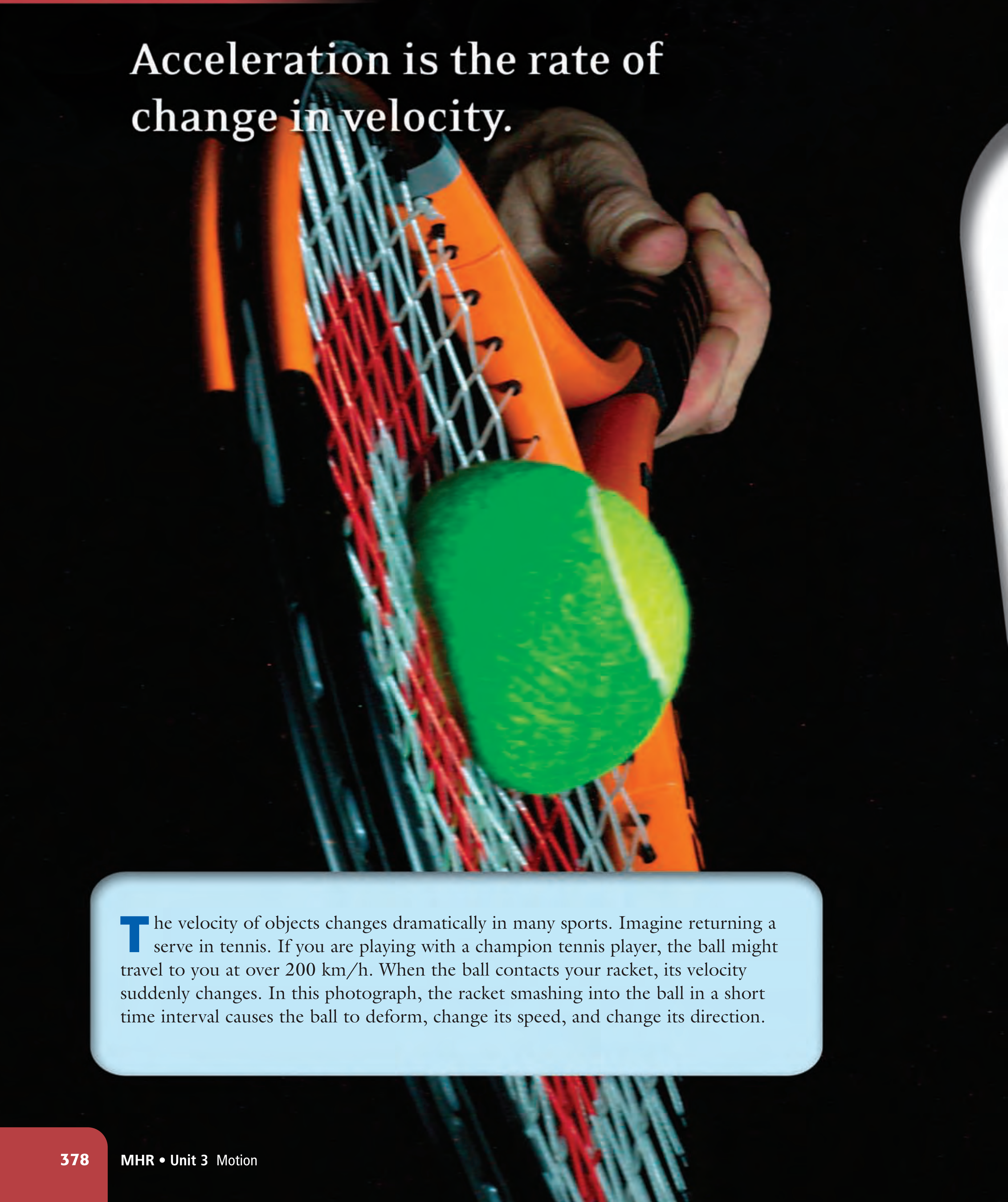
Acceleration is the rate of change in velocity.



The velocity of objects changes dramatically in many sports. Imagine returning a serve in tennis. If you are playing with a champion tennis player, the ball might travel to you at over 200 km/h. When the ball contacts your racket, its velocity suddenly changes. In this photograph, the racket smashing into the ball in a short time interval causes the ball to deform, change its speed, and change its direction.

What You Will Learn

In this chapter, you will
- **define** acceleration
- **demonstrate** the relationship of velocity, time interval, and acceleration
- **determine** acceleration given initial velocity, final velocity, and time interval
- **distinguish** and give examples of positive, negative, and zero acceleration

Why It Is Important

To understand motion, it is important to investigate objects whose velocity is changing. Many living things—including you—change their velocity, speeding up and slowing down many times each day.

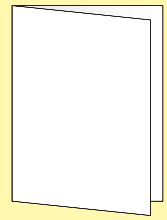
Skills You Will Use

In this chapter, you will
- **measure** velocity and time using appropriate equipment
- **graph** the relationship between velocity and time
- **calculate** using $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$
- **demonstrate** respect for precision

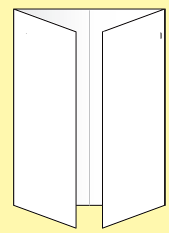
FOLDABLES™
Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 9.

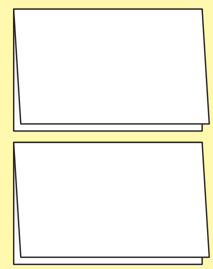
STEP 1 **Fold** a sheet of paper (28 cm by 43 cm) in half lengthwise but instead of creasing the paper, pinch it to show the midpoint.



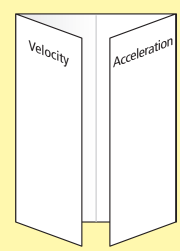
STEP 2 **Flatten** the paper, and **fold** the outer edges of the paper to meet at the pinch, or midpoint, forming a shutterfold.



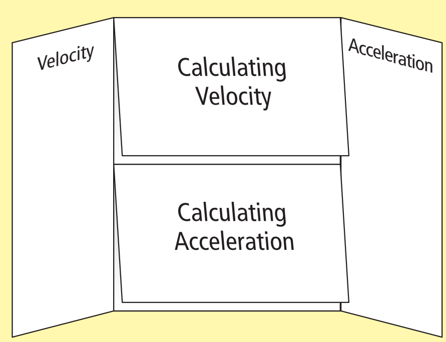
STEP 3 **Fold** two sheets of paper (22 cm by 28 cm) to create two half-books. **Glue** (or staple) them onto the interior centre section. **Use** these half-books to practise calculating velocity and acceleration.



STEP 4 **Label** one exterior tab "Velocity" and the other "Acceleration."



STEP 5 **Label** the interior tabs as shown. As you progress through the chapter, **record** information and take notes under the appropriate tab.



