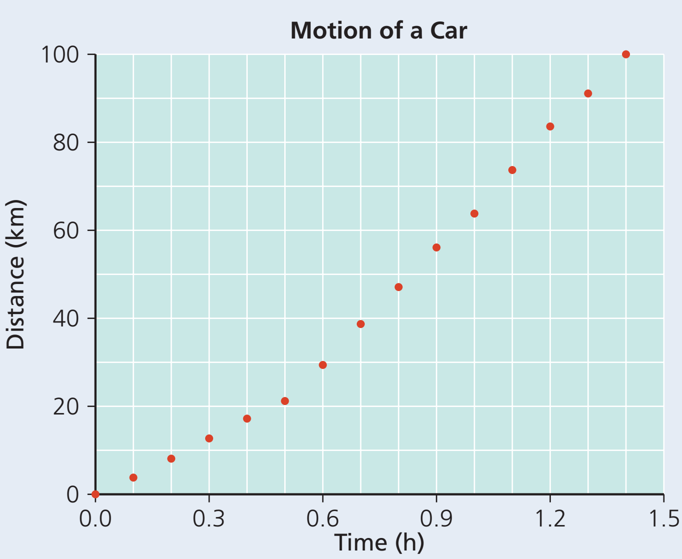


Figure 6

   (a) What was the car's average speed in town?
   (b) What was the car's average speed on the highway?
   (c) Did the car travel at a constant speed on the highway? How do you know?

4. Write a description of how to determine instantaneous speed from a distance–time graph.

5. Figure 7 shows the distance–time graph for the flight of a butterfly.

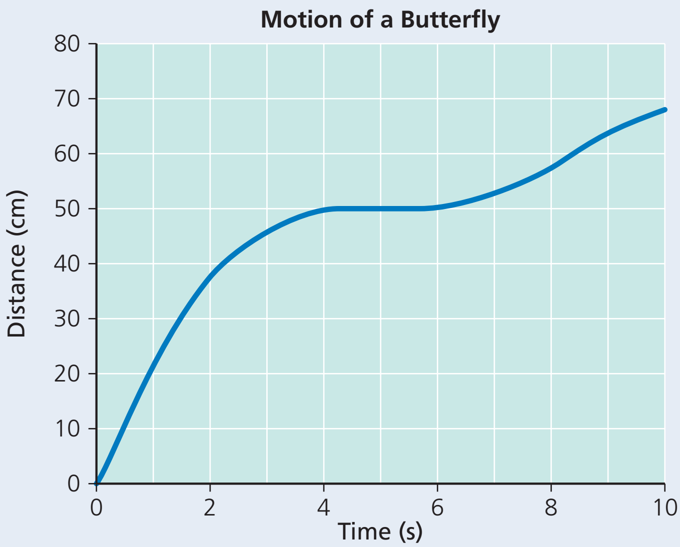


Figure 7

   (a) Using the graph, write a short description of the butterfly's motion.
   (b) What was the average speed of the butterfly for the 10 s?
   (c) What was the instantaneous speed of the butterfly at the following times: 2 s, 5.5 s, and 9 s?

12.4 Displacement and Velocity

In the study of motion, it is sometimes important to know the direction so that you can describe the position of a place in relation to a reference point. For example, Kamloops is located 300 km northeast of Nanaimo. In some situations, it is necessary to know not only the speed at which a vehicle is moving, but also the direction. For example, the Thalys high-speed train travels from Brussels, Belgium southwest to Paris, France at 300 km/h. Both displacement and velocity are quantities that require direction.

STUDY TIP

There are many new vocabulary words in this section. As you read, make a study card for each term. You can use these cards later to study for a chapter exam.

Displacement

Distance is a scalar quantity. A **scalar quantity** has a number and a unit. A quantity that has both a number and a unit is called a magnitude. The distance to an object tells you how far away it is, but does not indicate the direction. For example, a student's home is a distance of 500 m from the school. Figure 1 shows a map of the student's home in relation to the school. You can see that the student's home is actually 500 m north of the school. This is known as the displacement of the student's home from the school.

The **displacement** of an object is defined as the change in position of the object. Displacement is a vector quantity. A **vector quantity** has both magnitude and direction. We use the letter d to represent both distance and displacement. To distinguish between the two quantities, we put a small arrow over the vector symbol. An example of each is shown below.

