9.2 Calculating Acceleration

The slope of a velocity-time graph is average acceleration. Acceleration is measured in m/s^2. The relationship of acceleration, change in velocity, and time interval is given by the equation $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$. The acceleration due to gravity near the surface of Earth is $9.8\ m/s^2$ downward.

Words to Know

acceleration due to gravity
air resistance
average acceleration
constant acceleration
gravity
velocity-time graph

It is estimated that more than 1100 lives are saved each year in Canada by seat belt and air bag use. Air bags were first introduced into personal vehicles in 1980. Since then, the quality and efficiency of air bags has continued to improve.

A person in a car has the same forward velocity as the car when the car is moving. During a collision, the person's velocity will decrease to zero very quickly. The change in velocity and therefore the acceleration will be opposite the original motion.

In a car crash, there is no way to avoid bringing the driver and passengers to an abrupt stop from their initial velocities. The purpose of the air bag is to bring the person from high velocity to a stop as gradually as possible (Figure 9.10). By hitting the soft air bag, the change in velocity takes a longer period of time as compared to striking the solid dashboard of the car. The longer the stopping time, the smaller the acceleration. By decreasing the acceleration of the person, there is less chance of injury.

Engineers need to calculate acceleration in order to design effective air bags. Crashes can occur in less than the blink of an eye, so the air bag must be able to inflate and deflate very rapidly. During inflation, the air bag comes out of the dashboard at more than 500 km/h. Once fully inflated, vents in the air bag allow it to deflate immediately. It takes about 100 milliseconds (100 thousandths of a second) to deflate, and during this time the person's head, neck, and chest are in contact with the air bag.

Connection

Chapter 6 has more information about air bags.

Figure 9.10 The air bag slows down the crash-test dummy in a longer time interval than if the dummy collided with the steering wheel.

9-2A Crash-test Eggs

Find Out ACTIVITY

In this activity, you will design a method of protecting a falling egg from breaking when its velocity decreases to zero.

Safety

- Never eat anything in the science room.
- Wash your hands thoroughly when you have completed this activity.

Materials

- raw eggs
- metre stick
- various soft materials (foam, crushed paper, bubble wrap, etc.)

What to Do

1. Your teacher will drop a raw egg onto the counter from a height of 50 cm. Observe the results.
2. Design and construct a flat surface that will allow a raw egg to fall 50 cm without breaking. Use materials you have chosen that have been approved by your teacher. The thickness of your landing material cannot exceed 5 cm.
3. Release an egg from a height of 50 cm above your new surface.
4. If the egg breaks, repeat steps 2 and 3 until you have successfully stopped a raw egg from breaking after falling 50 cm.
5. Clean up and dispose of the materials as directed by your teacher. Wash your hands.

What Did You Find Out?

1. In both step 1 and step 4, the egg experienced a change in velocity when it landed. Compare the egg's change in velocity in these two situations.
2. From your observations, how did the time required to stop the egg in step 4 compare to the time to stop the egg in step 1?
3. Explain why the egg in step 4 did not break yet the egg in step 1 did break. Use the following terms in your answer: change in velocity, time, and acceleration.
4. Relate what you learned in this activity to how air bags in cars are used to save lives and reduce injury.

Velocity-Time Graphs

Roller coasters like the one pictured at the beginning of this unit take their riders through a spectacular journey of changing velocities. Some roller coasters travel from rest to 50 m/s (180 km/h) in just 4.0 s. As the ride continues, the direction and speed of the roller coaster continually change until it accelerates smoothly to a stop at the end.

If you wish to represent the motion of objects travelling at a constant velocity, or changing from one constant velocity to another, then you would use a *position-time* graph. However, you would use a *velocity-time* graph to represent the motion of an object, such as a roller coaster, whose velocity is changing. A **velocity-time graph** provides information about the object's velocity and acceleration.

Did You Know?

Stopping your motion with an air bag could be compared to falling from a height. Falling into a foam pit from a height is safer than falling from the same height onto solid ground. The longer time it takes to change your velocity, the smaller your acceleration.

Velocity and best-fit line

Table 9.1 shows the velocity at given times for the roller coaster as it accelerates forward at the beginning of the ride.

Table 9.1 Velocity of a Roller Coaster

Time (s)	0.0	1.0	2.0	3.0	4.0
Velocity (m/s)	0.0	12.5	25.0	37.5	50.0

When you plot the data from Table 9.1 on a graph, you can create a best-fit line (Figure 9.11). You can then find the slope of the line to determine the rate at which the roller coaster's velocity is changing. This graph shows the slope as:

$$\begin{aligned} \text{Slope} &= \frac{\text{rise}}{\text{run}} \\ &= \frac{25 \text{ m/s}}{2.0 \text{ s}} \\ &= \frac{13 \text{ m/s}}{\text{s}} \\ &= 13 \text{ m/s}^2 \end{aligned}$$

Did You Know?

Mathematically, (m/s)/s can be written as (m/s)(1/s) since dividing by a number is the same as multiplying by the inverse. Therefore, (m/s)/s is the same as m/s^2.

The unit (m/s)/s simplifies to m/s^2. The SI unit for acceleration is m/s^2. The slope of this velocity-time graph is 13 m/s^2, which means that the roller coaster's velocity increased in the forward direction by 13 m/s every 1.0 s.

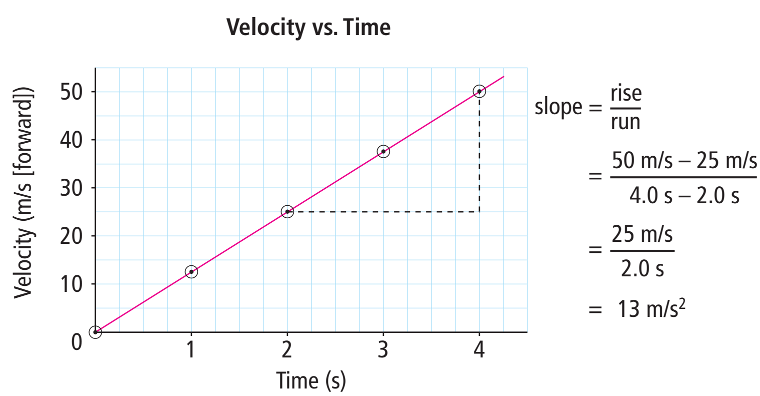


Figure 9.11 The slope of a velocity-time graph is the average acceleration of the object.

Suggested Activity

Conduct an Investigation 9-2C on page 401

Acceleration and best-fit line

When the best-fit line on a velocity-time graph passes through all the data points, the object's velocity is changing at a constant rate and the motion is described as **constant acceleration**. However, since not all of the actual velocities may be directly on the best-fit line, the slope of a velocity-time graph is the **average acceleration**.

Determining Motion from a Velocity-Time Graph

Figure 9.12 represents the motion of a school bus that has three different motions with uniform acceleration. Table 9.2 summarizes the motion depicted by the graph.

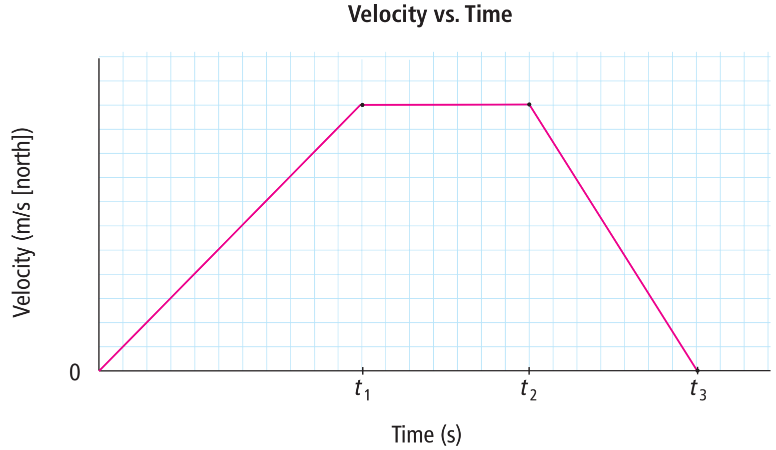


Figure 9.12 The graph shows motion with positive acceleration (0 to t_1), zero acceleration (t_1 to t_2), and negative acceleration (t_2 to t_3).

Table 9.2 Motion of a School Bus

Time interval	0 to t_1	t_1 to t_2	t_2 to t_3
Acceleration	Positive [N]	Zero	Negative [S]
Velocity	Starts from rest and increases speed at a constant rate travelling north	Travels north at a constant speed	Slows down to a stop at a constant rate while still travelling north

Assume that the positive direction has been chosen to be north. Notice the following information shown on the graph.

– During the time interval 0 to t_1, the school bus has a constant positive acceleration, which indicates that it increases its velocity [N] at a constant rate.
– From t_1 to t_2, the school bus has a zero acceleration, which indicates that it maintains a constant velocity [N]. In other words, the school bus heads north with a constant speed.
– During the time interval t_2 to t_3, the school bus has a constant negative acceleration, which indicates that it uniformly decreases its velocity [N] until it stops. During this negative acceleration, the passengers are still moving forward while slowing down.
– During the complete 0 to t_3 time interval, the school bus has been moving north, and therefore its final displacement would be north from where it started.

