**SUMMARY**

The goals of Chapter 3 have been to learn more about vectors and to use vectors as a tool to analyze motion in two dimensions.

**GENERAL PRINCIPLES**

**Projectile Motion**

A projectile is an object that moves through the air under the influence of gravity and nothing else.

The path of the motion is a parabola.

**Circular Motion**

The motion consists of two pieces:

1. Vertical motion with free-fall acceleration, \( a_y = -g \).
2. Horizontal motion with constant velocity.

Kinematic equations:

\[
\begin{align*}
x_f &= x_i + (v_x) \Delta t \\
(v_y)_f &= (v_y)_i + g \Delta t
\end{align*}
\]

**IMPORTANT CONCEPTS**

**Vectors and Components**

A vector can be decomposed into \( x \)- and \( y \)-components.

The magnitude and direction of a vector can be expressed in terms of its components.

**The Acceleration Vector**

We define the acceleration vector as

\[ \vec{a} = \frac{\Delta \vec{v}}{\Delta t} \]

We find the acceleration vector on a motion diagram as follows:

Dots show positions at equal time intervals.

Velocity vectors go dot to dot.

The difference in the velocity vectors is found by adding the negative of \( \vec{v}_f \) to \( \vec{v}_i \).

**APPLICATIONS**

**Relative motion**

Velocities can be expressed relative to an observer. We can add relative velocities to convert to another observer’s point of view.

The speed of the car with respect to the runner is:

\[ (v_x)_c = (v_x)_g + (v_x)_r \]

**Motion on a ramp**

An object sliding down a ramp will accelerate parallel to the ramp:

\[ a_x = \pm g \sin \theta \]

The correct sign depends on the direction in which the ramp is tilted.
Conceptual Questions

1. a. Can a vector have nonzero magnitude if a component is zero? If no, why not? If yes, give an example.
   b. Can a vector have zero magnitude and a nonzero component? If no, why not? If yes, give an example.
2. Is it possible to add a scalar to a vector? If so, demonstrate. If not, explain why not.
3. Suppose two vectors have unequal magnitudes. Can their sum be 0? Explain.
4. Suppose \( \vec{C} = \vec{A} + \vec{B} \)
   a. Under what circumstances does \( \vec{C} = \vec{A} + \vec{B} \) ?
   b. Could \( \vec{C} = \vec{A} - \vec{B} \)? If so, how? If not, why not?
5. For a projectile, which of the following quantities are constant during the flight: \( x, y, v_x, v_y, a_x, a_y \)? Which of the quantities are zero throughout the flight?
6. A baseball player throws a ball at a 40° angle to the ground. The ball lands on the ground some distance away.
   a. Is there any point on the trajectory where \( \vec{v} \) and \( \vec{a} \) are parallel to each other? If so, where?
   b. Is there any point where \( \vec{v} \) and \( \vec{a} \) are perpendicular to each other? If so, where?
7. An athlete performing the long jump tries to achieve the maximum distance from the point of takeoff to the first point of touching the ground. After the jump, rather than land upright, she extends her legs forward as in the photo. How does this affect the time in the air? How does this give the jumper a longer range?
8. A person trying to throw a ball as far as possible will run forward during the throw. Explain why this increases the distance of the throw.
9. A passenger on a jet airplane claims to be able to walk at a speed in excess of 500 mph. Can this be true? Explain.
10. If you go to a ski area, you'll likely find that the beginner's slope has the smallest angle. Use the concept of acceleration on a ramp to explain why this is so.
11. In an amusement-park ride, cars rolling along at high speed suddenly head up a long, straight ramp. They roll up the ramp, reverse direction at the highest point, then roll backward back down the ramp. In each of the following segments of the motion, are the cars accelerating, or is their acceleration zero? If accelerating, which way does their acceleration vector point?
   a. As the cars roll up the ramp.
   b. At the highest point on the ramp.
   c. As the cars roll back down the ramp.
12. There are competitions in which pilots fly small planes low over the ground and drop weights, trying to hit a target. A pilot flying low and slow drops a weight; it takes 2.0 s to hit the ground, during which it travels a horizontal distance of 100 m. Now the pilot does a run at the same height but twice the speed. How much time does it take the weight to hit the ground? How far does it travel before it lands?
13. A cyclist goes around a level, circular track at constant speed. Do you agree or disagree with the following statement: "Because the cyclist's speed is constant, her acceleration is zero." Explain.
14. You are driving your car in a circular path on level ground at a constant speed of 20 mph. At the instant you are driving north, and turning left, are you accelerating? If so, toward what point of the compass (N, S, E, W) does your acceleration vector point? If not, why not?
15. An airplane has been directed to fly in a clockwise circle, as seen from above, at constant speed until another plane has landed. When the plane is going north, is it accelerating? If so, in what direction does the acceleration vector point? If not, why not?
16. When you go around a corner in your car, your car follows a path that is a segment of a circle. To turn safely, you should keep your car's acceleration below some safe upper limit. If you want to make a "tightly" turn—that is, turn in a circle with a smaller radius—how should you adjust your speed? Explain.

