chapter 1

Motion and Momentum

The BIG Idea

The motion of an object can be described by its velocity.

SECTION 1
What is motion?
Main Idea Motion is a change in position.

SECTION 2
Acceleration
Main Idea Acceleration occurs when an object speeds up, slows down, or changes direction.

SECTION 3
Momentum
Main Idea In a collision, momentum can be transferred from one object to another.

Springing into Action

The hunt might just be over for this pouncing leopard. A leopard can run as fast as 60 km/h over short distances and can jump as high as 3 m. However, a leopard must be more than fast and strong. To catch its prey, it must also be able to change its speed and direction quickly.

Science Journal Describe how your motion changed as you moved from your school's entrance to your classroom.

Brian Snyder/Reuters Newmedia Inc/Corbis

Start-Up Activities

Launch LAB

Motion After a Collision

How is it possible for a 70-kg football player to knock down a 110-kg football player? The smaller player usually must be running faster. Mass makes a difference when two objects collide, but the speed of the objects also matters. Explore the behavior of colliding objects during this lab.

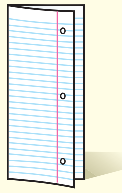
1. Space yourself about 2 m away from a partner. Slowly roll a baseball on the floor toward your partner, and have your partner roll a baseball quickly into your ball.
2. Have your partner slowly roll a baseball as you quickly roll a tennis ball into the baseball.
3. Roll two tennis balls toward each other at the same speed.
4. **Think Critically** In your Science Journal, describe how the motion of the balls changed after the collisions, including the effects of speed and type of ball.

Science Online: Preview this chapter's content and activities at bookm.msscience.com

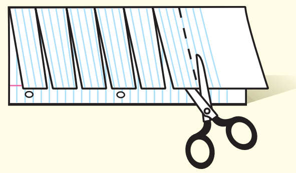
FOLDABLES™ Study Organizer

Motion and Momentum Make the following Foldable to help you understand the vocabulary terms in this chapter.

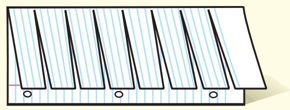
STEP 1 **Fold** a vertical sheet of notebook paper from side to side.



STEP 2 **Cut** along every third line of only the top layer to form tabs.



STEP 3 **Label** each tab.



Build Vocabulary As you read the chapter, list the vocabulary words about motion and momentum on the tabs. As you learn the definitions, write them under the tab for each vocabulary word.

Brian Snyder/Reuters Newmedia Inc/Corbis

Get Ready to Read

Summarize

1 Learn It! Summarizing helps you organize information, focus on main ideas, and reduce the amount of information to remember. To summarize, restate the important facts in a short sentence or paragraph. Be brief and do not include too many details.

2 Practice It! Read the text on page 21 labeled *Conservation of Momentum.* Then read the summary below and look at the important facts from that passage.

Important Facts

- A collision doesn't change the total momentum of a group of objects.
- Friction is an outside force that causes the total momentum to decrease.
- Objects can bounce off each other when they collide.
- Objects can stick together when they collide.

Summary

The total momentum of a group of objects remains constant unless an outside force acts on the objects.

3 Apply It! Practice summarizing as you read this chapter. Stop after each section and write a brief summary.

Reading Tip

Reread your summary to make sure you didn't change the author's original meaning or ideas.

Target Your Reading

Use this to focus on the main ideas as you read the chapter.

1. **Before you read** the chapter, respond to the statements below on your worksheet or on a numbered sheet of paper.
   - Write an **A** if you **agree** with the statement.
   - Write a **D** if you **disagree** with the statement.

2. **After you read** the chapter, look back to this page to see if you've changed your mind about any of the statements.
   - If any of your answers changed, explain why.
   - Change any false statements into true statements.
   - Use your revised statements as a study guide.

Before You Read A or D	Statement		After You Read A or D
	1	Distance traveled and displacement are always equal.	
	2	When an object changes direction, it is accelerating.	
	3	A horizontal line on a distance-time graph means the speed is zero.	
	4	If two objects are moving at the same speed, the heavier object is harder to stop.	
	5	The instantaneous speed of an object is always equal to its average speed.	
	6	Momentum equals mass divided by velocity.	
	7	Speed always is measured in kilometers per hour.	
	8	An object's momentum increases if its speed increases.	
	9	If a car is accelerating, its speed must be increasing.	
	10	Speed and velocity are the same thing.	

Science Online

Print out a worksheet of this page at bookm.msscience.com

section 1

What is motion?

as you read

What You'll Learn

- **Define** distance, speed, and velocity.
- **Graph** motion.

Why It's Important

The different motions of objects you see every day can be described in the same way.

Review Vocabulary

meter: SI unit of distance, abbreviated m; equal to 39.37 in

New Vocabulary

- speed
- average speed
- instantaneous speed
- velocity

Matter and Motion

All matter in the universe is constantly in motion, from the revolution of Earth around the Sun to electrons moving around the nucleus of an atom. Leaves rustle in the wind. Lava flows from a volcano. Bees move from flower to flower as they gather pollen. Blood circulates through your body. These are all examples of matter in motion. How can the motion of these different objects be described?

Changing Position

To describe an object in motion, you must first recognize that the object is in motion. Something is in motion if it is changing position. It could be a fast-moving airplane, a leaf swirling in the wind, or water trickling from a hose. Even your school, attached to Earth, is moving through space. When an object moves from one location to another, it is changing position. The runners shown in **Figure 1** sprint from the start line to the finish line. Their positions change, so they are in motion.

Figure 1 These sprinters are in motion because their positions change.

Relative Motion Determining whether something changes position requires a point of reference. An object changes position if it moves relative to a reference point. To visualize this, picture yourself competing in a 100-m dash. You begin just behind the start line. When you pass the finish line, you are 100 m from the start line. If the start line is your reference point, then your position has changed by 100 m relative to the start line, and motion has occurred. Look at **Figure 2.** How can you determine that the dog has been in motion?

Reading Check *How do you know if an object has changed position?*

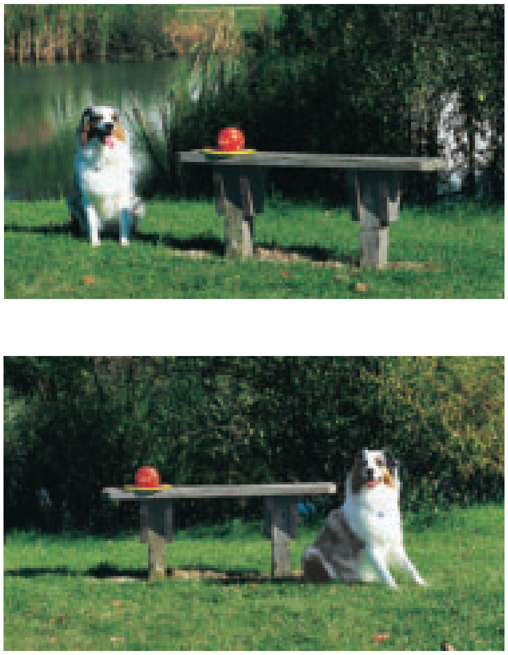
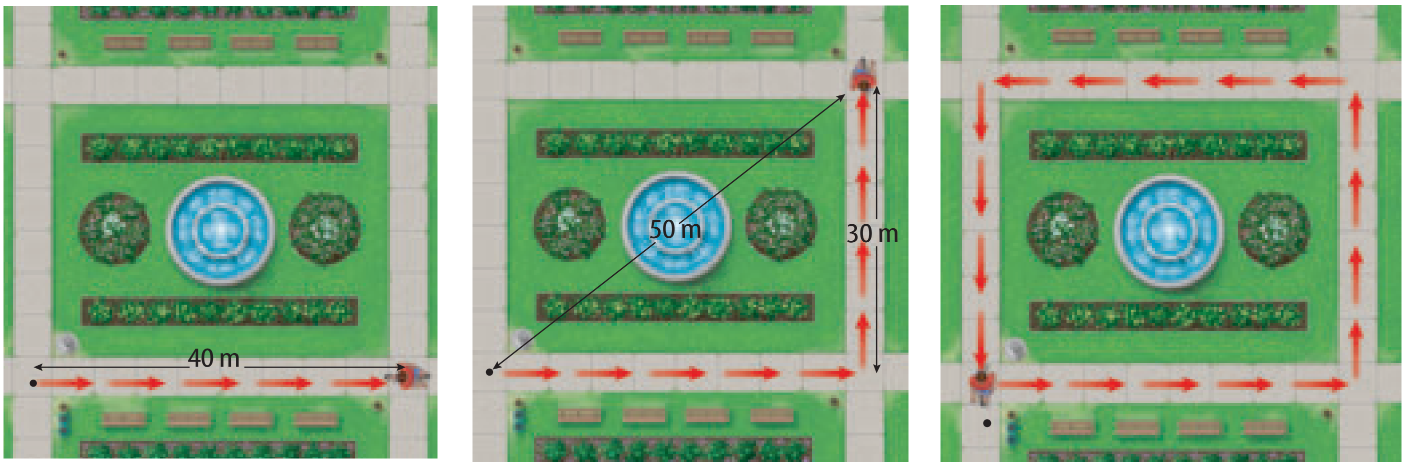


Figure 2 Motion occurs when something changes position relative to a reference point.
Explain *how the position of the dog changed.*

Distance and Displacement Suppose you are to meet your friends at the park in five minutes. Can you get there on time by walking, or should you ride your bike? To help you decide, you need to know the distance you will travel to get to the park. This distance is the length of the route you will travel from your house to the park.

