SECTION 2

Acceleration

SECTION OBJECTIVES

- **Describe motion in terms of changing velocity.**
- **Compare graphical representations of accelerated and nonaccelerated motions.**
- **Apply kinematic equations to calculate distance, time, or velocity under conditions of constant acceleration.**

SCI LINKS.
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Topic: Acceleration
Code: HF60007

CHANGES IN VELOCITY

Many bullet trains have a top speed of about 300 km/h. Because a train stops to load and unload passengers, it does not always travel at that top speed. For some of the time the train is in motion, its velocity is either increasing or decreasing. It loses speed as it slows down to stop and gains speed as it pulls away and heads for the next station.

Acceleration is the rate of change of velocity with respect to time

Similarly, when a shuttle bus approaches a stop, the driver begins to apply the brakes to slow down 5.0 s before actually reaching the stop. The speed changes from 9.0 m/s to 0 m/s over a time interval of 5.0 s. Sometimes, however, the shuttle stops much more quickly. For example, if the driver slams on the brakes to avoid hitting a dog, the bus slows from 9.0 m/s to 0 m/s in just 1.5 s.

Clearly, these two stops are very different, even though the shuttle's velocity changes by the same amount in both cases. What is different in these two examples is the time interval during which the change in velocity occurs. As you can imagine, this difference has a great effect on the motion of the bus, as well as on the comfort and safety of the passengers. A sudden change in velocity feels very different from a slow, gradual change.

The quantity that describes the rate of change of velocity in a given time interval is called **acceleration.** The magnitude of the average acceleration is calculated by dividing the total change in an object's velocity by the time interval in which the change occurs.

acceleration

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

AVERAGE ACCELERATION

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

$$\textbf{average acceleration} = \frac{\textbf{change in velocity}}{\textbf{time required for change}}$$

Acceleration has dimensions of length divided by time squared. The units of acceleration in SI are meters per second per second, which is written as meters per second squared, as shown below. When measured in these units, acceleration describes how much the velocity changes in each second.

$$\frac{(\text{m/s})}{\text{s}} = \frac{\text{m}}{\text{s}} \times \frac{1}{\text{s}} = \frac{\text{m}}{\text{s}^2}$$

SAMPLE PROBLEM B

Average Acceleration

PROBLEM

A shuttle bus slows down with an average acceleration of -1.8 m/s^2. How long does it take the bus to slow from 9.0 m/s to a complete stop?

SOLUTION

Given: $v_i = 9.0$ m/s
$v_f = 0$ m/s
$a_{avg} = -1.8$ m/s^2

Unknown: $\Delta t = ?$

TIP: *Watch for implied data in problem statements, such as "starts at rest" ($v_i = 0$ m/s) or "comes to rest" ($v_f = 0$ m/s).*

Rearrange the average acceleration equation to solve for the time interval.

$$a_{avg} = \frac{\Delta v}{\Delta t}$$

$$\Delta t = \frac{\Delta v}{a_{avg}} = \frac{v_f - v_i}{a_{avg}} = \frac{0 \text{ m/s} - 9.0 \text{ m/s}}{-1.8 \text{ m/s}^2}$$

$$\boxed{\Delta t = 5.0 \text{ s}}$$

PRACTICE B

Average Acceleration

1. As the shuttle bus comes to a sudden stop to avoid hitting a dog, it accelerates uniformly at -4.1 m/s^2 as it slows from 9.0 m/s to 0.0 m/s. Find the time interval of acceleration for the bus.
2. A car traveling at 7.0 m/s accelerates uniformly at 2.5 m/s^2 to reach a speed of 12.0 m/s. How long does it take for this acceleration to occur?
3. With an average acceleration of -1.2 m/s^2, how long will it take a cyclist to bring a bicycle with an initial speed of 6.5 m/s to a complete stop?
4. Turner's treadmill runs with a velocity of -1.2 m/s and speeds up at regular intervals during a half-hour workout. After 25 min, the treadmill has a velocity of -6.5 m/s. What is the average acceleration of the treadmill during this period?
5. Suppose a treadmill has an average acceleration of 4.7×10^{-3} m/s^2.
   a. How much does its speed change after 5.0 min?
   b. If the treadmill's initial speed is 1.7 m/s, what will its final speed be?

Figure 9
High-speed trains such as this one can travel at speeds of about 300 km/h (186 mi/h).

Acceleration has direction and magnitude

Figure 9 shows a high-speed train leaving a station. Imagine that the train is moving to the right so that the displacement and the velocity are positive. The velocity increases in magnitude as the train picks up speed. Therefore, the final velocity will be greater than the initial velocity, and Δv will be positive. When Δv is positive, the acceleration is positive.

On long trips with no stops, the train may travel for a while at a constant velocity. In this situation, because the velocity is not changing, $\Delta v = 0$ m/s. When the velocity is constant, the acceleration is equal to zero.