Reading Check

1. What does the slope of a velocity-time graph represent?
2. State what a straight line on a velocity-time graph indicates about:
   (a) an object's change in velocity
   (b) an object's acceleration

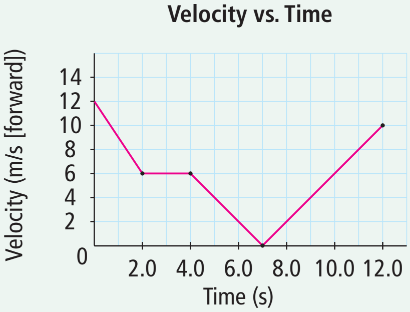
9-2B Analyzing Motion on a Velocity-Time Graph

Think About It

In this activity, you will interpret the motion of an object by analyzing a velocity-time graph.

What to Do

1. Sketch the following velocity-time graph.



2. What is the velocity (magnitude and direction) of the object at each of the following times?
   (a) $t = 0.0$ s (b) $t = 3.0$ s (c) $t = 7.0$ s (d) $t = 12.0$ s
3. What is the acceleration during each of the time intervals? Be sure to include direction.
   (a) 0.0 s–2.0 s (b) 4.0 s–7.0 s

What Did You Find Out?

1. In a short sentence, describe the motion of the object during each of the following time intervals.
   (a) 2.0 s–4.0 s (b) 7.0 s–12.0 s

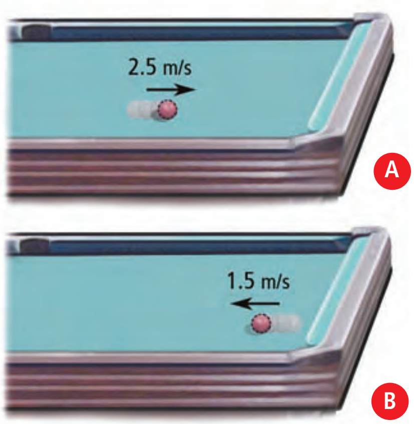


Figure 9.13 The ball's velocity changes from 2.5 m/s toward the cushion (A) to 1.5 m/s away from the cushion (B) in a time interval of 0.20 s.

Calculating Acceleration

You can determine the acceleration of an object without drawing a velocity-time graph. You can use the fact that the slope of a velocity-time graph is the average acceleration to determine a formula for calculating acceleration. In this textbook, we will consider only situations where the acceleration is considered constant (a straight line on a velocity-time graph). In these situations, the average acceleration is the same as the acceleration at any instant, so there is no need to refer to "average."

The slope (acceleration) of a velocity-time graph is calculated as $\frac{\text{rise}}{\text{run}}$ or $\frac{\Delta\vec{v}}{\Delta t}$. For constant acceleration, acceleration ($\vec{a}$) is equal to the change in velocity ($\Delta\vec{v}$) divided by the time interval (Δt).

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

Suppose that you shoot a pool ball at 2.5 m/s toward the cushion. The ball bounces off the cushion at a velocity of 1.5 m/s away from the cushion (Figure 9.13). Assuming that the ball was in contact with the cushion for 0.20 s and the acceleration was constant, what is the ball's acceleration if the negative direction is away from the cushion?

$$\begin{aligned}\vec{a} &= \frac{\Delta\vec{v}}{\Delta t} \text{ where } \Delta\vec{v} = \vec{v}_{\text{f}} - \vec{v}_{\text{i}} \\ &= \frac{-1.5\text{ m/s} - 2.5\text{ m/s}}{0.20\text{ s}} \\ &= \frac{-4.0\text{ m/s}}{0.20\text{ s}} \\ &= -20\text{ m/s}^2\end{aligned}$$

The acceleration is 20 m/s^2 away from the cushion.

Calculating change in velocity and time

The equation $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$ can be used to calculate both the change in velocity and the time interval. Mathematically, $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$ can be rewritten as:

$$\Delta\vec{v} = \vec{a}\Delta t$$

Or

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

Suppose the bullet train in Japan accelerates from rest at 2.0 m/s² forward for 37 s. What is the velocity of the bullet train at the end of 37 s? Remember that the forward motion is positive (+).

$$\begin{aligned}\Delta\vec{v} &= \vec{a}\Delta t\\ &= (2.0\ \text{m/s}^2)(37\ \text{s})\\ &= 74\ \text{m/s}\end{aligned}$$

The train's change in velocity is 74 m/s forward. Since the train started from rest, $\vec{v}_i = 0$, therefore

$$\begin{aligned}\Delta\vec{v} &= \vec{v}_f - \vec{v}_i\\ 74\ \text{m/s} &= \vec{v}_f - 0\\ \vec{v}_f &= 74\ \text{m/s}\end{aligned}$$

The velocity of the train after 37 s is 74 m/s forward.

Suppose a car is travelling north at 22 m/s. How long would it take to slow this car to 12 m/s north if it accelerates at 2.5 m/s² south? Remember that the north direction is positive (+). First, find the value of $\Delta\vec{v}$:

$$\Delta\vec{v} = \vec{v}_f - \vec{v}_i = (12\ \text{m/s}) - (22\ \text{m/s}) = -10\ \text{m/s}$$

Then find the value of Δt:

$$\begin{aligned}\Delta t &= \frac{\Delta\vec{v}}{\vec{a}}\\ &= \frac{-10\ \text{m/s}}{-2.5\ \text{m/s}^2}\\ &= 4.0\ \text{s}\end{aligned}$$

Note: acceleration is (−) since it is south.

It would take 4.0 s to slow the car.

Practice Problems

Try the following acceleration problems yourself.

1. A car starting from rest accelerates uniformly to 15 m/s [E] in 5.0 s. What is the car's acceleration?
2. A skier moving 6.0 m/s forward begins to slow down, accelerating at −2.0 m/s² for 1.5 s. What is the skier's velocity at the end of the 1.5 s?
3. A motorcycle is travelling north at 11 m/s. How much time would it take for the motorcycle to increase its velocity to 26 m/s [N] if it accelerated at 3.0 m/s²?

Answers

1. 3.0 m/s² [E]
2. 3.0 m/s forward
3. 5.0 s

Gravity and Acceleration

One of the most common examples of constant acceleration is an object falling freely near Earth's surface. When an object falls near Earth's surface, it is attracted downward by the force of **gravity**, which is an attractive force that acts between two or more masses.

Figure 9.14 shows a motion diagram and a velocity-time graph of a ball being thrown straight up into the air. On the way up, the ball's velocity is decreasing. "Up" is positive (+), so the ball's change in velocity while rising into the air is negative (−) because the velocity is decreasing. This means that the acceleration of the ball is also negative (−); therefore, the ball is slowing down.

At its maximum height, the ball's velocity is zero for an instant since the direction of the ball is changing. However, it is still accelerating. After the ball has reached its maximum height and starts to come down, the ball's velocity increases on its way down. The change in velocity of the ball would be negative (−) because the ball is heading "down"; therefore, the acceleration of the ball is also negative (−). During this complete trip, the ball's acceleration was constantly towards the ground. Its acceleration is due to Earth's gravity.

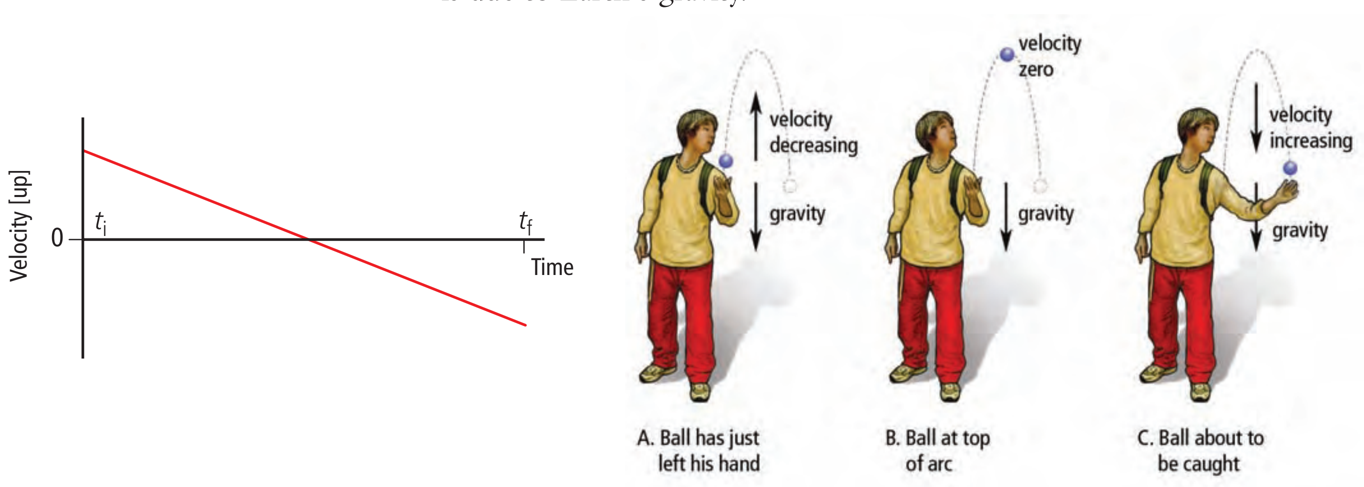


Figure 9.14 Even though the speed of the ball decreases on its way up and increases on its way down, the acceleration is always toward the ground.