Suppose the distance you traveled from your house to the park was 200 m. When you get to the park, how would you describe your location? You could say that your location was 200 m from your house. However, your final position depends on both the distance you travel and the direction. Did you go 200 m east or west? To describe your final position exactly, you also would have to tell the direction from your starting point. To do this, you would specify your displacement. Displacement includes the distance between the starting and ending points and the direction in which you travel. **Figure 3** shows the difference between distance and displacement.

Figure 3 Distance is how far you have walked. Displacement is the direction and difference in position between your starting and ending points.



Distance: 40 m
Displacement: 40 m east

Distance: 70 m
Displacement: 50 m northeast

Distance: 140 m
Displacement: 0 m

INTEGRATE Life Science

Animal Speeds Different animals can move at different top speeds. What are some of the fastest animals? Research the characteristics that help animals run, swim, or fly at high speed.

Speed

To describe motion, you usually want to describe how fast something is moving. The faster something is moving, the greater the distance it can travel in a unit of time, such as one second or one hour. **Speed** is the distance an object travels in a unit of time. For example, an object with a speed of 5 m/s can travel 5 m in 1 s. Speed can be calculated from this equation:

Speed Equation

$$\textbf{speed}\text{ (in meters/second)} = \frac{\textbf{distance}\text{ (in meters)}}{\textbf{time}\text{ (in seconds)}}$$

$$s = \frac{d}{t}$$

The unit for speed is the unit of distance divided by the unit of time. In SI units, speed is measured in units of m/s—meters per second. However, speed can be calculated using other units such as kilometers for distance and hours for time.

Applying Math

Solve a Simple Equation

SPEED OF A SWIMMER Calculate the speed of a swimmer who swims 100 m in 56 s.

Solution

1. *This is what you know:*
   - distance: $d = 100$ m
   - time: $t = 56$ s
2. *This is what you need to know:* speed: $s = ?$ m/s
3. *This is the procedure you need to use:* Substitute the known values for distance and time into the speed equation and calculate the speed:

$$s = \frac{d}{t} = \frac{100\text{ m}}{56\text{ s}} = \frac{100}{56}\,\frac{\text{m}}{\text{s}} = 1.8\text{ m/s}$$

4. *Check your answer:* Multiply your answer by the time. You should get the distance that was given.

Practice Problems

1. A runner completes a 400-m race in 43.9 s. In a 100-m race, he finishes in 10.4 s. In which race was his speed faster?
2. A passenger train travels from Boston to New York, a distance of 350 km, in 3.5 h. What is the train's speed?

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Average Speed A car traveling in city traffic might have to speed up and slow down many times. How could you describe the speed of an object whose speed is changing? One way is to determine the object's average speed between where it starts and stops. The speed equation on the previous page can be used to calculate the average speed. **Average speed** is found by dividing the total distance traveled by the total time taken.

Reading Check *How is average speed calculated?*

Instantaneous Speed An object in motion can change speeds many times as it speeds up or slows down. The speed of an object at one instant of time is the object's **instantaneous speed.** To understand the difference between average and instantaneous speeds, think about walking to the library. If it takes you 0.5 h to walk 2 km to the library, your average speed would be as follows:

$$s = \frac{d}{t}$$

$$= \frac{2\text{ km}}{0.5\text{ h}} = 4\text{ km/h}$$

However, you might not have been moving at the same speed throughout the trip. At a crosswalk, your instantaneous speed might have been 0 km/h. If you raced across the street, your speed might have been 7 km/h. If you were able to walk at a steady rate of 4 km/h during the entire trip, you would have moved at a constant speed. Average speed, instantaneous speed, and constant speed are illustrated in **Figure 4.**

Mini LAB

Measuring Average Speed

Procedure

1. Choose two points, such as two doorways, and mark each with a small piece of **masking tape.**
2. Measure the distance between the two points.
3. Use a **watch, clock,** or **timer** that indicates seconds to time yourself walking from one mark to the other.
4. Time yourself walking slowly, walking safely and quickly, and walking with a varying speed; for example, slow/fast/slow.

Analysis

1. Calculate your average speed in each case.
2. Predict how long it would take you to walk 100 m slowly, at your normal speed, and quickly.

Try at Home

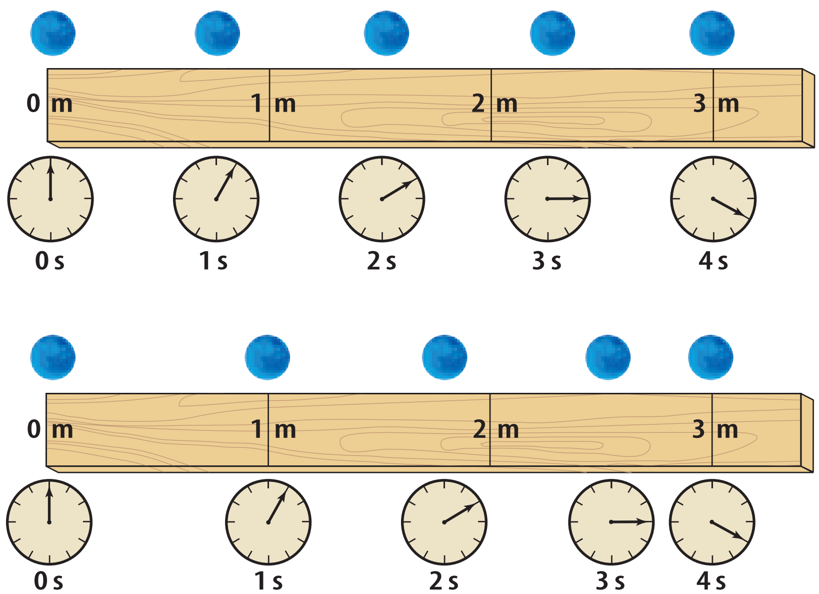


Figure 4 The average speed of each ball is the same from 0 s to 4 s.

The top ball is moving at a constant speed. In each second, the ball moves the same distance.

The bottom ball has a varying speed. Its instantaneous speed is fastest between 0 s and 1 s, slower between 2 s and 3 s, and slowest between 3 s and 4 s.

Graphing Motion

You can represent the motion of an object with a distance-time graph. For this type of graph, time is plotted on the horizontal axis and distance is plotted on the vertical axis. **Figure 5** shows the motion of two students who walked across a classroom plotted on a distance-time graph.

Science Online

Topic: Land Speed Record
Visit bookm.msscience.com for Web links to information about how the land speed record has changed over the past century.

Activity Make a graph showing the increase in the land speed over time.

Distance-Time Graphs and Speed A distance-time graph can be used to compare the speeds of objects. Look at the graph shown in **Figure 5.** According to the graph, after 1 s student A traveled 1 m. Her average speed during the first second is as follows:

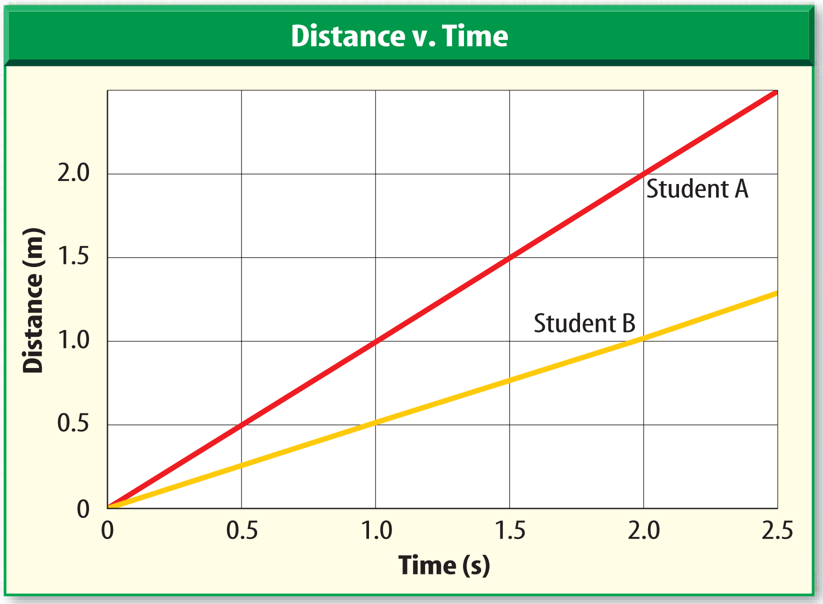
$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{1\text{ m}}{1\text{ s}} = 1\text{ m/s}$$

Student B, however, traveled only 0.5 m in the first second. His average speed is

$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{0.5\text{ m}}{1\text{ s}} = 0.5\text{ m/s}$$

So student A traveled faster than student B. Now compare the steepness of the lines on the graph in **Figure 5.** The line representing the motion of student A is steeper than the line for student B. A steeper line on the distance-time graph represents a greater speed. A horizontal line on the distance-time graph means that no change in position occurs. In that case, the speed of the object is zero.

