End-of-Chapter Exercises

Exercises 1 – 12 are conceptual questions designed to see whether you understand the main concepts of the chapter.

1. You are going to paddle your kayak from one side of a river to the other side. The current in the river is directed downstream, as is usual for a river. How should you point your kayak (upstream, perpendicular to the riverbank, or downstream) so that you cross from one side of the river to (a) anywhere on the other side in the shortest possible time? (b) the point directly across the river from your starting point? Briefly justify your answers.

2. A ballistic cart is a wheeled cart that can launch a ball in a direction perpendicular to the way the cart moves and can then catch the ball again if it falls back down on the cart. Holding the cart stationary on a horizontal track, you confirm that the ball does indeed land in the cart after it is launched. You now give the cart a quick push so that, after you release it, the cart rolls along the track with a constant velocity. If the ball is launched while the cart is rolling, will it land in front of the cart, behind the cart, or in the cart? Briefly justify your answer.

3. On an assignment, you are asked to find the time it takes for a ball launched with a particular initial velocity to reach the surface of the water some distance below. When setting up the exercise, you choose the origin to be at the base of the cliff. Your friend chooses the origin to be at the top of the cliff, from where the ball was launched. Who is right, or is there no one right place to choose as the origin? What do you and your friend agree on? What do you disagree on? Explain.

4. On an assignment, you are asked to find the time it takes for a ball launched with a particular initial velocity to reach the surface of the water some distance below. When setting up the exercise, you choose an x-y coordinate system in which the positive y direction is up, while your friend chooses an x-y coordinate system in which the positive y direction is down. Who is right, or is there no one correct direction for the positive y-axis? What do you and your friend agree on? What do you disagree on? Explain.

5. Consider the trajectories of three objects, labeled A, B, and C, shown in Figure 4.20. Rank these objects from largest to smallest, based on (a) their times of flight, (b) the y component of their initial velocities, (c) the x component of their initial velocities, and (d) their launch speeds.

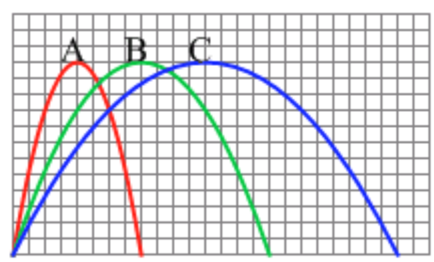

Figure 4.20: The trajectories of three projectiles, for Exercise 5.

6. The trajectories of two objects, D and E, are shown in Figure 4.21. The grid shown on the diagram is square. (a) Which object has the longer time of flight? Briefly explain. (b) If object E has a time of flight of T, what is object D's time of flight? (c) If object E has a constant horizontal velocity of v_{ix} to the right, what is the constant horizontal velocity of object D?

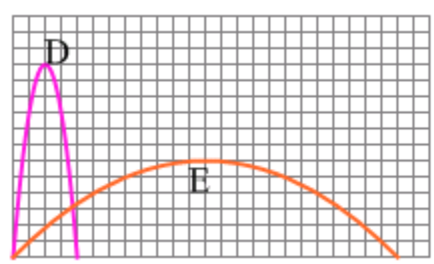

Figure 4.21: The trajectories of two projectiles, for Exercise 6.

7. The trajectories of three objects, *E*, *F*, and *G*, are shown in Figure 4.22. Assume that the grid shown on the diagram is square, and note that object *E* is launched at an angle of 45˚ with respect to the horizontal. Rank these three projectiles from largest to smallest, based on (a) their times of flight, (b) the *y* component of their initial velocities, (c) the *x* component of their initial velocities, and (d) their launch speeds.

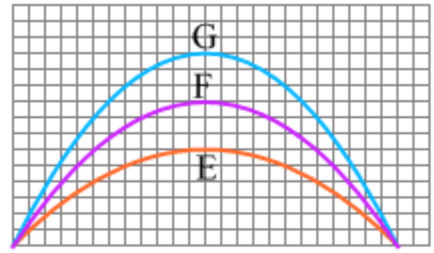

Figure 4.22: The trajectories of three projectiles, for Exercise 7.

