SECTION 1

Measuring Motion

KEY TERMS
motion
displacement
speed
velocity

OBJECTIVES

- **Explain** the relationship between motion and a frame of reference.
- **Relate** speed to distance and time.
- **Distinguish** between speed and velocity.
- **Solve** problems related to time, distance, displacement, speed, and velocity.

We are surrounded by moving things. From a car moving in a straight line to a satellite traveling in a circle around Earth, objects move in many ways. In everyday life, **motion** is so common that it seems very simple. But understanding and describing motion scientifically requires some advanced concepts. To begin, how do we know when an object is moving?

motion an object's change in position relative to a reference point

Observing Motion

You may think that the motion of an object is easy to detect—just observe the object. But you actually must observe the object in relation to another object that stays in place, called a *stationary* object. The stationary object is a *reference point,* sometimes called a *reference frame.* Earth is a common reference point. In ***Figure 1,*** a mountain is used as a reference point.

When an object changes position in comparison to a reference point, the object is in motion. You can describe the direction of an object in motion with a reference direction. Typical reference directions are north, south, east, west, up, or down.

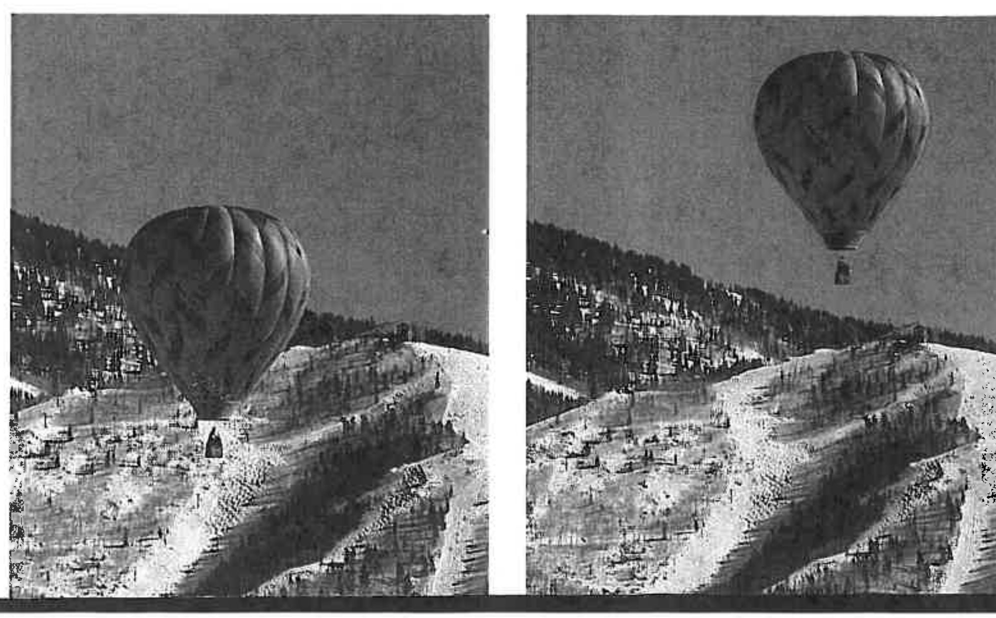

Figure 1
During the time required to take these two photographs, the hot-air balloon changed position compared with a stationary reference point—the mountain. Therefore, the balloon was in motion.

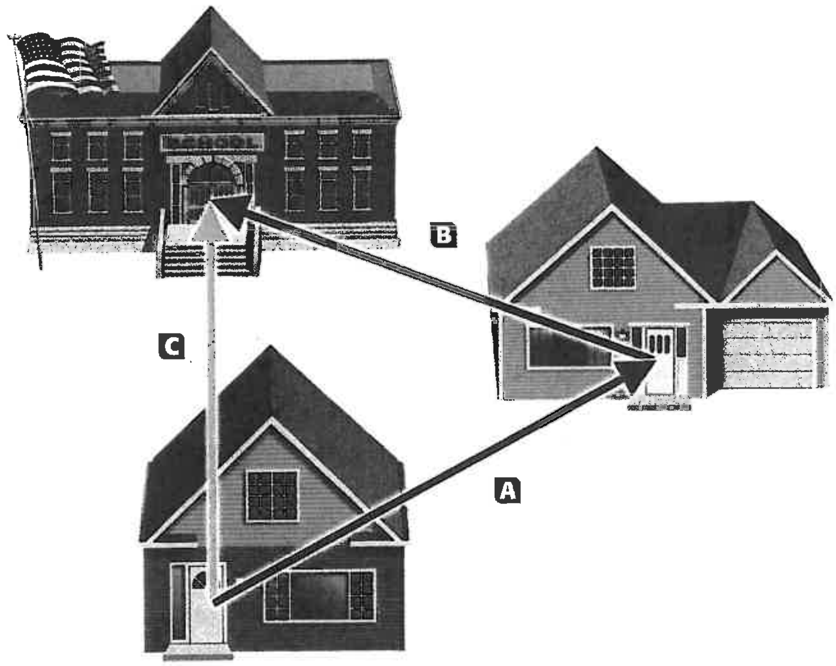

Figure 2
A student walks from his house to his friend's house (A), and then from his friend's house to the school (B). Line (A) plus line (B) equals the total distance he traveled. Line (C) is the displacement he traveled.

Distance measures the path taken

In addition to direction, you also need to know how far an object moves if you want to accurately describe its motion. To measure distance, you measure the actual path you took. If you started at your home and wandered around your neighborhood for a while by changing directions a few times, a string that followed your path would be as long as the distance you traveled.

Displacement is the change of an object's position

If you stretched a string in a straight line from your home directly to your final destination, the length of that string would be your **displacement.** This concept is illustrated in ***Figure 2*** above. In that illustration, the total of line (A) plus line (B) represents the actual distance traveled. Line (C) represents displacement, which is the change in position.

displacement the change in position of an object

There are two differences between distance and displacement: straightness and direction. Distance can be a straight line, but it doesn't have to be. Displacement must be a straight line. So, displacement is shorter than the actual distance traveled unless the actual distance traveled is a straight line from the initial position to the final position.

Also, displacement must be in a particular direction. The distance between your home and school may be twelve blocks, but that information doesn't indicate whether you are going toward or away from school. Displacement must always indicate the direction, such as twelve blocks *toward school.*

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Speed and Velocity

As has been stated, an object is moving if its position changes against some background that stays the same. In ***Figure 3,*** a horse is seen galloping against the background of stationary trees. The change in position as compared to a reference frame or reference point is measured in terms of an object's displacement from a fixed point.