Figure 5 The motion of two students walking across a classroom is plotted on this distance-time graph.
Use the graph *to determine which student had the faster average speed.*



Velocity

The motion of an object also depends on the direction in which the object is moving. The direction of an object's motion can be described with its velocity. The **velocity** of an object is the speed of the object and the direction of its motion. For example, if a car is moving west with a speed of 80 km/h, the car's velocity is 80 km/h west. The velocity of an object is sometimes represented by an arrow. The arrow points in the direction in which the object is moving. **Figure 6,** uses arrows to show the velocities of two hikers.

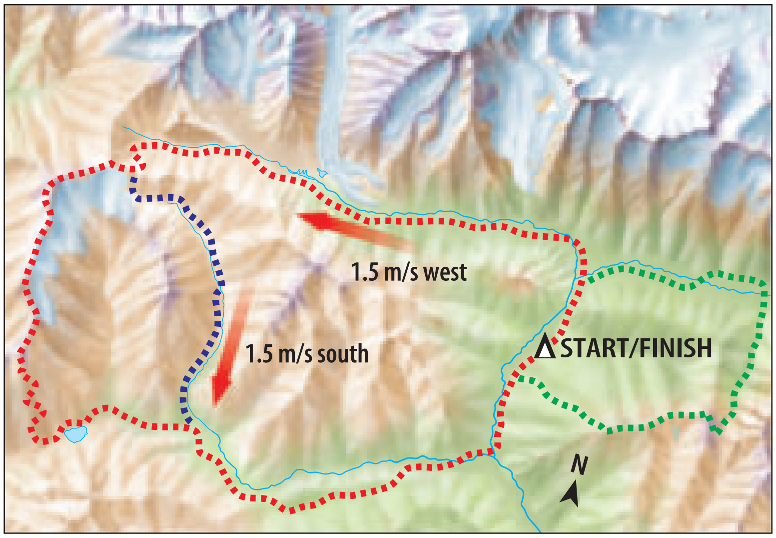


Figure 6 The arrows show the velocities of two hikers. Although the hikers have the same speed, they have different velocities because they are moving in different directions.

The velocity of an object can change if the object's speed changes, its direction of motion changes, or they both change. For example, suppose a car is traveling at a speed of 40 km/h north and then turns left at an intersection and continues on with a speed of 40 km/h. The speed of the car is constant at 40 km/h, but the velocity changes from 40 km/h north to 40 km/h west. Why can you say the velocity of a car changes as it comes to a stop at an intersection?

section 1 review

Summary

Changing Position

- An object is in motion if it changes position relative to a reference point.
- Motion can be described by distance, speed, displacement, and velocity, where displacement and velocity also include direction.

Speed and Velocity

- The speed of an object can be calculated by dividing the distance traveled by the time needed to travel the distance.
- For an object traveling at constant speed, its average speed is the same as its instantaneous speed.
- The velocity of an object is the speed of the object and its direction of motion.

Graphing Motion

- A line on a distance-time graph becomes steeper as an object's speed increases.

Self Check

1. **Identify** the two pieces of information you need to know the velocity of an object.
2. **Make and Use Graphs** You walk forward at 1.5 m/s for 8 s. Your friend decides to walk faster and starts out at 2.0 m/s for the first 4 s. Then she slows down and walks forward at 1.0 m/s for the next 4 s. Make a distance-time graph of your motion and your friend's motion. Who walked farther?
3. **Think Critically** A bee flies 25 m north of the hive, then 10 m east, 5 m west, and 10 m south. How far north and east of the hive is it now? Explain how you calculated your answer.

Applying Math

4. **Calculate** the average velocity of a dancer who moves 5 m toward the left of the stage over the course of 15 s.
5. **Calculate Travel Time** An airplane flew a distance of 650 km at an average speed of 300 km/h. How much time did the flight take?

section 2

Acceleration

as you read

What You'll Learn

- **Define** acceleration.
- **Predict** what effect acceleration will have on motion.

Why It's Important

Whenever the motion of an object changes, it is accelerating.

Review Vocabulary

kilogram: SI unit of mass, abbreviated kg; equal to approximately 2.2 lbs

New Vocabulary

- acceleration

Acceleration and Motion

When you watch the first few seconds of a liftoff, a rocket barely seems to move. With each passing second, however, you can see it move faster until it reaches an enormous speed. How could you describe the change in the rocket's motion? When an object changes its motion, it is accelerating. **Acceleration** is the change in velocity divided by the time it takes for the change to occur.

Like velocity, acceleration has a direction. If an object speeds up, the acceleration is in the direction that the object is moving. If an object slows down, the acceleration is opposite to the direction that the object is moving. What if the direction of the acceleration is at an angle to the direction of motion? Then the direction of motion will turn toward the direction of the acceleration.

Speeding Up You get on a bicycle and begin to pedal. The bike moves slowly at first, but speeds up as you keep pedaling. Recall that the velocity of an object is the speed of an object and its direction of motion. Acceleration occurs whenever the velocity of an object changes. Because the bike's speed is increasing, the velocity of the bike is changing. As a result, the bike is accelerating.

For example, the toy car in **Figure 7** is accelerating because it is speeding up. The speed of the car is 10 cm/s after 1s, 20 cm/s after 2s, and 30 cm/s after 3s. Here the direction of the car's acceleration is in the same direction as the car's velocity—to the right.

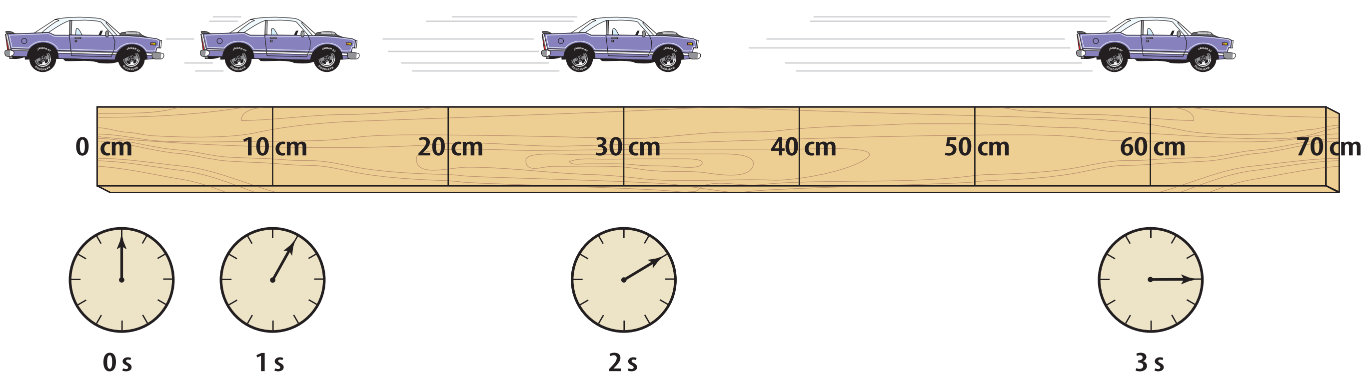
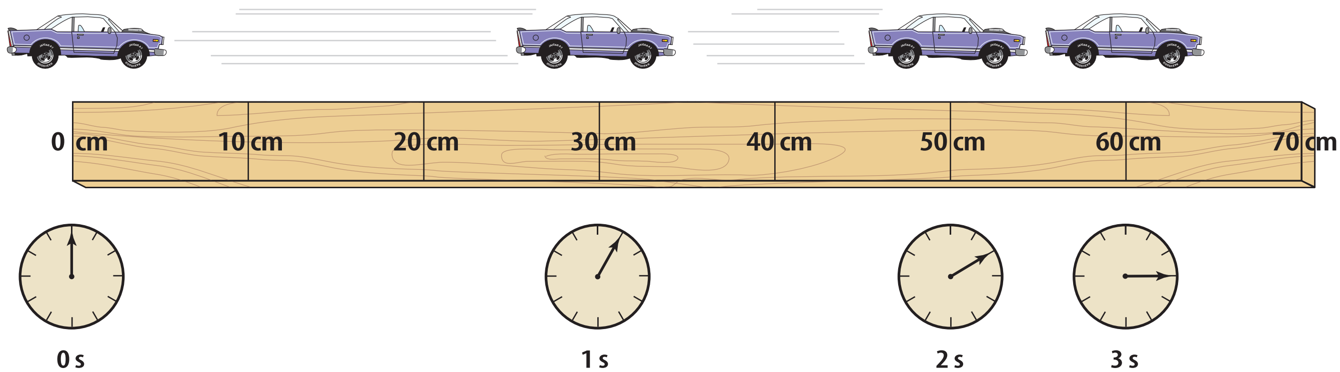


Figure 7 The toy car is accelerating because its speed is increasing.