9.1 Describing Acceleration

Acceleration is the rate of change in velocity. A change in velocity is calculated by subtracting the initial velocity from the final velocity. If an object's acceleration is in the same direction as its velocity, the object's speed increases. If an object's acceleration is in the opposite direction to its velocity, the object's speed decreases. Zero acceleration means that the object is moving at a constant velocity.

Words to Know

acceleration
change in velocity
deceleration

The countdown begins. At lift-off time (T) minus 6.6 s, the main engines of the space shuttle are started, one after the other. At T minus 0 s, the solid rocket boosters are ignited and the space shuttle begins its voyage into space (Figure 9.1). The power output needed to launch the space shuttle is 30 times greater than the maximum power output of British Columbia's largest dam.

The space shuttle's motion is not uniform. Within 60 s of launching, the space shuttle is travelling at 350 m/s and is 16 km above Earth. During the next 60 s, the space shuttle increases its speed by over 1200 m/s and travels an additional 30 km away from Earth's surface. In order to launch the space shuttle correctly, scientists need to be able to analyze and predict motion that is changing in speed and direction.

Did You Know?

When astronauts such as Bjarni Tryggvason of British Columbia are orbiting Earth in a space shuttle, they are travelling at 8 km/s. At this speed, it would take less than 10 min to travel across Canada.

Figure 9.1 A space shuttle is one of the most complex machines ever built. During lift-off, the space shuttle's velocity continuously increases until it reaches a speed of over 27 000 km/h.

internet connect

To find out more about the motion of a space shuttle, go to **www.bcscience10.ca**.

9-1A What Is Happening to This Motion?

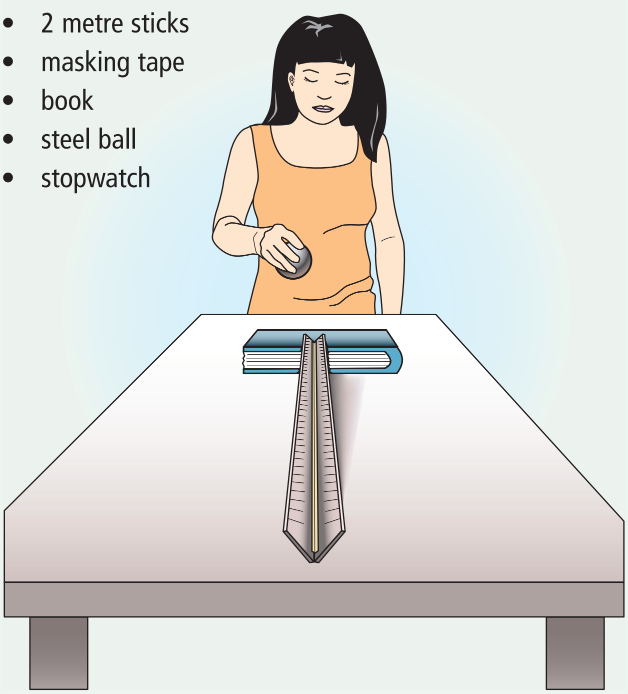
Find Out ACTIVITY

An object travelling with uniform motion has equal displacements in equal time intervals.

In this activity, you will investigate the motion of a ball rolling down a ramp. You will then analyze your data to examine the basis for determining whether the motion has equal displacements in equal time intervals.

Materials

- 2 metre sticks
- masking tape
- book
- steel ball
- stopwatch



What to Do

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

Displacement (cm [down the ramp])	Time (s)				
	Predicted Time	Trial 1	Trial 2	Trial 3	Average Time
50					
100					
Average time to travel from 0 cm to 50 cm = __________					
Average time to travel from 50 cm to 100 cm = _________					

2. Tape two metre sticks together along their edges to make a V-shaped channel. Set up one end of the metre sticks on a book so that they act a ramp.
3. Predict how much time it would take the ball to roll 50 cm. Record your prediction in your data table.
4. Release the steel ball from 0 cm so that it rolls down the ramp. Using a stopwatch, measure the time it takes to roll 50 cm. Record the time in your data table. Repeat twice more, and average your result of the three trials.
5. Write a sentence describing the motion of the ball.
6. Predict how much time it would take the ball to roll 100 cm. Record your prediction.
7. Release the steel ball from 0 cm so that it rolls down the ramp. Using a stopwatch, measure the time it takes to roll 100 cm. Record the time in your data table. Repeat twice more, and average your results of the three trials.
8. Determine the time it takes the ball to travel from 50 cm to 100 cm by subtracting your average time in step 4 from your average time in step 7. Record this time.
9. Clean up and put away the equipment you have used.

What Did You Find Out?

1. How does the time it took the ball to roll 0 cm to 50 cm compare to the time it took the ball to roll 50 cm to 100 cm?
2. Was the ball's motion down the ramp uniform? Explain, using the data you obtained.

Positive and Negative Changes in Velocity

A **change in velocity** ($\Delta\vec{v}$) occurs when the speed of an object changes, or its direction of motion changes, or both (Figure 9.2). Changes in velocity can be classed as either positive or negative. To find a change in velocity, subtract the initial velocity ($\vec{v}_i$) from the final velocity ($\vec{v}_f$).

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

Positive changes in velocity

Suppose you are riding a bicycle travelling forward at 6 m/s. You need to get somewhere in a hurry, so you increase your velocity to 9 m/s forward. You would calculate your change in velocity as shown below. In this example, + represents the forward direction.

$$\begin{aligned}\Delta\vec{v} &= \vec{v}_f - \vec{v}_i\\ &= +9\ \text{m/s} - (+6\ \text{m/s})\\ &= +3\ \text{m/s}\end{aligned}$$

The change in velocity is 3 m/s in the forward direction. In other words, you are speeding up by 3 m/s in the original direction. Your initial forward direction is *positive*, so your change in velocity is *positive* when you speed up.

Figure 9.2 Cyclists riding in the middle of a pack have to be very careful when they make changes to their velocity.

Negative changes in velocity

Suppose as you are riding you apply the brakes to slow down. If you slow down from 9 m/s forward to 2 m/s forward, your change in velocity is

$$\begin{aligned}\Delta\vec{v} &= \vec{v}_f - \vec{v}_i\\ &= +2\ \text{m/s} - (+9\ \text{m/s})\\ &= -7\ \text{m/s}\end{aligned}$$

Your change in velocity is 7 m/s opposite the forward motion. In other words, you are slowing down by 7 m/s in the original direction. Your initial forward direction is *positive*, so your change in velocity is *negative* when you slow down.

Constant velocity

If you were to pedal at a constant velocity, your initial and final velocities would be equal. Therefore, the change in velocity for that time interval would be zero. Any object travelling with uniform motion in a straight line would have zero change in velocity.

