For Thought and Discussion

1. Explain why measurement standards based on laboratory procedures are preferable to those based on specific objects such as the international prototype kilogram.
2. Which measurement standards are now defined operationally? Which are not?
3. When a computer that carries seven significant figures adds 1.000000 and 2.5×10^{-15}, what answer does it display? Why?
4. Why does Earth's rotation not provide a suitable standard of time?
5. To raise a power of 10 to another power, you multiply the exponent by the power. Explain why this works.
6. A scientist and a creationist are arguing about the age of the Earth. What facts might the scientist use in estimating this age?
7. How would you determine the length of a curved line?
8. Write $1/\sqrt{x}$ as x to some power.
9. Emissions of carbon dioxide from fossil-fuel combustion are often expressed in gigatonnes per year, where 1 tonne = 1000 kg. But sometimes CO_2 emissions are given in petagrams per year. How are the two units related?

Exercises and Problems

Exercises

Section 1.2 Measurements and Units

10. The power output of a typical large power plant is 1000 megawatts (MW). Express this result in (a) W, (b) kW, and (c) GW.
11. The diameter of a hydrogen atom is about 0.1 nm, and the diameter of a proton is about 1 fm. How much bigger is a hydrogen atom than a proton?
12. Use the definition of the meter to determine how far light travels in 1 ns.
13. How long, in nanoseconds, is the period of the cesium-133 radiation used to define the second?
14. Lake Baikal in Siberia holds the world's largest quantity of fresh water, about 14 Eg. How many kilograms is that?
15. A hydrogen atom is about 0.1 nm in diameter. How many hydrogen atoms lined up side by side would make a line 1 cm long?
16. How long a piece of wire would you need to form a circular arc subtending an angle of 1.4 rad, if the radius of the arc is 8.1 cm?
17. Making a turn, a jetliner flies 2.1 km on a circular path of radius 3.4 km. Through what angle does it turn?
18. A car is moving at 35.0 mi/h. Express its speed in (a) m/s and (b) ft/s.
19. I have enough postage for a 1-oz letter but only a metric scale. What's the maximum mass for my letter, in grams?
20. A year is very nearly $\pi \times 10^7$ s. By what percentage is this figure in error?
21. How many cubic centimeters (cm^3) are in a cubic meter (m^3)?
22. By what percentage do the 1500-m and 1-mile races differ?
23. A gallon of paint covers 350 ft^2. What is its coverage in m^2/L?
24. Superhighways in Canada have speed limits of 100 km/h. How does this compare with the 65 mi/h speed limit common in the United States?
25. One m/s is how many km/h?
26. A 3.0-lb box of grass seed will seed 2100 ft^2 of lawn. Express this coverage in m^2/kg.
27. A radian is how many degrees?

Section 1.3 Working with Numbers

28. Add 3.6×10^5 m and 2.1×10^3 km.
29. Divide 4.2×10^3 m/s by 0.57 ms, and express your answer in m/s^2.
30. Add 5.1×10^{-2} cm and 6.8×10^3 μm, and multiply the result by 1.8×10^4 N (1 N is the SI unit of force).
31. What is the cube root of 6.4×10^{19}? Do this without a calculator.
32. Add 1.46 m and 2.3 cm.
33. A 3.6-cm-long radio antenna is added to the front of an airplane 41 m long. What is the overall length?
34. Repeat Exercise 33 given that the airplane's length is 41.05 m.

