Acceleration is the change of velocity per unit time. An object's **average acceleration** over a time interval Δt is

$$\bar{a} = \frac{\Delta v}{\Delta t}, \qquad \textbf{(2–4)}$$

where Δv is the change of velocity during the time interval Δt. **Instantaneous acceleration** is the average acceleration taken over an infinitesimally short time interval.

If an object has position x_0 and velocity v_0 at time $t = 0$ and moves in a straight line with **constant acceleration**, the velocity v and position x at a later time t are related to the acceleration a, the initial position x_0, and the initial velocity v_0 by Eqs. 2–11:

$$\begin{aligned} v &= v_0 + at, \\ x &= x_0 + v_0 t + \tfrac{1}{2}at^2, \\ v^2 &= v_0^2 + 2a(x - x_0), \\ \bar{v} &= \frac{v + v_0}{2}. \end{aligned} \qquad \textbf{(2–11)}$$

Objects that move vertically near the surface of the Earth, either falling or having been projected vertically up or down, move with the constant downward **acceleration due to gravity**, whose magnitude is $g = 9.80\,\mathrm{m/s^2}$ if air resistance can be ignored. We can apply Eqs. 2–11 for constant acceleration to objects that move up or down freely near the Earth's surface.

The slope of a curve at any point on a graph is the slope of the tangent to the curve at that point. On a graph of position vs. time, the **slope** is equal to the instantaneous velocity. On a graph of velocity vs. time, the slope is the acceleration.

Questions

1. Does a car speedometer measure speed, velocity, or both? Explain.

2. When an object moves with constant velocity, does its average velocity during any time interval differ from its instantaneous velocity at any instant? Explain.

3. If one object has a greater speed than a second object, does the first necessarily have a greater acceleration? Explain, using examples.

4. Compare the acceleration of a motorcycle that accelerates from 80 km/h to 90 km/h with the acceleration of a bicycle that accelerates from rest to 10 km/h in the same time.

5. Can an object have a northward velocity and a southward acceleration? Explain.

6. Can the velocity of an object be negative when its acceleration is positive? What about vice versa? If yes, give examples in each case.

7. Give an example where both the velocity and acceleration are negative.

8. Can an object be increasing in speed as its acceleration decreases? If so, give an example. If not, explain.

9. Two cars emerge side by side from a tunnel. Car A is traveling with a speed of 60 km/h and has an acceleration of 40 km/h/min. Car B has a speed of 40 km/h and has an acceleration of 60 km/h/min. Which car is passing the other as they come out of the tunnel? Explain your reasoning.

10. A baseball player hits a ball straight up into the air. It leaves the bat with a speed of 120 km/h. In the absence of air resistance, how fast would the ball be traveling when it is caught at the same height above the ground as it left the bat? Explain.

11. As a freely falling object speeds up, what is happening to its acceleration—does it increase, decrease, or stay the same? (*a*) Ignore air resistance. (*b*) Consider air resistance.

12. You travel from point A to point B in a car moving at a constant speed of 70 km/h. Then you travel the same distance from point B to another point C, moving at a constant speed of 90 km/h. Is your average speed for the entire trip from A to C equal to 80 km/h? Explain why or why not.

13. Can an object have zero velocity and nonzero acceleration at the same time? Give examples.

14. Can an object have zero acceleration and nonzero velocity at the same time? Give examples.

15. Which of these motions is *not* at constant acceleration: a rock falling from a cliff, an elevator moving from the second floor to the fifth floor making stops along the way, a dish resting on a table? Explain your answers.

16. Describe in words the motion plotted in Fig. 2–32 in terms of velocity, acceleration, etc. [*Hint*: First try to duplicate the motion plotted by walking or moving your hand.]

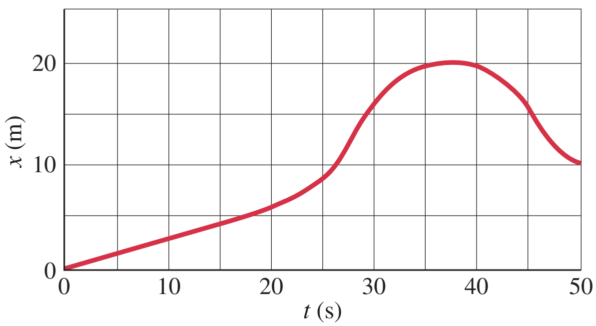

FIGURE 2–32 Question 16.

17. Describe in words the motion of the object graphed in Fig. 2–33.

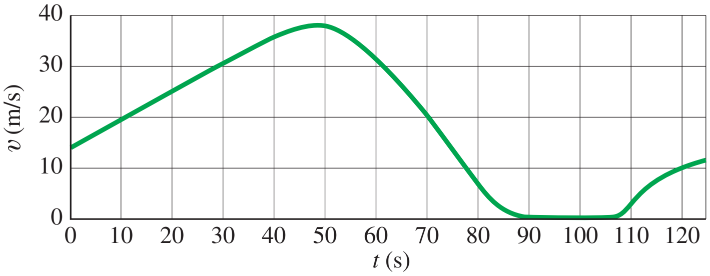

FIGURE 2–33 Question 17.

MisConceptual Questions

[List all answers that are valid.]