You know from everyday experience that some objects move faster than others. **Speed** describes how fast an object moves. ***Figure 3*** shows speeds for some familiar things. A speeding race car moves faster than a galloping horse. But how do we determine speed?

speed the distance traveled divided by the time interval during which the motion occurred

Speed measurements involve distance and time

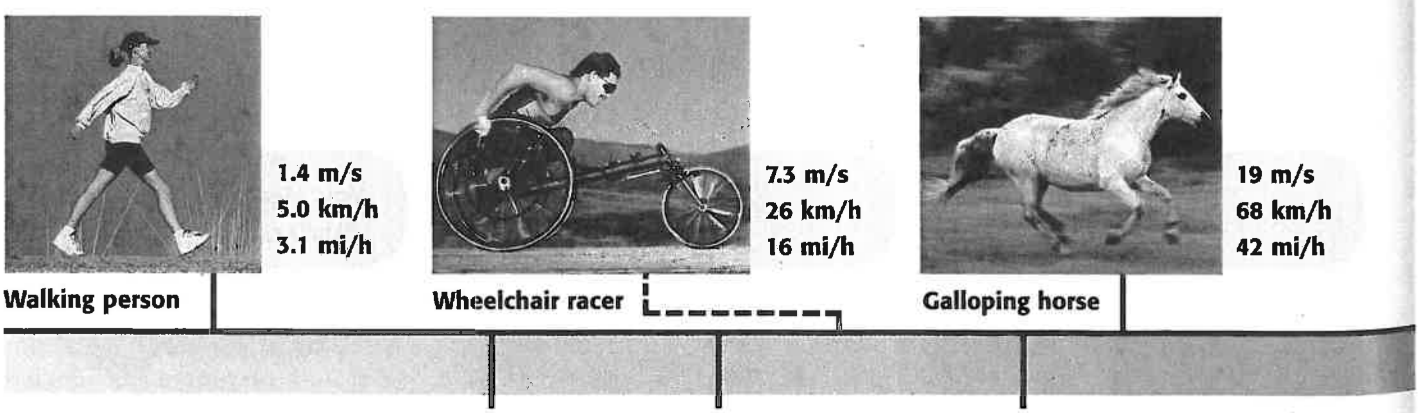
To find speed, you must measure two quantities: the distance traveled by an object and the time it took to travel that distance. Notice that all the speeds shown in ***Figure 3*** are expressed as a distance unit divided by a time unit. The SI unit for speed is meters per second (m/s). Speed is sometimes expressed in other units, such as kilometers per hour (km/h) or miles per hour (mi/h). The captions for ***Figure 3*** express speed in all three of these units of measurement.

When an object covers equal distances in equal amounts of time, it is moving at a *constant speed.* For example, if a race car has a constant speed of 96 m/s, the race car travels a distance of 96 meters every second, as shown in ***Table 1.*** So, the term *constant speed* means that the speed does not change. As you probably know, most objects do not move with constant speed.

Table 1
Distance-Time Values for a Race Car

Time (s)	Distance (m)
0	0
1	96
2	192
3	288
4	384

Figure 3
We encounter a wide range of speeds in our everyday life.



Speed can be studied with graphs and equations

You can investigate the relationship between distance and time in many ways. You can plot a graph with distance on the vertical axis and time on the horizontal axis, you can use mathematical equations and calculations, or you can combine these two approaches. Whatever method you use, your measurements are always either distances or displacements and time intervals during which the distances or displacements occur.

Speed can be determined from a distance-time graph

In a distance-time graph the distance covered by an object is noted at regular intervals of time, as shown on the line graph in ***Figure 4.*** Line graphs are usually made with the *x*-axis (horizontal axis) representing the independent variable and the *y*-axis (vertical axis) representing the dependent variable.

On our graph, time is the independent variable because time will pass whether distance is traveled or not. Distance is the dependent variable because the distance traveled depends upon the amount of time the object is moving. So, time is plotted on the *x*-axis and distance is plotted on the *y*-axis.

For a race car moving at a constant speed, the distance-time graph is a straight line. The speed of the race car can be found by calculating the slope of the line. The slope of any distance-time graph gives the speed of the object.

Suppose all objects in ***Figure 3*** are moving at a constant speed. The distance-time graph of each object is drawn in ***Figure 4.*** Notice that the distance-time graph for a faster moving object is steeper than the graph for a slower moving object. An object at rest, such as a parked car, has a speed of 0 m/s. Its position does not change as time goes by. So, the distance-time graph of a resting object is a flat line with a slope of zero.

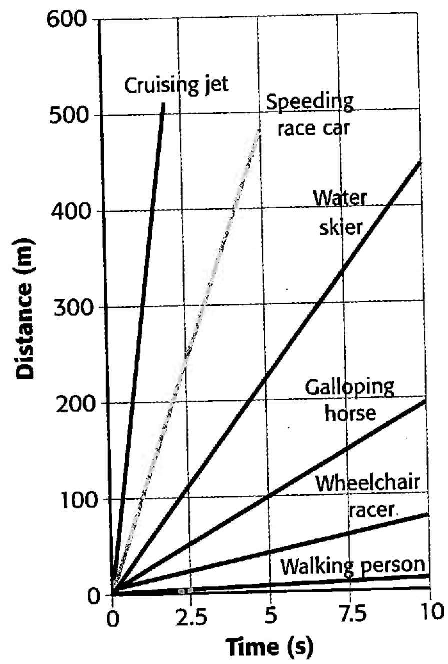


Figure 4

When an object's motion is graphed by plotting distance on the *y*-axis and time on the *x*-axis, the slope of the graph is speed.

44.4 m/s
161 km/h
100 mi/h

Water skier

96.0 m/s
346 km/h
215 mi/h

Speeding race car

257 m/s
925 km/h
575 mi/h

Cruising jet

Average speed is calculated as distance divided by time

Most objects do not move at a constant speed. The speed of an object can change from one instant to another. One way to describe the motion of an object moving at changing speeds is to use *average speed*. Average speed is simply the distance traveled by an object divided by the time the object takes to travel that distance. Average speed can also be expressed as a simple mathematical formula.

Equation for Average Speed

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

Figure 5

A wheelchair racer's speed can be determined by timing the racer on a set course.

Suppose a wheelchair racer, such as the one shown in ***Figure 5,*** finishes a 132 m race in 18 s. By inserting the time and distance measurements into the formula, you can calculate the racer's average speed.

$$v = \frac{d}{t} = \frac{132 \text{ m}}{18 \text{ s}} = 7.3 \text{ m/s}$$

The racer's average speed over the entire distance is 7.3 m/s. But the racer probably did not travel at this speed for the whole race. For instance, the racer's pace may have been faster near the start of the race and slower near the end as the racer became tired.

