Position Vector  The location of a particle relative to the origin of a coordinate system is given by a position vector \( \vec{r} \), which in unit-vector notation is

\[
\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}.
\]

(4-1)

Here \( x\hat{i}, y\hat{j}, \) and \( z\hat{k} \) are the vector components of position vector \( \vec{r} \), and \( x, y, \) and \( z \) are its scalar components (as well as the coordinates of the particle). A position vector is described either by a magnitude and one or two angles for orientation, or by its vector or scalar components.

Displacement  If a particle moves so that its position vector changes from \( \vec{r}_1 \) to \( \vec{r}_2 \), the particle’s displacement \( \Delta \vec{r} \) is

\[
\Delta \vec{r} = \vec{r}_2 - \vec{r}_1.
\]

(4-2)

The displacement can also be written as

\[
\Delta \vec{r} = (x_2 - x_1)\hat{i} + (y_2 - y_1)\hat{j} + (z_2 - z_1)\hat{k}
\]

(4-3)

Average Velocity and Instantaneous Velocity  If a particle undergoes a displacement \( \Delta \vec{r} \) in time interval \( \Delta t \), its average velocity \( \vec{v}_{avg} \) for that time interval is

\[
\vec{v}_{avg} = \frac{\Delta \vec{r}}{\Delta t}.
\]

(4-8)

As \( \Delta t \) in Eq. 4-8 is shrunk to 0, \( \vec{v}_{avg} \) reaches a limit called either the velocity or the instantaneous velocity \( \vec{v} \):

\[
\vec{v} = \frac{d\vec{r}}{dt}.
\]

(4-10)

which can be rewritten in unit-vector notation as

\[
\vec{v} = v_x\hat{i} + v_y\hat{j} + v_z\hat{k},
\]

(4-11)

where \( v_x = \frac{dx}{dt}, v_y = \frac{dy}{dt}, \) and \( v_z = \frac{dz}{dt} \). The instantaneous velocity \( \vec{v} \) of a particle is always directed along the tangent to the particle’s path at the particle’s position.

Average Acceleration and Instantaneous Acceleration  If a particle’s velocity changes from \( \vec{v}_1 \) to \( \vec{v}_2 \) in time interval \( \Delta t \), its average acceleration during \( \Delta t \) is

\[
\vec{a}_{avg} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{\Delta \vec{v}}{\Delta t}.
\]

(4-15)

As \( \Delta t \) in Eq. 4-15 is shrunk to 0, \( \vec{a}_{avg} \) reaches a limiting value called either the acceleration or the instantaneous acceleration \( \vec{a} \):

\[
\vec{a} = \frac{d\vec{v}}{dt}.
\]

(4-16)

In unit-vector notation,

\[
\vec{a} = a_x\hat{i} + a_y\hat{j} + a_z\hat{k},
\]

(4-17)

where \( a_x = \frac{dv_x}{dt}, a_y = \frac{dv_y}{dt}, \) and \( a_z = \frac{dv_z}{dt} \).

Projectile Motion  Projectile motion is the motion of a particle that is launched with an initial velocity \( \vec{v}_0 \). During its flight, the particle’s horizontal acceleration is zero and its vertical acceleration is the free-fall acceleration \( -g \). (Upward is taken to be a positive direction.) If \( \vec{v}_0 \) is expressed as a magnitude (the speed \( v_0 \)) and an angle \( \theta_0 \) (measured from the horizontal), the particle’s equations of motion along the horizontal \( x \) axis and vertical \( y \) axis are

\[
x - x_0 = (v_0 \cos \theta_0)t,
\]

(4-21)

\[
y - y_0 = (v_0 \sin \theta_0)t - \frac{1}{2}gt^2,
\]

(4-22)

\[
v_x = v_0 \cos \theta_0 - gt,
\]

(4-23)

\[
v_y^2 = (v_0 \sin \theta_0)^2 - 2g(y - y_0).
\]

(4-24)

The trajectory (path) of a particle in projectile motion is parabolic and is given by

\[
y = (\tan \theta_0)x - \frac{g x^2}{2(v_0 \cos \theta_0)^2}.
\]

(4-25)

if \( x_0 \) and \( y_0 \) of Eqs. 4-21 to 4-24 are zero. The particle’s horizontal range \( R \), which is the horizontal distance from the launch point to the point at which the particle returns to the launch height, is

\[
R = \frac{v_0^2}{g} \sin 2\theta_0.
\]

(4-26)

Uniform Circular Motion  If a particle travels along a circle or circular arc of radius \( r \) at constant speed \( v \), it is said to be in uniform circular motion and has an acceleration \( \vec{a} \) of constant magnitude

\[
a = \frac{v^2}{r}.
\]

(4-34)

The direction of \( \vec{a} \) is toward the center of the circle or circular arc, and \( \vec{a} \) is said to be centripetal. The time for the particle to complete a circle is

\[
T = \frac{2\pi r}{v}.
\]

(4-35)

\( T \) is called the period of revolution, or simply the period, of the motion.

Relative Motion  When two frames of reference \( A \) and \( B \) are moving relative to each other at constant velocity, the velocity of a particle \( P \) as measured by an observer in frame \( A \) usually differs from that measured from frame \( B \). The two measured velocities are related by

\[
\vec{v}_{PA} = \vec{v}_{PB} + \vec{v}_{BA},
\]

(4-44)

where \( \vec{v}_{BA} \) is the velocity of \( B \) with respect to \( A \). Both observers measure the same acceleration for the particle:

\[
\vec{a}_{PA} = \vec{a}_{PB}.
\]

(4-45)
1 Figure 4-21 shows the path taken by a skunk foraging for trash food, from initial point i. The skunk took the same time $T$ to go from each labeled point to the next along its path. Rank points $a$, $b$, and $c$ according to the magnitude of the average velocity of the skunk to reach them from initial point $i$, greatest first.

2 Figure 4-22 shows the initial position $i$ and the final position $f$ of a particle. What are the (a) initial position vector $\vec{r}_i$ and (b) final position vector $\vec{r}_f$, both in unit-vector notation? (c) What is the $x$ component of displacement $\Delta \vec{r}$?

3 When Paris was shelled from 100 km away with the WWI long-range artillery piece “Big Bertha,” the shells were fired at an angle greater than 45° to give them a greater range, possibly even twice as long as at 45°. Does that result mean that the air density at high altitudes increases with altitude or decreases?