9-1B Change in Velocity

Think About It

In this activity, you will analyze data for an object's velocity at given times. You will then calculate the object's change in velocity for specified time intervals.

What to Do

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

Time (s)	0	20	40	60	80	100
Velocity (m/s [forward])	11	16	18	18	14	11

2. Calculate the change in velocity ($\Delta\vec{v}$) for each of the following time intervals. Let the forward direction represent positive (+) velocity.
   (a) 0 s–20 s
   (b) 20 s–40 s
   (c) 40 s–60 s
   (d) 60 s–80 s
   (e) 80 s–100 s

What Did You Find Out?

1. During which of the 20 s time intervals was the object speeding up?
2. During which of the 20 s time intervals was the object slowing down?
3. During which of the 20 s time intervals was the change in velocity zero?

Non-Uniform Motion

You can feel the difference between motion that is nearly uniform and motion that is changing in speed or direction. Imagine that you are riding on a roller coaster. The chain pulls the roller coaster car up the first hill with a constant velocity and relatively uniform motion. If you closed your eyes, it would feel as though you were hardly moving at all (Figure 9.3A). Once the cars of the roller coaster have travelled over the top of the first hill, your velocity quickly increases as you travel down the other side of the hill. Whether your eyes are open or closed, you know your motion is changing. For the rest of the ride, your velocity keeps on changing as the roller coaster car turns in different directions and speeds up and slows down. You feel pushed and pulled from side to side and forward and backward (Figure 9.3B).

Figure 9.3A Passengers have a smooth ride with relatively uniform motion.

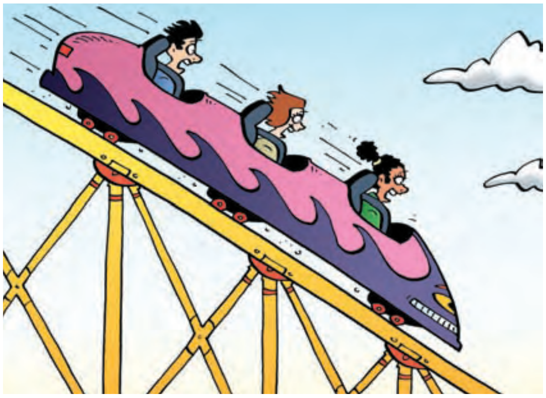


Figure 9.3B Passengers feel pushed and pulled as the velocity of the roller coaster car changes.

Did You Know?

A cheetah can run short distances at speeds greater than 90 km/h. What is even more impressive is that it can accelerate from 0 to 70 km/h in less than 2 s.

Acceleration

The rate at which an object changes its velocity is called **acceleration**. Another way to say this is that acceleration is a way of calculating how the velocity of a moving object changes. Velocity is a vector, so it has two parts: the speed at which the object is moving and also the direction in which the object is moving. A change in velocity can be a change in either speed or direction (Figure 9.4). When we talk about acceleration, we need to include the magnitude of the change in the velocity of the moving object. We also need to indicate the change in direction of the object's velocity.

Figure 9.4 A predator needs to accelerate quickly and make rapid changes in velocity.

Comparing acceleration

There is more to accelerating than just changing velocity. Imagine two cars are going to have a race (Figure 9.5). One car is a powerful dragster. The other is an old car. This race is not about how fast the cars can go but instead about how quickly they can get to a forward velocity of 60 km/h. Even though both cars will have the same change in velocity, the dragster will be able to change velocity faster and therefore will have a greater acceleration. When comparing the acceleration of two objects, the object with the greater acceleration changes its velocity in a shorter time interval or has a greater change in velocity during the same time interval.

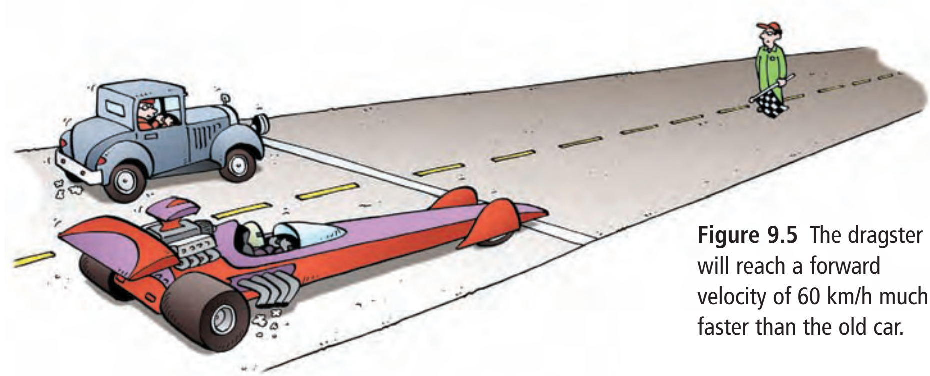


Figure 9.5 The dragster will reach a forward velocity of 60 km/h much faster than the old car.

Suggested Activity

Find Out Activity 9-1C on page 387

Reading Check

1. What two aspects of motion can change when velocity changes?
2. What is the definition of acceleration?
3. How can you tell which of two objects has the greater acceleration?

Positive and Negative Acceleration

Whenever the velocity of an object changes, its motion is not uniform, and we say that the object is accelerating. Acceleration occurs when the speed of an object changes, or its direction of motion changes, or both.

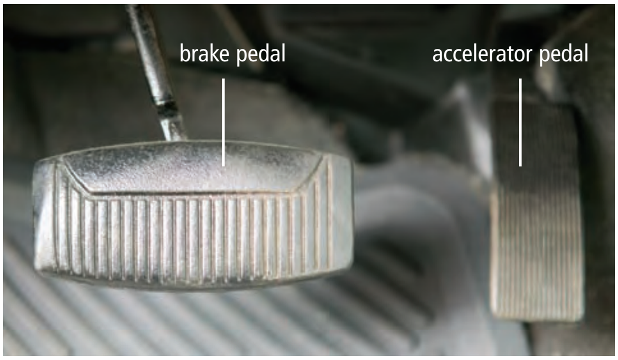


Figure 9.6 A more common name for the accelerator pedal is the gas pedal.

Positive acceleration

When you think of acceleration, you probably think of something speeding up. However, an object that is slowing down is also changing its velocity and therefore is accelerating. In straight-line motion, acceleration can be either positive or negative.