1. Which of the following should be part of solving any problem in physics? Select all that apply:
(*a*) Read the problem carefully.
(*b*) Draw a picture of the situation.
(*c*) Write down the variables that are given.
(*d*) Think about which physics principles to apply.
(*e*) Determine which equations can be used to apply the correct physics principles.
(*f*) Check the units when you have completed your calculation.
(*g*) Consider whether your answer is reasonable.

2. In which of the following cases does a car have a negative velocity and a positive acceleration? A car that is traveling in the
(*a*) $-x$ direction at a constant 20 m/s.
(*b*) $-x$ direction increasing in speed.
(*c*) $+x$ direction increasing in speed.
(*d*) $-x$ direction decreasing in speed.
(*e*) $+x$ direction decreasing in speed.

3. At time $t = 0$ an object is traveling to the right along the $+x$ axis at a speed of 10.0 m/s with acceleration $-2.0\ \mathrm{m/s^2}$. Which statement is true?
(*a*) The object will slow down, eventually coming to a complete stop.
(*b*) The object cannot have a negative acceleration and be moving to the right.
(*c*) The object will continue to move to the right, slowing down but never coming to a complete stop.
(*d*) The object will slow down, momentarily stopping, then pick up speed moving to the left.

4. A ball is thrown straight up. What are the velocity and acceleration of the ball at the highest point in its path?
(*a*) $v = 0,\ a = 0$.
(*b*) $v = 0,\ a = 9.8\ \mathrm{m/s^2}$ up.
(*c*) $v = 0,\ a = 9.8\ \mathrm{m/s^2}$ down.
(*d*) $v = 9.8$ m/s up, $a = 0$.
(*e*) $v = 9.8$ m/s down, $a = 0$.

5. You drop a rock off a bridge. When the rock has fallen 4 m, you drop a second rock. As the two rocks continue to fall, what happens to their velocities?
(*a*) Both increase at the same rate.
(*b*) The velocity of the first rock increases faster than the velocity of the second.
(*c*) The velocity of the second rock increases faster than the velocity of the first.
(*d*) Both velocities stay constant.

6. You drive 4 km at 30 km/h and then another 4 km at 50 km/h. What is your average speed for the whole 8-km trip?
(*a*) More than 40 km/h.
(*b*) Equal to 40 km/h.
(*c*) Less than 40 km/h.
(*d*) Not enough information.

7. A ball is dropped from the top of a tall building. At the same instant, a second ball is thrown upward from ground level. When the two balls pass one another, one on the way up, the other on the way down, compare the magnitudes of their acceleration:
(*a*) The acceleration of the dropped ball is greater.
(*b*) The acceleration of the ball thrown upward is greater.
(*c*) The acceleration of both balls is the same.
(*d*) The acceleration changes during the motion, so you cannot predict the exact value when the two balls pass each other.
(*e*) The accelerations are in opposite directions.

8. A ball is thrown downward at a speed of 20 m/s. Choosing the $+y$ axis pointing up and neglecting air resistance, which equation(s) could be used to solve for other variables? The acceleration due to gravity is $g = 9.8\ \mathrm{m/s^2}$ downward.
(*a*) $v = (20\ \mathrm{m/s}) - gt$.
(*b*) $y = y_0 + (-20\ \mathrm{m/s})t - (1/2)gt^2$.
(*c*) $v^2 = (20\ \mathrm{m/s})^2 - 2g(y - y_0)$.
(*d*) $(20\ \mathrm{m/s}) = (v + v_0)/2$.
(*e*) All of the above.

9. A car travels along the x axis with increasing speed. We don't know if to the left or the right. Which of the graphs in Fig. 2–34 most closely represents the motion of the car?

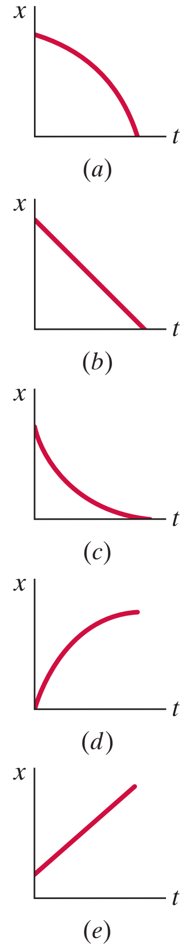

FIGURE 2–34 MisConceptual Question 9.

For assigned homework and other learning materials, go to the MasteringPhysics website.

Problems

[*The Problems at the end of each Chapter are ranked* I, II, *or* III *according to estimated difficulty, with level* I *Problems being easiest. Level* III *are meant as challenges for the best students. The Problems are arranged by Section, meaning that the reader should have read up to and including that Section, but not only that Section—Problems often depend on earlier material. Next is a set of "General Problems" not arranged by Section and not ranked. Finally, there are "Search and Learn" Problems that require rereading parts of the Chapter and sometimes earlier Chapters.*]

(Note: *In Problems, assume a number like* 6.4 *is accurate to* ± 0.1; *and* 950 *is* ± 10 *unless* 950 *is said to be "precisely" or "very nearly"* 950, *in which case assume* 950 ± 1. *See Section 1–4.)*

2–1 to 2–3 Speed and Velocity

1. (I) If you are driving 95 km/h along a straight road and you look to the side for 2.0 s, how far do you travel during this inattentive period?

