section 1

Motion

as you read

What You'll Learn

- **Define** speed and acceleration.
- **Relate** acceleration to change in speed.
- **Calculate** distance, speed, and acceleration.

Why It's Important

Motion can be described using distance, time, speed, and acceleration.

Review Vocabulary
meter: SI unit of distance, abbreviated "m," equal to approximately 39.37 in

New Vocabulary
- average speed
- instantaneous speed
- velocity
- acceleration

Speed

Imagine you're a snowboarder speeding down the side of a halfpipe. Your heart pounds as you move faster. As you reach the bottom, you are going fast, and you feel excitement and maybe even fear. You flow through the change in direction as you start up the other side. Your speed decreases as you move higher up the slope. When you reach the top, you are at a near standstill. If you think fast, you can grab hold of the ledge and take a break. Otherwise, you change direction and back down you go, speeding up again as you make your way along the U-shaped ramp.

To understand how to describe even complicated motion like this, think about the simpler movement of the bicycle in **Figure 1.** To describe how fast the bicycle is traveling, you have to know two things about its motion. One is the distance it has traveled, or how far it has gone. The other is how much time it took to travel that distance.

Average Speed A bike rider can speed up and slow down several times in a certain time period. One way to describe the bike rider's motion over this time period is to give the average speed. To calculate **average speed,** divide the distance traveled by the time it takes to travel that distance.

Speed Equation

$$\textbf{average speed} \text{ (in m/s)} = \frac{\textbf{distance traveled} \text{ (in m)}}{\textbf{time} \text{ (in s)}}$$

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

Because average speed is calculated by dividing distance by time, its units always will be a distance unit divided by a time unit. For example, the average speed of a bicycle is usually given in meters per second. The speed of a car usually has units of kilometers per hour instead.

Figure 1 To find the biker's average speed, divide the distance traveled down the hill by the time taken to cover that distance.
Infer *what would happen to the average speed if the hill were steeper.*

Applying Math — Solve a Simple Equation

BICYCLE SPEED Riding your bike, it takes you 30 min to get to your friend's house, which is 9 km away. What is your average speed?

Solution

1. *This is what you know:*
   - distance: $d = 9$ km
   - time: $t = 30$ min $= 0.5$ h
2. *This is what you need to find:* 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:
   $s = \frac{d}{t}, \frac{9\text{ km}}{0.5\text{ h}} = 18$ km/h
4. *Check your answer:* Multiply your answer by the time. You should calculate the distance that was given.

Practice Problems

1. If an airplane travels 1,350 km in 3 h, what is its average speed?
2. Determine the average speed, in km/h, of a runner who finishes a 5-km race in 18 min.

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Instantaneous Speed Average speed is useful if you don't care about the details of the motion. For example, suppose you went on a long road trip and traveled 640 km in 8 h. Your average speed was 80 km/h, even though you might have been stuck in a traffic jam for some of the time.

When your motion is speeding up and slowing down, it might be useful to know how fast you are going at a certain time. For example, suppose the speed limit on a part of the above trip was 50 km/h. Does your average speed of 80 km/h mean you were speeding during that part of the trip?

To keep from exceeding the speed limit, the driver would need to know the **instantaneous speed**—the speed of an object at any instant of time. When you ride in a car, the instantaneous speed is given by the speedometer, as shown in **Figure 2.** How does your instantaneous speed change as you coast on a bicycle down one hill and then up another one?

Reading Check *How is instantaneous speed different from average speed?*

Figure 2 The odometer in a car measures the distance traveled. The speedometer measures instantaneous speed.
Describe *how you could use an odometer to measure average speed.*

INTEGRATE Earth Science

Movement of Earth's Crust The outer part of Earth is the crust. Earth's crust is broken into huge pieces called plates that move slowly. Research how fast plates can move. In your Science Journal, make a table showing the speeds of some plates.

Constant Speed Sometimes an object is moving such that its instantaneous speed doesn't change. When the instantaneous speed doesn't change, an object is moving with constant speed. Then the average speed and the instantaneous speed are the same.