4 You are to launch a rocket, from just above the ground, with one of the following initial velocity vectors: (1) $\vec{v}_0 = 20\hat{i} + 70\hat{j}$, (2) $\vec{v}_0 = -20\hat{i} + 70\hat{j}$, (3) $\vec{v}_0 = 20\hat{i} - 70\hat{j}$, (4) $\vec{v}_0 = -20\hat{i} - 70\hat{j}$. In your coordinate system, $x$ runs along level ground and $y$ increases upward. (a) Rank the vectors according to the launch speed of the projectile, greatest first. (b) Rank the vectors according to the time of flight of the projectile, greatest first.

5 Figure 4-23 shows three situations in which identical projectiles are launched (at the same level) at identical initial speeds and angles. The projectiles do not land on the same terrain, however. Rank the situations according to the final speeds of the projectiles just before they land, greatest first.

6 The only good use of a fruitcake is in catapult practice. Curve 1 in Fig. 4-24 gives the height $y$ of a catapulted fruitcake versus the angle $\theta$ between its velocity vector and its acceleration vector during flight. (a) Which of the lettered points on that curve corresponds to the landing of the fruitcake on the ground? (b) Curve 2 is a similar plot for the same launch speed but for a different launch angle. Does the fruitcake now land farther away or closer to the launch point?

7 An airplane flying horizontally at a constant speed of 350 km/h over level ground releases a bundle of food supplies. Ignore the effect of the air on the bundle. What are the bundle’s initial (a) vertical and (b) horizontal components of velocity? (c) What is its horizontal component of velocity just before hitting the ground? (d) If the airplane’s speed were, instead, 450 km/h, would the time of fall be longer, shorter, or the same?

8 In Fig. 4-25, a cream tangerine is thrown up past windows 1, 2, and 3, which are identical in size and regularly spaced vertically. Rank those three windows according to (a) the time the cream tangerine takes to pass them and (b) the average speed of the cream tangerine during the passage, greatest first.

9 Figure 4-26 shows three paths for a football kicked from ground level. Ignoring the effects of air, rank the paths according to (a) time of flight, (b) initial vertical velocity component, (c) initial horizontal velocity component, and (d) initial speed, greatest first.

10 A ball is shot from ground level over level ground at a certain initial speed. Figure 4-27 gives the range $R$ of the ball versus its launch angle $\theta_0$. Rank the three lettered points on the plot according to (a) the total flight time of the ball and (b) the
CHAPTER 4 MOTION IN TWO AND THREE DIMENSIONS

At what values of \( \theta \) is the vertical component \( r \), of the position vector greatest in magnitude? (b) At what values of \( \theta \) is the vertical component \( v_y \) of the particle’s velocity greatest in magnitude? (c) At what values of \( \theta \) is the vertical component \( a_y \) of the particle’s acceleration greatest in magnitude?

13 (a) Is it possible to be accelerating while traveling at constant speed? Is it possible to round a curve with (b) zero acceleration and (c) a constant magnitude of acceleration?

**Answers**

11 Figure 4-28 shows four tracks (either half- or quarter-circles) that can be taken by a train, which moves at a constant speed. Rank the tracks according to the magnitude of a train’s acceleration on the curved portion, greatest first.

12 In Fig. 4-29, particle \( P \) is in uniform circular motion, centered on the origin of an \( xy \) coordinate system. (a) Fig. 4-28 Question 11. What are the (a) magnitude and (b) direction of the plane’s displacement, the (c) magnitude and (d) direction of its average velocity, and (e) its average speed?

**sec. 4-2 Position and Displacement**

1. The position vector for an electron is \( \vec{r} = (5.0 \text{ m})\hat{i} - (3.0 \text{ m})\hat{j} + (2.0 \text{ m})\hat{k} \). (a) Find the magnitude of \( \vec{r} \). (b) Sketch the vector on a right-handed coordinate system.

2. A watermelon seed has the following coordinates: \( x = -5.0 \text{ m} \), \( y = 8.0 \text{ m} \), and \( z = 0 \text{ m} \). Find its position vector \( \vec{r} \) in unit-vector notation and as \( (a) \) a magnitude and \( (b) \) an angle relative to the positive direction of the \( x \) axis. (d) Sketch the vector on a right-handed coordinate system. If the seed is moved to the \( xz \) coordinates \( (3.00 \text{ m}, 0 \text{ m}, 0 \text{ m}) \), what is its displacement \( \Delta \vec{r} \) in unit-vector notation as \( (f) \) a magnitude and \( (g) \) an angle relative to the positive \( x \) direction?

3. A positron undergoes a displacement \( \Delta \vec{r} = 2.0\hat{i} - 3.0\hat{j} + 6.0\hat{k} \), ending with the position vector \( \vec{r} = 3.0\hat{j} - 4.0\hat{k} \), in meters. What was the positron’s initial position vector?

4. The minute hand of a wall clock measures 10 cm from its tip to the axis about which it rotates. The magnitude and angle of the displacement vector of the tip are to be determined for three time intervals. What are the (a) magnitude and (b) angle from a quarter after the hour to half past, the (c) magnitude and (d) angle for the next half hour, and the (e) magnitude and (f) angle for the hour after that?

**sec. 4-3 Average Velocity and Instantaneous Velocity**

5. SSM A train at a constant 60.0 km/h moves east for 40.0 min, then in a direction 50.0° east of due north for 20.0 min, and then west for 50.0 min. What are the (a) magnitude and (b) angle of its average velocity during this trip?

6. An electron’s position is given by \( \vec{r} = 3.00t\hat{i} - 4.00t^2\hat{j} + 2.00t\hat{k} \), with \( t \) in seconds and \( \vec{r} \) in meters. (a) In unit-vector notation, what is the electron’s velocity \( \vec{v}(t) \)? At \( t = 2.00 \text{ s} \) what is \( \vec{v} \) (b) in unit-vector notation and as \( (c) \) a magnitude and \( (d) \) an angle relative to the positive direction of the \( x \) axis?

7. An ion’s position vector is initially \( \vec{r} = 5.0\hat{i} - 6.0\hat{j} + 2.0\hat{k} \), and 10 s later it is \( \vec{r} = -2.0\hat{i} + 8.0\hat{j} - 2.0\hat{k} \), all in meters. In unit-vector notation, what is its \( \vec{v}_{\text{avg}} \) during the 10 s?

8. A plane flies 483 km east from city \( A \) to city \( B \) in 45.0 min and then 966 km south from city \( B \) to city \( C \) in 1.50 h. For the total trip, what are the (a) magnitude and (b) direction of the plane’s displacement, the (c) magnitude and (d) direction of its average velocity, and (e) its average speed?

