section 2

Acceleration

Reading Guide

What You'll Learn
- **Identify** how acceleration, time, and velocity are related.
- **Explain** how positive and negative acceleration affect motion.
- **Describe** how to calculate the acceleration of an object.

Why It's Important
Acceleration occurs all around you as objects speed up, slow down, or change direction.

Review Vocabulary
speed: rate of change of position; can be calculated by dividing the distance traveled by the time taken to travel the distance

New Vocabulary
- acceleration

Acceleration, Speed, and Velocity

You're sitting in a car at a stoplight when the light turns green. The driver steps on the gas pedal and the car starts moving faster and faster. Just as speed is the rate of change of position, **acceleration** is the rate of change of velocity. When the velocity of an object changes, the object is accelerating.

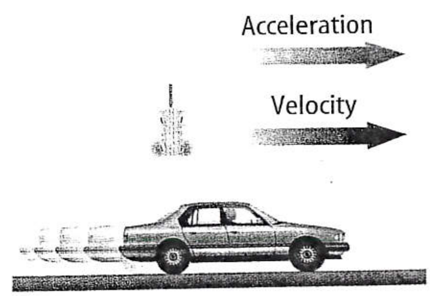
Remember that velocity includes the speed and direction of an object. Therefore, a change in velocity can be either a change in how fast something is moving or a change in the direction it is moving. Acceleration occurs when an object changes its speed, its direction, or both.

Speeding Up and Slowing Down When you think of acceleration, you probably think of something speeding up. However, an object that is slowing down also is accelerating.

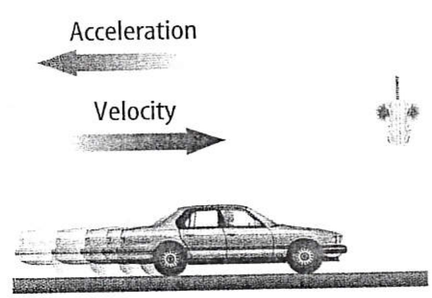
Imagine a car traveling through a city. If the speed is increasing, the car has positive acceleration. When the car slows down its speed is decreasing and the car has negative acceleration. In both cases the car is accelerating because its speed is changing.

Acceleration also has direction, just as velocity does. If the acceleration is in the same direction as the velocity, as in **Figure 10,** the speed increases and the acceleration is positive. If the speed decreases, the acceleration is in the opposite direction from the velocity, and the acceleration is negative for the car shown in **Figure 10.**

Figure 10 These cars are both accelerating because their speed is changing.



The speed of this car is increasing. The car has positive acceleration.



The speed of this car is decreasing. The car has negative acceleration.

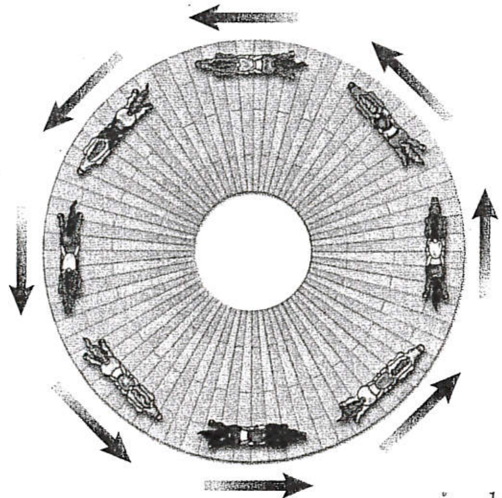


Figure 11 The speed of the horses in this carousel is constant, but the horses are accelerating because their direction is changing constantly.

INTEGRATE History

Aircraft Carriers An aircraft carrier provides a landing strip for airplanes to land and take off at sea. The carrier must be equipped to provide enough negative acceleration to stop a moving plane. The carrier also must be equipped to quickly accelerate planes to allow them to take off on a short runway. In 1911, American pilot Eugene Ely landed on a specially equipped deck on the battleship *Pennsylvania*. The experiment was successful, and today aircraft carriers are an important part of navies worldwide.

Changing Direction A change in velocity can be either a change in how fast something is moving or a change in the direction of movement. Any time a moving object changes direction, its velocity changes and it is accelerating. Think about a horse on a carousel. Although the horse's speed remains constant, the horse is accelerating because it is changing direction constantly as it travels in a circular path, as shown in **Figure 11.** In the same way, Earth is accelerating constantly as it orbits the Sun in a nearly circular path.