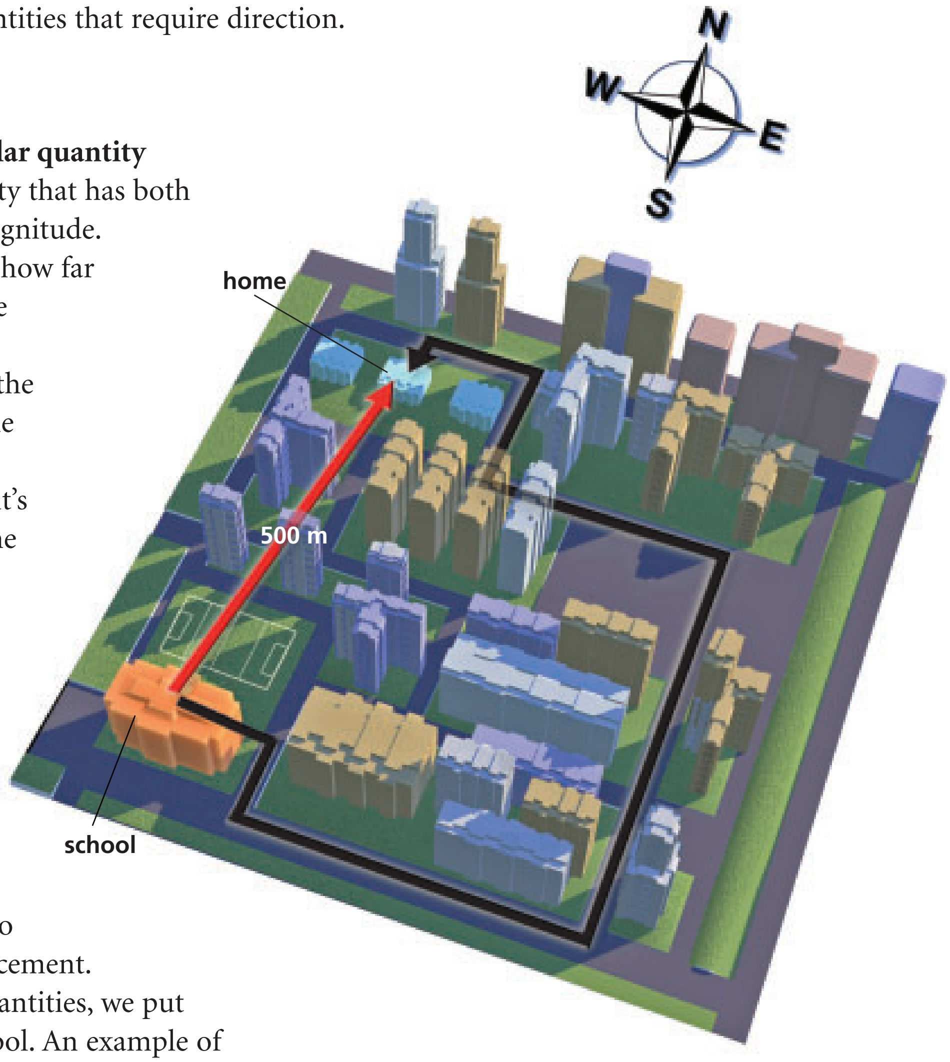
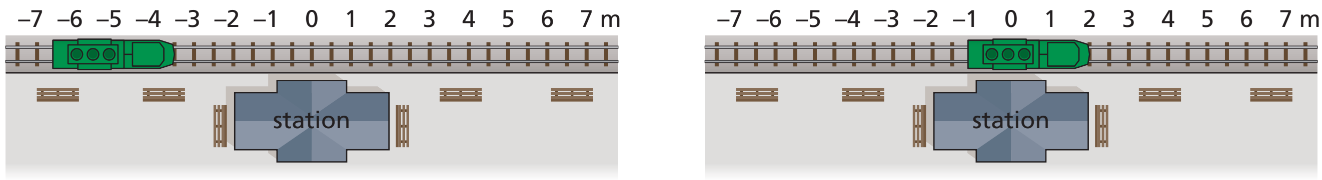


Figure 1 The student's home is 500 m [N] from the school.

$$\text{distance} = \Delta d = 1.5 \text{ km}$$
$$\text{displacement} = \Delta \vec{d} = 312 \text{ m [E]}$$

Note that the symbol for displacement is $\Delta \vec{d}$, which means "change in position."

To calculate the displacement of an object, we need to know its position relative to a reference point. We calculate a change in position by subtracting the initial position, $\vec{d}_i$, from the final position, $\vec{d}_f$. For example, look at Figure 2(a).



(a) **(b)**

Figure 2 (a) A train is 3.5 units to the left of the train station. We can also indicate the direction by saying −3.5 units. (b) The train moves so that it is 2.0 units to the right of the train station. We can also indicate the direction as +2.0 units.

If the train moves from its position 3.5 units left of the station as shown in Figure 2(a) to a position of 2.0 units right of the station as shown in Figure 2(b), then its displacement from its original position can be calculated as

$$\Delta\vec{d} = \vec{d}_f - \vec{d}_i = 2.0\text{ m} - (-3.5\text{ m}) = 5.5\text{ m}$$

This means that the displacement of the train was 5.5 m to the right.