**sec. 4-4 Average Acceleration and Instantaneous Acceleration**

11 SSM The position \( \vec{r} \) of a particle moving in an \( xy \) plane is given by \( \vec{r} = (2.00t^3 - 5.00t^2)i + (6.00 - 7.00t^3)j \). (a) Find the instantaneous velocity \( \vec{v}(t) \) and (b) \( \vec{a}(t) \). What is its \( r \) at \( t = 0 \) s? What is the magnitude of the particle’s acceleration greatest magnitude?
for \( t = 2.00 \) s. (d) What is the angle between the positive direction of the \( x \) axis and a line tangent to the particle’s path at \( t = 2.00 \) s?

12. At one instant a bicyclist is 40.0 m due east of a park’s flagpole, going due south with a speed of 10.0 m/s. Then 30.0 s later, the cyclist is 40.0 m due north of the flagpole, going due east with a speed of 10.0 m/s. For the cyclist in this 30.0 s interval, what are the (a) magnitude and (b) direction of the displacement, the (c) magnitude and (d) direction of the average velocity, and the (e) magnitude and (f) direction of the average acceleration?

13. SSM A particle moves so that its position (in meters) as a function of time (in seconds) is \( \mathbf{r} = \mathbf{i} + 4t^2 \mathbf{j} + 5k \). Write expressions for (a) its velocity and (b) its acceleration as functions of time.

14. A proton initially has \( \mathbf{v} = 4.0 \mathbf{i} - 2.0 \mathbf{j} + 5.0 \mathbf{k} \) in meters per second. For that 4.0 s, what are (a) the proton’s average acceleration \( \mathbf{a}_{av} \) in unit-vector notation, (b) the magnitude of \( \mathbf{a}_{av} \), and (c) the angle between \( \mathbf{a}_{av} \) and the positive direction of the \( x \) axis?

15. SSM ILW A particle leaves the origin with an initial velocity \( \mathbf{v} = (3.00i) \) m/s and a constant acceleration \( \mathbf{a} = (-1.00i - 0.500j) \) m/s\(^2\). When it reaches its maximum \( x \) coordinate, what are its (a) velocity and (b) position vector?

16. The velocity \( \mathbf{v} \) of a particle moving in the \( xy \) plane is given by \( \mathbf{v} = (6.0t - 4.0t^2) \mathbf{i} + 8.0j \), with \( \mathbf{v} \) in meters per second and \( t \) (\( > 0 \)) in seconds. (a) What is the acceleration when \( t = 3.0 \) s? (b) When (if ever) is the acceleration zero? (c) When (if ever) is the velocity zero? (d) When (if ever) does the speed equal 10 m/s?

17. A cart is propelled over an \( xy \) plane with acceleration components \( a_x = 4.0 \) m/s\(^2\) and \( a_y = -2.0 \) m/s\(^2\). Its initial velocity has components \( v_{0x} = 8.0 \) m/s and \( v_{0y} = 12 \) m/s. In unit-vector notation, what is the velocity of the cart when it reaches its greatest \( y \) coordinate?

18. A moderate wind accelerates a pebble over a horizontal \( xy \) plane with a constant acceleration \( \mathbf{a} = (5.00 \text{ m/s}^2) \mathbf{i} + (7.00 \text{ m/s}^2) \mathbf{j} \). At time \( t = 0 \), the velocity is \((4.00 \text{ m/s}) \mathbf{i} \). What are the (a) magnitude and (b) angle of its velocity when it has been displaced by 12.0 m parallel to the \( x \) axis?

19. The acceleration of a particle moving only on a horizontal \( xy \) plane is given by \( \mathbf{a} = 3 \mathbf{i} + 4 \mathbf{j} \), where \( \mathbf{a} \) is in meters per second-squared and \( t \) is in seconds. At \( t = 0 \), the position vector \( \mathbf{r} = (20.0 \text{ m}) \mathbf{i} + (40.0 \text{ m}) \mathbf{j} \) locates the particle, which then has the velocity vector \( \mathbf{v} = (5.00 \text{ m/s}) \mathbf{i} + (2.00 \text{ m/s}) \mathbf{j} \). At \( t = 4.00 \) s, what are (a) its position vector in unit-vector notation and (b) the angle between its direction of travel and the positive direction of the \( x \) axis?

20. In Fig. 4-32, particle A moves along the line \( y = 30 \) m with a constant velocity \( \mathbf{v} \) of magnitude 3.0 m/s and parallel to the \( x \) axis. At the instant particle A passes the \( y \) axis, particle B leaves the origin with a zero initial speed and a constant acceleration \( \mathbf{a} \) of magnitude 0.40 m/s\(^2\). What angle \( \theta \) between \( \mathbf{a} \) and the positive direction of the \( y \) axis would result in a collision?

**sec. 4-6 Projectile Motion Analyzed**

21. A dart is thrown horizontally with an initial speed of 10 m/s toward point \( P \), the bull’s-eye on a dart board. It hits at point \( Q \) on the rim, vertically below \( P \), 0.19 s later. (a) What is the distance \( PQ \)? (b) How far away from the dart board is the dart released?

22. A small ball rolls horizontally off the edge of a tabletop that is 1.20 m high. It strikes the floor at a point 1.52 m horizontally from the table edge. (a) How long is the ball in the air? (b) What is its speed at the instant it leaves the table?

23. A projectile is fired horizontally from a gun that is 45.0 m above flat ground, emerging from the gun with a speed of 250 m/s. (a) How long does the projectile remain in the air? (b) At what horizontal distance from the firing point does it strike the ground? (c) What is the magnitude of the vertical component of its velocity as it strikes the ground?

24. In the 1991 World Track and Field Championships in Tokyo, Mike Powell jumped 8.95 m, breaking by a full 5 cm the 23-year long-jump record set by Bob Beamon. Assume that Powell’s speed on takeoff was 9.5 m/s (about equal to that of a sprinter) and that \( g = 9.80 \text{ m/s}^2 \) in Tokyo. How much less was Powell’s range than the maximum possible range for a particle launched at the same speed?

25. The current world-record motorcycle jump is 77.0 m, set by Jason Renie. Assume that he left the take-off ramp at 12.0º to the horizontal and that the take-off and landing heights are the same. Neglecting air drag, determine his take-off speed.

26. A stone is catapulted at time \( t = 0 \), with an initial velocity of magnitude 20.0 m/s and at an angle of 40.0º above the horizontal. What are the magnitudes of the (a) horizontal and (b) vertical components of its displacement from the catapult site at \( t = 1.10 \) s? Repeat for the (c) horizontal and (d) vertical components at \( t = 1.80 \) s, and for the (e) horizontal and (f) vertical components at \( t = 5.00 \) s.

