ANALYSIS MODELS FOR PROBLEM-SOLVING

Particle Under Constant Velocity. If a particle moves in a straight line with a constant speed $v_x$, its constant velocity is given by

$$v_x = \frac{\Delta x}{\Delta t} \quad (2.6)$$

and its position is given by

$$x_f = x_i + v_x t \quad (2.7)$$

Particle Under Constant Acceleration. If a particle moves in a straight line with a constant acceleration $a_x$, its motion is described by the kinematic equations:

$$v_y = v_{yi} + a_x t \quad (2.13)$$

$$v_{x, \text{ avg}} = \frac{v_{xi} + v_{xf}}{2} \quad (2.14)$$

$$x_f = x_i + \frac{1}{2}(v_{xi} + v_{yi}) t \quad (2.15)$$

$$x_f = x_i + v_{xi} t + \frac{1}{2}a_x t^2 \quad (2.16)$$

$$v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i) \quad (2.17)$$

Particle Under Constant Speed. If a particle moves a distance $d$ along a curved or straight path with a constant speed, its constant speed is given by

$$v = \frac{d}{\Delta t} \quad (2.8)$$

Questions

□ denotes answer available in Student Solutions Manual/Study Guide; O denotes objective question

1. O One drop of oil falls straight down onto the road from the engine of a moving car every 5 s. Figure Q2.1 shows the pattern of the drops left behind on the pavement. What is the average speed of the car over this section of its motion? (a) 20 m/s (b) 24 m/s (c) 30 m/s (d) 100 m/s (e) 120 m/s

Two cars are moving in the same direction in parallel lanes along a highway. At some instant, the velocity of car A exceeds the velocity of car B. Does that mean that the acceleration of A is greater than that of B? Explain.

6. O When the pilot reverses the propeller in a boat moving north, the boat moves with an acceleration directed south. If the acceleration of the boat remains constant in magnitude and direction, what would happen to the boat (choose one)? (a) It would eventually stop and then remain stopped. (b) It would eventually stop and then start to speed up in the forward direction. (c) It would eventually stop and then start to speed up in the reverse direction. (d) It would never quite stop but lose speed more and more slowly forever. (e) It would never stop but continue to speed up in the forward direction.

7. O Each of the strobe photographs (a), (b), and (c) in Figure Q2.7 was taken of a single disk moving toward the right, which we take as the positive direction. Within each photograph, the time interval between images is constant. (i) Which photograph(s), if any, shows constant zero velocity? (ii) Which photograph(s), if any, shows constant zero acceleration? (iii) Which photograph(s), if any, shows constant positive velocity? (iv) Which photograph(s), if any, shows constant positive acceleration? (v) Which photograph(s), if any, shows some motion with negative acceleration?
8. Try the following experiment away from traffic where you can do it safely. With the car you are driving moving slowly on a straight, level road, shift the transmission into neutral and let the car coast. At the moment the car comes to a complete stop, step hard on the brake and notice what you feel. Now repeat the same experiment on a fairly gentle uphill slope. Explain the difference in what a person riding in the car feels in the two cases. (Brian Popp suggested the idea for this question.)

9. A skateboarder coasts down a long hill, starting from rest and moving with constant acceleration to cover a certain distance in 6 s. In a second trial, he starts from rest and moves with the same acceleration for only 2 s. How is his displacement different in this second trial compared with the first trial? (a) one-third as large (b) three times larger (c) one-ninth as large (d) nine times larger (e) none of these answers

10. Can the equations of kinematics (Eqs. 2.13–2.17) be used in a situation in which the acceleration varies in time? Can they be used when the acceleration is zero?

11. A student at the top of a building of height $h$ throws one ball upward with a speed of $v_i$ and then throws a second ball downward with the same initial speed $|v_i|$. How do the final velocities of the balls compare when they reach the ground?

12. A pebble is released from rest at a certain height and falls freely, reaching an impact speed of 4 m/s at the floor. (i) Next, the pebble is thrown down with an initial speed of 3 m/s from the same height. In this trial, what is its speed at the floor? (a) less than 4 m/s (b) 4 m/s (c) between 4 m/s and 5 m/s (d) $\sqrt{3^2 + 4^2}$ m/s = 5 m/s (e) between 5 m/s and 7 m/s (f) $(3 + 4)$ m/s = 7 m/s (g) greater than 7 m/s (ii) In a third trial, the pebble is tossed upward with an initial speed of 3 m/s from the same height. What is its speed at the floor in this trial? Choose your answer from the same list (a) through (g).