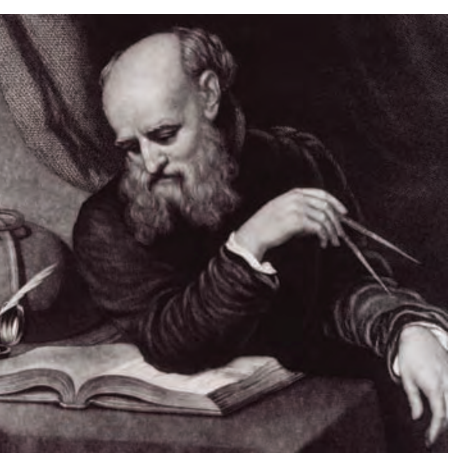


Figure 9.15 Galileo Galilei (1564–1642) is often referred to as the "father of modern science."

Gravity and air resistance

If you dropped a baseball and a piece of paper at the same time, which would hit the ground first? Prior to the time of Galileo (Figure 9.15), it was widely believed that heavier objects fall faster than lighter objects. Our common sense may agree with this early thinking. If we dropped a baseball and a horizontal piece of paper at the same time, the heavier baseball would reach the ground first (Figure 9.16A on the next page). However, the reason the baseball reaches the ground before the sheet of paper is not because of their different masses. If you repeat this experiment, this time tightly crumpling the paper, the baseball and the paper would hit the ground at approximately the same time (Figure 9.16B on the next page).

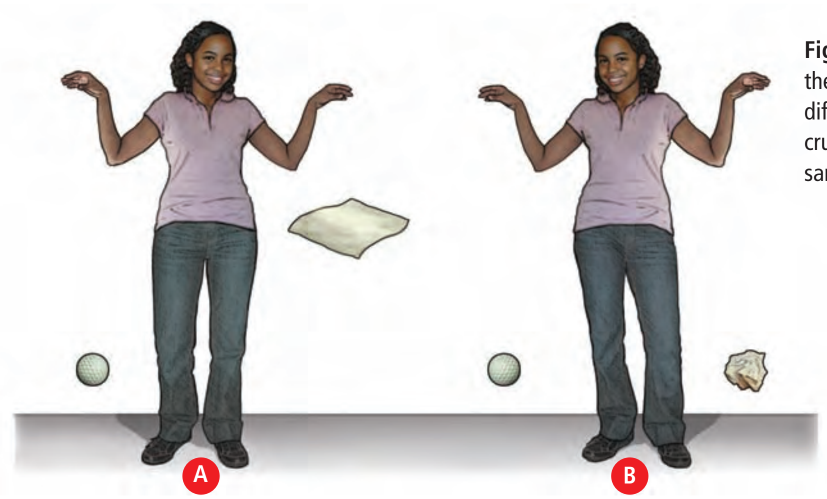


Figure 9.16 The baseball and the sheet of paper fall at different rates (A). When crumpled, the paper falls at the same rate as the baseball (B).

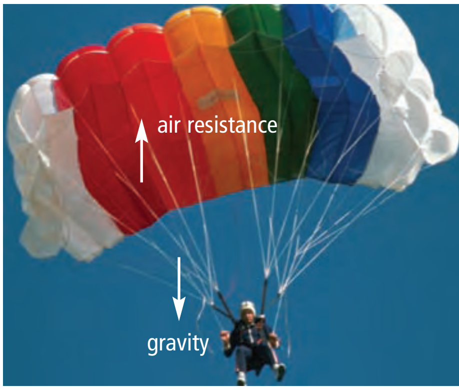


Figure 9.17 The air resistance force on an open parachute is much greater than the air resistance on a sky diver with a closed parachute. With the parachute open, the velocity of the sky diver becomes small enough that the sky diver can land safely.

Galileo proposed that objects fall at different rates because of the air resistance acting on them. **Air resistance** is a friction-like force that opposes the motion of objects that move through the air. If the object is falling downward, air resistance acts upward on the object (Figure 9.17). The amount of the air resistance force depends on the speed, size, and shape of the object. Air resistance is why a flat piece of paper falls more slowly than a crumpled piece of paper.

Acceleration due to gravity

Galileo suggested that in the absence of air resistance all objects, regardless of their weight, would fall with the same constant acceleration. Scientists in Galileo's time had no way of producing a vacuum (a region where there is no air) to prove his theory. However, modern science has since found many ways to collect evidence to support Galileo's theory (Figure 9.18). On Earth, we call this acceleration the **acceleration due to gravity** and give it the symbol g. The value of acceleration due to gravity is approximately $g = 9.8\ \text{m/s}^2$, downward.

Figure 9.18 *Apollo 15* astronaut David Scott dropped a hammer and a feather in the vacuum of the Moon's surface. The two objects fell at the same rate, providing evidence in support of Galileo's theory.

Did You Know?

Astronauts and pilots of high-speed aircraft are subjected to high levels of acceleration. They need to wear a special suit called a "G-suit" to prevent loss of consciousness caused by blood pooling in the lower part of their body. The first G-suit used water-filled bladders around the legs and was developed at the University of Toronto in 1941.

Calculating Motion Due to Gravity

In many situations on Earth, the air resistance acting on a falling object is so small that we can assume that the object has a constant downward acceleration of 9.8 m/s². In the equation $\vec{a} = \frac{\triangle \vec{v}}{\triangle t}$, the value of $\vec{a}$ is 9.8 m/s² downward for any object falling or being thrown upward.

Suppose a rock falls from the top of a high cliff. What is the change in velocity of the rock after it has fallen for 1.5 s? Remember that "down" is negative (−).

$$\begin{aligned} \triangle \vec{v} &= (\vec{a})(\triangle t) \\ &= (-9.8\ \text{m/s}^2)(1.5\ \text{s}) \\ &= -15\ \text{m/s} \end{aligned}$$

The rock's velocity changed by −15 m/s downward. Since the rock started from rest, we could say that the rock's final velocity at 1.5 s is −15 m/s down.

Acceleration due to gravity is also used for objects thrown up into the air. Suppose a rock is tossed up and leaves the person's hand at 12.0 m/s. How long would it take for the rock's velocity to slow to 4.0 m/s? "Up" is positive (+).

$$\begin{aligned} \triangle t &= \frac{\triangle \vec{v}}{\vec{a}} \\ &= \frac{4.0\ \text{m/s} - 12.0\ \text{m/s}}{-9.8\ \text{m/s}^2} \\ &= \frac{-8.0\ \text{m/s}}{-9.8\ \text{m/s}^2} \\ &= 0.82\ \text{s} \end{aligned}$$

It would take 0.82 s for the rock to slow from 12.0 m/s to 4.0 m/s.

Practice Problems

Try the following acceleration due to gravity problems yourself.

1. What is the change in velocity of a hailstone that falls for 3.0 s?
2. A ball is thrown up into the air. How much time does it take to go from 16 m/s up to 2.0 m/s up?
3. A rock is thrown up into the air with an initial velocity of 14 m/s up. What will be the rock's velocity after 0.61 s?
4. A brick falls from the top of a chimney. What is the velocity of the brick after 1.5 s?
5. A ball is thrown straight up into the air at 12 m/s. How long does it take for the ball to reach its maximum height? (Hint: The velocity of the ball at its maximum height is zero.)
6. A rock is thrown downward from a roof at 11 m/s. What is the velocity of the rock after 0.75 s?

Suggested Activity

Conduct an Investigation 9-2D on page 402

Answers

1. 29 m/s down
2. 1.4 s
3. 8.0 m/s up
4. 15 m/s down
5. 1.2 s
6. 18 m/s down

Explore More

Galileo made many contributions to our understanding of motion and how we study it. Find out more about Galileo's contributions to science. Begin your research at **www.bcscience10.ca**.

9-2C Acceleration Due to Gravity

Design an INVESTIGATION

Inquiry Focus

SkillCheck

- Observing
- Measuring
- Controlling variables
- Graphing

All objects near the surface of Earth and in the absence of air resistance accelerate at 9.8 m/s^2 downward. In this activity, you will design and perform an experiment to measure the acceleration due to gravity of an object in your classroom.

Materials

- measuring tapes
- metre sticks
- stopwatches
- recording timers
- ticker tape
- motion sensors
- data-collection devices, such as computers or graphing calculators

Problem

Design and perform an experiment that will measure the acceleration due to gravity on an object in your classroom.