Imagine that the train, still traveling in the positive direction, slows down as it approaches the next station. In this case, the velocity is still positive, but the initial velocity is larger than the final velocity, so Δv will be negative. When Δv is negative, the acceleration is negative.

The slope and shape of the graph describe the object's motion

As with all motion graphs, the slope and shape of the velocity-time graph in **Figure 10** allow a detailed analysis of the train's motion over time. When the train leaves the station, its speed is increasing over time. The line on the graph plotting this motion slopes up and to the right, as at point **A** on the graph.

When the train moves with a constant velocity, the line on the graph continues to the right, but it is horizontal, with a slope equal to zero. This indicates that the train's velocity is constant, as at point **B** on the graph.

Finally, as the train approaches the station, its velocity decreases over time. The graph segment representing this motion slopes down to the right, as at point **C** on the graph. This downward slope indicates that the velocity is decreasing over time.

A negative value for the acceleration does not always indicate a decrease in speed. For example, if the train were moving in the negative direction, the acceleration would be negative when the train gained speed to leave a station and positive when the train lost speed to enter a station.

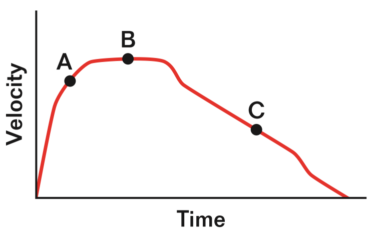

Figure 10
When the velocity in the positive direction is increasing, the acceleration is positive, as at point A. When the velocity is constant, there is no acceleration, as at point B. When the velocity in the positive direction is decreasing, the acceleration is negative, as at point C.

Why it Matters

Conceptual Challenge

1. Fly Ball If a baseball has zero velocity at some instant, is the acceleration of the baseball necessarily zero at that instant? Explain, and give examples.

2. Runaway Train If a passenger train is traveling on a straight track with a negative velocity and a positive acceleration, is it speeding up or slowing down?

3. Hike-and-Bike Trail When Jennifer is out for a ride, she slows down on her bike as she approaches a group of hikers on a trail. Explain how her acceleration can be positive even though her speed is decreasing.

Table 3 shows how the signs of the velocity and acceleration can be combined to give a description of an object's motion. From this table, you can see that a negative acceleration can describe an object that is speeding up (when the velocity is negative) or an object that is slowing down (when the velocity is positive). Use this table to check your answers to problems involving acceleration.

For example, in **Figure 10** the initial velocity v_i of the train is positive. At point **A** on the graph, the train's velocity is still increasing, so its acceleration is positive as well. The first entry in **Table 3** shows that in this situation, the train is speeding up. At point **C,** the velocity is still positive, but it is decreasing, so the train's acceleration is negative. **Table 3** tells you that in this case, the train is slowing down.

Table 3 Velocity and Acceleration

v_i	a	Motion
+	+	speeding up
–	–	speeding up
+	–	slowing down
–	+	slowing down
– or +	0	constant velocity
0	– or +	speeding up from rest
0	0	remaining at rest

MOTION WITH CONSTANT ACCELERATION

Figure 11 is a strobe photograph of a ball moving in a straight line with constant acceleration. While the ball was moving, its image was captured ten times in one second, so the time interval between successive images is 0.10 s. As the ball's velocity increases, the ball travels a greater distance during each time interval. In this example, the velocity increases by exactly the same amount during each time interval. Thus, the acceleration is constant. Because the velocity increases for each time interval, the successive change in displacement for each time interval increases. You can see this in the photograph by noting that the distance between images increases while the time interval between images remains constant. The relationships between displacement, velocity, and constant acceleration are expressed by equations that apply to any object moving with constant acceleration.

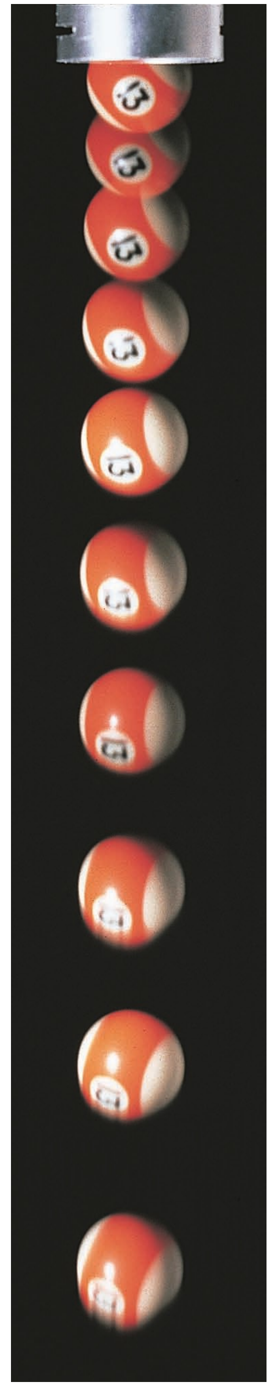

Figure 11
The motion in this picture took place in about 1.00 s. In this short time interval, your eyes could only detect a blur. This photo shows what really happens within that time.