13. A hard rubber ball, not affected by air resistance in its motion, is tossed upward from shoulder height, falls to the sidewalk, rebounds to a somewhat smaller maximum height, and is caught on its way down again. This motion is represented in Figure Q2.13, where the successive positions of the ball A through G are not equally spaced in time. At point G the center of the ball is at its lowest point in the motion. The motion of the ball is along a straight line, but the diagram shows successive positions offset to the right to avoid overlapping. Choose the positive $y$ direction to be upward. (i) Rank the situations A through G according to the speed of the ball $|v_y|$ at each point, with the largest speed first. (ii) Rank the same situations according to the velocity of the ball at each point. (iii) Rank the same situations according to the acceleration $a_y$ of the ball at each point. In each ranking, remember that zero is greater than a negative value. If two values are equal, show that they are equal in your ranking.

14. You drop a ball from a window located on an upper floor of a building. It strikes the ground with speed $v$. You now repeat the drop, but you ask a friend down on the ground to throw another ball upward at speed $v$. Your friend throws the ball upward at the same moment that you drop yours from the window. At some location, the balls pass each other. Is this location (a) at the halfway point between window and ground, (b) above this point, or (c) below this point?

Problems

WebAssign The Problems from this chapter may be assigned online in WebAssign.

ThomsonNOW Sign in at www.thomsonedu.com and go to ThomsonNOW to assess your understanding of this chapter’s topics with additional quizzing and conceptual questions.

1, 2, 3 denotes straightforward, intermediate, challenging; □ denotes full solution available in Student Solutions Manual/Study Guide; ▲ denotes coached solution with hints available at www.thomsonedu.com; ■ denotes developing symbolic reasoning; ● denotes asking for qualitative reasoning; ■ denotes computer useful in solving problem
Section 2.1 Position, Velocity, and Speed

1. The position versus time for a certain particle moving along the x axis is shown in Figure P2.1. Find the average velocity in the following time intervals. (a) 0 to 2 s (b) 0 to 4 s (c) 2 s to 4 s (d) 4 s to 7 s (e) 0 to 8 s

2. The position of a pinewood derby car was observed at various moments; the results are summarized in the following table. Find the average velocity of the car for (a) the first 1-s time interval, (b) the last 3 s, and (c) the entire period of observation.

<table>
<thead>
<tr>
<th>t (s)</th>
<th>x (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.0</td>
<td>2.3</td>
</tr>
<tr>
<td>2.0</td>
<td>9.2</td>
</tr>
<tr>
<td>3.0</td>
<td>20.7</td>
</tr>
<tr>
<td>4.0</td>
<td>36.8</td>
</tr>
<tr>
<td>5.0</td>
<td>57.5</td>
</tr>
</tbody>
</table>

3. A person walks first at a constant speed of 5.00 m/s along a straight line from point A to point B and then back along the line from B to A at a constant speed of 3.00 m/s. (a) What is her average speed over the entire trip? (b) What is her average velocity over the entire trip?

4. A particle moves according to the equation \( x = 10t^2 \), where x is in meters and t is in seconds. (a) Find the average velocity for the time interval from 2.00 s to 3.00 s. (b) Find the average velocity for the time interval from 2.00 s to 2.10 s.

Section 2.2 Instantaneous Velocity and Speed

5. A position–time graph for a particle moving along the x axis is shown in Figure P2.5. (a) Find the average velocity in the time interval \( t = 1.50 \) s to \( t = 4.00 \) s. (b) Determine the instantaneous velocity at \( t = 2.00 \) s by measuring the slope of the tangent line shown in the graph. (c) At what value of t is the velocity zero?

6. The position of a particle moving along the x axis varies in time according to the expression \( x = 5t^2 \), where x is in meters and t is in seconds. Evaluate its position (a) at \( t = 3.00 \) s and (b) at \( t = 3.00 \) s + \( \Delta t \). (c) Evaluate the limit of \( \Delta x/\Delta t \) as \( \Delta t \) approaches zero to find the velocity at \( t = 3.00 \) s.

7. (a) Use the data in Problem 2.2 to construct a smooth graph of position versus time. (b) By constructing tangents to the x(t) curve, find the instantaneous velocity of the car at several instants. (c) Plot the instantaneous velocity versus time and, from the graph, determine the average acceleration of the car. (d) What was the initial velocity of the car?

8. Find the instantaneous velocity of the particle described in Figure P2.1 at the following times: (a) \( t = 1.00 \) s (b) \( t = 3.00 \) s (c) \( t = 4.50 \) s (d) \( t = 7.50 \) s

Section 2.3 Analysis Models: The Particle

9. A hare and a tortoise compete in a race over a course 1.00 km long. The hare crawls straight and steadily at its maximum speed of 0.200 m/s toward the finish line. The hare runs at its maximum speed of 8.00 m/s toward the goal for 0.800 km and then stops to tease the tortoise. How close to the goal can the hare let the tortoise approach before resuming the race, which the tortoise wins in a photo finish? Assume both animals, when moving, move steadily at their respective maximum speeds.