Direction is important when determining displacement. We calculate changes in position by subtracting the initial position from the final position. In addition, all positions must be relative to the same point. For example, in Figure 2, all positions of the train are relative to the train station. Directions can be left/right, forward/backward, north/south, east/west, or up/down. Remember that we choose one direction to be the reference direction, which will be a positive number, and that the opposite direction will be a negative number. For example, if up is the positive direction, then down will be negative. In Figure 2, right of the train station was positive and left was negative.

SAMPLE PROBLEM 1

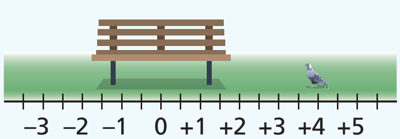


Figure 3 A pigeon stands 4 m right of a bench.

Determine Displacement

A pigeon standing 4 m to the right of a bench walks (Figure 3) to a position 2.5 m to the left of the bench. What is the displacement of the pigeon?

Solution

Let the direction right be positive. Substitute the values into the displacement equation.

$$\begin{aligned}\Delta\vec{d} &= \vec{d}_f - \vec{d}_i \\ &= -2.5\text{ m} - (+4.0\text{ m}) \\ \Delta\vec{d} &= -6.5\text{ m}\end{aligned}$$

The displacement of the pigeon is −6.5 m, or 6.5 m left.

Practice

A dog is sitting 1.5 m to the left of a bench. The dog walks so that it is 3.5 m right of the bench. What was the dog's displacement?

Velocity

Speed is the rate of change of distance. As with distance, speed (v) is a scalar quantity because it only has magnitude. **Velocity** ($\vec{v}$) is the rate of change of displacement. Velocity is a vector quantity because it has a magnitude and a direction. The symbol has an arrow over it, in the same way that displacement ($\vec{d}$) does, to indicate that it is a vector quantity. The differences in the equations of speed and velocity are shown below.

$$\text{speed} = v = \frac{\text{distance}}{\text{time}} = \frac{\Delta d}{\Delta t}$$

$$\text{velocity} = \vec{v} = \frac{\text{displacement}}{\text{time}} = \frac{\Delta \vec{d}}{\Delta t}$$

Distance and speed depend on the path taken. Displacement and velocity only depend on the initial and final positions, not the path taken. The following examples illustrate this point. GO

To learn more about the concepts of scalar and vector, go to
www.science.nelson.com GO

SAMPLE PROBLEM 2

Determine Average Speed and Average Velocity

A cyclist trains on the circular track shown in Figure 4. The track has a radius of 100. m and the circumference is 628 m. The cyclist goes 3.5 times around the track in 91.6 s.

(a) What was the average speed of the cyclist?

(b) What was the average velocity of the cyclist?

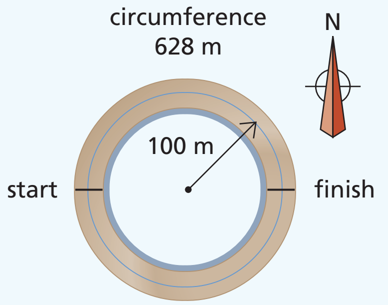


Figure 4 A circular bicycle training track

Solutions

(a) Substitute the values into the average speed equation.

$$v_{av} = \frac{\Delta d}{\Delta t}$$
$$= \frac{3.5\ (628\ \text{m})}{91.6\ \text{s}}$$
$$v_{av} = 24.0\ \text{m/s}$$

The average speed of the cyclist was 24.0 m/s.

(b) First, find the displacement of the cyclist.

$$\Delta\vec{d} = \vec{d}_f - \vec{d}_i$$
$$= 200.\ \text{m [E]} - 0\ \text{m [E]}$$
$$\Delta\vec{d} = 200.\ \text{m [E]}$$

Now, substitute the values into the average velocity equation.

$$\vec{v}_{av} = \frac{\Delta\vec{d}}{\Delta t}$$
$$= \frac{200.\ \text{m [E]}}{91.6\ \text{s}}$$
$$\vec{v}_{av} = 2.18\ \text{m/s [E]}$$

The average velocity of the cyclist was 2.18 m/s [E].

Practice

A swimming pool is 50 m long. A swimmer completes 150 m in a time of 83 s. The swimmer begins at the south end of the pool and finishes at the north end.

(a) What was the average speed of the swimmer?

(b) What was the average velocity of the swimmer?

Graphing Position and Velocity

Positions can be plotted on a graph in the same way that distances can be plotted. Since the displacement of an object is equal to the change in position of an object, a position-time graph can be used to determine displacements. While the slope of the line of a distance–time graph is equal to the speed, the slope of the line of a position–time graph is equal to the velocity of the object. The major difference is that displacements have a direction.

Table 1 shows the positions of a hiker going on a walk. A graph of the data is shown in Figure 5.

