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?

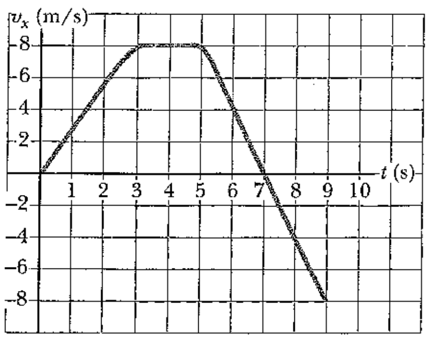


FIGURE P2.14

15. Figure P2 15 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

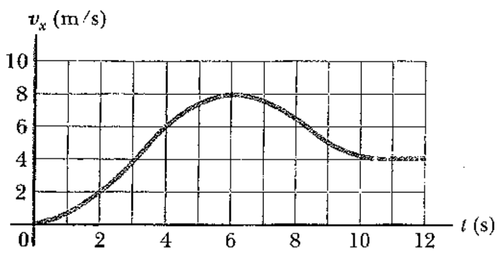


FIGURE P2.15

Section 2 5 ■ Motion Diagrams

16. 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

17. 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

18. The minimum distance required to stop a car moving at 35 0 mi/h is 40 0 ft. What is the minimum stopping distance for the same car moving at 70 0 mi/h, assuming the same rate of acceleration?

19. PhysicsNow™ 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?

20. A speedboat moving at 30 0 m/s approaches a no-wake buoy marker 100 m ahead The pilot slows the boat with a constant acceleration of -3.50 m/s^2 by reducing the throttle (a) How long does it take the boat to reach the buoy? (b) What is the velocity of the boat when it reaches the buoy?

21. A jet plane comes in for a landing with a speed of 100 m/s and can accelerate at a maximum rate 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 at a small tropical island airport where the runway is 0 800 km long?

22 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 $t = 0$

23. 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 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?

24. *Help! One of our equations is missing!* We describe constant-acceleration motion with the variables and parameters v_{xi}, v_{xf}, a_x, 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_x, the third omits v_{xf}, and the last leaves out t. So, to complete the set there should be an equation *not* involving v_{xi}. Derive it from the others. Use it to solve Problem 2.23 in one step.

25. A truck on a straight road starts from rest, accelerating at 2.00 m/s^2 until it reaches a speed of 20 0 m/s Then the truck travels for 20.0 s at constant speed until the brakes are applied, stopping the truck in a uniform manner in an additional 5 00 s (a) How long is the truck in motion? (b) What is the average velocity of the truck for the motion described?

26. An electron in a cathode-ray tube accelerates uniformly from 2 00 × 10^4 m/s to 6.00 × 10^6 m/s over 1.50 cm (a) In what time interval does the electron travel this 1.50 cm? (b) What is its acceleration?

27. Speedy Sue, driving at 30.0 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 m/s^2 because the road is wet Will there be a collision? 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

4. Can the instantaneous velocity of an object at an instant of time ever be greater in magnitude than the average velocity over a time interval containing the instant? Can it ever be less?

5. If an object's average velocity is nonzero over some time interval, does that mean that its instantaneous velocity is never zero during the interval? Explain your answer

6. An object's average velocity is zero over some time interval Show that its instantaneous velocity must be zero at some time during the interval It may be useful in your proof to sketch a graph of x versus t and to note that $v_x(t)$ is a continuous function

7. If the velocity of a particle is nonzero, can its acceleration be zero? Explain

8. If the velocity of a particle is zero, can its acceleration be nonzero? Explain

9. 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

10. Is it possible for the velocity and the acceleration of an object to have opposite signs? If not, state a proof. If so, give an example of such a situation and sketch a velocity–time graph to prove your point

11. Consider the following combinations of signs and values for velocity and acceleration of a particle with respect to a one-dimensional x axis:

Velocity	Acceleration
a Positive	Positive
b. Positive	Negative
c Positive	Zero
d Negative	Positive
e. Negative	Negative
f. Negative	Zero
g. Zero	Positive
h Zero	Negative

Describe what a particle is doing in each case and give a real-life example for an automobile on an east–west one-dimensional axis, with east considered the positive direction.

12. Can the kinematic equations (Eqs. 2.9 through 2.13) be used in a situation where the acceleration varies in time? Can they be used when the acceleration is zero?

13. A child throws a marble into the air with an initial speed v_i. Another child drops a ball at the same instant Compare the accelerations of the two objects while they are in flight.

14. An object falls freely from height h It is released at time zero and strikes the ground at time t (a) When the object is at height $0.5h$, is the time earlier than $0.5t$, equal to $0.5t$, or later than $0.5t$? (b) When the time is $0.5t$, is the height of the object greater than $0.5h$, equal to $0.5h$, or less than $0.5h$? Give reasons for your answers

15. 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. How do the final velocities of the balls compare when they reach the ground?

16. You drop a ball from a window on an upper floor of a building It strikes the ground with speed v You now repeat the drop, but you have a friend down on the street who throws another ball upward at speed v. Your friend throws the ball upward at precisely the same time that you drop yours from the window. At some location, the balls pass each other Is this location *at* the halfway point between window and ground, *above* this point, or *below* this point?

PROBLEMS

1, 2, 3 = straightforward, intermediate, challenging
☐ = full solution available in the *Student Solutions Manual and Study Guide*
Physics Now™ = coached problem with hints available at www.pop4e.com
= computer useful in solving problem
= paired numerical and symbolic problems
= biomedical application

Section 2.1 Average Velocity

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

t (s)	0	1.0	2.0	3.0	4.0	5.0
x (m)	0	2.3	9.2	20.7	36.8	57.5

2. 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.

3. The position versus time for a certain particle moving along the x axis is shown in Figure P2.3 Find the average velocity in the time intervals (a) 0 to 2 s, (b) 0 to 4 s, (c) 2 s to 4 s, (d) 4 s to 7 s, and (e) 0 to 8 s.

4. 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?

Section 2.2 Instantaneous Velocity

5. **Physics Now™** A position–time graph for a particle moving along the x axis is shown in Figure P2.5. (a) Find

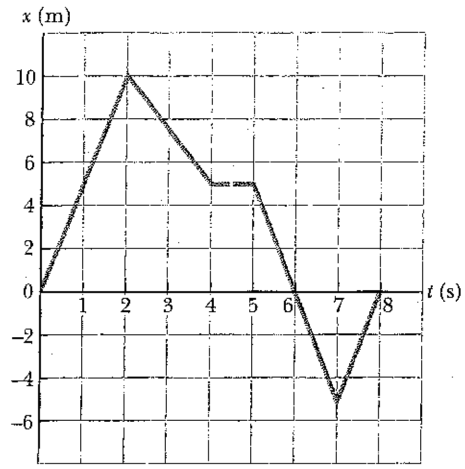


FIGURE P2.3 Problems 2.3 and 2.8.

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?

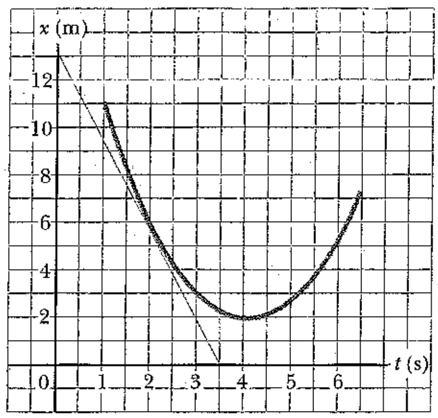


FIGURE P2.5

6. The position of a particle moving along the x axis varies in time according to the expression $x = 3t^2$, where x is in meters and t is in seconds. Evaluate its position (a) at $t = 3.00$ s and (b) at 3.00 s + Δt. (c) Evaluate the limit of $\Delta x/\Delta t$ as Δt approaches zero to find the velocity at $t = 3.00$ s.

7. (a) Use the data in Problem 2.1 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 this information, 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 P2.3 at the following times: (a) $t = 1.0$ s, (b) $t = 3.0$ s, (c) $t = 4.5$ s, (d) $t = 7.5$ s.

Section 2.3 Analysis Models—The Particle Under Constant Velocity

9. A hare and a tortoise compete in a race over a course 1.00 km long. The tortoise 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 taunt 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 that, when moving, both animals move steadily at their respective maximum speeds.

Section 2.4 Acceleration

10. A 50.0-g superball 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.

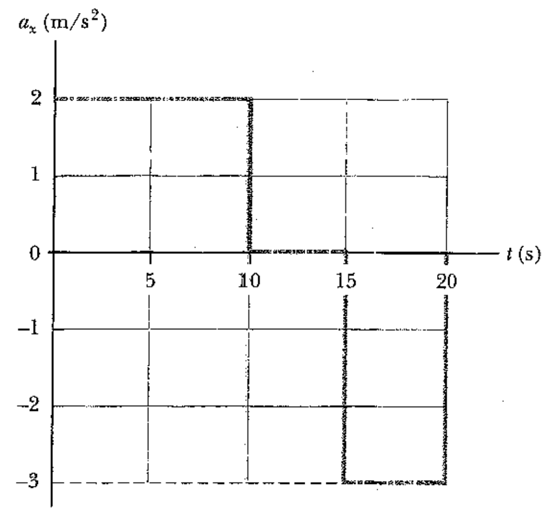


FIGURE P2.11

12. 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.

13. **PhysicsNow™** 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 student drives a moped along a straight road as described by the velocity versus time graph in Figure P2.14. Sketch this graph in the middle of a sheet of graph paper. (a) Directly above your graph, sketch a graph of the

Section 2.7 Freely Falling Objects

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

28. 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 the position and velocity of the cat after (a) 0.100 s, (b) 0.200 s, and (c) 0.300 s.

29. 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) its initial velocity and (b) the height it reaches.

30. *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.

31. **Physics Now™** 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?

32. 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?

33. **Physics Now™** 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 from the limb to the level of the saddle is 3.00 m. (a) What must be the horizontal distance between the saddle and limb when the ranch hand makes his move? (b) How long is he in the air?

34. It is possible to shoot an arrow at a speed as high as 100 m/s. (a) If friction can be ignored, how high would an arrow launched at this speed rise if shot straight up? (b) How long would the arrow be in the air?

Section 2.8 Context Connection—Acceleration Required by Consumers

35. (a) Show that the largest and smallest average accelerations in Table 2.3 are correctly computed from the measured time intervals required for the cars to speed up from 0 to 60 mi/h. (b) Convert both of these accelerations to the standard SI unit. (c) Modeling each acceleration as constant, find the distance traveled by both cars as they speed up. (d) If an automobile were able to maintain an acceleration of magnitude $a = g = 9.80\ \text{m/s}^2$ on a horizontal roadway, what time interval would be required to accelerate from zero to 60.0 mi/h?

36. A certain automobile manufacturer claims that its deluxe sports car will accelerate from rest to a speed of 42.0 m/s in 8.00 s. (a) Determine the average acceleration of the car. (b) Assume that the car moves with constant acceleration. Find the distance the car travels in the first 8.00 s. (c) What is the speed of the car 10.0 s after it begins its motion if it can continue to move with the same acceleration?

37. A steam catapult launches a jet aircraft from the aircraft carrier *John C. Stennis*, giving it a speed of 175 mi/h in 2.50 s. (a) Find the average acceleration of the plane. (b) Modeling the acceleration as constant, find the distance the plane moves in this time interval.

38. *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 · s. In the adjoining bike lane, a cyclist speeds up from rest to 20.0 mi/h with constant acceleration 13.0 mi/h · 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?

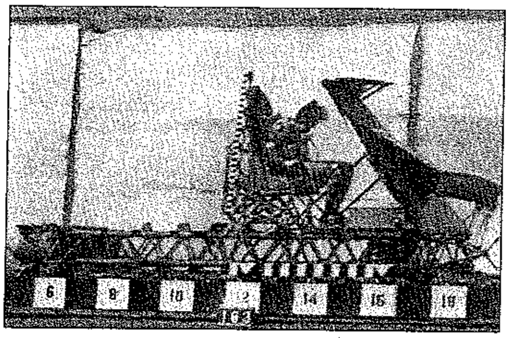
Additional Problems

Note. The human body can undergo brief accelerations up to 15 times the free-fall acceleration without injury or with only strained ligaments. Acceleration of long duration can do damage by preventing circulation of blood. Acceleration of larger magnitude can cause severe internal injuries, such as by tearing the aorta away from the heart. Problems 2.35, 2.37, and 2.39 through 2.41 deal with variously large accelerations of the human body that you can compare with the 15*g* datum.

39. 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 632 mi/h. He and the sled were safely brought to rest in 1.40 s (Fig. P2.39). Determine (a) the negative acceleration he experienced and (b) the distance he traveled during this negative acceleration, assumed to be constant.

40. A woman is reported to have fallen 144 ft from the 17th floor of a building, landing on a metal ventilator box that she crushed to a depth of 18.0 in. She suffered only minor injuries. Ignoring air resistance, calculate (a) the speed of the woman just before she collided with the ventilator and (b) her average acceleration while in contact with the box. (c) Modeling her acceleration as constant, calculate the time interval it took to crush the box.

41. Jules Verne in 1865 suggested sending people to the Moon by firing a space capsule from a 220-m-long cannon with a final velocity of 10.97 km/s. What would have been



(Courtesy of the U.S. Air Force)

(Photri, Inc.)