Problems

35. To see that it is important to carry more digits in intermediate calculations, determine $(\sqrt{3})^3$ to three significant figures in two ways: (a) Find $\sqrt{3}$ and round to three significant figures, then cube and again round; and (b) find $\sqrt{3}$ to four significant figures, then cube and round to three significant figures.
36. Paper is made from wood pulp. Estimate the number of trees that must be cut down to make one day's run of a big city's daily newspaper. Assume no recycling.
37. The average dairy cow produces about 10^4 kg of milk per year. Estimate the number of dairy cows needed to keep the United States supplied with milk.
38. How many Earths would fit inside the Sun?
39. The average American uses electrical energy at the rate of about 1.5 kilowatts (kW). Solar energy reaches Earth's surface at an average rate of about 300 watts on every square meter. What fraction of the United States' land area would have to be covered with solar cells to provide all of our electrical energy? Assume the cells are 20% efficient at converting sunlight to electricity.
40. (a) Estimate the volume of water going over Niagara Falls each second. (b) The falls provides the outlet for Lake Erie; if the falls were shut off, estimate how long it would take Lake Erie to rise 1 m.
41. Estimate the number of air molecules in your dormitory room.
42. A human hair is about 100 μm across. Estimate the number of hairs in a typical braid.
43. The density of bubble gum is about 1 g/cm^3. You blow an 8-g wad of gum into a bubble 10 cm in diameter. What is the thickness of the bubble? *Hint:* Think about spreading the bubble into a flat sheet. The surface area of a sphere is $4\pi r^2$.
44. The Moon barely covers the Sun at a solar eclipse. Given that the Moon is 4×10^5 km from Earth and that the Sun is 1.5×10^8 km from Earth, determine how much bigger the Sun's diameter is than the Moon's. If the Moon's radius is 1800 km, how big is the Sun?
45. The semiconductor chip at the heart of a personal computer is a square 4 mm on a side and contains 10^9 electronic components. (a) If each component is a square, what is the distance across each component? (b) If a calculation requires that electrical impulses traverse 10^4 elements on the chip, each a million times, how many such calculations can the computer perform each second? The maximum speed of an electrical impulse is close to the speed of light, 3×10^8 m/s.
46. Estimate the number of (a) atoms and (b) cells in your body.
47. When we write the number 3.6 as typical of a number with two significant figures, we're saying that the actual value is closer to 3.6 than to 3.5 or 3.7; that is, the actual value lies between 3.55 and 3.65. Show that the percent uncertainty implied by two-significant-figure accuracy varies with the value of the number, being the lowest for numbers beginning with 9 and the highest for numbers beginning with 1. In particular, what is the percent uncertainty implied by the numbers (a) 1.1, (b) 5.0, and (c) 9.9?
48. Continental drift occurs at about the rate at which your fingernails grow. Estimate the age of the Atlantic Ocean, assuming the eastern and western hemispheres have been drifting apart.
49. In the 1908 London Olympic Games, the originally intended marathon distance of 26 miles was extended by 385 yards so that the end was in front of the royal reviewing stand. This distance subsequently became standard. What is the marathon distance in kilometers, to the nearest meter?
50. Express the following with appropriate units and significant figures: (a) 1.0 m plus 1 mm, (b) 1.0 m times 1 mm, (c) 1.0 m minus 999 mm, (d) 1.0 m divided by 999 mm.
51. Estimation problems were a favorite of the famous physicist Enrico Fermi. Here is one such problem attributed to him: What is the number of piano tuners in Chicago? Explain how you would estimate this number.
52. You are the owner of a small manufacturing company and wish to install some new computer-aided manufacturing equipment. A sales representative tells you the computer his company sells contains "super chips" that no one else has. He claims each chip contains more than 10 billion electronic components. Each chip measures 5.0 mm by 5.0 mm, and you know that each component is 90 nm on a side. Is the sales rep correct?
53. Café Milagro in Costa Rica sells coffee via the Internet. A 0.5-kg bag of coffee costs \$8.95, excluding shipping. How much does this coffee cost per pound? If you order six 0.5-kg bags, the shipping costs ~~\$1.92 per bag~~. How much does a bag cost when you include the shipping?
54. Suppose you drive your old classic car to an auto show in Canada. Your speedometer shows only miles per hour (mph). All the Canadian speed limits are in km/h (kph)! What speed limit in mph corresponds to these Canadian speed limits: 40 kph, 50 kph, 80 kph, and 100 kph?
55. While in Canada, you go to a grocery store and purchase some deli meats and cheese for sandwiches. You normally request one-half pound of each in the United States. About how many kilograms of meat and cheese should you ask the clerk to slice?

Answers to Chapter Questions

Answer to Chapter Opening Question

All of them!