Criteria

- Create a procedure that will allow you to determine the acceleration due to gravity for your chosen object.
- Your analysis must include a data table, velocity-time graph, and calculations.

Design and Construct

1. Choose an object that air resistance will not significantly affect. Obtain your teacher's permission to find the acceleration due to gravity for this object.
2. Record your procedure for determining the object's acceleration due to gravity. Visit **www.bcscience10.ca** if you need more information about using a motion sensor and computer. 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 velocity-time graph to interpret your data.

Evaluate

1. What is the average acceleration of your object? Show how you obtained your answer.
2. Was the acceleration of your object perfectly constant? Use your graph to justify your answer.
3. How close was your answer to the accepted value of 9.8 m/s^2 downward? Suggest reasons why your answer is not exactly 9.8 m/s^2 downward.
4. Describe any changes you would make to your procedure in order to improve your accuracy.

Safety standards and guidelines are extremely important in bungee jumping. Calculations and fittings must be double-checked before every jump. The bungee jumper accelerates downward due to gravity until the bungee cord causes a deceleration.

9-2D Acceleration Down a Ramp

SkillCheck

- Measuring
- Controlling variables
- Graphing
- Evaluating information

Materials

- dynamics cart
- ramp
- ticker tape
- recording timer
- masking tape
- ruler

Science Skills

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

The velocity of a cart that rolls freely down a ramp changes at a nearly uniform rate. In this activity, you will determine the cart's acceleration by measuring the displacement for each time interval and plotting your data on a velocity-time graph.

Question

How does a velocity-time graph show uniform acceleration?

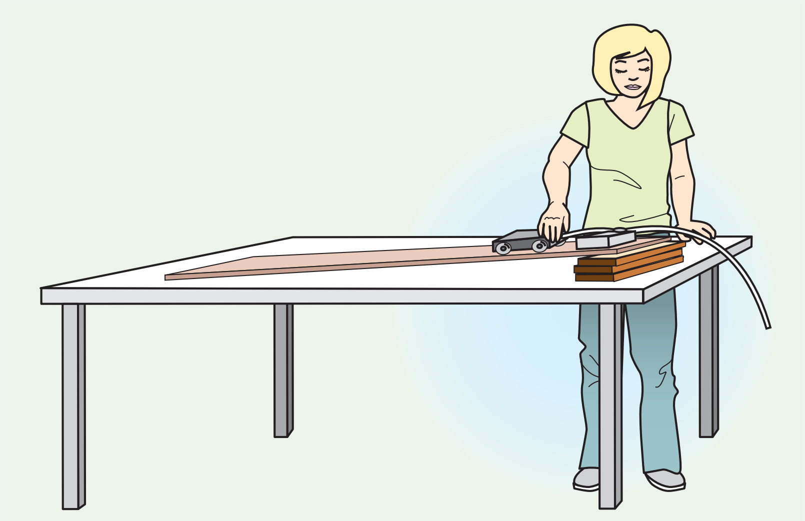
Procedure

Part 1 Collecting Data

1. Copy a data table, like the one shown, into your notebook. Give your data table a title.

Time interval (s)	0 to 0.1	0.1 to 0.2	0.2 to 0.3	0.3 to 0.4	0.4 to 0.5	0.5 to 0.6	0.6 to 0.7	0.7 to 0.8	0.8 to 0.9	0.9 to 1.0
Displacement for each 0.1 s time interval (m)										
Average velocity (m/s [down the ramp])										

2. Place the dynamics cart at the top of the ramp. Cut a piece of ticker tape that is about 30 cm shorter than the length of your ramp. Insert the ticker tape into the recording timer and fasten the ticker tape to the cart with the masking tape.
3. Turn on the recording timer and release the cart. Be sure someone stops the cart at the bottom of the ramp so that it does not fall off the table.
4. Clean up and put away the equipment you have used.



Step 2

Part 2 Graphing the Data

5. Draw a line through the first dot on the tape and label it $t = 0.0$ s. Count six dots from $t = 0.0$ s, and draw a line through the sixth dot. Label this line $t = 0.1$ s. Measure the distance between these two lines, and record this value as the displacement during time interval $t = 0.0$ to $t = 0.1$ s.
6. From the $t = 0.1$ s line, draw a line through the sixth dot. Label this line $t = 0.2$ s. Measure the distance between the $t = 0.1$ s line and the $t = 0.2$ s line, and record this value as the displacement during time interval $t = 0.1$ to $t = 0.2$ s.
7. Continue measuring and recording the displacements for each of the times until you have completed your ticker tape. Depending on the length and incline of your ramp, you may have more or less data than what is suggested in the example data table. You can adjust your data table to include all your data.
8. Use the equation $\vec{v}_{av} = \frac{\Delta \vec{d}}{\Delta t}$ to calculate the average velocity for each of the 0.1 s time intervals. Record these values in your data table.
9. Plot a velocity-time graph for your data. The average velocity is most accurately plotted as the velocity in the middle of the time interval. For example, the displacement measured for the $t = 0.0$ to $t = 0.10$ time interval should be plotted at $t = 0.05$ s on your graph.
10. Draw a best-fit line that best represents your data.

Analyze

1. Calculate the slope of your velocity-time graph. Be sure to include the correct units.
2. What is the average acceleration of the cart down the ramp?
3. Was the cart's acceleration perfectly constant? Explain your answer.

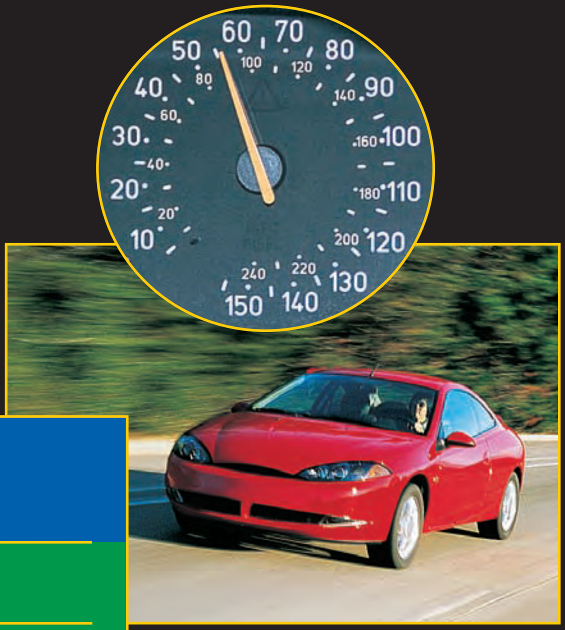
Conclude and Apply

1. If you were to repeat your experiment with a steeper ramp, how would the slope of the new motion compare with the original slope? Explain your answer.

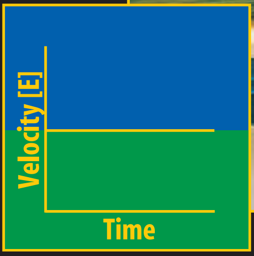
An analysis of large accelerations can be done for any insect.

Visualizing Acceleration

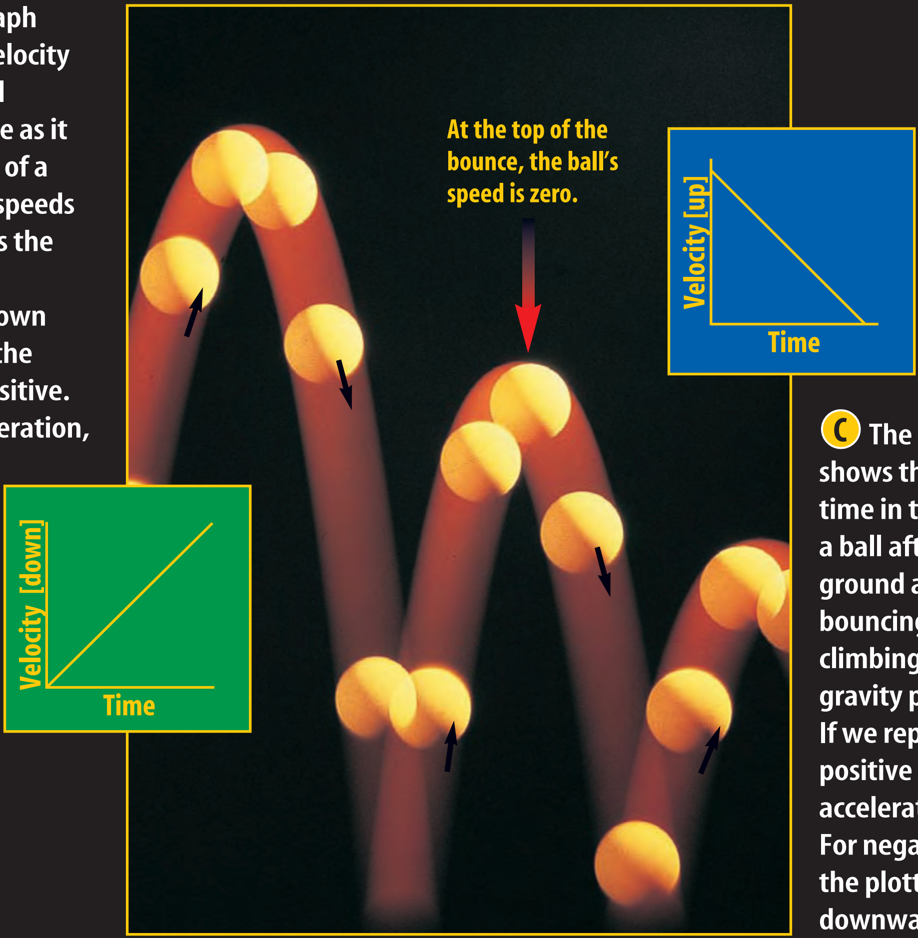
Acceleration can be positive, negative, or zero depending on the direction the object is travelling and whether the object is speeding up, slowing down, or moving at a constant speed. If the velocity of an object is plotted on a graph, with time along the horizontal axis, the slope of the line is related to the acceleration.