Calculating Distance If an object is moving with constant speed, then the distance it travels over any period of time can be calculated using the equation for average speed. When both sides of this equation are multiplied by the time, you have the following new equation.

Distance Equation

distance traveled (in m) = **average speed** (in m/s) × **time** (in s)

$$d = st$$

Notice that the units of time in the speed, s, and in the time, t, have to be the same. Otherwise, these units of time won't cancel.

Applying Math — Solve a Simple Equation

FAMILY TRIP DISTANCE It takes your family 2 h to drive to an amusement park at an average speed of 73 km/h. How far away is the amusement park?

Solution

1. *This is what you know:*
   - speed: $s = 73$ km/h
   - time: $t = 2$ h
2. *This is what you need to know:* distance: $d = ?$ m
3. *This is the procedure you need to use:* Substitute the known values for speed and time into the distance equation and calculate the distance: $d = st = (73 \text{ km/h})(2 \text{ h}) = 146 \text{ km}$
4. *Check your answer:* Divide your answer by the time. You should get the speed that was given.

Practice Problems

1. You and your friends walk at an average speed of 5 km/h on a nature hike. After 6 h, you reach the ranger station. How far did you hike?
2. An airplane flying from Boston to San Francisco traveled at an average speed of 830 km/h for 6 h. What distance did it fly?

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Velocity

Suppose you are walking at a constant speed on a street, headed north. You turn when you reach an intersection and start walking at the same speed, but you now are headed east, as shown in **Figure 3.** Your motion has changed, even though your speed has remained constant. To completely describe your movement, you would have to tell not only how fast you were moving, but also your direction. The **velocity** of an object is the speed of the object and its direction of motion.

Velocity changes when the speed changes, the direction of motion changes, or both change. When you turned the corner at the intersection, your direction of motion changed, even though your speed remained constant. Therefore, your velocity changed.

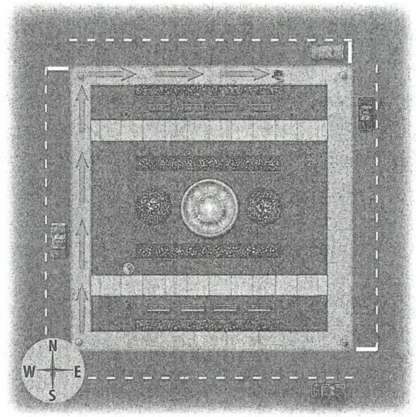


Figure 3 If you are walking north at a constant speed and then turn east, continuing at the same speed, you have changed your velocity.
Identify *another way to change your velocity.*

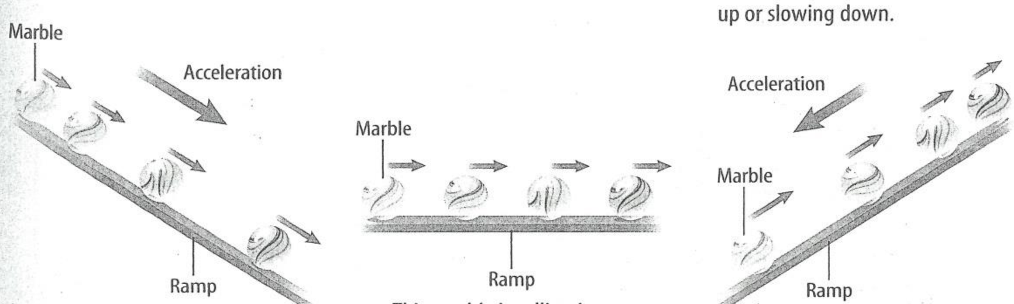
Acceleration

At the top of a skateboard halfpipe, you are at rest. Your speed is zero. When you start down, you smoothly speed up, going faster and faster. If the angle of the halfpipe were steeper, you would speed up at an even greater rate.

How could you describe how your speed is changing? If you changed direction, how could you describe how your velocity was changing? Just as speed describes how the distance traveled changes with time, acceleration describes how the velocity changes with time. **Acceleration** is the change in velocity divided by the time needed for the change to occur. **Figure 4** shows some examples of acceleration when the speed changes but the direction of motion stays the same.