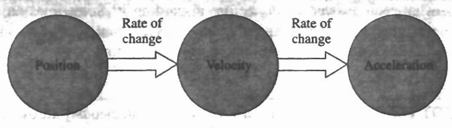
Answers to GOT IT? Question

1.1 (a) 2.998×10^{-9}, 0.0008, 3.14×10^7, 0.041×10^9, 55×10^6
(b) 0.0008, 0.041×10^9 and 55×10^6 (with two significant figures each), 3.14×10^7, 2.998×10^{-9}

CHAPTER 2 SUMMARY

Big Picture

The big ideas here are those of **kinematics**—the study of motion without regard to its cause. **Position, velocity,** and **acceleration** are the quantities that characterize motion:

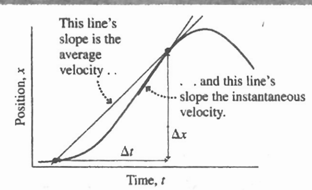


Key Concepts and Equations

Average velocity and acceleration involve changes in position and velocity, respectively, occurring over a time interval Δt:

$$\bar{v} = \frac{\Delta x}{\Delta t}$$

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

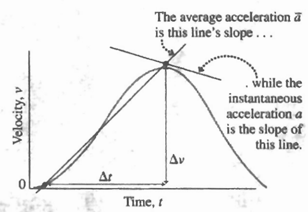


Here Δx is the **displacement**, or change in position, and Δv is the change in velocity.

Instantaneous values are the limits of infinitesimally small time intervals and are given by calculus as the time derivatives of position and velocity:

$$v = \frac{dx}{dt}$$

$$a = \frac{dv}{dt}$$



Cases and Uses

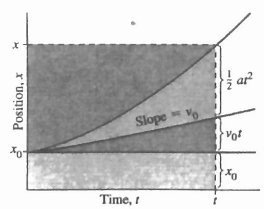
Constant acceleration is a special case that yields simple equations describing one-dimensional motion:

$$v = v_0 + at$$

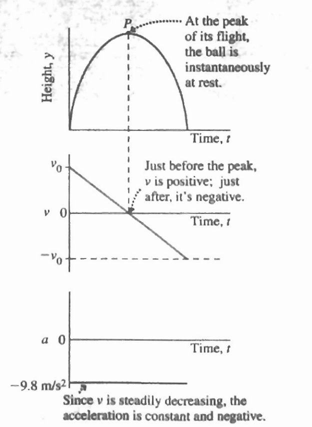
$$x = x_0 + v_0t + \tfrac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

These equations apply only in the case of constant acceleration.



An important example is the acceleration of gravity, essentially constant near Earth's surface, with a magnitude of approximately 9.8 m/s^2.



For Thought and Discussion

1. Under what conditions are average and instantaneous velocity equal?
2. You're driving straight at a steady 80 km/h but stop a while for a picnic lunch. How does the stop affect your average velocity?
3. Does a speedometer measure speed or velocity?
4. You check your odometer at the beginning of a day's driving and again at the end. Under what conditions would the difference between the two readings represent your displacement?
5. Consider two possible definitions of average speed: (a) average speed is the average of the values of the instantaneous speed over a time interval; and (b) average speed is the magnitude of the average velocity. Are these definitions equivalent? Give examples to demonstrate your conclusion.
6. Is it possible to be at position $x = 0$ and still be moving?
7. Is it possible to have zero velocity and still be accelerating?
8. If you know the initial velocity v_0 and the initial and final heights y_0 and y, you can use Equation 2.10 to solve for the time t when the object will be at height y. But the equation is quadratic in t, so you'll get two answers. Physically, why is this?
9. Starting from rest, an object undergoes an acceleration given by $a = bt$, where t is time and b is a constant. Can you use the expression bt for a in Equation 2.10 to predict the object's position as a function of time? Why or why not?
10. In which of the velocity-versus-time graphs shown in Fig. 2.14 would the average velocity over the interval shown equal the average of the velocities at the ends of the interval?