Multiple-Choice Questions

17. Which combination of the vectors shown in Figure Q3.17 has the largest magnitude?
   A. \( \vec{A} + \vec{B} + \vec{C} \)
   B. \( \vec{B} + \vec{A} - \vec{C} \)
   C. \( \vec{A} - \vec{B} + \vec{C} \)
   D. \( \vec{C} - \vec{A} - \vec{C} \)

18. Two vectors appear as in Figure Q3.18. Which combination points directly to the left?
   A. \( \vec{P} + \vec{Q} \)
   B. \( \vec{P} - \vec{Q} \)
   C. \( \vec{Q} - \vec{P} \)
   D. \( -\vec{Q} - \vec{P} \)

19. The gas pedal in a car is sometimes referred to as "the accelerator." Which other controls on the vehicle can be used to produce acceleration?
   A. The brakes.
   B. The steering wheel.
   C. The gear shift.
   D. All of the above.
20. A car travels at constant speed along the curved path shown from above in Figure Q3.20. Five possible vectors are also shown in the figure; the letter E represents the zero vector. Which vector best represents
a. The car’s velocity at position 1?
b. The car’s acceleration at point 1?
c. The car’s velocity at position 2?
d. The car’s acceleration at point 2?
e. The car’s velocity at position 3?
f. The car’s acceleration at point 3?

![FIGURE Q3.20](image)

21. A ball is fired from a cannon at point 1 and follows the trajectory shown in Figure Q3.21. Air resistance may be neglected. Five possible vectors are also shown in the figure; the letter E represents the zero vector. Which vector best represents
a. The ball’s velocity at position 2?
b. The ball’s acceleration at point 2?
c. The ball’s velocity at position 3?
d. The ball’s acceleration at point 3?

![FIGURE Q3.21](image)

22. A ball thrown at an initial angle of 37.0° and initial velocity of 23.0 m/s reaches a maximum height \( h \), as shown in Figure Q3.22. With what initial speed must a ball be thrown straight up to reach the same maximum height \( h \)?
A. 13.8 m/s  
B. 17.3 m/s  
C. 18.4 m/s  
D. 23.0 m/s

![FIGURE Q3.22](image)

23. A cannon, elevated at 40° is fired at a wall 300 m away on level ground, as shown in Figure Q3.23. The initial speed of the cannonball is 89 m/s.

![FIGURE Q3.23](image)

a. How long does it take for the ball to hit the wall?
A. 1.3 s  
B. 3.3 s  
C. 4.4 s  
D. 6.8 s  
E. 7.2 s

b. At what height \( h \) does the ball hit the wall?
A. 39 m  
B. 47 m  
C. 74 m  
D. 160 m  
E. 210 m

24. A car drives horizontally off a 73-m-high cliff at a speed of 27 m/s. Ignore air resistance.

a. How long will it take the car to hit the ground?
A. 1 s  
B. 2 s  
C. 3 s  
D. 4 s  
E. 5 s

b. How far from the base of the cliff will the car hit?
A. 74 m  
B. 88 m  
C. 100 m  
D. 170 m  
E. 280 m

25. A football is kicked at an angle of 30° with a speed of 20 m/s. To the nearest second, how long will the ball stay in the air?
A. 1 s  
B. 2 s  
C. 3 s  
D. 4 s  
E. 5 s

26. A football is kicked at an angle of 30° with a speed of 20 m/s. To the nearest 5 m, how far will the ball travel?
A. 15 m  
B. 25 m  
C. 35 m  
D. 45 m  
E. 55 m

27. Riders on a Ferris wheel move in a circle with a speed of 4.0 m/s. As they go around, they experience a centripetal acceleration of 2.0 m/s². What is the diameter of this particular Ferris wheel?
A. 4.0 m  
B. 6.0 m  
C. 8.0 m  
D. 16 m  
E. 24 m

Section 3.1 Using Vectors

1._TRACE THE VECTORS IN FIGURE P3.1 ONTO YOUR PAPER. THEN USE GRAPHICAL METHODS TO DRAW THE VECTORS (A) \( \vec{A} + \vec{B} \) AND (B) \( \vec{A} - \vec{B} \).