8. The motion diagram in Figure 4.23 shows a ball's position at regular intervals as the ball flies from left to right through the air. Copy the motion diagram onto a sheet of graph paper. (a) On the same graph, sketch the motion diagram for a ball that also starts at the lower left corner, has the same initial vertical velocity as the ball in Figure 4.23, but has a horizontal velocity 50% larger than that of the ball in Figure 4.23. (b) On the same graph, sketch the motion diagram for a ball that has the same starting point, half the initial vertical velocity, and twice the horizontal velocity, of the ball in Figure 4.23.

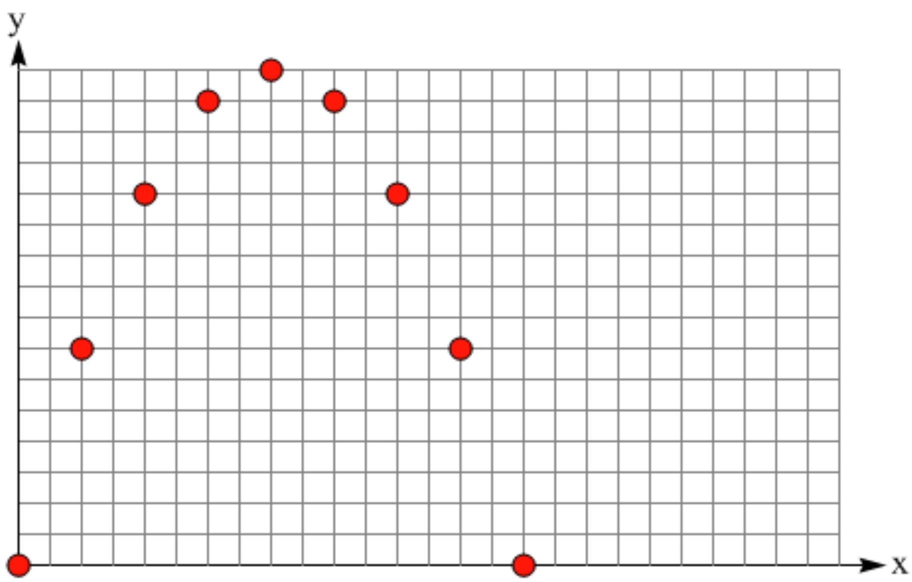

Figure 4.23: A motion diagram showing the position of a ball at regular time intervals, as the ball moves from left to right, for Exercises 8 and 9.

9. Consider the motion diagram shown in Figure 4.23. Assuming the ball's position is shown at 1-second intervals and that $g = 10$ m/s^2, sketch graphs of the ball's: (a) *y* velocity as a function of time, (b) *y* position as a function of time, (c) *x* velocity as a function of time, and (d) *x* position as a function of time.

10. To answer a typical projectile-motion problem, it is not necessary to know the mass of the projectile. Why is this?

11. You find that when you throw a ball with a particular initial velocity, the ball reaches a maximum height *H*, has a time of flight *T*, and covers a range *R* when landing at the same height from which it was launched. If you throw the ball again but now you double the launch speed, keeping everything else the same, what are the ball's (a) maximum height, (b) time of flight, and (c) range?

12. You find that when you throw a ball on Earth with a particular initial velocity, the ball reaches a maximum height H, has a time-of-flight T, and covers a range R when landing at the same height from which it was launched. You now travel to the Moon, where the acceleration due to gravity is one-sixth of what it is on Earth, and throw the ball with the same initial velocity. What are (a) the maximum height, (b) the time of flight, and (c) the range of the ball on the Moon?

Exercises 13 – 20 deal with relative-velocity situations.

13. You are driving your car on a highway, traveling at a constant velocity of 110 km/h north. Ahead of you on the road is a truck traveling at a constant velocity of 90 km/h north. On the other side of the road, coming toward you, is a motorcycle traveling at a constant velocity of 100 km/h south. (a) What is your velocity relative to the truck? (b) What is the truck's velocity relative to you? (c) What is your velocity relative to the motorcycle? (d) What is the motorcycle's velocity relative to the truck? (e) After you pass the truck and the motorcycle roars past on the other side of the road, do any of the answers above change? Explain.

14. You paddle your canoe at a constant speed of 4.0 km/h relative to the water. You are canoeing along a river that is flowing at a constant speed of 1.0 km/h. If you paddle for 60 minutes downstream (with the current) and then turn around, how long does it take you to get back to your starting point?

15. Return to the situation described in Exercise 14, and let's say that the river is 300 m wide. (a) If you paddle your canoe so you cross from one side of the river to the other in the shortest possible time, how long does it take to cross the river? (b) If instead you paddle your canoe so that you land at the point directly across the river from where you started, following a straight line, how long does it take you?