A The car in the photograph on the right is maintaining a constant velocity of about 90 km/h [E]. Because the speed is constant, the car's acceleration is zero. A graph of the car's speed with time is a horizontal line.



B The green graph shows how the velocity of a bouncing ball changes with time as it falls from the top of a bounce. The ball speeds up as gravity pulls the ball downward. If we represent down as positive (+), the acceleration is positive. For positive acceleration, the plotted line slopes upward to the right.



C The blue graph shows the change with time in the velocity of a ball after it hits the ground and begins bouncing upward. The climbing ball slows as gravity pulls it downward. If we represent up as positive (+), the acceleration is negative. For negative acceleration, the plotted line slopes downward to the right.

Checking Concepts

1. What is the SI unit for acceleration?
2. What quantity does the slope of a velocity-time graph represent?
3. How is constant acceleration represented on a velocity-time graph?
4. If an object has constant acceleration, describe the change in velocity during equal time intervals.
5. For constant acceleration, what is the mathematical relationship between acceleration ($\vec{a}$), change in velocity ($\triangle\vec{v}$), and time interval ($\triangle t$)?
6. In the absence of air resistance, what is the magnitude and direction of the acceleration due to gravity near the surface of Earth?

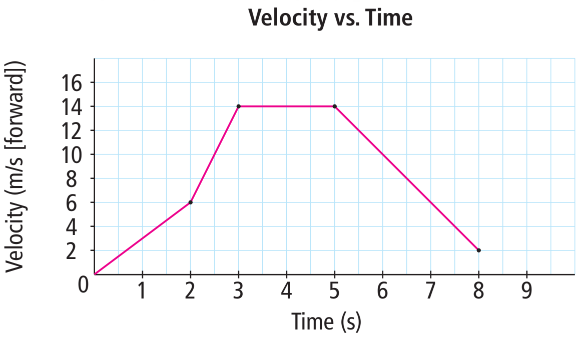
Use the diagram below to help you answer question 7.

7. A penny and a feather are located at the top of a vertical container with all air removed. If they are released at the same time, describe the motion of the two objects in terms of:
   (a) change in velocity
   (b) acceleration
   (c) time to fall

Understanding Key Ideas

8. What is the acceleration of a golf ball that is accelerated uniformly from rest to 55 m/s forward in 0.00045 s?
9. A car travelling south at 12 m/s stops uniformly in 3.0 s. What is the car's acceleration?
10. A ball changes its velocity from 25 m/s [S] to 32 m/s [N] in 0.65 s. What is the ball's average acceleration?

Use the graph below to help you answer questions 11 to 13.



11. What is the velocity of the object at the following times? Be sure to include direction.
    (a) $t = 1.0$ s
    (b) $t = 4.0$ s
    (c) $t = 6.0$ s
12. What is the acceleration during each of the following time intervals? Be sure to include direction.
    (a) $t = 0.0$ s–$t = 2.0$ s
    (b) $t = 2.0$ s–$t = 3.0$ s
    (c) $t = 3.0$ s–$t = 5.0$ s
    (d) $t = 5.0$ s–$t = 8.0$ s
13. In a short sentence, describe the motion of the object in each of the following time intervals.
    (a) $t = 0.0$ s–$t = 2.0$ s
    (b) $t = 2.0$ s–$t = 3.0$ s
    (c) $t = 3.0$ s–$t = 5.0$ s
    (d) $t = 5.0$ s–$t = 8.0$ s

Pause and Reflect

A circus trapeze artist falls 12 m into the safety net and stretches the net 1.5 m before coming to rest. What would you do to make the landing safer (that is, create a smaller acceleration): would you stiffen the net or loosen the net? Use the concepts of acceleration, change in velocity, and time interval to explain your answer.

Chapter 9

Chapter Review

Prepare Your Own Summary

In this chapter, you investigated the relationship between acceleration, change in velocity, 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. Describing Acceleration
2. Calculating Acceleration
3. Velocity-Time Graph
4. Acceleration Due to Gravity

Checking Concepts

1. Given the initial and final velocity of a car, describe how to find the change in velocity.
2. (a) Define "acceleration."
   (b) What is the SI unit for acceleration?
3. How does the direction of the change in velocity compare to the direction of the acceleration?
4. Describe an object's motion:
   (a) if the acceleration is in the same direction as the object's velocity
   (b) if the acceleration is opposite the direction of the object's velocity
5. What is another term for acceleration opposite the direction of motion?
6. Positive (+) and negative (−) are used to represent the direction of an object's velocity and acceleration. Copy the following table into your notebook. For each combination, indicate if the object is speeding up or slowing down.

	Initial Velocity	Acceleration	Speeding Up or Slowing Down
(a)	Positive (+)	Positive (+)	
(b)	Positive (+)	Negative (−)	
(c)	Negative (−)	Positive (+)	
(d)	Negative (−)	Negative (−)	

7. What concept does the slope of a velocity-time graph represent?
8. If the best-fit line on a velocity-time graph passes through all the plotted data, what does this indicate about the acceleration of the object?
9. A ball is thrown straight up into the air. On its way up, its acceleration is downward. Explain what observation proves this.
10. For constant acceleration, state the relationship between acceleration, change in velocity, and time interval.
11. A brick and a $5 bill are dropped from the same height. In the absence of air resistance, describe the motion of these two falling objects.
12. Near the surface of Earth, what is the magnitude and direction of the acceleration due to gravity?

Understanding Key Ideas

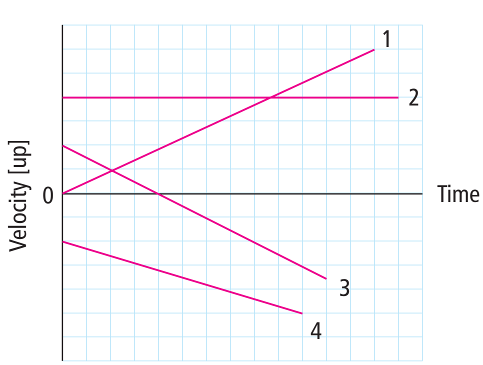
13. A girl riding her bike at 9 m/s [N] slows down to 5 m/s [N]. What is the girl's change in velocity?
14. A ball travelling west at 5 m/s strikes a wall and rebounds to the east at 3 m/s.
    (a) What is the ball's change in velocity?
    (b) What is the direction of the ball's acceleration?
15. Describe the direction of the acceleration for each of the situations shown in the photographs below.

16. The velocity of a jogger is recorded in the table below. If forward is positive (+), state during which 5.0 s time interval the jogger's acceleration was:
(a) positive (+)
(b) negative (−)
(c) zero

Time (s)	0	5	10	15
Velocity (m/s [forward])	7	4	5	5

17. An object has an acceleration of 0 m/s^2. Does this mean that the object must be stationary? Explain.

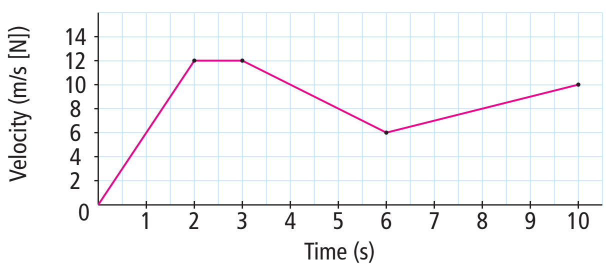
18. Use the following graph to match the correct line to the descriptions given.
(a) initially travelling up, accelerating to a stop, and then increasing its speed downward
(b) starting from rest and accelerating upward
(c) initially travelling down and increasing its speed in the downward direction
(d) travelling upward with a constant speed



19. A skateboarder on a half-pipe changes his velocity from 6.0 m/s forward to 4.0 m/s backward in 5.0 s. What is the acceleration of the skateboarder?

