Answer to Essential Question 2.6: Using $v_i = 0$ reduces Equation 2.9 to $v = at$. Doubling the time doubles the final velocity, so the object dropped from the building that is four times higher has a final velocity twice as large as that of the other object. Equation 2.12 gives the same result.

2-7 Example Problem

Let's look at the various representations of motion with constant acceleration, considering the example of a ball tossed straight up in the air.

EXPLORATION 2.7 – A ball tossed straight up

You toss a ball straight up into the air. The ball takes 2.0 s to reach its maximum height, and an additional 2.0 s to return to your hand. You catch the ball at the same height from which you let it go, and the ball has a constant acceleration because it is acted on only by gravity. Consider the motion from the instant just after you release the ball until just before you catch it.

Step 1 – *Picture the scene – draw a diagram of the situation.* The diagram in Figure 2.19 shows the initial conditions, the origin, and the positive direction. We are free to choose either up or down as the positive direction, and to choose any reference point as the origin. In this case let's choose the origin to be the point from which the ball was released, and choose up to be positive.

Step 2 – *Organize the data.* Table 2.2 summarizes what we know, including values for the acceleration and the initial position. We need these values for the constant-acceleration equations. Because the ball moves under the influence of gravity alone, and we can assume the ball is on the Earth, the acceleration is the acceleration due to gravity, 9.8 m/s^2 directed down. Because down is the negative direction, we include a negative sign: $a = -9.8\,\text{m/s}^2$.

Parameter	Value
Origin	Launch point
Positive direction	up
Initial position	$x_i = 0$
Initial velocity	$v_i = +$_____ m/s
Acceleration	$a = -9.8\text{ m/s}^2$
Position at t = 4.0 s	$x_{t=4\text{ s}} = x_i = 0$

Table 2.2: Summarizing the information that was given about the ball.

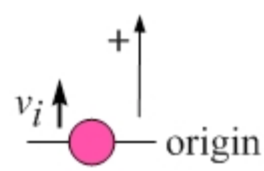

Figure 2.19: A diagram of the initial situation.

Step 3 – *Solve the problem.* In this case, we want to draw graphs of the acceleration, velocity, and position of the ball, all as a function of time. To do this we should first write equations for the acceleration, velocity, and position. The acceleration is constant at $a = -9.8\,\text{m/s}^2$. Knowing the acceleration allows us to solve for the initial velocity. One way to do this is to re-arrange Equation 2.9 to give $v_i = v - at$. Because $v = 0$ at t = 2.0 s (the ball is at rest for an instant when it reaches its maximum height) we get $v_i = v - at = 0 - \left(-9.8\text{ m/s}^2\right)\left(2.0\text{ s}\right) = +19.6\text{ m/s}$.

Knowing the initial velocity enables us to write equations for the ball's velocity (using Equation 2.9) and position (using Equation 2.11) as a function of time. The equations, and corresponding graphs, are part of the multiple representations of the motion shown in Figure 2.20. Note that the position versus time graph is parabolic, but the motion is confined to a line.

Step 4 - *Sketch a motion diagram for the ball.* The motion diagram is shown on the right in Figure 2.15. Note the symmetry of the up and down motions (this is also apparent from the graphs). The motion of the ball on the way down is a mirror image of its motion on the way up.

(a) Description of the motion: A ball you toss straight up into the air reaches its maximum height 2.0 s after being released, taking an addition 2.0 s to return to your hand. It experiences a constant acceleration from the moment you release it until just before you catch it.

(b) Equations (up is positive): Acceleration-versus-time: $a = -9.8\text{ m/s}^2$

Velocity-versus-time: $v = +19.6\text{ m/s} - (9.8\text{ m/s}^2)t$

Position-versus-time: $x = +(19.6\text{ m/s})t - (4.9\text{ m/s}^2)t^2$

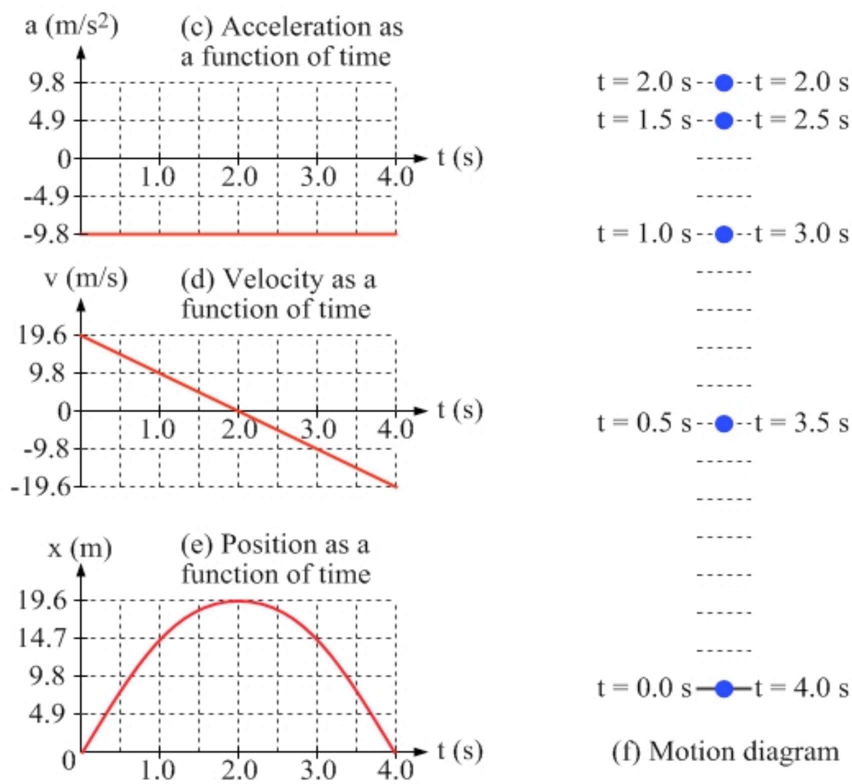

Figure 2.20: Multiple representations of a ball thrown straight up, including (a) a description in words; (b) equations for the ball's acceleration, velocity, and position; graphs giving the ball's (c) acceleration, (d) velocity, and (e) position as a function of time; and (f) a motion diagram. These different perspectives show how various aspects of the motion evolve with time.

Key ideas: At the Earth's surface the acceleration due to gravity has a constant value of $g = 9.8\text{ m/s}^2$ directed down. We can thus apply constant-acceleration methods to situations involving objects dropped or thrown into the air. For an object that is thrown straight up the downward part of the trip is a mirror image of the upward part of the trip.
Related End-of-Chapter Exercises: 33, 61, and 62.

Essential Question 2.7: Consider again the ball in Exploration 2.7. The ball comes to rest for an instant at its maximum-height point. What is the ball's acceleration at that point?