2._TRACE THE VECTORS IN FIGURE P3.2 ONTO YOUR PAPER. THEN USE GRAPHICAL METHODS TO DRAW THE VECTORS (A) \( \vec{A} + \vec{B} \) AND (B) \( \vec{A} - \vec{B} \).

Section 3.2 Using Vectors on Motion Diagrams

3. A car goes around a corner in a circular arc at constant speed. Draw a motion diagram including positions, velocity vectors, and acceleration vectors.

4. a. Is the object’s average speed between points 1 and 2 greater than, less than, or equal to its average speed between points 0 and 1? Explain how you can tell.

b. Find the average acceleration vector at point 1 of the three-point motion diagram in Figure P3.4.
Section 3.3 Coordinate Systems and Vector Components

5. Figure 3.11 showed the motion diagram for Anne as she rode a Ferris wheel that was turning at a constant speed. The inset to the figure showed how to find the acceleration vector at the lowest point in her motion. Use a similar analysis to find Anne’s acceleration vector at the 12 o’clock, 4 o’clock, and 8 o’clock positions of the motion diagram. Use a ruler so that your analysis is accurate.

Section 3.4 Motion on a Ramp

6. A position vector with magnitude 10 m points to the right and up. Its x-component is 6.0 m. What is the value of its y-component?

7. A velocity vector, 40° above the positive x-axis has a y-component of 10 m/s. What is the value of its x-component?

8. Jack and Jill ran up the hill at 3.0 m/s. The horizontal component of Jill’s velocity vector was 2.5 m/s. a. What was the angle of the hill? b. What was the vertical component of Jill’s velocity?

9. A cannon tilted upward at 30° fires a cannonball with a speed of 100 m/s. At that instant, what is the component of the cannonball’s velocity parallel to the ground?

10. Each of the following vectors is given in terms of its x- and y-components. Draw each of the following vectors, then find its x- and y-components.
   a. \( d = (100 \text{ m}, 45° \text{ below } +x\text{-axis}) \)
   b. \( v = (300 \text{ m/s}, 20° \text{ above } +x\text{-axis}) \)
   c. \( a = (5.0 \text{ m/s}^2, -y\text{-direction}) \)

12. Each of the following vectors is given in terms of its x- and y-components. Draw each of the following vectors, then find its x- and y-components.
   a. \( d = (2.0 \text{ km}, 30° \text{ left of } +y\text{-axis}) \)
   b. \( v = (5.0 \text{ cm/s}, -x\text{-direction}) \)
   c. \( a = (10 \text{ m/s}^2, 40° \text{ left of } -y\text{-axis}) \)

13. Each of the following vectors is given in terms of its x- and y-components. Draw the vector, label an angle that specifies the vector’s direction, then find the vector’s magnitude and direction.
   a. \( v_x = 20 \text{ m/s}, v_y = 40 \text{ m/s} \)
   b. \( a_x = 2.0 \text{ m/s}^2, a_y = -6.0 \text{ m/s}^2 \)

14. Each of the following vectors is given in terms of its x- and y-components. Draw the vector, label an angle that specifies the vector’s direction, then find the vector’s magnitude and direction.
   a. \( v_x = 10 \text{ m/s}, v_y = 30 \text{ m/s} \)
   b. \( a_x = 20 \text{ m/s}^2, a_y = 10 \text{ m/s}^2 \)

15. While visiting England, you decide to take a jog and find yourself in the neighborhood shown on the map in Figure P3.15. What is your displacement after running 2.0 km on Strawberry Fields, 1.0 km on Penny Lane, and 4.0 km on Abbey Road?

Section 3.5 Relative Motion

16. You begin sliding down a 15° ski slope. Ignoring friction and air resistance, how fast will you be moving after 10 s?

17. A car traveling at 30 m/s runs out of gas while traveling up a 5.0° slope. How far will it coast before starting to roll back down?

