particularly in free-fall and projectile problems. Take the initial direction of motion as positive and stick with it throughout the problem. This approach is not always necessary, but in the beginning it is certainly advisable. ***Draw diagrams***.

3. Consider Eq. (3.9), which varies with t and t^2 both. When t is given, it's easy to find s, v_i, or a_T. When t is the unknown to be determined, the most straightforward approach is to use the quadratic equation. Rearranging Eq. (3.9) yields $\frac{1}{2}a_T t^2 + v_i t - s = 0$, which has the general form $At^2 + Bt + C = 0$, where $A = \frac{1}{2}a$, $B = v_i$, and $C = -s$. The solution is then $t = (-B \pm \sqrt{B^2 - 4AC})/2A$ {see **MATH REVIEW: PART A-4** on the **CD** }. The quadratic equation can be avoided by using combinations of other equations: Eq. (3.10) to find v_f, and then Eq. (3.6) or (3.8) to get t. The wise choice of equations will save time and effort.

4. Think about your answers. Often an error will produce a result that is unrealistically large or small. If you think the problem through so that you can anticipate the size, direction, sign, and so on, most computational errors will be spotted. We all make computational errors; not all of us find them. A reindeer falling off the roof of a one-story building is not going to land on the ground at 5000 km/h. Given the real-world physical situation of a problem, ask yourself if your answer is reasonable.

5. ***Always check your answers***. The best way to do that (although it may not always be practical) is to recalculate the answer using a different approach. At least go over your calculations several times.

6. When a problem requests the distance traveled during a certain time interval, such as the fifth second of motion, this is not the same as asking how far the body moved in 5 s. The fifth second is the one that begins at $t = 4$ s and ends at $t = 5$ s.

7. It is not necessary to remember the whole set of equations for projectile motion: t_p is easily derived from the definition of a, where $v_y = 0$; t_T is just $2t_p$ and s_R is simply $v_x t_T$. The fact that $v_y = 0$ (and $v_x \neq 0$) at the peak altitude is important and should always be kept in mind.

8. The Mean Speed Theorem applies to straight-line motion in one direction and so is appropriate for dealing with the uniformly accelerated vertical component of a projectile's movement. *Do not apply it to the overall motion* (as for example, in an attempt to determine the total final speed v_f knowing s and t)—the projectile travels along an arc and $l \neq s$.

Problems + Coordinated Problems + Progressive Problems + Solutions

STUDY GUIDE **1. Coordinated Problems:** The three problems within each magenta-colored grouping are solvable in similar ways. Note that the first of these always has a hint; moreover, its solution is provided in the back of the book. *Work out each of these sets; they'll strengthen technique and build confidence.* **2. Progressive Problems:** The problems introduced in blue unfold step-by-step carrying along the analysis in a more suggestive way than is customary. *Work out all of these; they'll guide you through the analytic process and help develop problem-solving skills.* **3. Worked-Out Solutions:** Studying worked-out solutions is an important part of learning how to solve problems. Accordingly, additional ***solutions*** to a number of model problems are given below. *Make sure you understand each of them before you go on to the next problem.* **4.** Also provided in the back of the book are the ***Answers*** to all odd-numbered problems, as well as worked-out ***solutions*** to those with boldface numbers. Problem numbers in italic indicate that a solution appears in the Student Solutions Manual.

SECTION 3.1: AVERAGE ACCELERATION

1. [I] THIS PROBLEM WILL HELP US BETTER UNDERSTAND THE RELATIONSHIP BETWEEN SPEED AND AVERAGE ACCELERATION. Figure P1 depicts a speed versus time curve for a toy airplane. (a) What is the significance of the slope of the curve between any two points? (b) When, if ever, was the plane at rest? (c) What's the plane's average acceleration over the interval from 12 s to 14 s?

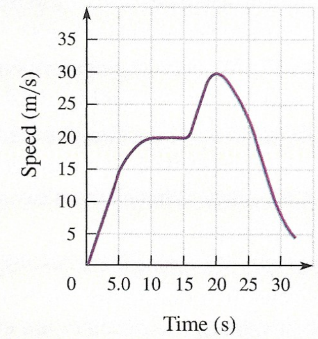

Figure P1

2. [I] THIS PROBLEM WILL ASSIST US IN UNDERSTANDING THE RELATIONSHIP BETWEEN SPEED AND AVERAGE ACCELERATION. Figure P1 depicts a speed versus time curve for a toy airplane. (a) At what time did the plane have its maximum speed? (b) Over what interval, roughly, did it have its maximum positive average acceleration? (c) When did it start to decelerate?

3. [I] A rocket lifts off its launchpad and travels straight up attaining a speed of 100 m/s in 10 s. Calculate its average acceleration.

4. [I] A canvasback duck heading south at 50 km/h at 2:02 A.M. is spotted at 2:06 A.M. still traveling south but at 40 km/h. Calculate its average acceleration over that interval—magnitude and direction.

5. [I] An android on guard duty in front of the Institute of Robotics is heading due south at 1:07 P.M. at a speed of 10 m/s when it receives a command to alter course. At 1:09 P.M. it is recorded to be moving at 10 m/s due north. Compute its average acceleration over that interval—magnitude and direction.