Section 2.4 Acceleration

10. A 50.0-g Super Ball traveling at 25.0 m/s bounces off a brick wall and rebounds at 22.0 m/s. A high-speed camera records this event. If the ball is in contact with the wall for 3.50 ms, what is the magnitude of the average acceleration of the ball during this time interval? Note: 1 ms = \( 10^{-3} \) s.

11. A particle starts from rest and accelerates as shown in Figure P2.11. Determine (a) the particle’s speed at \( t = 10.0 \) s and at \( t = 20.0 \) s and (b) the distance traveled in the first 20.0 s.

12. A velocity–time graph for an object moving along the x axis is shown in Figure P2.12. (a) Plot a graph of the acceleration versus time. (b) Determine the average acceleration of the object in the time intervals \( t = 5.00 \) s to \( t = 15.0 \) s and \( t = 0 \) to \( t = 20.0 \) s.

13. A particle moves along the x axis according to the equation \( x = 2.00 + 3.00t - 1.00t^2 \), where x is in meters and t is in seconds. At \( t = 3.00 \) s, find (a) the position of the particle, (b) its velocity, and (c) its acceleration.
14. A child rolls a marble on a bent track that is 100 cm long as shown in Figure P2.14. We use \( x \) to represent the position of the marble along the track. On the horizontal sections from \( x = 0 \) to \( x = 20 \) cm and from \( x = 40 \) cm to \( x = 60 \) cm, the marble rolls with constant speed. On the sloping sections, the speed of the marble changes steadily. At the places where the slope changes, the marble stays on the track and does not undergo any sudden changes in speed. The child gives the marble some initial speed at the top of the track and does not undergo any sudden changes in speed. Prepare graphs of \( x \) versus \( t \), \( v_x \) versus \( t \), and \( a_x \) versus \( t \), vertically aligned with their time axes identical, to show the motion of the marble. You will not be able to place numbers other than zero on the axes, but show the correct relative sizes on the graphs.

15. An object moves along the \( x \) axis according to the equation \( x(t) = (3.00t^2 - 2.00t + 3.00) \) m, where \( t \) is in seconds. Determine (a) the average speed between \( t = 2.00 \) s and \( t = 3.00 \) s, (b) the instantaneous speed at \( t = 2.00 \) s and at \( t = 3.00 \) s, (c) the average acceleration between \( t = 2.00 \) s and \( t = 3.00 \) s, and (d) the instantaneous acceleration at \( t = 2.00 \) s and \( t = 3.00 \) s.

16. Figure P2.16 shows a graph of \( v_x \) versus \( t \) for the motion of a motorcyclist as he starts from rest and moves along the road in a straight line. (a) Find the average acceleration for the time interval \( t = 0 \) to \( t = 6.00 \) s. (b) Estimate the time at which the acceleration has its greatest positive value and the value of the acceleration at that instant. (c) When is the acceleration zero? (d) Estimate the maximum negative value of the acceleration and the time at which it occurs.

**Section 2.5 Motion Diagrams**

17. Each of the strobe photographs (a), (b), and (c) in Figure Q2.7 was taken of a single disk moving toward the right, which we take as the positive direction. Within each photograph the time interval between images is constant. For each photograph, prepare graphs of \( x \) versus \( t \), \( v_x \) versus \( t \), and \( a_x \) versus \( t \), vertically aligned with their time axes identical, to show the motion of the disk. You will not be able to place numbers other than zero on the axes, but show the correct relative sizes on the graphs.

18. Draw motion diagrams for (a) an object moving to the right at constant speed, (b) an object moving to the right and speeding up at a constant rate, (c) an object moving to the right and slowing down at a constant rate, (d) an object moving to the left and speeding up at a constant rate, and (e) an object moving to the left and slowing down at a constant rate. (f) How would your drawings change if the changes in speed were not uniform; that is, if the speed were not changing at a constant rate?

**Section 2.6 The Particle Under Constant Acceleration**

19. Assume a parcel of air in a straight tube moves with a constant acceleration of \(-4.00 \text{ m/s}^2\) and has a velocity of \(13.0 \text{ m/s} \) at 10:05:00 a.m. on a certain date. (a) What is its velocity at 10:05:01 a.m.? (b) At 10:05:02 a.m.? (c) At 10:05:02.5 a.m.? (d) At 10:05:04 a.m.? (e) At 10:04:59 a.m.? (f) Describe the shape of a graph of velocity versus time for this parcel of air. (g) Argue for or against the statement, “Knowing the single value of an object’s constant acceleration is like knowing a whole list of values for its velocity.”