Instantaneous speed is the speed at a given point in time

You could find the racer's speed at any given point in time by measuring the distance traveled in a shorter time interval. The smaller the time interval, the more accurate the measurement of speed would be. Speed measured in an infinitely small time interval is called *instantaneous speed.* Although it is impossible to measure an infinitely small time interval, some devices measure speed over very small time intervals. For practical purposes, a car's speedometer gives the instantaneous speed of the car.

Velocity describes both speed and direction

velocity the speed of an object in a particular direction

Sometimes, describing the speed of an object is not enough. You may also need to know the direction in which the object is moving. In 1997, a 200 kg (450 lb) lion escaped from a zoo in Florida. The lion was located by searchers in a helicopter. The helicopter crew was able to guide searchers on the ground by reporting the lion's **velocity,** which is its speed *and* direction of motion. The escaped lion's velocity may have been reported as 4.5 m/s *to the north* or 2.0 km/h *toward the highway.* Without knowing the direction of the lion's motion, it would have been impossible to predict the lion's position.

The direction of motion can be described in various ways, such as east, west, south, or north of a fixed point. Or, it can be an angle from a fixed line. Also, direction can be described as positive or negative along the line of motion. So, if a body is moving in one direction, it has positive velocity. If it is moving in the opposite direction, it has negative velocity. In this book, velocity is considered to be positive in the direction of motion.

Math Skills

Velocity Metal stakes are sometimes placed in glaciers to help measure a glacier's movement. For several days in 1936, Alaska's Black Rapids glacier surged as swiftly as 89 meters per day down the valley. Find the glacier's velocity in m/s. Remember to include direction.

1 List the given and the unknown values.

Given: *time,* t = 1 day

displacement, d = 89 m down the valley

Unknown: *velocity,* v = ? (m/s and direction)

2 Perform any necessary conversions.

To find the velocity in meters per second, the value for time must be in seconds.

$$t = 1 \text{ day} = 24 \text{ h} \times \frac{60 \text{ min}}{1 \text{ h}} \times \frac{60 \text{ s}}{1 \text{ min}}$$

$$t = 86\,400 \text{ s} = 8.64 \times 10^4 \text{ s}$$

3 Write the equation for speed.

$$\text{speed} = \frac{\textit{displacement}}{\textit{time}} = \frac{d}{t}$$

4 Insert the known values into the equation, and solve.

$$v = \frac{d}{t} = \frac{89 \text{ m}}{8.64 \times 10^4 \text{ s}} \quad \text{(For velocity, include direction.)}$$

$$v = 1.0 \times 10^{-3} \text{ m/s down the valley}$$

Practice

Velocity

1. Find the velocity in m/s of a swimmer who swims 110 m toward the shore in 72 s.
2. Find the velocity in m/s of a baseball thrown 38 m from third base to first base in 1.7 s.
3. Calculate the displacement in meters a cyclist would travel in 5.00 h at an average velocity of 12.0 km/h to the southwest.

Practice HINT

- When a problem requires you to calculate velocity, you can use the speed equation. Remember to specify direction.
- The speed equation can also be rearranged to isolate distance or displacement on the left side of the equation in the following way.

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

Multiply both sides by t

$$v \times t = \frac{d}{t} \times t$$

$$vt = d$$

$$d = vt$$

You will need to use this form of the equation in Practice Problem 3. Remember to specify direction when you are asked for a displacement.

Figure 6
Determining Resultant Velocity

Person's resultant velocity
15 m/s east + 1 m/s east = 16 m/s east

A When you have two velocities that are in the same direction, add them together to find the resultant velocity, which is in the direction of the two velocities.

Person's resultant velocity
15 m/s east + (−1 m/s west) = 14 m/s east

B When you have two velocities that are in opposite directions, add the positive velocity to the negative velocity to find the resultant velocity, which is in the direction of the larger velocity.

Combine velocities to determine resultant velocities

If you are riding in a bus traveling east at 15 m/s, you and all the other passengers are traveling at a velocity of 15 m/s east. But suppose you stand up and walk down the bus's aisle while it is moving. Are you still moving at the same velocity as the bus? No! ***Figure 6*** shows how you can combine velocities to determine the *resultant velocity.*

SECTION 1 REVIEW

SUMMARY

- When an object changes position in comparison to a stationary reference point, the object is in motion.
- The average speed of an object is defined as the distance the object travels divided by the time of travel.
- The distance-time graph of an object moving at constant speed is a straight line. The slope of the line is the object's speed.
- The velocity of an object consists of both its speed and its direction of motion.

1. **Describe** the measurements necessary to find the average speed of a high school track athlete.
2. **Determine** the unit of a caterpillar's speed if you measure the distance in centimeters (cm) and the time it takes to travel that distance in minutes (min).
3. **Identify** the following measurements as speed or velocity.
   a. 88 km/h
   b. 19 m/s to the west
   c. 18 m/s down
   d. 10 m/s
4. **Critical Thinking** Imagine that you could ride a baseball that is hit high enough and far enough for a home run. Using the baseball as a reference frame, what does the Earth appear to do?

Math Skills

5. How much time does it take for a student running at an average speed of 5.00 m/s to cover a distance of 2.00 km?

SECTION 2

Acceleration

OBJECTIVES

- **Describe** the concept of acceleration as a change in velocity.
- **Explain** why circular motion is continuous acceleration even when the speed does not change.
- **Calculate** acceleration as the rate at which velocity changes.
- **Graph** acceleration on a velocity-time graph.

KEY TERMS
acceleration

When you increase speed, your velocity changes. Your velocity also changes if you decrease speed or if your motion changes direction. For example, your velocity changes when you turn a corner. Any time you change velocity, you are accelerating. Any change in velocity is called **acceleration.**

acceleration the rate at which velocity changes over time; an object accelerates if its speed, direction, or both change

Acceleration and Motion

Imagine that you are a race car driver. You press on the accelerator. The car goes forward, moving faster and faster each second. Like velocity, acceleration has direction. When the car is speeding up, it is accelerating positively. Positive acceleration is in the same direction as the motion and increases velocity.

Acceleration can be a change in speed

Suppose you are facing south on your bike and you start moving and speed up as you go. Every second, your southward velocity increases, as shown in ***Figure 7.*** After 1 s, your velocity is 1 m/s south. After 2 s, your velocity is 2 m/s south. Your velocity after 5 s is 5 m/s south. Your acceleration can be expressed as an increase of one meter per second per second (1 m/s/s) or 1 m/s^2 south.

Figure 7
You are accelerating whenever your speed changes. This cyclist's speed increases by 1 m/s every second.