FIGURE P2.39 (*Left*) Col. John Stapp on the rocket sled. (*Right*) Col. Stapp's face is contorted by the stress of rapid negative acceleration.

the unrealistically large acceleration experienced by the space travelers during launch? Compare your answer with the free-fall acceleration 9.80 m/s^2.

42. **Review problem.** The biggest stuffed animal in the world is a snake 420 m long constructed by Norwegian children. Suppose the snake is laid out in a park as shown in Figure P2.42, forming two straight sides of a 105° angle, with one side 240 m long. Olaf and Inge run a race they invent. Inge runs directly from the tail of the snake to its head and Olaf starts from the same place at the same time but runs along the snake. If both children run steadily at 12.0 km/h, Inge reaches the head of the snake how much earlier than Olaf?

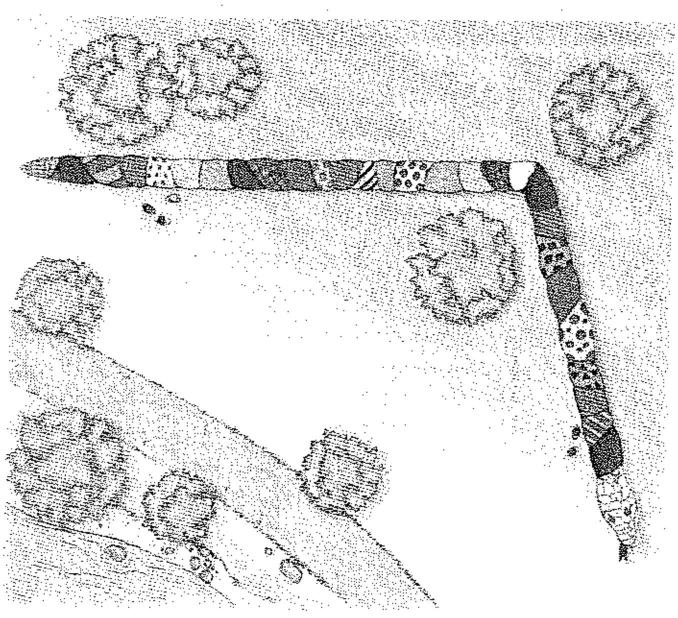


FIGURE P2.42

43. A ball starts from rest and accelerates at 0.500 m/s^2 while moving down an inclined plane 9.00 m long. When it reaches the bottom, the ball rolls up another plane, where it comes to rest after moving 15.0 m on that plane. (a) What is the speed of the ball at the bottom of the first plane? (b) During what time interval does the ball roll down the first plane? (c) What is the acceleration along the second plane? (d) What is the ball's speed 8.00 m along the second plane?

44. A glider on an air track carries a flag of length ℓ through a stationary photogate, which measures the time interval Δt_d during which the flag blocks a beam of infrared light passing across the photogate. The ratio $v_d = \ell/\Delta t_d$ is the average velocity of the glider over this part of its motion. Assume that 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.

45. Liz rushes down onto a subway platform to find her train already departing. She stops and watches the cars go by. Each car is 8.60 m long. The first moves past her in 1.50 s and the second in 1.10 s. Find the constant acceleration of the train.

46. The Acela is the Porsche of American trains. Shown in Figure P2.46a, the electric train whose name is pronounced ah-SELL-ah is in service on the Washington–New York–Boston run. With two power cars and six coaches, it can carry 304 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. Its braking mechanism uses electric generators to recover its energy of motion. A velocity–time graph for the Acela is shown in Figure P2.46b. (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.

47. A test rocket is fired vertically upward from a well. A catapult gives it initial speed 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 1 000 m. At that point its engines fail and the rocket goes into free-fall, with an acceleration of -9.80 m/s^2. (a) How long 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 separately from the free-fall motion.)

48. A motorist drives along a straight road at a constant speed of 15.0 m/s. Just as she passes a parked motorcycle police officer, the officer starts to accelerate at 2.00 m/s^2 to overtake her. Assuming that the officer maintains this acceleration, (a) determine the time interval required for the

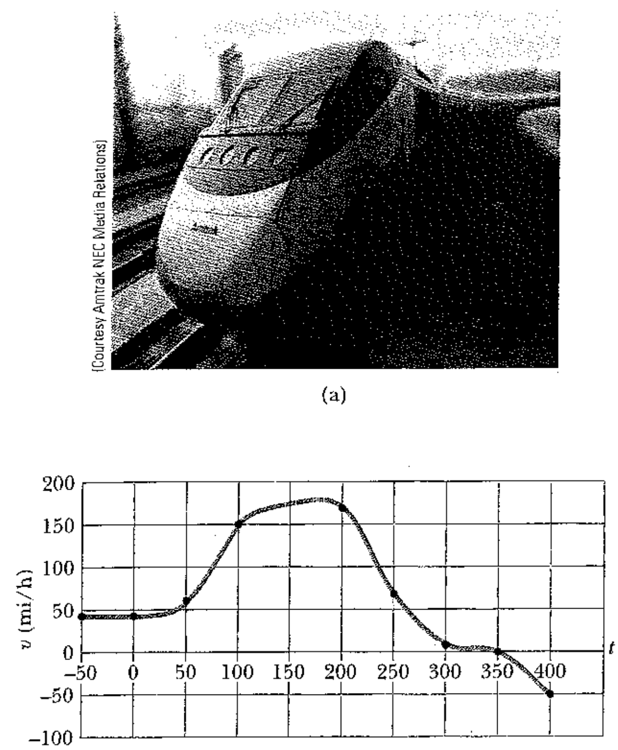


FIGURE **P2.46** (a) The Acela, 1 171 000 lb of cold steel thundering along at 150 mi/h (b) Velocity versus time graph for the Acela

police officer to reach the motorist Find (b) the speed and (c) the total displacement of the officer as he overtakes the motorist

49. 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 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?

50. 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 Δt between two stations by accelerating at a rate $a_1 = 0\ 100\ \text{m/s}^2$ for a time interval Δt_1 and then immediately braking with acceleration $a_2 = -0\ 500\ \text{m/s}^2$ for a time interval Δt_2. Find the minimum time interval of travel Δt and the time interval Δt_1.

51. 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 the two stones are to hit simultaneously? (c) What is the speed of each stone at the instant the two hit the water?

52. 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.

53. To protect his food from hungry bears, a Boy Scout raises his food pack with a rope that is thrown over a tree limb at height h above his hands. He walks away from the vertical rope with constant velocity v_{boy}, holding the free end of the rope in his hands (Fig P2 53). (a) Show that the speed v of the food pack is given by $x(x^2 + h^2)^{-1/2}\, v_{\text{boy}}$ where x is the distance he has walked away from the vertical rope. (b) Show that the acceleration a of the food pack is $h^2(x^2 + h^2)^{-3/2} v_{\text{boy}}^2$ (c) What values do the acceleration and velocity v have shortly after the boy leaves the point under the pack ($x = 0$)? (d) What values do the pack s velocity and acceleration approach as the distance x continues to increase?

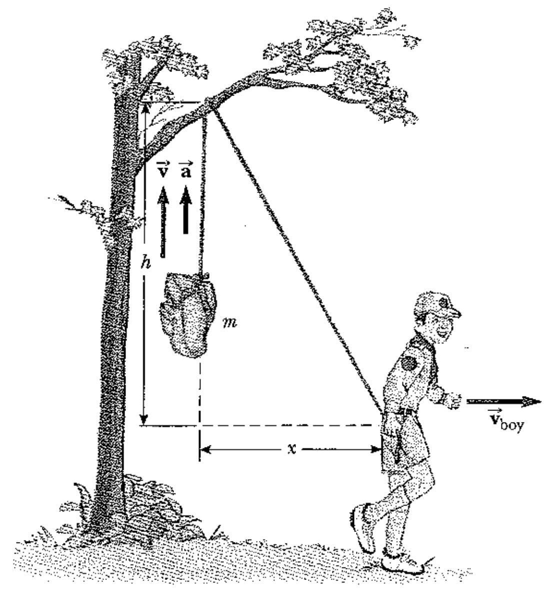


FIGURE **P2.53** Problems 2 53 and 2 54

54. In Problem 2 53, let the height h equal 6 00 m and the speed v_{boy} equal 2 00 m/s Assume that the food pack starts from rest (a) Tabulate and graph the speed–time graph (b) Tabulate and graph the acceleration–time graph Let the range of time be from 0 s to 5 00 s and the time intervals be 0 500 s

55. 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) If the travel time for the sound is ignored, what percentage error is introduced when the depth of the well is calculated?

PROBLEMS

1, 2, 3 = straightforward, intermediate, challenging
□ = full solution available in the *Student Solutions Manual and Study Guide*
PhysicsNow™ = coached problem with hints available at www.pop4e.com
= computer useful in solving problem
= paired numerical and symbolic problems
= biomedical application

Section 3.1 ▪ The Position, Velocity, and Acceleration Vectors

1. **PhysicsNow**™ A motorist drives south at 20.0 m/s for 3.00 min, then turns west and travels at 25.0 m/s for 2.00 min, and finally travels northwest at 30.0 m/s for 1.00 min. For this 6.00-min trip, find (a) the total vector displacement, (b) the average speed, and (c) the average velocity. Let the positive *x* axis point east.

2. Suppose the position vector for a particle is given as a function of time by $\vec{\mathbf{r}}(t) = x(t)\hat{\mathbf{i}} + y(t)\hat{\mathbf{j}}$, with $x(t) = at + b$ and $y(t) = ct^2 + d$, where $a = 1.00$ m/s, $b = 1.00$ m, $c = 0.125$ m/s^2, and $d = 1.00$ m. (a) Calculate the average velocity during the time interval from $t = 2.00$ s to $t = 4.00$ s. (b) Determine the velocity and the speed at $t = 2.00$ s.

Section 3.2 ▪ Two-Dimensional Motion with Constant Acceleration

3. A fish swimming in a horizontal plane has velocity $\vec{\mathbf{v}}_i = (4.00\hat{\mathbf{i}} + 1.00\hat{\mathbf{j}})$ m/s at a point in the ocean where the position relative to a certain rock is $\vec{\mathbf{r}}_i = (10.0\hat{\mathbf{i}} - 4.00\hat{\mathbf{j}})$ m. After the fish swims with constant acceleration for 20.0 s, its velocity is $\vec{\mathbf{v}}_f = (20.0\hat{\mathbf{i}} - 5.00\hat{\mathbf{j}})$ m/s. (a) What are the components of the acceleration? (b) What is the direction of the acceleration with respect to unit vector $\hat{\mathbf{i}}$? (c) If the fish maintains constant acceleration, where is it at $t = 25.0$ s and in what direction is it moving?

4. At $t = 0$, a particle moving in the *xy* plane with constant acceleration has a velocity of $\vec{\mathbf{v}}_i = (3.00\hat{\mathbf{i}} - 2.00\hat{\mathbf{j}})$ m/s and is at the origin. At $t = 3.00$ s, the particle's velocity is $\vec{\mathbf{v}}_f = (9.00\hat{\mathbf{i}} + 7.00\hat{\mathbf{j}})$ m/s. Find (a) the acceleration of the particle and (b) its coordinates at any time *t*.

5. A particle initially located at the origin has an acceleration of $\vec{\mathbf{a}} = 3.00\hat{\mathbf{j}}$ m/s^2 and an initial velocity of $\vec{\mathbf{v}}_i = 5.00\hat{\mathbf{i}}$ m/s. Find (a) the vector position and velocity at any time *t* and (b) the coordinates and speed of the particle at $t = 2.00$ s.

6. It is not possible to see very small objects, such as viruses, using an ordinary light microscope. An electron microscope, however, can view such objects using an electron beam instead of a light beam. Electron microscopy has proved invaluable for investigations of viruses, cell membranes and subcellular structures, bacterial surfaces, visual receptors, chloroplasts, and the contractile properties of muscles. The "lenses" of an electron microscope consist of electric and magnetic fields that control the electron beam. As an example of the manipulation of an electron beam, consider an electron traveling away from the origin along the *x* axis in the *xy* plane with initial velocity $\vec{\mathbf{v}}_i = v_i\hat{\mathbf{i}}$. As it passes through the region $x = 0$ to $x = d$, the electron experiences acceleration $\vec{\mathbf{a}} = a_x\hat{\mathbf{i}} + a_y\hat{\mathbf{j}}$, where a_x and a_y are constants. Taking $v_i = 1.80 \times 10^7$ m/s, $a_x = 8.00 \times 10^{14}$ m/s^2, and $a_y = 1.60 \times 10^{15}$ m/s^2, determine at $x = d = 0.010\ 0$ m (a) the position of the electron, (b) the velocity of the electron, (c) the speed of the electron, and (d) the direction of travel of the electron (i.e., the angle between its velocity and the *x* axis).

Section 3.3 ▪ Projectile Motion

Note. Ignore air resistance in all problems and take $g = 9.80$ m/s^2 at the Earth's surface.

7. **PhysicsNow**™ In a local bar, a customer slides an empty beer mug down the counter for a refill. The bartender is just deciding to go home and rethink his life. He does not see the mug, which slides off the counter and strikes the floor 1.40 m from the base of the counter. If the height of the counter is 0.860 m, (a) with what velocity did the mug leave the counter and (b) what was the direction of the mug's velocity just before it hit the floor?