Reading Check ***The motion of an object can change in what two ways when it accelerates?***

Figure 4 If the speed but not direction of an object is changing, the object is accelerating. The direction of the acceleration depends on whether the object is speeding up or slowing down.



A marble rolling in a straight line down a hill speeds up. Its motion and acceleration are in the same direction.

This marble is rolling in a straight line on a level surface with constant velocity. Its acceleration is zero.

A marble rolling in a straight line up a hill slows down. Its motion and acceleration are in opposite directions.

Calculating Acceleration If an object changes speed but not direction then its acceleration can be calculated from the following formula.

Acceleration Equation

acceleration (in m/s^2)

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

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

The SI units for acceleration are m/s^2, which means meters/(seconds × seconds). The units m/s^2 are the result when the units m/s are divided by the unit s.

Applying Math — Calculate Acceleration

ACCELERATION DOWN A HILL You are sliding on a snow-covered hill at a speed of 8 m/s. There is a drop that increases your speed to 18 m/s in 5 s. Find your acceleration.

Solution

1. *This is what you know:*
   - initial speed: $s_i = 8$ m/s
   - final speed: $s_f = 18$ m/s
   - time: $t = 5$ 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 for initial speed, final speed, and time into the acceleration equation

$$a = \frac{(s_f - s_i)}{t} = \frac{18 \text{ m/s} - 8 \text{ m/s}}{5 \text{ s}} = \frac{10 \text{ m/s}}{5 \text{ s}} = 2 \text{ m/s}^2$$

4. *Check your answer:* Multiply your answer by the time. Add the initial speed. You should get the final speed that was given.

Practice Problems

1. The roller coaster you are on is moving at 10 m/s. 5 s later it does a loop-the-loop and is moving at 25 m/s. What is the roller coaster's acceleration over this time?
2. A car you're riding in is slowing down for a stoplight. It was initially traveling at 16 m/s and comes to a stop in 9 s. What is the car's acceleration?

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Graphing Speed Picture yourself skating down the side of a hill, across a level valley, and then up another hill on the opposite side. If you were to graph your speed over time, it would look similar to the graph in **Figure 5.**

As you start down the hill, your speed will increase with time, as shown in segment A. The line on the graph rises when acceleration is in the direction of motion. When you travel across the level pavement, you move at a constant speed. Because your speed doesn't change, the line on the graph is horizontal, as shown in segment B. A horizontal line shows that the acceleration is zero. On the opposite side, when you are moving up the hill, your speed decreases, as shown in segment C. Anytime you slow down, acceleration is opposite the direction of motion, and the line on a speed-time graph will slant downward.

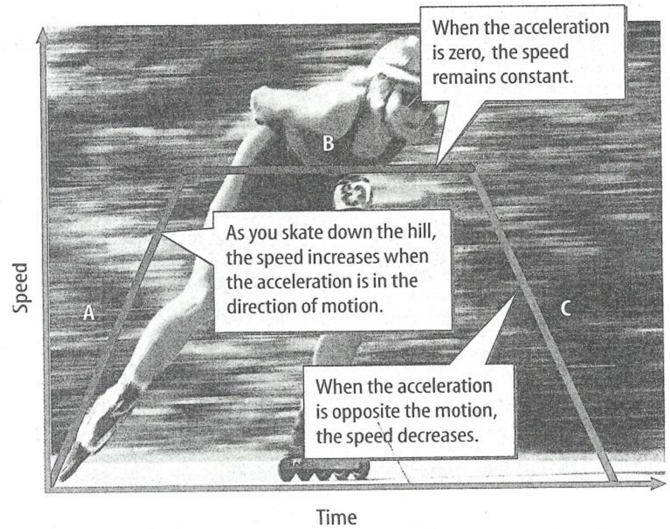


Figure 5 The acceleration of an object can be shown on a speed-time graph.

section 1 review

Summary

Speed and Velocity

- Average speed is the distance traveled divided by the travel time:

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

- The velocity of an object is the speed of the object and the direction of motion.