Table 1 Position of a Hiker

Time (min)	Position (m south)
0	0
5	275
10	615
15	865
20	1200
25	1200
30	1200
35	720
40	450

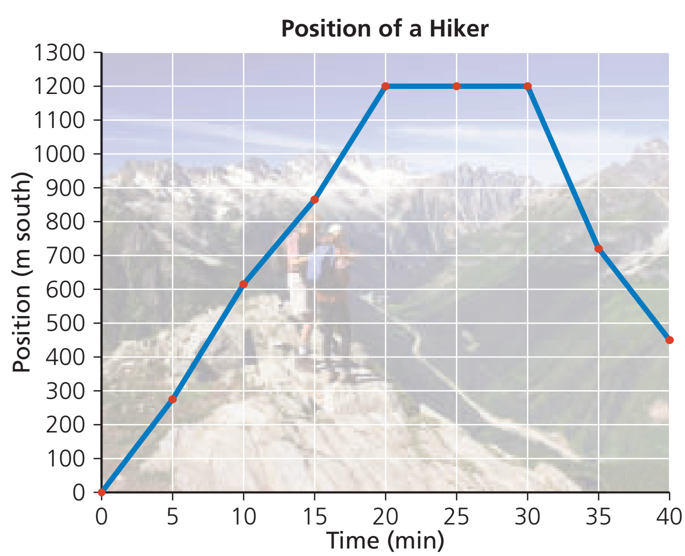


Figure 5 Position–time graph

We can see from the graph that after 20 min, the position of the hiker is 1200 m south. We can calculate the average velocity of the hiker for that time using the equation

$$\vec{v}_{av} = \frac{\Delta \vec{d}}{\Delta t} = \frac{1200 \text{ m [S]}}{20 \text{ min}} = 60 \text{ m/min [S]}$$

This is an average velocity of 60 m/min [S].

While speeds are always positive, velocities, because they are vector quantities, can be positive or negative with reference to a given direction. For example, the slope of the line between 30 and 35 min is –100 m/min or 100 m/min north.

A car travelling down a twisty road at 60 km/h has a constant speed. However, since the direction of the car is constantly changing, the velocity is constantly changing. If an object is travelling at a constant speed in a constant direction, then the object has constant velocity. This is known as **uniform motion**. A child riding a merry-go-round is travelling at constant speed. However, the child does not have uniform motion because the direction of motion is constantly changing.

To learn more about uniform motion, go to **www.science.nelson.com**

Although vectors have both magnitude and direction, sometimes we only need part of a vector quantity. For example, we may only need to know the direction of the displacement from the origin.

SAMPLE PROBLEM 3

Determine the Magnitude of Average Velocity

A bird flies 300 m [S] in 43 s, lands on a tree branch, and sits for 28 s. Then, the bird turns and flies north 500 m in 62 s. Which of the following is the magnitude of the velocity of the bird?

A. 1.50 m/s

B. 1.90 m/s

C. 6.00 m/s

D. 7.60 m/s

Solution

Let the direction south be positive. The initial position is 0 m. We know that the final position is 300 m + (−500 m) = −200 m, which is the same as 200 m [N]. Substitute the values into the velocity equation.

$$\vec{v}_{av} = \frac{\Delta\vec{d}}{\Delta t} = \frac{\vec{d}_f - \vec{d}_i}{\Delta t} = \frac{-200.\ \text{m} - 0\ \text{m}}{43\ \text{s} + 28\ \text{s} + 62\ \text{s}}$$

$$\vec{v}_{av} = -1.50\ \text{m/s}$$

Therefore, the velocity of the bird is −1.5 m/s, or 1.5 m/s [N]. However, since we only need the magnitude of the velocity, we do not need to include the direction. The best answer is A. 1.50 m/s.

Practice

A car travels east at 50 km/h and travels 100 km in 2 h. The driver stops for 1 h to have lunch. The driver then continues to travel east 50 km in 1 h. What is the magnitude of the average velocity of the car for this trip?

A. 12 km/h

B. 38 km/h

C. 50 km/h

D. 75 km/h

12.4 CHECK YOUR Understanding

1. Write a definition of magnitude in your own words.
2. Which of the following are vector quantities?
   (a) displacement
   (b) speed
   (c) time
   (d) velocity
3. (a) What is the difference between position and distance?
   (b) What is the difference between position and displacement?
4. Give two examples each of speed and velocity. Use your examples to explain the difference between speed and velocity.
5. A bicycle messenger rides a bicycle around a square city block that has sides that are 100 m long (Figure 6). The messenger begins the ride at corner A.
   (a) When the messenger reaches corner C, what is the distance and the displacement?
   (b) When the messenger returns back to corner A, what is the distance and displacement?