8. In a local bar, a customer slides an empty beer mug down the counter for a refill. The bartender is momentarily distracted and does not see the mug, which slides off the counter and strikes the floor at distance *d* from the base of the counter. The height of the counter is *h*. (a) With what velocity did the mug leave the counter? (b) What was the direction of the mug's velocity just before it hit the floor?

9. Mayan kings and many school sports teams are named for the puma, cougar, or mountain lion *Felis concolor*, the best jumper among animals. It can jump to a height of 12.0 ft when leaving the ground at an angle of 45.0°. With what speed, in SI units, does it leave the ground to make this leap?

10. An astronaut on a strange planet finds that she can jump a maximum horizontal distance of 15.0 m if her initial speed is 3.00 m/s. What is the free-fall acceleration on the planet?

11. A cannon with a muzzle speed of 1 000 m/s is used to start an avalanche on a mountain slope. The target is 2 000 m from the cannon horizontally and 800 m above the cannon. At what angle, above the horizontal, should the cannon be fired?

12. A ball is tossed from an upper-story window of a building. The ball is given an initial velocity of 8.00 m/s at an angle of 20.0° below the horizontal. It strikes the ground 3.00 s later. (a) How far horizontally from the base of the building does the ball strike the ground? (b) Find the height from which the ball was thrown. (c) How long does it take the ball to reach a point 10.0 m below the level of launching?

13. The speed of a projectile when it reaches its maximum height is one half its speed when it is at half its maximum

height. What is the initial projection angle of the projectile?

14. The small archerfish (length 20 to 25 cm) lives in brackish waters of Southeast Asia from India to the Philippines. This aptly named creature captures its prey by shooting a stream of water drops at an insect, either flying or at rest. The bug falls into the water and the fish gobbles it up. The archerfish has high accuracy at distances of 1 2 m to 1 5 m, and it sometimes makes hits at distances up to 3 5 m. A groove in the roof of its mouth, along with a curled tongue, forms a tube that enables the fish to impart high velocity to the water in its mouth when it suddenly closes its gill flaps. Suppose the archerfish shoots at a target that is 2 00 m away, measured along a line at an angle of 30 0° above the horizontal. With what velocity must the water stream be launched if it is not to drop more than 3 00 cm vertically on its path to the target?

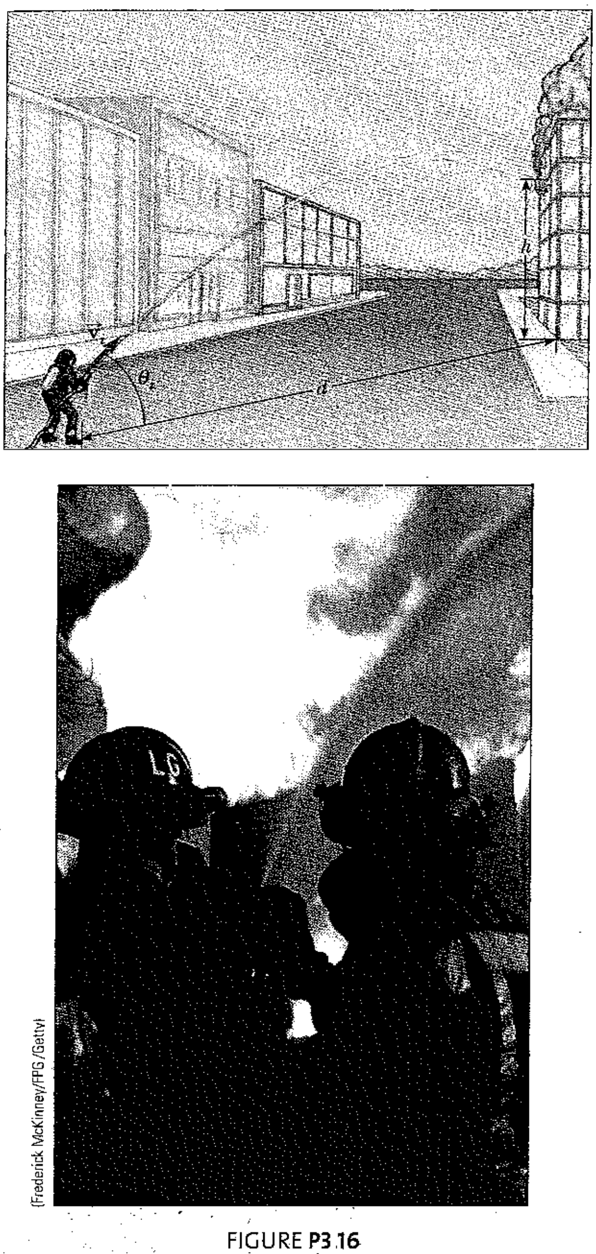

(Frederick McKinney/FPG/Getty)

FIGURE P3.16

15. PhysicsNow™ A placekicker must kick a football from a point 36 0 m (about 40 yards) from the goal, and half the crowd hopes the ball will clear the crossbar, which is 3 05 m high. When kicked, the ball leaves the ground with a speed of 20.0 m/s at an angle of 53 0° to the horizontal. (a) By how much does the ball clear or fall short of clearing the crossbar? (b) Does the ball approach the crossbar while still rising or while falling?

16. A firefighter a distance d from a burning building directs a stream of water from a fire hose at angle θ_i above the horizontal as shown in Figure P3 16. If the initial speed of the stream is v_i, at what height h does the water strike the building?

17. A playground is on the flat roof of a city school, 6.00 m above the street below. The vertical wall of the building is 7 00 m high, forming a 1 m-high railing around the playground. A ball has fallen to the street below, and a passerby returns it by launching it at an angle of 53.0° above the horizontal at a point 24 0 m from the base of the building wall. The ball takes 2 20 s to reach a point vertically above the wall. (a) Find the speed at which the ball was launched. (b) Find the vertical distance by which the ball clears the wall. (c) Find the distance from the wall to the point on the roof where the ball lands.

18. The motion of a human body through space can be precisely modeled as the motion of a particle at the body's center of mass, as we will study in Chapter 8. The components of the displacement of an athlete's center of mass from the beginning to the end of a certain jump are described by the two equations

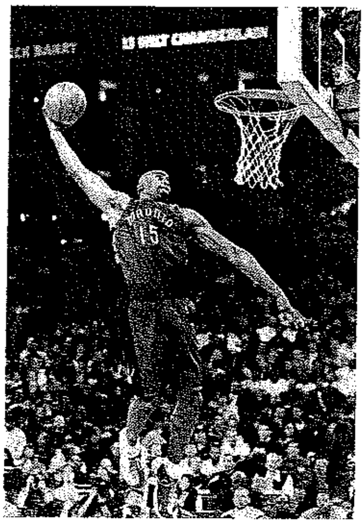
$$x_f = 0 + (11\ 2\ \text{m/s})(\cos 18\ 5°)t$$

$$0\ 360\ \text{m} = 0\ 840\ \text{m} + (11\ 2\ \text{m/s})(\sin 18.5°)t - \tfrac{1}{2}(9.80\ \text{m/s}^2)t^2$$

where t is the time at which the athlete lands after taking off at time $t = 0$. Identify (a) his position and (b) his vector velocity at the takeoff point. (c) The world long jump record is 8 95 m. How far did the athlete in this problem jump? (d) Make a sketch of the motion of his center of mass.

19. A soccer player kicks a rock horizontally off a 40 0-m-high cliff into a pool of water. If the player hears the sound of the splash 3.00 s later, what was the initial speed given to the rock? Assume that the speed of sound in air is 343 m/s.

20. A basketball star covers 2 80 m horizontally in a jump to dunk the ball (Fig. P3 20). His motion through space can be modeled precisely as that of a particle at his *center of mass*, which we will define in Chapter 8. His center of mass is at elevation 1 02 m when he leaves the floor. It reaches a maximum height of 1 85 m above the floor and is at elevation 0.900 m when he touches down again. Determine (a) his time of flight (his "hang time"), (b) his horizontal and (c) vertical velocity components at the instant of takeoff, and (d) his takeoff angle. (e) For comparison, determine the hang time of a whitetail deer making a jump with center of mass elevations $y_i = 1\ 20$ m, $y_{max} = 2\ 50$ m, and $y_f = 0\ 700$ m



(Top, Jed Jacobsohn/Getty Images; bottom, Bill Lee/Dembinsky Photo Associates)

FIGURE **P3.20**

21. A fireworks rocket explodes at height h, the peak of its vertical trajectory. It throws out burning fragments in all directions, but all at the same speed v. Pellets of solidified metal fall to the ground without air resistance. Find the smallest angle that the final velocity of an impacting fragment makes with the horizontal.

Section 3.4 The Particle in Uniform Circular Motion

22. From information on the endsheets of this book, compute the radial acceleration of a point on the surface of the Earth at the equator owing to the rotation of the Earth about its axis.

23. **Physics Now™** The athlete shown in Figure P3.23 rotates a 1.00-kg discus along a circular path of radius 1.06 m. The maximum speed of the discus is 20.0 m/s. Determine the magnitude of the maximum radial acceleration of the discus.

(Sam Sargent/Liaison International)

FIGURE **P3.23**

24. Casting of molten metal is important in many industrial processes. *Centrifugal casting* is used for manufacturing pipes, bearings, and many other structures. A variety of sophisticated techniques have been invented, but the basic idea is as illustrated in Figure P3.24. A cylindrical enclosure is rotated rapidly and steadily about a horizontal axis. Molten metal is poured into the rotating cylinder and then cooled, forming the finished product. Turning the cylinder at a high rotation rate forces the solidifying metal strongly to the outside. Any bubbles are displaced toward the axis, so unwanted voids will not be present in the casting. Sometimes it is desirable to form a composite casting, such as for a bearing. Here a strong steel outer surface is poured and then inside it a lining of special low-friction metal. In some applications, a very strong metal is given a coating of corrosion-resistant metal. Centrifugal casting results in strong bonding between the layers.

Suppose a copper sleeve of inner radius 2.10 cm and outer radius 2.20 cm is to be cast. To eliminate bubbles and give high structural integrity, the centripetal acceleration of each bit of metal should be at least 100g. What rate of rotation is required? State the answer in revolutions per minute.

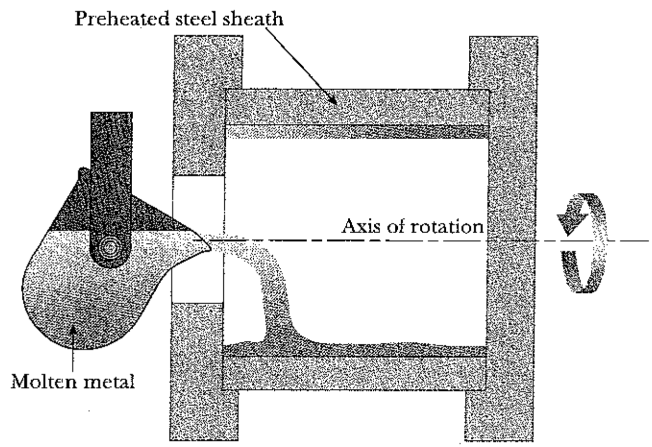


FIGURE **P3.24**

25. A tire 0.500 m in radius rotates at a constant rate of 200 rev/min. Find the speed and acceleration of a small stone lodged in the tread of the tire (on its outer edge).

26. As their booster rockets separate, Space Shuttle astronauts typically feel accelerations up to 3g, where $g = 9.80\text{ m/s}^2$. In their training, astronauts ride in a device where they experience such an acceleration as a centripetal acceleration. Specifically, the astronaut is fastened securely at the end of a mechanical arm, which then turns at constant speed in a horizontal circle. Determine the rotation rate, in revolutions per second, required to give an astronaut a centripetal acceleration of 3.00g while in circular motion with radius 9.45 m.

27. The astronaut orbiting the Earth in Figure P3.27 is preparing to dock with a Westar VI satellite. The satellite is in a circular orbit 600 km above the Earth's surface, where the free-fall acceleration is 8.21 m/s^2. Take the radius of the Earth as 6 400 km. Determine the speed of

the satellite and the time interval required to complete one orbit around the Earth, which is the period of the satellite

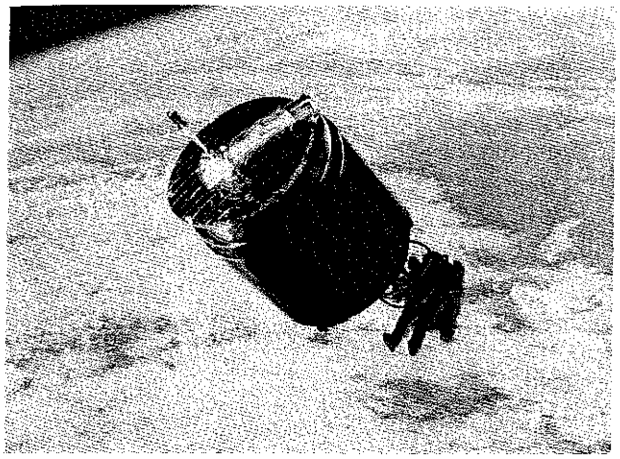


FIGURE P3.27

Section 3.5 Tangential and Radial Acceleration

28. A point on a rotating turntable 20.0 cm from the center accelerates from rest to a final speed of 0.700 m/s in 1.75 s. At $t = 1.25$ s, find the magnitude and direction of (a) the radial acceleration, (b) the tangential acceleration, and (c) the total acceleration of the point

29. A train slows down as it rounds a sharp horizontal turn, slowing from 90.0 km/h to 50.0 km/h in the 15.0 s that it takes to round the bend. The radius of the curve is 150 m. Compute the acceleration at the moment the train speed reaches 50.0 km/h. Assume that it continues to slow down at this time at the same rate.