16. Return again to the situation described in Exercises 14 and 15. Compare what happens if, in case 1, you aim your canoe at an angle of 15˚ upstream to what happens if, in case 2, you aim your canoe 15˚ downstream. (a) In which case does it take you longer to cross the river? How much time does it take you to cross in that case? (b) How far upstream or downstream are you when you reach the far side in (i) case 1? (ii) case 2?

17. Four people are moving along a sidewalk. Ron's velocity relative to Susan is 2.0 m/s east; Susan's velocity relative to Tamika is 6.0 m/s west; and Tamika's velocity relative to Ulrich is 3.0 m/s east. What is Ulrich's velocity relative to (a) Susan? (b) Ron? (c) a lamppost at rest with respect to the sidewalk?

18. Return to the situation described Exercise 17, except now Ron is crossing the street and his velocity relative to Susan has components of 3.0 m/s north and 2.0 m/s east. Find Ulrich's velocity relative to Ron now, expressing it in (a) component form and (b) magnitude-and-direction form.

19. You are flying your airplane at a constant speed of 200 km/h relative to the air. As you pass over Zurich, Switzerland, you check your map and find that Frankfurt, Germany, is 300 km due north, so you point your plane due north. (a) If there is no wind blowing, how long should it take you to get to Frankfurt? (b) After that amount of time has passed you are shocked to find that, instead of being over Frankfurt, you are near the town of Tenneville, Belgium, precisely 225 km due west of Frankfurt. What is the velocity of the wind? (c) You now immediately change direction so you can fly to Frankfurt. In which direction should you point your plane, and how long does it take you to reach Frankfurt? (Let's hope you have plenty of fuel!)

20. Having learned from your experience of Exercise 19, the next time you fly from Zurich to Frankfurt you account for the wind, which is blowing west at a speed of 120 km/h. (a) If your plane travels at a constant speed of 200 km/h relative to the air, in which direction should you point your plane so that you travel due north, toward Frankfurt? (b) How long does it take you to fly from Zurich to Frankfurt this time?

Exercises 21 – 24 deal with the concept of the independence of *x* and *y*.

21. You climb 20 meters up the mast of a tall ship and release a ball from rest so it hits the deck of the ship at the base of the mast. Use $g = 10$ m/s^2 to simplify the calculations. (a) How long does it take the ball to reach the deck of the ship? (b) From the same point, 20 meters up the mast, you launch a second ball so that its initial velocity is 1.0 m/s directed horizontally and east. How long does this ball take to reach the deck of the ship? (c) How far is the second ball from the base of the mast when it hits the deck?

22. Returning to the situation described in Exercise 21, assume now that the ship is traveling with a constant velocity of 4.0 m/s east, and that the water is calm so the mast remains vertical. Once again you climb 20 meters up the mast and release one ball from rest, relative to you, and give a second ball an initial velocity of 1.0 m/s, directed east, relative to you. (a) Does the fact that the ship is moving affect the time it takes either ball to fall to the deck of the ship? Explain. (b) How far from the base of the mast does the first ball land now? (c) How far from the base of the mast does the second ball land now? (d) From the point of view of a seagull sitting motionless on a buoy watching the tall ship sail past, what is the horizontal displacement of the second ball as it falls to the deck of the ship?

23. You are standing inside a bus that is traveling at a constant velocity of 8 m/s along a straight horizontal road. You toss an apple straight up into the air and then catch it again 1.2 seconds later at the same height from which you let it go. Use $g = 10$ m/s^2 to simplify the calculations. Answer these questions based on what you see. In other words, consider the motion of the apple relative to you. (a) What is the maximum height reached by the apple? (b) What is the initial velocity of the apple? (c) How far does the apple move horizontally (relative to you)?

24. Repeat Exercise 23, but now answer the questions from the perspective of a person at rest outside the bus, looking in through the bus windows. For part (c), in particular, how far does the apple move horizontally relative to the person at rest outside the bus?

Exercises 25 – 36 are designed to help you practice applying the general method for solving projectile-motion problems. For each exercise, (a) draw a diagram. (b) Sketch a free-body diagram, showing the forces acting on the object. (c) Choose an origin, and mark it on your diagram. (d) Choose an *x*-*y* coordinate system and draw it on your diagram, showing which way is positive for each coordinate axis. (e) Organize your data in a table, keeping the information for the *x* subproblem separate from the information for the *y* subproblem.

