SECTION 2

Acceleration

As You Read

What You'll Learn

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

Vocabulary

acceleration

Why It's Important

Whenever an object changes its motion, it accelerates.

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, then it accelerates because its speed increases. When an object that is already in motion speeds up, it also is accelerating. Imagine that you are biking along a level path and you start pedaling harder. Your speed increases. When its speed is increasing, an object is accelerating.

Suppose a toy car is speeding up, as shown in **Figure 7.** Each second, the car moves at a greater speed and travels a greater distance than it did in the previous second. When the car stops accelerating, it will move in a straight line at the speed it reached when the acceleration stopped.

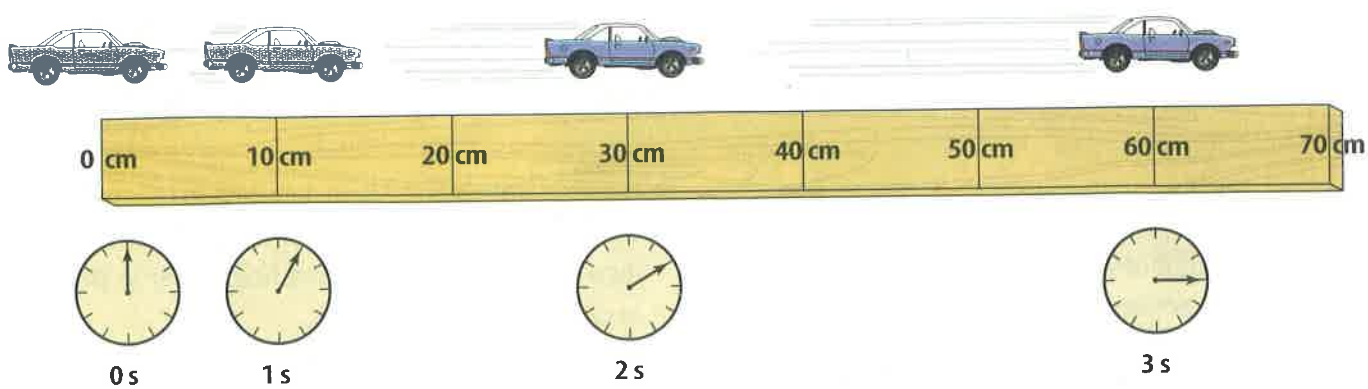
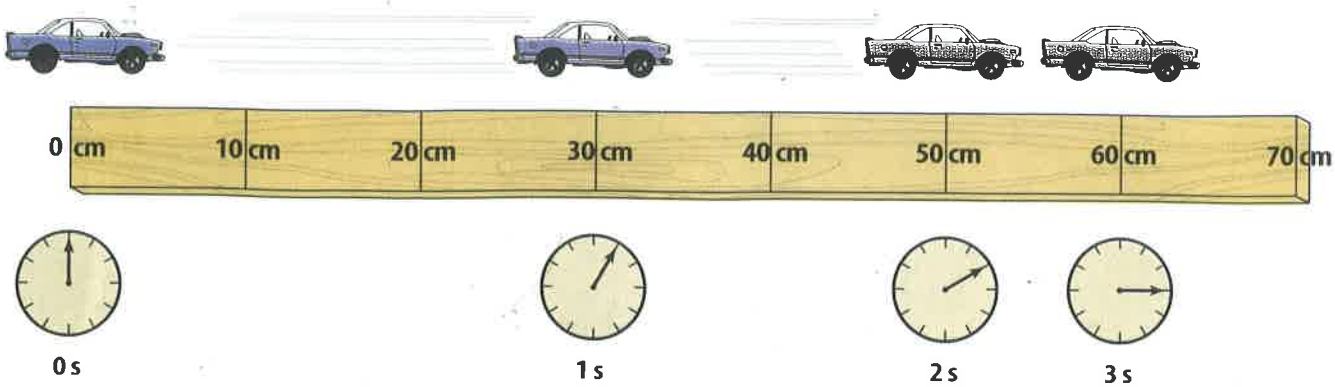


Figure 7
The toy car is accelerating to the right. The speed is increasing.



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. It might sound odd, but because your speed changes, you have accelerated. 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 each of these examples, speed is changing, so acceleration is occurring. Because speed is decreasing, the direction of the acceleration is opposite to the direction of motion. Any time an object slows down, its acceleration is in the opposite 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.

Changing Direction Motion is not always along a straight line. If the acceleration is at an angle to the direction of motion, the object will turn. At the same time, it might speed up, slow down, or have no change in speed.

Picture yourself again riding a bicycle. When you lean to one side and 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.

