at ground.

0.950 m high. It rolls off and hits the ground ... m from the edge of the table. How fast was the ball rolling?

Sand Blast

Answers question from page 148.

Projectiles Launched at an Angle

When a projectile is launched at an angle, the initial velocity has a vertical component as well as a horizontal component. If the object is launched upward, then it rises with slowing speed, reaches the top of its path, and descends with increasing speed. This is what happens to the sand in the photo at the beginning of this chapter. **Figure 7–7a** shows the separate vertical and horizontal motion diagrams for the trajectory. The coordinate system is chosen with $+x$ horizontal and $+y$ vertical. Note the symmetry. At each point in the vertical direction, the velocity of the object as it is moving up has the same magnitude as when it is moving down, but the directions of the two velocities are opposite.

Figure 7–7b defines two quantities associated with the trajectory. One is the **maximum height,** which is the height of the projectile when the vertical velocity is zero and the projectile has only its horizontal velocity component. The other quantity depicted is the **range,** R, which is the horizontal distance the projectile travels. Not shown is the **flight time,** which is the time the projectile is in the air. In the game of football, flight time is usually called hang time.

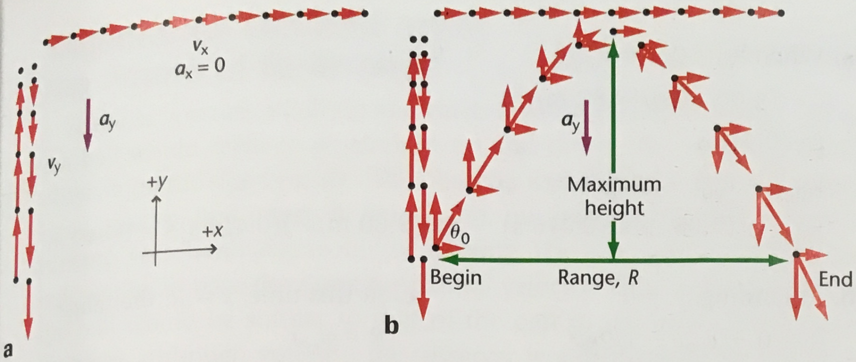
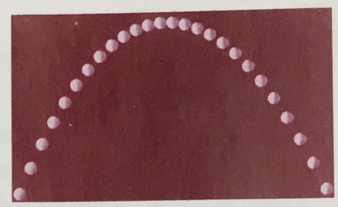


FIGURE 7–7 The vector sum of $\mathbf{v}_x$ and $\mathbf{v}_y$, at each position, points in the direction of the flight.

Example Problem

The Flight of a Ball



The ball in the strobe photo was launched with an initial velocity of 4.47 m/s at an angle of 66° above the horizontal.

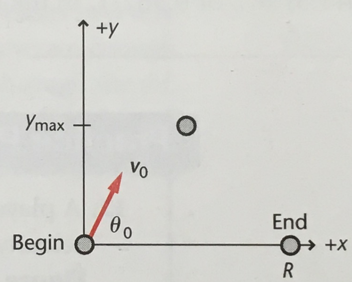
a. What was the maximum height the ball attained?

b. How long did it take the ball to return to the launching height?

c. What was its range?

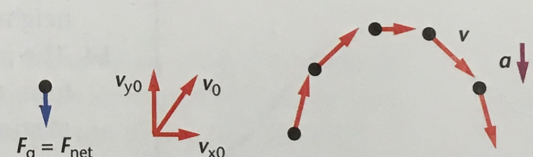
Sketch the Problem

- Establish a coordinate system. One choice for the initial position of the ball is at the origin.
- Show the positions of the ball at maximum height and at the end of the flight.
- Draw a motion diagram showing the $\boldsymbol{v}$, $\boldsymbol{a}$, and $\boldsymbol{F}_{net}$.



