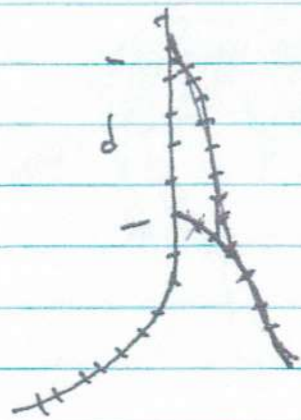
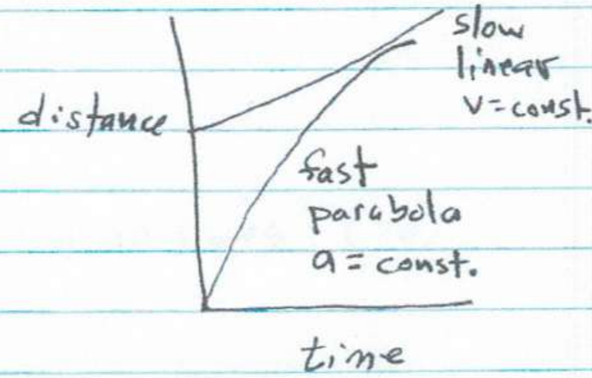
5th (2-57)

WHY



$v_1 = 100$ mph $x=0$ $t=0$
$v_2 = 18$ mph $x=0.42$ $t=0$
$d = 0.42$ mi

Use SI units 8^{th} Ed.



$a = 3.26\ ft/s^2$

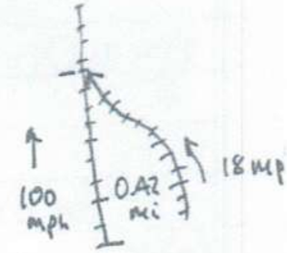
Simultaneous equations
How much information to solve
Picture to graph to solution
Understanding word problems - just misses means ??
position / velocity / acceleration
First and second derivatives
Constant acceleration (deceleration!)
Integration with initial conditions a = constant, $v(0)$, $x(0)$
O.D.E. / Initial value problem
Graph, graph, graph
Unit conversions, consistent set

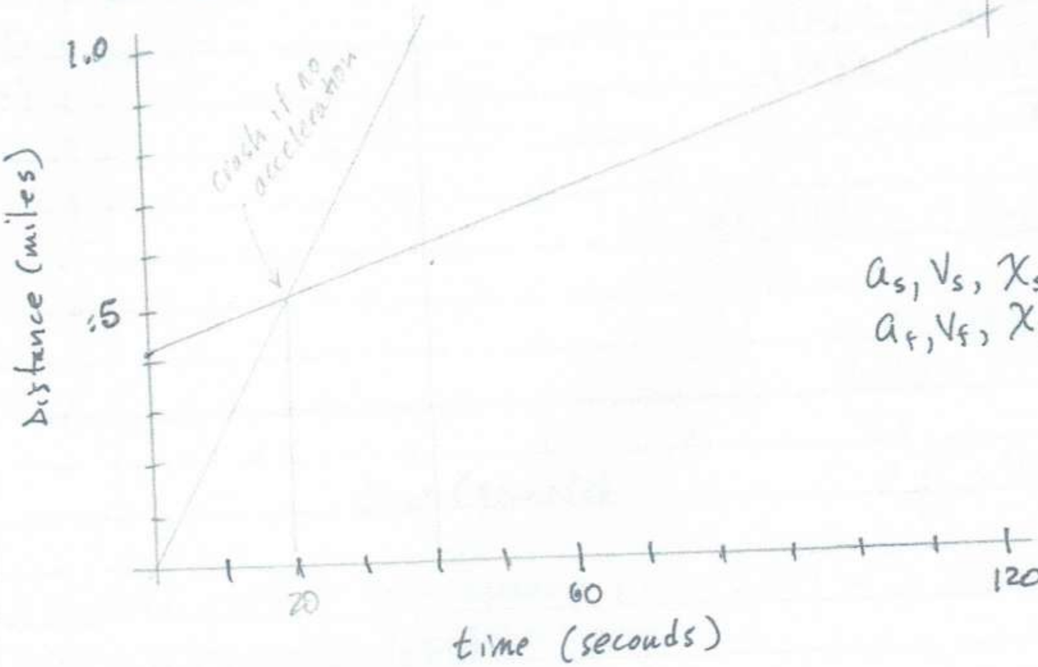
a. $3.26\ ft/s^2$

HOW

2-57

Passenger train 100 mph
Slow locomotive 0.42 miles ahead at 18 mph
a. acceleration to avoid collision?
b. $x(t)$ curves for each train





100 mph
= 5/3 mi

a_s, V_s, X_s - slow
a_f, V_f, X_f - fast

No acceleration $X_s = X_f$ hit!