27. ILW A certain airplane has a speed of 290.0 km/h and is diving at an angle of \( \theta = 30.0º \) below the horizontal when the pilot releases a radar decoy (Fig. 4-33). The horizontal distance between the release point and the point where the decoy strikes the ground is \( d = 700 \) m. (a) How long is the decoy in the air? (b) How high was the release point?

28. In Fig. 4-34, a stone is projected at a cliff of height \( h \) with an initial speed of 42.0 m directed at angle \( \theta_1 = 60.0º \) above the horizontal. The stone strikes at \( A \), 5.50 s after launching. Find (a) the height \( h \) of the cliff, (b) the speed of the stone just before impact at \( A \), and (c) the maximum height \( H \) reached above the ground.
29 A projectile’s launch speed is five times its speed at maximum height. Find launch angle \( \theta_0 \).

30 A soccer ball is kicked from the ground with an initial speed of 19.5 m/s at an upward angle of 45°. A player 55 m away in the direction of the kick starts running to meet the ball at that instant. What must be his average speed if he is to meet the ball just before it hits the ground?

31 In a jump spike, a volleyball player slams the ball from overhead and toward the opposite floor. Controlling the angle of the spike is difficult. Suppose a ball is spiked from a height of 2.30 m with an initial speed of 20.0 m/s at a downward angle of 18.0°. How much farther on the opposite floor would it have landed if the downward angle were, instead, 80°?

32 You throw a ball toward a wall at speed 25.0 m/s and at angle \( \theta_0 = 40.0° \) above the horizontal (Fig. 4-35). The wall is distance \( d = 22.0 \) m from the release point of the ball.
- (a) How far above the release point does the ball hit the wall? What are the (b) horizontal and (c) vertical components of its velocity as it hits the wall? (d) When it hits, has it passed the highest point on its trajectory?

33 A plane, diving with constant speed at an angle of 53.0° with the vertical, releases a projectile at an altitude of 730 m. The projectile hits the ground 5.00 s after release. (a) What is the speed of the plane? (b) How far does the projectile travel horizontally during its flight? What are the (c) horizontal and (d) vertical components of its velocity just before striking the ground?

34 A trebuchet was a hurling machine built to attack the walls of a castle under siege. A large stone could be hurled against a wall to break apart the wall. The machine was not placed near the wall because then arrows could reach it from the castle wall. Instead, it was positioned so that the stone hit the wall during the second half of its flight. Suppose a stone is launched with a speed of \( v_0 = 28.0 \) m/s and at an angle of \( \theta_0 = 40.0° \). What is the speed of the stone if it hits the wall (a) just as it reaches the top of its parabolic path and (b) when it has descended to half that height? (c) As a percentage, how much faster is it moving in part (b) than in part (a)?

35 A rifle that shoots bullets at 460 m/s is to be aimed at a target 45.7 m away. If the center of the target is level with the rifle, how high above the target must the rifle barrel be pointed so that the bullet hits dead center?

36 During a tennis match, a player serves the ball at 23.6 m/s, with the center of the ball leaving the court horizontally 2.37 m above the court surface. The net is 12 m away and 0.90 m high. When the ball reaches the net, (a) does the ball clear it and (b) what is the distance between the center of the ball and the top of the net? Suppose that, instead, the ball is served as before but now it leaves the racquet at 5.00° below the horizontal. When the ball reaches the net, (c) does the ball clear it and (d) what now is the distance between the center of the ball and the top of the net?

37 A lowly high diver pushes off horizontally with a speed of 2.00 m/s from the platform edge 10.0 m above the surface of the water. (a) At what horizontal distance from the edge is the diver 0.800 s after pushing off? (b) At what vertical distance above the surface of the water is the diver just then? (c) At what horizontal distance from the edge does the diver strike the water?

38 A golf ball is struck at ground level. The speed of the golf ball as a function of the time is shown in Fig. 4-36, where \( t = 0 \) at the instant the ball is struck. The scaling on the vertical axis is set by \( v_y = 19 \) m/s and \( v_x = 31 \) m/s.
- (a) How far does the golf ball travel horizontally before returning to ground level? (b) What is the maximum height above ground level attained by the ball?

39 In Fig. 4-37, a ball is thrown leftward from the left edge of the roof, at height \( h \) above the ground. The ball hits the ground 1.50 s later, at distance \( d = 25.0 \) m from the building and at angle \( \theta = 60.0° \) with the horizontal. (a) Find \( h \). (Hint: One way is to reverse the motion, as if on video.) What are the (b) magnitude and (c) angle relative to the horizontal of the velocity at which the ball is thrown? (d) Is the angle above or below the horizontal?

40 Suppose that a shot putter can put a shot at the world-class speed \( v_0 = 15.00 \) m/s and at a height of 2.160 m. What horizontal distance would the shot travel if the launch angle \( \theta_0 \) is (a) 45.00° and (b) 42.00°? The answers indicate that the angle of 45°, which maximizes the range of projectile motion, does not maximize the horizontal distance when the launch and landing are at different heights.

41 Upon spotting an insect on a twig overhanging water, an archer fish squirts water drops at the insect to knock it into the water (Fig. 4-38). Although the fish sees the insect along a straight-line path at angle \( \phi \) and distance \( d \), a drop must be launched at a different angle \( \theta_0 \) if its parabolic path is to intersect the insect. If \( \phi = 36.0° \) and \( d = 0.900 \) m, what launch angle \( \theta_0 \) is required for the drop to be at the top of the parabolic path when it reaches the insect?

42 In 1939 or 1940, Emanuel Zacchini took his human-cannonball act to an extreme: After being shot from a cannon, he soared over three Ferris wheels and into a net (Fig. 4-39). Assume that
he is launched with a speed of 26.5 m/s and at an angle of 53.0°. (a) Treating him as a particle, calculate his clearance over the first wheel. (b) If he reached maximum height over the middle wheel, by how much did he clear it? (c) How far from the cannon should the net's center have been positioned (neglect air drag)?

**43 uw** A ball is shot from the ground into the air. At a height of 9.1 m, its velocity is \( v = (7.6 \hat{i} + 6.1 \hat{j}) \) m/s, with \( \hat{i} \) horizontal and \( \hat{j} \) upward. (a) To what maximum height does the ball rise? (b) What total horizontal distance does the ball travel? What are the (c) magnitude and (d) angle (below the horizontal) of the ball's velocity just before it hits the ground?