20. How much time does it take to accelerate from 32 m/s [W] to 56 m/s [W] if the acceleration is 3.0 m/s^2 [W]?

21. Use the velocity-time graph below to calculate the acceleration during each of the following time intervals.
(a) 0.0 s−2.0 s
(b) 2.0 s−3.0 s
(c) 3.0 s−6.0 s
(d) 6.0 s−10.0 s



Applying Your Understanding

22. Peregrine falcons are the fastest-diving birds in the world. In fact, the peregrine falcon is the fastest animal on the planet in its hunting dive, called a stoop, in which it soars to heights of 600 m and then dives steeply towards its prey. During a stoop, the peregrine falcon folds its wings and makes its body shape as streamlined as possible, reducing air resistance to almost zero. A peregrine falcon dives with its talons closed and strikes its prey in mid-air, knocking it unconscious with a single blow. Then, as the prey falls through the air, the peregrine falcon circles back and picks its unconscious prey out of the air with its talons. Starting from rest at an altitude of 600 m, a peregrine falcon was clocked diving at 320 km/h.
(a) What was its final velocity in m/s?
(b) Assuming air resistance is negligible, how much time does it take the falcon to reach this top speed?
(c) Sketch a velocity-time graph that shows the dive. Let downward velocity be negative.

Pause and Reflect

When have you experienced rapid changes in velocity? How did they affect you? Describe your experiences.

Unit Summary

8 Average velocity is the rate of change in position.

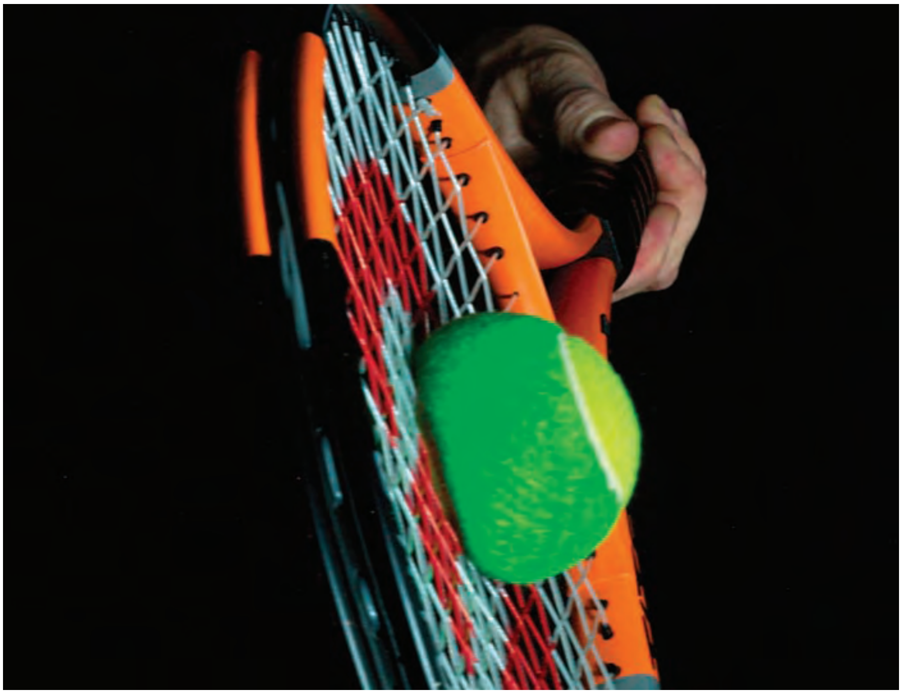
- Vector quantities, such as displacement and velocity, have both a magnitude and a direction. (8.1)
- An object in uniform motion will travel equal displacements in equal time intervals. (8.1)
- An object in uniform motion is represented as a straight line on a position-time graph. (8.1)
- Average velocity is the rate of change in position. (8.2)
- Average velocity is calculated by $\vec{v}_{av} = \frac{\Delta \vec{d}}{\Delta t}$. (8.2)
- The slope of the line on a position-time graph is average velocity. (8.2)

9 Acceleration is the rate of change in velocity.

- Acceleration is the rate of change in velocity. Change in velocity is calculated by $\Delta \vec{v} = \vec{v}_f - \vec{v}_i$. (9.1)
- When an object's velocity and acceleration are in the same direction, the object's speed increases. When an object's velocity and acceleration are in opposite directions, the object's speed decreases. (9.1)
- Zero acceleration means that the object is moving at a constant velocity. (9.1)
- The slope of a velocity-time graph is average acceleration. (9.2)
- The relationship between acceleration, change in velocity, and time interval is given by $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$. (9.2)
- In the absence of air resistance, the acceleration due to gravity near the surface of Earth is 9.8 m/s^2 downward. (9.2)

Key Terms

- average velocity
- displacement
- distance
- position
- position-time graph
- scalars
- slope
- speed
- uniform motion
- vectors
- velocity



Key Terms

- acceleration
- acceleration due to gravity
- air resistance
- average acceleration
- change in velocity
- constant acceleration
- deceleration
- gravity
- velocity-time graph

Project

Walk That Graph

In this activity, you will use words and movements to represent the motion shown on graphs.

Problem

How can you represent the motion shown on position-time graphs and velocity-time graphs?

Suggested Materials

- motion sensor
- data collection device, such as computer or graphing calculator (Option A)
  or
- long tape measure (Option B)
- stopwatch (Option B)

Visit **www.bcscience10.ca** for examples of starting data for your graphs.

Criteria

- Use words to describe the motion shown on a position-time graph and a velocity-time graph.
- Use movements to represent the motion shown on a position-time graph and a velocity-time graph.

Procedure

1. Your teacher will provide you with several position-time and velocity-time graphs that represent different types of motion.
2. Analyze the graphs, and record the motion each represents. Your analysis of a position-time graph may include statements like "Walk forward 1.5 m with uniform motion for 2.0 s, then remain stationary for 1.0 s, then walk backward 1.0 m with uniform motion for 2.0 s." Your analysis of the velocity-time graphs may include statements like "Accelerate forward for 2.0 s, then stay at a constant velocity of 3.0 m/s for another 2.0 s, then decelerate back to zero velocity, in the final 3.0 s." Discuss your analysis of each graph with a classmate.

Option A Using a Motion Sensor and Data Collection Device

3A. With one of the graphs displayed, turn on the motion sensor, and represent the motion shown on the graphs by moving toward and away from the motion sensor.

4A. Repeat step 3A for velocity-time graphs.

Option B Using a Tape Measure and Stopwatch

3B. To represent the motion on a position-time graph, place a long tape measure on the floor. Identify positions on your graph where the uniform velocity changed. Mark these identified positions on the floor by using a beanbag or other visible object. For example, if your graph starts with a constant positive slope and at 3.0 m the slope changes, then you should mark the 3.0 m forward location on the floor.

4B. With the graph displayed, position yourself at the starting location on the tape. Have your partner start the stopwatch and verbally count out the seconds. Represent the motion shown by the graph. Your arrival at the marked locations at the correct time will be an indication of your accuracy.

5B. Repeat steps 3B and 4B for velocity-time graphs. To represent the motion on a velocity-time graph, find a location in your room that has lots of open space. With the graph displayed, have your partner start the stopwatch and verbally count out the seconds. Represent the motion that you have discussed with your partner. Repeat this step for the remaining velocity-time graphs.

Report Out

1. Which graph, position-time or velocity-time, was harder to represent? Provide an explanation giving reasons for your choice.

The Physics of Sports and Human Motion

The world around you is in constant motion. For instance, in dance the human body changes motion. In sports, not only the human body changes motion—so does a ball, puck, discus, or javelin. In this activity, you will choose a segment of a particular sport or dance and analyze the motion involved.

Background

An analysis of any sport over the past 50 years will indicate that modern athletes are moving faster, throwing farther, and jumping higher. Some of this improvement is due to better nutrition, but much of it is due to a better understanding of the motions involved. By analyzing particular motions, we have been able to design better training programs and also improve technique. Information gathered by scientists has allowed the design of equipment that has increased performance and improved safety.

Kinesiologists are scientists who study human motion. Whether it is the motion of the body or the motion of the object involved in the sport, kinesiologists analyze displacement, velocity, acceleration, and time intervals.

Find Out More

Choose a particular sport or dance that you are familiar with. By analyzing video, pictures, simulations, or data, you should be able to discuss in both words and diagrams the motion involved. Use the Internet, encyclopedias, books, or other sources to analyze your selected motion. You can start your search at **www.bcscience10.ca**.