$X_s(t) = 18 \text{ mph} \times (t/3600) + 0.42$

$X_f(t) = 100 \text{ mph} \times (t/3600)$

$t\left[(100/3600) - (18/3600)\right] =$

$t = 23.8 \text{ s}$

No collision at T (seconds)

$X_f(T) = X_s(T)$

$V_f(T) = X_f(T)$

required to attain the speed of 30 ft/sec, (*d*) the distance moved from rest to the time the train had a speed of 30 ft/sec.

14. At the instant the traffic light turns green, an automobile starts with a constant acceleration a of 6.0 ft/sec^2. At the same instant a truck, traveling with a constant speed of 30 ft/sec, overtakes and passes the automobile. (*a*) How far beyond the starting point will the automobile overtake the truck? (*b*) How fast will the car be traveling at that instant? (It is instructive to plot a qualitative graph of x versus t for each vehicle.) 300' 60'/s

15. A car moving with constant acceleration covers the distance between two points 180 ft apart in 6.0 sec. Its speed as it passes the second point is 45 ft/sec. (*a*) What is its speed at the first point? (*b*) What is its acceleration? (*c*) At what prior distance from the first point was the car at rest?

16. The engineer of a train moving at a speed v_1 sights a freight train a distance d ahead of him on the same track moving in the same direction with a slower speed v_2. He puts on the brakes and gives his train a constant deceleration a. Show that

$$\text{if} \quad d > \frac{(v_1 - v_2)^2}{2a}, \quad \text{there will be no collision;}$$

$$\text{if} \quad d < \frac{(v_1 - v_2)^2}{2a}, \quad \text{there will be a collision.}$$

(It is instructive to plot a qualitative graph of x versus t for each train.)

17. Two trains, one traveling at 60 miles/hr and the other at 80 miles/hr, are headed toward one another along a straight level track. When they are 2.0 miles apart, both engineers simultaneously see the other's train and apply their brakes. If the brakes decelerate each train at the rate of 3.0 ft/sec^2, determine whether there is a collision.

18. A rocket-driven sled running on a straight level track is used to investigate the physiological effects of large accelerations on humans. One such sled can attain a speed of 1000 miles/hr in 1.8 sec starting from rest. (*a*) Assume the acceleration is constant and compare it to g. (*b*) What is the distance traveled in this time?

19. (*a*) With what speed must a ball be thrown vertically upward in order to rise to a height of 50 ft? (*b*) How long will it be in the air?

20. Water drips from the nozzle of a shower onto the stall floor 81 in. below. The drops fall at regular intervals of time, the first drop striking the floor at the instant the fourth drop begins to fall. Find the location of the individual drops when a drop strikes the floor.

21. If a body travels half its total path in the last second of its fall from rest, find the time and height of its fall. Explain the physically unacceptable solution of the quadratic time equation.

22. An artillery shell is fired directly up from a gun; a rocket, propelled by burning fuel, takes off vertically from a launching area. Plot qualitatively (numbers not required) *possible* graphs of a_y versus t, of v_y versus t, and of y versus t for each. Take $t = 0$ at the instant the shell leaves the gun barrel or the rocket leaves the ground. Continue the plots until the rocket and the shell fall back to earth; neglect air resistance; assume that up is positive and down is negative.

23. A rocket is fired vertically and ascends with a constant vertical acceleration of 64 ft/sec^2 for 1.0 min. Its fuel is then all used and it continues as a free particle. (*a*) What is the maximum altitude reached? (*b*) What is the total time elapsed from take-off until the rocket strikes the earth?

24. A lead ball is dropped into a lake from a diving board 16 ft above the water. It hits the water with a certain velocity and then sinks to the bottom with this same constant velocity. It reaches the bottom 5.0 sec after it is dropped. (*a*) How deep is

27. The engineer of a train moving at a speed v_1 sights a freight train a distance d ahead of him on the same track moving in the same direction with a slower speed v_2. He puts on the brakes and gives his train a constant deceleration a. Show that

$$\text{if } d > \frac{(v_1 - v_2)^2}{2a}, \text{ there will be no collision;}$$

$$\text{if } d < \frac{(v_1 - v_2)^2}{2a}, \text{ there will be a collision.}$$

(It is instructive to plot a qualitative graph of x versus t for each train.)