Slowing Down Now suppose you are biking at a speed of 4 m/s and you apply the brakes. This causes you to slow down. When you slow down, your velocity changes because your speed decreases. This means that acceleration occurs when an object slows down, as well as when it speeds up. The car in **Figure 8** is slowing down. During each time interval, the car travels a smaller distance, so its speed is decreasing.

In both of these examples, speed is changing, so acceleration is occurring. Because speed is decreasing in the second example, the direction of the acceleration is opposite to the direction of motion. Any time an object slows down, its acceleration is in the direction opposite to the direction of its motion.

Figure 8 The car is moving to the right but accelerating to the left. In each time interval, it covers less distance and moves more slowly.
Determine *how the car's velocity is changing.*

Changing Direction The velocity of an object also changes if the direction of motion changes. Then the object doesn't move in a straight line, but instead moves in a curved path. The object is accelerating because its velocity is changing. In this case the direction of acceleration is at an angle to the direction of motion.

Again imagine yourself riding a bicycle. When you turn the handlebars, the bike turns. Because the direction of the bike's motion has changed, the bike has accelerated. The acceleration is in the direction that the bicycle turned.

Figure 9 shows another example of an object that is accelerating. The ball starts moving upward, but its direction of motion changes as its path turns downward. Here the acceleration is downward. The longer the ball accelerates, the more its path turns toward the direction of acceleration.

Reading Check *What are three ways to accelerate?*

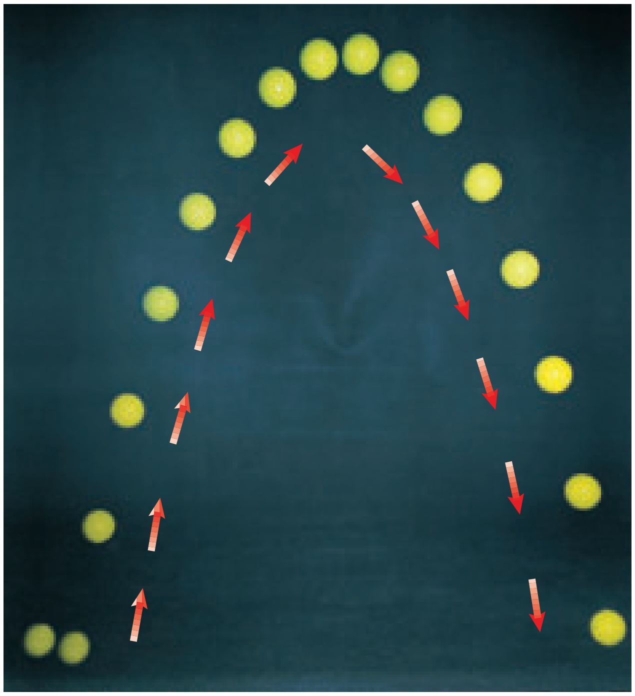


Figure 9 The ball starts out by moving forward and upward, but the acceleration is downward, so the ball's path turns in that direction.

Calculating Acceleration

If an object is moving in only one direction, its acceleration can be calculated using this equation.

Acceleration Equation

acceleration (in m/s^2) = $\frac{(\textbf{final speed} \text{ (in m/s)} - \textbf{initial speed} \text{ (in m/s)})}{\textbf{time} \text{ (in s)}}$

$$a = \frac{(s_f - s_i)}{t}$$

In this equation, time is the length of time over which the motion changes. In SI units, acceleration has units of meters per second squared (m/s^2).

Applying Math — Solve a Simple Equation

ACCELERATION OF A BUS Calculate the acceleration of a bus whose speed changes from 6 m/s to 12 m/s over a period of 3 s.

Solution

1. *This is what you know:*
   - initial speed: $s_i = 6$ m/s
   - final speed: $s_f = 12$ m/s
   - time: $t = 3$ s
2. *This is what you need to know:* acceleration: $a = ?$ m/s^2
3. *This is the procedure you need to use:* Substitute the known values of initial speed, final speed and time in the acceleration equation and calculate the acceleration:

$$a = \frac{(s_f - s_i)}{t} = \frac{(12 \text{ m/s} - 6 \text{ m/s})}{3 \text{ s}} = 6 \frac{\text{m}}{\text{s}} \times \frac{1}{3 \text{ s}} = 2 \text{ m/s}^2$$

4. *Check your answer:* Multiply the calculated acceleration by the known time. Then add the known initial speed. You should get the final speed that was given.

Practice Problems

1. Find the acceleration of a train whose speed increases from 7 m/s to 17 m/s in 120 s.
2. A bicycle accelerates from rest to 6 m/s in 2 s. What is the bicycle's acceleration?

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Figure 10 When skidding to a stop, you are slowing down. This means you have a negative acceleration.

Positive and Negative Acceleration An object is accelerating when it speeds up, and the acceleration is in the same direction as the motion. An object also is accelerating when it slows down, but the acceleration is in the direction opposite to the motion, such as the bicycle in **Figure 10.** How else is acceleration different when an object is speeding up and slowing down?

Suppose you were riding your bicycle in a straight line and increased your speed from 4 m/s to 6 m/s in 5 s. You could calculate your acceleration from the equation on the previous page.

$$a = \frac{(s_f - s_i)}{t}$$
$$= \frac{(6\ \text{m/s} - 4\ \text{m/s})}{5\ \text{s}} = \frac{+2\ \text{m/s}}{5\ \text{s}}$$
$$= +0.4\ \text{m/s}^2$$

When you speed up, your final speed always will be greater than your initial speed. So subtracting your initial speed from your final speed gives a positive number. As a result, your acceleration is positive when you are speeding up.

Suppose you slow down from a speed of 4 m/s to 2 m/s in 5 s. Now the final speed is less than the initial speed. You could calculate your acceleration as follows:

$$a = \frac{(s_f - s_i)}{t}$$
$$= \frac{(2\ \text{m/s} - 4\ \text{m/s})}{5\ \text{s}} = \frac{-2\ \text{m/s}}{5\ \text{s}}$$
$$= -0.4\ \text{m/s}^2$$

Because your final speed is less than your initial speed, your acceleration is negative when you slow down.

Mini LAB

Modeling Acceleration

Procedure

1. Use **masking tape** to lay a course on the floor. Mark a starting point and place marks along a straight path at 10 cm, 40 cm, 90 cm, 160 cm, and 250 cm from the start.
2. Clap a steady beat. On the first beat, the person walking the course should be at the starting point. On the second beat, the walker should be on the first mark, and so on.

Analysis

1. Describe what happens to your speed as you move along the course. Infer what would happen if the course were extended farther.
2. Repeat step 2, starting at the other end. Are you still accelerating? Explain.

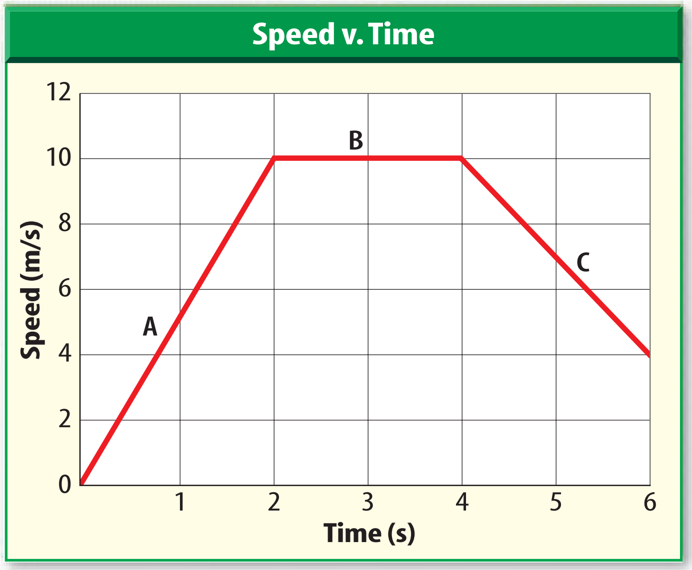

Figure 11 A speed-time graph can be used to find acceleration. When the line rises, the object is speeding up. When the line falls, the object is slowing down.
Infer *what acceleration a horizontal line represents.*

Graphing Accelerated Motion The motion of an object that is moving in a single direction can be shown with a graph. For this type of graph, speed is plotted on the vertical axis and time on the horizontal axis. Take a look at **Figure 11.** On section A of the graph, the speed increases from 0 m/s to 10 m/s during the first 2 s, so the acceleration is +5 m/s^2. The line in section A slopes upward to the right. An object that is speeding up will have a line on a speed-time graph that slopes upward.

Now look at section C. Between 4 s and 6 s, the object slows down from 10 m/s to 4 m/s. The acceleration is −3 m/s^2. On the speed-time graph, the line in section C is sloping downward to the right. An object that is slowing down will have a line on a speed-time graph that slopes downward.

On section B, where the line is horizontal, the change in speed is zero. So a horizontal line on the speed-time graph represents an acceleration of zero or constant speed.

section 2 review

Summary

Acceleration and Motion

- Acceleration is the change in velocity divided by the time it takes to make the change. Acceleration has direction.
- Acceleration occurs whenever an object speeds up, slows down, or changes direction.