Report Out

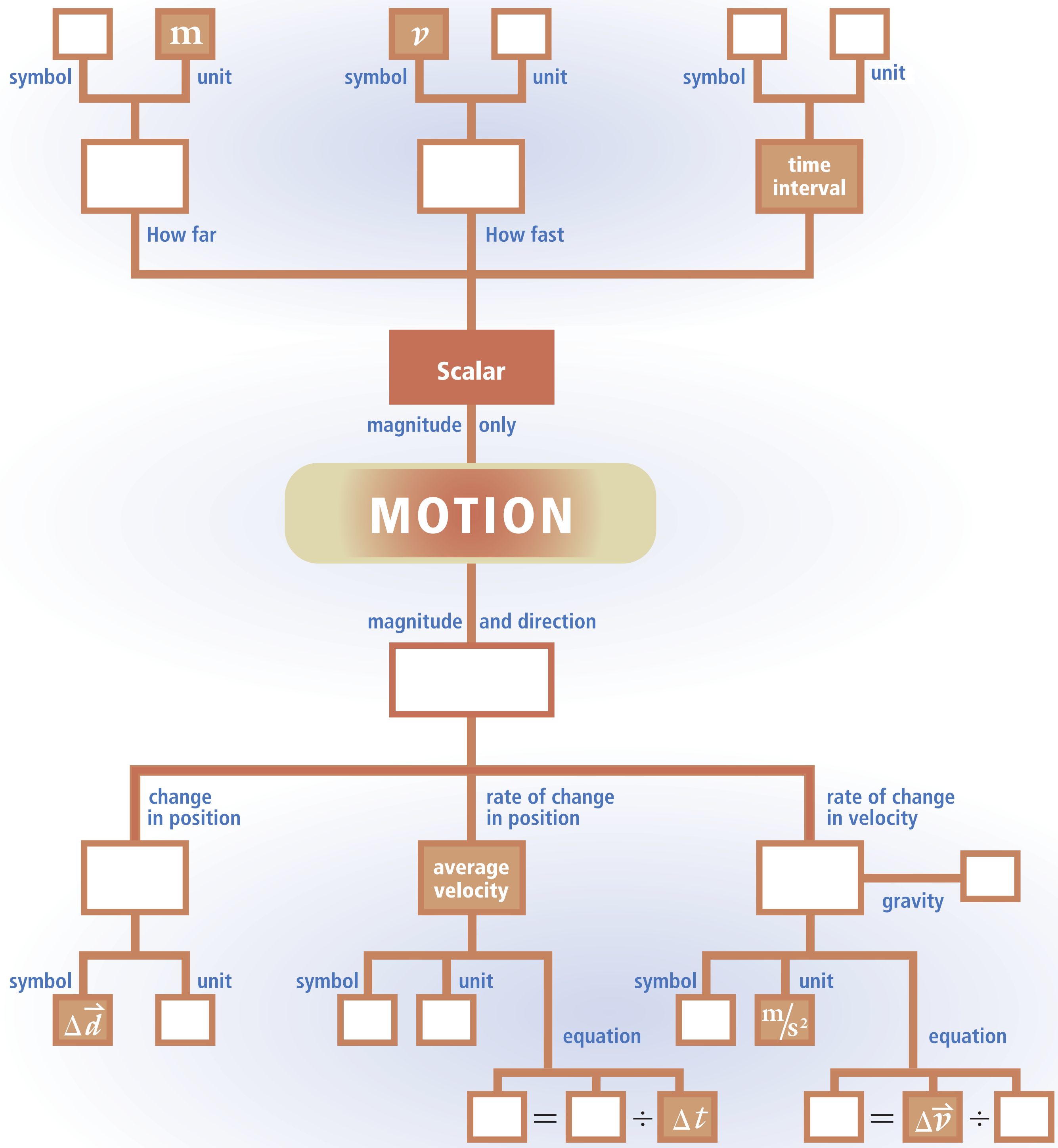
1. Create a presentation to explain the results of your research. Your presentation could include:
   - an analysis of the particular motion (displacement, velocity, acceleration, time interval)
   - a description of the methods used by kinesiologists to gather their data
   - a video of the selected sport or human motion
   - a comparison of motions used in your sport that are common to other sports
   - a description of the clothing and/or equipment worn for your sport and how its design allows for improved performance
2. Investigate the injuries associated with the particular motion you chose, and suggest ways of reducing the risk of injury.

A high jumper changes her motion as she travels over the bar.

Improvements to the design of body suits and skates have helped to increase average speed.

Visualizing Key Ideas

1. Copy and complete the following concept map about motion.



Using Key Terms

2. In your notebook, state whether the following statements are true or false. If a statement is false, rewrite it to make it true.
   (a) Uniform motion is represented by a straight line on a position-time graph.
   (b) Average velocity is the rate of change in distance.
   (c) Direction is not needed when calculating displacement.
   (d) The slope of a position-time graph is average acceleration.
   (e) A time interval can be calculated by subtracting the initial time from the final time.
   (f) If the direction of the velocity is opposite the direction of the acceleration, the object will speed up.
   (g) The slope of a velocity-time graph is average velocity.
   (h) An object with uniform motion has equal displacements in equal time intervals.
   (i) A change in velocity is always positive.
   (j) The rate of change in velocity is called acceleration.
   (k) In the absence of air resistance, all objects near the surface of Earth fall with the same acceleration.

Checking Concepts

8

3. Describe how a vector quantity is different from a scalar quantity.
4. Classify each of the following as vectors or scalars:
   (a) velocity
   (b) time
   (c) displacement
   (d) 35 km/h [E]
   (e) 14 m
   (f) 32 m forward
5. What term is used to describe final time minus initial time?
6. Express displacement in terms of initial and final position.
7. Positive (+) and negative (−) are used to express opposite directions for vector quantities. Copy and complete the following table in your notebook.

Direction	Left	Right	Up	Down	North	South	East	West
Sign			+			−		

8. Copy and complete the following table in your notebook.

Term	Symbol	SI Unit	Unit Symbol
Time interval			s
Displacement		Metre	
	$\vec{v}$		

9. An object travels 1.2 m forward in 3.0 s. If the object's motion is uniform, what is its displacement during the next 3.0 s time interval?
10. How is uniform motion represented on a position-time graph?
11. If a positive slope on a position-time graph represents the object travelling east, describe the motion of the object if the slope is:
   (a) negative
   (b) zero
12. On a position-time graph, what quantity does the slope represent?
13. What is the mathematical relationship of average velocity, displacement, and time interval?
14. What are two common units used for velocity?

9

15. Describe how to calculate an object's change in velocity.
16. A ball is rolling with a positive velocity. Describe what happens to the velocity of the ball if its change in velocity is:
   (a) positive
   (b) negative
   (c) zero

17. What is another term used to describe an acceleration that is opposite the direction of motion?
18. Suppose a motorcycle's change in velocity is 15 m/s [S]. What is the direction of the motorcycle's acceleration?
19. The direction of a car's initial velocity is given a negative (−) sign. If the car slows down, what sign (+ or −) would the acceleration have?
20. What does the slope of a velocity-time graph represent?
21. State the mathematical relationship of acceleration, change in velocity, and time interval.
22. Describe the effect of air resistance on falling objects.
23. What is the value of acceleration due to gravity near the surface of Earth?

Understanding Key Ideas

24. Describe a situation in which the magnitude of the displacement is equal to the distance travelled.
25. A tennis ball, initially travelling at 20 m/s, is hit by a racket and leaves the racket at 20 m/s. Explain how there is a change in velocity even though the initial and final speed of the ball is the same.
26. Two sprinters, initially at rest, start to race and reach a forward velocity of 9 m/s. Explain how it is possible for the two sprinters to have different accelerations.
27. Copy the following data table into your notebook. For each row, indicate if the acceleration is positive (+), negative (−), or zero.

Initial Velocity (m/s)	Final Velocity (m/s)	Acceleration + or − or zero
+3.6	+1.6	
−4.0	+1.0	
−5.0	−5.0	
−4.0	−6.0	
+2.5	0.0	

28. A rock and a table tennis ball are held above the surface of the Moon (which has no air resistance). Describe the motion of the two objects when they are released.
29. Identify which of the following situations are accelerated motion.
    (a) a runner poised at the starting line
    (b) the runner speeding up at the start of the race
    (c) the runner travelling at a steady speed around a corner (changing direction)
    (d) the runner slowing down after passing the finish line
30. What is the meaning of each of the following features of a velocity-time graph if forward velocity is given a positive (+) sign?
    (a) a horizontal section of the graph
    (b) an inclined (slanted) section of the graph
    (c) a line above the horizontal axis
    (d) a line below the horizontal axis
    (e) a point where the line crosses the horizontal axis

Thinking Critically

31. In a bicycle race of several laps around a circular track, which is more meaningful: the average speed of a cyclist or the average velocity of the cyclist? Explain your answer.
32. When you plot a graph based on experimental data, the points seldom lie exactly on a straight line. Sometimes, however, the points can be used to indicate the position of a best-fit line.
    (a) Why do scientists draw a best-fit line instead of joining the points exactly?
    (b) What are the disadvantages of drawing a best-fit line?
33. (a) How are velocity and acceleration similar?
    (b) How are velocity and acceleration different?

34. A speed skater starts a race with an initial velocity of zero. She speeds up, travels at a constant speed, slows down, and ends up with a final velocity of zero.
   (a) What is the skater's overall change in velocity?
   (b) What is her average acceleration during the race?