2. (I) What must your car's average speed be in order to travel 235 km in 2.75 h?

3. (I) A particle at $t_1 = -2.0$ s is at $x_1 = 4.8$ cm and at $t_2 = 4.5$ s is at $x_2 = 8.5$ cm. What is its average velocity over this time interval? Can you calculate its average speed from these data? Why or why not?

4. (I) A rolling ball moves from $x_1 = 8.4$ cm to $x_2 = -4.2$ cm during the time from $t_1 = 3.0$ s to $t_2 = 6.1$ s. What is its average velocity over this time interval?

5. (I) A bird can fly 25 km/h. How long does it take to fly 3.5 km?

6. (II) According to a rule-of-thumb, each five seconds between a lightning flash and the following thunder gives the distance to the flash in miles. (*a*) Assuming that the flash of light arrives in essentially no time at all, estimate the speed of sound in m/s from this rule. (*b*) What would be the rule for kilometers?

7. (II) You are driving home from school steadily at 95 km/h for 180 km. It then begins to rain and you slow to 65 km/h. You arrive home after driving 4.5 h. (*a*) How far is your hometown from school? (*b*) What was your average speed?

8. (II) A horse trots away from its trainer in a straight line, moving 38 m away in 9.0 s. It then turns abruptly and gallops halfway back in 1.8 s. Calculate (*a*) its average speed and (*b*) its average velocity for the entire trip, using "away from the trainer" as the positive direction.

9. (II) A person jogs eight complete laps around a 400-m track in a total time of 14.5 min. Calculate (*a*) the average speed and (*b*) the average velocity, in m/s.

10. (II) Every year the Earth travels about 10^9 km as it orbits the Sun. What is Earth's average speed in km/h?

11. (II) A car traveling 95 km/h is 210 m behind a truck traveling 75 km/h. How long will it take the car to reach the truck?

12. (II) Calculate the average speed and average velocity of a complete round trip in which the outgoing 250 km is covered at 95 km/h, followed by a 1.0-h lunch break, and the return 250 km is covered at 55 km/h.

13. (II) Two locomotives approach each other on parallel tracks. Each has a speed of 155 km/h with respect to the ground. If they are initially 8.5 km apart, how long will it be before they reach each other? (See Fig. 2–35.)

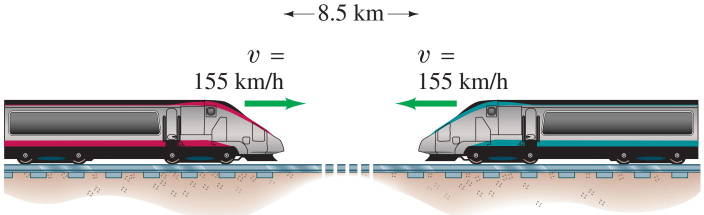

FIGURE 2–35 Problem 13.

14. (II) Digital bits on a 12.0-cm diameter audio CD are encoded along an outward spiraling path that starts at radius $R_1 = 2.5$ cm and finishes at radius $R_2 = 5.8$ cm. The distance between the centers of neighboring spiral-windings is 1.6 μm $(= 1.6 \times 10^{-6}\,\mathrm{m})$. (*a*) Determine the total length of the spiraling path. [*Hint*: Imagine "unwinding" the spiral into a straight path of width 1.6 μm, and note that the original spiral and the straight path both occupy the same area.] (*b*) To read information, a CD player adjusts the rotation of the CD so that the player's readout laser moves along the spiral path at a constant speed of about 1.2 m/s. Estimate the maximum playing time of such a CD.

15. (III) A bowling ball traveling with constant speed hits the pins at the end of a bowling lane 16.5 m long. The bowler hears the sound of the ball hitting the pins 2.80 s after the ball is released from his hands. What is the speed of the ball, assuming the speed of sound is 340 m/s?

16. (III) An automobile traveling 95 km/h overtakes a 1.30-km-long train traveling in the same direction on a track parallel to the road. If the train's speed is 75 km/h, how long does it take the car to pass it, and how far will the car have traveled in this time? See Fig. 2–36. What are the results if the car and train are traveling in opposite directions?

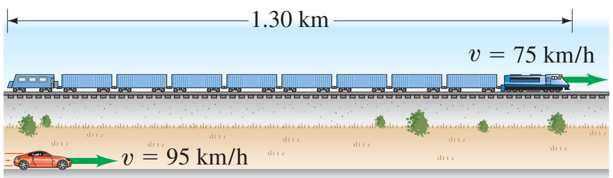

FIGURE 2–36 Problem 16.

2–4 Acceleration

17. (I) A sports car accelerates from rest to 95 km/h in 4.3 s. What is its average acceleration in m/s^2?

18. (I) A sprinter accelerates from rest to 9.00 m/s in 1.38 s. What is her acceleration in (*a*) m/s^2; (*b*) km/h^2?

19. (II) A sports car moving at constant velocity travels 120 m in 5.0 s. If it then brakes and comes to a stop in 4.0 s, what is the magnitude of its acceleration (assumed constant) in m/s^2, and in g's $(g = 9.80\,\mathrm{m/s^2})$?

20. (II) At highway speeds, a particular automobile is capable of an acceleration of about $1.8\ \mathrm{m/s^2}$. At this rate, how long does it take to accelerate from 65 km/h to 120 km/h?