Calculating Acceleration

- For motion in a single direction, acceleration can be calculated from this equation:

$$a = \frac{s_f - s_i}{t}$$

- If an object is speeding up, its acceleration is positive; if an object is slowing down, its acceleration is negative.
- On a speed-time graph, a line sloping upward represents increasing speed, a line sloping downward represents decreasing speed, and a horizontal line represents zero acceleration or constant speed.

Self Check

1. **Compare and contrast** speed, velocity, and acceleration.
2. **Infer** the motion of a car whose speed-time graph shows a horizontal line, followed by a straight line that slopes downward to the bottom of the graph.
3. **Think Critically** You start to roll backward down a hill on your bike, so you use the brakes to stop your motion. In what direction did you accelerate?

Applying Math

4. **Calculate** the acceleration of a runner who accelerates from 0 m/s to 3 m/s in 12 s.
5. **Calculate Speed** An object falls with an acceleration of 9.8 m/s^2. What is its speed after 2 s?
6. **Make and Use a Graph** A sprinter had the following speeds at different times during a race: 0 m/s at 0 s, 4 m/s at 2 s, 7 m/s at 4 s, 10 m/s at 6 s, 12 m/s at 8 s, and 10 m/s at 10 s. Plot these data on a speed-time graph. During what time intervals is the acceleration positive? Negative? Is the acceleration ever zero?

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section 3

Collisions

A collision occurs when a moving object collides with other objects. What happens when a cue ball collides with another ball in a game of pool? The answer is that the velocities of the two balls change. The collision can change the speed of each ball, the direction of motion of each ball, or both. When a collision occurs, changes in motion of the colliding objects depend on their masses and their velocities before the collision.

Mass and Inertia

The mass of an object affects how easy it is to change its motion. **Mass** is the amount of matter in an obejct. Imagine a person rushing toward you. To stop the person, you would have to push on him or her. However, you would have to push harder to stop an adult than to stop a child. The child would be easier to stop because it has less mass than the adult. The more mass an object has, the harder it is to change its motion. In **Figure 12,** the tennis ball has more mass than the table-tennis ball. A big racquet rather than a small paddle is used to change its motion. The tendency of an object to resist a change in its motion is called **inertia.** The amount of resistance to a change in motion increases as an object's mass increases.

Reading Check *What is inertia?*

as you read

What You'll Learn

- **Define** momentum.
- **Explain** why momentum might not be conserved after a collision.
- **Predict** motion using the law of conservation of momentum.

Why It's Important

Objects in motion have momentum. The motion of objects after they collide depends on their momentum.

Review Vocabulary

triple-beam balance: scientific instrument used to measure mass precisely by comparing the mass of a sample to known masses

New Vocabulary

- mass
- inertia
- momentum
- law of conservation of momentum

Figure 12 A tennis ball has more mass than a table-tennis ball. The tennis ball must be hit harder than the table-tennis ball to change its velocity by the same amount.

INTEGRATE Social Studies

Forensics and Momentum Forensic investigations of accidents and crimes often involve determining the momentum of an object. For example, the law of conservation of momentum sometimes is used to reconstruct the motion of vehicles involved in a collision. Research other ways momentum is used in forensic investigations.

Momentum

You know that the faster a bicycle moves, the harder it is to stop. Just as increasing the mass of an object makes it harder to stop, so does increasing the speed or velocity of the object. The **momentum** of an object is a measure of how hard it is to stop the object, and it depends on the object's mass and velocity. Momentum is usually symbolized by *p*.

Momentum Equation

momentum (in kg · m/s) = **mass** (in kg) × **velocity** (in m/s)

$$p = mv$$

Mass is measured in kilograms and velocity has units of meters per second, so momentum has units of kilograms multiplied by meters per second (kg · m/s). Also, because velocity includes a direction, momentum has a direction that is the same as the direction of the velocity.

Reading Check ***Explain how an object's momentum changes as its velocity changes.***

Applying Math — Solve a Simple Equation

MOMENTUM OF A BICYCLE Calculate the momentum of a 14-kg bicycle traveling north at 2 m/s.

Solution

1. *This is what you know:*
   - mass: $m = 14$ kg
   - velocity: $v = 2$ m/s north
2. *This is what you need to find:* momentum: $p = ?$ kg · m/s
3. *This is the procedure you need to use:* Substitute the known values of mass and velocity into the momentum equation and calculate the momentum:

   $p = mv = (14 \text{ kg})\ (2 \text{ m/s north}) = 28 \text{ kg} \cdot \text{m/s north}$
4. *Check your answer:* Divide the calculated momentum by the mass of the bicycle. You should get the velocity that was given.

Practice Problems

1. A 10,000-kg train is traveling east at 15 m/s. Calculate the momentum of the train.
2. What is the momentum of a car with a mass of 900 kg traveling north at 27 m/s?

Science Online — For more practice, visit bookm.msscience.com/math_practice

Conservation of Momentum

If you've ever played billiards, you know that when the cue ball hits another ball, the motions of both balls change. The cue ball slows down and may change direction, so its momentum decreases. Meanwhile, the other ball starts moving, so its momentum increases.

In any collision, momentum is transferred from one object to another. Think about the collision between two billiard balls. If the momentum lost by one ball equals the momentum gained by the other ball, then the total amount of momentum doesn't change. When the total momentum of a group of objects doesn't change, momentum is conserved.

The Law of Conservation of Momentum According to the **law of conservation of momentum,** the total momentum of a group of objects remains constant unless outside forces act on the group. The moving cue ball and the other billiard balls in **Figure 13** are a group of objects. The law of conservation of momentum means that collisions between these objects don't change the total momentum of all the objects in the group.

Only an outside force, such as friction between the billiard balls and the table, can change the total momentum of the group of objects. Friction will cause the billiard balls to slow down as they roll on the table and the total momentum will decrease.

Types of Collisions Objects can collide with each other in different ways. **Figure 14** shows two examples. Sometimes objects will bounce off each other like the bowling ball and bowling pins. In other collisions, objects will collide and stick to each other, as when one football player tackles another.

Figure 13 When the cue ball hits the other billiard balls, it slows down because it transfers some of its momentum to the other billiard balls.

Predict *what would happen to the speed of the cue ball if all of its momentum were transferred to the other billiard balls.*

Figure 14 When objects collide, they can bounce off each other, or they can stick to each other.

When the bowling ball hits the pins, the ball and the pins bounce off each other. The momentum of the ball and the pins changes during the collision.

When one player tackles the other, they stick together. The momentum of each player changes during the collision.

Before the student on skates and the backpack collide, she is not moving.

After the collision, the student and the backpack move together at a slower speed than the backpack had before the collision.

Figure 15 Momentum is transferred from the backpack to the student.

Using Momentum Conservation The law of momentum conservation can be used to predict the velocity of objects after they collide. To use the law of conservation of momentum, assume that the total momentum of the colliding objects doesn't change.

For example, imagine being on skates when someone throws a backpack to you, as in **Figure 15.** The law of conservation of momentum can be used to find your velocity after you catch the backpack. Suppose a 2-kg backpack initially has a velocity of 5 m/s east. Your mass is 48 kg, and initially you're at rest. Then the total initial momentum is:

$$\begin{aligned}\text{total momentum} &= \text{momentum of backpack} + \text{your momentum}\\ &= 2\text{ kg} \times 5\text{ m/s east} + 48\text{ kg} \times 0\text{ m/s}\\ &= 10\text{ kg}\cdot\text{m/s east}\end{aligned}$$

After the collision, the total momentum remains the same, and only one object is moving. Its mass is the sum of your mass and the mass of the backpack. You can use the equation for momentum to find the final velocity

$$\begin{aligned}\text{total momentum} &= (\text{mass of backpack} + \text{your mass}) \times \text{velocity}\\ 10\text{ kg}\cdot\text{m/s east} &= (2\text{ kg} + 48\text{ kg}) \times \text{velocity}\\ 10\text{ kg}\cdot\text{m/s east} &= (50\text{ kg}) \times \text{velocity}\\ 0.2\text{ m/s east} &= \text{velocity}\end{aligned}$$

This is your velocity right after you catch the backpack. The velocity of you and the backpack together is much smaller than the initial velocity of the backpack. **Figure 16** shows the results of collisions between two objects that don't stick to each other.

Science Online

Topic: Collisions

Visit bookm.msscience.com for Web links to information about collisions between objects with different masses.

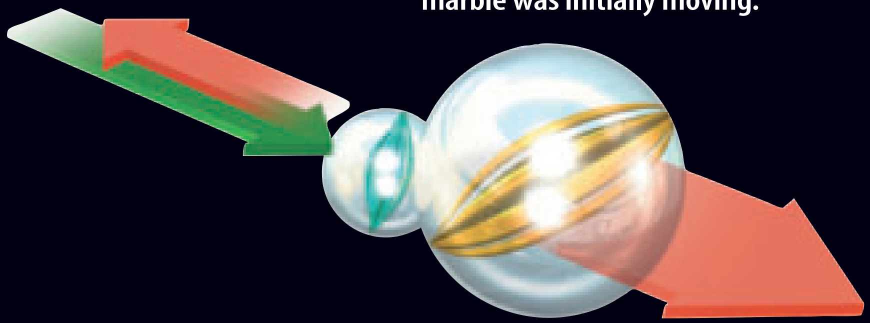
Activity Draw diagrams showing the results of collisions between a bowling ball and a tennis ball if they are moving in the same direction and if they are in opposite directions.