30. A ball swings in a vertical circle at the end of a rope 1.50 m long. When the ball is 36.9° past the lowest point on its way up, its total acceleration is $(-22.5\hat{i} + 20.2\hat{j})$ m/s^2. At that instant, (a) sketch a vector diagram showing the components of its acceleration, (b) determine the magnitude of its radial acceleration, and (c) determine the speed and velocity of the ball

31. Figure P3.31 represents the total acceleration of a particle moving clockwise in a circle of radius 2.50 m at a certain instant of time. At this instant, find (a) the radial acceleration, (b) the speed of the particle, and (c) its tangential acceleration.

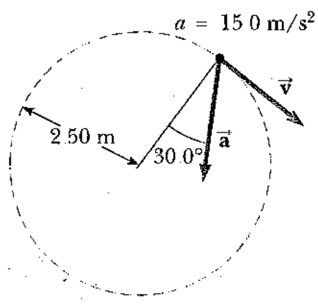


FIGURE P3.31

Section 3.6 Relative Velocity

32. How long does it take an automobile traveling in the left lane at 60.0 km/h to pull alongside a car traveling in the right lane at 40.0 km/h if the cars' front bumpers are initially 100 m apart?

33. A river has a steady speed of 0.500 m/s. A student swims upstream a distance of 1.00 km and swims back to the starting point. If the student can swim at a speed of 1.20 m/s in still water, how long does the trip take? Compare this answer with the time interval the trip would take if the water were still.

34. A car travels due east with a speed of 50.0 km/h. Raindrops are falling at constant speed vertically with respect to the Earth. The traces of the rain on the side windows of the car make an angle of 60.0° with the vertical. Find the velocity of the rain with respect to (a) the car and (b) the Earth.

35. The pilot of an airplane notes that the compass indicates a heading due west. The airplane's speed relative to the air is 150 km/h. The air is moving in a wind at 30.0 km/h toward the north. Find the velocity of the airplane relative to the ground

36. Two swimmers, Alan and Beth, start together at the same point on the bank of a wide stream that flows with a speed v. Both move at the same speed c ($c > v$) relative to the water. Alan swims downstream a distance L and then upstream the same distance. Beth swims so that her motion relative to the Earth is perpendicular to the banks of the stream. She swims the distance L and then back the same distance, so that both swimmers return to the starting point. Which swimmer returns first? (*Note*: First, guess the answer.)

37. A science student is riding on a flatcar of a train traveling along a straight horizontal track at a constant speed of 10.0 m/s. The student throws a ball into the air along a path that he judges to make an initial angle of 60.0° with the horizontal and to be in line with the track. The student's professor, who is standing on the ground nearby, observes the ball to rise vertically. How high does she see the ball rise?

38. A Coast Guard cutter detects an unidentified ship at a distance of 20.0 km in the direction 15.0° east of north. The ship is traveling at 26.0 km/h on a course at 40.0° east of north. The Coast Guard wishes to send a speedboat to intercept the vessel and investigate it. If the speedboat travels 50.0 km/h, in what direction should it head? Express the direction as a compass bearing with respect to due north.

Section 3.7 Context Connection—Lateral Acceleration of Automobiles

39. The cornering performance of an automobile is evaluated on a skid pad, where the maximum speed a car can maintain around a circular path on a dry, flat surface is measured. Then the magnitude of the centripetal acceleration, also called the lateral acceleration, is calculated as a multiple of the free-fall acceleration g. Along with the height and width of the car, factors affecting its performance are the tire characteristics and the suspension system. A Dodge Viper GTS-R can negotiate a skid pad of radius 156 m at 139 km/h. Calculate its maximum lateral acceleration from these data to verify the corresponding entry in Table 3.1.

40. A certain light truck can go around an unbanked curve having a radius of 150 m with a maximum speed of 32 0 m/s. With what maximum speed can it go around a curve having a radius of 75 0 m?

Additional Problems

41. *The "Vomit Comet"* In zero-gravity astronaut training and equipment testing, NASA flies a KC135A aircraft along a parabolic flight path. As shown in Figure P3 41, the aircraft climbs from 24 000 ft to 31 000 ft, where it enters the zero-*g* parabola with a velocity of 143 m/s at 45 0° nose high and exits with velocity 143 m/s at 45 0° nose low. During this portion of the flight, the aircraft and objects inside its padded cabin are in free-fall; they have gone ballistic. The aircraft then pulls out of the dive with an upward acceleration of 0 800*g*, moving in a vertical circle with radius 4 13 km. (During this portion of the flight, occupants of the plane perceive an acceleration of 1 800*g*.) What are the aircraft (a) speed and (b) altitude at the top of the maneuver? (c) What is the time interval spent in zero gravity? (d) What is the speed of the aircraft at the bottom of the flight path?

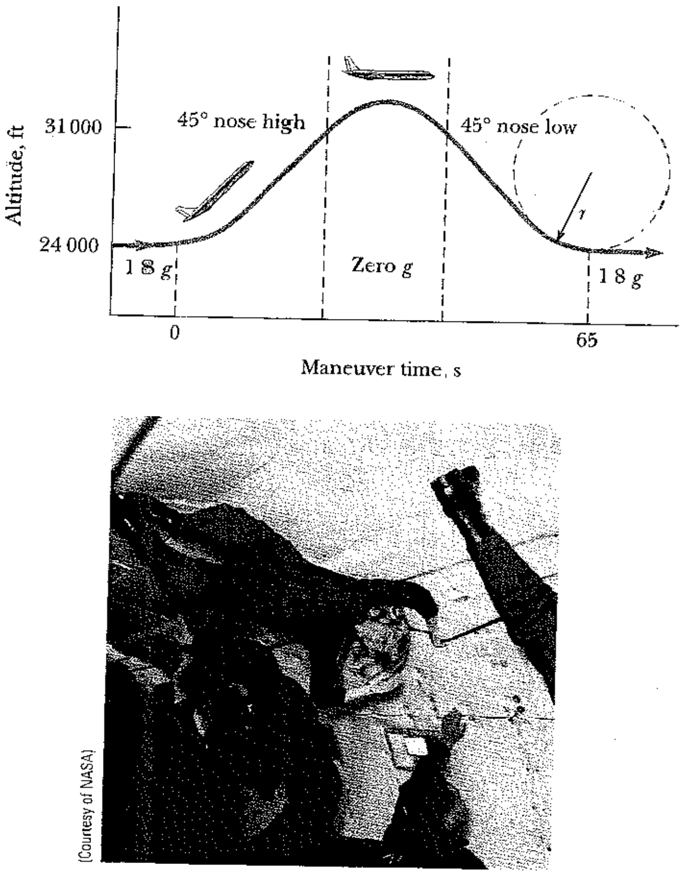


FIGURE P3.41

42. A landscape architect is planning an artificial waterfall in a city park. Water flowing at 1 70 m/s will leave the end of a horizontal channel at the top of a vertical wall 2 35 m high and from there fall into a pool. (a) Will there be a wide enough space for a walkway on which people can go behind the waterfall? (b) To sell her plan to the city council, the architect wants to build a model to standard scale, one-twelfth actual size. How fast should the water in the channel flow in the model?

43. A ball on the end of a string is whirled around in a horizontal circle of radius 0 300 m. The plane of the circle is 1 20 m above the ground. The string breaks and the ball lands 2 00 m (horizontally) away from the point on the ground directly beneath the ball's location when the string breaks. Find the radial acceleration of the ball during its circular motion.

44. A projectile is fired up an incline (incline angle ϕ) with an initial speed v_i at an angle θ_i with respect to the horizontal ($\theta_i > \phi$), as shown in Figure P3 44. (a) Show that the projectile travels a distance d up the incline, where

$$d = \frac{2v_i^2 \cos\theta_i \sin(\theta_i - \phi)}{g \cos^2\phi}$$

(b) For what value of θ_i is d a maximum, and what is that maximum value?

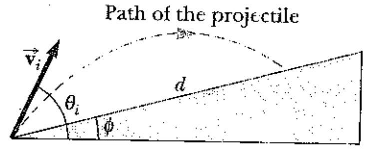


FIGURE P3.44

45. Barry Bonds hits a home run so that the baseball just clears the top row of bleachers, 21 0 m high, located 130 m from home plate. The ball is hit at an angle of 35 0° to the horizontal, and air resistance is negligible. Find (a) the initial speed of the ball, (b) the time interval that elapses before the ball reaches the top row, and (c) the velocity components and the speed of the ball when it passes over the top row. Assume that the ball is hit at a height of 1 00 m above the ground.

46. An astronaut on the surface of the Moon fires a cannon to launch an experiment package, which leaves the barrel moving horizontally. (a) What must be the muzzle speed of the probe so that it travels completely around the Moon and returns to its original location? (b) How long does this trip around the Moon take? Assume that the free-fall acceleration on the Moon is one sixth that on the Earth.

47. A basketball player who is 2 00 m tall is standing on the floor 10 0 m from the basket, as shown in Figure P3 47. If he shoots the ball at a 40 0° angle with the horizontal, at

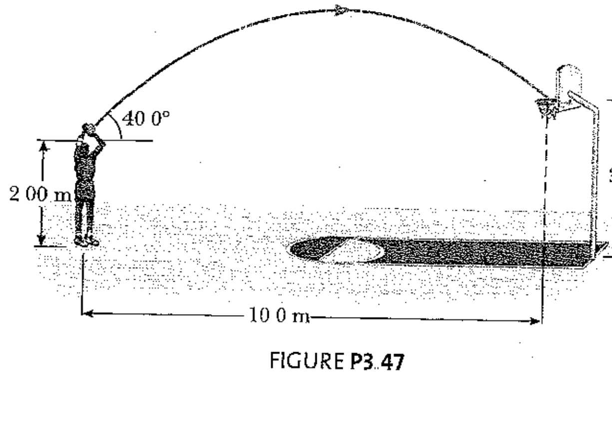


FIGURE P3.47

what initial speed must he throw so that it goes through the hoop without striking the backboard? The basket height is 3.05 m.

48. When baseball players throw the ball in from the outfield, they usually allow it to take one bounce before it reaches the infield, on the theory the ball arrives sooner that way. Suppose the angle at which a bounced ball leaves the ground is the same as the angle at which the outfielder threw it, as shown in Figure P3.48, but that the ball's speed after the bounce is one half what it was before the bounce. (a) Assume that the ball is always thrown with the same initial speed. At what angle θ should the fielder throw the ball to make it go the same distance D with one bounce (blue path) as a ball thrown upward at 45.0° with no bounce (green path)? (b) Determine the ratio of the time intervals required for the one-bounce and no-bounce throws.

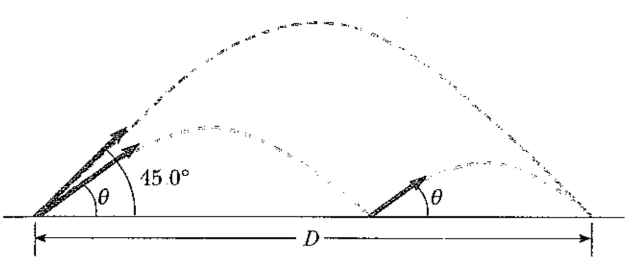


FIGURE P3.48

49. Your grandfather is copilot of a bomber, flying horizontally over level terrain, with a speed of 275 m/s relative to the ground at an altitude of 3 000 m. (a) The bombardier releases one bomb. How far will the bomb travel horizontally between its release and its impact on the ground? Ignore the effects of air resistance. (b) Firing from the people on the ground suddenly incapacitates the bombardier before he can call, 'Bombs away!' Consequently, the pilot maintains the plane's original course, altitude, and speed through a storm of flak. Where will the plane be when the bomb hits the ground? (c) The plane has a telescopic bomb sight set so that the bomb hits the target seen in the sight at the moment of release. At what angle from the vertical was the bomb sight set?

50. A person standing at the top of a hemispherical rock of radius R kicks a ball (initially at rest on the top of the rock) to give it horizontal velocity $\vec{v}_i$ as shown in Figure P3.50.

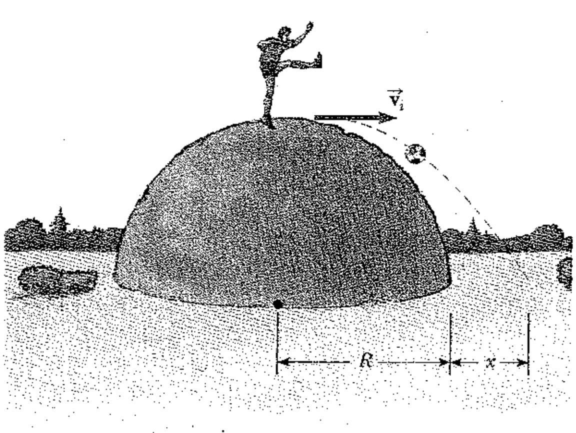


FIGURE P3.50

(a) What must be its minimum initial speed if the ball is never to hit the rock after it is kicked? (b) With this initial speed, how far from the base of the rock does the ball hit the ground?