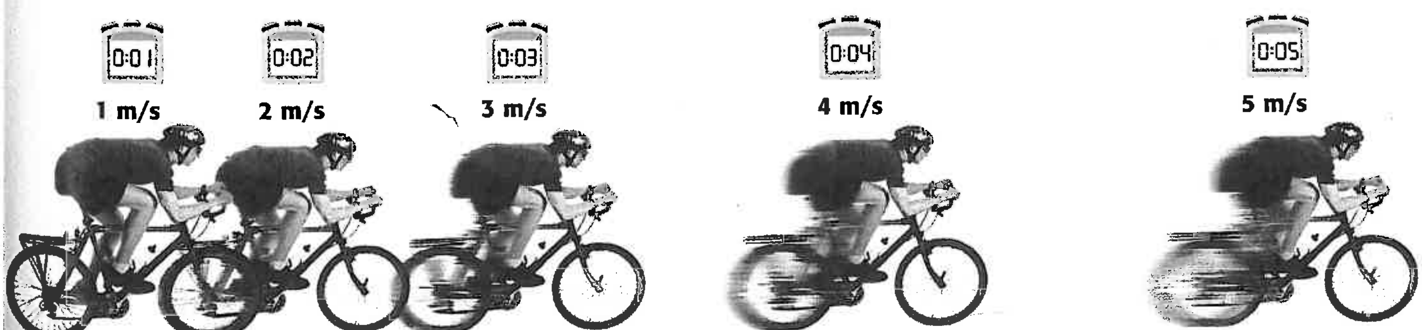


Figure 8

These skaters accelerate when changing direction, even if their speed doesn't change.

Acceleration can also be a change in direction

Besides being a change in speed, acceleration can also be a change in direction. The skaters in ***Figure 8*** are accelerating because they are changing direction. Why is changing direction considered to be an acceleration? Acceleration is defined as the rate at which velocity changes over time. Velocity includes both speed and direction, so an object accelerates if its speed, direction, or both change. This idea leads to the seemingly strange but correct conclusion that you can constantly accelerate while never speeding up or slowing down.

If you travel at a constant speed in a circle, even though your speed is never changing, your direction is always changing. So, you are always accelerating. The moon is constantly accelerating in its orbit around Earth. A motorcyclist who rides around the inside of a large barrel is constantly accelerating. When you ride a Ferris wheel at an amusement park, you are accelerating. All these examples have one thing in common—change in direction as the cause of acceleration.

Uniform circular motion is constant acceleration

Are you surprised to find out that as you stand on Earth you are accelerating? After all, you are not changing speed, and you are not changing direction—or are you? In fact, you are traveling in a circle as Earth revolves. An object traveling in a circular motion is always changing its direction. As a result, its velocity is always changing, even if its speed does not change. Thus, acceleration is occurring. The acceleration that occurs in uniform circular motion is known as centripetal acceleration. Another example of *centripetal acceleration* is shown in ***Figure 9.***

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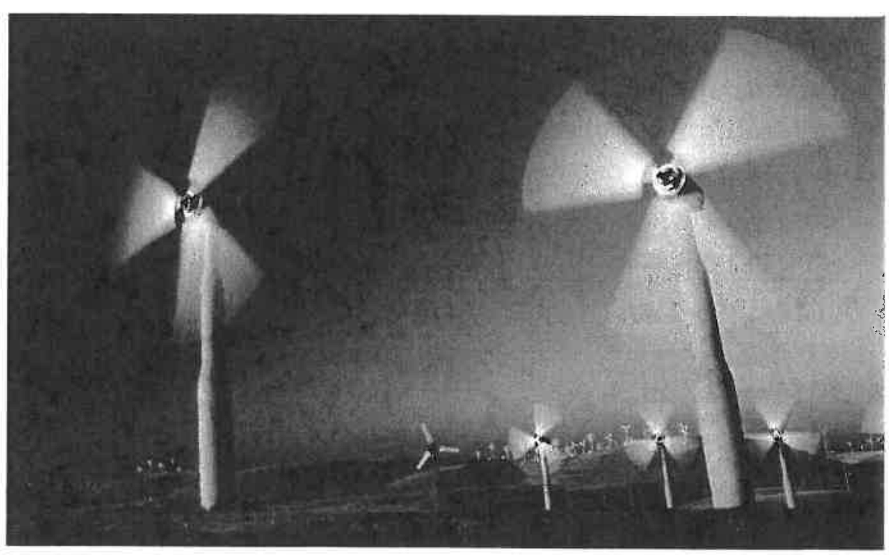


Figure 9

The blades of these windmills are constantly changing direction as they travel in a circle. So, centripetal acceleration is occurring.

Calculating Acceleration

To find the acceleration of an object moving in a straight line, you need to measure the object's velocity at different times. The average acceleration over a given time interval can be calculated by dividing the change in the object's velocity by the time in which the change occurs. The change in an object's velocity is symbolized by Δv.

Acceleration Equation (for straight-line motion)

$$acceleration = \frac{final\ velocity - initial\ velocity}{time} \qquad a = \frac{\Delta v}{t}$$

If the acceleration is small, the velocity is increasing very gradually. If the acceleration has a greater value, the velocity is increasing more rapidly. For example, a human can accelerate at about 2 m/s^2. On the other hand, a sports car that goes from 0 km/h to 96 km/h (60 mi/h) in 3.7 s has an acceleration of 7.2 m/s^2.

Because we use only positive velocity in this book, a positive acceleration always means the object's velocity is increasing—the object is speeding up. Negative acceleration means the object's velocity is decreasing—the object is slowing down.

INTEGRATING

MATHEMATICS

In the seventeenth century, both Sir Isaac Newton and Gottfried Leibniz studied acceleration and other rates of change. Independently, each created calculus, a branch of math that allows for describing rates of change of a quantity like velocity.

Acceleration is the rate at which velocity changes

People often use the word *accelerate* to mean "speed up," but in science it describes any change in velocity. Imagine that you are skating down the sidewalk. You see a large rock in your path. You slow down and swerve to avoid the rock. A friend says, "That was great acceleration. I'm amazed that you could slow down and turn so quickly!" You accelerated because your velocity changed. The velocity decreased in speed, and you changed directions. So, your velocity changed in two different ways.

The student in ***Figure 10*** is accelerating to a stop. Suppose this student was originally going at 20 m/s and stopped in 0.50 s. The change in velocity is 0 m/s − 20 m/s = −20 m/s, which is negative because the student is slowing down. The student's acceleration is

$$\frac{0\ m/s - 20\ m/s}{0.50\ s} = -40\ m/s^2$$

Figure 10

The rate of velocity change is acceleration, whether it is direction or speed that changes.