VISUALIZING CONSERVATION OF MOMENTUM

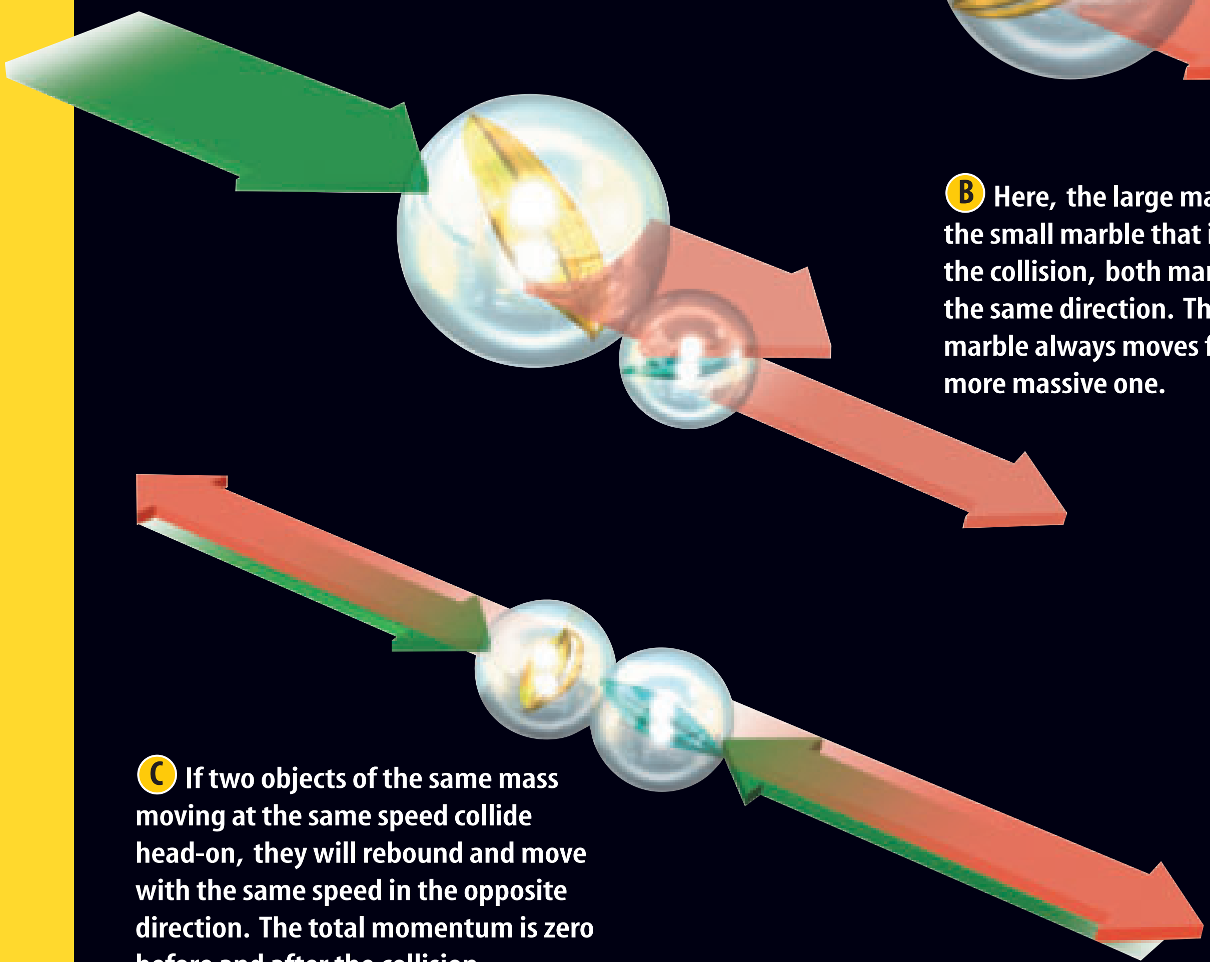
Figure 16

The law of conservation of momentum can be used to predict the results of collisions between different objects, whether they are subatomic particles smashing into each other at enormous speeds, or the collisions of marbles, as shown on this page. What happens when one marble hits another marble initially at rest? The results of the collisions depend on the masses of the marbles.

A Here, a less massive marble strikes a more massive marble that is at rest. After the collision, the smaller marble bounces off in the opposite direction. The larger marble moves in the same direction that the small marble was initially moving.



B Here, the large marble strikes the small marble that is at rest. After the collision, both marbles move in the same direction. The less massive marble always moves faster than the more massive one.



C If two objects of the same mass moving at the same speed collide head-on, they will rebound and move with the same speed in the opposite direction. The total momentum is zero before and after the collision.

Figure 17 When bumper cars collide, they bounce off each other, and momentum is transferred.

Colliding and Bouncing Off In some collisions, the objects involved, like the bumper cars in **Figure 17,** bounce off each other. The law of conservation of momentum can be used to determine how these objects move after they collide.

For example, suppose two identical objects moving with the same speed collide head on and bounce off. Before the collision, the momentum of each object is the same, but in opposite directions. So the total momentum before the collision is zero. If momentum is conserved, the total momentum after the collision must be zero also. This means that the two objects must move in opposite directions with the same speed after the collision. Then the total momentum once again is zero.

section 3 review

Summary

Inertia and Momentum

- Inertia is the tendency of an object to resist a change in motion.
- The momentum of an object in motion is related to how hard it is to stop the object, and can be calculated from the following equation:
$$p = mv$$
- The momentum of an object is in the same direction as its velocity.

The Law of Conservation of Momentum

- According to the law of conservation of momentum, the total momentum of a group of objects remains constant unless outside forces act on the group.
- When objects collide, they can bounce off each other or stick together.

Self Check

1. **Explain** how momentum is transferred when a golfer hits a ball with a golf club.
2. **Determine** if the momentum of an object moving in a circular path at constant speed is constant.
3. **Explain** why the momentum of a billiard ball rolling on a billiard table changes.
4. **Think Critically** Two identical balls move directly toward each other with equal speeds. How will the balls move if they collide and stick together?

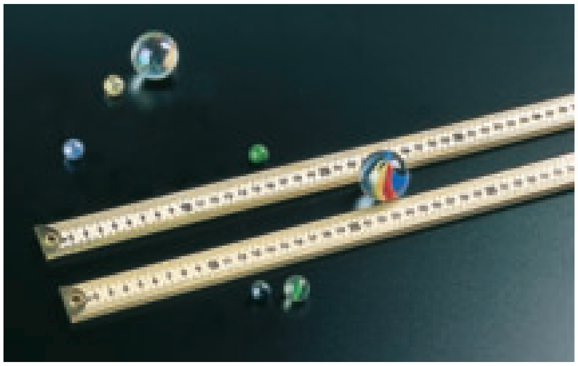
Applying Math

5. **Momentum** What is the momentum of a 0.1-kg mass moving with a velocity of 5 m/s west?
6. **Momentum Conservation** A 1-kg ball moving at 3 m/s east strikes a 2-kg ball and stops. If the 2-kg ball was initially at rest, find its velocity after the collision.

Science Online bookm.msscience.com/self_check_quiz

LAB

Collisions



A collision occurs when a baseball bat hits a baseball or a tennis racket hits a tennis ball. What would happen if you hit a baseball with a table-tennis paddle or a table-tennis ball with a baseball bat? How do the masses of colliding objects change the results of collisions?

Real-World Question

How does changing the size and number of objects in a collision affect the collision?

Goals

- **Compare and contrast** different collisions.
- **Determine** how the velocities after a collision depend on the masses of the colliding objects.

Materials

small marbles (5)
large marbles (2)
metersticks (2)
tape

Safety Precautions

Procedure

1. Tape the metersticks next to each other, slightly farther apart than the width of the large marbles. This limits the motion of the marbles to nearly a straight line.
2. Place a small target marble in the center of the track formed by the metersticks. Place another small marble at one end of the track. Flick the small marble toward the target marble. Describe the collision.
3. Repeat step 2, replacing the two small marbles with the two large marbles.
4. Repeat step 2, replacing the small shooter marble with a large marble.
5. Repeat step 2, replacing the small target marble with a large marble.
6. Repeat step 2, replacing the small target marble with four small marbles that are touching.
7. Place two small marbles at opposite ends of the metersticks. Shoot the marbles toward each other and describe the collision.
8. Place two large marbles at opposite ends of the metersticks. Shoot the marbles toward each other and describe the collision.
9. Place a small marble and a large marble at opposite ends of the metersticks. Shoot the marbles toward each other and describe the collision.

Conclude and Apply

1. **Describe** In which collisions did the shooter marble change direction? How did the mass of the target marble compare with the mass of the shooter marble in these collisions?
2. **Describe** how the velocity of the shooter marble changed when the target marble had the same mass and was at rest.