25. Before game 1 of the 2004 World Series, Johnny Damon and Trot Nixon are playing catch in the outfield at Fenway Park. The two players are 23.0 m apart. Damon throws the ball to Nixon so that it reaches a maximum height of 15.5 m above the point he released it. Assume that Nixon catches the ball at the same level from which Damon releases it, that air resistance is negligible, and that $g = 9.81$ m/s^2. Answer parts (a) through (e), as described above. (f) At what initial velocity did Damon throw the ball?

26. Working as an accident reconstruction expert, you find that a car that was driven off a horizontal road over the edge of a 15-m-high cliff traveled 42 m horizontally before impact. Use $g = 9.8$ m/s^2. Answer parts (a) through (e) as described above. (f) At what speed was the car moving when it left the road? Express the speed in m/s, km/h, and miles/h. (g) At what speed was the car moving just before impact?

27. You toss a set of keys up to your friend, who is leaning out a window above you. You are at ground level in front of the window, and you release the keys 2.0 m horizontally from, and 6.0 m vertically below, the point where your friend catches them. The keys happen to be at their maximum height point when they are caught by your friend. Answer parts (a) through (e) as described above. (f) With what initial velocity did you launch the keys?

28. You throw a ball with an initial speed v_i at an angle of θ above the horizontal. The ball lands at a point some distance away that is a height *h* below the point from which it was launched. Answer parts (a) through (e) as described above. (f) In terms of *g*, v_i, θ, and *h*, determine an expression for the time the ball is in flight. Think about what would happen if *h* was zero, or if the landing point was some height *h* above the launch point instead.

29. You throw a ball so that it is in the air for 4.56 s and travels a horizontal distance of 50.0 m. Use $g = 9.81$ m/s^2, and assume the ball lands at the same height from which it was launched. Answer parts (a) through (e) as described above. (f) What was the ball's initial velocity?

30. Repeat Exercise 29, but now assume the ball lands at a height 20.0 m below the point from which it was launched.

31. Taking a corner kick in a soccer game, you kick the ball from ground level so that, after reaching a maximum height of 3.5 m above the ground, the ball reaches your teammate 22 meters away. Your teammate makes contact with the ball when the ball is 2.0 m off the ground and heads the ball into the net. Set the origin to be the point from which you kicked the ball, take up to be the positive *y* direction, and point the positive *x* direction from you toward your teammate. Answer parts (a) through (e) as described above. (f) Determine the *x* and *y* components of the ball's initial velocity. (g) Plot graphs of the ball's *x* position, *y* position, *x* velocity, and *y* velocity, all as a function of time. (h) Plot a graph of the ball's *y* position as a function of its *x* position.

32. You throw a ball from the edge of a vertical cliff overlooking the ocean. The ball is launched with an initial velocity of 12.0 m/s at an angle of 34.0˚ above the horizontal, from a height of 55.0 m above the water. Neglect air resistance, and use $g = 9.81$ m/s^2. Answer parts (a) through (e), as described above. (f) How long does it take the ball to reach the water? (g) Assuming you throw the ball so the horizontal component of its velocity is perpendicular to the cliff face, how far is it from the base of the cliff when it hits the water?

33. Repeat parts (a) through (e) of Exercise 32, but, this time, choose a different origin. Show that you still get the same answers for parts (f) and (g).

34. Repeat parts (a) through (e) of Exercise 32, but, this time, reverse the direction you take to be positive for the vertical coordinate axis. Show that you still get the same answers for parts (f) and (g).

35. A spacecraft with a mass of 8000 kg is drifting through deep space with a constant velocity of 5.0 m/s in the positive *y* direction. The thrusters are then turned on so the craft experiences a constant acceleration of 4.0 m/s^2 in the positive *x* direction for a period of 5.0 s (assume the mass lost in this process is negligible). The thrusters are then turned off. Take the origin to be the position of the spacecraft when the thrusters are first turned on. Answer parts (a) through (e) as described above. (f) How far is the spacecraft from the origin when the thrusters are turned off? (g) How far is the spacecraft from the origin after another 5.0 s has passed?