6. [I] The 1997 Corvette Sport Coupe (16-valve V8, 5.7-liter engine) goes from 0 to 60 mph (i.e., 26.8 m/s) in 4.8 s. What's its average acceleration in SI units?

7. [I] A finalist in the Soap Box Derby starts with a push down a long straight run at an initial speed of 1.0 m/s. At the bottom, 1.0 min 2.0 s later, it reaches a speed of 15.0 m/s. Find its average acceleration.

8. [I] Pushing backward, a sprinter leaves the blocks at 3.0 m/s. If 1.0 s later he is moving at 5.2 m/s, what was his average acceleration during that 1.0-s interval?

9. [I] A piston-engine dragster set a world record by starting from rest and hitting a top speed of 244 mi/h in 6.2 s over a straight measured track of 440 yd. Compute the scalar value of its average acceleration in m/s^2. [*Hint: 1 mi/h = 0.447 0 m/s; the average scalar acceleration is the change in the speed divided by the time, regardless of the distance traveled.*]

10. [I] During a typical launch a Space Shuttle goes from a vertical speed of 5.75 m/s at $t = 1.20$ s to a vertical speed of 6.90 m/s at $t = 1.60$ s, while rising 2.30 m. Determine the average acceleration—magnitude and direction—over that interval.

11. [I] A bag of sand drops from a hot-air balloon; 12.0 s later having fallen 700 m it's traveling straight down at 116 m/s. Determine the average acceleration vector for the bag during that descent.

12. [II] THIS PROBLEM WILL HELP US BETTER UNDERSTAND ACCELERATION. Operating on an automatic program, the belt on a treadmill moving at 2.5 m/s increases its speed to 3.7 m/s in 2.4 min. (a) What was the change in its speed. (b) Over what time interval did

that change occur? (c) Determine the belt's average acceleration.

13. [II] THIS PROBLEM WILL HELP US BETTER UNDERSTAND ACCELERATION. A kid coasting along at 12.0 m/s, holds down the brake on a bicycle. With a resulting average tangential acceleration of −0.60 m/s^2, she soon comes to rest. (a) During the braking, what was her initial speed? (b) During the braking, what was her final speed? (c) How long did it take her to come to a stop? (d) Does it matter that she's traveling a curved path?

14. [II] A VW Rabbit can go from rest to 80.5 km/h (50.0 mi/h) in a modest 8.20 s. How long will it take to speed up from 48.3 km/h to 64.4 km/h, along a straight run, if the average acceleration is the same as before?

15. [II] During a baseball game a runner traveling at 4.0 m/s slides into second base. Given that it takes her 0.50 s to come to rest, what was her average acceleration? Approximately how fast was she moving 0.30 s into the slide?

16. [II] Having been kicked, a soccer ball rolls in a straight line past a kid holding a stopwatch. At the moment the ball passes the kid it has an instantaneous speed of 4.0 m/s and the watch reads 10.0 s. If the watch reads 23.3 s when the ball comes to rest, what's its average acceleration?

SOLUTION: The initial speed is 4.0 m/s at $t = 10.0$ s. At $t = 23.3$ s, $v = 0$. By definition $a_{av} = \Delta v/\Delta t = (0 - 4.0 \text{ m/s})/(23.3 \text{ s} - 10.0 \text{ s}) = (-4.0 \text{ m/s})/(13.3 \text{ s}) = -0.30 \text{ m/s}^2$.

17. [II] Videos taken of a typical male sprinter show that he goes from 0 up to 3.0 m/s in the first step, reaches 4.2 m/s in the next step, and 5.0 m/s in the third step. Given that each step takes essentially the same amount of time, what can be said about his acceleration?

18. [II] A motorboat starting from a dead stop accelerates at an average rate of 2.0 m/s^2 for 3.0 s, then very rapidly roars up to 4.0 m/s^2 and holds it constant for 4.0 s. What is its approximate average acceleration over the first 5.0 s of motion?

19. [II] Superman slams head-on into a locomotive speeding along at 60 km/h, bringing it smoothly to rest in an amazing 1/1000 s and saving Lois Lane, who was tied to the tracks. Calculate the average deceleration of the train in m/s^2.

20. [III] Two motorcycle stuntpersons are driving directly toward one another, each having started at rest and each accelerating at an average rate of 5.5 m/s^2. At what speed will they be approaching each other 2.0 s into this lunacy?

SECTION 3.2: INSTANTANEOUS ACCELERATION

21. [I] THIS PROBLEM DEALS WITH THE RELATIONSHIP BETWEEN SPEED AND INSTANTANEOUS ACCELERATION. Figure P1 depicts a speed versus time curve for a toy airplane. (a) What is the significance of the slope of the curve at any point? (b) Did the plane's instantaneous acceleration change between 0 and 3 s? (c) What's its instantaneous acceleration at 12 s? (d) What's its instantaneous acceleration at 20 s?

22. [I] THIS PROBLEM EXAMINES THE RELATIONSHIP BETWEEN SPEED AND INSTANTANEOUS ACCELERATION. Figure P1 depicts a speed versus time curve for a toy airplane. (a) What's its average acceleration over the interval from 0 s to 5.0 s? (b) What's its instantaneous acceleration at 2.5 s? (c) Compare these two answers and explain why they are as they are.