51. **Physics Now™** A car is parked on a steep incline overlooking the ocean, where the incline makes an angle of 37.0° below the horizontal. The negligent driver leaves the car in neutral, and the parking brakes are defective. The car rolls from rest down the incline with a constant acceleration of 4.00 m/s^2, traveling 50.0 m to the edge of a vertical cliff. The cliff is 30.0 m above the ocean. Find (a) the speed of the car when it reaches the edge of the cliff and the time interval it takes to get there, (b) the velocity of the car when it lands in the ocean, (c) the total time interval during which the car is in motion, and (d) the position of the car when it lands in the ocean, relative to the base of the cliff.

52. A truck loaded with cannonball watermelons stops suddenly to avoid running over the edge of a washed-out bridge (Fig. P3.52). The quick stop causes a number of melons to fly off the truck. One melon rolls over the edge with an initial speed $v_i = 10.0$ m/s in the horizontal direction. A cross-section of the bank has the shape of the bottom half of a parabola with its vertex at the edge of the road and with the equation $y^2 = 16x$, where x and y are measured in meters. What are the x and y coordinates of the melon when it splatters on the bank?

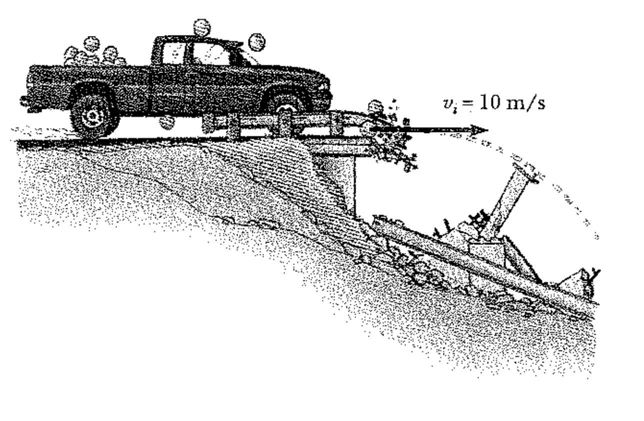


FIGURE P3.52

53. The determined coyote is out once more in pursuit of the elusive roadrunner. The coyote wears a pair of Acme jet-powered roller skates, which provide a constant horizontal acceleration of 15.0 m/s^2 (Fig. P3.53). The coyote starts at rest 70.0 m from the brink of a cliff at the instant the roadrunner zips past him in the direction of the cliff. (a) The roadrunner moves with constant speed. Determine the minimum speed he must have so as to reach the cliff before the coyote. At the edge of the cliff, the roadrunner escapes by making a sudden turn, while the coyote continues straight ahead. The coyote's skates remain horizontal and continue to operate while he is in flight so that his acceleration while in the air is $(15.0\hat{i} - 9.80\hat{j})$ m/s^2. (b) The cliff is 100 m above the flat floor of a wide canyon. Determine

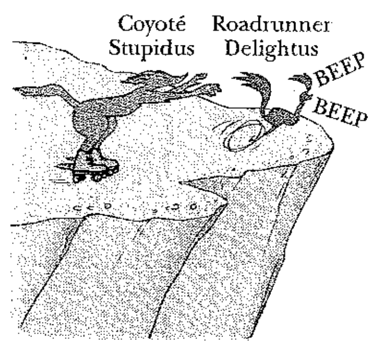


FIGURE P3.53

where the coyote lands in the canyon. (c) Determine the components of the coyote's impact velocity.

54. A ball is thrown with an initial speed v_i at an angle θ_i with the horizontal. The horizontal range of the ball is R, and the ball reaches a maximum height $R/6$. In terms of R and g, find (a) the time interval during which the ball is in motion, (b) the ball's speed at the peak of its path, (c) the initial vertical component of its velocity, (d) its initial speed, and (e) the angle θ_i. (f) Suppose the ball is thrown at the same initial speed found in (d) but at the angle appropriate for reaching the greatest height that it can. Find this height. (g) Suppose the ball is thrown at the same initial speed but at the angle for greatest possible range. Find this maximum horizontal range.

55. A catapult launches a rocket at an angle of 53.0° above the horizontal with an initial speed of 100 m/s. The rocket engine immediately starts a burn, and for 3.00 s the rocket moves along its initial line of motion with an acceleration of 30.0 m/s^2. Then its engine fails, and the rocket proceeds to move in free-fall. Find (a) the maximum altitude reached by the rocket, (b) its total time of flight, and (c) its horizontal range.

56. Do not hurt yourself; do not strike your hand against anything. Within these limitations, describe what you do to give your hand a large acceleration. Compute an order-of-magnitude estimate of this acceleration, stating the quantities you measure or estimate and their values.

57. A skier leaves the ramp of a ski jump with a velocity of 10.0 m/s, 15.0° above the horizontal, as shown in Figure P3.57. The slope is inclined at 50.0°, and air resistance is negligible. Find (a) the distance from the ramp to where the jumper lands and (b) the velocity components just before the landing. (How do you think the results might be affected if air resistance were included? Note that jumpers lean forward in the shape of an airfoil, with their hands at their sides, to increase their distance. Why does this method work?)

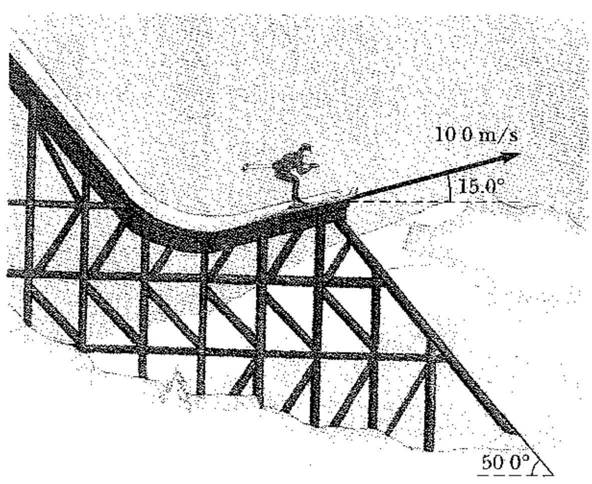


FIGURE P3.57

58. In a television picture tube (a cathode-ray tube), electrons are emitted with velocity $\vec{v}_i$ from a source at the origin of coordinates. The initial velocities of different electrons make different angles θ with the x axis. As they move a distance D along the x axis, the electrons are acted on by a constant electric field, giving each a constant acceleration $\vec{a}$ in the x direction. At $x = D$, the electrons pass through a circular aperture, oriented perpendicular to the x axis. At the aperture, the velocity imparted to the electrons by the electric field is much larger than $\vec{v}_i$ in magnitude. Show that velocities of the electrons going through the aperture radiate from a certain point on the x axis, which is not the origin. Determine the location of this point. This point is called a *virtual source*, and it is important in determining where the electron beam hits the screen of the tube.

59. An angler sets out upstream from Metaline Falls on the Pend Oreille River in northwestern Washington State. His small boat, powered by an outboard motor, travels at a constant speed v in still water. The water flows at a lower constant speed v_w. He has traveled upstream for 2.00 km when his ice chest falls out of the boat. He notices that the chest is missing only after he has gone upstream for another 15.0 minutes. At that point, he turns around and heads back downstream, all the time traveling at the same speed relative to the water. He catches up with the floating ice chest just as it is about to go over the falls at his starting point. How fast is the river flowing? Solve this problem in two ways. (a) First, use the Earth as a reference frame. With respect to the Earth, the boat travels upstream at speed $v - v_w$ and downstream at $v + v_w$. (b) A second much simpler and more elegant solution is obtained by using the water as the reference frame. This approach has important applications in many more complicated problems, such as calculating the motion of rockets and Earth satellites and analyzing the scattering of subatomic particles from massive targets.

60. The water in a river flows uniformly at a constant speed of 2.50 m/s between parallel banks 80.0 m apart. You are to deliver a package directly across the river, but you can swim only at 1.50 m/s. (a) If you choose to minimize the time you spend in the water, in what direction should you head? (b) How far downstream will you be carried? (c) If you choose to minimize the distance downstream that the river carries you, in what direction should you head? (d) How far downstream will you be carried?

QUESTIONS

☐ = answer available in the *Student Solutions Manual and Study Guide*

1. A ball is held in a person's hand. (a) Identify all the external forces acting on the ball and the reaction to each. (b) If the ball is dropped, what force is exerted on it while it is falling? Identify the reaction force in this case.

2. What is wrong with the statement, "Because the car is at rest, there are no forces acting on it"? How would you correct this sentence?

3. In the motion picture *It Happened One Night* (Columbia Pictures, 1934), Clark Gable is standing inside a stationary bus in front of Claudette Colbert, who is seated. The bus suddenly starts moving forward and Clark falls into Claudette's lap. Why did that happen?

4. As you sit in a chair, the chair pushes up on you with a normal force. The force is equal to your weight and in the opposite direction. Is this force the Newton's third law reaction to your weight?

5. A passenger sitting in the rear of a bus claims that she was injured as the driver slammed on the brakes, causing a suitcase to come flying toward her from the front of the bus. If you were the judge in this case, what disposition would you make? Why?

6. A space explorer is moving through space in a space ship far from any planet or star. She notices a large rock, taken as a specimen from an alien planet, floating around the cabin of the ship. Should she push it gently or kick it toward the storage compartment? Why?

7. A rubber ball is dropped onto the floor. What force causes the ball to bounce?

8. While a football is in flight, what forces act on it? What are the action–reaction pairs while the football is being kicked and while it is in flight?

9. If gold were sold by weight, would you rather buy it in Denver or in Death Valley? If it were sold by mass, at which of the two locations would you prefer to buy it? Why?

10. If you hold a horizontal metal bar several centimeters above the ground and move it through grass, each leaf of grass bends out of the way. If you increase the speed of the bar, each leaf of grass will bend more quickly. How then does a rotary power lawn mower manage to cut grass? How can it exert enough force on a leaf of grass to shear it off?

11. A weightlifter stands on a bathroom scale. He pumps a barbell up and down. What happens to the reading on the bathroom scale as he does so? What if he is strong enough to actually *throw* the barbell upward? How does the reading on the scale vary now?

12. The mayor of a city decides to fire some city employees because they will not remove the obvious sags from the cables that support the city traffic lights. If you were a lawyer, what defense would you give on behalf of the employees? Who do you think would win the case in court?

13. Suppose a truck loaded with sand accelerates along a highway. If the driving force on the truck remains constant, what happens to the truck's acceleration if its trailer leaks sand at a constant rate through a hole in its bottom?

14. As a rocket is fired from a launching pad, its speed and acceleration increase with time as its engines continue to operate. Explain why that occurs even though the thrust of the engines remains constant.

15. Twenty people participate in a tug-of-war. The two teams of ten people are so evenly matched that neither team wins. After the game they notice that one person's car is mired in mud. They attach the tug-of-war rope to the bumper of the car, and all the people pull on the rope. The heavy car has just moved a couple of decimeters when the rope breaks. Why did the rope break in this situation when it did not break when the same twenty people pulled on it in a tug-of-war?

16. When the locomotive in Figure Q4.16 broke through the wall of the train station, the force exerted by the locomotive on the wall was greater than the force the wall could exert on the locomotive." Is this statement true or in need of correction? Explain your answer.

(Roger Viollet, Mill Valley, CA, University Science Books, 1982)

FIGURE Q4.16

17. An athlete grips a light rope that passes over a low-friction pulley attached to the ceiling of a gym. A sack of sand precisely equal in weight to the athlete is tied to the rope's other end. Both the sand and the athlete are initially at rest. The athlete climbs the rope, sometimes speeding up and slowing down as he does so. What happens to the sack of sand? Explain.

18. If action and reaction forces are always equal in magnitude and opposite in direction to each other, doesn't the net vector force on any object necessarily add up to zero? Explain your answer.

19. Can an object exert a force on itself? Argue for your answer.

PROBLEMS

1, 2, 3 = straightforward, intermediate, challenging
☐ = full solution available in the *Student Solutions Manual and Study Guide*
Physics⊗Now™ = coached problem with hints available at www.pop4e.com
= computer useful in solving problem
= paired numerical and symbolic problems
= biomedical application

Section 4.3 ■ Mass

1. A force $\vec{F}$ applied to an object of mass m_1 produces an acceleration of 3.00 m/s^2. The same force applied to a second object of mass m_2 produces an acceleration of 1.00 m/s^2. (a) What is the value of the ratio m_1/m_2? (b) If m_1 and m_2 are combined, find their acceleration under the action of the force $\vec{F}$.

2. (a) A car with a mass of 850 kg is moving to the right with a constant speed of 1.44 m/s. What is the total force on the car? (b) What is the total force on the car if it is moving to the left?

Section 4.4 ■ Newton's Second Law—The Particle Under a Net Force

3. A 3.00-kg object undergoes an acceleration given by $\vec{a} = (2.00\hat{i} + 5.00\hat{j})$ m/s^2. Find the resultant force acting on it and the magnitude of the resultant force.