21. (II) A car moving in a straight line starts at $x = 0$ at $t = 0$. It passes the point $x = 25.0\ \mathrm{m}$ with a speed of 11.0 m/s at $t = 3.00\ \mathrm{s}$. It passes the point $x = 385\ \mathrm{m}$ with a speed of 45.0 m/s at $t = 20.0\ \mathrm{s}$. Find (*a*) the average velocity, and (*b*) the average acceleration, between $t = 3.00\ \mathrm{s}$ and $t = 20.0\ \mathrm{s}$.

2–5 and 2–6 Motion at Constant Acceleration

22. (I) A car slows down from 28 m/s to rest in a distance of 88 m. What was its acceleration, assumed constant?

23. (I) A car accelerates from 14 m/s to 21 m/s in 6.0 s. What was its acceleration? How far did it travel in this time? Assume constant acceleration.

24. (I) A light plane must reach a speed of 35 m/s for takeoff. How long a runway is needed if the (constant) acceleration is $3.0\ \mathrm{m/s^2}$?

25. (II) A baseball pitcher throws a baseball with a speed of 43 m/s. Estimate the average acceleration of the ball during the throwing motion. In throwing the baseball, the pitcher accelerates it through a displacement of about 3.5 m, from behind the body to the point where it is released (Fig. 2–37).

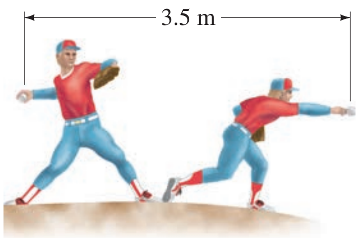

FIGURE 2–37 Problem 25.

26. (II) A world-class sprinter can reach a top speed (of about 11.5 m/s) in the first 18.0 m of a race. What is the average acceleration of this sprinter and how long does it take her to reach that speed?

27. (II) A car slows down uniformly from a speed of 28.0 m/s to rest in 8.00 s. How far did it travel in that time?

28. (II) In coming to a stop, a car leaves skid marks 65 m long on the highway. Assuming a deceleration of $4.00\ \mathrm{m/s^2}$, estimate the speed of the car just before braking.

29. (II) A car traveling 75 km/h slows down at a constant $0.50\ \mathrm{m/s^2}$ just by "letting up on the gas." Calculate (*a*) the distance the car coasts before it stops, (*b*) the time it takes to stop, and (*c*) the distance it travels during the first and fifth seconds.

30. (II) Determine the stopping distances for an automobile going a constant initial speed of 95 km/h and human reaction time of 0.40 s: (*a*) for an acceleration $a = -3.0\ \mathrm{m/s^2}$; (*b*) for $a = -6.0\ \mathrm{m/s^2}$.

31. (II) A driver is traveling 18.0 m/s when she sees a red light ahead. Her car is capable of decelerating at a rate of $3.65\ \mathrm{m/s^2}$. If it takes her 0.350 s to get the brakes on and she is 20.0 m from the intersection when she sees the light, will she be able to stop in time? How far from the beginning of the intersection will she be, and in what direction?

32. (II) A 75-m-long train begins uniform acceleration from rest. The front of the train has a speed of 18 m/s when it passes a railway worker who is standing 180 m from where the front of the train started. What will be the speed of the last car as it passes the worker? (See Fig. 2–38.)

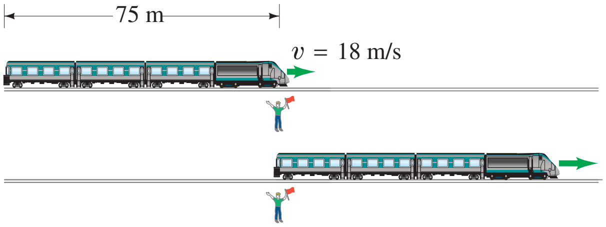

FIGURE 2–38 Problem 32.

33. (II) A space vehicle accelerates uniformly from 85 m/s at $t = 0$ to 162 m/s at $t = 10.0\ \mathrm{s}$. How far did it move between $t = 2.0\ \mathrm{s}$ and $t = 6.0\ \mathrm{s}$?

34. (III) A fugitive tries to hop on a freight train traveling at a constant speed of 5.0 m/s. Just as an empty box car passes him, the fugitive starts from rest and accelerates at $a = 1.4\ \mathrm{m/s^2}$ to his maximum speed of 6.0 m/s, which he then maintains. (*a*) How long does it take him to catch up to the empty box car? (*b*) What is the distance traveled to reach the box car?

35. (III) Mary and Sally are in a foot race (Fig. 2–39). When Mary is 22 m from the finish line, she has a speed of 4.0 m/s and is 5.0 m behind Sally, who has a speed of 5.0 m/s. Sally thinks she has an easy win and so, during the remaining portion of the race, decelerates at a constant rate of $0.40\ \mathrm{m/s^2}$ to the finish line. What constant acceleration does Mary now need during the remaining portion of the race, if she wishes to cross the finish line side-by-side with Sally?