18. In the Soapbox Derby, young participants build nonmotorized cars with very low-friction wheels. Cars race by rolling down a hill. The track at Akron’s Derby Downs, where the national championship is held, begins with a 55-ft-long section tilted 13° below horizontal.
   a. What is the maximum possible acceleration of a car moving down this stretch of track?
   b. If a car starts from rest and undergoes this acceleration for the full 55 ft, what is its final speed in m/s?

19. A piano has been pushed to the top of the ramp at the back of a moving van. The workers think it is safe, but as they walk away, it begins to roll down the ramp. If the back of the truck is 1.0 m above the ground and the ramp is inclined at 20°, how much time do the workers have to get to the piano before it reaches the bottom of the ramp?

20. Starting from rest, several toy cars roll down ramps of differing lengths and angles. Rank them according to their speed at the bottom of the ramp, from slowest to fastest. Car A goes down a 10 m ramp inclined at 15°, car B goes down a 10 m ramp inclined at 20°, car C goes down an 8.0 m ramp inclined at 20°, and car D goes down a 12 m ramp inclined at 12°.
Section 3.6 Motion in Two Dimensions: Projectile Motion

23. A boat takes 3.0 h to travel 30 km down a river, then 5.0 h to return. How fast is the river flowing?

24. Two children who are bored while waiting for their flight at the airport decide to race from one end of the 20-m-long moving sidewalk to the other and back. Phillippe runs on the sidewalk at 2.0 m/s (relative to the sidewalk). Renee runs on the floor at 2.0 m/s. The sidewalk moves at 1.5 m/s relative to the floor. Both make the turn instantly with no loss of speed.
   a. Who wins the race?
   b. By how much time does the winner win?

25. A skydiver deploys his parachute when he is 1000 m directly above his desired landing spot. He then falls through the air at a steady 5.0 m/s. There is a breeze blowing to the west at 2.0 m/s.
   a. At what angle with respect to vertical does he fall?
   b. By what distance will he miss his desired landing spot?

Section 3.7 Projectile Motion: Solving Problems

26. An object is launched with an initial velocity of 50.0 m/s at a launch angle of 36.9° above the horizontal.
   a. Make a table showing values of \( x, y, v_x, v_y \), and the speed \( v \) every 1 s from \( t = 0 \) s to \( t = 6 \) s.
   b. Plot a graph of the object’s trajectory during the first 6 s of motion.

27. A ball is thrown horizontally from a 20-m-high building with a speed of 5.0 m/s.
   a. Make a sketch of the ball’s trajectory.
   b. Draw a graph of \( v_x \), the horizontal velocity, as a function of time. Include units on both axes.
   c. Draw a graph of \( v_y \), the vertical velocity, as a function of time. Include units on both axes.
   d. How far from the base of the building does the ball hit the ground?

28. A ball with a horizontal speed of 1.25 m/s rolls off a bench 1.00 m above the floor.
   a. How long will it take the ball to hit the floor?
   b. How far from a point on the floor directly below the edge of the bench will the ball land?

29. King Arthur’s knights use a catapult to launch a rock from their vantage point on top of the castle wall, 12 m above the moat. The rock is launched at a speed of 25 m/s and an angle of 30° above the horizontal. How far from the castle wall does the launched rock hit the ground?

30. Two spheres are launched horizontally from a 1.0-m-high table. Sphere A is launched with an initial speed of 5.0 m/s. Sphere B is launched with an initial speed of 2.5 m/s.
   a. What are the times for each sphere to hit the floor?
   b. What are the distances that each travels from the edge of the table?

31. A rifle is aimed horizontally at a target 50 m away. The bullet hits the target 2.0 cm below the aim point.
   a. What was the bullet’s flight time?
   b. What was the bullet’s speed as it left the barrel?

32. A gray kangaroo can bound across a flat stretch of ground with each jump carrying it 10 m from the takeoff point. If the kangaroo leaves the ground at a 20° angle, what are its (a) takeoff speed and (b) horizontal speed?

33. On the Apollo 14 mission to the moon, astronaut Alan Shepard hit a golf ball with a golf club improvised from a tool. The free-fall acceleration on the moon is 1/6 of its value on earth. Suppose he hit the ball with a speed of 25 m/s at an angle 30° above the horizontal.
   a. How long was the ball in flight?
   b. How far did it travel?
   c. Ignoring air resistance, how much farther would it travel on the moon than on earth?

Section 3.8 Motion in Two Dimensions: Circular Motion

34. An old-fashioned LP record rotates at 33 1/3 rpm.
   a. What is its frequency, in rev/s?
   b. What is its period, in seconds?