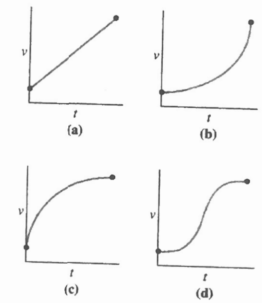


FIGURE 2.14 For Thought and Discussion 10

11. If you travel in a straight line at 50 km/h for 1 h and at 100 km/h for another hour, is your average velocity 75 km/h? If not, is it more or less?
12. If you travel in a straight line at 50 km/h for 50 km and then at 100 km/h for another 50 km, is your average velocity 75 km/h? If not, is it more or less?

Exercises and Problems

Exercises

Section 2.1 Average Motion

13. In 2005 Asafa Powell of Jamaica set a world record in the 100-m dash, with a time of 9.77 s. What was his average speed?
14. In 2004 Mizuki Noguchi of Japan won the Women's Olympic Marathon, completing the 26-mi, 385-yd course in 2 h, 26 min, 20 s. What was Noguchi's average speed, in meters per second?
15. Starting from home, you bicycle 24 km north in 2.5 h and then turn around and pedal straight home in 1.5 h. What are your (a) displacement at the end of the first 2.5 h, (b) average velocity over the first 2.5 h, (c) average velocity for the homeward leg of the trip, (d) displacement for the entire trip, and (e) average velocity for the entire trip?
16. On January 14, 2005, the Huygens probe from the Cassini Orbiter landed on Saturn's moon Titan, approximately 1.2 billion km from Earth. How long did it take Huygens's radio signals, traveling at the speed of light, to reach Earth?
17. Australian Peter Robertson won the 2005 triathlon world championship, completing the 1500-m swim, 40-km bicycle ride, and 10-km run in 1 h, 49 min, 31 s. What was Robertson's average speed?
18. Taking Earth's orbit to be a circle of radius 1.5×10^8 km, determine the speed of Earth's orbital motion in (a) meters per second and (b) miles per second.
19. What is the conversion factor from meters per second to miles per hour?
20. If the average American driver goes 5000 mi each year on interstate highways, how much less time did the average driver spend on interstate highways each year as a result of the 1995 increase in the speed limit from 55 mi/h to 65 mi/h?

Section 2.2 Instantaneous Velocity

21. On a single graph, plot distance versus time for the two trips from Houston to Des Moines described on page 15. For each trip, identify graphically the average velocity and, for each segment of the trip, the instantaneous velocity.
22. For the motion plotted in Fig. 2.15, estimate (a) the greatest velocity in the positive x direction, (b) the greatest velocity in the negative x direction, (c) any times when the object is instantaneously at rest, and (d) the average velocity over the interval shown.

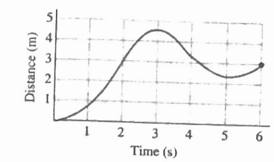


FIGURE 2.15 Exercise 22

23. A model rocket is launched straight upward. Its altitude y as a function of time is given by $y = bt - ct^2$, where $b = 82$ m/s, $c = 4.9 \text{ m/s}^2$, t is the time in seconds, and y is in meters. (a) Use differentiation to find a general expression for the rocket's velocity as a function of time. (b) When is the velocity zero?

Section 2.3 Acceleration

24. A giant eruption on the Sun propels solar material from rest to a final speed of 450 km/s over a period of 1 h. What is the average acceleration of this material in m/s^2?
25. Starting from rest, a subway train first accelerates to 25 m/s and then begins to brake. Forty-eight seconds after starting, it is moving at 17 m/s. What is its average acceleration in this 48-s interval?
26. A space shuttle's main engines cut off 8.5 min after launch, at which time the shuttle's speed is 7.6 km/s. What is the shuttle's average acceleration during this interval?
27. An egg drops from a second-story window, taking 1.12 s to fall and reaching a speed of 11.0 m/s just before hitting the ground. On contact with the ground, the egg stops completely in 0.131 s. Calculate the average magnitudes of its acceleration while falling and while stopping.
28. An airplane's takeoff speed is 320 km/h. If its average acceleration is 2.9 m/s^2, how long is it on the runway after starting its takeoff roll?
29. ThrustSSC, the world's first supersonic car, accelerates from rest to 1000 km/h in 16 s. What is its acceleration in m/s^2?