**44** A baseball leaves a pitcher's hand horizontally at a speed of 161 km/h. The distance to the batter is 18.3 m. (a) How long does the ball take to travel the first half of that distance? (b) The second half? (c) How far does the ball fall freely during the first half? (d) During the second half? (e) Why aren't the quantities in (c) and (d) equal?

**45** In Fig. 4-40, a ball is launched with a velocity of magnitude 10.0 m/s, at an angle of 50.0° to the horizontal. The launch point is at the base of a ramp of horizontal length \( d_1 = 6.00 \) m and height \( d_2 = 3.60 \) m. A plateau is located at the top of the ramp. (a) Does the ball land on the ramp or the plateau? When it lands, what are the (b) magnitude and (c) angle of its displacement from the launch point?

**46** In basketball, **hang** is an illusion in which a player seems to weaken the gravitational acceleration while in midair. The illusion depends much on a skilled player's ability to rapidly shift the ball between hands during the flight, but it might also be supported by the longer horizontal distance the player travels in the upper part of the jump than in the lower part. If a player jumps with an initial speed of \( v_0 = 7.00 \) m/s at an angle of \( \theta_0 = 35.0° \), what percent of the jump's range does the player spend in the upper half of the jump (between maximum height and half maximum height)?

**47** A batter hits a pitched ball when the center of the ball is 1.22 m above the ground. The ball leaves the bat at an angle of 45° with the ground. With that launch, the ball should have a horizontal range (returning to the launch level) of 107 m. (a) Does the ball clear a 7.32-m-high fence that is 97.5 m horizontally from the launch point? (b) At the fence, what is the distance between the fence top and the ball center?

**48** In Fig. 4-41, a ball is thrown up onto a roof, landing 4.00 s later at height \( h = 20.0 \) m above the release level. The ball's path just before landing is angled at \( \theta = 60.0° \) with the roof. (a) Find the horizontal distance \( d \) it travels. (See the hint to Problem 39.) What are the (b) magnitude and (c) angle (relative to the horizontal) of the ball's initial velocity?

**49** A football kicker can give the ball an initial speed of 25 m/s. What are the (a) least and (b) greatest elevation angles at which he can kick the ball to score a field goal from a point 50 m in front of goalposts whose horizontal bar is 3.44 m above the ground?

**50** Two seconds after being projected from ground level, a projectile is displaced 40 m horizontally and 53 m vertically above its launch point. What are the (a) horizontal and (b) vertical components of the initial velocity of the projectile? (c) At the instant the projectile achieves its maximum height above ground level, how far is it displaced horizontally from the launch point?

**51** A skilled skier knows to jump upward before reaching a downward slope. Consider a jump in which the launch speed is \( v_0 = 10 \) m/s, the launch angle is \( \theta_0 = 9.0° \), the initial course is approximately flat, and the steeper track has a slope of 11.3°. Figure 4-42a shows a **prejump** that allows the skier to land on the top portion of the steeper track. Figure 4-42b shows a jump at the edge of the steeper track. In Fig. 4-42a, the skier lands at approximately the launch level. (a) In the landing, what is the angle \( \phi \) between the skier's path and the slope? In Fig. 4-42b, (b) how far below the launch level does the skier land and (c) what is \( \phi' \)? (The greater fall and greater \( \phi \) can result in loss of control in the landing.)

**52** A ball is to be shot from level ground toward a wall at distance \( x \) (Fig. 4-43a). Figure 4-43b shows the \( y \) component \( v_y \) of the ball's velocity just as it would reach the wall, as a function of that distance \( x \). The scaling is set by \( v_y = 5.0 \) m/s and \( x_s = 20 \) m. What is the launch angle?

**53** In Fig. 4-44, a baseball is hit at a height \( h = 1.00 \) m and then caught at the same height. It travels alongside a wall, moving up past the top of the wall 1.00 s after it is hit and then down past the top of the wall 4.00 s later, at distance \( D = 50.0 \) m farther along the wall. (a) What horizontal distance is traveled by the ball from hit to catch? What are the (b) magnitude and (c) angle (relatively to the horizontal) of the ball's velocity just after being hit? (d) How high is the wall?
A ball is to be shot from level ground with a certain speed. Figure 4-45 shows the range $R$ it will have versus the launch angle $\theta_0$. The value of $\theta_0$ determines the flight time; let $t_{\text{max}}$ represent the maximum flight time. What is the least speed the ball will have during its flight if $\theta_0$ is chosen such that the flight time is 0.500 $t_{\text{max}}$?

A ball rolls horizontally off the top of a stairway with a speed of 1.52 m/s. The steps are 20.3 cm high and 20.3 cm wide. Which step does the ball hit first?

An Earth satellite moves in a circular orbit 640 km above Earth’s surface with a period of 98.0 min. What are the (a) speed and (b) magnitude of the centripetal acceleration of the satellite?

A carnival Ferris wheel at radius 15 m, completing five turns about its horizontal axis every minute. What is the period of the motion? What distance does the tip move in one revolution? What are (b) the magnitude and (c) direction of her centripetal acceleration at the top?

A rotating fan completes 1200 revolutions every minute. Consider the tip of a blade, at a radius of 0.15 m. (a) Through what distance does the tip move in one revolution? What are (b) the tip’s speed and (c) the magnitude of its acceleration? (d) What is the period of the motion?

A woman rides a carnival Ferris wheel at radius 15 m, completing five turns about its horizontal axis every minute. What are (a) the period of the motion, the (b) magnitude and (c) direction of her centripetal acceleration at the highest point, and the (d) magnitude and (c) direction of her centripetal acceleration at the lowest point?

A centripetal-acceleration addict rides in uniform circular motion with period $T = 2.0$ s and radius $r = 3.00$ m. At $t_1 = 1.00$ s, his acceleration is $\vec{a} = (6.00 \text{ m/s}^2)\hat{j} + (-4.00 \text{ m/s}^2)\hat{i}$. At that instant, what are the values of (a) $\vec{v} \cdot \vec{a}$ and (b) $\vec{r} \times \vec{a}$?

When a large star becomes a supernova, its core may be compressed so tightly that it becomes a neutron star, with a radius of about 20 km (about the size of the San Francisco area). If a neutron star rotates once every second, (a) what is the speed of a particle on the star’s equator and (b) what is the magnitude of the particle’s centripetal acceleration? (c) If the neutron star rotates faster, do the answers to (a) and (b) increase, decrease, or remain the same?

What is the magnitude of the acceleration of a sprinter running at 10 m/s when rounding a turn of radius 25 m?