20. A truck covers 40.0 m in 8.50 s while smoothly slowing down to a final speed of 2.80 m/s. (a) Find its original speed. (b) Find its acceleration.

21. An object moving with uniform acceleration has a velocity of 12.0 cm/s in the positive \( x \) direction when its \( x \) coordinate is 3.00 cm. If its \( x \) coordinate 2.00 s later is \(-5.00 \) cm, what is its acceleration?
22. Figure P2.22 represents part of the performance data of a car owned by a proud physics student. (a) Calculate the total distance traveled by computing the area under the graph line. (b) What distance does the car travel between the times $t = 10\, \text{s}$ and $t = 40\, \text{s}$? (c) Draw a graph of its acceleration versus time between $t = 0$ and $t = 50\, \text{s}$. (d) Write an equation for acceleration versus time for each phase of the motion, represented by (i) $0a$, (ii) $ab$, and (iii) $bc$. (c) What is the average velocity of the car between $t = 0$ and $t = 50\, \text{s}$?

![Figure P2.22](image)

23. A jet plane comes in for a landing with a speed of 100 m/s, and its acceleration can have a maximum magnitude of 5.00 m/s$^2$ as it comes to rest. (a) From the instant the plane touches the runway, what is the minimum time interval needed before it can come to rest? (b) Can this plane land on a small tropical island airport where the runway is 0.800 km long? Explain your answer.

24. At $t = 0$, one toy car is set rolling on a straight track with initial position $15.0\, \text{cm}$, initial velocity $-3.50\, \text{cm/s}$, and constant acceleration $2.40\, \text{cm/s}^2$. At the same moment, another toy car is set rolling on an adjacent track with initial position $10.0\, \text{cm}$, an initial velocity of $+5.50\, \text{cm/s}$, and constant acceleration zero. (a) At what time, if any, do the two cars have equal speeds? (b) What are their speeds at that time? (c) At what time(s), if any, do the cars pass each other? (d) What are their locations at that time? (e) Explain the difference between question (a) and question (c) as clearly as possible. Write (or draw) a target audience of students who do not immediately understand the conditions are different.

25. The driver of a car slams on the brakes when he sees a tree blocking the road. The car slows uniformly with an acceleration of $-5.60\, \text{m/s}^2$ for 4.20 s, making straight skid marks 62.4 m long ending at the tree. With what speed does the car then strike the tree?

26. Help! One of our equations is missing! We describe constant-acceleration motion with the variables and parameters $v_{op}$, $v_o$, $a$, $t$, and $x_f - x_i$. Of the equations in Table 2.2, the first does not involve $x_f - x_i$, the second does not contain $a_3$, the third omits $v_{op}$ and the last leaves out $t$. So, to complete the set there should be an equation not involving $v_{op}$. Derive it from the others. Use it to solve Problem 25 in one step.

27. For many years Colonel John P. Stapp, USAF, held the world’s land speed record. He participated in studying whether a jet pilot could survive emergency ejection. On March 19, 1954, he rode a rocket-propelled sled that moved down a track at a speed of 632 mi/h. He and the sled were safely brought to rest in 1.40 s (Fig. P2.27). Determine (a) the negative acceleration he experienced and (b) the distance he traveled during this negative acceleration.

![Figure P2.27](image)

28. A particle moves along the $x$ axis. Its position is given by the equation $x = 2 + 3t - 4t^2$, with $x$ in meters and $t$ in seconds. Determine (a) its position when it changes direction and (b) its velocity when it returns to the position it had at $t = 0$.

29. An electron in a cathode-ray tube accelerates from a speed of $2.00 \times 10^4\, \text{m/s}$ to $6.00 \times 10^4\, \text{m/s}$ over 1.50 cm. (a) In what time interval does the electron travel this 1.50 cm? (b) What is its acceleration?

30. Within a complex machine such as a robotic assembly line, suppose one particular part glides along a straight track. A control system measures the average velocity of the part during each successive time interval $\Delta t_0 = t_0 - 0$, compares it with the value $v_f$ it should be, and switches a servo motor on and off to give the part a correcting pulse of acceleration. The pulse consists of a constant acceleration $a_p$ applied for time interval $\Delta t_m = t_m - 0$ within the next control time interval $\Delta t_0$. As shown in Figure P2.30, the part may be modeled as having zero acceleration when the motor is off (between $t_0$ and $t_m$). A computer in the control system chooses the size of the acceleration so that the final velocity of the part will have the correct value $v_f$. Assume the part is initially at rest and is to have instantaneous velocity $v_f$ at time $t_m$. (a) Find the required value of $a_p$ in terms of $v_f$ and $t_m$. (b) Show that the displacement $\Delta x$ of the part during the time interval $\Delta t_0$ is given by $\Delta x = v_f (t_0 - 0.5a_p)$. For specified values of $v_f$ and $t_m$, (c) what is the minimum displacement of the part? (d) What is the maximum displacement of the part? (e) Are both the minimum and maximum displacements physically attainable?