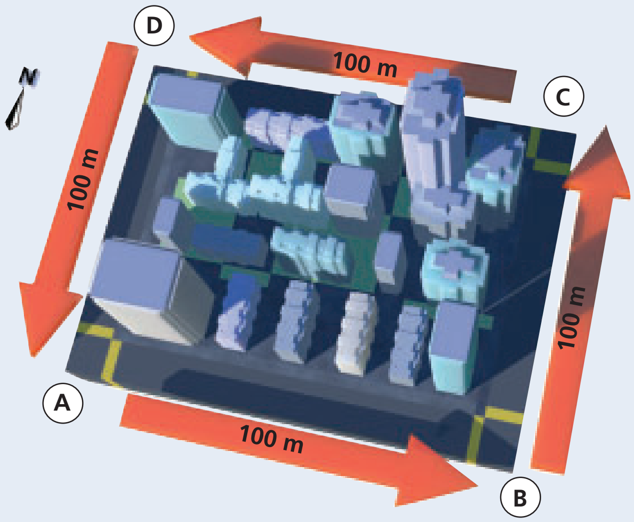


Figure 6

6. A turtle moves 3.5 m [E] in 136 s and then moves 1.7 m [W] in 88 s.
   (a) What is the average speed of the turtle?
   (b) What is the average velocity of the turtle?
7. A cyclist rode a bicycle for a little over 4 min. Her positions were recorded, and a position–time graph for the cyclist is shown in Figure 7.

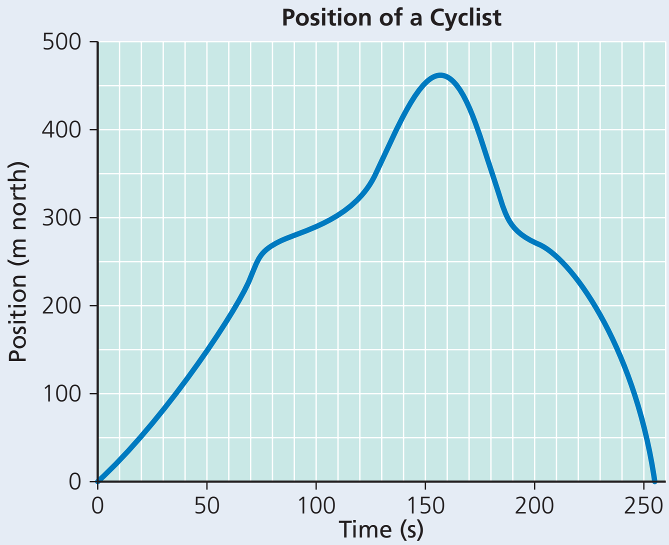


Figure 7

   (a) When was the cyclist's velocity the greatest?
   (b) When was the cyclist's speed the greatest?
   (c) When was the cyclist's position 300 m north?
   (d) What was the cyclist's average velocity for the first 70 s?
   (e) What was the cyclist's average speed for the entire trip?
   (f) What was the cyclist's instantaneous velocity at 240 s?
   (g) Did the cyclist stop at any time during the ride? If so, at what time?
   (h) What was the cyclist's average velocity for the first 200 s?
   (i) What was the cyclist's average velocity for the entire trip?

Tech
CONNECT

DETECTING SPEED

In Canada, there were about 3000 fatalities in traffic collisions in 2005. About 17 % of these fatalities were because of inappropriate or excessive speeds. Radar and laser speed guns are used by police to detect speeds.

Speed limits on roads are set to identify a reasonable limit that will ensure public safety (Figure 1). However, most drivers (a staggering 85 %) have no idea how fast they are going at a particular time. To enforce speed limits, police use radar and laser speed guns to catch speeding drivers.

Radar, which stands for RAdio Detection And Ranging, was developed in World War II. A radar speed gun is basically a radio transmitter, which produces radio waves, and a receiver (Figure 2). The device sends out a radio wave that has a particular frequency and waits for the reflection of the signal to bounce off a vehicle. If the radar gun and a car are both standing still, the reflected signal will have the same wave frequency as the original signal. If the car is moving away from the radar gun, the first part of the radio wave has to travel a shorter distance to reach the car than the second part of the wave, which changes the frequency. Depending on how much the frequency changes, a radar gun can determine how quickly a car is moving toward or away from it. Police officers have been catching speeders this way for more than 50 years.

Figure 1 Speeding is the leading cause of accidents.

Many police departments are now using a speed detector that uses light instead of radio waves. A laser (or LIDAR for LIght Detection And Ranging) speed gun shoots many bursts of infrared laser light, and then measures the time for the light to reach a car and reflect back (Figure 3). By multiplying this time by the speed of light, the laser gun determines how far away the object is. Because it sends out many laser bursts of light, it can collect multiple distances. By comparing these different distances, it can calculate the speed of the car. A laser gun can be used to target a specific vehicle and is very accurate.