23. [I] What is the instantaneous acceleration of the object whose motion is depicted in Fig. 3.2*a* (p. 55) at a time of 1.58 s?

24. [I] Figure P24 is a velocity-time graph for a test car on a straight track. The test car initially moved backward in the negative x-direction at 20 m/s. It slowed, came to a stop, and then moved off in the positive x-direction at $t = 2.0$ s. What was its average acceleration during each of the time intervals 0 to 0.5 s, 1.5 s to 2.0 s, and 2.0 s to 2.5 s? What was its instantaneous acceleration at $t = 2.25$ s?

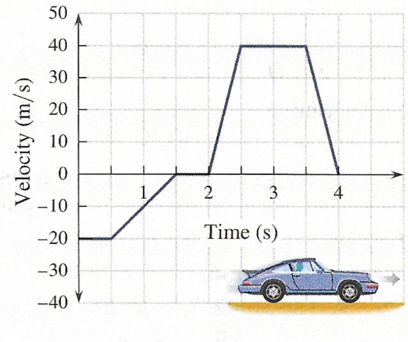

Figure P24

25. [I] In Fig. P24, what was the car's instantaneous acceleration at $t = 3.0$ s? Is the instantaneous acceleration positive or negative at $t = 3.7$ s. How about at $t = 1.1$ s? What is the instantaneous acceleration of the car at $t = 0.25$ s?

26. [I] Figure P26 shows the speed-time curves of three cyclists traveling a straight course. What are their respective instantaneous speeds at $t = 2$ s? Which if any starts out at $t = 2$ s with the greatest instantaneous acceleration?

27. [I] Figure P26 shows the speed-time curves of three cyclists traveling a straight course. Which one has the greatest instantaneous acceleration at each of the following times, $t = 2.1$ s, 3.3 s, and 6.5 s?

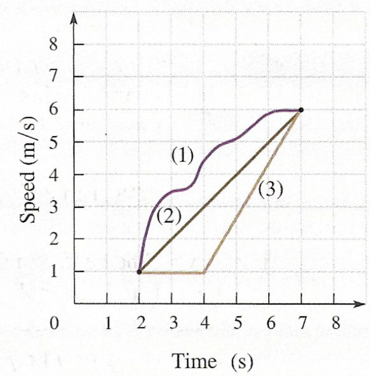

Figure P26

28. [I] Figure P26 still shows the speed-time curves of three cyclists traveling a straight course. What are their respective instantaneous speeds at $t = 7$ s? Which, if any, has the greatest instantaneous acceleration at $t = 7$ s?

29. [I] What is the instantaneous acceleration of the object whose motion is depicted in Fig. 3.2*b* (p. 55) at $t = 4$ s?

30. [I] A car on a straight road goes from rest to 10 km/h in 10 s; at the end of 20 s it's moving at 20 km/h; at the end of 30 s it reaches 30 km/h. What can you say about its acceleration? Make a graph of a versus t.

31. [II] Referring back to Fig. P24, what was the car's average acceleration during the interval from $t = 0$ to $t = 3.0$ s? What was its instantaneous acceleration at $t = 0$ and $t = 3.0$ s?

32. [II] Referring back to Fig. P26, which shows the speed-time curves for three cyclists traveling a straight course, describe their motions and compute their average accelerations over the entire interval shown. Which of the cyclists has the greater average acceleration over the interval from 2.0 s to 4.6 s? Which one has the greatest instantaneous acceleration at $t = 4.6$ s?

33. [II] Using Fig. 3.3 (p. 56), graphically determine the car's approximate acceleration at 3.8 s into the run.

34. [II] At time $t = 0$, a body located at $s = 0$ has a scalar velocity of $v = 0$ and an instantaneous acceleration of 1 m/s^2. It travels in a straight line maintaining that acceleration for 4 s and then

immediately ceases accelerating. That condition lasts for 1 s at which point it decelerates at 2 m/s^2 for 2 s and then again ceases accelerating. Draw graphs of a-versus-t and v-versus-t.

35. [II] Suppose that in Problem 18, after holding at 4.0 m/s^2 for 4.0 s, the boat next decelerates to a stop 20 s later at a rate of 1.1 m/s^2. (a) What is its average acceleration during the first 27 s of the run? (b) What is its instantaneous acceleration 10 s into the trip?

36. [II] A rocket accelerates straight up at 10 m/s^2 toward a helicopter that is descending uniformly at 5.0 m/s^2. What is the relative acceleration of the missile with respect to the aircraft as seen by the pilot who is about to bail out?

37. [III] The speed of a flying saucer in ascent mode-4 as reported by an alleged eyewitness (who got it straight from the talkative alien navigator) is given by the expression $v = At + Bt^2$. Amazingly, A and B are constants in SI units, but the little green navigator would not reveal their values. Determine the instantaneous acceleration of the craft. [*Hint: At* $(t + \Delta t)$ *the speed is* $(v + \Delta v)$.]