Graphs of speed versus time can provide information about accelerated motion. The shape of the plotted curve shows when an object is speeding up or slowing down. **Figure 12** shows how motion graphs are constructed.

Calculating Acceleration

Acceleration is the rate of change in velocity. To calculate the acceleration of an object, the change in velocity is divided by the length of the time interval over which the change occurred.

To calculate the change in velocity, subtract the initial velocity—the velocity at the beginning of the time interval—from the final velocity—the velocity at the end of the time interval. Let v_i stand for the initial velocity and v_f stand for the final velocity. Then the change in velocity is:

$$\text{change in velocity} = \text{final velocity} - \text{initial velocity} = v_f - v_i$$

Using this expression for the change in velocity, the acceleration can be calculated from the following equation:

Acceleration Equation

$$\textbf{acceleration} \text{ (in meters/second}^2\text{)} = \frac{\textbf{change in velocity} \text{ (in meters/second)}}{\textbf{time} \text{ (in seconds)}}$$

$$a = \frac{v_f - v_i}{t}$$

Recall that velocity includes both speed and direction. However, if the direction of motion doesn't change and the object moves in a straight line, the change in velocity is the same as the change in speed. The change in velocity then is the final speed minus the initial speed.

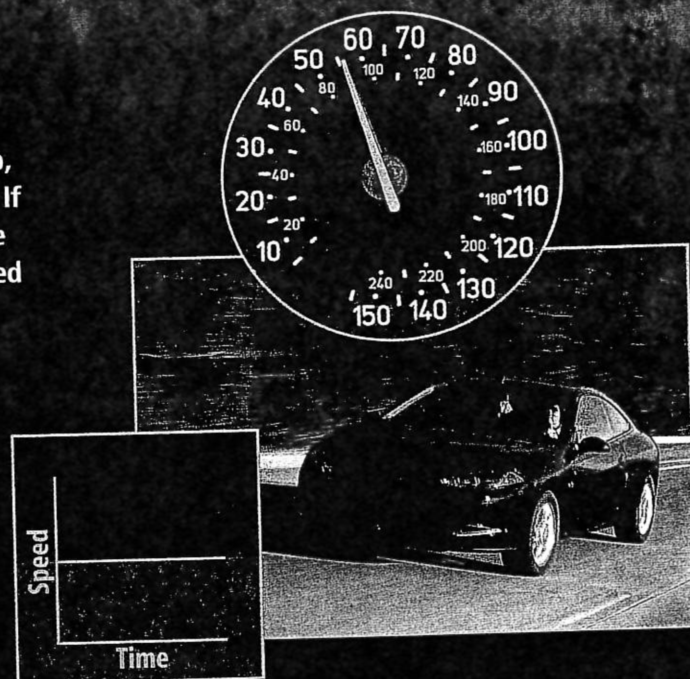
The unit for acceleration is a unit for velocity divided by a unit for time. In SI units, velocity has units of m/s, and time has units of s, so acceleration has units of m/s^2.