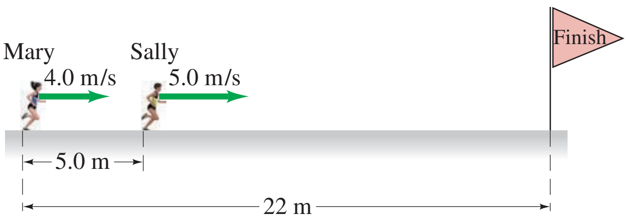

FIGURE 2–39 Problem 35.

36. (III) An unmarked police car traveling a constant 95 km/h is passed by a speeder traveling 135 km/h. Precisely 1.00 s after the speeder passes, the police officer steps on the accelerator; if the police car's acceleration is $2.60\ \mathrm{m/s^2}$, how much time passes before the police car overtakes the speeder (assumed moving at constant speed)?

2–7 Freely Falling Objects (neglect air resistance)

37. (I) A stone is dropped from the top of a cliff. It is seen to hit the ground below after 3.55 s. How high is the cliff?

38. (I) Estimate (*a*) how long it took King Kong to fall straight down from the top of the Empire State Building (380 m high), and (*b*) his velocity just before "landing."

39. (II) A ball player catches a ball 3.4 s after throwing it vertically upward. With what speed did he throw it, and what height did it reach?

40. (II) A baseball is hit almost straight up into the air with a speed of 25 m/s. Estimate (*a*) how high it goes, (*b*) how long it is in the air. (*c*) What factors make this an estimate?

41. (II) The best rebounders in basketball have a vertical leap (that is, the vertical movement of a fixed point on their body) of about 120 cm. (*a*) What is their initial "launch" speed off the ground? (*b*) How long are they in the air?

42. (II) An object starts from rest and falls under the influence of gravity. Draw graphs of (*a*) its speed and (*b*) the distance it has fallen, as a function of time from $t = 0$ to $t = 5.00$ s. Ignore air resistance.

43. (II) A stone is thrown vertically upward with a speed of 24.0 m/s. (*a*) How fast is it moving when it is at a height of 13.0 m? (*b*) How much time is required to reach this height? (*c*) Why are there two answers to (*b*)?

44. (II) For an object falling freely from rest, show that the distance traveled *during* each successive second increases in the ratio of successive odd integers (1, 3, 5, etc.). (This was first shown by Galileo.) See Figs. 2–19 and 2–22.

45. (II) A rocket rises vertically, from rest, with an acceleration of 3.2 m/s^2 until it runs out of fuel at an altitude of 775 m. After this point, its acceleration is that of gravity, downward. (*a*) What is the velocity of the rocket when it runs out of fuel? (*b*) How long does it take to reach this point? (*c*) What maximum altitude does the rocket reach? (*d*) How much time (total) does it take to reach maximum altitude? (*e*) With what velocity does it strike the Earth? (*f*) How long (total) is it in the air?

46. (II) A helicopter is ascending vertically with a speed of 5.40 m/s. At a height of 105 m above the Earth, a package is dropped from the helicopter. How much time does it take for the package to reach the ground? [*Hint*: What is v_0 for the package?]

47. (II) Roger sees water balloons fall past his window. He notices that each balloon strikes the sidewalk 0.83 s after passing his window. Roger's room is on the third floor, 15 m above the sidewalk. (*a*) How fast are the balloons traveling when they pass Roger's window? (*b*) Assuming the balloons are being released from rest, from what floor are they being released? Each floor of the dorm is 5.0 m high.

48. (II) Suppose you adjust your garden hose nozzle for a fast stream of water. You point the nozzle vertically upward at a height of 1.8 m above the ground (Fig. 2–40). When you quickly turn off the nozzle, you hear the water striking the ground next to you for another 2.5 s. What is the water speed as it leaves the nozzle?

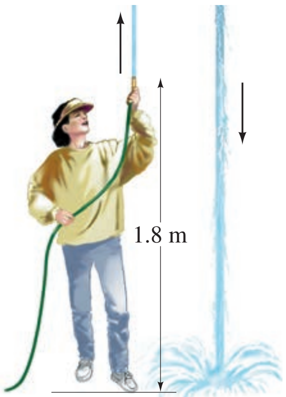

FIGURE 2–40 Problem 48.

49. (III) A falling stone takes 0.31 s to travel past a window 2.2 m tall (Fig. 2–41). From what height above the top of the window did the stone fall?

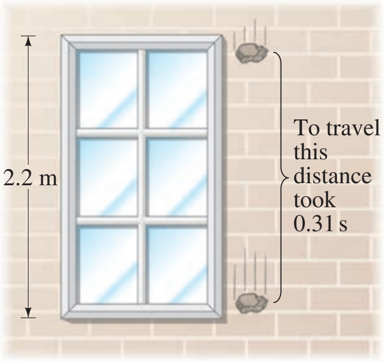

FIGURE 2–41 Problem 49.

50. (III) A rock is dropped from a sea cliff, and the sound of it striking the ocean is heard 3.4 s later. If the speed of sound is 340 m/s, how high is the cliff?

2–8 Graphical Analysis

51. (II) Figure 2–42 shows the velocity of a train as a function of time. (*a*) At what time was its velocity greatest? (*b*) During what periods, if any, was the velocity constant? (*c*) During what periods, if any, was the acceleration constant? (*d*) When was the magnitude of the acceleration greatest?