PHYSICAL SCIENCE INTERACTIVE TUTOR

Disc Two, Module 9:
Speed and Acceleration
Use the Interactive Tutor to learn more about these topics.

Practice HINT

- When a problem asks you to calculate acceleration, you can use the acceleration equation.

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

To solve for other variables, rearrange it as follows.

- To isolate t, first multiply both sides by t.

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

$$\Delta v = at$$

Next divide both sides by a.

$$\frac{\Delta v}{a} = \frac{at}{a}$$

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

You will need to use this form of the equation in Practice Problem 4.

- In Practice Problem 5, isolate final velocity.

$$v_f = v_i + at$$

When you press on the gas pedal in a car, you speed up. Your acceleration is in the direction of the motion and therefore is positive. When you press on the brake pedal, your acceleration is opposite the direction of motion. You slow down, and your acceleration is negative. When you turn the steering wheel, your velocity changes because you are changing direction.

Math Skills

Acceleration A flowerpot falls off a second-story windowsill. The flowerpot starts from rest and hits the sidewalk 1.5 s later with a velocity of 14.7 m/s. Find the average acceleration of the flowerpot.

1 List the given and unknown values.

Given: *time*, $t = 1.5$ s
initial velocity, $v_i = 0$ m/s
final velocity, $v_f = 14.7$ m/s down

Unknown: *acceleration*, $a = ?$ m/s^2 (and direction)

2 Write the equation for acceleration.

$$acceleration = \frac{final\ velocity - initial\ velocity}{time} = \frac{v_f - v_i}{t}$$

3 Insert the known values into the equation, and solve.

$$a = \frac{v_f - v_i}{t} = \frac{14.7\ \text{m/s} - 0\ \text{m/s}}{1.5\ \text{s}}$$

$$a = \frac{14.7\ \text{m/s}}{1.5\ \text{s}} = 9.8\ \text{m/s}^2\ \text{down}$$

Practice

Acceleration

1. Natalie accelerates her skateboard along a straight path from 0 m/s to 4.0 m/s in 2.5 s. Find her average acceleration.
2. A turtle swimming in a straight line toward shore has a speed of 0.50 m/s. After 4.0 s, its speed is 0.80 m/s. What is the turtle's average acceleration?
3. Find the average acceleration of a northbound subway train that slows down from 12 m/s to 9.6 m/s in 0.8 s.
4. Marisa's car accelerates at an average rate of 2.6 m/s^2. Calculate how long it takes her car to speed up from 24.6 m/s to 26.8 m/s.
5. A cyclist travels at a constant velocity of 4.5 m/s westward, and then speeds up with a steady acceleration of 2.3 m/s^2. Calculate the cyclist's speed after accelerating for 5.0 s.

Acceleration can be determined from a velocity-time graph

You have learned that an object's speed can be determined from a distance-time graph of its motion. You can also make a velocity-time graph by plotting velocity on the vertical axis and time on the horizontal axis.

A straight line on a velocity-time graph means that the velocity changes by the same amount over each time interval. This is called *constant acceleration.* The slope of a line on a velocity-time graph gives you the value of the acceleration. A line with a positive slope represents an object that is speeding up. A line with a negative slope represents an object that is slowing down. A straight horizontal line represents an object that has an unchanging velocity and therefore has no acceleration.

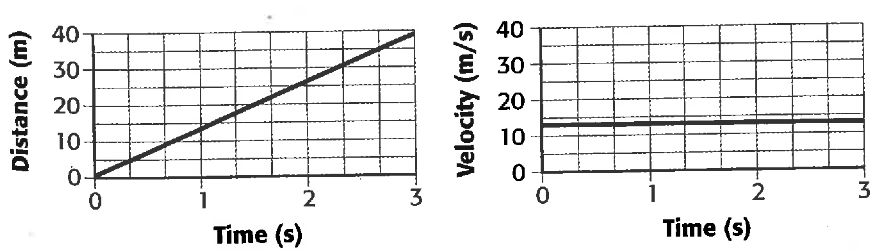
The bicyclists in ***Figure 11A*** are riding in a straight line at a constant speed of 13.00 m/s, as shown by the data in ***Table 2.*** ***Figure 11B*** is a distance-time graph for the cyclists. Because the velocity is constant, the graph is a straight line. The slope of the line equals the cyclists' velocity. ***Figure 11C*** is a velocity-time graph for the same cyclists. The slope of this line represents the cyclists' acceleration. In this case, the slope is zero (a horizontal line) because the acceleration is zero.

Did You Know?

The faster a car goes, the longer it takes a given braking force to bring the car to a stop. *Braking distance* describes how far a car travels between the moment the brakes are applied and the moment the car stops. As a car's speed increases, so does its braking distance. For example, when a car's speed is doubled, its braking distance is four times as long.

Figure 11

A When you ride your bike straight ahead at constant speed, you are not accelerating, because neither your velocity nor your direction changes.

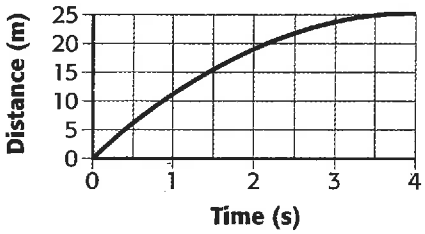


B If you plot the distance traveled against the time it takes, the resulting graph is a straight line with a slope of 13.00 m/s.

C Plotting the velocity against time results in a horizontal line because the velocity does not change. The acceleration is 0 m/s^2.

Table 2
Data for a Bicycle with Constant Speed

Time (s)	Speed (m/s)
0	13.00
1	13.00
2	13.00
3	13.00
4	13.00



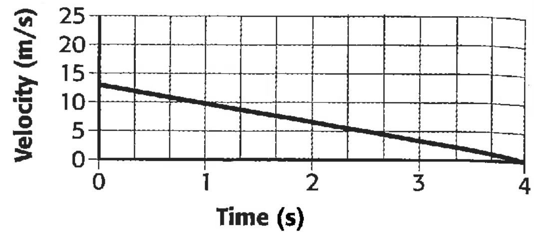


Figure 12

A When you slow down, your velocity changes. Your acceleration is negative because you are decreasing your velocity.

B If you plot the distance you travel against the time it takes you, the distance you travel each second becomes shorter and shorter until you finally stop.

C Plotting the velocity against time results in a line that has a negative slope, which means the acceleration is negative.