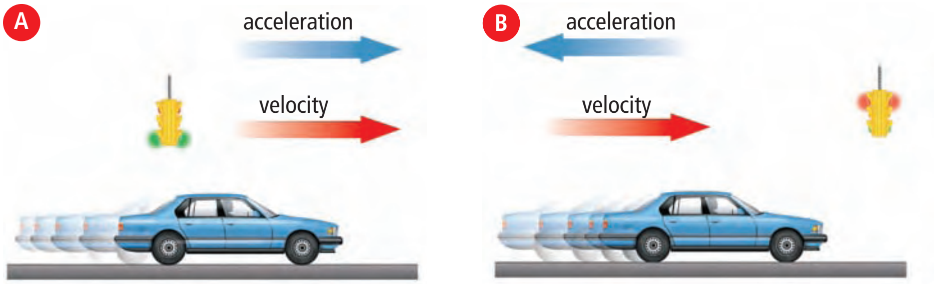
Imagine you are driving along a straight, level road at 40 km/h. Since your velocity is constant, you are travelling with a relatively uniform motion and passengers in your car will be experiencing a smooth ride. If you need to speed up to 60 km/h, you must press on the accelerator pedal (Figure 9.6). Suppose the forward motion of the car is represented as positive (+). When the car's speed is *increasing*, the car has a *positive* acceleration.

Negative acceleration

If you need to slow down, you press on the brake pedal (Figure 9.6). Again, suppose the forward motion of the car is represented as positive (+). When the car's speed is *decreasing*, the car has a *negative* acceleration.

Acceleration is the rate of change in velocity. Therefore, the direction of the acceleration is the same direction as the change in velocity. If an object's acceleration is in the same direction as its velocity, the object's speed increases (Figure 9.7A). If the acceleration is in an opposite direction to its velocity, the object's speed decreases (Figure 9.7B). Acceleration that is opposite to the direction of motion is sometimes called **deceleration** (Figure 9.8 on the next page).

Figure 9.7 The speed of both cars is changing, so they are both accelerating.



If forward motion is represented as positive, the speed of this car is increasing so the car has positive acceleration (A).

If forward motion is represented as positive, the speed of this car is decreasing so the car has negative acceleration (B).

Figure 9.8 A parachute reduces the landing run of a space shuttle, reducing wear on the brakes and providing increased directional stability.

Direction

Positive (+) and negative (−) acceleration are also dependent upon the direction of an object's motion. Suppose a car driving forward increases its velocity from 2 m/s to 6 m/s (Figure 9.9A). If forward motion is positive (+), then the change in velocity would be +4 m/s. Because the change in velocity is positive (+), which represents forward, the acceleration must also be forward.

Suggested Activity

Conduct an Investigation 9-1D on page 388

Figure 9.9A Since the car speeds up in a forward direction, its sign is positive (+).

Suppose that a different car is increasing its speed going backward (Figure 9.9B). If we define forward motion as positive (+), then backward motion must be negative (−). If the car's velocity as it travels backward changes from −1 m/s to −4 m/s, the change in velocity would be −3 m/s. Because the change in velocity is negative (−), which represents backward, the direction of the change in velocity, and therefore acceleration, must also be backward.

Explore More

Find out more about the effects of acceleration on the human body. Start your search at **www.bcscience10.ca**.

Figure 9.9B Since the car speeds up in a backward direction, its sign is negative (−).

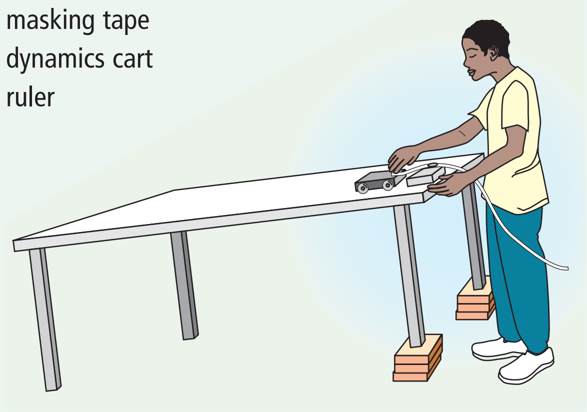
9-1C Accelerated Motion

Find Out ACTIVITY

In this activity, you will analyze accelerated motion using a recording timer and ticker tape.

Materials

- lab table
- several books or other flat objects
- C-clamp
- recording timer
- ticker tape
- masking tape
- dynamics cart
- ruler



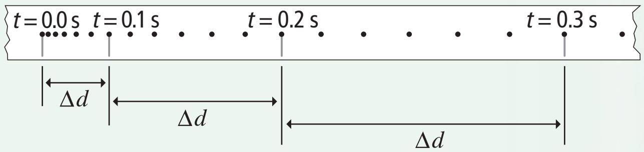
Step 3

What to Do

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

Time interval (s)	0.0 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
Displacement (cm/s)								
Average velocity (cm/s [forward])								

2. Raise one end of a lab table 10 cm to 15 cm by placing several books or other flat objects under the back legs.
3. Use the C-clamp to fasten a recording timer to the raised end of the table. Cut a piece of ticker tape 1 m long. Insert the ticker tape into the timer, and use the masking tape to attach the ticker tape to the back of a dynamics cart.
4. Hold the dynamics cart stationary next to the timer and release it after the timer is turned on. Have a partner catch the cart before it falls off the table.
5. Draw a line through the first dot on the tape and label it $t = 0.0$ s. Count six dots from the $t = 0.0$ s line, and draw another line through the sixth dot. Label this line $t = 0.1$ s. Measure the distance between these two lines, and record this value in the table as the displacement during the time interval $t = 0.0$ to $t = 0.1$ s.



An example of how to mark the ticker tape

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. Record this value as the displacement during the time interval $t = 0.1$ to $t = 0.2$ s.
7. Continue measuring and recording the displacements for each of the time intervals in your data table.
8. Using the equation $\vec{v}_{av} = \frac{\Delta\vec{d}}{\Delta t}$, calculate the average velocity for each of the 0.1 s time intervals. Record these values in your data table.
9. Clean up and put away the equipment you have used.

What Did You Find Out?

1. Use a sentence to describe how the spacing of the dots for the accelerated motion is different from the spacing of the dots you would expect for uniform motion.
2. As the cart moved down the incline, how did the displacement of the cart change for each of the 0.1 s time intervals?
3. As the cart moved down the incline, how did the average velocity of the cart change for each of the 0.1 s time intervals?

9-1D The Direction of Acceleration

Conduct an INVESTIGATION

Inquiry Focus

Skill Check

- Observing
- Measuring
- Controlling variables
- Evaluating information

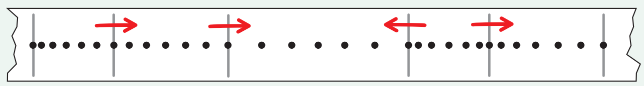
Materials

- 2 m of ticker tape
- recording timer
- C-clamp

We usually define forward motion of an object as positive (+). If an object increases its forward velocity, the acceleration would also be positive (+), which means it is accelerating forward. If the object slows down in its forward motion, then the acceleration is backward or negative (−). In this activity, you will analyze acceleration by comparing average velocity during equal time intervals. Remember, for equal time intervals, greater displacements represent greater average velocity.