4. Two forces, $\vec{F}_1 = (-6\hat{i} - 4\hat{j})$ N and $\vec{F}_2 = (-3\hat{i} + 7\hat{j})$ N, act on a particle of mass 2.00 kg that is initially at rest at coordinates (−2.00 m, +4.00 m). (a) What are the components of the particle's velocity at t = 10.0 s? (b) In what direction is the particle moving at t = 10.0 s? (c) What displacement does the particle undergo during the first 10.0 s? (d) What are the coordinates of the particle at t = 10.0 s?

5. Physics⊗Now™ To model a spacecraft, a toy rocket engine is securely fastened to a large puck that can glide with negligible friction over a horizontal surface, taken as the xy plane. The 4.00-kg puck has a velocity of $3.00\hat{i}$ m/s at one instant. Eight seconds later, its velocity is to be $(8.00\hat{i} + 10.0\hat{j})$ m/s. Assuming that the rocket engine exerts a constant horizontal force, find (a) the components of the force and (b) its magnitude.

6. A 3.00-kg object is moving in a plane, with its x and y coordinates given by $x = 5t^2 - 1$ and $y = 3t^3 + 2$, where x and y are in meters and t is in seconds. Find the magnitude of the net force acting on this object at t = 2.00 s.

7. Two forces $\vec{F}_1$ and $\vec{F}_2$ act on a 5.00-kg object. If F_1 = 20.0 N and F_2 = 15.0 N, find the accelerations in (a) and (b) of Figure P4.7.

8. Three forces, given by $\vec{F}_1 = (-2.00\hat{i} + 2.00\hat{j})$ N, $\vec{F}_2 = (5.00\hat{i} - 3.00\hat{j})$ N, and $\vec{F}_3 = (-45.0\hat{i})$ N, act on an object to give it an acceleration of magnitude 3.75 m/s^2.

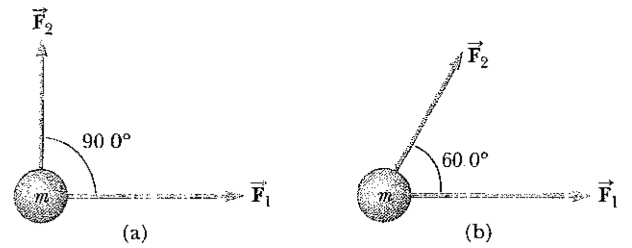


FIGURE P4.7

(a) What is the direction of the acceleration? (b) What is the mass of the object? (c) If the object is initially at rest, what is its speed after 10.0 s? (d) What are the velocity components of the object after 10.0 s?

Section 4.5 ■ The Gravitational Force and Weight

9. A woman weighs 120 lb. Determine (a) her weight in newtons and (b) her mass in kilograms.

10. If a man weighs 900 N on the Earth, what would he weigh on Jupiter, where the free-fall acceleration is 25.9 m/s^2?

11. The distinction between mass and weight was discovered after Jean Richer transported pendulum clocks from Paris, France, to Cayenne, French Guiana in 1671. He found that they quite systematically ran slower in Cayenne than in Paris. The effect was reversed when the clocks returned to Paris. How much weight would you personally lose in traveling from Paris, where g = 9.809 5 m/s^2, to Cayenne, where g = 9.780 8 m/s^2? (We will consider how the free-fall acceleration influences the period of a pendulum in Section 12.4.)

12. The gravitational force on a baseball is $-F_g\hat{j}$. A pitcher throws the baseball with velocity $v\hat{i}$ by uniformly accelerating it straight forward horizontally for a time interval $\Delta t = t - 0 = t$. If the ball starts from rest, (a) through what distance does it accelerate before its release? (b) What force does the pitcher exert on the ball?

13. An electron of mass 9.11×10^{-31} kg has an initial speed of 3.00×10^5 m/s. It travels in a straight line, and its speed increases to 7.00×10^5 m/s in a distance of 5.00 cm. Assuming that its acceleration is constant, (a) determine the net force exerted on the electron and (b) compare this force with the weight of the electron.

14. Besides its weight, a 2.80-kg object is subjected to one other constant force. The object starts from rest and in 1.20 s experiences a displacement of $(4.20\hat{i} - 3.30\hat{j})$ m, where the direction of $\hat{j}$ is the upward vertical direction. Determine the other force.

Section 4.6 ■ Newton's Third Law

15. You stand on the seat of a chair and then hop off. (a) During the time you are in flight down to the floor, the Earth is lurching up toward you with an acceleration of what order of magnitude? In your solution, explain your logic. Model the Earth as a perfectly solid object. (b) The Earth moves up through a distance of what order of magnitude?

16. The average speed of a nitrogen molecule in air is about $6\ 70 \times 10^2$ m/s, and its mass is $4\ 68 \times 10^{-26}$ kg (a) If it takes $3\ 00 \times 10^{-13}$ s for a nitrogen molecule to hit a wall and rebound with the same speed but moving in the opposite direction, what is the average acceleration of the molecule during this time interval? (b) What average force does the molecule exert on the wall?

17. A 15 0-lb block rests on the floor. (a) What force does the floor exert on the block? (b) A rope is tied to the block and is run vertically over a pulley. The other end of the rope is attached to a free-hanging 10 0-lb weight What is the force exerted by the floor on the 15 0-lb block? (c) If we replace the 10.0-lb weight in part (b) with a 20 0-lb weight, what is the force exerted by the floor on the 15 0-lb block?

Section 4.7 ▪ Applications of Newton's Laws

18. A bag of cement of weight 325 N hangs in equilibrium from three wires as suggested in Figure P4.18. Two of the wires make angles $\theta_1 = 60.0°$ and $\theta_2 = 25.0°$ with the horizontal. Find the tensions T_1, T_2, and T_3 in the wires.

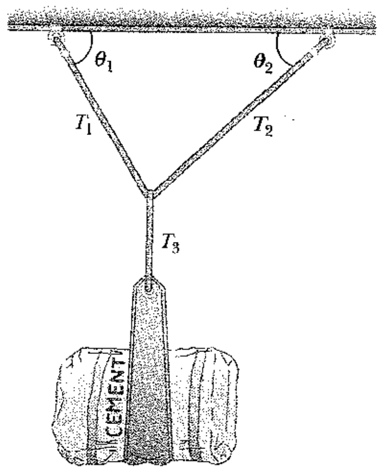


FIGURE **P4.18** Problems 4 18 and 4 19

19. A bag of cement of weight F_g hangs in equilibrium from three wires as shown in Figure P4.18 Two of the wires make angles θ_1 and θ_2 with the horizontal. Show that the tension in the left-hand wire is

$$T_1 = \frac{F_g \cos \theta_2}{\sin(\theta_1 + \theta_2)}$$

20. Figure P4 20 shows a worker poling a boat—a very efficient mode of transportation—across a shallow lake. He pushes parallel to the length of the light pole, exerting on the bottom of the lake a force of 240 N The pole lies in the vertical plane containing the keel of the boat. At one moment the pole makes an angle of 35 0° with the vertical and the water exerts a horizontal drag force of 47 5 N on the boat, opposite to its forward motion at 0 857 m/s. The mass of the boat including its cargo and the worker is 370 kg. (a) The water exerts a buoyant force vertically upward on the boat. Find the magnitude of this force (b) Model the forces as constant over a short interval of time to find the velocity of the boat 0.450 s after the moment described.

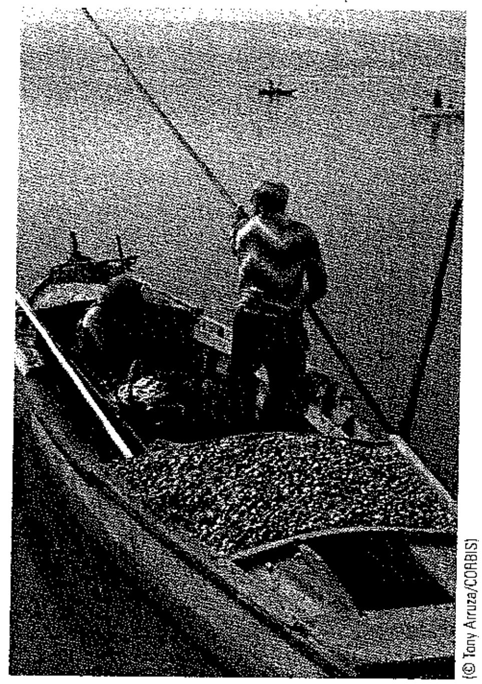


FIGURE **P4.20**

21. You are a judge in a children's kite-flying contest, and two children will win prizes for the kites that pull most strongly and least strongly on their strings To measure string tensions, you borrow a weight hanger, some slotted weights, and a protractor from your physics teacher, and you use the following protocol, illustrated in Figure P4.21: Wait for a child to get her kite well controlled, hook the hanger onto the kite string about 30 cm from her hand, pile on weight until that section of string is horizontal, record the mass required, and record the angle between the horizontal and the string running up to the kite (a) Explain how this method works. As you construct your explanation, imagine that the children's parents ask you about your method, that they might make false assumptions about your ability without concrete evidence, and that your

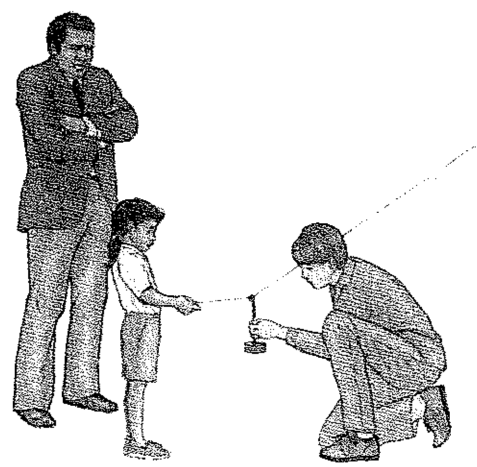


FIGURE **P4 21**

explanation is an opportunity to give them confidence in your evaluation technique. (b) Find the string tension assuming that the mass is 132 g and the angle of the kite string is 46.3°.

22. The systems shown in Figure P4.22 are in equilibrium. If the spring scales are calibrated in newtons, what do they read? (Ignore the masses of the pulleys and strings, and assume that the incline is frictionless.)

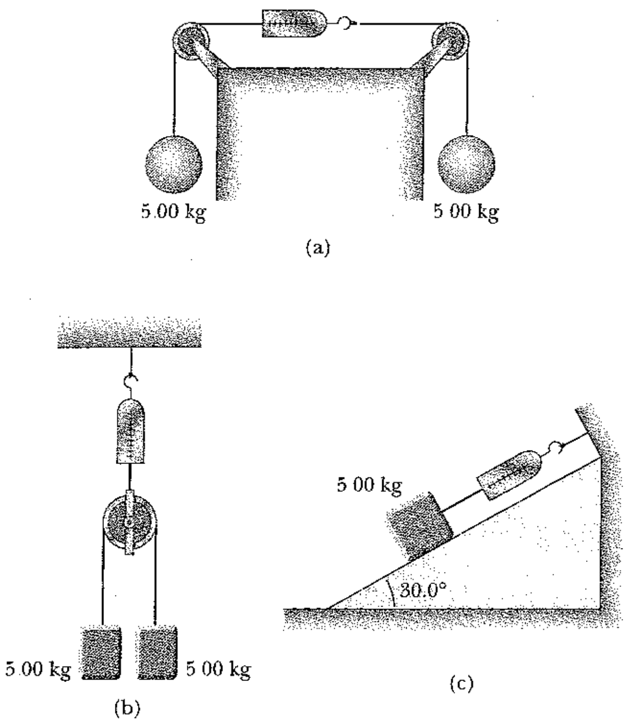


FIGURE P4.22

23. A simple accelerometer is constructed inside a car by suspending an object of mass m from a string of length L that is tied to the car's ceiling. As the car accelerates the string–object system makes a constant angle of θ with the vertical. (a) Assuming that the string mass is negligible compared with m, derive an expression for the car's acceleration in terms of θ and show that it is independent of the mass m and the length L. (b) Determine the acceleration of the car when $\theta = 23.0°$.

24. Figure P4.24 shows loads hanging from the ceiling of an elevator that is moving at constant velocity. Find the tension in each of the three strands of cord supporting each load.

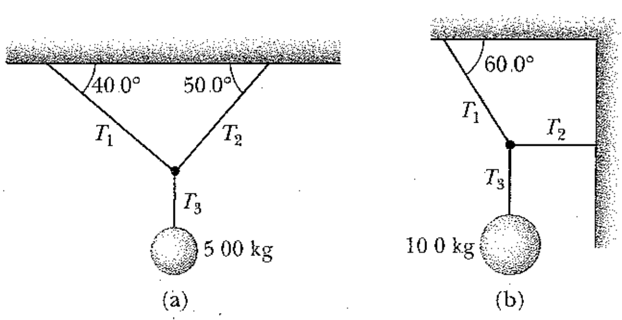


FIGURE P4.24

25. Two people pull as hard as they can on horizontal ropes attached to a boat that has a mass of 200 kg. If they pull in the same direction, the boat has an acceleration of 1.52 m/s^2 to the right. If they pull in opposite directions, the boat has an acceleration of 0.518 m/s^2 to the left. What is the magnitude of the force each person exerts on the boat? Disregard any other horizontal forces on the boat.

26. Draw a free-body diagram of a block that slides down a frictionless plane having an inclination of $\theta = 15.0°$ (Fig. P4.26). Assuming that the block starts from rest at the top and that the length of the incline is 2.00 m, find (a) the acceleration of the block and (b) its speed when it reaches the bottom of the incline.