35. A typical hard disk in a computer spins at 5400 rpm.
   a. What is the frequency, in rev/s?
   b. What is the period, in seconds?

36. Racing greyhounds are capable of rounding corners at very high speeds. A typical greyhound track has turns that are 45-m-diameter semicircles. A greyhound can run around these turns at a constant speed of 15 m/s. What is its acceleration in m/s² and in units of \( g \)?

37. A CD-ROM drive in a computer spins the 12-cm-diameter disks at 10,000 rpm.
   a. What are the disk’s period (in s) and frequency (in rev/s)?
   b. What would be the speed of a spec of dust on the outside edge of this disk?
   c. What is the acceleration in units of \( g \) that this spec of dust experiences?

38. To withstand “g-forces” of up to 10 \( g \)'s, caused by suddenly pulling out of a steep dive, fighter jet pilots train on a “human centrifuge.” 10 \( g \)'s is an acceleration of 98 m/s². If the length of the centrifuge arm is 12 m, at what speed is the rider moving when she experiences 10 \( g \)'s?

39. A particle rotates in a circle with centripetal acceleration \( a = 8.0 \text{ m/s}^2 \). What is \( a \) if
   a. The radius is doubled without changing the particle’s speed?
   b. The speed is doubled without changing the circle’s radius?

40. Entrance and exit ramps for freeways are often circular stretches of road. As you go around one at a constant speed, you will experience a constant acceleration. Suppose you drive through an entrance ramp at a modest speed and your acceleration is 3.0 m/s². What will be the acceleration if you double your speed?

41. A peregrine falcon in a tight, circular turn can attain a centripetal acceleration 1.5 times the free-fall acceleration. If the falcon is flying at 20 m/s, what is the radius of the turn?

General Problems

42. Suppose \( \vec{C} = \vec{A} + \vec{B} \) where vector \( \vec{A} \) has components \( A_x = 5 \), \( A_y = 2 \) and vector \( \vec{B} \) has components \( B_x = -3 \), \( B_y = -5 \).
   a. What are the \( x \)- and \( y \)-components of vector \( \vec{C} \)?
   b. Draw a coordinate system and on it show vectors \( \vec{A} \), \( \vec{B} \), and \( \vec{C} \).
   c. What are the magnitude and direction of vector \( \vec{C} \)?
43. Suppose \( \vec{D} = \vec{A} - \vec{B} \) where vector \( \vec{A} \) has components \( A_x = 5, A_y = 2 \) and vector \( \vec{B} \) has components \( B_x = -3, B_y = -5 \).
   a. What are the \( x \)- and \( y \)-components of vector \( \vec{D} \)?
   b. Draw a coordinate system and on it show vectors \( \vec{A}, \vec{B}, \) and \( \vec{D} \).
   c. What are the magnitude and direction of vector \( \vec{D} \)?

44. Suppose \( \vec{E} = 2\vec{A} + 3\vec{B} \) where vector \( \vec{A} \) has components \( A_x = 5, A_y = 2 \) and vector \( \vec{B} \) has components \( B_x = -3, B_y = -5 \).
   a. What are the \( x \)- and \( y \)-components of vector \( \vec{E} \)?
   b. Draw a coordinate system and on it show vectors \( \vec{A}, \vec{B}, \) and \( \vec{E} \).
   c. What are the magnitude and direction of vector \( \vec{E} \)?

45. For the three vectors shown in Figure P3.45, the vector sum \( \vec{D} = \vec{A} + \vec{B} + \vec{C} \) has components \( D_x = 2 \) and \( D_y = 0 \).
   a. What are the \( x \)- and \( y \)-components of vector \( \vec{B} \)?
   b. Write \( \vec{B} \) as a magnitude and a direction.

46. Let \( \vec{A} = (3.0 \text{ m}, 20^\circ \text{ south of east}), \vec{B} = (2.0 \text{ m}, \text{ north}), \) and \( \vec{C} = (5.0 \text{ m}, 70^\circ \text{ south of west}) \).
   a. Draw and label \( \vec{A}, \vec{B}, \) and \( \vec{C} \) with their tails at the origin. Use a coordinate system with the \( x \)-axis to the east.
   b. Write the \( x \)- and \( y \)-components of vectors \( \vec{A}, \vec{B}, \) and \( \vec{C} \).
   c. Find the magnitude and the direction of \( \vec{D} = \vec{A} + \vec{B} + \vec{C} \).

