Galileo's specific contribution to our understanding of the motion of falling objects can be summarized as follows:

Galileo's hypothesis: free fall is at constant acceleration g

at a given location on the Earth and in the absence of air resistance, all objects fall with the same constant acceleration.

We call this acceleration the **acceleration due to gravity** on the Earth, and we give it the symbol g. Its magnitude is approximately

Acceleration due to gravity

$$g = 9.80\ \mathrm{m/s^2}. \qquad \text{[at surface of Earth]}$$

In British units g is about 32 ft/s^2. Actually, g varies slightly according to latitude and elevation, but these variations are so small that we will ignore them for most purposes. The effects of air resistance are often small, and we will neglect them for the most part. However, air resistance will be noticeable even on a reasonably heavy object if the velocity becomes large.† Acceleration due to gravity is a vector, as is any acceleration, and its direction is toward the center of the Earth.

When dealing with freely falling objects we can make use of Eqs. 2–11, where for a we use the value of g given above. Also, since the motion is vertical we will substitute y in place of x, and y_0 in place of x_0. We take $y_0 = 0$ unless otherwise specified. *It is arbitrary whether we choose y to be positive in the upward direction or in the downward direction; but we must be consistent about it throughout a problem's solution.*

PROBLEM SOLVING
You choose y to be positive either up or down

EXAMPLE 2–10 **Falling from a tower.** Suppose that a ball is dropped $(v_0 = 0)$ from a tower 70.0 m high. How far will the ball have fallen after a time $t_1 = 1.00\ \mathrm{s}$, $t_2 = 2.00\ \mathrm{s}$, and $t_3 = 3.00\ \mathrm{s}$?

"Drop" means $v_0 = 0$

APPROACH Let us take y as positive downward. We neglect any air resistance. Thus the acceleration is $a = g = +9.80\ \mathrm{m/s^2}$, which is positive because we have chosen downward as positive. We set $v_0 = 0$ and $y_0 = 0$. We want to find the position y of the ball after three different time intervals. Equation 2–11b, with x replaced by y, relates the given quantities (t, a, and v_0) to the unknown y.

SOLUTION We set $t = t_1 = 1.00\ \mathrm{s}$ in Eq. 2–11b:

$$y_1 = v_0 t_1 + \tfrac{1}{2}at_1^2$$
$$= 0 + \tfrac{1}{2}at_1^2 = \tfrac{1}{2}(9.80\ \mathrm{m/s^2})(1.00\ \mathrm{s})^2 = 4.90\ \mathrm{m}.$$

The ball has fallen a distance of 4.90 m during the time interval $t = 0$ to $t_1 = 1.00\ \mathrm{s}$. Similarly, after 2.00 s $(= t_2)$, the ball's position is

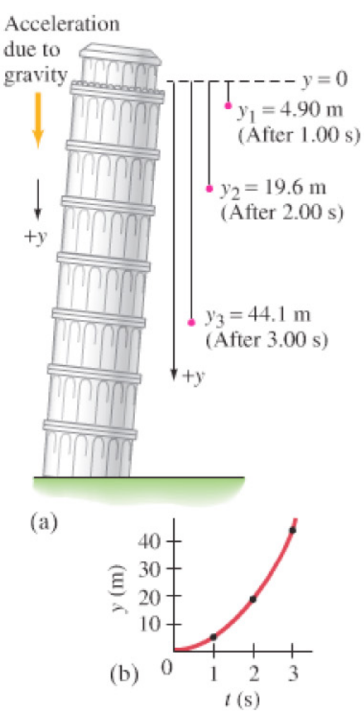
$$y_2 = \tfrac{1}{2}at_2^2 = \tfrac{1}{2}(9.80\ \mathrm{m/s^2})(2.00\ \mathrm{s})^2 = 19.6\ \mathrm{m}.$$

Finally, after 3.00 s $(= t_3)$, the ball's position is (see Fig. 2–21)

$$y_3 = \tfrac{1}{2}at_3^2 = \tfrac{1}{2}(9.80\ \mathrm{m/s^2})(3.00\ \mathrm{s})^2 = 44.1\ \mathrm{m}.$$

NOTE Whenever we say "dropped," we mean $v_0 = 0$.

FIGURE 2–21 Example 2–10. (a) An object dropped from a tower falls with progressively greater speed and covers greater distance with each successive second. (See also Fig. 2–18.) (b) Graph of y vs. t.



EXAMPLE 2–11 **Thrown down from a tower.** Suppose the ball in Example 2–10 is *thrown* downward with an initial velocity of 3.00 m/s, instead of being dropped. (*a*) What then would be its position after 1.00 s and 2.00 s? (*b*) What would its speed be after 1.00 s and 2.00 s? Compare with the speeds of a dropped ball.

APPROACH We can approach this in the same way as in Example 2–10. Again we use Eq. 2–11b, but now v_0 is not zero, it is $v_0 = 3.00\ \mathrm{m/s}$.

SOLUTION (*a*) At $t = 1.00\ \mathrm{s}$, the position of the ball as given by Eq. 2–11b is

$$y = v_0 t + \tfrac{1}{2}at^2 = (3.00\ \mathrm{m/s})(1.00\ \mathrm{s}) + \tfrac{1}{2}(9.80\ \mathrm{m/s^2})(1.00\ \mathrm{s})^2 = 7.90\ \mathrm{m}.$$

At $t = 2.00\ \mathrm{s}$, (time interval $t = 0$ to $t = 2.00\ \mathrm{s}$), the position is

$$y = v_0 t + \tfrac{1}{2}at^2 = (3.00\ \mathrm{m/s})(2.00\ \mathrm{s}) + \tfrac{1}{2}(9.80\ \mathrm{m/s^2})(2.00\ \mathrm{s})^2 = 25.6\ \mathrm{m}.$$

As expected, the ball falls farther each second than if it were dropped with $v_0 = 0$.

†The speed of an object falling in air (or other fluid) does not increase indefinitely. If the object falls far enough, it will reach a maximum velocity called the **terminal velocity** due to air resistance.