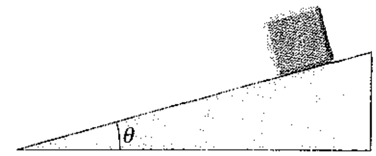


FIGURE P4.26 Problems 4.26, 4.29, and 4.46

27. **PhysicsNow™** A 1.00-kg object is observed to accelerate at 10.0 m/s^2 in a direction 30.0° north of east (Fig. P4.27). The force $\vec{\mathbf{F}}_2$ acting on the object has magnitude 5.00 N and is directed north. Determine the magnitude and direction of the force $\vec{\mathbf{F}}_1$ acting on the object.

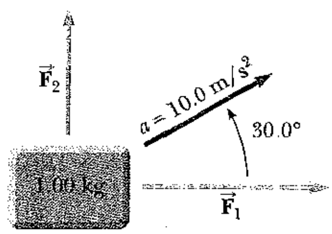


FIGURE P4.27

28. A 5.00-kg object placed on a frictionless, horizontal table is connected to a cable that passes over a pulley and then is fastened to a hanging 9.00-kg object as shown in Figure P4.28. Draw free-body diagrams of both objects. Find the acceleration of the two objects and the tension in the string.

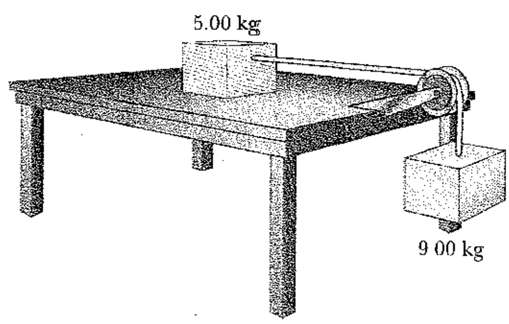


FIGURE P4.28

29. **Physics Now™** A block is given an initial velocity of 5.00 m/s up a frictionless 20.0° incline (Fig. P4.26). How far up the incline does the block slide before coming to rest?

30. Two objects are connected by a light string that passes over a frictionless pulley as shown in Figure P4.30. Draw free-body diagrams of both objects. The incline is frictionless, and $m_1 = 2.00$ kg, $m_2 = 6.00$ kg, and $\theta = 55.0°$. Find (a) the accelerations of the objects, (b) the tension in the string, and (c) the speed of each of the objects 2.00 s after they are released simultaneously from rest.

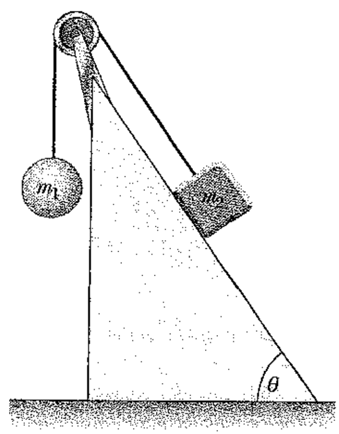


FIGURE P4.30

31. A car is stuck in the mud. A tow truck pulls on the car with a force of 2 500 N as shown in Fig. P4.31. The tow cable is under tension and therefore pulls downward and to the left on the pin at its upper end. The light pin is held in equilibrium by forces exerted by the two bars A and B. Each bar is a *strut*, that is, each is a bar whose weight is small compared to the forces it exerts and which exerts forces only through hinge pins at its ends. Each strut exerts a force directed parallel to its length. Determine the force of tension or compression in each strut. Proceed as follows. Make a guess as to which way (pushing or pulling) each force acts on the top pin. Draw a free-body diagram of the pin. Use the condition for equilibrium of the pin to translate the free-body diagram into equations. From the equations calculate the forces exerted by struts A and B. If you obtain a positive answer, you correctly guessed the direction of the force. A negative answer means that the direction should be reversed, but the absolute value correctly gives the magnitude of the force. If a strut pulls on a pin, it is in tension. If it pushes, the strut is in compression. Identify whether each strut is in tension or in compression.

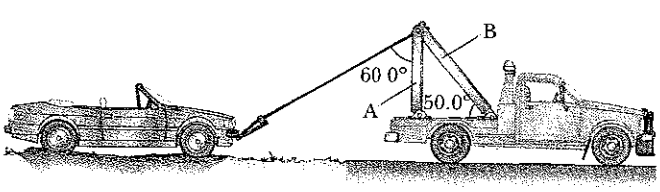


FIGURE P4.31

32. Two objects with masses of 3.00 kg and 5.00 kg are connected by a light string that passes over a light frictionless pulley to form an Atwood machine as shown in Active Figure 4.12a. Determine (a) the tension in the string, (b) the acceleration of each object, and (c) the distance each object will move in the first second of motion if they start from rest.

33. In Figure P4.33, the man and the platform together weigh 950 N. The pulley can be modeled as frictionless. Determine how hard the man has to pull on the rope to lift himself steadily upward above the ground. (Or is it impossible? If so, explain why.)

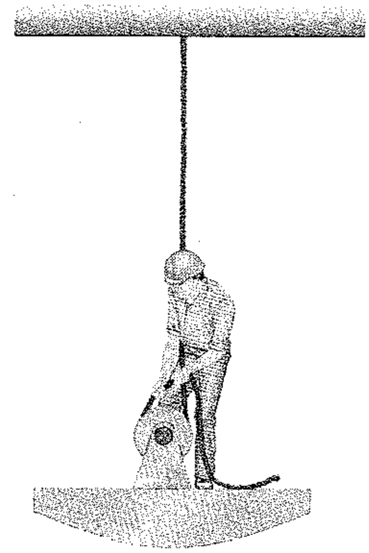


FIGURE P4.33

34. In the Atwood machine shown in Active Figure 4.12a, $m_1 = 2.00$ kg and $m_2 = 7.00$ kg. The masses of the pulley and string are negligible by comparison. The pulley turns without friction, and the string does not stretch. The lighter object is released with a sharp push that sets it into motion at $v_i = 2.40$ m/s downward. (a) How far will m_1 descend below its initial level? (b) Find the velocity of m_1 after 1.80 s.

35. **Physics Now™** In the system shown in Figure P4.35, a horizontal force $\vec{F}_x$ acts on the 8.00-kg object. The horizontal surface is frictionless. (a) For what values of F_x does the 2.00-kg object accelerate upward? (b) For what values of F_x is the tension in the cord zero? (c) Plot the acceleration of the 8.00-kg object versus F_x. Include values of F_x from −100 N to +100 N.

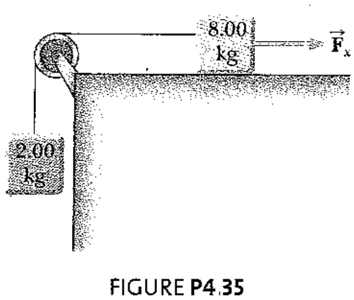


FIGURE P4.35

36. A frictionless plane is 10.0 m long and inclined at 35.0°. A sled starts at the bottom with an initial speed of 5.00 m/s up the incline. When it reaches the point at which it momentarily stops, a second sled is released from the top of this incline with an initial speed v_i. Both sleds reach the bottom of the incline at the same moment. (a) Determine the distance that the first sled traveled up the incline. (b) Determine the initial speed of the second sled.

37. A 72.0-kg man stands on a spring scale in an elevator. Starting from rest, the elevator ascends, attaining its maximum speed of 1.20 m/s in 0.800 s. It travels with this constant speed for the next 5.00 s. The elevator then undergoes a uniform acceleration in the negative y direction for 1.50 s and comes to rest. What does the spring scale register (a) before the elevator starts to move, (b) during the first 0.800 s, (c) while the elevator is traveling at constant speed, and (d) during the time it is slowing down?

38. An object of mass m_1 on a frictionless horizontal table is connected to an object of mass m_2 through a very light pulley P_1 and a light fixed pulley P_2 as shown in Figure P4.38. (a) If a_1 and a_2 are the accelerations of m_1 and m_2, respectively, what is the relation between these accelerations? Express (b) the tensions in the strings and (c) the accelerations a_1 and a_2 in terms of g and the masses m_1 and m_2.

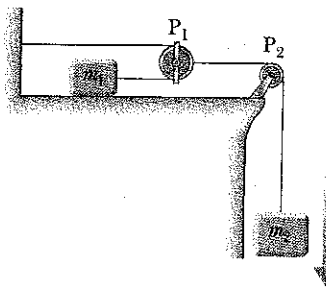


FIGURE P4.38

Section 4.8 ■ Context Connection—Forces on Automobiles

39. A young woman buys an inexpensive used car for stock car racing. It can attain highway speed with an acceleration of 8.40 mi/h·s. By making changes to its engine, she can increase the net horizontal force on the car by 24.0%. With much less expense, she can remove material from the body of the car to decrease its mass by 24.0%. (a) Which of these two changes, if either, will result in the greater increase in the car's acceleration? (b) If she makes both changes, what acceleration can she attain?

40. A 1 000-kg car is pulling a 300-kg trailer. Together the car and trailer move forward with an acceleration of 2.15 m/s^2. Ignore any force of air drag on the car and all frictional forces on the trailer. Determine (a) the net force on the car, (b) the net force on the trailer, (c) the force exerted by the trailer on the car, and (d) the resultant force exerted by the car on the road.

Additional Problems

41. An inventive child named Pat wants to reach an apple in a tree without climbing the tree. While sitting in a chair connected to a rope that passes over a frictionless pulley (Fig. P4.41), Pat pulls on the loose end of the rope with such a force that the spring scale reads 250 N. Pat's true weight is 320 N, and the chair weighs 160 N. (a) Draw free-body diagrams for Pat and the chair considered as separate systems and another diagram for Pat and the chair considered as one system. (b) Show that the acceleration of the system is *upward* and find its magnitude. (c) Find the force Pat exerts on the chair.

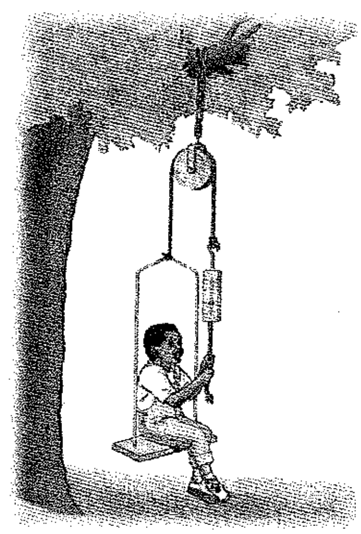


FIGURE P4.41 Problems 4.41 and 4.42.

42. In the situation described in Problem 4.41 and Figure P4.41, the masses of the rope, spring balance, and pulley are negligible. Pat's feet are not touching the ground. (a) Assume that Pat is momentarily at rest when he stops pulling down on the rope and passes the end of the rope to another child, of weight 440 N, who is standing on the ground next to him. The rope does not break. Describe the ensuing motion. (b) Instead, assume that Pat is momentarily at rest when he ties the rope to a strong hook projecting from the tree trunk. Explain why this action can make the rope break.

43. Three blocks are in contact with one another on a frictionless, horizontal surface as shown in Figure P4.43. A horizontal force $\vec{F}$ is applied to m_1. Taking $m_1 = 2.00$ kg, $m_2 = 3.00$ kg, $m_3 = 4.00$ kg, and $F = 18.0$ N, draw a separate free-body diagram for each block and find (a) the acceleration of the blocks, (b) the *resultant* force on each block, and (c) the magnitudes of the contact forces between the blocks. (d) You are working on a construction project. A coworker is nailing up plasterboard on one side of a light partition, and you are on the opposite side, providing "backing" by leaning against the wall with your back pushing on it. Every hammer blow makes your back sting.

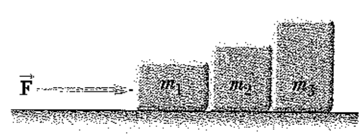


FIGURE P4.43

The supervisor helps you put a heavy block of wood between the wall and your back Using the situation analyzed in parts (a), (b), and (c) as a model, explain how this change works to make your job more comfortable

44. **Review problem** A block of mass $m = 2.00$ kg is released from rest at $h = 0.500$ m above the surface of a table, at the top of a $\theta = 30.0°$ incline as shown in Figure P4.44. The frictionless incline is fixed on a table of height $H = 2.00$ m (a) Determine the acceleration of the block as it slides down the incline. (b) What is the velocity of the block as it leaves the incline? (c) How far from the table will the block hit the floor? (d) What time interval elapses between when the block is released and when it hits the floor? (e) Does the mass of the block affect any of the above calculations?