47. A typical set of stairs is angled at \( 38^\circ \). You climb a set of stairs at a speed of \( 3.5 \text{ m/s} \).
   a. How much height will you gain in \( 2.0 \text{ s} \)?
   b. How much horizontal distance will you cover in \( 2.0 \text{ s} \)?

48. The minute hand on a watch is \( 2.0 \text{ cm} \) long. What is the displacement vector of the tip of the minute hand
   a. From 8:00 to 8:20 A.M.?
   b. From 8:00 to 9:00 A.M.?

49. A field mouse trying to escape a hawk runs east for \( 5.0 \text{ m} \), darts southeast for \( 3.0 \text{ m} \), then drops \( 1.0 \text{ m} \) down a hole into its burrow. What is the magnitude of the net displacement of the mouse?

50. A pilot in a small plane encounters shifting winds. He flies \( 26.0 \text{ km} \) northeast, then \( 45.0 \text{ km} \) due north. From this point, he flies an additional distance in an unknown direction, only to find himself at a small airstrip that his map shows to be \( 70.0 \text{ km} \) directly north of his starting point. What were the length and direction of the third leg of his trip?

51. A small plane is \( 100 \text{ km} \) south of the equator. The plane is flying at \( 150 \text{ km/h} \) at a heading of \( 30^\circ \) to the west of north. In how many minutes will the plane cross the equator?

52. The bacterium *Escherichia coli* (or *E. coli*) is a single-celled organism that lives in the gut of healthy humans and animals. When grown in a uniform medium rich in salts and amino acids, these bacteria swim along zig-zag paths at a constant speed of \( 20 \mu \text{m/s} \). Figure P3.52 shows the trajectory of an *E. coli* as it moves from point A to point E. Each segment of the motion can be identified by two letters, such as segment BC.
   a. For each of the four segments in the bacterium's trajectory, calculate the \( x \)- and \( y \)-components of its displacement and of its velocity.
   b. Calculate both the total distance traveled and the magnitude of the net displacement for the entire motion.
   c. What are the magnitude and the direction of the bacterium's average velocity for the entire trip?

53. A skier is gliding along at \( 3.0 \text{ m/s} \) on horizontal, frictionless snow. He suddenly starts down a \( 10^\circ \) incline. His speed at the bottom is \( 15 \text{ m/s} \).
   a. What is the length of the incline?
   b. How long does it take him to reach the bottom?

54. A block slides along the frictionless track shown in Figure P3.54 with an initial speed of \( 5.0 \text{ m/s} \). Assume it turns all the corners smoothly, with no loss of speed.
   a. What is the block's speed as it goes over the top?
   b. What is its speed when it reaches the level track on the right side?
   c. By what percentage does the block's final speed differ from its initial speed? Is this surprising?

55. One game at the amusement park has you push a puck up a long, frictionless ramp. You win a stuffed animal if the puck, at its highest point, comes to within \( 10 \text{ cm} \) of the end of the ramp without going off. You give the puck a push, releasing it with a speed of \( 5.0 \text{ m/s} \) when it is \( 8.5 \text{ m} \) from the end of the ramp. The puck's speed after traveling \( 3.0 \text{ m} \) is \( 4.0 \text{ m/s} \). Are you a winner?

56. When the moving sidewalk at the airport is broken, as it often seems to be, it takes you \( 50 \text{ s} \) to walk from your gate to the baggage claim. When it is working and you stand on the moving sidewalk the entire way, without walking, it takes \( 75 \text{ s} \) to travel the same distance. How long will it take you to travel from the gate to baggage claim if you walk while riding on the moving sidewalk?

57. Ships A and B leave port together. For the next two hours, ship A travels at 20 mph in a direction \( 30^\circ \) west of north while ship B travels \( 20^\circ \) east of north at 25 mph.
   a. What is the distance between the two ships two hours after they depart?
   b. What is the speed of ship A as seen by ship B?

58. Mary needs to row her boat across a 100-m-wide river that is flowing to the east at a speed of \( 1.0 \text{ m/s} \). Mary can row the boat with a speed of \( 2.0 \text{ m/s} \) relative to the water.
   a. If Mary rows straight north, how far downstream will she land?
   b. Draw a picture showing Mary's displacement due to rowing, her displacement due to the river's motion, and her net displacement.