At $t_1 = 2.00$ s, the acceleration of a particle in counterclockwise circular motion is $(6.00 \text{ m/s}^2)\hat{j} + (-4.00 \text{ m/s}^2)\hat{i}$. It moves at constant speed. At time $t_2 = 5.00$ s, the particle’s acceleration is $(4.00 \text{ m/s}^2)\hat{j} + (-6.00 \text{ m/s}^2)\hat{i}$. What is the radius of the path taken by the particle if $t_2 - t_1$ is less than one period?

A particle moves horizontally in uniform circular motion, over a horizontal $xy$ plane. At one instant, it moves through the point at coordinates $(4.00 \text{ m}, 4.00 \text{ m})$ with a velocity of $-5.00 \text{ m/s}$ and an acceleration of $+12.5 \text{ m/s}^2$. What are the (a) $x$ and (b) $y$ coordinates of the center of the circular path?

A purse at radius 2.00 m and a wallet at radius 3.00 m travel in uniform circular motion on the floor of a merry-go-round as the ride turns. They are on the same radial line. At one instant, the acceleration of the purse is $(2.00 \text{ m/s}^2)\hat{j} + (4.00 \text{ m/s}^2)\hat{i}$. At that instant and in unit-vector notation, what is the acceleration of the wallet?

A particle moves along a circular path over a horizontal $xy$ coordinate system, at constant speed. At time $t_1 = 4.00$ s, it is at point $(5.00 \text{ m}, 6.00 \text{ m})$ with velocity $(3.00 \text{ m/s})\hat{j}$ and acceleration in the positive $x$ direction. At time $t_2 = 10.0$ s, it has velocity $(-3.00 \text{ m/s})\hat{i}$ and acceleration in the positive $y$ direction. What are the (a) $x$ and (b) $y$ coordinates of the center of the circular path if $t_2 - t_1$ is less than one period?

A ball rolls horizontally off the top of a stairway with a speed of 1.52 m/s. The steps are 20.3 cm high and 20.3 cm wide. Which step does the ball hit first?

An Earth satellite moves in a circular orbit 640 km above Earth’s surface with a period of 98.0 min. What are the (a) speed and (b) magnitude of the centripetal acceleration of the satellite?

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A centripetal-acceleration addict rides in uniform circular motion with period $T = 2.0$ s and radius $r = 3.00$ m. At $t_1 = 1.00$ s, his acceleration is $\vec{a} = (6.00 \text{ m/s}^2)\hat{j} + (-4.00 \text{ m/s}^2)\hat{i}$. At that instant, what are the values of (a) $\vec{v} \cdot \vec{a}$ and (b) $\vec{r} \times \vec{a}$?

When a large star becomes a supernova, its core may be compressed so tightly that it becomes a neutron star, with a radius of about 20 km (about the size of the San Francisco area). If a neutron star rotates once every second, (a) what is the speed of a particle on the star’s equator and (b) what is the magnitude of the particle’s centripetal acceleration? (c) If the neutron star rotates faster, do the answers to (a) and (b) increase, decrease, or remain the same?

What is the magnitude of the acceleration of a sprinter running at 10 m/s when rounding a turn of radius 25 m?

At $t_1 = 2.00$ s, the acceleration of a particle in counterclockwise circular motion is $(6.00 \text{ m/s}^2)\hat{j} + (-4.00 \text{ m/s}^2)\hat{i}$. It moves at constant speed. At time $t_2 = 5.00$ s, the particle’s acceleration is $(4.00 \text{ m/s}^2)\hat{j} + (-6.00 \text{ m/s}^2)\hat{i}$. What is the radius of the path taken by the particle if $t_2 - t_1$ is less than one period?

A particle moves horizontally in uniform circular motion, over a horizontal $xy$ plane. At one instant, it moves through the point at coordinates $(4.00 \text{ m}, 4.00 \text{ m})$ with a velocity of $-5.00 \text{ m/s}$ and an acceleration of $+12.5 \text{ m/s}^2$. What are the (a) $x$ and (b) $y$ coordinates of the center of the circular path?
and moving at speed \( v_P = 80 \text{ km/h} \). Motorist \( M \) is distance \( d_M = 600 \text{ m} \) from the intersection and moving at speed \( v_M = 60 \text{ km/h} \). (a) In unit-vector notation, what is the velocity of the motorist with respect to the police car? (b) For the instant shown in Fig. 4-46, what is the angle between the velocity found in (a) and the line of sight between the two cars? (c) If the cars maintain their velocities, do the answers to (a) and (b) change as the cars move nearer the intersection?

**Fig. 4-46** Problem 73.

> PROBLEMS

### 79 SSM ILW Two ships, \( A \) and \( B \), leave port at the same time. Ship \( A \) travels northwest at 24 knots, and ship \( B \) travels at 28 knots in a direction 40° west of south. (1 knot = 1 nautical mile per hour; see Appendix D.) What are the (a) magnitude and (b) direction of the velocity of ship \( A \) relative to \( B' \)? (c) After what time will the ships be 160 nautical miles apart? (d) What will be the bearing of \( B \) (the direction of \( B \)'s position) relative to \( A \) at that time?

### 80 *** A 200-m-wide river flows due east at a uniform speed of 2.0 m/s. A boat with a speed of 8.0 m/s relative to the water leaves the south bank pointed in a direction 30° west of north. What are the (a) magnitude and (b) direction of the boat’s velocity relative to the ground? (c) How long does the boat take to cross the river?

### 81 ** A train travels due south at 30 m/s (relative to the ground) in a rain that is blown toward the south by the wind. The path of each raindrop makes an angle of 70° with the vertical, as measured by an observer stationary on the ground. An observer on the train, however, sees the drops fall perfectly vertically. Determine the speed of the raindrops relative to the ground.

### 82 ** A 200-m-wide river has a uniform flow speed of 1.1 m/s through a jungle and toward the east. An explorer wishes to leave a small clearing on the south bank and cross the river in a powerboat that moves at a constant speed of 4.0 m/s with respect to the water. There is a clearing on the north bank 82 m upstream from a point directly opposite the clearing on the south bank. (a) In what direction must the boat be pointed in order to travel in a straight line and land in the clearing on the north bank? (b) How long will the boat take to cross the river and land in the clearing?

### Additional Problems

**83** A woman who can row a boat at 6.4 km/h in still water faces a long, straight river with a width of 6.4 km and a current of 3.2 km/h. Let \( \mathbf{i} \) point directly across the river and \( \mathbf{j} \) point directly downstream. If she rows in a straight line to a point directly opposite her starting point, \( \theta_1 \) at what angle to \( \mathbf{i} \) must she point the boat and (b) how long will she take? (c) How long will she take if, instead, she rows 3.2 km down the river and then back to her starting point? (d) How long if she rows 3.2 km up the river and then back to her starting point? (e) At what angle to \( \mathbf{i} \) should she point the boat if she wants to cross the river in the shortest possible time? (f) How long is that shortest time?