Section 2.4 Constant Acceleration

30. You're driving at 70 km/h when you accelerate with constant acceleration to pass another car. Six seconds later, you're doing 80 km/h. How far did you go in this time?
31. Differentiate both sides of Equation 2.10, and show that you get Equation 2.7.
32. Electrons that "paint" the picture in a TV tube undergo constant acceleration over a distance of 3.8 cm. If they reach a final speed of 1.2×10^7 m/s, what are (a) the electrons' acceleration and (b) the time spent accelerating?
33. A rocket rises with constant acceleration to an altitude of 85 km, at which point its speed is 2.8 km/s. (a) What is its acceleration? (b) How long does the ascent take?
34. Starting from rest, a car accelerates at a constant rate, reaching 88 km/h in 12 s. (a) What is its acceleration? (b) How far does it go in this time?
35. A car moving initially at 50 mi/h begins decelerating at a constant rate 100 ft short of a stoplight. If the car comes to a full stop just at the light, what is the magnitude of its deceleration?
36. In an X-ray tube, electrons are accelerated to a velocity of 10^8 m/s and then slammed into a tungsten target. The electrons undergo rapid deceleration, producing X rays. If the stopping time for an electron is on the order of 10^{-19} s, approximately how far does an electron move while decelerating? Assume constant deceleration.
37. The Barringer meteor crater in northern Arizona is 180 m deep and 1.2 km in diameter. The fragments of the meteor lie just below the bottom of the crater. If these fragments decelerated at a constant rate of 4×10^5 m/s^2 as they ploughed through the Earth in forming the crater, what was the speed of the meteor's impact at Earth's surface?
38. A gazelle accelerates from rest at 4.1 m/s^2 over a distance of 60 m to outrun a predator. What is its final speed?

Section 2.5 The Acceleration of Gravity

39. You drop a rock into a deep well and 4.4 s later hear the splash. How far down is the water? Neglect the travel time of the sound.
40. Your friend is sitting 6.5 m above you in a tree branch. How fast should you throw an apple so that it just reaches her?
41. A model rocket leaves the ground, heading straight up at 49 m/s. (a) What is its maximum altitude? What are its speed and altitude at (b) 1 s, (c) 4 s, and (d) 7 s?
42. A foul ball leaves the bat going straight upward at 23 m/s. (a) How high does it rise? (b) How long is it in the air? Neglect the distance between the bat and the ground.
43. A Frisbee is lodged in a tree branch 6.5 m above the ground. A rock thrown from below must be going at least 3 m/s to dislodge the Frisbee. How fast must such a rock be thrown upward if it leaves the thrower's hand 1.3 m above the ground?
44. Space pirates kidnap an earthling and hold him imprisoned on one of the planets of the solar system. With nothing else to do, the prisoner amuses himself by dropping his watch from eye level (170 cm) to the floor. He observes that the watch takes 0.95 s to fall. On what planet is he being held? *Hint.* Consult Appendix E.

Problems

45. You allow yourself 40 min to drive 25 mi to the airport, but you're caught in heavy traffic and average only 20 mi/h for the first 15 min. What must your average speed be on the rest of the trip if you are to get to the airport on time?
46. A fast base runner can get from first to second base in 3.4 s. If he leaves first base as the pitcher throws a 90 mi/h fastball the 61-ft distance to the catcher, and if the catcher takes 0.45 s to catch and rethrow the ball, how fast does the catcher have to throw the ball to second base to make an out? Home plate to second base is the diagonal of a square 90 ft on a side.
47. You drive the 4600 km from coast to coast of the United States at 65 mi/h (105 km/h), stopping an average of 30 min for rest and refueling after every 2 h of driving. (a) What is your average velocity for the entire trip? (b) How long does the trip take?
48. I can run 90 m/s, 20% faster than my kid brother. How much head start should I give him in order to have a tie race over 100 m?
49. A jetliner leaves San Francisco for New York, 4600 km away. With a strong tailwind, its speed is 1100 km/h. At the same time, a second jet leaves New York for San Francisco. Flying into the wind, it makes only 700 km/h. When and where do the two planes pass each other?
50. The position of an object as a function of time is given by $x = bt + ct^3$, where $b = 1.50$ m/s and $c = 0.640$ m/s^3. To study the limiting process leading to the definition of instantaneous velocity, calculate the average velocity of the object over time intervals from (a) 1.00 s to 3.00 s, (b) 1.50 s to 2.50 s, and (c) 1.95 s to 2.05 s. (d) Find the instantaneous velocity as a function of time by differentiating, and compare its value at 2 s with your average velocities.
51. The position of an object as a function of time is given by $x = bt^4$, where b is a constant. Find an expression for the instantaneous velocity as a function of time, and show that the average velocity over the interval from $t = 0$ to any time t is one-fourth of the instantaneous velocity at t.
52. In a drag race, the position of a car as a function of time is given by $x = bt^2$, with $b = 2.000$ m/s^2. In an attempt to determine the car's velocity midway down a 400-m track, two observers stand at the 180-m and 220-m marks and note the time when the car passes them. (a) What value do the two observers compute for the car's velocity? Give your answer to four significant figures. (b) By what percentage does this observed value differ from the actual instantaneous value at $x = 200$ m?