59. A flock of ducks is trying to migrate south for the winter, but they keep being blown off course by a wind blowing from the west at \( 12 \text{ m/s} \). A wise elder duck finally realizes that the solution is to fly at an angle to the wind. If the ducks can fly at \( 16 \text{ m/s} \) relative to the air, in what direction should they head in order to move directly south?
60. A kayaker needs to paddle north across a 100-m-wide harbor. The tide is going out, creating a tidal current flowing east at 2.0 m/s. The kayaker can paddle with a speed of 3.0 m/s.
   a. In which direction should he paddle in order to travel straight across the harbor?
   b. How long will it take him to cross?

61. A plane has an airspeed of 200 mph. The pilot wishes to reach a destination 600 m due east, but a wind is blowing at 50 mph in the direction 30° north of east.
   a. In what direction must the pilot head the plane in order to reach her destination?
   b. How long will the trip take?

62. The Gulf Stream off the east coast of the United States can flow at a rapid 3.6 m/s to the north. A ship in this current has a cruising speed of 10 m/s. The captain would like to reach land at a point due west from the current position.
   a. In what direction with respect to the water should the ship sail?
   b. At this heading, what is the ship's speed with respect to land?

63. A physics student on Planet Exidor throws a ball, and it follows the parabolic trajectory shown in Figure P3.63. The ball’s position is shown at 1.0 s intervals until \( t = 3.0 \) s. At \( t = 1.0 \) s, the ball’s velocity has components \( v_x = 2.0 \) m/s, \( v_y = 2.0 \) m/s.
   a. Determine the \( x \)- and \( y \)-components of the ball’s velocity at \( t = 0.0 \) s, 2.0 s, and 3.0 s.
   b. What is the value of \( g \) on Planet Exidor?
   c. What was the ball’s launch angle?

64. A ball thrown horizontally at 25 m/s travels a horizontal distance of 50 m before hitting the ground. From what height was the ball thrown?

65. In 1780, in what is now referred to as “Brady’s Leap,” Captain Sam Brady of the U.S. Continental Army escaped certain death from his enemies by running over the edge of the cliff above Ohio’s Cuyahoga River, which is confined at that spot to a gorge. He landed safely on the far side of the river. It was reported that he leapt 22 ft across while falling 20 ft.
   a. Representing the distance jumped as \( L \) and the vertical drop as \( h \), as shown in Figure P3.65, derive an expression for the minimum speed \( v \) he would need to make his leap if he ran straight off the cliff.
   b. Evaluate your expression for a 22 ft jump with a 20 ft drop to the other side.
   c. Is it reasonable that a person could make this leap? Use the fact that the world record for the 100 m dash is approximately 10 s to estimate the maximum speed such a runner would have.

66. The longest recorded pass in an NFL game traveled 83 yards in the air from the quarterback to the receiver. Assuming that the pass was thrown at the optimal 45° angle, what was the speed at which the ball left the quarterback’s hand?

67. A spring-loaded gun, fired vertically, shoots a marble 6.0 m straight up in the air. What is the marble’s range if it is fired horizontally from 1.5 m above the ground?

68. In a shot-put event, an athlete throws the shot with an initial speed of 12.0 m/s at a 40.0° angle from the horizontal. The shot leaves her hand at a height of 1.80 m above the ground.
   a. How far does the shot travel?
   b. Repeat the calculation of part (a) for angles 42.5°, 45.0°, and 47.5°. Put all your results, including 40.0°, in a table. At what angle of release does she throw the farthest?

69. A tennis player hits a ball 2.0 m above the ground. The ball leaves his racquet with a speed of 20 m/s at an angle 5.0° above the horizontal. The horizontal distance to the net is 7.0 m, and the net is 1.0 m high. Does the ball clear the net? If so, by how much? If not, by how much does it miss?

70. Water at the top of Horseshoe Falls (part of Niagara Falls) is moving horizontally at 9.0 m/s as it goes off the edge and plunges 53 m to the pool below. If you ignore air resistance, at what angle is the falling water moving as it enters the pool?

71. Figure 3.37 shows that the range of a projectile launched at a 60° angle has the same range as a projectile launched at a 30° angle—but they won’t be in the air for the same amount of time. Suppose a projectile launched at a 30° angle is in the air for 2.0 s. How long will the projectile be in the air if it is launched with the same speed at a 60° angle?

72. A supply plane needs to drop a package of food to scientists working on a glacier in Greenland. The plane flies 100 m above the glacier at a speed of 150 m/s. How far short of the target should it drop the package?