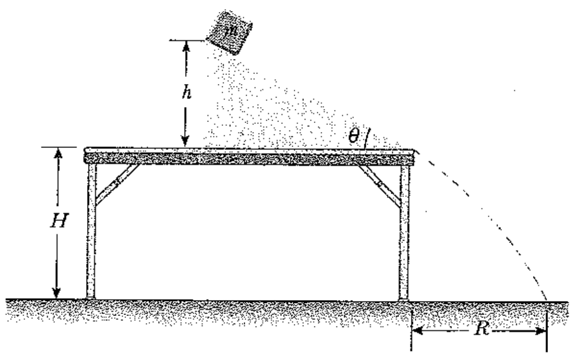


FIGURE **P4.44** Problems 4.44 and 4.55

45. PhysicsNow™ An object of mass M is held in place by an applied force $\vec{F}$ and a pulley system as shown in Figure P4.45. The pulleys are massless and frictionless. Find (a) the tension in each section of rope, T_1, T_2, T_3, T_4, and T_5 and (b) the magnitude of $\vec{F}$ *Suggestion* Draw a free-body diagram for each pulley

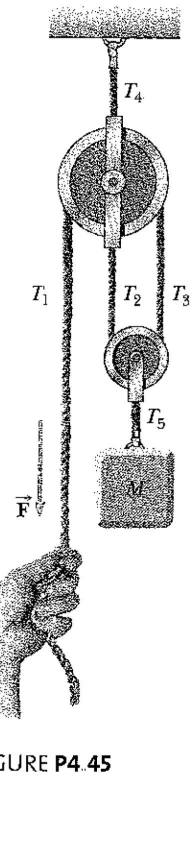


FIGURE **P4.45**

46. A student is asked to measure the acceleration of a cart on a "frictionless" inclined plane as shown in Figure P4.26 and analyzed in Example 4.3, using an air track, a stopwatch, and a meter stick The height of the incline is measured to be 1.774 cm, and the total length of the incline is measured to be $d = 127.1$ cm. Hence, the angle of inclination θ is determined from the relation $\sin\theta = 1.774/127.1$. The cart is released from rest at the top of the incline, and its position x along the incline is measured as a function of time, where $x = 0$ refers to the initial position of the cart For x values of 10.0 cm, 20.0 cm, 35.0 cm, 50.0 cm, 75.0 cm, and 100 cm, the measured times at which these positions are reached (averaged over five runs) are 1.02 s, 1.53 s, 2.01 s, 2.64 s, 3.30 s, and 3.75 s, respectively. Construct a graph of x versus t^2 and perform a linear least-squares fit to the data Determine the acceleration of the cart from the slope of this graph and compare it with the value you would get using $a = g \sin\theta$, where $g = 9.80$ m/s^2

47. What horizontal force must be applied to the cart shown in Figure P4.47 so that the blocks remain stationary relative to the cart? Assume that all surfaces, wheels, and pulley are frictionless (*Suggestion* Note that the force exerted by the string accelerates m_1.)

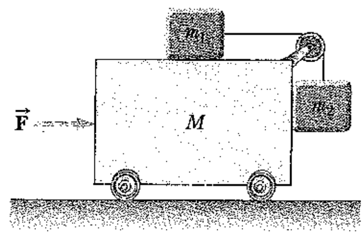


FIGURE **P4.47** Problems 4.47 and 4.48

48. Initially, the system of objects shown in Figure P4.47 is held motionless The pulley and all surfaces and wheels are frictionless. Let the force $\vec{F}$ be zero and assume that m_2 can move only vertically At the instant after the system of objects is released, find (a) the tension T in the string, (b) the acceleration of m_2, (c) the acceleration of M, and (d) the acceleration of m_1 (*Note* The pulley accelerates along with the cart.)

49. A 1.00-kg glider on a horizontal air track is pulled by a string at an angle θ. The taut string runs over a pulley and is attached to a hanging object of mass 0.500 kg as shown in Figure P4.49 (a) Show that the speed v_x of the glider and the speed v_y of the hanging object are related by $v_x = uv_y$, where $u = z(z^2 - h_0^2)^{-1/2}$ (b) The glider is released from rest Show that at that instant the acceleration a_x of the glider and the acceleration a_y of the hanging object are related by $a_x = ua_y$. (c) Find the tension in the string at the instant the glider is released for $h_0 = 80.0$ cm and $\theta = 30.0°$

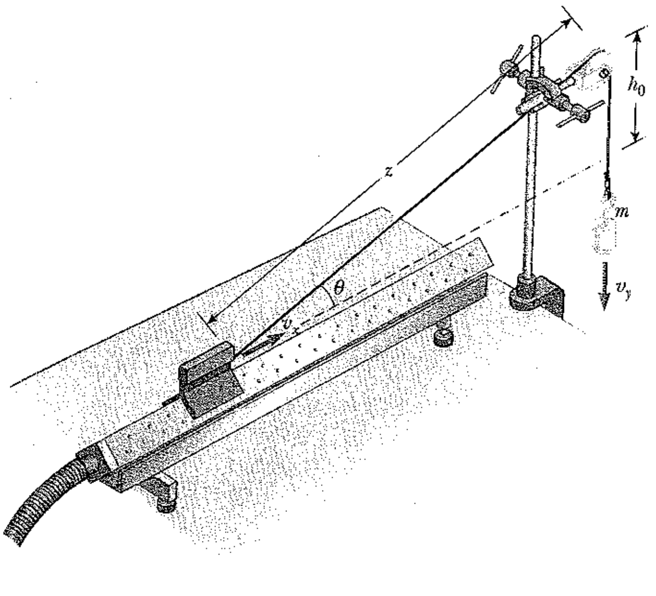


FIGURE P4.49

50. Cam mechanisms are used in many machines For example, cams open and close the valves in your car engine to admit gasoline vapor to each cylinder and to allow the escape of exhaust The principle is illustrated in Figure P4 50, showing a follower rod (also called a pushrod) of mass m resting on a wedge of mass M. The sliding wedge duplicates the function of a rotating eccentric disk on a car's camshaft. Assume that there is no friction between the wedge and the base, between the pushrod and the wedge, or between the rod and the guide through which it slides. When the wedge is pushed to the left by the force $\vec{\mathbf{F}}$, the rod moves upward and does something such as opening a valve By varying the shape of the wedge, the motion of the follower rod could be made quite complex, but assume that the wedge makes a constant angle of $\theta = 15\ 0°$ Suppose you want the wedge and the rod to start from rest and move with constant acceleration, with the rod moving upward 1 00 mm in 8.00 ms. Take $m = 0\ 250$ kg and $M = 0\ 500$ kg What force F must be applied to the wedge?

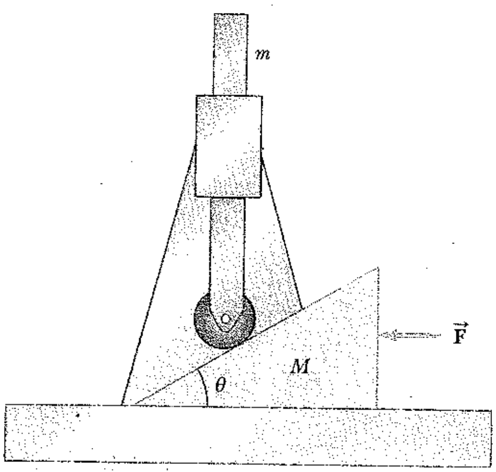


FIGURE P4.50

51. If you jump from a desktop and land stiff-legged on a concrete floor, you run a significant risk that you will break a leg. To see how that happens, consider the average force stopping your body when you drop from rest from a height of 1 00 m and stop in a much shorter distance d Your leg is likely to break at the point where the cross-sectional area of the bone (the tibia) is smallest. This point is just above the ankle, where the cross-sectional area of one bone is about 1.60 cm^2 A bone will fracture when the compressive stress on it exceeds about 1.60×10^8 N/m^2 If you land on both legs, the maximum force that your ankles can safely exert on the rest of your body is then about

$$2(1\ 60 \times 10^8\ \text{N/m}^2)(1.60 \times 10^{-4}\ \text{m}^2) = 5.12 \times 10^4\ \text{N}$$

Calculate the minimum stopping distance d that will not result in a broken leg if your mass is 60 0 kg Don't try it! Bend your knees!

52. Any device that allows you to increase the force you exert is a kind of *machine* Some machines, such as the prybar or the inclined plane, are very simple. Some machines do not even look like machines For example, your car is stuck in the mud and you can't pull hard enough to get it out. You do, however, have a long cable that you connect taut between your front bumper and the trunk of a stout tree You now pull sideways on the cable at its midpoint, exerting a force f. Each half of the cable is displaced through a small angle θ from the straight line between the ends of the cable (a) Deduce an expression for the force acting on the car (b) Evaluate the cable tension for the case where $\theta = 7\ 00°$ and $f = 100$ N

53. A van accelerates down a hill (Fig P4.53), going from rest to 30 0 m/s in 6 00 s During the acceleration, a toy ($m = 0\ 100$ kg) hangs by a string from the van s ceiling The acceleration is such that the string remains perpendicular to the ceiling Determine (a) the angle θ and (b) the tension in the string

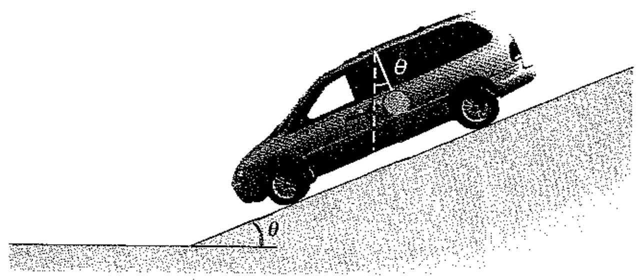


FIGURE P4 53

54. Two blocks of mass 3 50 kg and 8 00 kg are connected by a massless string that passes over a frictionless pulley (Fig P4 54) The inclines are frictionless Find (a) the

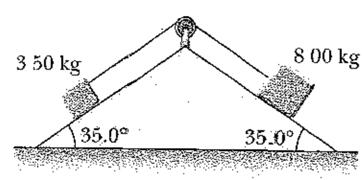


FIGURE P4.54 Problems 4 54 and 5 41

magnitude of the acceleration of each block and (b) the tension in the string.

55. In Figure P4.44, the incline has mass M and is fastened to the stationary horizontal tabletop. The block of mass m is placed near the bottom of the incline and is released with a quick push that sets it sliding upward. It stops near the top of the incline, as shown in the figure, and then slides down again, always without friction. Find the force that the tabletop exerts on the incline throughout this motion.

56. An 8.40-kg object slides down a fixed, frictionless inclined plane. Use a computer to determine and tabulate the normal force exerted on the object and its acceleration for a series of incline angles (measured from the horizontal) ranging from 0° to 90° in 5° increments. Plot a graph of the normal force and the acceleration as functions of the incline angle. In the limiting cases of 0° and 90°, are your results consistent with the known behavior?

57. A mobile is formed by supporting four metal butterflies of equal mass m from a string of length L. The points of support are evenly spaced a distance ℓ apart as shown in Figure P4.57. The string forms an angle θ_1 with the ceiling at each end point. The center section of string is horizontal. (a) Find the tension in each section of string in terms of θ_1, m, and g. (b) In terms of θ_1, find the angle θ_2 that the sections of string between the outside butterflies and the inside butterflies form with the horizontal. (c) Show that the distance D between the end points of the string is

$$D = \frac{L}{5}\left(2\cos\theta_1 + 2\cos\left[\tan^{-1}\left(\tfrac{1}{2}\tan\theta_1\right)\right] + 1\right)$$

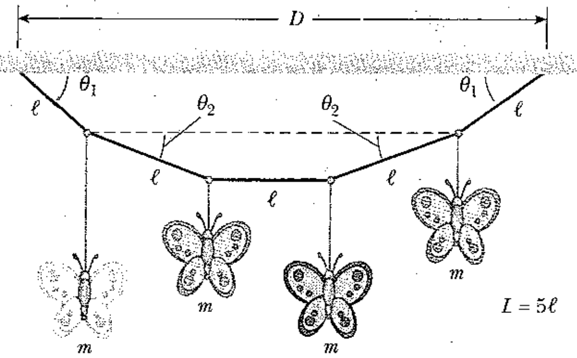


FIGURE P4.57

ANSWERS TO QUICK QUIZZES

4.1 (d). Choice (a) is true. Newton's first law tells us that motion requires no force: An object in motion continues to move at constant velocity in the absence of external forces. Choice (b) is also true: A stationary object can have several forces acting on it, but if the vector sum of all these external forces is zero, there is no net force and the object remains stationary.

4.2 (a). If a single force acts, this force constitutes the net force and there is an acceleration according to Newton's second law.

4.3 (d). With twice the force, the object will experience twice the acceleration. Because the force is constant, the acceleration is constant, and the speed of the object, starting from rest, is given by $v = at$. With twice the acceleration, the object will arrive at speed v at half the time.

4.4 (b). Because the value of g is smaller on the Moon than on the Earth, more mass of gold would be required to represent 1 N of weight on the Moon. Therefore, your friend on the Moon is richer, by about a factor of 6!

4.5 (c), (d). In accordance with Newton's third law, the fly and the bus experience forces that are equal in magnitude but opposite in direction. Because the fly has such a small mass, Newton's second law tells us that it undergoes a very large acceleration. The huge mass of the bus means that it more effectively resists any change in its motion and exhibits a small acceleration.

4.6 (c). The reaction force to the gravitational force on you is an upward gravitational force on the Earth caused by you.

4.7 (c). The scale is in equilibrium in both situations, so it experiences a net force of zero. Because each individual pulls with a force F and there is no acceleration, each individual is in equilibrium. Therefore, the tension in the ropes must be equal to F. In case (i), the individual pulls with force F on a spring mounted rigidly to a brick wall. The resulting tension F in the rope causes the scale to read a force F. In case (ii), the individual on the left can be modeled as simply holding the rope tightly while the individual on the right pulls. Therefore, the individual on the left is doing the same thing that the wall does in case (i). The resulting scale reading is the same whether a wall or a person is holding the left side of the scale.