36. Repeat Exercise 35, but this time assume that, when the thrusters are turned on, the spacecraft experiences a constant acceleration of 4.0 m/s^2 in the positive *x* direction as well as a constant acceleration of 3.0 m/s^2 in the positive *y* direction. Once again, the thrusters are turned off after 5.0 s.

Exercises 37 – 40 deal with common applications of projectile motion.

37. For a typical kickoff in a football game, the “hang time” (the time the ball spends in the air) is 4.0 s, and the ball travels 50 m. Neglecting air resistance, determine (a) the vertical component of the initial velocity, (b) the horizontal component of the initial velocity, (c) the magnitude and direction, relative to the horizontal, of the initial velocity.

38. A basketball hoop is 3.05 m above the floor, and the horizontal distance from the free-throw line to a point directly below the center of the hoop is 4.60 m. Assuming that a basketball player releases the ball at an angle of 60.0° with respect to the horizontal, from a point that is located exactly 1.70 m above the free-throw line, what should the launch speed be so the ball passes through the center of the hoop?

39. In 1983, Chris Bromham set a world record by jumping a motorcycle over 18 double-decker buses. If Mr. Bromham launched the motorcycle off a ramp with a launch speed of 42 m/s and traveled a horizontal distance of 63 m, landing at the same height from which he left the ramp, at what angle was the launch ramp inclined? Note that such ramps are inclined at angles considerably less than 45°.

40. The Russian shot-putter Natalya Lisovskaya set a world record, in 1987, for the shot put that was still unbroken at the time this book went to press. Neglect air resistance. Assume the shot was launched from a height of 1.800 m above the ground, at an angle of 43.00° above the horizontal, and with a speed of 14.32 m/s. Use $g = 9.810$ m/s, and determine the distance of the record throw.

General Problems and Conceptual Questions

41. In Exploration 4.2, let's say L = 36.0 m and v = 8.0 m/s. By what distance does Brandi win the race?

42. In Exploration 4.2, let's say L = 36.0 m and v = 8.0 m/s. (a) Aside from the very start of the race, at how many different instants are the two women the same distance from the start line at the same time, between the time the race starts and the time Brandi arrives at the finish line? (b) When are these instants, and how far from the start line are the two women when these instants occur?

43. You are driving your car at a constant velocity of 110 km/h north. As you pass under a bridge, a train is passing over the bridge, traveling at a constant speed of 60 km/h. What is your velocity relative to the train if (a) the train is traveling due east? (b) the train is traveling at an angle of 15° south of east?

44. A ballistic cart is a wheeled cart that can launch a ball in a direction perpendicular to the way the cart moves and can then catch the ball again if it falls back down on the cart. Holding the cart stationary on a horizontal track, you confirm that the ball does indeed land in the cart after it is launched. Let's say that the cart launches the ball with an initial velocity of 4.00 m/s up relative to the cart while the cart is rolling with a constant velocity of 3.00 m/s to the right. Using g = 9.81 m/s^2, determine (a) the time it takes the ball to return to the height from which it was launched, (b) the displacement of the cart during this time, and (c) the displacement of the ball during this time.

45. In 1991, Mike Powell of the United States set a world record of 8.95 m in the long jump. With this jump, Powell broke Bob Beamon's record of 8.90 m, which was set at the Mexico City Olympic Games in 1968. Estimate how fast Powell was going when he left the ground, knowing that he was trying to jump as far as he could. How does your value compare to the top speed of a world-class sprinter?

46. While playing catch with your friend, who is located due north of you, you throw a ball such that its initial velocity components are 20 m/s up and 7.0 m/s north. Some time later, your friend catches the ball at the same height from which you released it. Considering the motion from the instant just after you released it until just before your friend caught it, what is (a) the ball's average velocity over this interval? (b) the ball's average acceleration over this interval?

47. Consider the trajectory of object B in Figure 4.24. At what angle from the horizontal was it launched? Assume the grid shown on the diagram is square.

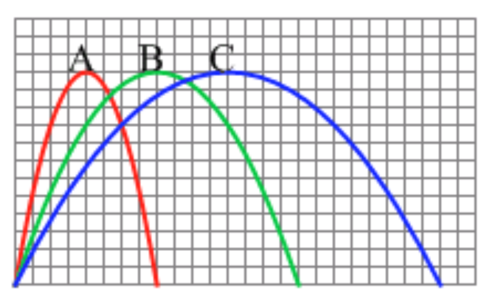

Figure 4.24: The trajectories of three projectiles. For Exercise 47, just focus on object B.