SECTION 3.3: CONSTANT ACCELERATION

SECTION 3.4: THE MEAN SPEED

38. [I] An R75 maintenance robot on a spaceship is standing in front of the bathroom when it begins to move down the straight passageway. It accelerates at a constant 2.0 m/s^2. Find its speed at the end of 5.0 s.

39. [I] With the previous problem in mind, how far did the robot travel in the 5.0 s?

40. [I] During a swing the head of a golf club is in contact with the ball for about 0.5 ms and the ball goes from zero to 70 m/s. Assuming the acceleration is constant, determine its value.

41. [I] If a truck traveling 40.0 km/h uniformly accelerates up to 60.0 km/h, what's its average speed in the process?

42. [I] Slamming on the brakes, a driver decelerates her car from 25.0 m/s to 15.0 m/s in 3.5 s. Find her average speed assuming the acceleration was uniform.

43. [I] If during a race, a horse accelerates fairly constantly up to 16 m/s, what's its average speed?

44. [I] How far does the car in Problem 42 travel while dropping in speed from 25.0 m/s to 15.0 m/s in 3.5 s?

45. [II] According to the *New York Times*, a 1997 Corvette Sport Coupe, starting from rest, can travel 1/4 mile (i.e., 402 m) in 13.3 s. What's its average speed in SI units? Assuming the acceleration is constant (which it isn't), what would be its maximum speed?

46. [II] THIS PROBLEM WILL HELP US BETTER UNDERSTAND THE RELATIONSHIP BETWEEN SPEED AND ACCELERATION. An elevator accelerates upward from rest at 0.98 m/s^2. (a) What was its initial speed? (b) How fast is it moving after 3.0 s? (c) How high has it risen in those 3.0 s ?

47. [II] THIS PROBLEM DEALS WITH THE RELATIONSHIP BETWEEN SPEED AND ACCELERATION. A robot accelerates in a straight line at a constant rate from 1.20 m/s to 6.20 m/s while traveling 30.0 m. (a) What was its average speed? (b) How long did that portion of its journey take? (c) Determine its acceleration.

48. [II] The Corvette in Problem 45 can come to a stop from 60 mph (i.e., 26.8 m/s) in 116 ft (i.e., 35.4 m). Determine the deceleration (in SI units) assuming it to be constant.

49. [II] A good male sprinter can run 100 m in 10 s. What's his average speed? He will typically reach a peak speed of 11 m/s at about 5 s and slow down toward the finish. Assuming his acceleration is fairly constant for the first 5 s, how fast will he be going 3 s into the race?

50. [II] If a van moving at 50.0 km/h uniformly accelerates up to 70.0 km/h in 20.0 s, how far along the straight road will it travel in the process?

SOLUTION: The acceleration is constant, and we know the initial and final speeds so we can compute the average speed and with that the distance. Convert to m/s using 1 km/h = 0.2778 m/s; 50.0 km/h = 13.89 m/s and 70.0 km/h = 19.45 m/s. $v_{av} = \frac{1}{2}(19.45 \text{ m/s} + 13.89 \text{ m/s}) =$ 16.67 m/s therefore $l = v_{av}t = 333$ m.

51. [II] Supposing that the acceleration of the 1997 Corvette Sport Coupe in Problem 6 is constant (which it really isn't) how much road will it travel in going from 0 to 60 mph (i.e., 26.8 m/s) in 4.8 s?

SECTION 3.5: THE EQUATIONS OF CONSTANT ACCELERATION

52. [I] THIS PROBLEM WILL HELP US BETTER UNDERSTAND THE RELATIONSHIP BETWEEN DISTANCE TRAVELED AND ACCELERATION. During takeoff a small plane has an average tangential acceleration of 5.0 m/s^2 and travels for 20 s before becoming airborne. (a) What is the initial speed of the plane? (b) How long must the runway be?

53. [I] THIS PROBLEM EXPLORES THE RELATIONSHIP BETWEEN DISTANCE TRAVELED AND ACCELERATION. A driver stops his test car at a rate of 6.0 m/s^2 in a distance of 410 m. (a) What was the car's final speed? (b) What was the car's acceleration? (c) How fast was the car going when he applied the brakes?

54. [I] A locust, extending its hind legs over a distance of 4 cm, leaves the ground at a speed of 340 cm/s. Determine its acceleration, presuming it to be constant.

55. [I] A wayward robot, R2D3, is moving along at 1.5 m/s when it suddenly shifts gears and roars off, accelerating uniformly at 1.0 m/s^2 straight toward a wall 10 m away. At what speed will it crash into the wall? [*Hint: We have the initial speed, the constant acceleration, and the distance traveled. To find the final speed use a constant-*$\vec{a}$ *equation that relates these quantities.*]

56. [I] The driver of a car traveling at 10.0 m/s along a straight road depresses the accelerator and uniformly increases her speed at a rate of 2.50 m/s^2. How fast will the car be moving as it passes a parked police cruiser 100 m away?

57. [I] The length of a straight tunnel through a mountain is 25.0 m. A cyclist heads directly toward it, accelerating at a constant rate of 0.20 m/s^2. If at the instant he enters the tunnel he is traveling at a speed of 5.00 m/s, how fast will he be moving as he emerges?