Table 3
Data for a Slowing Bicycle

Time (s)	Speed (m/s)
0	13.00
1	9.75
2	6.50
3	3.25
4	0

The rider in ***Figure 12A*** is slowing down from 13.00 m/s to 3.25 m/s over a period of 3.00 s, as shown by the data in ***Table 3.*** You can find out the rate at which velocity changes by calculating the acceleration.

$$a = \frac{3.25 \text{ m/s} - 13.00 \text{ m/s}}{3.00 \text{ s}} = -3.25 \text{ m/s}^2$$

The rider's velocity decreases by 3.25 m/s each second. The acceleration has a negative sign because the rider is slowing down. ***Figure 12B*** is a distance-time graph of the rider's motion, and ***Figure 12C*** is a velocity-time graph.

SECTION 2 REVIEW

SUMMARY

- Acceleration is a change in an object's velocity. Accelerating means speeding up, slowing down, or changing direction.
- For straight-line motion, average acceleration is defined as the change in an object's velocity per unit of time.
- Circular motion is acceleration because of the constant change of direction.
- A velocity-time graph can be used to determine acceleration.

1. **Identify** the straight-line accelerations below as either speeding up or slowing down.
   a. 5.7 m/s^2
   b. -9.8 m/s^2
   c. -2.43 m/s^2
   d. 9.8 m/s^2
2. **Critical Thinking** Joshua skates in a straight line at a constant speed for one minute, then begins going in circles at the same rate of speed, and then finally begins to increase speed. When is he accelerating? Explain your answer.

Math Skills

3. What is the final speed of a skater who accelerates at a rate of 2.0 m/s^2 from rest for 3.5 s?
4. Graph the velocity of a car accelerating at a uniform rate from 7.0 m/s to 12.0 m/s in 2.0 s. Calculate the acceleration.

SECTION 3

Motion and Force

OBJECTIVES

- **Explain** the effects of unbalanced forces on the motion of objects.
- **Compare and contrast** static and kinetic friction.
- **Describe** how friction may be either harmful or helpful.
- **Identify** ways in which friction can be reduced or increased.

KEY TERMS
force
friction
static friction
kinetic friction

You often hear the word **force** in everyday conversation: "That storm had a lot of force!" "Our basketball team is a force to be reckoned with." But what exactly is a force? In science, force is defined as anything that changes the state of rest or motion of an object. This section will explore how forces change motions.

force an action exerted on a body in order to change the body's state of rest or motion; force has magnitude and direction

Balanced and Unbalanced Forces

When you throw or catch a ball, you exert a force to change the ball's velocity. What causes an object to change its velocity, or accelerate? Usually, many forces are acting on an object at any given time. The *net force* is the combination of all of the forces acting on the object. Whenever there is a net force acting on an object, the object accelerates in the direction of the net force. An object will not accelerate if the net force acting on it is zero.

Balanced forces do not change motion

When the forces applied to an object produce a net force of zero, the forces are balanced. *Balanced forces* do not cause an object at rest to start moving. Furthermore, balanced forces do not cause a change in the motion of a moving object.

Many objects have only balanced forces acting on them. For example, a light hanging from the ceiling does not move up or down, because an elastic force due to tension pulls the light up and balances the force of gravity pulling the light down. A hat resting on your head is also an example of balanced forces. In ***Figure 13,*** the opposing forces on the piano are balanced. Therefore, the piano remains at rest.

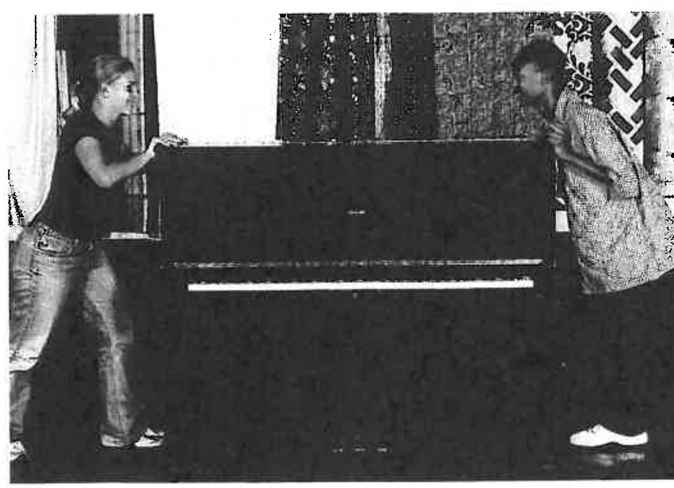
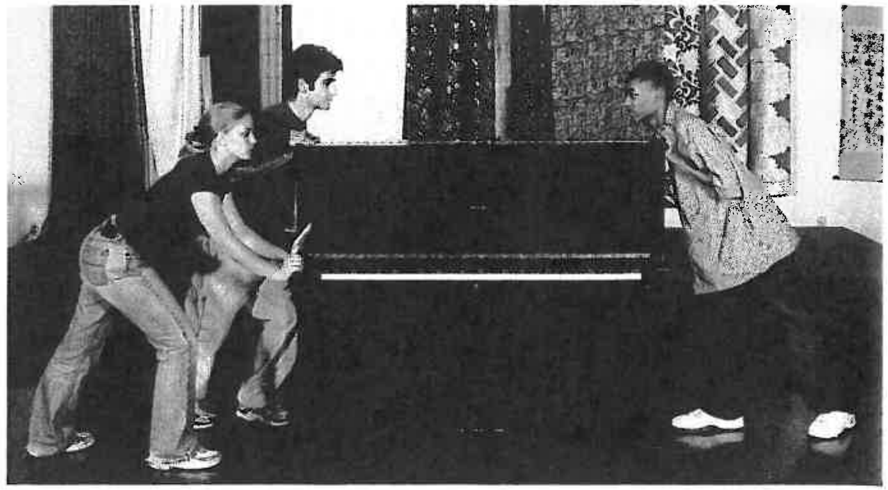


Figure 13
The forces applied by these two students balance each other, so the piano does not move.

Figure 14

When two opposite forces acting on the same object are unequal, the forces are unbalanced. A change in motion occurs in the direction of the greater force.



Unbalanced forces do not cancel completely

In ***Figure 14,*** another student pushes on one side of the piano. In this case, there are two students pushing against the piano on one side and only one student pushing against the piano on the other side. If the students all have the same mass and are all pushing with the same force, there is an *unbalanced force:* two students pushing against one student. Because the net force on the piano is greater than zero, the piano will begin to accelerate in the direction of the greater force.

What happens if forces act in different directions that are not opposite each other? In this situation, the combination of forces acts like a single force on the object, which causes acceleration in a direction that combines the directions of the applied forces. If you push eastward on a box, and your friend pushes northward, the box will accelerate in a northeasterly direction.