48. The motion diagram in Figure 4.25 shows a ball's position at regular intervals as the ball flies from left to right through the air. (a) On the *x*-axis, draw the motion diagram corresponding to the *x* subproblem. What does this tell you about the ball's velocity and acceleration in the *x* direction? (b) On the *y*-axis, draw the motion diagram corresponding to the *y* subproblem. What does this tell you about the ball's velocity and acceleration in the *y* direction? If the ball's position is shown at 1-second intervals and $g = 10$ m/s^2, (c) what is the maximum height reached by the ball? (d) How far does the ball travel horizontally?

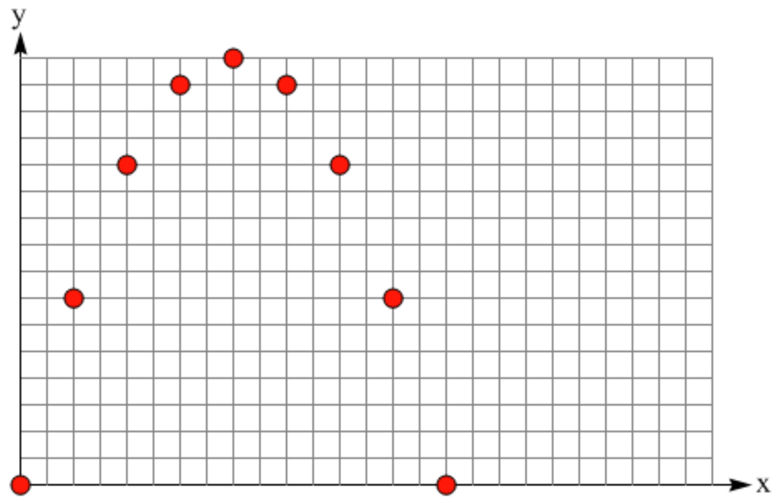

Figure 4.25: A motion diagram showing the position of a ball at regular time intervals, as the ball moves from left to right, for Exercise 48.

49. A ball is launched and travels for exactly 3 seconds before being caught. Graphs of the ball's *x* velocity and *y* velocity are shown in Figure 4.26, where the acceleration due to gravity is assumed to be $g = 10$ m/s^2. (a) Is the ball caught at a level that is higher, lower, or the same as the level from which it was launched? How do you know? (b) How far does the ball travel horizontally during the 3-second period? (c) At what instant does the ball reach its maximum height? Justify your answer.

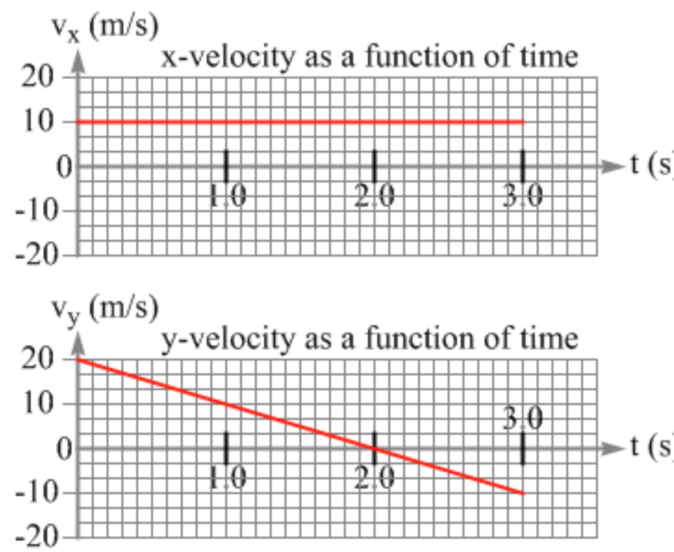

Figure 4.26: Graphs of the *x*-velocity and *y*-velocity for a ball thrown into the air. For Exercises 49 – 51.

50. Consider again the situation described in Exercise 49, and the graphs of the ball's *x* and *y* velocity shown in Figure 4.26. Sketch corresponding graphs of the ball's (a) *x* acceleration, (b) *y* acceleration, (c) *x* position, and (d) *y* position. Draw each graph as a function of time.

51. On a piece of graph paper, sketch the motion diagram corresponding to the velocity graphs in Figure 4.26, showing the position of the ball at 0.50-second intervals between $t = 0$ and $t = 3$ seconds.