Calculate Your Answer

Known:	Unknown:
$x_0 = 0$	y, when $v_y = 0$
$y_0 = 0$	$t = ?$
$v_0 = 4.47$ m/s	x, when $y = 0$
$\theta_0 = 66°$	
$a = -g$	



Strategy:

a. Write the equations for the initial velocity components, the velocity components at time t, and the position in both directions. The vertical velocity is zero when the ball reaches maximum height. Solve the velocity equation for the time of maximum height. Substitute this time into the vertical-position equation to find the height.

b. Solve the vertical-position equation for the time of the end of the flight, when $y = 0$.

c. Substitute that time into the equation for horizontal distance to get the range.

Continued on next page

Calculations:

y-direction:

$v_{y0} = v_0 \sin \theta_0$

$v_{y0} = (4.47 \text{ m/s})\sin 66°$

$v_{y0} = 4.08 \text{ m/s}$

$v_y = v_{y0} - gt$

$y = y_0 + v_{y0}t - 1/2gt^2$

x-direction:

$v_{x0} = v_0 \cos \theta_0$

$v_x = v_{x0}$

$x = x_0 + v_{x0}t$

a. When $v_y = 0$, $t = v_{y0}/g$

$t = (4.08 \text{ m/s})/(9.80 \text{ m/s}^2)$

$t = 0.416 \text{ s}$

$y_{max} = v_{y0}t - 1/2gt^2$

$y_{max} = (4.08 \text{ m/s})(0.416 \text{ s}) - 1/2(9.80 \text{ m/s}^2)(0.416 \text{ s})^2 = 0.849 \text{ m}$

b. At landing, $y = 0$

$0 = 0 + v_{y0}t - 1/2gt^2$

$t = 2v_{y0}/g$

$= 2(4.08 \text{ m/s})/(9.80 \text{ m/s}^2)$

$= 0.833 \text{ s}$

c. At this time, $x = R$, the range

$R = v_{x0}t$

$= (4.47 \text{ m/s})(\cos 66°)(0.833 \text{ s})$

$= 1.51 \text{ m}$

Check Your Answer

- Are the units correct? Performing algebra on the units verifies that time is in s, velocity is in m/s, and distance is in m.
- Do the signs make sense? All should be positive.
- Are the magnitudes realistic? Compare them with those in the photo. The calculated flight time is 0.833 s. At 30 flashes/s, this would be 25 flashes, and 25 are visible. The scale of the photo is unknown, as it is, but the ratio of the maximum height to range is (0.849 m)/(1.51 m), or 0.562/1, in the photo.

Practice Problems

12. A player kicks a football from ground level with an initial velocity of 27.0 m/s, 30.0° above the horizontal, as shown in **Figure 7–8.** Find the ball's hang time, range, and maximum height. Assume air resistance is negligible.

13. The player then kicks the ball with the same speed, but at 60.0° from the horizontal. What is the ball's hang time, range, and maximum height?

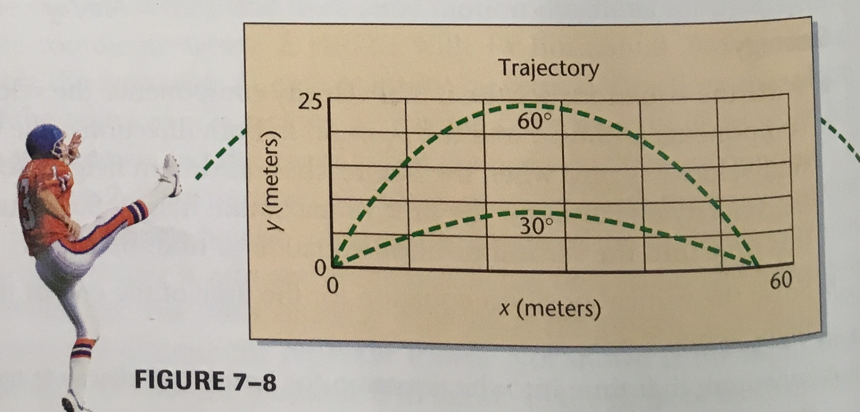


FIGURE 7–8