The Force of Friction

VOCABULARY Skills Tip

The word force *comes from the Latin word* fortis, *which means "strength." The word* fortress *comes from the same root.*

Imagine a car that is rolling along a flat, evenly paved street. Experience tells you that the car will keep slowing down until it eventually stops. This steady change in the car's speed gives you a clue that a force must be acting on the car. The unbalanced force that acts against the car's direction of motion is **friction.**

friction a force that opposes motion between two surfaces that are in contact

Friction occurs because the surface of any object is rough. Even surfaces that look or feel very smooth are actually covered with microscopic hills and valleys. When two surfaces are in contact, the hills and valleys of one surface stick to the hills and valleys of the other surface.

Friction opposes the applied force

Because of friction, a constant force must be applied to a car just to keep it moving. The force pushing the car forward must be greater than the force of friction opposing the car's motion, as shown in ***Figure 15A.*** Once the car reaches its desired speed, the car will maintain this speed if the forces acting on the car are balanced, as shown in ***Figure 15B.***

Friction also affects objects that aren't moving. For example, when a truck is parked on a hill with its brakes set, as shown in ***Figure 15C,*** friction provides the force of gravity along the hill and prevents the truck from rolling away.

Static friction is greater than kinetic friction

The friction between surfaces that are stationary is called **static friction.** The friction between moving surfaces is called **kinetic friction.** Because of forces between molecules of the two surfaces, the force required to make a stationary object start moving is usually greater than the force necessary to keep it moving. In other words, static friction is usually greater than kinetic friction.

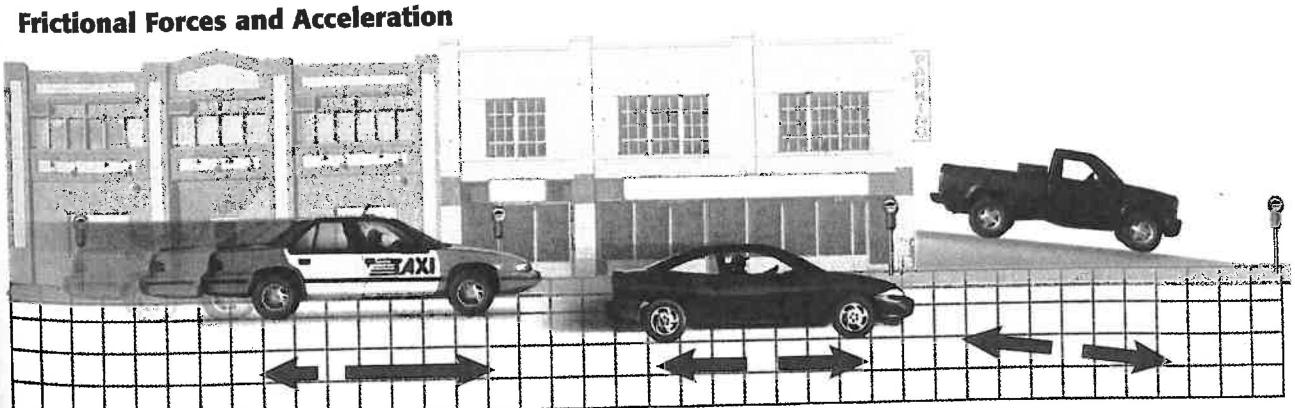
static friction the force that resists the initiation of sliding motion between two surfaces that are in contact and at rest

kinetic friction the force that opposes the movement of two surfaces that are in contact and are sliding over each other

Not all kinetic friction is the same

There are different kinds of kinetic friction. The type of friction depends on the motion and the nature of the objects. For example, when objects slide past each other, the friction that occurs is called *sliding friction.* If a round object rolls over a flat surface, the friction is called *rolling friction.* Rolling friction is usually less than sliding friction.

Figure 15
Frictional Forces and Acceleration



Unbalanced forces: acceleration

A When a car is accelerating, the forces are unbalanced. The force moving the car forward is greater than the opposing force of friction.

Balanced forces: constant speed

B When a car is cruising at constant speed, the force moving the car forward is balanced by the force of friction.

Balanced forces: no motion

C This truck does not roll, because the force of friction between the brakes and the wheels balances the gravity.

Figure 16

With the need for better fuel efficiency and increased speed, car designs have been changed to reduce air resistance. Modern cars are much more aerodynamic than cars of earlier eras.

Air resistance also opposes motion

Any object moving through a fluid such as air encounters friction between the air and the surface of the moving object. That friction is called *fluid friction.* Air slides past a car as it moves, which causes fluid friction. Fluid friction can be minimized by very smooth surfaces.

In addition to fluid friction, another factor involved in air resistance is the displacement of air. For example, as a car moves, it must push air out of the way. The car must displace a certain volume of air for each car length that it moves. Air resistance to the car's motion increases as the car travels faster, because more air must be moved each second. This effect is very different from kinetic friction. The amount of air moved depends on the shape of the car. Designing the shape of the car so that less air must be displaced, as shown in ***Figure 16,*** is called *streamlining.*

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Friction and Motion

Without friction, the tires of a car would not be able to push against the ground and move the car forward, the brakes would not be able to stop the car, and you would not even be able to grip the door handle to get inside! Without friction, a car is useless. Friction between your pencil and your paper is necessary for the pencil to leave a mark. Without friction, balls and other sports equipment would slip from your fingers when you tried to pick them up, and you would slip and fall when you tried to walk.

However, friction can cause some problems, too. In a car, friction between moving engine parts increases their temperature and causes the parts to wear down. Motor oil must be regularly added to the engine to keep it from overheating due to friction, and engine parts need to be changed as they wear out.

Harmful friction can be reduced

Because friction can be both harmful and helpful, it is sometimes desirable to reduce or increase friction. One way to reduce harmful friction is to use *lubricants*. Lubricants are substances that are applied to surfaces to reduce the friction between them. Some examples of common lubricants are motor oil, wax, and grease. ***Figure 17*** shows why lubricants are important to maintaining car parts.

Lubricants are usually liquids, but they can be solids or gases, too. An example of a lubricant gas is the air that comes out of the tiny holes of an air-hockey table.

Friction can also be reduced by replacing sliding friction with rolling friction. Ball bearings are placed between the wheels and axles of in-line skates and bicycles to reduce friction and thereby make the wheels turn more easily.

Another way to reduce friction is to make the surfaces smoother. For example, sliding across rough wood on a park bench can be uncomfortable if there is a large amount of friction between your legs and the bench. Rubbing the bench with sandpaper makes it smoother and therefore more comfortable for sitting, because the friction between the bench and your legs is reduced.