53. The position of an object is given by $x = bt^3$, where x is in meters, t is in seconds, and the constant b is 1.5 m/s^3. Determine (a) the instantaneous velocity and (b) the instantaneous acceleration at the end of 2.5 s. Find (c) the average velocity and (d) the average acceleration during the first 2.5 s.
54. If you square Equation 2.7, you'll have an expression for v^2. Equation 2.11 also gives an expression for v^2. Equate the two expressions for v^2, and show that the resulting equation reduces to Equation 2.10.
55. On packed snow, the use of computerized antilock brakes can reduce the stopping distance for a car by 55%. By what percentage is the stopping *time* reduced?
56. A particle leaves its initial position x_0 at time $t = 0$, moving in the positive x direction with speed v_0 but undergoing acceleration of magnitude a in the negative x direction. Find expressions for (a) the time when it returns to the position x_0 and (b) its speed when it passes that point.
57. A hockey puck moving at 32 m/s slams through a wall of snow 35 cm thick. It emerges moving at 18 m/s. (a) How much time does it spend in the snow? (b) How thick a wall of snow would be needed to stop the puck entirely?
58. Amtrak's 20th-Century Limited is en route from Chicago to New York at 110 km/h when the engineer spots a cow on the track. The train brakes to a halt in 1.2 min, stopping just in front of the cow. (a) What is the magnitude of the train's (constant) acceleration? (b) What is the direction of the acceleration? (c) How far was the train from the cow when the engineer first applied the brakes?
59. A jetliner touches down at 220 km/h, reverses its engines to provide braking, and comes to a halt 29 s later. What is the shortest runway on which this aircraft can land, assuming constant deceleration starting at touchdown?
60. A motorist suddenly notices a stalled car and slams on the brakes, decelerating at the rate of 6.3 m/s^2. Unfortunately this isn't good enough, and a collision ensues. From the damage sustained, police estimate that the car was moving at 18 km/h at the time of the collision. They also measure skid marks 34 m long. (a) How fast was the motorist going when the brakes were first applied? (b) How much time elapsed from the initial braking to the collision?
61. A racing car undergoing constant acceleration covers 140 m in 3.6 s. (a) If it's moving at 53 m/s at the end of this interval, what was its speed at the beginning of the interval? (b) How far did it travel *from rest* to the end of the 140-m distance?
62. The maximum deceleration of a car on a dry road is about 8 m/s^2. If two cars are moving head-on toward each other at 88 km/h (55 mi/h), and their drivers apply their brakes when they are 85 m apart, will they collide? If so, at what relative speed? If not, how far apart will they be when they stop? On the same graph, plot distance versus time for both cars.
63. After 35 minutes of running, at the 9-km point in a 10-km race, you find yourself 100 m behind the leader and moving at the same speed. What should your acceleration be if you are to catch up by the finish line? Assume that the leader maintains a constant speed throughout the entire race.
64. You're speeding at 85 km/h when you notice that you're only 10 m behind the car in front of you, which is moving at the legal speed limit of 60 km/h. You slam on your brakes, and your car decelerates at 4.2 m/s^2. Assuming the car in front of you continues at constant speed, will you collide? If so, at what relative speed? If not, what will be the distance between the cars at their closest approach?