![Figure P2.30](image)

31. A glider on an air track carries a flag of length $\ell$ through a stationary photogate, which measures the time
interval \( \Delta t_g \) during which the flag blocks a beam of infrared light passing across the photogate. The ratio \( v_d = \ell / \Delta t_g \) is the average velocity of the glider over this part of its motion. Suppose the glider moves with constant acceleration. (a) Argue for or against the idea that \( v_d \) is equal to the instantaneous velocity of the glider when it is halfway through the photogate in space. (b) Argue for or against the idea that \( v_d \) is equal to the instantaneous velocity of the glider when it is halfway through the photogate in time.

32. ◆ Speedy Sue, driving at 50.0 m/s, enters a one-lane tunnel. She then observes a slow-moving van 155 m ahead traveling at 5.00 m/s. Sue applies her brakes but can accelerate only at \(-2.00 \text{ m/s}^2\) because the road is wet. Will there be a collision? State how you decide. If yes, determine how far into the tunnel and at what time the collision occurs. If no, determine the distance of closest approach between Sue’s car and the van.

33. ◆ Vroom, vroom! As soon as a traffic light turns green, a car speeds up from rest to 50.0 mi/h with constant acceleration 9.00 mi/h \cdot s. In the adjoining bike lane, a cyclist speeds up from rest to 20.0 mi/h with constant acceleration 13.0 mi/h \cdot s. Each vehicle maintains constant velocity after reaching its cruising speed. (a) For what time interval is the bicycle ahead of the car? (b) By what maximum distance does the bicycle lead the car?

34. Solve Example 2.8 (Watch Out for the Speed Limit!) by a graphical method. On the same graph plot position versus time for the car and the police officer. From the intersection of the two curves read the time at which the trooper overtakes the car.

35. ◆ A glider of length 12.4 cm moves on an air track with constant acceleration. A time interval of 0.628 s elapses between the moment when its front end passes a fixed point \( \text{a} \) along the track and the moment when its back end passes this point. Next, a time interval of 1.39 s elapses between the moment when the back end of the glider passes point \( \text{a} \) and the moment when the front end of the glider passes a second point \( \text{b} \) farther down the track. After that, an additional 0.431 s elapses until the back end of the glider passes point \( \text{b} \). (a) Find the average speed of the glider as it passes point \( \text{a} \). (b) Find the acceleration of the glider. (c) Explain how you can compute the acceleration without knowing the distance between points \( \text{a} \) and \( \text{b} \).

### Section 2.7 Freely Falling Objects

**Note:** In all problems in this section, ignore the effects of air resistance.

36. In a classic clip on *America’s Funniest Home Videos*, a sleeping cat rolls gently off the top of a warm TV set. Ignoring air resistance, calculate (a) the position and (b) the velocity of the cat after 0.100 s, 0.200 s, and 0.300 s.

37. ◆ Every morning at seven o’clock

   There’s twenty terriers drilling on the rock.
   The boss comes around and he says, “Keep still
   And bear down heavy on the cast-iron drill
   And drill, ye terriers, drill.” And drill, ye terriers, drill.
   It’s work all day for sugar in your tea
   Down beyond the railway. And drill, ye terriers, drill.

The foreman’s name was John McAnn.
By God, he was a blamed mean man.
One day a premature blast went off
And a mile in the air went big Jim Goff. And drill . . .
Then when next payday came around
Jim Goff a dollar short was found.
When he asked what for, came this reply:
“You were docked for the time you were up in the sky.”
And drill . . .

—American folksong

What was Goff’s hourly wage? State the assumptions you make in computing it.

38. A ball is thrown directly downward, with an initial speed of 8.00 m/s, from a height of 30.0 m. After what time interval does the ball strike the ground?

39. ◆ A student throws a set of keys vertically upward to her sorority sister, who is in a window 4.00 m above. The keys are caught 1.50 s later by the sister’s outstretched hand. (a) With what initial velocity were the keys thrown? (b) What was the velocity of the keys just before they were caught?