Acceleration

- Acceleration is the change in the velocity divided by the time for the change to occur.
- For motion in a straight line acceleration can be calculated from this equation:

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

- The slope of a line on a speed-time graph shows an object's acceleration. The line slopes upward if the object is speeding up, and slopes downward if it is slowing down.

Self Check

1. **Explain** If an airplane is flying at a constant speed of 500 km/h, can it be accelerating?
2. **Infer** whether the instantaneous speed of an object can be greater than its average speed.
3. **Determine** If your speed is constant, can your velocity be changing?
4. **Think Critically** Describe the motion of a skateboard as it accelerates down one side of a halfpipe and up the other side. What would happen if the up side of the pipe were not as steep as the down side?

Applying Math

5. **Calculate Average Speed** During rush-hour traffic in a big city, it can take 1.5 h to travel 45 km. What is the average speed in km/h for this trip?
6. **Compare** the distances traveled and average speeds of the following two people: Sam walked 1.5 m/s for 30 s and Jill walked 2.0 m/s for 15 s and then 1.0 m/s for 15 s.

section 2

Newton's Laws of Motion

as you read

What You'll Learn

- **Describe** how forces affect motion.
- **Calculate** acceleration using Newton's second law of motion.
- **Explain** Newton's third law of motion.

Why It's Important

Newton's laws explain motions as simple as walking and as complicated as a rocket's launch.

Review Vocabulary

gravity: attractive force between any two objects that depends on the masses of the objects and the distance between them

New Vocabulary

- force
- Newton's laws of motion
- friction
- inertia

Force

What causes objects to move? In the lunchroom, you pull a chair away from a table before you sit down and push it back under the table when you leave. You exert a force on the chair and cause it to move. A **force** is a push or a pull. In SI units, force is measured in newtons (N). One newton is about the amount of force it takes to lift a quarter-pound hamburger.

Force and Acceleration For an object's motion to change, a force must be applied to the object. This force causes the object to accelerate. For example, when you throw a ball, as in **Figure 6,** your hand exerts a force on the ball, causing it to speed up. The ball has acceleration because the speed of the ball has increased.

A force also can change the direction of an object's motion. After the ball leaves your hand, if no one catches it, its path curves downward, and it hits the ground. Gravity pulls the ball downward and causes it to change direction, as shown in **Figure 6.** Recall that an object has acceleration when its direction of motion changes. The force of gravity has caused the ball to accelerate. Anytime an object's speed, or direction of motion, or both change, a force must have acted on the object.

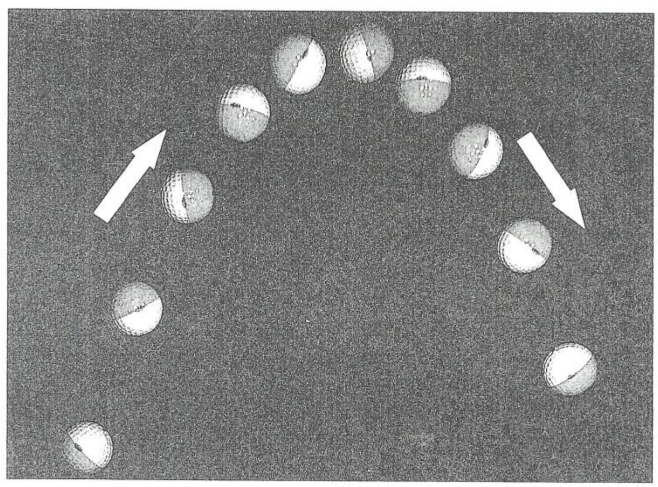
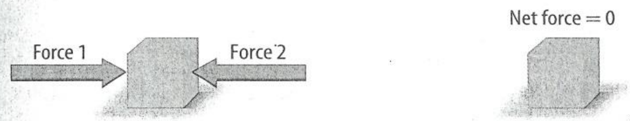
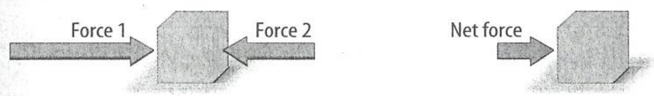


Figure 6 After a golf ball is thrown, it follows a curved path toward the ground.
Explain *how this curved path shows that the ball is accelerating.*

When two forces act in the same direction on an object, like a box, the net force is equal to the sum of the two forces.