52. A ball is launched with an initial velocity of 12.0 m/s at an angle of 30.0° above the horizontal. It lands some time later at the same height from which it was launched. Using the standard component method of analysis, and using $g = 9.81$ m/s^2, determine the time the ball is in flight.

53. You kick a soccer ball from ground level with an initial velocity of 7.50 m/s at an angle of 30.0˚ above the horizontal. The ball hits a wall 8.00 m away. How far up the wall is the point of impact?

54. You kick a soccer ball from ground level with an initial velocity of 7.50 m/s at an angle of 30.0˚ above the horizontal. When the ball strikes a wall that is some distance from you, the ball is 50.0 cm off the ground. How far away is the wall? Find all possible answers, assuming that the ball does not bounce before hitting the wall. Use $g = 9.80$ m/s^2.

55. Standing in the middle of a perfectly flat field, you kick a soccer ball from ground level, launching it with an initial speed of 20 m/s. Using $g = 10$ m/s^2 to simplify the calculations, and assuming you can use any launch angle between 0 and 90˚, measured from the horizontal, determine the following: (a) the shortest and longest times the ball can spend in the air before hitting the ground, (b) the maximum height the ball can reach in its flight, and (c) the maximum range of the ball.

56. Returning to the situation of Exercise 55, what launch angle(s) give a range that is 75% of the maximum range?

57. You are playing catch with your friend, who is standing 20.0 m from you. When you first throw the ball, you launch it at an angle of 65.0˚ and the ball falls 5.00 m short of reaching your friend. (a) At what speed did you launch the ball? (b) If you kept the launch angle the same, at what initial speed should you launch the ball on the next throw so the ball reaches your friend? (c) If instead you kept the launch speed the same as in part (a), at what launch angle should you launch the ball so it reaches your friend? Assume the ball lands at the same height from which it was launched for all parts of this exercise.

58. You are having a snowball fight with your friend, who is 7.0 m away from you. Knowing some physics, you throw one snowball at an angle of 70˚ above the horizontal, launching it so that the snowball will hit your friend at the same height from which you let it go. You wait for a short time interval, and then launch a second snowball from the same point, but at an angle of 20˚ above the horizontal. If you want both snowballs to hit your friend in the same place simultaneously, how long should the time interval be between throwing the two snowballs?

59. You repeat the two-snowball situation described in Exercise 58, but this time with different launch angles. You observe that the maximum height (measured from the launch point) of one snowball is exactly 5 times higher than the maximum height reached by the other snowball. At what angles were the two snowballs launched, assuming they were launched with the same speed?

60. You repeat the two-snowball situation described in Exercise 58, but this time with different launch angles. You observe that the time of flight for one snowball is exactly 5 times longer than the time of flight of the other snowball. At what angles were the two snowballs launched, assuming they were launched with the same speed?

61. You flick a coin from a tabletop that is 1.30 m above the floor, giving the coin an initial speed of 2.40 m/s when it leaves the table. Calculate the horizontal distance between the launch point and the point of impact if the launch angle, relative to the horizontal, is (a) 0˚, (b) 30˚, and (c) 45˚.

Figure 4.27: This decorative fountain shows the water following parabolic trajectories. After being sprayed from a pipe in the fountain, each stream of water is acted upon by gravity and follows a two-dimensional path as the stream deflects toward the Earth. (Photo credit: Edward Hor / iStockphoto.)

62. The photograph in Figure 4.27 shows the parabolic paths followed by water in a decorative fountain. If the water emerging from one of the pipes has an initial speed of 4.0 m/s, and is projected at an angle of 60° above the horizontal, determine the maximum height reached by the water above the level of the top end of the pipe.

63. Three students are trying to solve a problem that involves a ball being launched, at a 30° angle above the horizontal, from the top of a cliff, and landing on the flat ground some distance below. The students know the launch speed, the acceleration due to gravity, and the height of the cliff. They are looking for the time the ball spends in the air. Comment on the part of their conversation that is recorded below.

Avi : I think we have to do the problem in two steps. First, we find the point where the ball reaches its maximum height, and then we go from that point down to the ground.

T.J. : I think we can do it all in one step. The equations can handle it, just going all the way from the initial point to the ground.

Kristin: I think we need two steps, too, but I would do it differently than Avi. What if we first find the point where the ball comes down to the same height from where it was launched, and then we go from that point down to the ground?