EXERCISE C Two balls are thrown from a cliff. One is thrown directly up, the other directly down. Both balls have the same initial speed, and both hit the ground below the cliff. Which ball hits the ground at the greater speed: (*a*) the ball thrown upward, (*b*) the ball thrown downward, or (*c*) both the same? Ignore air resistance. [*Hint*: See the result of Example 2–14, part (*b*).]

The acceleration of objects such as rockets and fast airplanes is often given as a multiple of $g = 9.80\,\mathrm{m/s^2}$. For example, a plane pulling out of a dive and undergoing 3.00 g's would have an acceleration of $(3.00)(9.80\,\mathrm{m/s^2}) = 29.4\,\mathrm{m/s^2}$.

Acceleration expressed in g's

EXERCISE D If a car is said to accelerate at $0.50\,g$, what is its acceleration in $\mathrm{m/s^2}$?

Additional Example—Using the Quadratic Formula

EXAMPLE 2–15 **Ball thrown upward, III.** For the ball in Example 2–14, calculate at what time t the ball passes a point 8.00 m above the person's hand.

APPROACH We choose the time interval from the throw ($t = 0$, $v_0 = 15.0\,\mathrm{m/s}$) until the time t (to be determined) when the ball is at position $y = 8.00\,\mathrm{m}$, using Eq. 2–11b.

SOLUTION We want t, given $y = 8.00\,\mathrm{m}$, $y_0 = 0$, $v_0 = 15.0\,\mathrm{m/s}$, and $a = -9.80\,\mathrm{m/s^2}$. We use Eq. 2–11b:

$$y = y_0 + v_0 t + \tfrac{1}{2}at^2$$

$$8.00\,\mathrm{m} = 0 + (15.0\,\mathrm{m/s})\,t + \tfrac{1}{2}(-9.80\,\mathrm{m/s^2})t^2.$$

To solve any quadratic equation of the form $at^2 + bt + c = 0$, where a, b, and c are constants (a is *not* acceleration here), we use the **quadratic formula** (see Appendix A–4):

PROBLEM SOLVING
Using the quadratic formula

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.$$

We rewrite our y equation just above in standard form, $at^2 + bt + c = 0$:

$$(4.90\,\mathrm{m/s^2})t^2 - (15.0\,\mathrm{m/s})\,t + (8.00\,\mathrm{m}) = 0.$$

So the coefficient a is $4.90\,\mathrm{m/s^2}$, b is $-15.0\,\mathrm{m/s}$, and c is 8.00 m. Putting these into the quadratic formula, we obtain

$$t = \frac{15.0\,\mathrm{m/s} \pm \sqrt{(15.0\,\mathrm{m/s})^2 - 4(4.90\,\mathrm{m/s^2})(8.00\,\mathrm{m})}}{2(4.90\,\mathrm{m/s^2})},$$

which gives us $t = 0.69\,\mathrm{s}$ and $t = 2.37\,\mathrm{s}$. Are both solutions valid? Yes, because the ball passes $y = 8.00\,\mathrm{m}$ when it goes up ($t = 0.69\,\mathrm{s}$) and again when it comes down ($t = 2.37\,\mathrm{s}$).

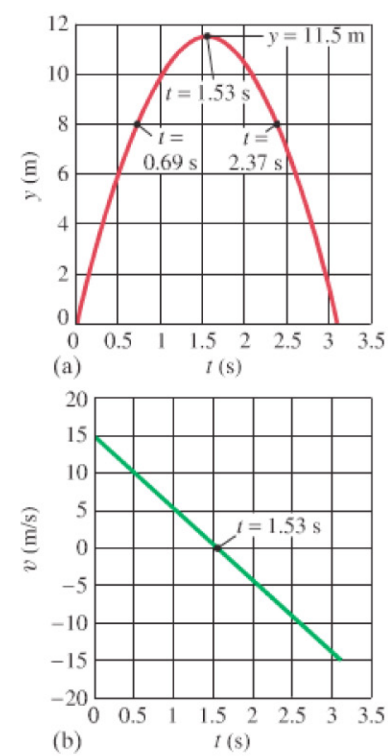

FIGURE 2–23 Graphs of (a) y vs. t, (b) v vs. t for a ball thrown upward, Examples 2–12, 2–14, and 2–15.

For some people, graphs can be a help in understanding. Figure 2–23 shows graphs of y vs. t and v vs. t for the ball thrown upward in Fig. 2–22, incorporating the results of Examples 2–12, 2–14, and 2–15. We shall discuss some useful properties of graphs in the next Section.

We will use the word "vertical" a lot in this book. What does it mean? (Try to respond before reading on.) Vertical is defined as the line along which an object falls. Or, if you put a small sphere on the end of a string and let it hang, the string represents a vertical line (sometimes called a *plumb line*).

EXERCISE E What does *horizontal* mean?