58. [I] Regarding Problem 19, Lois was a mere 10 cm down the tracks from the point where Superman struck the train. How far away from her did the "Man of Steel" finally stop the engine? (Thank goodness he arrived in time!)

59. [I] A Jaguar in an auto accident in England in 1960 left the longest recorded skid marks on a public road: an incredible 290-m long. As we will see later, the friction force between the tires and the pavement varies with speed, producing a deceleration that increases as the speed decreases. Assuming an average acceleration of -3.9 m/s^2 (that is, -0.4 g), calculate the Jag's speed when the brakes locked.

60. [I] A modern supertanker is gigantic: 1200- to 1300-ft long

with a 200-ft beam. Fully loaded, it chugs along at about 16 knots (i.e., 30 km/h or 18 mi/h). It can take 20 min to bring such a monster to a full stop. Calculate the corresponding deceleration in m/s^2 and determine the stopping distance.

61. [I] A bullet traveling at 300 m/s slams into a block of moist clay, coming to rest with a fairly uniform acceleration after penetrating 5 cm. Calculate its acceleration.

62. [I] Consider an automobile collision in which a vehicle traveling at 30.0 m/s is brought to rest in a distance of 50.0 cm. What is the deceleration, assuming it to be constant?

63. [II] A driver traveling at 60 km/h sees a chicken dash out onto the road and slams on the brakes. Accelerating at $-7\ m/s^2$, the car stops just in time 23.3 m down the road. What was the driver's reaction time (i.e., the time that elapsed before he engaged the brake)?

64. [II] The longest passenger liner ever built was the *France*, at 66 348 tons and 315.5-m long. Suppose its bow passes the edge of a pier at a speed of 2.50 m/s while the ship is accelerating uniformly at $0.01\ m/s^2$. At what speed will the stern of the vessel pass the pier?

65. [II] A swimmer stroking along at a fast 2.2 m/s ceases all body movement and uniformly coasts to a dead stop in 10 m. Determine how far she moved during her third second of unpowered drift.

66. [II] A little electric car having a maximum speed of 40.0 km/h can speed up uniformly at any rate from $1.00\ m/s^2$ to $4.00\ m/s^2$ and slow down uniformly at any rate from 0.00 to $-6.00\ m/s^2$. What is the shortest time in which such a vehicle can traverse a distance of 1.00 km starting and ending at rest?

67. [II] Two trains heading straight for each other on the same track are 250 m apart when their engineers see each other and hit the brakes. The Express, heading west at 96 km/h, slows down, decelerating at an average of $4\ m/s^2$ while the eastbound Flyer, traveling at 110 km/h, slows down, decelerating at an average of 3 m/s^2. Will they collide?

68. [II] The drivers of two cars in a demolition derby are at rest 100 m apart. A clock on a billboard reads 12:17:00 at the moment they begin heading straight toward each other. If both are accelerating at a constant $2.5\ m/s^2$, at what time will they collide?

SOLUTION: The accelerations are constant, and we know their initial separation. How long will it take for either car to cover 50.0 m? $l = \frac{1}{2}at^2 = 50.0\ \text{m} = \frac{1}{2}(2.5\ \text{m/s}^2)t^2$ and so $t = 6.3$ s.

69. [II] A rocket-launching device contains several solid-propellant missiles that are successively fired horizontally at 1-s intervals. (a) What is the horizontal separation of the first and second missiles just at the moment the second one is fired, if each has an initial speed of 60 m/s and a constant acceleration of $20\ m/s^2$ lasting for 10 s? (b) What is the horizontal separation of the first and second just as the third is launched?

70. [II] Referring to the previous problem, what is the relative acceleration of the first missile with respect to the second missile once both are in the air and accelerating? What will be their horizontal separation 6 s into the flight?

71. [II] Imagine that you are driving toward an intersection at a speed v_i just as the light changes from green to yellow. Assuming a response time of 0.6 s and an acceleration of $-6.9\ m/s^2$, write an expression for the smallest distance (s_S) from the corner in which you could stop in time. How much is that if you are traveling 35 km/h?

72. [II] Considering the previous problem, it should be clear that the yellow light might reasonably be set for a time t_Y, which is long enough for a car to traverse the distance equal to both s_S and the width of the intersection s_I. Assuming a constant speed v_i equal to the legal limit, write an equation for t_Y, which is independent of s_S.

73. [II] The driver of a pink Cadillac traveling at a constant 26.8 m/s (i.e., 60 mi/h) in a 55-mi/h zone is being chased by the law. The police car is 20 m behind the perpetrator when it too reaches 26.8 m/s (i.e., 60 mi/h), and at that moment the officer floors the gas pedal. If her car roars up to the rear of the Cadillac 2.0 s later, what was the scalar value of her acceleration, assuming it to be constant? [*Hint: This problem really begins when the cop gets to a point 20 m behind the Cadillac. At that moment the two cars are at rest with respect to one another. The cop then takes 2.0 s to cover the 20-m distance.*]

74. [II] While making a movie, a cowboy on a horse rides up to a moving train traveling at 5.0 km/h along a long straight length of track. After running next to the last car for a while, he charges ahead toward the engine 100 m away and gets there in 1.10 min. Assuming it was constant, determine the scalar value of his acceleration.