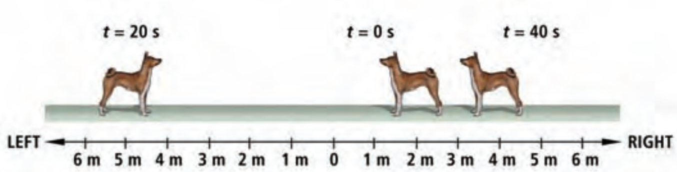
Developing Skills

35. Copy and complete the table below in your notebook. Let positive (+) represent motion to the right.

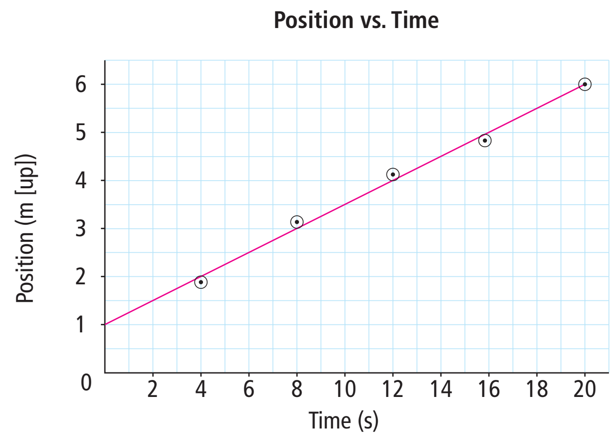
t_i (s)	t_f (s)	Δt (s)	d_i (m)	d_f (m)	Δd (m)	Direction of Motion [left or right]
5.0	6.5		+17.3	+20.0		
	8.3	2.1	+26.9		+5.3	
0.0		105.4		+26.8	−15.4	

36. Copy and complete the following table in your notebook. Use the illustration below to help you.

Time Interval	Displacement (m [left or right])	Distance (m)
0 s–20 s		
20 s–40 s		
0 s–40 s		



37. Examine the position-time graph below. Identify or calculate each of the following quantities.
   (a) direction of motion
   (b) initial position
   (c) final position
   (d) displacement
   (e) time interval



Applying Your Understanding

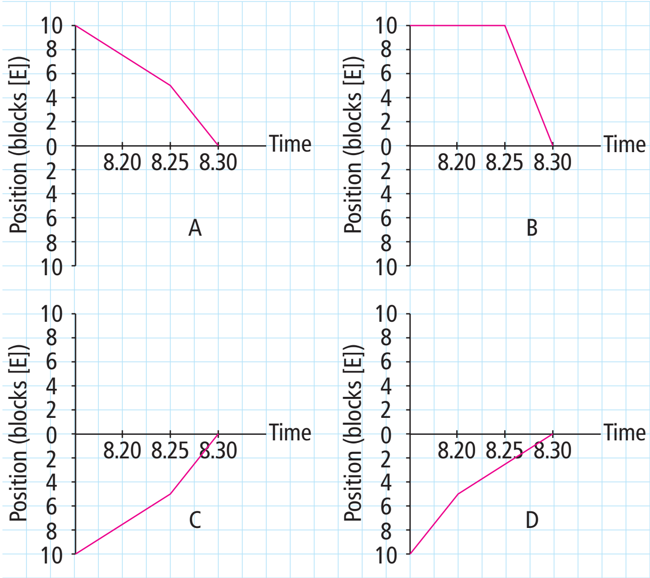
38. A new world acceleration record for electrically powered motorcycles was set in 1999 by a motorcycle that started from rest and took 14.57 s to reach a maximum forward velocity of 18.3 m/s (almost 66 km/h).What was the motorcycle's average acceleration during the 14.57 s?
   A. 0.796 m/s²
   B. 1.26 m/s²
   C. 4.53 m/s²
   D. 9.8 m/s²

39. In 1999, the most powerful production car in the world (a McLaren F1) could reach a speed of 26.8 m/s (over 96 km/h) from a standing start in just 3.2 s. What was the car's average acceleration?
   A. 0.50 m/s²
   B. 3.2 m/s²
   C. 8.4 m/s²
   D. 30 m/s²

Use the following information to answer questions 40 and 41.

Jan lives ten blocks west from his school, which starts at 8:30 A.M. One day he leaves his house at 8:15 A.M. He walks steadily until 8:25 A.M., when he has five blocks left to cover. He speeds up and jogs the rest of the way at a uniform pace, arriving just as the bell rings. Assume that each block is 150 m long.

40. Which of the following position-time graphs best represents Jan's motion?



41. What is Jan's average velocity for the entire trip?
A. 0.67 m/s [east]
B. 0.67 m/s [west]
C. 1.7 m/s [east]
D. 1.7 m/s [west]

42. An athlete on an interval training program alternates jogging forward 100 paces, which takes 41 s, and walking forward 50 paces, which takes 27 s. Each jogging pace is 0.90 m long, and each walking pace is 0.60 m long. What is the average velocity over the entire 68 s?
A. 1.1 m/s [forward]
B. 1.8 m/s [forward]
C. 2.2 m/s [forward]
D. 3.3 m/s [forward]

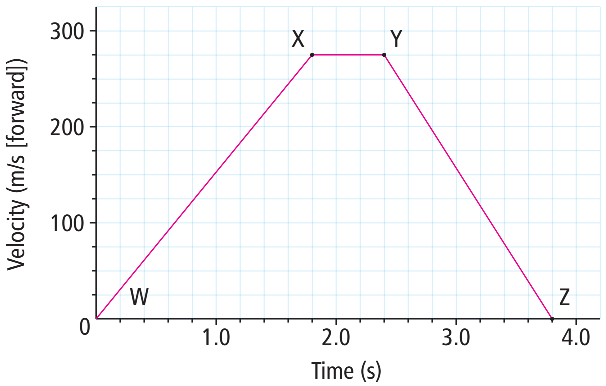
43. An activity that is similar to bungee jumping occurs in the New Hebrides Islands. Divers jump from a platform with a vine tied to their ankles. After falling freely for 1.5 s, they reach a velocity of 15 m/s downward. The vine halts their fall just above the ground, stopping them in a few milliseconds with an acceleration of 1070 m/s^2 upward. What is the time that the divers take to stop?
A. 0.014 s
B. 1.5 s
C. 10 s
D. 71 s

44. The fastest flying insect is the Australian dragonfly. It can reach a forward velocity of 16 m/s (58 km/h). If an Australian dragonfly maintained its maximum velocity for 7.8 s, what would be its displacement?
A. 2.1 m [forward]
B. 120 m [forward]
C. 250 m [forward]
D. 450 m [forward]

45. The horsefly can fly forward 250 m in about 23 s. What is a horsefly's maximum flying velocity?
A. 1.5 m/s [forward]
B. 2.5 m/s [forward]
C. 11 m/s [forward]
D. 16 m/s [forward]

Use the following information to answer questions 46 to 48.

U.S. Air Force colonel John Stapp took several dozen test rides on a rocket-driven sled in the early 1950s. After reaching a maximum forward velocity of over 1000 km/h on a 2 km track, the sled hit a long trough of water, which slowed it very rapidly. The graph below shows a typical sled run.



46. Which of the following correctly describes the motion of the sled in each interval?

		Interval	
	W to X	**X to Y**	**Y to Z**
A.	Moving forward with a constant velocity	Zero velocity	Moving backward with a decreasing velocity
B.	Moving backward with a constant velocity	Zero velocity	Moving backward with an increasing velocity
C.	Moving forward with a constant acceleration	Constant velocity	Moving forward with a decreasing velocity
D.	Moving backward with a constant acceleration	Constant velocity	Moving forward with a decreasing velocity

47. What is the acceleration of the sled in the intervals between W and X?
A. 150 m/s^2 [forward]
B. 150 m/s^2 [backward]
C. 275 m/s^2 [forward]
D. 275 m/s^2 [backward]

48. What is the acceleration of the sled in the intervals between Y and Z?
A. 200 m/s^2 [forward]
B. 200 m/s^2 [backward]
C. 275 m/s^2 [forward]
D. 275 m/s^2 [backward]

Use the following information to answer questions 49 to 51.

A baseball pitcher, who is standing 18.5 m from the batter, throws a fastball moving at 40 m/s (over 140 km/h). The batter swings, contacts the ball for 0.03 s, and hits the ball straight back to the pitcher at 50.0 m/s. Assume air resistance has little effect over the short distance that the ball travels, so the velocities are constant.

49. How long does the ball take to reach the batter?
A. 0.13 s
B. 0.37 s
C. 0.46 s
D. 2.2 s

50. What is the ball's change in velocity when it is hit?
A. 10 m/s [toward the pitcher]
B. 10 m/s [away from the pitcher]
C. 90 m/s [toward the pitcher]
D. 90 m/s [away from the pitcher]

51. What is the ball's average acceleration while it is being hit?
A. 330 m/s^2 [toward the pitcher]
B. 330 m/s^2 [away from the pitcher]
C. 3000 m/s^2 [toward the pitcher]
D. 3000 m/s^2 [away from the pitcher]

Pause and Reflect

Suppose you had to explain to a friend, who has never studied physics, the difference between uniform motion and accelerated motion. List the key points of your explanation.