The use of radar and LIDAR guns to catch and deter speeders is a controversial topic. There are many radar detectors available to the speeding public that make it possible to pick up the radio signal emitted by the radar gun. Light sensitive detectors are used to detect the beams from LIDAR guns. However, the use of these detectors may have a benefit besides possibly avoiding a speeding ticket. Detectors alert motorists to the speed at which they are driving. Being aware of speed and slowing down may save lives.

Figure 2 A police officer using a radar gun.

Figure 3 A LIDAR gun

Motion with Two Speeds

INQUIRY SKILLS

○ Questioning	● Conducting	● Evaluating
○ Hypothesizing	● Recording	● Synthesizing
○ Predicting	● Analyzing	● Communicating
○ Planning		

The motion of an object can be observed and its distance and time recorded. The information about the motion can be described in words, in a data table, or with a graph. What information can the graph give in an efficient manner?

Scientists use a variety of different instruments to investigate motion. One instrument is a recording timer (Figure 1). In this investigation, you will use a recording timer to obtain data. You will then draw and analyze the distance–time graph.

Figure 1 A recording timer can be used to time motion.

Question

How are two different speeds shown on a distance–time graph?

Experimental Design

The tickertape recording timer uses electricity from an outlet that has a frequency of 60 Hz. That means that the time interval between dots is $\frac{1}{60}$ of a second or 0.0167 s. This is an awkward number for graphing. However, if we put a line through the first dot, which is at line number zero, and then put another line through the sixth dot after that one (the seventh dot), it will be $\frac{6}{60}$ of a second later (Figure 2). This is equal to 0.1 s and is much easier to graph.

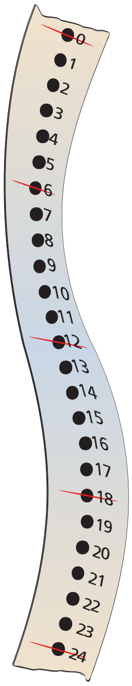


Figure 2 Sometimes it is more convenient to use time intervals of six dots rather than using every dot.

Doing this will also reduce the number of data points produced from a length of tickertape. If you find that using every sixth dot produces too many data points from a length of tickertape, then use every twelfth dot.

Materials

- tickertape
- recording timer

Procedure

1. Thread 1–2 m of tape into the recording timer.
2. Turn on the timer and begin to pull the tape at a constant speed through the timer (Figure 3). After pulling half the tape through the timer, double the speed of the tape (without stopping) and pull the rest of the tape through the timer. It is not necessary to exactly double the speed—the speed just needs to be a faster constant speed.

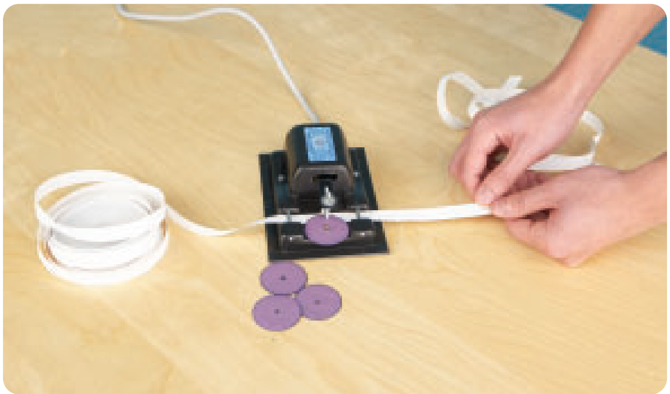


Figure 3

3. Using a convenient time interval, mark your tape into the data points you will use. Determine how many data points you will use.
4. Copy Table 1 into your notebook and add enough rows for your data.

Table 1

Time (s)	Distance (m)
0	0

5. Record the time and the distance travelled by the tape in your table. The distance travelled is the distance from the starting point each time, not just the distance travelled during the time interval.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) Draw a distance–time graph for your data. Draw a line of best fit for the first half of the tape and a line of best fit for the second half of the tape.

(b) Determine the slopes of the two lines of best fit. What do these lines represent?

(c) Draw a line joining the first dot on your graph to the last dot. Determine the slope of the line. What does this slope represent?

(d) How are constant speeds shown on a distance–time graph?

(e) How are different constant speeds shown on a distance–time graph?

(f) Draw a line of best fit for all of the data on your graph.

Evaluation

(g) What happened to the slope of the line when you were increasing the speed of the tape?

Synthesis

(h) If you repeated the experiment and pulled the tickertape quickly and then slowed down, what changes would this make to your graph? Draw a sketch of the graph.

CHAPTER 12

Review

Displacement, Time, and Velocity

Key Ideas

The motion of an object can be described by displacement, time, and velocity.