75. [II] Ed, the leading runner in a race taking place along a straight track, is traveling at his top speed, a constant 10.0 m/s. He has been 4.0 m in front of Harry, his chief rival, for the last 10.0 s. But aware that Ed will hit the finish line in 20.0 s, Harry puts on a burst of speed. At what minimum constant rate must he accelerate if he's not to lose the race?

76. [II] With Problems 71 and 72 in mind, how long should the yellow light stay lit if we assume a driver-response time of 0.6 s, an acceleration of $-6.9\ m/s^2$, a speed of 35 km/h, and an intersection 25-m wide? Which of the several contributing aspects requires the greatest time?

77. [II] In Problem 63, how far does the police car travel in the process of closing the Cadillac's 20-m lead?

78. [III] Having taken a nap under a tree only 20 m from the finish line, Rabbit wakes up to find Turtle 19.5 m beyond him, grinding along at 1/4 m/s. If the bewildered hare can accelerate at $9\ m/s^2$ up to his top speed of 18 m/s (40 mi/h) and sustain that speed, will he win?

79. [III] Superman is jogging alongside the railroad tracks on the outskirts of Metropolis at 100 km/h. He overtakes the caboose of a 500-m-long freight train traveling at 50 km/h. At that moment he begins to accelerate at $+10\ m/s^2$. How far will the train have traveled before Superman passes the locomotive?

80. [III] A motorcycle cop, parked at the side of a highway reading a magazine, is passed by a woman in a red Ferrari 308 GTS doing 90.0 km/h. After a few attempts to get his cycle started, the officer roars off 2.00 s later. At what average rate must he accelerate if 110 km/h is his top speed and he is to catch her just at the state line 2.00 km away?

SECTION 3.8: STRAIGHT UP & DOWN

81. [I] THIS PROBLEM EXAMINES FREE-FALL. A boulder on the mythical planet Mongo drops off a cliff and falls from rest 1000 m in 10.0 s. (a) What's the initial speed of the boulder? (b) Determine the acceleration due to gravity on Mongo. Ignore friction.

82. [I] THIS PROBLEM IS ABOUT FREE-FALL. It takes 3.75 s for a bowling ball to strike the sidewalk when dropped from the window

of a building. (a) What's the initial speed of the ball? (b) How high up is the point of release? Ignore friction.

83. [I] EXPLORING PHYSICS ON YOUR OWN: Ask a friend to hold his or her thumb and forefinger parallel to each other in a horizontal plane. The fingers should be about an inch apart. Now you hold a 1-ft ruler vertically in the gap just above and between these fingers so that it can be dropped between them. Have your friend look at the ruler and catch it when you, without warning, let it fall. Calculate the corresponding response time. Now position a dollar bill vertically so that Washington's face is between your friend's fingers—is it likely to be caught when dropped?

84. [I] A kangaroo can jump straight up about 2.5 m—what is its takeoff speed?

85. [I] At what speed would you hit the floor if you stepped off a chair 0.50-m high? Ignore friction. Express your answer in m/s, ft/s, and mi/h.

86. [I] If a stone dropped (not thrown) from a bridge takes 3.7 s to hit the water, how high is the rock-dropper? Ignore friction.

87. [I] Ignoring air friction, how fast will an object be moving and how far will it have fallen after dropping from rest for 1.0 s, 2.0 s, 5.0 s, and 10 s?

88. [I] A cannonball is fired straight up at a rather modest speed of 9.81 m/s. Compute its maximum altitude and the time it takes to reach that height (ignoring air friction).

SOLUTION: We have the initial vertical speed and need the peak altitude and corresponding time. On the way up g is negative:

$$l_p = -v_i^2/2g = -(9.81\text{ m/s})^2/2(-9.81\text{ m/s}^2) = 4.91\text{ m}$$
$$t_p = -v_i/g = -(9.81\text{ m/s})/(-9.81\text{ m/s}^2) = 1.00\text{ s}$$

89. [I] Calculate the speed at which a hailstone, falling from a height of 0.914 4×10^4 m (i.e., 3.00×10^4 ft) out of a cumulonimbus cloud, would strike the ground, presuming air friction is negligible (which it certainly is not). Give your answer in m/s.

90. [I] A circus performer juggling while standing on a platform 15.0-m high tosses a ball directly upward into the air at a speed of 5.0 m/s. If it leaves his hand 1.0 m above the platform, what is the ball's maximum altitude? If the juggler misses the ball, at what speed will it hit the floor? Ignore air friction.

91. [I] Draw a curve of s in meters versus t in seconds for a free-falling body dropped from rest. Restrict the analysis to the first second of fall, and make up a table of values of t, t^2, and s at 1/10-s intervals. Draw a curve of s versus t^2. Explain your findings.

92. [I] The acceleration due to gravity on the surface of the Moon is about $g/6$. If you can throw a ball straight up to a height of 25 m on Earth, how high would it reach on the Moon when launched at the same speed? Ignore the minor effects of air friction.