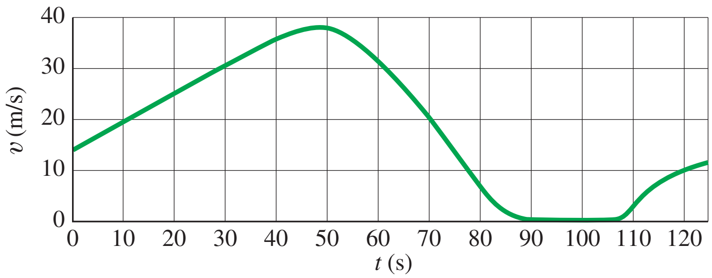

FIGURE 2–42 Problem 51.

52. (II) A sports car accelerates approximately as shown in the velocity–time graph of Fig. 2–43. (The short flat spots in the curve represent manual shifting of the gears.) Estimate the car's average acceleration in (*a*) second gear and (*b*) fourth gear.

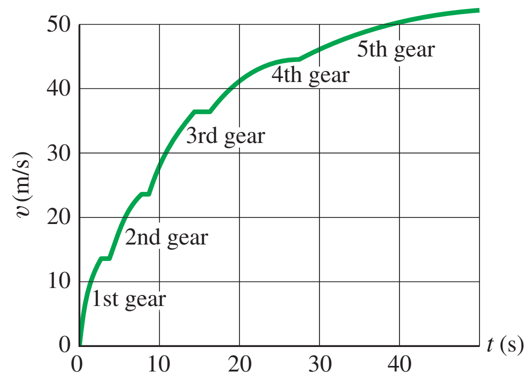

FIGURE 2–43 Problem 52. The velocity of a car as a function of time, starting from a dead stop. The flat spots in the curve represent gear shifts.

53. (II) The position of a rabbit along a straight tunnel as a function of time is plotted in Fig. 2–44. What is its instantaneous velocity (*a*) at $t = 10.0\,\mathrm{s}$ and (*b*) at $t = 30.0\,\mathrm{s}$? What is its average velocity (*c*) between $t = 0$ and $t = 5.0\,\mathrm{s}$, (*d*) between $t = 25.0\,\mathrm{s}$ and $t = 30.0\,\mathrm{s}$, and (*e*) between $t = 40.0\,\mathrm{s}$ and $t = 50.0\,\mathrm{s}$?

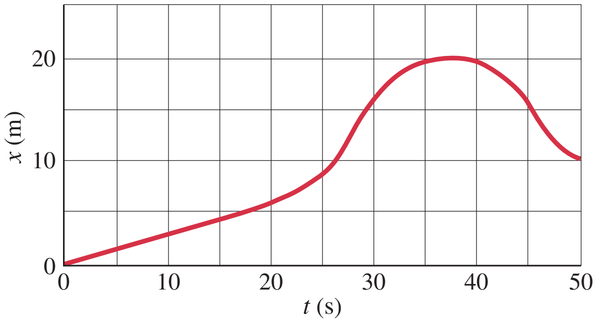

FIGURE 2–44 Problems 53, 54, and 55.

54. (II) In Fig. 2–44, (*a*) during what time periods, if any, is the velocity constant? (*b*) At what time is the velocity greatest? (*c*) At what time, if any, is the velocity zero? (*d*) Does the object move in one direction or in both directions during the time shown?

55. (III) Sketch the v vs. t graph for the object whose displacement as a function of time is given by Fig. 2–44.

General Problems

56. The acceleration due to gravity on the Moon is about one-sixth what it is on Earth. If an object is thrown vertically upward on the Moon, how many times higher will it go than it would on Earth, assuming the same initial velocity?

57. A person who is properly restrained by an over-the-shoulder seat belt has a good chance of surviving a car collision if the deceleration does not exceed 30 "g's" $(1.00\,g = 9.80\,\mathrm{m/s^2})$. Assuming uniform deceleration at 30 g's, calculate the distance over which the front end of the car must be designed to collapse if a crash brings the car to rest from 95 km/h.

58. A person jumps out a fourth-story window 18.0 m above a firefighter's safety net. The survivor stretches the net 1.0 m before coming to rest, Fig. 2–45. (*a*) What was the average deceleration experienced by the survivor when she was slowed to rest by the net? (*b*) What would you do to make it "safer" (that is, to generate a smaller deceleration): would you stiffen or loosen the net? Explain.

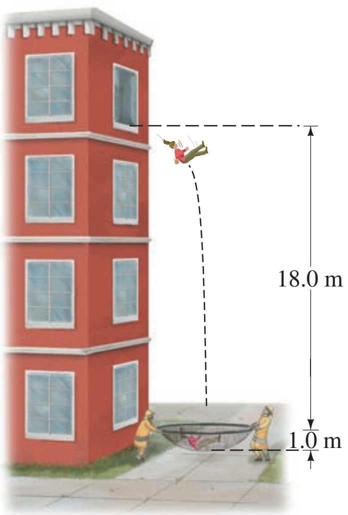

FIGURE 2–45 Problem 58.

59. A bicyclist in the Tour de France crests a mountain pass as he moves at 15 km/h. At the bottom, 4.0 km farther, his speed is 65 km/h. Estimate his average acceleration (in $\mathrm{m/s^2}$) while riding down the mountain.