Question

How is acceleration represented on a motion diagram created by a recording timer?



An example of how to mark the ticker tape

Procedure

1. Use the C-clamp to fasten the timer to the end of the table. Cut a 2 m length of ticker tape and insert it into the recording timer.
2. Turn on the recording timer, and pull approximately 1.5 m of the tape through the timer with non-uniform motion. Make sure that the speed you pull the tape increases and decreases several times during the time you are pulling.
3. Turn off the timer.
4. Using a pencil, draw a line through the first dot on the tape.
5. Draw a line through every sixth dot all the way along the tape.
6. Make a sketch of the ticker tape in your notebook.
7. Clean up and put away the equipment you have used.

Analyze

1. The displacement for each of these equal time intervals is proportional to the average velocity that the tape was being pulled. If the interval distance is increasing, then the average velocity of the tape is increasing. This indicates the tape is accelerating in the direction of motion. If the interval distance is decreasing, then the average velocity of the tape is also decreasing. This indicates either the tape is accelerating or the direction of the acceleration is opposite the direction of the velocity. Draw an arrow indicating the direction of the acceleration for successive time intervals.

Conclude and Apply

1. Explain why some of the acceleration arrows point in different directions.
2. Turn your ticker tape so that it is backward. Analyze the acceleration arrows that you have marked on your tape. Are they still correct? Explain.

Wild, Weird, Wonderful

www Science

The Motion of a Falling Object

Our understanding of science helps us find answers to real world problems. But you can also use your scientific knowledge to analyze the world of science fiction. Many of our superheroes possess powers and perform stunts that appear out of the ordinary. But does this mean that these feats are not scientifically possible? Mostly science fiction is fantasy, but many times the writers of science fiction get it right. Not only do these fantasy characters sometimes use scientific principles, they also behave like true scientists and learn from their mistakes.

Spider-Man was first introduced in comic books in 1962. After being bitten by a radioactive spider, Peter Parker gains the attributes of a spider, including the ability to shoot a web from his wrist. These spider abilities allow him to save people from villains such as the Green Goblin.

One such event was portrayed in a 1973 Spider-Man comic. Spider-Man's girlfriend, Gwen Stacy, is pushed off a 100 m high tower by the Green Goblin. To save her life, Spider-Man shoots a web that attaches to her ankle. The web stops the girl before she hits the ground, but unfortunately the deceleration is too large for her to survive.

After falling 80 m, Gwen would have a downward velocity of approximately 140 km/h. To safely come to a stop from this velocity, she would need a time interval greater than 1.0 s. Spider-Man's web slowed her down too quickly to come to a stop safely.

Spider-Man learned from his mistake. In the Spider-Man movie of 2002, the Green Goblin pushes Mary Jane Watson from the top of a tall bridge. This time, Spider-Man does not shoot a web to stop her fall. Instead, he dives after the falling girl. Since his initial downward velocity is greater than her initial velocity, he can catch up to her. Once he catches her, he shoots a web to a nearby building and they swing to safety. By swinging to safety, they slow down over a long period of time. This is much the same as slowing down while on a playground swing. Spider-Man was able to save Mary Jane due to understanding the concept of acceleration. In the real world, scientists have used this understanding of acceleration to increase passenger safety in automobiles.

Even a superhero needs to understand the physics of motion.

Science Watch

Human Acceleration

In the late 1940s, there was an increasing emphasis on speed in transportation. Refinements to the design of the jet plane had allowed it to reach speeds of more than 700 km/h. Grand Prix race cars were travelling at more than 150 km/h. However, the faster speeds came with a huge cost: crashes at these speeds were usually fatal due to the large acceleration experienced by pilots, drivers, and passengers.

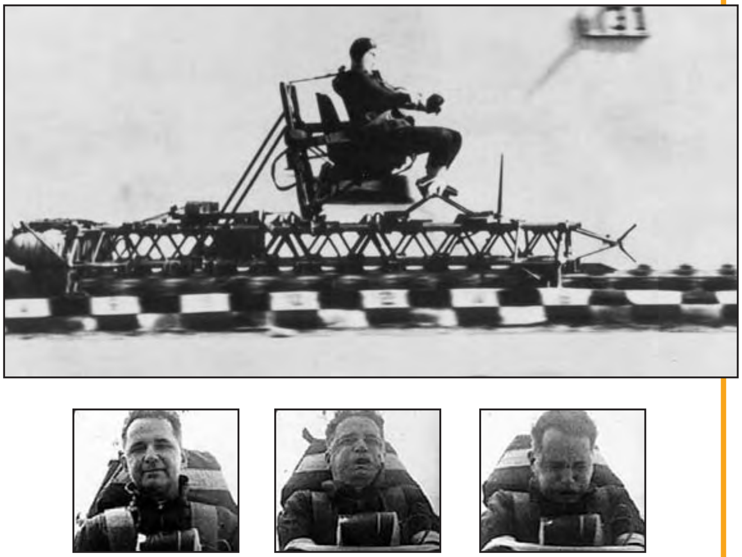
Colonel John Stapp (1910–1999) was a pioneer in studying the effects of acceleration on the human body. He was called "the fastest man on Earth." Colonel Stapp did most of his research at Edwards Air Force Base, in California, where he was stationed as a medical doctor.

Back in 1947, scientists did not have computers and complex crash-test dummies to use in analyzing accelerations on humans. In order to do his research, Stapp subjected himself to large accelerations. Acceleration of 1 g (g is the symbol for the value of the acceleration due to gravity) is equivalent to the acceleration of an object dropped near the surface of Earth. It was believed that an acceleration of more than 18 g (176 m/s^2) would cause death, but Stapp experienced up to 46 g (451 m/s^2) and survived.

The results of John Stapp's research are evident in today's safety features. Stapp was dedicated to safety and took every opportunity to support the use of safety belts in cars. The lap belts and shoulder straps in cars today are a result of Stapp's research. Stapp also discovered that humans can withstand a larger acceleration when riding backward than when riding forward. This finding has led to infant seats being positioned facing backward in the rear seats of cars.

John Stapp even made an impact on our language. You may have heard of Murphy's law, which states "If anything can go wrong, it will." Murphy was a test engineer working with Stapp on his experiments.

In one of the first rides on the "human decelerator," Stapp was fitted with 16 accelerometers placed on various parts of his body. Unfortunately, all 16 were mounted backward. After the very uncomfortable acceleration, no measurements were recorded due to the backward sensors, making Stapp's effort wasted. In future experiments, Stapp was famous for always trying to consider everything that could possibly go wrong before undertaking the experiment.