Communicating Your Data

Make a chart showing your results. You might want to make before-and-after sketches, with short arrows to show slow movement and long arrows to show fast movement.

LAB Design Your Own

Car Safety Testing

Goals
- **Construct** a fast car.
- **Design** a safe car that will protect a plastic egg from the effects of inertia when the car crashes.

Possible Materials
insulated foam meat trays or fast food trays
insulated foam cups
straws, narrow and wide
straight pins
tape
plastic eggs

Safety Precautions

WARNING: *Protect your eyes from possible flying objects.*

Real-World Question

Imagine that you are a car designer. How can you create an attractive, fast car that is safe? When a car crashes, the passengers have inertia that can keep them moving. How can you protect the passengers from stops caused by sudden, head-on impacts?

Form a Hypothesis

Develop a hypothesis about how to design a car to deliver a plastic egg quickly and safely through a race course and a crash at the end.

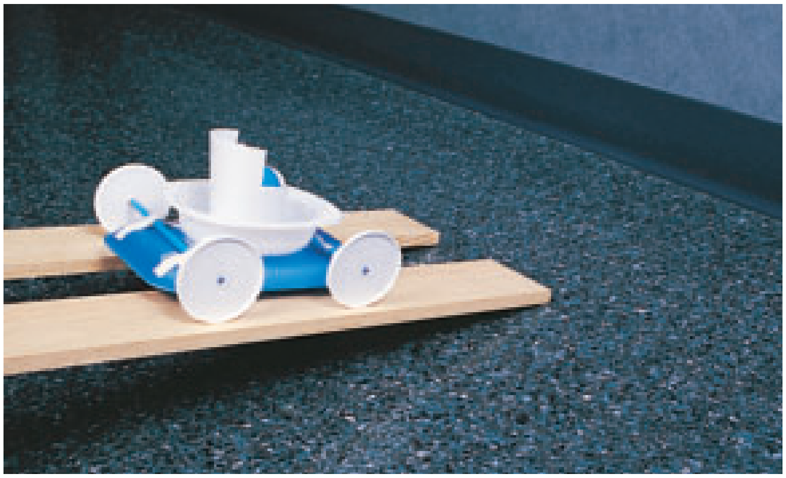
Test Your Hypothesis

Make a Plan

1. Be sure your group has agreed on the hypothesis statement.
2. **Sketch** the design for your car. List the materials you will need. Remember that to make the car move smoothly, narrow straws will have to fit into the wider straws.

(t)Richard Olivier/CORBIS, (b)Icon Images

3. As a group, make a detailed list of the steps you will take to test your hypothesis.
4. Gather the materials you will need to carry out your experiment.



Follow Your Plan

1. Make sure your teacher approves your plan before you start. Include any changes suggested by your teacher in your plans.
2. Carry out the experiment as planned.
3. **Record** any observations that you made while doing your experiment. Include suggestions for improving your design.

Analyze Your Data

1. **Compare** your car design to the designs of the other groups. What made the fastest car fast? What slowed the slowest car?
2. **Compare** your car's safety features to those of the other cars. What protected the eggs the best? How could you improve the unsuccessful designs?
3. **Predict** What effect would decreasing the speed of your car have on the safety of the egg?

Conclude and Apply

1. **Summarize** How did the best designs protect the egg?
2. **Apply** If you were designing cars, what could you do to better protect passengers from sudden stops?

Communicating Your Data

Write a descriptive paragraph about ways a car could be designed to protect its passengers effectively. Include a sketch of your ideas.

Oops! Accidents in SCIENCE

SOMETIMES GREAT DISCOVERIES HAPPEN BY ACCIDENT!

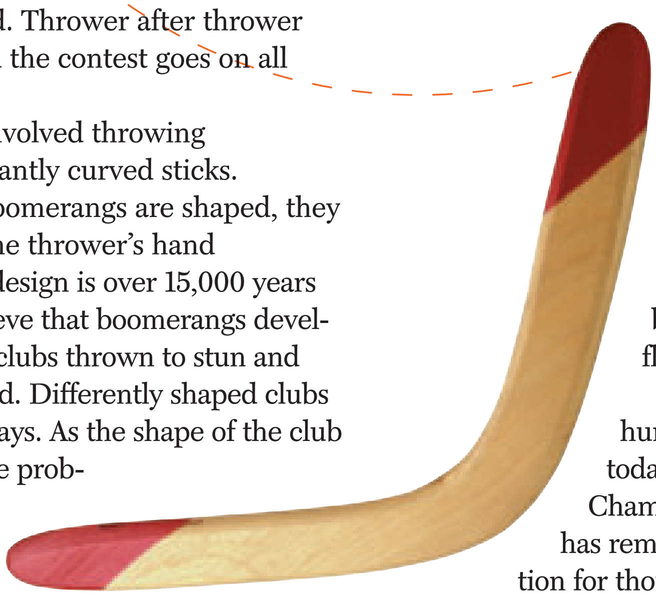
What Goes Around Comes Around

The Story of Boomerangs

Imagine a group gathered on a flat, yellow plain on the Australian Outback. One youth steps forward and, with the flick of an arm, sends a long, flat, angled stick soaring and spinning into the sky. The stick's path curves until it returns right back into the thrower's hand. Thrower after thrower steps forward, and the contest goes on all afternoon.

This contest involved throwing boomerangs—elegantly curved sticks. Because of how boomerangs are shaped, they always return to the thrower's hand

This amazing design is over 15,000 years old. Scientists believe that boomerangs developed from simple clubs thrown to stun and kill animals for food. Differently shaped clubs flew in different ways. As the shape of the club was refined, people probably started throwing them for fun too. In fact, today, using boomerangs for fun is still a popular sport, as world-class throwers compete in contests of strength and skill.



Boomerangs come in several forms, but all of them have several things in common. First a boomerang is shaped like an airplane's wing: flat on one side and curved on the other. Second, boomerangs are angled, which makes them spin as they fly. These two features determine the aerodynamics that give the boomerang its unique flight path.

From its beginning as a hunting tool to its use in today's World Boomerang Championships, the boomerang has remained a source of fascination for thousands of years.

Design Boomerangs are made from various materials. Research to find instructions for making boomerangs. After you and your friends build some boomerangs, have a competition of your own.

Science Online
For more information, visit bookm.msscience.com/oops

Alexis Duclos/Liaison/Getty Images

Reviewing Main Ideas

Section 1 What is motion?

1. The position of an object depends on the reference point that is chosen.
2. An object is in motion if the position of the object is changing.
3. The speed of an object equals the distance traveled divided by the time:
$$s = \frac{d}{t}$$
4. The velocity of an object includes the speed and the direction of motion.
5. The motion of an object can be represented on a speed-time graph.

Section 2 Acceleration

1. Acceleration is a measure of how quickly velocity changes. It includes a direction.
2. An object is accelerating when it speeds up, slows down, or turns.
3. When an object moves in a straight line, its acceleration can be calculated by
$$a = \frac{(s_f - s_i)}{t}$$

Section 3 Momentum

1. Momentum equals the mass of an object times its velocity:
$$p = mv$$
2. Momentum is transferred from one object to another in a collision.
3. According to the law of conservation of momentum, the total amount of momentum of a group of objects doesn't change unless outside forces act on the objects.

Visualizing Main Ideas

Copy and complete the following table on motion.



Describing Motion

Quantity	Definition	Direction
Distance	length of path traveled	no
Displacement	direction and change in position	
Speed		no
Velocity	rate of change in position and direction	
Acceleration		
Momentum		yes

Using Vocabulary

acceleration p. 14
average speed p. 11
inertia p. 19
instantaneous speed p. 11
law of conservation of momentum p. 21
mass p. 19
momentum p. 20
speed p. 10
velocity p. 13

Explain the relationship between each pair of terms.

1. speed—velocity
2. velocity—acceleration
3. velocity—momentum
4. momentum—law of conservation of momentum
5. mass—momentum
6. mass—inertia
7. momentum—inertia
8. average speed—instantaneous speed

Checking Concepts

Choose the word or phrase that best answers the question.

9. What measures the quantity of matter?
   A) speed
   B) weight
   C) acceleration
   D) mass

10. Which of the following objects is NOT accelerating?
   A) a jogger moving at a constant speed
   B) a car that is slowing down
   C) Earth orbiting the Sun
   D) a car that is speeding up

11. Which of the following equals speed?
   A) acceleration/time
   B) (change in velocity)/time
   C) distance/time
   D) displacement/time

12. Which of these is an acceleration?
   A) 5 m east
   B) 15 m/s east
   C) 52 m/s^2 east
   D) 32 s^2 east

13. Resistance to a change in motion increases when which of these increases?
   A) velocity
   B) speed
   C) instantaneous speed
   D) mass

14. What is 18 cm/h north an example of?
   A) speed
   B) velocity
   C) acceleration
   D) momentum

15. Which is true when the velocity and the acceleration of an object are in the same direction?
   A) The object's speed is constant.
   B) The object changes direction.
   C) The object speeds up.
   D) The object slows down.