60. Consider the street pattern shown in Fig. 2–46. Each intersection has a traffic signal, and the speed limit is 40 km/h. Suppose you are driving from the west at the speed limit. When you are 10.0 m from the first intersection, all the lights turn green. The lights are green for 13.0 s each. (*a*) Calculate the time needed to reach the third stoplight. Can you make it through all three lights without stopping? (*b*) Another car was stopped at the first light when all the lights turned green. It can accelerate at the rate of $2.00\,\mathrm{m/s^2}$ to the speed limit. Can the second car make it through all three lights without stopping? By how many seconds would it make it, or not make it?

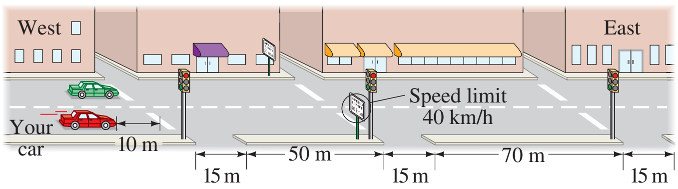

FIGURE 2–46 Problem 60.

61. An airplane travels 2100 km at a speed of 720 km/h, and then encounters a tailwind that boosts its speed to 990 km/h for the next 2800 km. What was the total time for the trip? What was the average speed of the plane for this trip? [*Hint*: Does Eq. 2–11d apply?]

62. A stone is dropped from the roof of a high building. A second stone is dropped 1.30 s later. How far apart are the stones when the second one has reached a speed of 12.0 m/s?

63. A person jumps off a diving board 4.0 m above the water's surface into a deep pool. The person's downward motion stops 2.0 m below the surface of the water. Estimate the average deceleration of the person while under the water.

64. In putting, the force with which a golfer strikes a ball is planned so that the ball will stop within some small distance of the cup, say 1.0 m long or short, in case the putt is missed. Accomplishing this from an uphill lie (that is, putting the ball downhill, see Fig. 2–47) is more difficult than from a downhill lie. To see why, assume that on a particular green the ball decelerates constantly at $1.8\ \mathrm{m/s^2}$ going downhill, and constantly at $2.6\ \mathrm{m/s^2}$ going uphill. Suppose we have an uphill lie 7.0 m from the cup. Calculate the allowable range of initial velocities we may impart to the ball so that it stops in the range 1.0 m short to 1.0 m long of the cup. Do the same for a downhill lie 7.0 m from the cup. What in your results suggests that the downhill putt is more difficult?

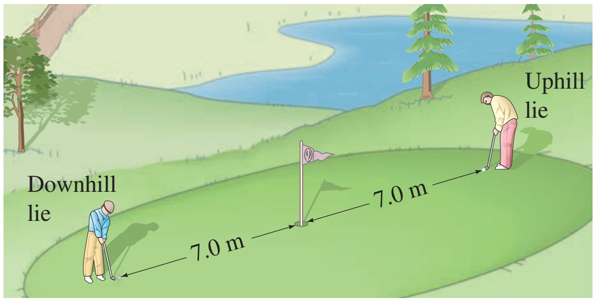

FIGURE 2–47 Problem 64.

65. A stone is thrown vertically upward with a speed of 15.5 m/s from the edge of a cliff 75.0 m high (Fig. 2–48). (*a*) How much later does it reach the bottom of the cliff? (*b*) What is its speed just before hitting? (*c*) What total distance did it travel?

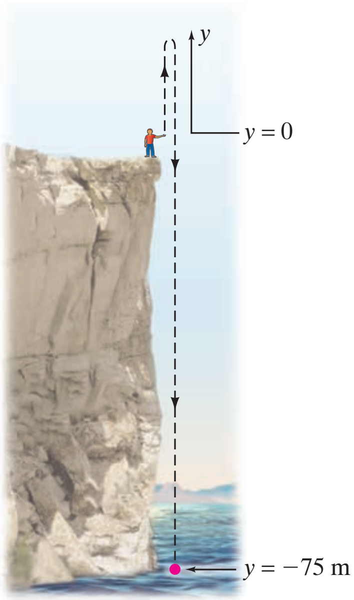

FIGURE 2–48 Problem 65.

66. In the design of a **rapid transit system**, it is necessary to balance the average speed of a train against the distance between station stops. The more stops there are, the slower the train's average speed. To get an idea of this problem, calculate the time it takes a train to make a 15.0-km trip in two situations: (*a*) the stations at which the trains must stop are 3.0 km apart (a total of 6 stations, including those at the ends); and (*b*) the stations are 5.0 km apart (4 stations total). Assume that at each station the train accelerates at a rate of $1.1\ \mathrm{m/s^2}$ until it reaches 95 km/h, then stays at this speed until its brakes are applied for arrival at the next station, at which time it decelerates at $-2.0\ \mathrm{m/s^2}$. Assume it stops at each intermediate station for 22 s.

67. A person driving her car at 35 km/h approaches an intersection just as the traffic light turns yellow. She knows that the yellow light lasts only 2.0 s before turning to red, and she is 28 m away from the near side of the intersection (Fig. 2–49). Should she try to stop, or should she speed up to cross the intersection before the light turns red? The intersection is 15 m wide. Her car's maximum deceleration is $-5.8\ \mathrm{m/s^2}$, whereas it can accelerate from 45 km/h to 65 km/h in 6.0 s. Ignore the length of her car and her reaction time.