The "human decelerator" consisted of 610 m of railway track stretching across the air base. Rockets propelled the 680 kg carriage. Once the carriage was moving fast enough, a 14 m long braking system, the most powerful ever constructed, was controlled to stop the passenger with a calculated acceleration.

Questions

1. What was the purpose of John Stapp's research?
2. What maximum acceleration did John Stapp withstand?
3. What modern safety features resulted from John Stapp's research?

Checking Concepts

1. Describe two ways to change the velocity of a moving car.
2. (a) Define "acceleration."
   (b) Define "deceleration."
3. In terms of initial velocity ($\vec{v}_i$) and final velocity ($\vec{v}_f$), how is change in velocity ($\Delta\vec{v}$) determined?
4. Determine the change in velocity of a car that starts at rest and has a final velocity of 20 m/s [N].
5. How are the direction of an object's acceleration and the direction of the same object's change in velocity related?
6. Suppose motion toward the east is positive (+). Is the acceleration positive, negative, or zero for each of the following situations?
   (a) slowing down while travelling east
   (b) travelling with a constant velocity west
   (c) increase in speed while travelling east
   (d) increase in speed while travelling west
   (e) decrease in speed while travelling west

Understanding Key Ideas

7. Given the following data, calculate the change in velocity ($\Delta\vec{v}$) for the following time intervals. Let motion to the north represent positive (+) velocity.
   (a) 0 s–5 s
   (b) 5 s–10 s
   (c) 10 s–15 s
   (d) 15 s–20 s
   (e) 20 s–25 s

Time (s)	Velocity (m/s [N])
0	0
5	8
10	12
15	12
20	15
25	9

8. (a) If the acceleration is in the same direction as the velocity, what happens to the speed of an object?
   (b) If the acceleration is in the opposite direction to the velocity, what happens to the speed of an object?
9. A car travelling forward at 25.0 m/s stops and backs up at 4.0 m/s.
   (a) What is the car's change in velocity?
   (b) What is the direction of the car's acceleration?
10. Describe the direction of the acceleration for each of the following situations.

A Sliding in to home plate

B Starting the race

Pause and Reflect

Give an example from your own life of two objects that can accelerate to the same speed but have different accelerations. Explain why their accelerations are different.

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

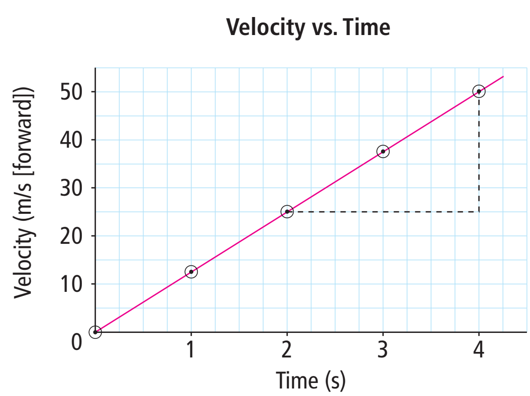
When you plot the data from Table 9.1 on a graph, you can create a best-fit line (Figure 9.11). You can then find the slope of the line to determine the rate at which the roller coaster's velocity is changing. This graph shows the slope as:

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

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 $13\ \text{m/s}^2$, which means that the roller coaster's velocity increased in the forward direction by 13 m/s every 1.0 s.

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.



$$\begin{aligned}\text{slope} &= \frac{\text{rise}}{\text{run}}\\ &= \frac{50\ \text{m/s} - 25\ \text{m/s}}{4.0\ \text{s} - 2.0\ \text{s}}\\ &= \frac{25\ \text{m/s}}{2.0\ \text{s}}\\ &= 13\ \text{m/s}^2\end{aligned}$$

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.

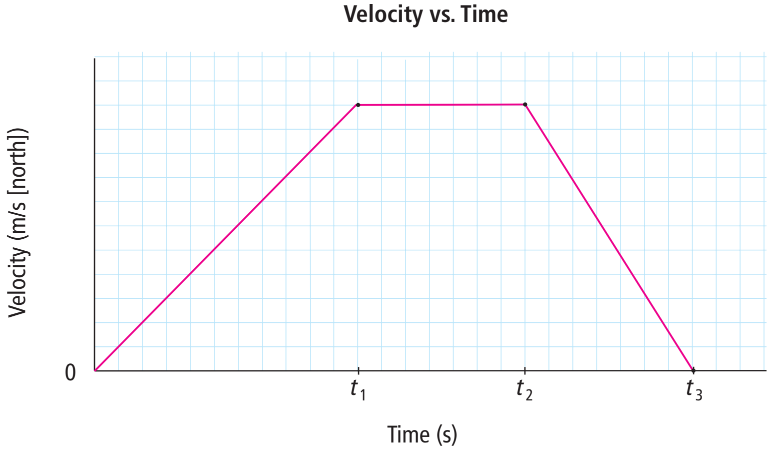


Figure 9.12 The graph shows motion with positive acceleration (0 to t_1), zero acceleration (t_1 to t_2), and negative acceleration (t_2 to t_3).

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

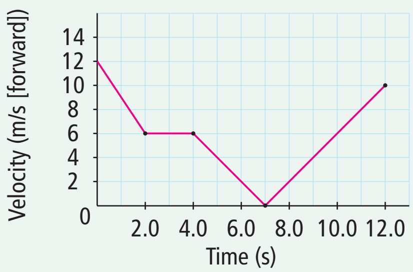
Think About It

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.

Velocity vs. Time



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

Calculating Acceleration

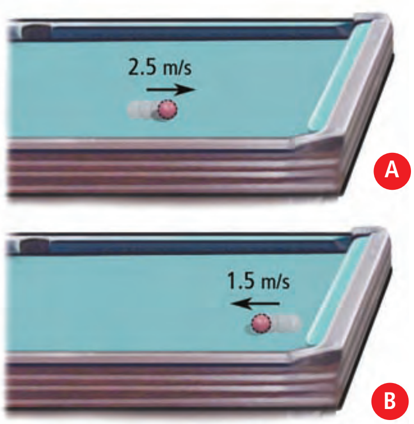


Figure 9.13 The ball's velocity changes from 2.5 m/s toward the cushion (A) to 1.5 m/s away from the cushion (B) in a time interval of 0.20 s.

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?

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

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/s^2 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/s^2 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/s^2 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/s^2?

Answers

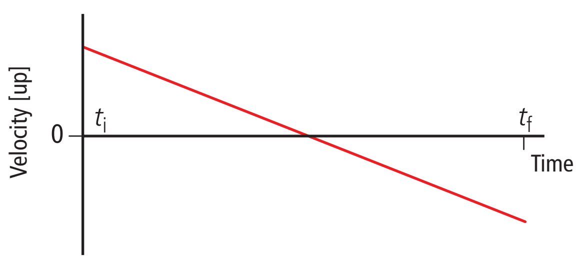
1. 3.0 m/s^2 [E]
2. 3.0 m/s forward
3. 5.0 s

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.



