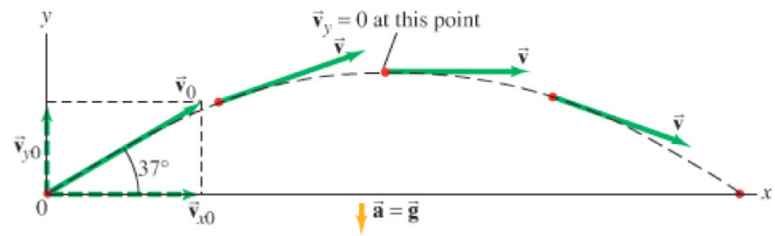

FIGURE 3–22 Example 3–5.

PHYSICS APPLIED
Sports

EXAMPLE 3–5 **A kicked football.** A football is kicked at an angle $\theta_0 = 37.0°$ with a velocity of 20.0 m/s, as shown in Fig. 3–22. Calculate (*a*) the maximum height, (*b*) the time of travel before the football hits the ground, (*c*) how far away it hits the ground, (*d*) the velocity vector at the maximum height, and (*e*) the acceleration vector at maximum height. Assume the ball leaves the foot at ground level, and ignore air resistance and rotation of the ball.

APPROACH This may seem difficult at first because there are so many questions. But we can deal with them one at a time. We take the y direction as positive upward, and treat the x and y motions separately. The total time in the air is again determined by the y motion. The x motion occurs at constant velocity. The y component of velocity varies, being positive (upward) initially, decreasing to zero at the highest point, and then becoming negative as the football falls.

SOLUTION We resolve the initial velocity into its components (Fig. 3–22):

$$v_{x0} = v_0 \cos 37.0° = (20.0\text{ m/s})(0.799) = 16.0\text{ m/s}$$
$$v_{y0} = v_0 \sin 37.0° = (20.0\text{ m/s})(0.602) = 12.0\text{ m/s}.$$

(*a*) We consider a time interval that begins just after the football loses contact with the foot until it reaches its maximum height. During this time interval, the acceleration is g downward. At the maximum height, the velocity is horizontal (Fig. 3–22), so $v_y = 0$; and this occurs at a time given by $v_y = v_{y0} - gt$ with $v_y = 0$ (see Eq. 2–11a in Table 3–2). Thus

$$t = \frac{v_{y0}}{g} = \frac{(12.0\text{ m/s})}{(9.80\text{ m/s}^2)} = 1.22\text{ s}.$$

From Eq. 2–11b, with $y_0 = 0$, we have

$$y = v_{y0}t - \tfrac{1}{2}gt^2$$
$$= (12.0\text{ m/s})(1.22\text{ s}) - \tfrac{1}{2}(9.80\text{ m/s}^2)(1.22\text{ s})^2 = 7.35\text{ m}.$$

Alternatively, we could have used Eq. 2–11c, solved for y, and found

$$y = \frac{v_{y0}^2 - v_y^2}{2g} = \frac{(12.0\text{ m/s})^2 - (0\text{ m/s})^2}{2(9.80\text{ m/s}^2)} = 7.35\text{ m}.$$

The maximum height is 7.35 m.

(*b*) To find the time it takes for the ball to return to the ground, we consider a different time interval, starting at the moment the ball leaves the foot $(t = 0,\ y_0 = 0)$ and ending just before the ball touches the ground ($y = 0$ again). We can use Eq. 2–11b with $y_0 = 0$ and also set $y = 0$ (ground level):

$$y = y_0 + v_{y0}t - \tfrac{1}{2}gt^2$$
$$0 = 0 + (12.0\text{ m/s})t - \tfrac{1}{2}(9.80\text{ m/s}^2)t^2.$$

This equation can be easily factored:

$$\left[\tfrac{1}{2}(9.80\text{ m/s}^2)t - 12.0\text{ m/s}\right]t = 0.$$

There are two solutions, $t = 0$ (which corresponds to the initial point, y_0), and

$$t = \frac{2(12.0\text{ m/s})}{(9.80\text{ m/s}^2)} = 2.45\text{ s},$$

which is the total travel time of the football.