40. ◆ Emily challenges her friend David to catch a dollar bill as follows. She holds the bill vertically, as shown in Figure P2.40, with the center of the bill between David’s index finger and thumb. David must catch the bill after Emily releases it without moving his hand downward. If his reaction time is 0.2 s, will he succeed? Explain your reasoning.

41. A baseball is hit so that it travels straight upward after being struck by the bat. A fan observes that it takes 3.00 s for the ball to reach its maximum height. Find (a) the ball’s initial velocity and (b) the height it reaches.

42. ◆ An attacker at the base of a castle wall 3.65 m high throws a rock straight up with speed 7.40 m/s at a height of 1.55 m above the ground. (a) Will the rock reach the top of the wall? (b) If so, what is its speed at the top? If not, what initial speed must it have to reach the top? (c) Find the change in speed of a rock thrown straight down from the top of the wall at an initial speed of 7.40 m/s and moving between the same two points. (d) Does the change in speed of the downward-moving rock agree with the magnitude of the speed change of the rock moving upward between the same elevations? Explain physically why it does or does not agree.

43. ◆ A daring ranch hand sitting on a tree limb wishes to drop vertically onto a horse galloping under the tree. The constant speed of the horse is 10.0 m/s, and the distance

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2 = intermediate; 3 = challenging; □ = SSM/SG; ▲ = ThomsonNOW; ■ = symbolic reasoning; ◆ = qualitative reasoning
from the limb to the level of the saddle is 3.00 m. (a) What must the horizontal distance between the saddle and limb be when the ranch hand makes his move? (b) For what time interval is he in the air?

44. The height of a helicopter above the ground is given by \( h = 3.00t^2 \), where \( h \) is in meters and \( t \) is in seconds. After 2.00 s, the helicopter releases a small mailbag. How long after its release does the mailbag reach the ground?

45. A freely falling object requires 1.50 s to travel the last 30.0 m before it hits the ground. From what height above the ground did it fall?

Section 2.8 Kinematic Equations Derived from Calculus

46. A student drives a moped along a straight road as described by the velocity-versus-time graph in Figure P2.46. Sketch this graph in the middle of a sheet of graph paper. (a) Directly above your graph, sketch a graph of the position versus time, aligning the time coordinates of the two graphs. (b) Sketch a graph of the acceleration versus time directly below the \( v_x-t \) graph, again aligning the time coordinates. On each graph, show the numerical values of \( x \) and \( a_x \) for all points of inflection. (c) What is the acceleration at \( t = 6 \) s? (d) Find the position (relative to the starting point) at \( t = 6 \) s. (e) What is the moped’s final position at \( t = 9 \) s?

47. Automotive engineers refer to the time rate of change of acceleration as the “jerk.” Assume an object moves in one dimension such that its jerk \( J \) is constant. (a) Determine expressions for its acceleration \( a_x(t) \), velocity \( v_x(t) \), and position \( x(t) \), given that its initial acceleration, velocity, and position are \( a_{x0} \), \( v_{x0} \), and \( x_0 \), respectively. (b) Show that \( a_x^2 = a_{x0}^2 + 2J(v_x - v_{x0}) \).

48. The speed of a bullet as it travels down the barrel of a rifle toward the opening is given by \( v = (-5.00 \times 10^3)t^2 + (3.00 \times 10^4)t \), where \( v \) is in meters per second and \( t \) is in seconds. The acceleration of the bullet just as it leaves the barrel is zero. (a) Determine the acceleration and position of the bullet as a function of time when the bullet is in the barrel. (b) Determine the time interval over which the bullet is accelerated. (c) Find the speed at which the bullet leaves the barrel. (d) What is the length of the barrel?

Additional Problems

49. An object is at \( x = 0 \) at \( t = 0 \) and moves along the \( x \) axis according to the velocity–time graph in Figure P2.49. (a) What is the acceleration of the object between 0 and 4 s? (b) What is the acceleration of the object between 4 s and 9 s? (c) What is the acceleration of the object between 13 s and 18 s? (d) At what time(s) is the object moving with the lowest speed? (e) At what time is the object farthest from \( x = 0 \)? (f) What is the final position \( x \) of the object at \( t = 18 \) s? (g) Through what total distance has the object moved between \( t = 0 \) and \( t = 18 \) s?

50. The Acela (pronounced ah-SELL-ah and shown in Fig. P2.50a) is an electric train on the Washington–New York–Boston run, carrying passengers at 170 mi/h. The carriages tilt as much as 6° from the vertical to prevent passengers from feeling pushed to the side as they go around curves. A velocity-time graph for the Acela is shown in Figure P2.50b. (a) Describe the motion of the train in each successive time interval. (b) Find the peak positive acceleration of the train in the motion graphed. (c) Find the train’s displacement in miles between \( t = 0 \) and \( t = 200 \) s.