Competitive swimmers and bikers reduce the amount of fluid friction by wearing clothes that fit closely. Even their headgear is designed to decrease fluid friction in both the air and the water.

Figure 17

Motor oil is used as a lubricant in car engines. Without oil, engine parts would wear down quickly, like the connecting rod shown in the bottom of this photograph.

Helpful friction can be increased

One way to increase helpful friction is to make surfaces rougher. For example, sand scattered on icy roads keeps cars from skidding. Baseball players sometimes wear textured batting gloves to increase the friction between their hands and the bat so that the bat does not slide or fly out of their hands.

Another way to increase friction is to increase the force pushing the surfaces together. For example, you can ensure that your magazine will not blow away at the park by putting a heavy rock on it. The added mass of the rock increases the friction between the magazine and the ground or park bench. If you are sanding a piece of wood, you can sand the wood faster by pressing harder on the sandpaper. ***Figure 18*** gives another example of a way to increase helpful friction.

Figure 18

No one enjoys cleaning pans with baked-on food! To make the chore pass quickly, press down on the pan with the scrubber to increase friction.

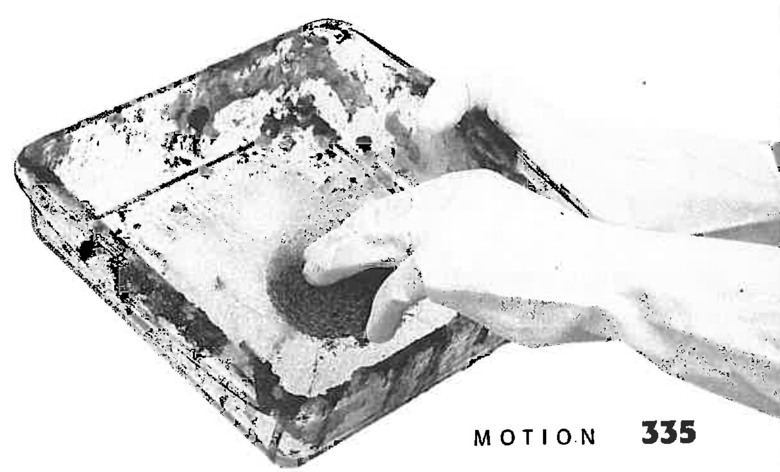


Figure 19
Without friction, a car cannot be controlled.

Cars could not move without friction

What causes a car to move? A car's wheels turn, and they push against the road. The road pushes back on the car and causes the car to accelerate. Without friction between the tires and the road, the tires would not be able to push against the road, and the car would not experience a net force. Friction, therefore, causes the acceleration (whether speeding up, slowing down, or changing direction).

Water, snow, and ice provide less friction between the road and the car than usual. Normally, as a car moves slowly over water on the road, the water is pushed out from under the tires. However, if the car moves too quickly, the water becomes trapped and cannot be pushed out from under the tires. The water trapped between the tires and the road may lift the car off the road, as shown in ***Figure 19.*** This is called *hydroplaning*. When hydroplaning occurs, there is very little friction between the tires and the water, and the car becomes difficult to control. This dangerous situation is an example of the need for friction.

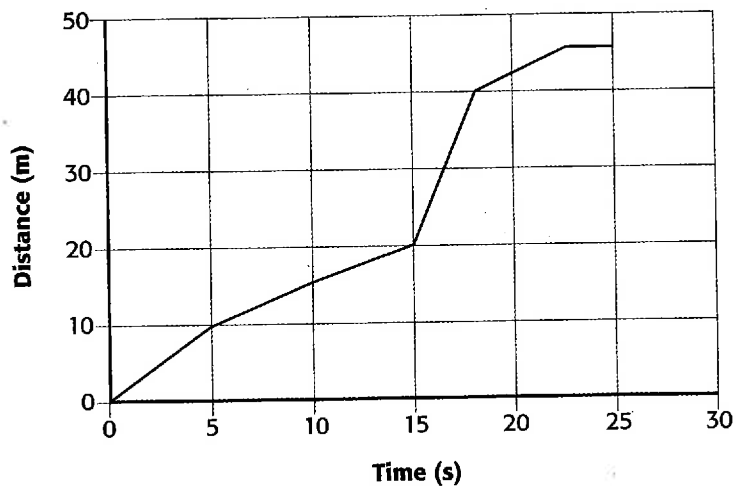
SECTION 3 REVIEW

SUMMARY

- Objects subjected to balanced forces either do not move or move at constant velocity.
- An unbalanced force must be present to cause any change in an object's state of motion or rest.
- Friction is a force that opposes motion between the surfaces of objects moving, or attempting to move, past each other.
- Static friction opposes motion between two stationary surfaces. Kinetic friction opposes motion between two surfaces that are moving past one another.
- Friction can be helpful or harmful. There are many ways to decrease or increase friction.

1. **Describe** a situation in which unbalanced forces are acting on an object. What is the net force on the object, and how does the net force change the motion of the object?
2. **Identify** the type of friction in each situation described below.
   - **a.** Two students are pushing a box that is at rest.
   - **b.** The box pushed by the students is now sliding.
   - **c.** The students put rollers under the box and push it forward.
3. **Explain** why friction is necessary to drive a car on a road. How could you increase friction on an icy road?
4. **Describe** three different ways to decrease the force of friction between two surfaces that are moving past each other.
5. **Critical Thinking** When you wrap a sandwich in plastic food wrap to protect it, you must first unroll the plastic wrap from the container, and then wrap the plastic around the sandwich. In both steps you encounter friction. In each step, is friction helpful or harmful? Explain your answer.
6. **Critical Thinking** The force pulling a truck downhill is 2000 N. What is the size of the static friction acting on the truck if the truck doesn't move?

Graphing Skills



Examine the above graph, and answer the following questions. (See Appendix A for help in interpreting a graph.)

1 Does the graph indicate an increase or decrease of the quantities? Explain your answer.

2 Identify the independent and dependent variables. What is the relationship between the two variables?

3 What information about the runner's speed can be determined from the graph? Is the speed constant during the run?

4 What is the runner's maximum speed? During what 5-second time interval does the runner reach this speed? What is the runner's minimum speed?

5 What is the total distance traveled by the runner? What trend suggests that this is the total distance run even when the graph is continued beyond the 25.0 s mark?

6 How is this graph similar to any graph showing distance traveled in a single direction over a given time interval?

7 Construct a graph best suited for the information in the table below. Assuming all measurements are made in 7.0 s, which car has the greatest acceleration? If the time interval for car B is 8.0 s instead of 7.0 s, which car has the greatest acceleration?

Car type	Maximum speed (m/s)
A	23.3
B	28.0
C	26.2