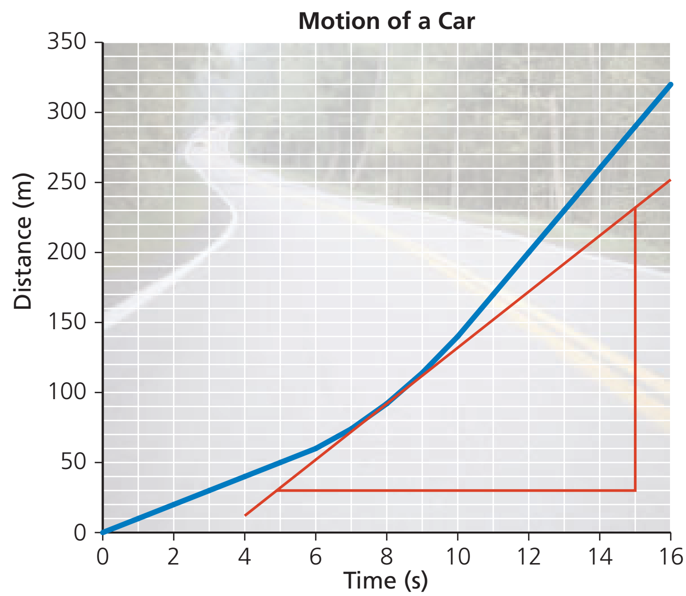
- Distance and displacement are similar, but not identical concepts in science. Speed and velocity are also similar, but not identical concepts.
- The displacement of an object is its change in position in relation to a point of reference, and the time interval for the change is how long the object took to get to the final position from the initial position.
- Velocity is the rate of change of displacement and is given by the equation

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

- If an object is travelling at a constant velocity, neither the magnitude nor the direction of its velocity changes.

Distance–time graphs and position–time graphs can visually display information about an object's motion.

- If the line of best fit of a distance–time graph or a position–time graph is a straight line, the object is travelling at constant speed or velocity.
- The slope of the line is equal to the speed or velocity of the object.
- If the slope of the line is changing, the speed or velocity is not constant (it is changing).
- Distance and position are always on the vertical axis and time is always on the horizontal axis.
- If the forward direction is defined as positive, then a negative velocity implies the object is moving in a backwards direction. The same is true for displacement.



Vocabulary

time interval, p. 342
slope, p. 344
speed, p. 346
average speed, p. 346
instantaneous speed, p. 349
scalar quantity, p. 359
displacement, p. 359
vector quantity, p. 359
velocity, p. 361
uniform motion, p. 363

Quantities can be either scalar or vector.

- Scalar quantities only have magnitude, which is a number with a unit.
- Vector quantities have both a magnitude and a direction.
- Time, distance, and speed are scalar quantities.
- Displacement and velocity are vector quantities.
- Vector quantities are indicated by an arrow over the symbol. For example speed is v, whereas velocity is $\vec{v}$.

Table 1 Summary of Quantities

Quantity	Symbol	Scalar or vector
time	t	scalar
distance	d	scalar
displacement	$\Delta\vec{d}$	vector
speed	v	scalar
velocity	$\vec{v}$	vector

An object's speed and velocity can be described in different ways.

- The average velocity of an object is the displacement divided by the total time, regardless of changes in motion.
- The instantaneous speed of an object is its speed at a specific time.
- An object in uniform motion has a constant velocity.
- For an object in uniform motion, its average speed is equal to its instantaneous speed at any time.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

1. Use an example to explain the difference between distance and displacement.
2. Write a definition of "period" in your own words.

K 3. What does the slope of a distance–time graph determine?
A. time
B. speed
C. distance
D. direction

Use What You've Learned

U 4. A student uses the pulse in her wrist to measure her heart rate. She counts 72 beats in 1 min. What are the period and frequency of her heartbeat?

	Period	Frequency
A.	0.014 s	72 Hz
B.	0.83 s	1.2 Hz
C.	1.2 s	0.83 Hz
D.	72 s	0.014 Hz

U 5. A jet plane travels at an average speed of 800 km/h. How much time, in hours, is required for the plane to travel from Vancouver to Winnipeg, a distance of 2400 km?
A. 0.25
B. 0.33
C. 1.0
D. 3.0

U 6. Devon is riding his bicycle at 15 m/s. How far will he travel in 12 s?
A. 1.2 m
B. 3.0 m
C. 27 m
D. 180 m

7. An ant was sitting on the 50 cm mark of a metre stick. The ant then started to move. Table 1 gives the position of the ant over 28 s.

Table 1 Position of an Ant

Time (s)	Position (cm)
0	50
4	50
8	10
12	10
16	75
20	75
24	30
28	30

(a) What distance did the ant travel?
(b) What was the average speed of the ant?
(c) What was the average velocity of the ant?

8. A stroboscopic light was used to illuminate a moving golf club in a dark room while a camera recorded the golf club's motion (Figure 1).