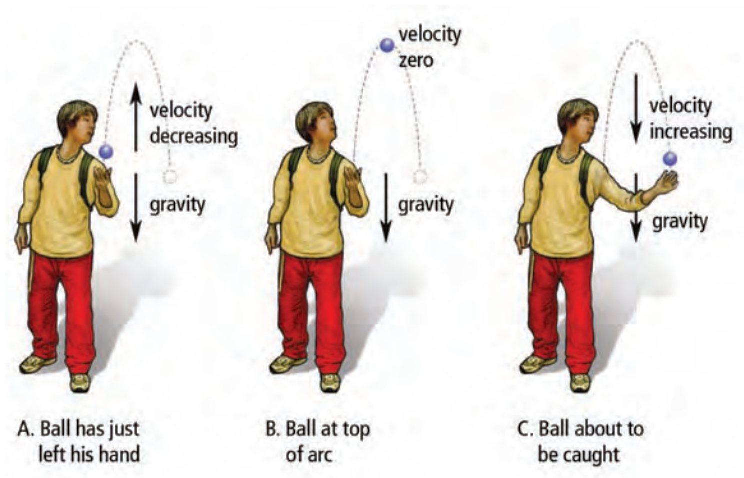


Figure 9.14 Even though the speed of the ball decreases on its way up and increases on its way down, the acceleration is always toward the ground.

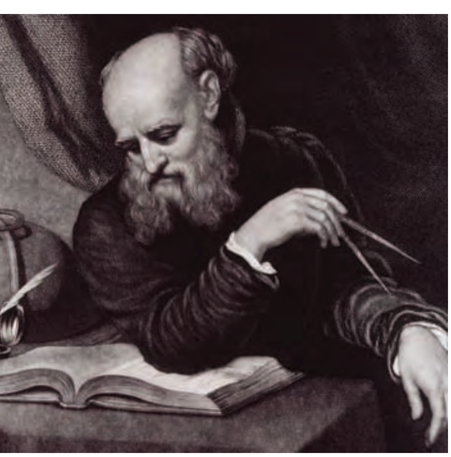


Figure 9.15 Galileo Galilei (1564–1642) is often referred to as the "father of modern science."

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).

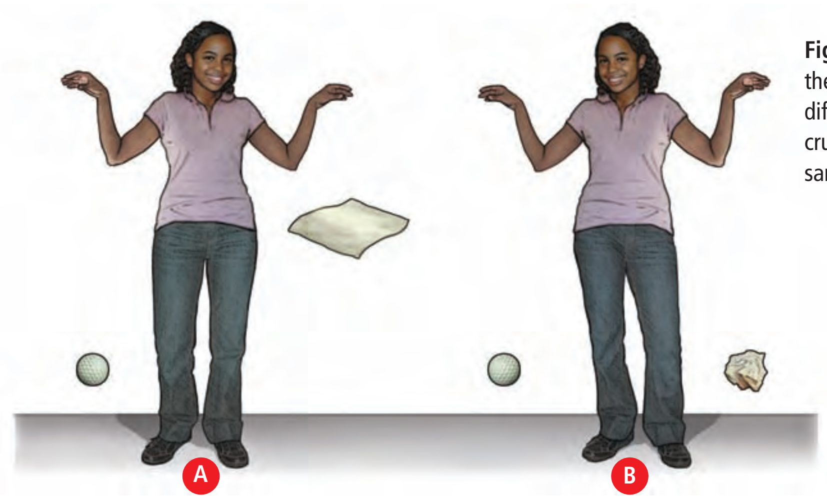


Figure 9.16 The baseball and the sheet of paper fall at different rates (A). When crumpled, the paper falls at the same rate as the baseball (B).

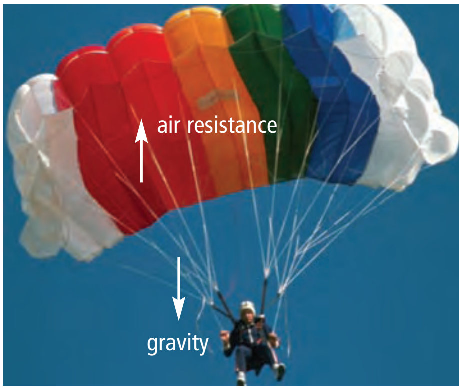


Figure 9.17 The air resistance force on an open parachute is much greater than the air resistance on a sky diver with a closed parachute. With the parachute open, the velocity of the sky diver becomes small enough that the sky diver can land safely.

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 $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$, 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 (−).

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

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 (+).

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

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

Suggested Activity

Conduct an Investigation 9-2D on page 402

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?

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

Skill Check

- Observing
- Measuring
- Controlling variables
- Graphing

Materials

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

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.

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

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])										

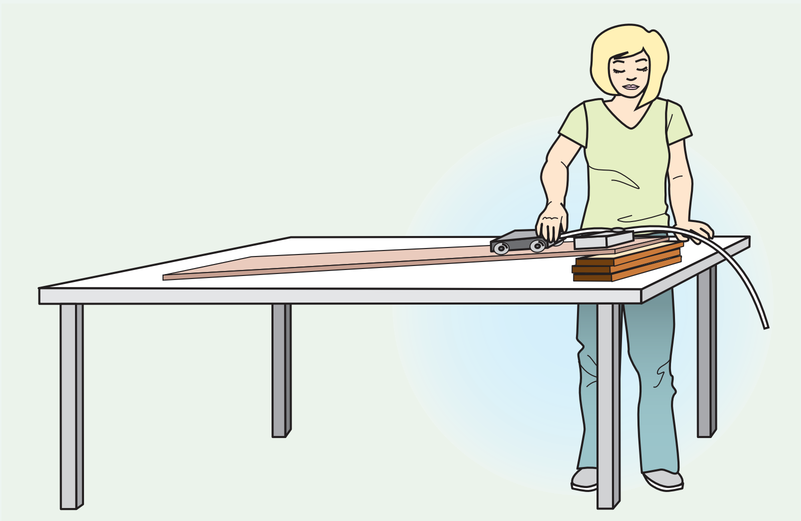
2. Place the dynamics cart at the top of the ramp. Cut a piece of ticker tape that is about 30 cm shorter than the length of your ramp. Insert the ticker tape into the recording timer and fasten the ticker tape to the cart with the masking tape.
3. Turn on the recording timer and release the cart. Be 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.

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.