If two forces of equal strength act on the box in opposite directions, the forces will cancel, resulting in a net force of zero.



When two unequal forces act in opposite directions on the box, the net force is the difference of the two forces.

Figure 7 When more than one force acts on an object, the forces combine to form a net force.

Balanced and Unbalanced Forces More than one force can act on an object without causing its motion to change. If both you and your friend push on a door with the same force in opposite directions, the door doesn't move. Two or more forces are balanced forces if their effects cancel each other and they do not cause a change in an object's motion. If the effects of the forces don't cancel each other, the forces are unbalanced forces.

Combining Forces Suppose you push on a door to open it. At the same time, someone on the other side of the door also is pushing. What is the motion of the door? When more than one force acts on an object, the forces combine. The combination of all the forces acting on an object is the net force.

How do forces combine to form the net force? If the forces are in the same direction, they add together to form the net force. If two forces are in opposite directions, the net force is the difference between the two forces and is in the direction of the larger force. **Figure 7** shows some examples of how forces combine to form the net force. If you push on a door with a larger force than the person on the other side pushes, the door moves in the direction of your push. If you push with the same force as the other person, the two forces cancel, and the net force is zero. In this case, the door doesn't move.

INTEGRATE Life Science

Force and Seed Germination For a fragile seedling to grow, it must exert enough force to push through the soil above it. The force exerted by the seedling as it pushes its way through the soil is due to the water pressure created inside its cells. New cells form as the seedling begins to grow underground. These cells take up water and expand, exerting a pressure that can be 20 times greater than atmospheric pressure. Research some of the factors that can affect how seedlings germinate. Write a paragraph in your Science Journal summarizing what you learned.

Mini LAB

Determining Weights in Newtons

Procedure:

1. Stand on a **bathroom scale** and measure your weight.
2. Hold a **large book,** stand on the scale, and measure the combined weight of you and the book.
3. Repeat step 2 using a **chair, heavy coat,** and a **fourth object** of your choice.

Analysis

1. Subtract your weight from each of the combined weights to calculate the weight of each object in pounds.
2. Multiply the weight of each object in pounds by 4.4 to calculate its weight in newtons.
3. Calculate your own weight in newtons.

Try at Home

Newton's Laws of Motion

In 1665, Sir Isaac Newton was in college in London. The school temporarily closed down, though, because a deadly plague was spreading rapidly across Europe. Newton, who was 23 years old, returned to his house in the country to wait for the plague to end. During this time, he spent his days observing nature and performing simple experiments. As a result, he made many discoveries, including how to explain the effects of gravity. One of his great discoveries was how forces cause motion. He realized that he could explain the motion of objects using a set of principles, which in time came to be called **Newton's laws of motion.**

Newton's First Law

When you give a book on a table a push, it slides and comes to a stop. After you throw or hit a baseball, it soon hits the ground and rolls to a stop. In fact, it seems that anytime you set something in motion, it stops moving after awhile. You might conclude that to keep an object moving, a net force must always be exerted on the object. In reality, that's not true.

Newton and a few others before him realized that an object could be moving even if no net force was acting on it. Newton's first law of motion states that an object will not change its motion unless an unbalanced force acts on it. Therefore, an object that is not moving, like a book sitting on a table, remains at rest until something pushes or pulls it.

What if an object is already moving, like a ball you've just thrown to someone? Newton's first law says the motion of the ball won't change unless an unbalanced force is exerted on it. This means that after the ball is in motion, a force has to be applied to make it speed up, slow down, or change direction. In other words, a moving object, like the ball in **Figure 8,** moves in a straight line with constant speed unless an unbalanced force acts on it.