51. A test rocket is fired vertically upward from a well. A catapult gives it an initial speed of 80.0 m/s at ground level.
Its engines then fire and it accelerates upward at 4.00 m/s$^2$ until it reaches an altitude of 1000 m. At that point its engines fail and the rocket goes into free fall, with an acceleration of $-9.80$ m/s$^2$. (a) For what time interval is the rocket in motion above the ground? (b) What is its maximum altitude? (c) What is its velocity just before it collides with the Earth? (You will need to consider the motion while the engine is operating separate from the free-fall motion.)

52. In Active Figure 2.11b, the area under the velocity versus time curve and between the vertical axis and time $t$ (vertical dashed line) represents the displacement. As shown, this area consists of a rectangle and a triangle. Compute their areas and state how the sum of the two areas compares with the expression on the right-hand side of Equation 2.16.

53. Setting a world record in a 100-m race, Maggie and Judy cross the finish line in a dead heat, both taking 10.2 s. Accelerating uniformly, Maggie took 2.00 s and Judy took 3.00 s to attain maximum speed, which they maintained for the rest of the race. (a) What was the acceleration of each sprinter? (b) What were their respective maximum speeds? (c) Which sprinter was ahead at the 6.00-s mark, and by how much?

54. How long should a traffic light stay yellow? Assume you are driving at the speed limit $v_0$. As you approach an intersection 22.0 m wide, you see the light turn yellow. During your reaction time of 0.600 s, you travel at constant speed as you recognize the warning, decide whether to stop or to go through the intersection, and move your foot to the brake if you must stop. Your car has good brakes and can accelerate at $-2.40$ m/s$^2$. Before it turns red, the light should stay yellow long enough for you to be able to get to the other side of the intersection without speeding up, if you are too close to the intersection to stop before entering it. (a) Find the required time interval $\Delta t_1$ that the light should stay yellow in terms of $v_0$. Evaluate your answer for (b) $v_0 = 8.00$ m/s = 28.8 km/h, (c) $v_0 = 11.0$ m/s = 40.2 km/h, (d) $v_0 = 18.0$ m/s = 64.8 km/h, and (e) $v_0 = 25.0$ m/s = 90.0 km/h. What If? Evaluate your answer for (f) $v_0$ approaching zero, and (g) $v_0$ approaching infinity. (h) Describe the pattern of variation of $\Delta t_1$ with $v_0$. You may wish also to sketch a graph of it. Account for the answers to parts (f) and (g) physically. (i) For what value of $v_0$ would $\Delta t_1$ be minimal, and (j) what is this minimum time interval? Suggestion: You may find it easier to do part (a) after first doing part (b).

55. A commuter train travels between two downtown stations. Because the stations are only 1.00 km apart, the train never reaches its maximum possible cruising speed. During rush hour the engineer minimizes the time interval $\Delta t$ between two stations by accelerating for a time interval $\Delta t_1$ at a rate $a_1 = 0.100$ m/s$^2$ and then immediately braking with acceleration $a_2 = -0.500$ m/s$^2$ for a time interval $\Delta t_2$. Find the minimum time interval of travel $\Delta t$ and the time interval $\Delta t_1$.

56. A Ferrari F50 of length 4.52 m is moving north on a roadway that intersects another perpendicular roadway. The width of the intersection from near edge to far edge is 28.0 m. The Ferrari has a constant acceleration of magnitude 2.10 m/s$^2$ directed south. The time interval required for the nose of the Ferrari to move from the near (south) edge of the intersection to the north edge of the intersection is 3.10 s. (a) How far is the nose of the Ferrari from the south edge of the intersection when it stops? (b) For what time interval is any part of the Ferrari within the boundaries of the intersection? (c) A Corvette is at rest on the perpendicular intersecting roadway. As the nose of the Ferrari enters the intersection, the Corvette starts from rest and accelerates east at 5.60 m/s$^2$. What is the minimum distance from the near (west) edge of the intersection at which the nose of the Corvette can begin its motion if the Corvette is to enter the intersection after the Ferrari has entirely left the intersection? (d) If the Corvette begins its motion at the position given by your answer to part (c), with what speed does it enter the intersection?

57. Kathy Kool buys a sports car that can accelerate at the rate of 4.90 m/s$^2$. She decides to test the car by racing with another speedster, Stan Speedy. Both start from rest, but experienced Stan leaves the starting line 1.00 s before Kathy. Stan moves with a constant acceleration of 3.50 m/s$^2$ and Kathy maintains an acceleration of 4.90 m/s$^2$. Find (a) the time at which Kathy overtakes Stan, (b) the distance she travels before she catches him, and (c) the speeds of both cars at the instant she overtakes him.