73. A child slides down a frictionless 3.0-m-long playground slide tilted upward at an angle of 40°. At the end of the slide, there is an additional section that curves so that the child is launched off the end of the slide horizontally.
   a. How fast is the child moving at the bottom of the slide?
   b. If the end of the slide is 0.40 m above the ground, how far from the end does she land?

74. A sports car is advertised to be able to "reach 60 mph in 5 seconds flat, corner at 0.85g, and stop from 70 mph in only 168 feet."
   a. In which of those three situations is the magnitude of the car’s acceleration the largest? In which is it the smallest?
   b. At 60 mph, what is the smallest turning radius that this car can navigate?

75. A Ford Mustang can accelerate from 0 to 60 mph in a time of 5.6 s. A Mini Cooper isn’t capable of such a rapid start, but it can turn in a very small circle 34 ft in diameter. How fast would you need to drive the Mini Cooper in this tight circle to match the magnitude of the Mustang’s acceleration?

76. The “Screaming Swing” is a carnival ride that is—not surprisingly—a giant swing. It’s actually two swings moving in opposite directions. At the bottom of its arc, riders are moving at 30 m/s with respect to the ground in a 50-m-diameter circle.
   a. What is the acceleration, in m/s², and in units of g, that riders experience?
   b. At the bottom of the ride, as they pass each other, how fast do the riders move with respect to each other?

77. On an otherwise straight stretch of road near Moffat, Colorado, the road suddenly turns. This bend in the road is a segment of a circle with radius 110 m. Drivers are cautioned to slow down to 40 mph as they navigate the curve.
   a. If you heed the sign and slow to 40 mph, what will be your acceleration going around the curve at this constant speed? Give your answer in m/s² and in units of g.
   b. At what speed would your acceleration be double that at the recommended speed?
Riding the Water Slide

A rider on a water slide goes through three different kinds of motion, as illustrated in Figure P3.78. Use the data and details from the figure to answer the following questions.

1. The first section of the motion is a ramp with no friction: riders start at rest and accelerate down the ramp.

2. The second section of the motion is a circular segment that changes the direction of motion: riders go around this circular segment at a constant speed and end with a velocity horizontal.

3. The third section of the motion is a parabolic trajectory through the air at the end of which riders land in the water.

**Figure P3.78**

78. | At the end of the first section of the motion, riders are moving at what approximate speed?  
   A. 3 m/s  
   B. 6 m/s  
   C. 9 m/s  
   D. 12 m/s

79. | Suppose the acceleration during the second section of the motion is too large to be comfortable for riders. What change could be made to decrease the acceleration during this section?  
   A. Reduce the radius of the circular segment.  
   B. Increase the radius of the circular segment.  
   C. Increase the angle of the ramp.  
   D. Increase the length of the ramp.

80. | What is the vertical component of the velocity of a rider as he or she hits the water?  
   A. 2.4 m/s  
   B. 3.4 m/s  
   C. 5.2 m/s  
   D. 9.1 m/s

81. | Suppose the designers of the water slide want to adjust the height above the water so that riders land twice as far away from the bottom of the slide. What would be the necessary height above the water?  
   A. 1.2 m  
   B. 1.8 m  
   C. 2.4 m  
   D. 3.0 m

82. | During which section of the motion is the magnitude of the acceleration experienced by a rider the greatest?  
   A. The first.  
   B. The second.  
   C. The third.  
   D. It is the same in all sections.

**Stop to Think Answers**

**Stop to Think 3.1:** A. The graphical construction of $2\vec{P} - \vec{Q}$ is shown at right.

**Stop to Think 3.2:** From the axes on the graph, we can see that the $x$- and $y$-components are $-4\, \text{cm}$ and $+2\, \text{cm}$, respectively.

**Stop to Think 3.3:** C. Vector $\vec{C}$ points to the left and down, so both $C_x$ and $C_y$ are negative. $C_x$ is in the numerator because it is the side opposite $\phi$.

**Stop to Think 3.4:** B. The angle of the slope is greatest in this case, leading to the greatest acceleration.

**Stop to Think 3.5:** D. Mass does not appear in the kinematic equations, so the mass has no effect; the balls will follow the same path.

**Stop to Think 3.6:** B. The magnitude of the acceleration is $v^2/r$. Acceleration is largest for the combination of highest speed and smallest radius.