93. [II] THIS PROBLEM DEALS WITH FREE-FALL. While falling toward the ground at 100 km/h a skydiver releases a bag of rocks and then opens his parachute. (a) What was the initial downward speed (in m/s) of the bag at the moment it was released, at a height of 800 m? (b) At what speed will the bag hit the ground? Ignore air friction.

94. [II] THIS PROBLEM EXAMINES FALLING AT THE EARTH'S SURFACE. (a) Make a sketch of how far an object falls from rest in a total of 1 s, 2 s, 3 s, etc. (b) Show that the distances traversed by a body in free-fall during consecutive equal intervals of time (e.g., the first second, the second second, the third second, etc.) are in the ratios of 1:3:5:7:9 etc.

95. [II] A young kid with a huge baseball cap is playing catch with himself by throwing a ball straight up. How fast does he throw it if the ball comes back to his hands a second later? At low speeds air friction is negligible.

96. [II] An arrow is launched vertically upward from a crossbow at 98.1 m/s. Ignoring air friction, what is its instantaneous speed at the end of 10.0 s of flight? What is its average speed up to that moment? How high has it risen? What is its instantaneous acceleration 4.20 s into the flight?

SOLUTION: To find out if it is still going up determine $t_p = -v_i/g = -(98.1\text{ m/s})/(-9.81\text{ m/s}^2) = 10.0$ s. In fact, it is at peak altitude and its speed is zero. $l_p = -v_i^2/2g = -(98.1\text{ m/s})^2/2(-9.81\text{ m/s}^2) = 491$ m. Its average speed is $v_{av} = \frac{1}{2}(98.1\text{ m/s} + 0\text{ m/s}) = 49.1$ m/s. Its acceleration is always g.

97. [II] A lit firecracker is shot straight up into the air at a speed of 50.00 m/s. How high is it above ground level 5.000 s later when it explodes? How fast is it moving when it blows up? How far has it fallen, if at all, from its maximum height? Ignore drag and take g equal to 9.800 m/s^2.

98. [II] The observation deck of a skyscraper is 1377 ft above ground. Ignoring air friction, how long will it take for a massive object to free-fall that far? Use $g = 9.81$ m/s^2. Considering the discussion in the text, is it reasonable to ignore air drag in this problem? Explain.

99. [II] A human being performing a vertical jump generally squats and then springs upward, accelerating with feet touching the Earth through a distance s_a. Once fully extended, the jumper leaves the ground and glides upward, decelerating until the feet are a maximum height s_{max} off the floor. Assuming the jumping acceleration a to be constant, derive an expression for it in terms of s_a and s_{max}. Ignore friction.

100. [II] A small rocket is launched vertically, attaining a maximum speed at burnout of 1.0×10^2 m/s and thereafter coasting straight up to a maximum altitude of 1510 m. Assuming the rocket accelerated uniformly while the engine was on, how long did it fire and how high was it at engine cutoff? Ignore air friction.

101. [II] The illustrative Example 3.11 did not use the equation $s = v_i t + \frac{1}{2}at^2$ because it required the quadratic formula. Carry out that calculation, solving it for the two values of t. Notice the symmetry around the time of peak altitude.

102. [III] Imagine that someone dropped a firecracker off the roof of a building and heard it explode exactly 10 s later. Ignoring air friction, taking $g = 9.81$ m/s^2 and using 330 m/s as the speed of sound, calculate how far the cherry bomb had fallen at the very moment it blew up.

103. [III] A bag of sand dropped by a would-be assassin from the roof of a building just misses Tough Tony, a gangster 2-m tall. The missile traverses the height of Tough Tony in 0.20 s, landing with a thud at his feet. How high was the building? Ignore friction.

SECTION 3.9: TWO-DIMENSIONAL MOTION: PROJECTILES

104. [I] A shoe is flung into the air such that at the end of 2.0 s it is at its maximum altitude, moving at 6.0 m/s. How far away from the thrower will it be when it returns to the height from which it was tossed? Ignore air friction.

105. [I] THIS PROBLEM DEALS WITH PROJECTILE MOTION. A ball is thrown horizontally at a height of 4.91 m above the ground. It has

an initial speed of 16.0 m/s. (a) What's its initial vertical speed? (b) How long will it take to drop to the ground? (c) How far, measured horizontally from the launch point, will the ball strike the ground?

106. [I] THIS PROBLEM EXPLORES HORIZONTAL PROJECTILE MOTION. Fired at 60.0 m/s from a horizontal compressed-gas gun, a tennis ball strikes the ground 80.0 m away. (a) What's its initial vertical speed? (b) How long will the ball be in the air? (c) How high above the ground is the gun?

107. [I] Show that the range of a projectile can be expressed as

$$s_R = \frac{-2v_{ix}v_{iy}}{g}$$

Ignore air friction.

108. [I] Suppose you point a rifle horizontally directly at the center of a paper target 100 m away from you. If the muzzle speed of the bullet is 1000 m/s, where will it strike the target? Assume aerodynamic effects are negligible.