58. A hard rubber ball, released at chest height, falls to the pavement and bounces back to nearly the same height. When it is in contact with the pavement, the lower side of the ball is temporarily flattened. Suppose the maximum depth of the dent is on the order of 1 cm. Compute an order-of-magnitude estimate for the maximum acceleration of the ball while it is in contact with the pavement. State your assumptions, the quantities you estimate, and the values you estimate for them.

59. An inquisitive physics student and mountain climber climbs a 50.0-m cliff that overhangs a calm pool of water. He throws two stones vertically downward, 1.00 s apart, and observes that they cause a single splash. The first stone has an initial speed of 2.00 m/s. (a) How long after release of the first stone do the two stones hit the water? (b) What initial velocity must the second stone have if they are to hit simultaneously? (c) What is the speed of each stone at the instant the two hit the water?

60. A rock is dropped from rest into a well. (a) The sound of the splash is heard 2.40 s after the rock is released from rest. How far below the top of the well is the surface of the water? The speed of sound in air (at the ambient temperature) is 336 m/s. (b) What If? If the sound travel time for the sound is ignored, what percentage error is introduced when the depth of the well is calculated?

61. In a California driver’s handbook, the following data were given about the minimum distance a typical car travels in stopping from various original speeds. The “thinking distance” represents how far the car travels during the driver’s reaction time, after a reason to stop can be seen but before the driver can apply the brakes. The “braking distance” is the displacement of the car after the brakes are applied. (a) Is the thinking-distance data
consistent with the assumption that the car travels with constant speed? Explain. (b) Determine the best value of the reaction time suggested by the data. (c) Is the braking-distance data consistent with the assumption that the car travels with constant acceleration? Explain. (d) Determine the best value for the acceleration suggested by the data.

<table>
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<tr>
<th>Speed (mi/h)</th>
<th>Thinking Distance (ft)</th>
<th>Braking Distance (ft)</th>
<th>Total Stopping Distance (ft)</th>
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<tr>
<td>65</td>
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<td>302</td>
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62. Astronauts on a distant planet toss a rock into the air. With the aid of a camera that takes pictures at a steady rate, they record the height of the rock as a function of time as given in the table in the next column. (a) Find the average velocity of the rock in the time interval between each measurement and the next. (b) Using these average velocities to approximate instantaneous velocities at the midpoints of the time intervals, make a graph of velocity as a function of time. Does the rock move with constant acceleration? If so, plot a straight line of best fit on the graph and calculate its slope to find the acceleration.

Answers to Quick Quizzes

2.1 (c). If the particle moves along a line without changing direction, the displacement and distance traveled over any time interval will be the same. As a result, the magnitude of the average velocity and the average speed will be the same. If the particle reverses direction, however, the displacement will be less than the distance traveled. In turn, the magnitude of the average velocity will be smaller than the average speed.

2.2 (b). Regardless of your speeds at all other times, if your instantaneous speed at the instant it is measured is higher than the speed limit, you may receive a speeding ticket.

2.3 (b). If the car is slowing down, a force must be pulling in the direction opposite to its velocity.

2.4 False. Your graph should look something like the following.

This \( v_x-t \) graph shows that the maximum speed is about 5.0 m/s, which is 18 km/h (= 11 mi/h), so the driver was not speeding.

2.5 (c). If a particle with constant acceleration stops and its acceleration remains constant, it must begin to move again in the opposite direction. If it did not, the acceleration would change from its original constant value to zero. Choice (a) is not correct because the direction of acceleration is not specified by the direction of the velocity. Choice (b) is also not correct by counterexample; a car moving in the \(-x\) direction and slowing down has a positive acceleration.

2.6 Graph (a) has a constant slope, indicating a constant acceleration; it is represented by graph (e).

Graph (b) represents a speed that is increasing constantly but not at a uniform rate. Therefore, the acceleration must be increasing, and the graph that best indicates that is (d).

Graph (c) depicts a velocity that first increases at a constant rate, indicating constant acceleration. Then the velocity stops increasing and becomes constant, indicating zero acceleration. The best match to this situation is graph (f).

2.7 (i), (e). For the entire time interval that the ball is in free fall, the acceleration is that due to gravity. (ii), (d). While the ball is rising, it is slowing down. After reaching the highest point, the ball begins to fall and its speed increases.

2 = intermediate; 3 = challenging; ■ = SSM/SG; ▲ = ThomsonNOW; □ = symbolic reasoning; ● = qualitative reasoning