**84** In Fig. 4-48a, a sled moves in the negative \( x \) direction at constant speed \( v_x \) while a ball of ice is shot from the sled with a velocity \( \mathbf{v}_0 = v_{0x} \mathbf{i} + v_{0y} \mathbf{j} \) relative to the sled. When the ball lands, its
horizontal displacement \( \Delta x_{bg} \) relative to the ground (from its launch position to its landing position) is measured. Figure 4-48b gives \( \Delta x_{bg} \) as a function of \( v_\lambda \). Assume the ball lands at approximately its launch height. What are the values of (a) \( v_\theta \) and (b) \( v_{\lambda bg} \)? The ball’s displacement \( \Delta x_{bg} \), relative to the sled can also be measured. Assume that the sled’s velocity is not changed when the ball is shot. What is \( \Delta x_{bg} \) when \( v_\lambda \) is (c) 5.0 m/s and (d) 15 m/s?

85 You are kidnapped by political-science majors (who are upset because you told them political science is not a real science). Although blindfolded, you can tell the speed of their car (by the whine of the engine), the time of travel (by mentally counting off seconds), and the direction of travel (by turns along the rectangular street system). From these clues, you know that you are taken along the following course: 50 km/h for 2.0 min, turn 90° to the right, 20 km/h for 4.0 min, turn 90° to the right, 20 km/h for 60 s, turn 90° to the left, 50 km/h for 60 s, turn 90° to the right, 20 km/h for 2.0 min, turn 90° to the left, 50 km/h for 30 s. At that point, (a) how far are you from your starting point, and (b) in what direction relative to your initial direction of travel are you?

86 In Fig. 4-49, a radar station detects an airplane approaching directly from the east. At first observation, the airplane is at distance \( d_1 = 360 \) m from the station and at angle \( \theta_0 = 40° \) above the horizon. The airplane is tracked through an angular change \( \Delta \theta = 123° \) in the vertical east–west plane; its distance is then \( d_2 = 790 \) m. Find the (a) magnitude and (b) direction of the airplane’s displacement during this period.

**Fig. 4-49** Problem 86.

87 SSM A baseball is hit at ground level. The ball reaches its maximum height above ground level 3.0 s after being hit. Then 2.5 s after reaching its maximum height, the ball barely clears a fence that is 97.5 m from where it was hit. Assume the ground is level. (a) What maximum height above ground level is reached by the ball? (b) How high is the fence? (c) How far beyond the fence does the ball strike the ground?

88 Long flights at midlatitudes in the Northern Hemisphere encounter the jet stream, an eastward airflow that can affect a plane’s speed relative to Earth’s surface. If a pilot maintains a certain speed relative to the air (the plane’s airspeed), the speed relative to the surface (the plane’s ground speed) is more when the flight is in the direction of the jet stream and less when the flight is opposite the jet stream. Suppose a round-trip flight is scheduled between two cities separated by 4000 km, with the outgoing flight in the direction of the jet stream and the return flight opposite it. The airline computer advises an airspeed of 1000 km/h, for which the difference in flight times for the outgoing and return flights is 70.0 min. What jet-stream speed is the computer using?

89 SSM A particle starts from the origin at \( t = 0 \) with a velocity of 8.0\( \hat{j} \) m/s and moves in the \( xy \) plane with constant acceleration \( (4.0\hat{i} + 2.0\hat{j}) \) m/s². When the particle’s \( x \) coordinate is 29 m, what are its (a) \( y \) coordinate and (b) speed?

90 At what initial speed must the basketball player in Fig. 4-50 throw the ball, at angle \( \theta_0 = 55° \) above the horizontal, to make the foul shot? The horizontal distances are \( d_1 = 1.0 \) ft and \( d_2 = 7.0 \) ft and \( h_1 = 10 \) ft.

91 During volcanic eruptions, chunks of solid rock can be blasted out of the volcano; these projectiles are called volcanic bombs. Figure 4-51 shows a cross section of Mt. Fuji, in Japan. (a) At what initial speed would a bomb have to be ejected, at angle \( \theta_0 = 35° \) to the horizontal, from the vent at \( A \) in order to fall at the foot of the volcano at \( B \), at vertical distance \( h = 3.30 \) km and horizontal distance \( d = 9.40 \) km? Ignore, for the moment, the effects of air on the bomb’s travel. (b) What would be the time of flight? (c) Would the effect of the air increase or decrease your answer in (a)?

**Fig. 4-50** Problem 90.

**Fig. 4-51** Problem 91.

92 An astronaut is rotated in a horizontal centrifuge at a radius of 5.0 m. (a) What is the astronaut’s speed if the centripetal acceleration has a magnitude of 7.0g? (b) How many revolutions per minute are required to produce this acceleration? (c) What is the period of the motion?

93 SSM Oasis A is 90 km due west of oasis B. A desert camel leaves \( A \) and takes 50 h to walk 75 km at 37° north of due east. Next it takes 35 h to walk 65 km due south. Then it rests for 5.0 h. What are the (a) magnitude and (b) direction of the camel’s displacement relative to \( A \) at the resting point? From the time the camel leaves \( A \) until the end of the rest period, what are the (c) magnitude and (d) direction of its average velocity and (e) its average speed? The camel’s last drink was at \( A \); it must be at \( B \) no more than 120 h later for its next drink. If it is to reach \( B \) just in time, what must be the (f) magnitude and (g) direction of its average velocity after the rest period?

94 Curtain of death. A large metallic asteroid strikes Earth and quickly digs a crater into the rocky material below ground level by launching rocks upward and outward. The following table gives five pairs of launch speeds and angles (from the horizontal) for such rocks, based on a model of crater formation. (Other rocks, with intermediate speeds and angles, are also launched.) Suppose that you are at \( x = 20 \) km when the asteroid strikes the ground at
time \( t = 0 \) and position \( x = 0 \) (Fig. 4-52). (a) At \( t = 20 \) s, what are the \( x \) and \( y \) coordinates of the rocks headed in your direction from launches \( A \) through \( E? \) (b) Plot these coordinates and then sketch a curve through the points to include rocks with intermediate launch speeds and angles. The curve should indicate what you would see as you look up into the approaching rocks and what dinosaurs must have seen during asteroid strikes long ago.