109. [I] A raw egg is thrown horizontally straight out of the open window of a fraternity house. If its initial speed is 20 m/s and it hits ground 2.0 s later, at what height was it launched? At such low speeds air friction is negligible. [*Hint: Even though it's been thrown horizontally, the egg falls vertically for 2.0 s exactly as if it were simply dropped.*]

110. [I] While rolling marbles on a horizontal window sill a youngster accidentally shoots one at 3.0 m/s out the open window. He sees it land in a flower pot on a neighbor's fire escape 3.0 s later. How far beneath the sill is the pot?

111. [I] Several clowns in a circus are performing high up in the riggings of the tent. One throws a plastic bag full of water (at a height of 20.0 m) directly at a companion who is 10 m away and also 20.0 m above the ground. The bag just misses and 1.5 s later lands on the head of a third clown. Ignoring air friction, how high is his wet head above the ground?

112. [I] A golfer wishes to chip a shot into a hole 50 m away on flat level ground. If the ball sails off at 45°, what speed must it have initially? Ignore aerodynamic effects.

113. [I] Check the dimensions of both sides of the equation $v_i s_y^2 = tv_i^2 \cos\theta + \frac{1}{2}gv_i t^2$ to see if they are the same; if not, the equation is wrong. This technique was introduced by the French mathematician and physicist, J.B.J. Fourier, around 1822. Is it possible that the above equation is correct?

114. [II] THIS PROBLEM DEALS WITH HORIZONTAL PROJECTILE MOTION. Hurled horizontally through an open window at a height of 20.0 m above the ground, a rock leaves the thrower's hand at 60.0 m/s. (a) What are its initial vertical and horizontal speeds? (b) How long will it take to fall to the ground? (b) At what net speed will it land?

115. [II] THIS PROBLEM IS ABOUT PROJECTILE MOTION. Making an angle of 50.0° with the horizontal, a cannon fires a ball with a muzzle speed of 100 m/s. (a) What are its initial vertical and horizontal speeds? (b) What's its peak altitude? (c) On the way up, how long will it take to reach an altitude of 100 m?

116. [II] A flea jumps into the air and lands about 8.0 in. away, having risen to an altitude of about 130 times its own height (that's comparable to you jumping 650 ft up). Assuming a 45° launch, compute the flea's take-off speed. Make use of the mathematical fact that $2\sin\theta\cos\theta = \sin 2\theta$ and ignore air friction.

SOLUTION: Its range is (8.0 in.)(2.54 cm/in.) = 20.32 cm where,

$$s_R = \frac{2v_i^2}{9.81\text{ m/s}^2}\cos\theta\sin\theta = \frac{v_i^2}{9.81\text{ m/s}^2}\sin 2\theta$$

$$v_i^2 = \frac{(20.32\times 10^{-2}\text{ m})(9.81\text{ m/s}^2)}{\sin 90°}\text{ and } v_i = 1.4\text{ m/s}$$

117. [II] Two diving platforms 10-m high terminate just at the edge of each end of a swimming pool 30-m long. How fast must two clowns run straight off their respective boards if they are to collide at the surface of the water midpool? Ignore friction.

118. [II] A golf ball hit with a 7-iron soars into the air at 40.0° with a speed of 54.86 m/s (i.e., 180 ft/s). Overlooking the effect of the atmosphere on the ball, determine (a) its range and (b) when it will strike the ground.

119. [II] A silver dollar is thrown downward at an angle of 60.0° below the horizontal from a bridge 50.0 m above a river. If its initial speed is 40.0 m/s, where and at what speed will it strike the water? Ignore the effects of the air. [*Hint: Find the final vertical speed knowing the height; get the time of flight from the Mean Speed Theorem. Use that to compute the horizontal distance. And finally from the Pythagorean Theorem get the total speed.*]

120. [II] Someone at a third-floor window (12.0 m above the ground) hurls a ball downward at 45.0° at a speed of 25.0 m/s. How fast will it be traveling when it strikes the sidewalk?

121. [II] A small rocket is fired in a test range. It rises high into the air and soon runs out of fuel. On the way down it passes near an observer (sitting in a 20.0-m-high tower) who sees the rocket traveling at a speed of 30.0 m/s and moving in a vertical plane at an angle of 80.0° below horizontal. How fast will it be traveling when it hits the ground?

122. [II] Using Fig. 3.17 (p. 73) and extending it where necessary, show that an angle less than 45° with respect to the ground will result in a greater horizontal displacement when the landing point is lower than the launch point. Neglect friction.

123. [II] Show that at any time t, where friction is negligible, the velocity of a projectile (launched at an angle θ with a speed v_i) makes an angle θ_t with the horizontal given by the expression

$$\theta_t = \tan^{-1}\left(\tan\theta + \frac{gt}{v_i\cos\theta}\right)$$

where $g < 0$.

124. [III] A baseball is hit as it comes in, 1.30 m over the plate. The blast sends it off at an angle of 30° above the horizontal with a speed of 45.0 m/s. The outfield fence is 100 m away and 11.3-m high. Ignoring aerodynamic effects, will the ball clear the fence?

125. [III] A burning firecracker is tossed into the air at an angle of 60° up from the horizon. If it leaves the hand of the hurler at a speed of 30 m/s, how long should the fuse be set to burn if the explosion is to occur 20 m away? Ignoring friction, just set up the equation for t.