NATIONAL GEOGRAPHIC

VISUALIZING ACCELERATION

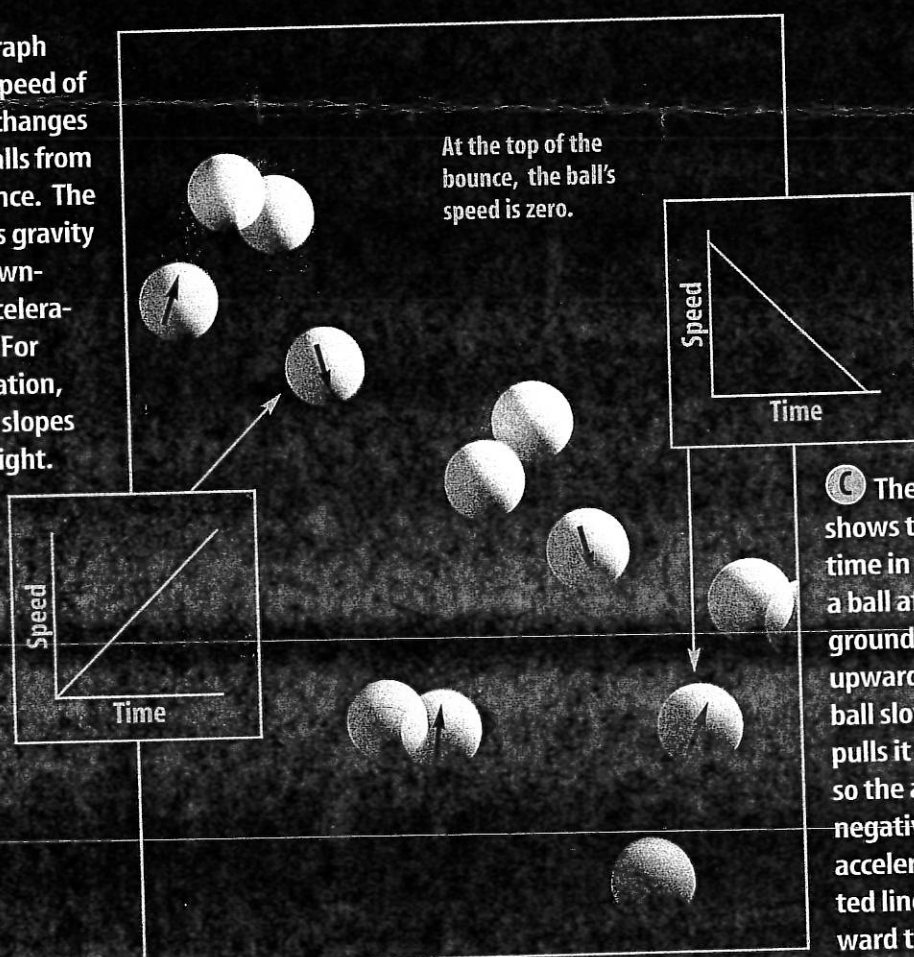
Figure 12

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



A The car in the photograph on the right is maintaining a constant speed of about 90 km/h. Because the speed is constant, the car's acceleration is zero. A graph of the car's speed with time is a horizontal line.

B The green graph shows how the speed of a bouncing ball changes with time as it falls from the top of a bounce. The ball speeds up as gravity pulls the ball downward, so the acceleration is positive. For positive acceleration, the plotted line slopes upward to the right.



C The blue graph shows the change with time in the speed of a ball after it hits the ground and bounces upward. The climbing ball slows as gravity pulls it downward, so the acceleration is negative. For negative acceleration, the plotted line slopes downward to the right.

Calculating Positive Acceleration How is the acceleration for an object that is speeding up different from that of an object that is slowing down? Suppose the jet airliner in **Figure 13** starts at rest at the end of a runway and reaches a speed of 80 m/s in 20 s. The airliner is traveling in a straight line down the runway, so its change in speed and velocity are the same. Because it started from rest, its initial speed was zero. Its acceleration can be calculated as follows:

$$a = \frac{(v_f - v_i)}{t} = \frac{(80 \text{ m/s} - 0 \text{ m/s})}{20 \text{ s}} = 4 \text{ m/s}^2$$

The airliner is speeding up, so the final speed is greater than the initial speed and the acceleration is positive.

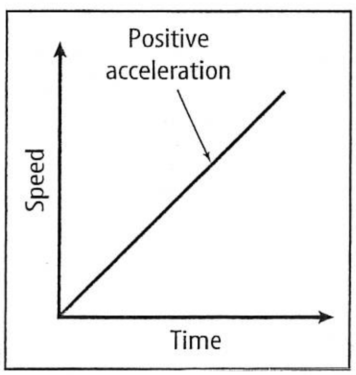
Calculating Negative Acceleration Now imagine that the skateboarder in **Figure 13** is moving in a straight line at a constant speed of 3 m/s and comes to a stop in 2 s. The final speed is zero and the initial speed was 3 m/s. The skateboarder's acceleration is calculated as follows:

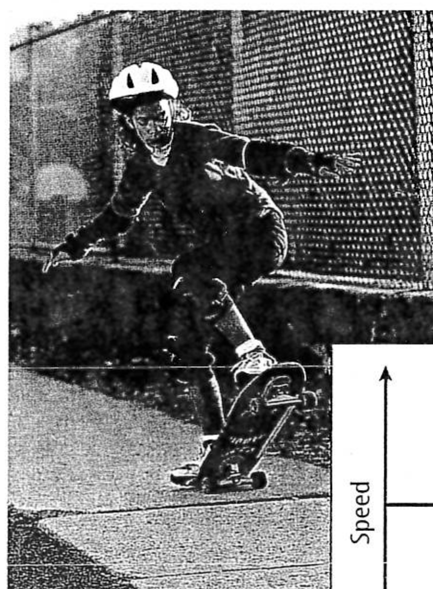
$$a = \frac{(v_f - v_i)}{t} = \frac{(0 \text{ m/s} - 3 \text{ m/s})}{2 \text{ s}} = -1.5 \text{ m/s}^2$$

The skateboarder is slowing down, so the final speed is less than the initial speed and the acceleration is negative. The acceleration always will be positive if an object is speeding up and negative if the object is slowing down.