<table>
<thead>
<tr>
<th>Launch</th>
<th>Speed (m/s)</th>
<th>Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A )</td>
<td>520</td>
<td>14.0</td>
</tr>
<tr>
<td>( B )</td>
<td>630</td>
<td>16.0</td>
</tr>
<tr>
<td>( C )</td>
<td>750</td>
<td>18.0</td>
</tr>
<tr>
<td>( D )</td>
<td>870</td>
<td>20.0</td>
</tr>
<tr>
<td>( E )</td>
<td>1000</td>
<td>22.0</td>
</tr>
</tbody>
</table>

A projectile is launched with an initial speed of \( 30 \) m/s at an angle of 60° above the horizontal. What is the initial speed?

An iceboat sails across the surface of a frozen lake with constant acceleration produced by the wind. At a certain instant the boat’s velocity is \((6.30\hat{i} - 8.42\hat{j}) \) m/s. Three seconds later, because of a wind shift, the boat is instantaneously at rest. What is its average acceleration for this 3.00 s interval?

In Fig. 4-55, a ball is shot directly upward from the ground with an initial speed of \( v_0 = 7.00 \) m/s. Simultaneously, a construction elevator cab begins to move upward from the ground with a constant speed of \( v_c = 3.00 \) m/s. What maximum height does the ball reach relative to (a) the ground and (b) the cab floor? At what rate does the speed of the ball change relative to (c) the ground and (d) the cab floor?

A magnetic field can force a charged particle to move in a circular path. Suppose that an electron moving in a circle experiences a radial acceleration of magnitude \( 3.0 \times 10^{-14} \) m/s\(^2\) in a particular magnetic field. (a) What is the speed of the electron if the radius of its circular path is 15 cm? (b) What is the period of the motion?

In 3.50 h, a balloon drifts 21.5 km north, 9.70 km east, and 2.88 km upward from its release point on the ground. Find (a) the magnitude of its average velocity and (b) the angle its average velocity makes with the horizontal.

A ball is thrown horizontally from a height of 20 m and hits the ground with a speed that is three times its initial speed. What is the initial speed?

A projectile is launched with an initial speed of 30 m/s at an angle of 60° above the horizontal. What are the (a) magnitude and (b) angle of its velocity 2.0 s after launch, and (c) is the angle above or below the horizontal? What are the (d) magnitude and (e) angle of its velocity 5.0 s after launch, and (f) is the angle above or below the horizontal?

The position vector for a proton is initially \( \vec{r} = 5.0\hat{i} - 6.0\hat{j} + 2.0\hat{k} \) and then later is \( \vec{r} = -2.0\hat{i} + 6.0\hat{j} + 2.0\hat{k} \), all in meters. (a) What is the proton’s displacement vector, and (b) to what plane is that vector parallel?

A particle \( P \) travels with constant speed on a circle of radius \( r = 3.00 \) m (Fig. 4-56) and completes one revolution in 20.0 s. The particle passes through \( O \) at time \( t = 0 \). State the following vectors in magnitude-angle notation (angle relative to the positive direction of \( x \)). With respect to \( O \), find the particle’s position vector at the times \( t \) of (a) 5.00 s, (b) 7.50 s, and (c) 10.0 s.

(d) For the 5.00 s interval from the end of the fifth second to the end of the tenth second, find the particle’s displacement. For that interval, find (e) its average velocity and its velocity at the (f) beginning and (g) end. Next, find the acceleration at the (h) beginning and (i) end of that interval.
The fast French train known as the TGV (Train à Grande Vitesse) has a scheduled average speed of 216 km/h. (a) If the train goes around a curve at that speed and the magnitude of the acceleration experienced by the passengers is to be limited to 0.050 g, what is the smallest radius of curvature for the track that can be tolerated? (b) At what speed must the train go around a curve with a 1.00 km radius to be at the acceleration limit?

A person walks up a stalled 15-m-long escalator in 90 s. When standing on the same escalator, now moving, the person is carried up in 60 s. How much time would it take that person to walk up the moving escalator? Does the answer depend on the length of the escalator?

(a) What is the magnitude of the centripetal acceleration of an object on Earth’s equator due to the rotation of Earth? (b) What would Earth’s rotation period have to be for objects on the equator to have a centripetal acceleration of magnitude 9.8 m/s²?

The range of a projectile depends not only on the particle moving in the xy-plane for the interval 0 ≤ t ≤ 4.0 s. Show that the velocity is tangent to the path of the particle and in the direction the particle is moving at each time by drawing the velocity vectors on the plot of the particle’s path in part (a). (c) Calculate the components of the particle’s acceleration at t = 1.0, 2.0, and 3.0 s.

An electron having an initial horizontal velocity of magnitude 1.00 × 10⁸ cm/s travels into the region between two horizontal metal plates that are electrically charged. In that region, the electron travels a horizontal distance of 2.00 cm and has a constant downward acceleration of magnitude 1.00 × 10⁻²⁷ cm/s² due to the charged plates. Find (a) the time the electron takes to travel the 2.00 cm, (b) the vertical distance it travels during that time, and the magnitudes of its (c) horizontal and (d) vertical velocity components as it emerges from the region.

An elevator without a ceiling is ascending with a constant speed of 10 m/s. A boy on the elevator shoots a ball directly upward, from a height of 2.0 m above the elevator floor, just as the elevator floor is 28 m above the ground. The initial speed of the ball with respect to the elevator is 20 m/s. (a) What maximum height above the ground does the ball reach? (b) How long does the ball take to return to the elevator floor?

A football player punts the football so that it will have a “hang time” (time of flight) of 4.5 s and land 46 m away. If the ball leaves the player’s foot 150 cm above the ground, what must be the (a) magnitude and (b) angle (relative to the horizontal) of the ball’s initial velocity?

An airport terminal has a moving sidewalk to speed passengers through a long corridor. Larry does not use the moving sidewalk; he takes 150 s to walk through the corridor. Curly, who simply stands on the moving sidewalk, covers the same distance in 70 s. Moe boards the sidewalk and walks along it. How long does Moe take to move through the corridor? Assume that Larry and Moe walk at the same speed.

A wooden boxcar is moving along a straight railroad track at speed \( v_1 \). A sniper fires a bullet (initial speed \( v_2 \)) at it from a high-powered rifle. The bullet passes through both lengthwise walls of the car, its entrance and exit holes being exactly opposite each other as viewed from within the car. From what direction, relative to the track, is the bullet fired? Assume that the bullet is not deflected upon entering the car, but that its speed decreases by 20%. Take \( v_1 = 85 \text{ km/h} \) and \( v_2 = 650 \text{ m/s} \). (Why don’t you need to know the width of the boxcar?)