65. The Mars rover Spirit landed in 2004 to explore the Martian surface. Its landing was cushioned by airbags, and the rover bounced some 15 m vertically after its first impact. Assuming no loss of speed at contact with the Martian surface, what was Spirit's impact speed?
66. Calculate the speed with which cesium atoms must be "tossed" in the NIST-F1 atomic clock so that their up-and-down travel time is 1.0 s. See Application on page 25.
67. A falling object travels one-fourth of its total distance in the last second of its fall. From what height was it dropped?
68. The defenders of a castle throw rocks down on their attackers from a 15-m-high wall. If the rocks are thrown with an initial speed of 10 m/s, how much faster are they moving when they hit the ground than if they were simply dropped?
69. Two divers jump from a 3.00-m platform. One jumps upward at 1.80 m/s, and the second steps off the platform as the first passes it on the way down. (a) What are their speeds as they hit the water? (b) Which hits the water first and by how much?
70. A balloon is rising at 10 m/s when its passenger throws a ball straight up at 12 m/s. How much later does the passenger catch the ball?
71. Landing on the Moon, a spacecraft fires its retrorockets and comes to a complete stop just 12 m above the lunar surface. It then drops freely to the surface. How long does it take to fall, and what is its impact speed? *Hint:* Consult Appendix E.
72. Launched from the ground, a rocket accelerates vertically upward at 4.6 m/s^2. It passes through a band of clouds 5.3 km thick, extending upward from an altitude of 1.9 km. How long is it in the clouds?
73. A subway train is traveling at 80 km/h when it approaches a slower train 50 m ahead traveling in the same direction at 25 km/h. If the faster train begins decelerating at 2.1 m/s^2 while the slower train continues at constant speed, how soon and at what relative speed will they collide?
74. You toss a book into your dorm room, just clearing a windowsill 4.2 m above the ground. (a) If the book leaves your hand 1.5 m above the ground, how fast must it be going to clear the sill? (b) How long after it leaves your hand will it hit the floor, 0.87 m below the windowsill?
75. Consider an object traversing a distance L, part of the way at speed v_1 and the rest of the way at speed v_2. Find expressions for the average speeds (a) when the object moves at each of the two speeds for half the total *time* and (b) when the object moves at each of the two speeds for half the *distance*.
76. The position of a particle as a function of time is given by $x = x_0 \sin \omega t$, where x_0 and ω are constants. (a) Take derivatives to find expressions for the velocity and acceleration. (b) What are the maximum values of velocity and acceleration? *Hint:* Consult the table of derivatives in Appendix A.
77. Ice skaters, ballet dancers, and basketball players executing vertical leaps often give the illusion of "hanging" almost motionless near the top of the leap. To see why this is, consider a leap that takes an athlete up a vertical distance h. Of the total time spent in the air, what fraction is spent in the upper half (i.e., at $y > \frac{1}{2}h$)?
78. A student is staring idly out her dormitory window when she sees a water balloon fall past. If the balloon takes 0.22 s to cross the 130-cm-high window, from what height above the top of the window was it dropped?
79. A police radar has an effective range of 1.0 km, and a motorist's radar detector has a range of 1.9 km. The motorist is going 110 km/h in a 70 km/h zone when the radar detector beeps. At what rate must the motorist decelerate to avoid a speeding ticket?