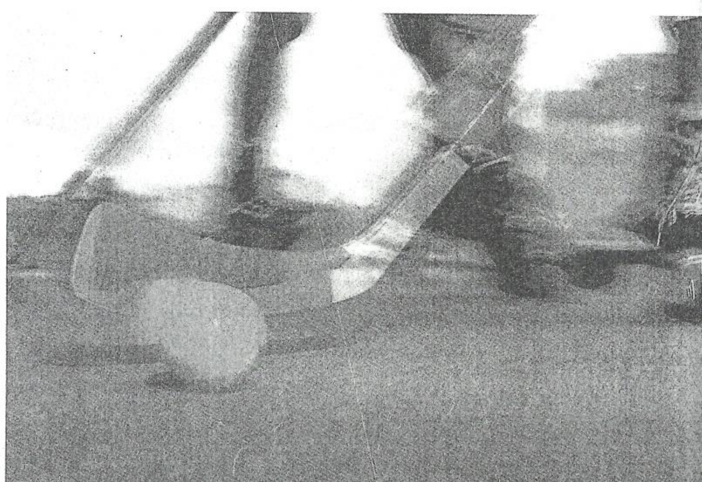


Figure 8 After the ball has been hit, it will move along the ground in a straight line until it is acted on by another force.

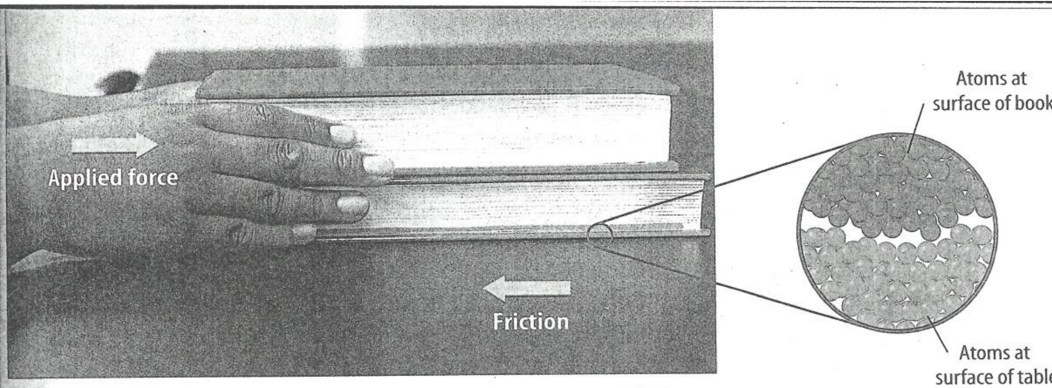


Figure 9 Friction is caused by the roughness of the surfaces in contact. The enlargement shows how the table and book surfaces might look if you could see their atoms.

Friction Newton's first law states that a moving object should never slow down or change direction until a force is exerted on it. Can you think of any moving objects that never slow down or change direction? A book slides across a table, slows down, and comes to a stop. Because its motion changes, a force must be acting on it and causing it to stop. This force is called friction. **Friction** is a force between two surfaces in contact that resists the motion of the surfaces past each other. It always acts opposite to the direction of motion, as shown in **Figure 9.** To keep an object moving when friction is acting on it, you have to keep pushing or pulling on the object to overcome the frictional force.

Reading Check *In what direction is the force of friction exerted?*

The size of the friction force depends on the two surfaces involved. In general, the rougher the surfaces are, the greater the friction will be. For example, if you push a hockey puck on an ice rink, it will go a great distance before it stops. If you try to push it with the same force on a smooth floor, it won't slide as far. If you push the puck on a rough carpet, it will barely move.

Figure 10 The cart has inertia and resists moving when you push it. **Compare** *the inertia of the cart when empty to the inertia of the cart when holding the projector.*

Inertia and Mass You might have noticed how hard it is to move a heavy object, such as a refrigerator, even when it has wheels. If you try pushing someone who is much bigger than you are—even someone who is wearing skates or standing on a skateboard—that person won't budge easily. It's easier to push someone who is smaller. You also might have noticed that it is hard to stop someone who is much bigger than you are when that person is moving. In each case, including the one shown in **Figure 10,** the object resists having its motion changed. This tendency to resist a change in motion is called **inertia.**

You know from experience that heavy objects are harder to move and harder to stop than light objects are. The more matter an object has, the harder it will be to move or stop. Mass measures the quantity of matter. The more mass an object has, the greater its inertia is.