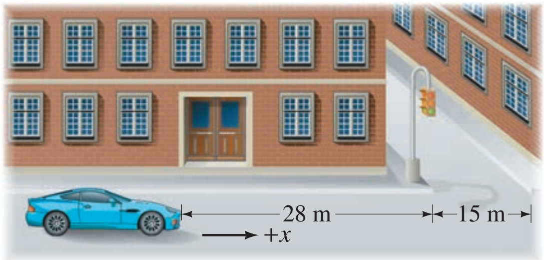

FIGURE 2–49 Problem 67.

68. A car is behind a truck going 18 m/s on the highway. The car's driver looks for an opportunity to pass, guessing that his car can accelerate at $0.60\ \mathrm{m/s^2}$ and that he has to cover the 20-m length of the truck, plus 10-m extra space at the rear of the truck and 10 m more at the front of it. In the oncoming lane, he sees a car approaching, probably at the speed limit, 25 m/s (55 mph). He estimates that the car is about 500 m away. Should he attempt the pass? Give details.

69. Agent Bond is standing on a bridge, 15 m above the road below, and his pursuers are getting too close for comfort. He spots a flatbed truck approaching at 25 m/s, which he measures by knowing that the telephone poles the truck is passing are 25 m apart in this region. The roof of the truck is 3.5 m above the road, and Bond quickly calculates how many poles away the truck should be when he drops down from the bridge onto the truck, making his getaway. How many poles is it?

70. A conveyor belt is used to send burgers through a grilling machine. If the grilling machine is 1.2 m long and the burgers require 2.8 min to cook, how fast must the conveyor belt travel? If the burgers are spaced 25 cm apart, what is the rate of burger production (in burgers/min)?

71. Two students are asked to find the height of a particular building using a barometer. Instead of using the barometer as an altitude measuring device, they take it to the roof of the building and drop it off, timing its fall. One student reports a fall time of 2.0 s, and the other, 2.3 s. What % difference does the 0.3 s make for the estimates of the building's height?

72. Two children are playing on two trampolines. The first child bounces up one-and-a-half times higher than the second child. The initial speed up of the second child is 4.0 m/s. (*a*) Find the maximum height the second child reaches. (*b*) What is the initial speed of the first child? (*c*) How long was the first child in the air?

73. If there were no air resistance, how long would it take a free-falling skydiver to fall from a plane at 3200 m to an altitude of 450 m, where she will open her parachute? What would her speed be at 450 m? (In reality, the air resistance will restrict her speed to perhaps 150 km/h.)

74. You stand at the top of a cliff while your friend stands on the ground below you. You drop a ball from rest and see that she catches it 1.4 s later. Your friend then throws the ball up to you, such that it just comes to rest in your hand. What is the speed with which your friend threw the ball?

75. On an audio compact disc (CD), digital bits of information are encoded sequentially along a spiral path. Each bit occupies about 0.28 μm. A CD player's readout laser scans along the spiral's sequence of bits at a constant speed of about 1.2 m/s as the CD spins. (*a*) Determine the number N of digital bits that a CD player reads every second. (*b*) The audio information is sent to each of the two loudspeakers 44,100 times per second. Each of these samplings requires 16 bits, and so you might expect the required bit rate for a CD player to be

$$N_0 = 2\left(44{,}100\,\frac{\text{samplings}}{\text{s}}\right)\left(16\,\frac{\text{bits}}{\text{sampling}}\right) = 1.4 \times 10^6\,\frac{\text{bits}}{\text{s}},$$

where the 2 is for the 2 loudspeakers (the 2 stereo channels). Note that N_0 is less than the number N of bits actually read per second by a CD player. The excess number of bits $(= N - N_0)$ is needed for encoding and error-correction. What percentage of the bits on a CD are dedicated to encoding and error-correction?

Search and Learn

1. Discuss two conditions given in Section 2–7 for being able to use a constant acceleration of magnitude $g = 9.8\ \text{m/s}^2$. Give an example in which one of these conditions would not be met and would not even be a reasonable approximation of motion.

2. In a lecture demonstration, a 3.0-m-long vertical string with ten bolts tied to it at equal intervals is dropped from the ceiling of the lecture hall. The string falls on a tin plate, and the class hears the clink of each bolt as it hits the plate. (*a*) The sounds will not occur at equal time intervals. Why? (*b*) Will the time between clinks increase or decrease as the string falls? (*c*) How could the bolts be tied so that the clinks occur at equal intervals? (Assume the string is vertical with the bottom bolt touching the tin plate when the string is released.)

3. The position of a ball rolling in a straight line is given by $x = 2.0 - 3.6t + 1.7t^2$, where x is in meters and t in seconds. (*a*) What do the numbers 2.0, 3.6, and 1.7 refer to? (*b*) What are the units of each of these numbers? (*c*) Determine the position of the ball at $t = 1.0$ s, 2.0 s, and 3.0 s. (*d*) What is the average velocity over the interval $t = 1.0$ s to $t = 3.0$ s?

ANSWERS TO EXERCISES

A: (*a*) displacement $= -30$ cm; (*b*) total distance $= 50$ cm.
B: (*b*).
C: (*a*) +; (*b*) −; (*c*) −; (*d*) +.
D: (*b*).
E: (*e*).
F: (*c*).