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

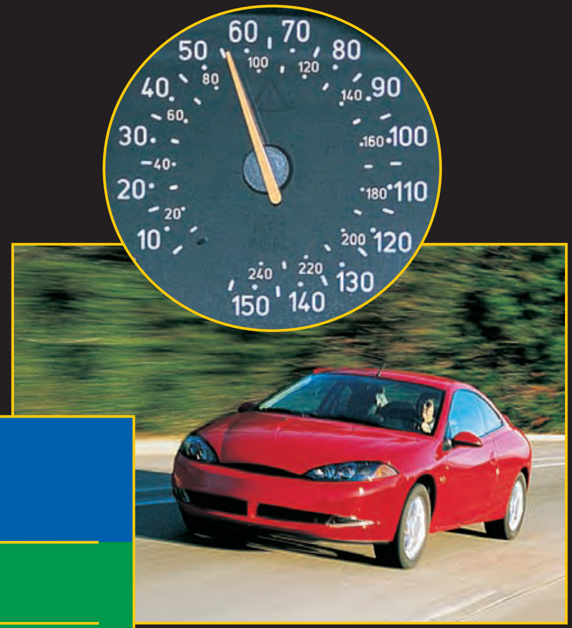
1. If you were to repeat your experiment with a steeper ramp, how would the slope of the new motion compare with the original slope? Explain your answer.

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

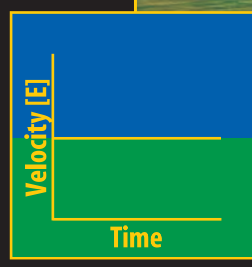
NATIONAL GEOGRAPHIC

Visualizing Acceleration

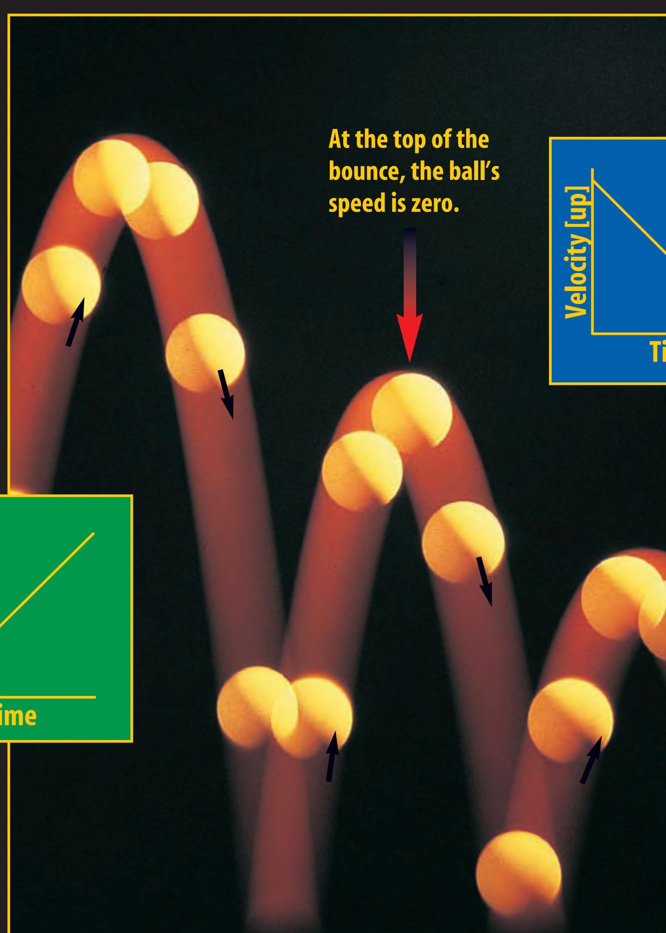
Acceleration can be positive, negative, or zero depending on the direction the object is travelling and whether the object is speeding up, slowing down, or moving at a constant speed. If the velocity of an object is plotted on a graph, with time along the horizontal axis, the slope of the line is related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

Check Your Understanding

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 ($\Delta\vec{v}$), and time interval (Δt)?
6. In the absence of air resistance, what is the magnitude and direction of the acceleration due to gravity near the surface of Earth?

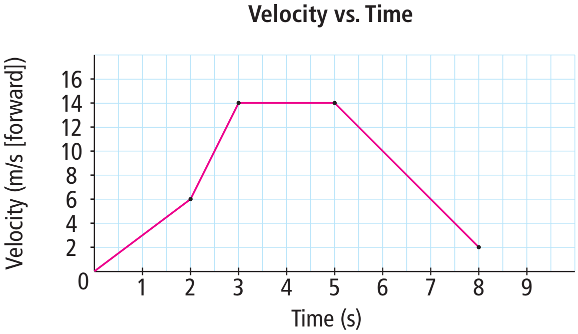
Use the diagram below to help you answer question 7.

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 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

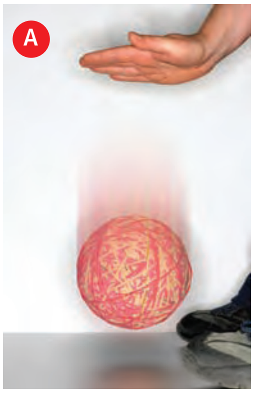
1. Given the initial and final velocity of a car, describe how to find the change in velocity.
2. (a) Define "acceleration."
   (b) What is the SI unit for acceleration?
3. How does the direction of the change in velocity compare to the direction of the acceleration?
4. Describe an object's motion:
   (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.


A


B


C

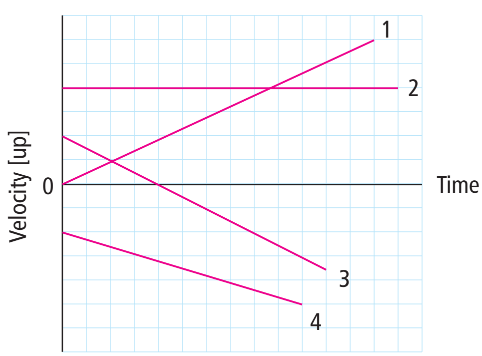
16. The velocity of a jogger is recorded in the table below. If forward is positive (+), state during which 5.0 s time interval the jogger's acceleration was:
(a) positive (+)
(b) negative (−)
(c) zero

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

Velocity vs. Time

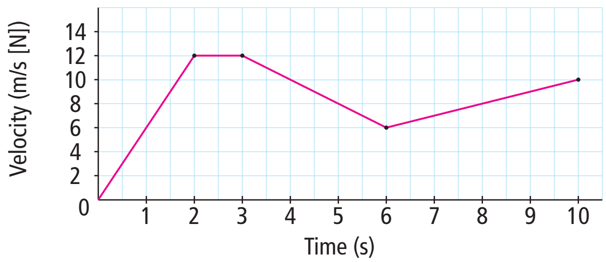


19. A skateboarder on a half-pipe changes his velocity from 6.0 m/s forward to 4.0 m/s backward in 5.0 s. What is the acceleration of the skateboarder?

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

Velocity vs. Time



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.