16. Which of the following equals the change in velocity divided by the time?
   A) speed
   B) displacement
   C) momentum
   D) acceleration

17. You travel to a city 200 km away in 2.5 hours. What is your average speed in km/h?
   A) 180 km/h
   B) 12.5 km/h
   C) 80 km/h
   D) 500 km/h

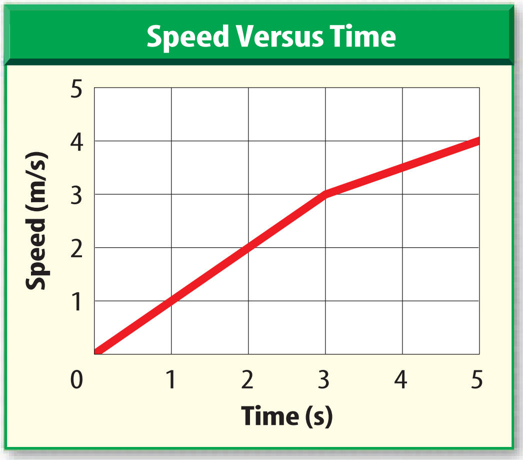
18. A cue ball hits another billiard ball and slows down. Why does the speed of the cue ball decrease?
   A) The cue ball's momentum is positive.
   B) The cue ball's momentum is negative.
   C) Momentum is transferred to the cue ball.
   D) Momentum is transferred from the cue ball.

Science Online bookm.msscience.com/vocabulary_puzzlemaker

Thinking Critically

19. Explain You run 100 m in 25 s. If you later run the same distance in less time, explain if your average speed increase or decrease.

Use the graph below to answer questions 20 and 21.



20. Compare For the motion of the object plotted on the speed-time graph above, how does the acceleration between 0 s and 3 s compare to the acceleration between 3 s and 5 s?

21. Calculate the acceleration of the object over the time interval from 0 s to 3 s.

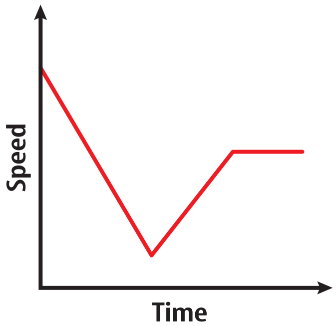
22. Infer The molecules in a gas are often modeled as small balls. If the molecules all have the same mass, infer what happens if two molecules traveling at the same speed collide head on.

23. Calculate What is your displacement if you walk 100 m north, 20 m east, 30 m south, 50 m west, and then 70 m south?

24. Infer You are standing on ice skates and throw a basketball forward. Infer how your velocity after you throw the basketball compares with the velocity of the basketball.

25. Determine You throw a ball upward and then it falls back down. How does the velocity of the ball change as it rises and falls?

Use the graph below to answer question 26.



26. Make and Use Graphs The motion of a car is plotted on the speed-time graph above. Over which section of the graph is the acceleration of the car zero?

Performance Activities

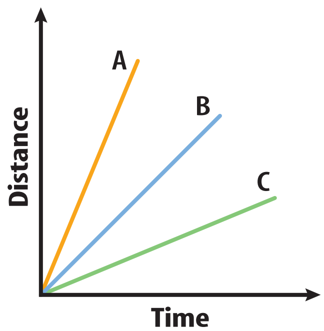
27. Demonstrate Design a racetrack and make rules that specify the types of motion allowed. Demonstrate how to measure distance, measure time, and calculate speed accurately.

Applying Math

28. Velocity of a Ball Calculate the velocity of a 2-kg ball that has a momentum of 10 kg · m/s west.

29. Distance Traveled A car travels for a half hour at a speed of 40 km/h. How far does the car travel?

Use the graph below to answer question 30.



30. Speed From the graph determine which object is moving the fastest and which is moving the slowest.

chapter 1 Standardized Test Practice

Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

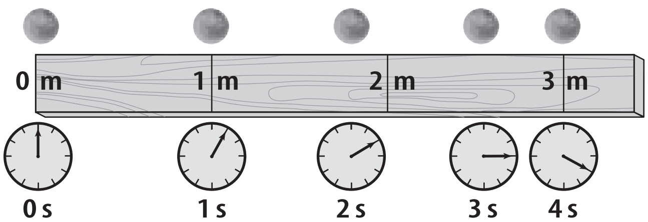
1. What is the distance traveled divided by the time taken to travel that distance?

A. acceleration **C.** speed
B. velocity **D.** inertia

2. Sound travels at a speed of 330 m/s. How long does it take for the sound of thunder to travel 1,485 m?

A. 45 s **C.** 4,900 s
B. 4.5 s **D.** 0.22 s

Use the figure below to answer questions 3 and 4.



3. During which time period is the ball's average speed the fastest?

A. between 0 and 1 s
B. between 1 and 2 s
C. between 2 and 3 s
D. between 3 and 4 s

4. What is the average speed of the ball?

A. 0.75 m/s **C.** 10 m/s
B. 1 m/s **D.** 1.3 m/s

5. A car accelerates from 15 m/s to 30 m/s in 3.0 s. What is the car's acceleration?

A. 10 m/s^2 **C.** 15 m/s^2
B. 25 m/s^2 **D.** 5.0 m/s^2

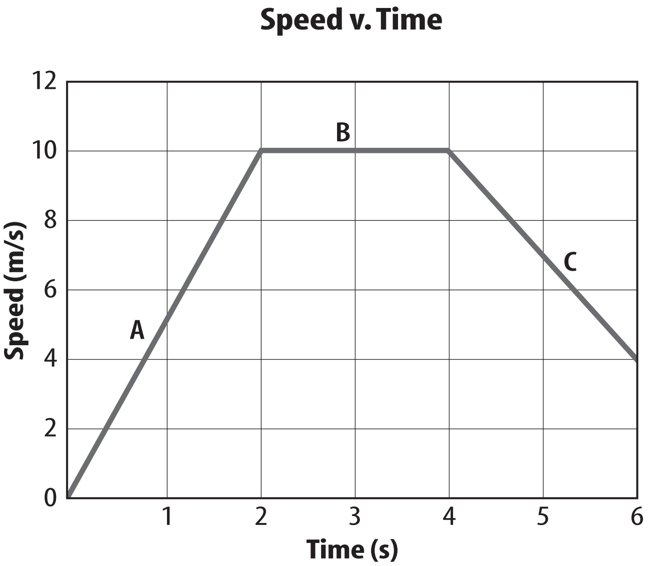
6. Which of the following can occur when an object is accelerating?

A. It speeds up. **C.** It changes direction.
B. It slows down. **D.** all of the above

7. What is the momentum of a 21-kg bicycle traveling west at 3.0 m/s?

A. 7 kg · m/s west **C.** 18 kg · m/s west
B. 63 kg · m/s west **D.** 24 kg · m/s west

Use the figure below to answer questions 8–10.



8. What is the acceleration between 0 and 2 s?

A. 10 m/s^2 **C.** 0 m/s^2
B. 5 m/s^2 **D.** -5 m/s^2

9. During what time period does the object have a constant speed?

A. between 1 and 2 s
B. between 2 and 3 s
C. between 4 and 5 s
D. between 5 and 6 s

10. What is the acceleration between 4 and 6 s?

A. 10 m/s^2 **C.** 6 m/s^2
B. 4 m/s^2 **D.** -3 m/s^2

11. An acorn falls from the top of an oak and accelerates at 9.8 m/s^2. It hits the ground in 1.5 s. What is the speed of the acorn when it hits the ground?

A. 9.8 m/s **C.** 15 m/s
B. 20 m/s **D.** 30 m/s

Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

12. Do two objects that have the same mass always have the same momentum? Why or why not?

13. What is the momentum of a 57 kg cheetah running north at 27 m/s?

14. A sports car and a moving van are traveling at a speed of 30 km/h. Which vehicle will be easier to stop? Why?

Use the figure below to answer questions 15 and 16.

15. What happens to the momentum of the bowling ball when it hits the pins?

16. What happens to the speed of the ball and the speed of the pins?

17. What is the speed of a race horse that runs 1,500 m in 125 s?

18. A car travels for 5.5 h at an average speed of 75 km/h. How far did it travel?

19. If the speedometer on a car indicates a constant speed, can you be certain the car is not accelerating? Explain.

20. A girl walks 2 km north, then 2 km east, then 2 km south, then 2 km west. What distance does she travel? What is her displacement?

Part 3 Open Ended

Record your answers on a sheet of paper.

Use the figure below to answer questions 21 and 22.

21. Describe the motion of the ball in terms of its speed, velocity, and acceleration.

22. During which part of its path does the ball have positive acceleration? During which part of its path does it have negative acceleration? Explain.

23. Describe what will happen when a baseball moving to the left strikes a bowling ball that is at rest.

24. A girl leaves school at 3:00 and starts walking home. Her house is 2 km from school. She gets home at 3:30. What was her average speed? Do you know her instantaneous speed at 3:15? Why or why not?

25. Why is it dangerous to try to cross a railroad track when a very slow-moving train is approaching?

Test-Taking Tip

Look for Missing Information Questions sometimes will ask about missing information. Notice what is missing as well as what is given.