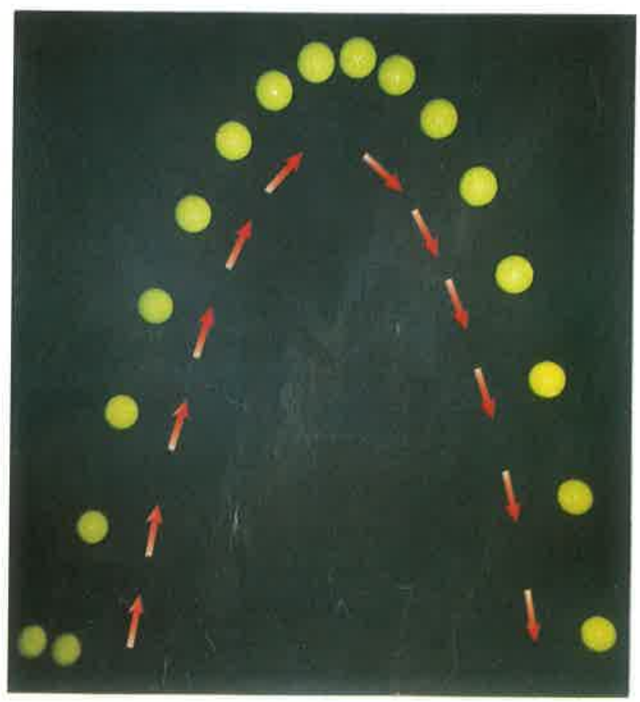


Figure 9
The ball starts out by moving forward and upward, but the acceleration is downward, so the ball's path turns in that direction.

Calculating Acceleration

If an object is moving in a straight line, its acceleration can be calculated using this equation.

$$\text{acceleration} = \frac{\text{final speed} - \text{initial speed}}{\text{time}}$$

In this equation, the final speed is the speed at the end of the time period and the initial speed is the speed at the beginning of the time period. Also, time is the length of time over which the motion changes.

This equation also can be written in a simpler way by using symbols. Let a stand for acceleration and t stand for time. Then let s_f stand for the final speed and s_i stand for the initial speed. Then the above equation can be written as follows.

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

The unit of acceleration is distance divided by time squared. In SI units, acceleration has units of meters per second squared (m/s^2).

Math Skills Activity

Calculating Acceleration

Example Problem

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

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
3. *This is the equation you need to use:* $a = (s_f - s_i)/t$
4. *Substitute the known values:* $a = (12 \text{ m/s} - 6 \text{ m/s})/(3 \text{ s}) = (6 \text{ m/s})/(3 \text{ s}) = 2 \text{ m/s}^2$

Check your answer by multiplying the calculated acceleration by the time. Then add the initial speed. Did you calculate the final speed given in the problem?

Practice Problem

A train's velocity increases from 7 m/s to 18 m/s over a period of 120 s. Calculate its acceleration.

For more help, refer to the Math Skill Handbook.

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 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 speeded up 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 the initial speed from the 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 is at the starting point. On the second beat, the walker is 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.

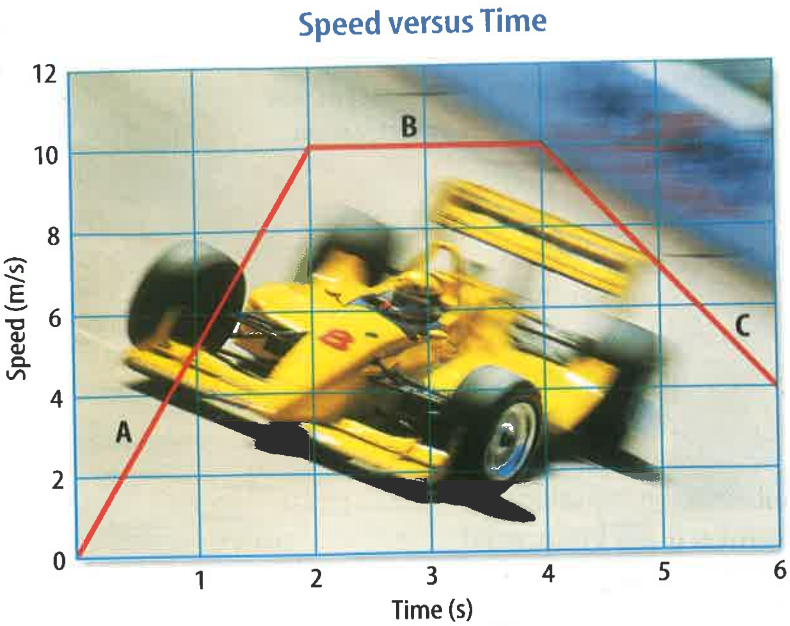


Figure 11
The speed-time graph can be used to find acceleration. When the line rises, the object is speeding up. When it is horizontal, the acceleration is zero. When the line falls, the object is slowing down.

Graphing Accelerated Motion

The motion of an object that is accelerating 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 changes from 0 m/s to 10 m/s during the first 2 s. The acceleration over this time period is 5 m/s^2. The object is speeding up, so the acceleration is positive. Look at the line in section A. It 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 speed changes from 10 m/s to 4 m/s. The acceleration is –3 m/s^2. The object is slowing down, so the acceleration is negative. 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.

Reading Check ***How is an acceleration of zero represented on a speed-time graph?***

Section 2 Assessment

1. A runner accelerates from 0 m/s to 3 m/s in 12 s. What was the acceleration?
2. A speed-time graph shows a line sloping downward. How was the speed changing?
3. In what three ways can acceleration change an object's motion?
4. An object falls with an acceleration of 9.8 m/s^2. What is its speed after 2 s?
5. **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?

Skill Builder Activities

6. **Forming Operational Definitions** Give an operational definition of acceleration. **For more help, refer to the Science Skill Handbook.**
7. **Making and Using Graphs** 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? **For more help, refer to the Science Skill Handbook.**