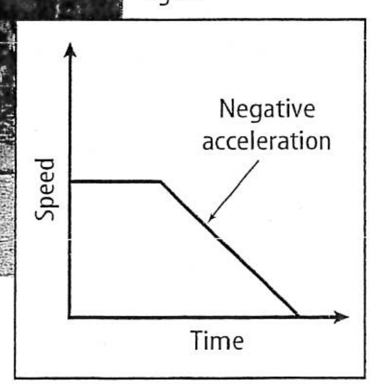
Figure 13 A speed-time graph tells you if acceleration is a positive or negative number.

If acceleration is a positive number, the line slopes upward to the right.





If acceleration is a negative number, the line slopes downward to the right.



Amusement Park Acceleration

Riding roller coasters in amusement parks can give you the feeling of danger, but these rides are designed to be safe. Engineers use the laws of physics to design amusement park rides that are thrilling, but harmless. Roller coasters are constructed of steel or wood. Because wood is not as rigid as steel, wooden roller coasters do not have hills that are as high and steep as some steel roller coasters have. As a result, the highest speeds and accelerations usually are produced on steel roller coasters.

Steel roller coasters can offer multiple steep drops and inversion loops, which give the rider large accelerations. As the rider moves down a steep hill or an inversion loop, he or she will accelerate toward the ground due to gravity. When riders go around a sharp turn, they also are accelerated. This acceleration makes them feel as if a force is pushing them toward the side of the car. **Figure 14** shows the fastest roller coaster in the United States.

✔ Reading Check *What happens when riders on a roller coaster go around a sharp turn?*

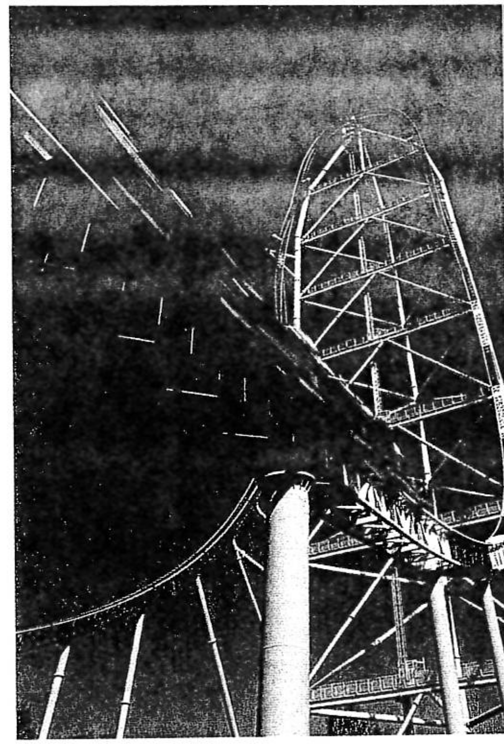


Figure 14 This roller coaster can reach a speed of about 150 km/h in 4 s.

section 2 review

Summary

Acceleration, Speed, and Velocity

- Acceleration is the rate of change of velocity.
- A change in velocity occurs when the speed of an object changes, or its direction of motion changes, or both occur.
- The speed of an object increases if the acceleration is in the same direction as the velocity.
- The speed of an object decreases if the acceleration and the velocity of the object are in opposite directions.

Calculating Acceleration

- Acceleration can be calculated by dividing the change in velocity by the time according to the following equation:

$$a = \frac{v_f - v_i}{t}$$

- The SI unit for acceleration is m/s^2.
- If an object is moving in a straight line, the change in velocity equals the final speed minus the initial speed.

Self Check

1. **Describe** three ways to change the velocity of a moving car.
2. **Determine** the change in velocity of a car that starts at rest and has a final velocity of 20 m/s north.
3. **Explain** why streets and highways have speed limits rather than velocity limits.
4. **Describe** the motion of an object that has an acceleration of 0 m/s^2.
5. **Think Critically** Suppose a car is accelerating so that its speed is increasing. Describe the plotted line on a distance-time graph of the motion of the car.

Applying Math

6. **Calculate Time** A ball is dropped from a cliff and has an acceleration of 9.8 m/s^2. How long will it take the ball to reach a speed of 24.5 m/s?
7. **Calculate Speed** A sprinter leaves the starting blocks with an acceleration of 4.5 m/s^2. What is the sprinter's speed 2 s later?