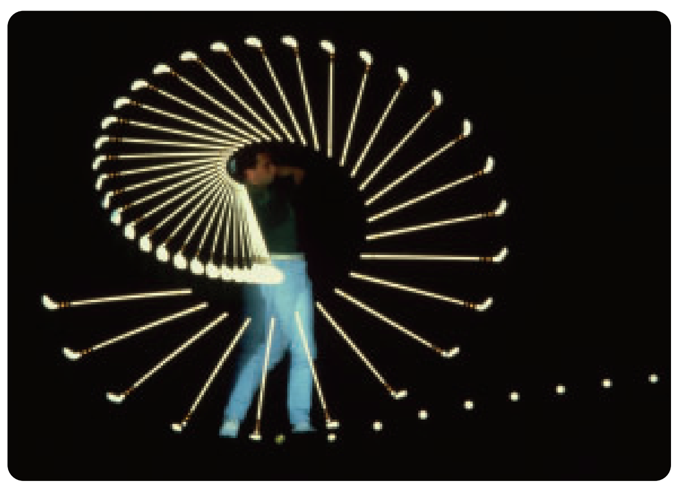


Figure 1

(a) Is the golf club moving with a uniform speed?
(b) At which part of the swing is the club moving the fastest?
(c) At which part of the swing is the club moving the slowest?

9. Drivers in a Volkswagen and a Cadillac take the same 140 km trip. The Volkswagen travels at 80 km/h for the entire trip. The Cadillac starts at the same time, driving at 100 km/h, but the driver stops for 10 min to fill the gas tank. Which car has the higher average speed? Which car arrives first at the destination? How many minutes separate the arrival times of the cars?

10. A hiker leaves a campsite and travels by car for 45 min at an average speed of 60 km/h, and then hikes for 1.5 h at 0.75 m/s.
   (a) How far did the hiker drive?
   (b) How far did the hiker walk?
   (c) What total distance did the hiker travel?
   (d) What was the hiker's average speed for the trip?

Use Figure 2 to answer questions 11 and 12.

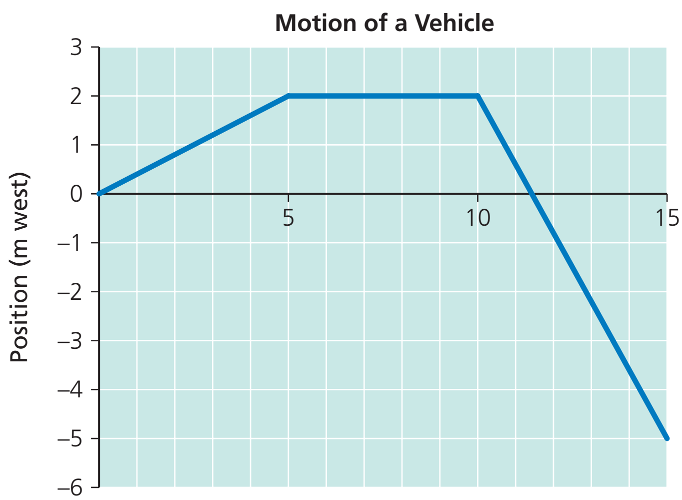


Figure 2

U 11. At what time was the position closest to 1 m [E]?
   A. 2.4 s
   B. 12.1 s
   C. 2.4 s and 10.7 s
   D. 10.7 s and 12.1 s

U 12. What was the average velocity from 0 s to 15 s?
   A. 0.33 m/s [E]
   B. 0.33 m/s [W]
   C. 0.6 m/s [E]
   D. 0.6 m/s [W]

13. A bird's flight along the side of an office building was recorded on a video camera that also recorded the time. The distance was estimated using the size of the office building windows. Table 2 shows the data for the bird's flight.

Table 2 Distance of a Bird

Time (s)	1.2	1.7	2.1	2.7	2.9	3.3	3.7	4.1
Distance (m)	2.9	6.2	9.2	14.9	18.2	24.0	29.7	33.1

   (a) Use the data to make a distance–time graph.
   (b) What was the average speed of the bird along the building?
   (c) What was the instantaneous speed of the bird at 3.0 s?

U 14. A car travels 3 km [W], 4 km [E], and 1 km [W]. What is the displacement of the car?
   A. 0 km
   B. 4 km
   C. 7 km
   D. 8 km

Think Critically

HMP 15. Why is distance usually on the vertical axis even if distance is the independent variable?
   A. It is a convention.
   B. It is used to calculate speed.
   C. Distance is a scalar quantity.
   D. Time cannot be controlled as a variable.

16. An object undergoes motion. Is it possible for the magnitude of the displacement to be the same as the distance? Explain your answer (you should use an example to support your answer).

Reflect on Your Learning

17. What have you learned about graphing and interpreting graphs that has helped you understand the concepts presented in this chapter?

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