80. For the trip in Exercise 15, find the average speed for the entire trip. Show that this speed is equal to the time-weighted average of the speeds for the individual trip segments.

81. An object starts moving in a straight line from position x_0, at time $t=0$, with velocity v_0. Its acceleration is given by $a=a_0+bt$, where a_0 and b are constants. Find expressions for (a) the instantaneous velocity and (b) the position, as functions of time.

82. You are keeping pace with another runner, at 6 minutes per mile, but are 10 m behind her when she is 100 m from the finish line. What constant acceleration do you need to catch her at the finish if she maintains a constant speed? At what pace will you be running at the finish? Express acceleration in m/s^2 and pace in minutes per mile. (Pace is the reciprocal of speed.)

83. For the ball tossed in Example 2.6, (a) find its velocity just before it hits the floor. Suppose you had tossed a second ball straight down at 7.3 m/s (from the same place 1.5 m above the floor). (b) What would its velocity be just before it hits the floor? (c) When would the second ball hit the floor? (Interpret any multiple answers.)

84. Undaunted when you threw him out of your office on a previous visit (see Problem 52 in Chapter 1), a computer sales representative now tries to sell you on the speed of his computer. Your manufacturing process requires that the computer be located such that the travel time between the computer and the machinery is 10 μs or less. The sales rep claims it will take data 8 μs to travel between the computer and the machine if the distance is 2 ft. Is he still trying to fool you?

85. Your roommate is an aspiring novelist. Because you are taking physics your roommate asks your opinion on a matter of physics. It seems the central character in the novel is kept awake at night by a leaky faucet. The sink is 19.6 cm below the leaky faucet. At the instant one drop leaves the faucet, another strikes the sink below and two more drops are in between on the way down. How many drops per second are keeping the annoyed protagonist awake?

86. You and your physics major roommate become involved in a sinister plot to drop water balloons on students entering your dorm. Your room is 64 ft above the sidewalk. You plan to place an X on the sidewalk to mark the spot a student must be when the balloon is dropped. The student will walk the distance from the X to the place the balloon hits in the time the balloon falls. After observing several students, you conclude most students walk at about 2 m/s when coming into the dorm. How far from the impact point do you place the X?

87. Estimate the time it would take you to travel from Los Angeles to New York (about 2800 miles) if you walk at 3 mi/h, ride a bike at 25 km/h, or drive a car at an average speed of 55 mi/h.

Answers to Chapter Questions

Answer to Chapter Opening Question

Although the ball's velocity is zero at the top of its motion, its acceleration is -9.8 m/s^2, as it is throughout the toss.

Answers to GOT IT? Questions

2.1 (a) and (b); average speed is greater for (c).

2.2 (b) moves with constant speed; (a) reverses; (d) speeds up.

2.3 Halfway between the times. Because its acceleration is constant, the police car's speed increases by equal amounts in equal times. So it gets from 0 to half its final velocity—which is twice the car's velocity—in half the total time.

2.4 The dropped ball hits first; the thrown ball hits moving faster.

3 Motion in Two and Three Dimensions

At what angle should this penguin leave the water to maximize the range of its jump?

▶ To Learn

By the end of this chapter you should be able to

- Describe position, velocity, and acceleration in three-dimensional space using the language of vectors (3.1, 3.2).
- Add and subtract vectors, and multiply them by scalars (3.1).
- Explain how the effects of acceleration depend on the direction of acceleration in relation to velocity (3.2).
- Transform velocities to different reference frames (3.3).
- Solve quantitative problems involving motion in two dimensions with constant acceleration, including projectile motion with the constant acceleration of gravity (3.4, 3.5).
- Explain why circular motion necessarily entails acceleration, and solve quantitative problems involving uniform circular motion (3.6).

◀ To Know

- You should understand the concepts of position, velocity, and acceleration in one dimension (2.1–2.3).
- You should know how to solve problems in one-dimensional motion with constant acceleration (2.4).
- You should be familiar with the acceleration of gravity near Earth's surface, and be able to apply it to one-dimensional motion under the influence of gravity (2.5).

What's the speed of an orbiting satellite? How should I leap to win the long-jump competition? How do I engineer a curve in the road for safe driving? These and many other questions involve motion in more than one dimension. In this chapter we extend the ideas of one-dimensional motion to these more complex—and more interesting—situations.

3.1 Vectors

We've seen that quantities describing motion have direction as well as magnitude. In Chapter 2, a simple plus or minus sign took care of direction. But now, in two or three dimensions, we need a way to account for all possible directions. We do this with mathematical quantities called **vectors**, which express both magnitude and direction. Vectors stand in contrast to **scalars**, which are quantities that have no direction.

Position and Displacement

The simplest vector quantity is position. Given an origin, we can characterize any position in space by drawing an arrow from the origin to that position. That arrow is a pictorial representation of a **position vector**, which we call $\vec{r}$. The arrow over the r indicates that this