3rd

28. A driver's handbook states that an automobile with good brakes and going 50 mi/h can stop in a distance of 186 ft. The corresponding distance for 30 mi/h is 80 ft. Assume that the driver reaction time, during which the acceleration is zero, and the acceleration after he applies the brakes are both the same for the two speeds. Calculate (*a*) the driver reaction time and (*b*) the acceleration.

SECTION 3-9

29. The position of a particle along the x-axis depends on the time according to the equation

$$x = at^2 - bt^3,$$

where x is in meters and t in seconds. (*a*) What dimensions and units must a and b have? For the following, let their numerical values be 3.0 and 1.0, respectively. (*b*) At what time does the particle reach its maximum positive x-position? (*c*) What total length of path does the particle cover in the first 4.0 s? (*d*) What is its displacement during the first 4.0 s? (*e*) What is the particle's velocity at the end of each of the first four seconds? (*f*) What is the particle's acceleration at the end of each of the first four seconds? (*g*) What is the average velocity for the time interval $t = 2.0$ to $t = 4.0$ seconds? *Answer:* (*a*) *a*: LT^{-2}, m/s^2; *b*: LT^{-3}, m/s^3. (*b*) t = 2 s. (*c*) 24 m. (*d*) −16 m. (*e*) 3.0, 0.0, −9.0, −24.0 m/s. (*f*) 0.0, −6.0, −12.0, −18.0 m/s^2. (*g*) −10 m/s.

SECTION 3-11

30. (*a*) With what speed must a ball be thrown vertically upward in order to rise to a height of 50 ft? (*b*) How long will it be in the air?

31. A tennis ball is dropped onto the floor from a height of 4.0 ft. It rebounds to a height of 3.0 ft. If the ball was in contact with the floor for 0.010 s, what was its average acceleration during contact? *Answer:* 3000 ft/s^2

32. While thinking of Isaac Newton, a person standing on a bridge overlooking a highway inadvertently drops an apple over the railing just as the front end of a truck passes directly below the railing. If the vehicle is moving at 55 km/h (34 mi/h) and is 12 m (39 ft) long, how far above the truck must the railing be if the apple just misses hitting the rear end of the truck?

33. A lead ball is dropped into a lake from a diving board 16 ft above the water. It hits the water with a certain velocity and then sinks to the bottom with this same constant velocity. It reaches the bottom 5.0 s after it is dropped. (*a*) How deep is the lake? (*b*) What is the average velocity of the ball? (*c*) Suppose all the water is drained from the lake. The ball is thrown from the diving board so that it again reaches the bottom in 5.0 s. What is the initial velocity of the ball? *Answer:* (*a*) 128 ft. (*b*) 29 ft/s. (*c*) 51 ft/s upward.

34. A rocket is fired vertically and ascends with a constant vertical acceleration of 64 ft/s^2 for 1.0 min. Its fuel is then all used and it continues as a free particle. (*a*) What is the maximum altitude reached? (*b*) What is the total time elapsed from takeoff until the rocket strikes the earth?

35. A balloon is ascending at the rate of 12 m/s at a height 80 m above the ground when a package is dropped. How long does it take the package to reach the ground? *Answer:* 5.4 s.

46P. A hot rod can accelerate from 0 to 60 km/h in 5.4 s. (a) What is its average acceleration, in m/s², during this time? (b) How far will it travel during the 5.4 s, assuming its acceleration is constant? (c) How much time would it require to go a distance of 0.25 km if its acceleration could be maintained at the value in (a)?

47P. A train started from rest and moved with constant acceleration. At one time it was traveling 30 m/s, and 160 m farther on it was traveling 50 m/s. Calculate (a) the acceleration, (b) the time required to travel the 160 m mentioned, (c) the time required to attain the speed of 30 m/s, and (d) the distance moved from rest to the time the train had a speed of 30 m/s. (e) Graph x versus t and v versus t for the train, from rest.

48P. A car traveling 56.0 km/h is 24.0 m from a barrier when the driver slams on the brakes. The car hits the barrier 2.00 s later. (a) What was the car's constant deceleration before impact? (b) How fast was the car traveling at impact?

49P. A car moving with constant acceleration covers the distance between two points 60.0 m apart in 6.00 s. Its speed as it passes the second point is 15.0 m/s. (a) What is the speed at the first point? (b) What is the acceleration? (c) At what prior distance from the first point was the car at rest? (d) Graph x versus t and v versus t for the car, from rest.

50P. Two subway stops are separated by 1100 m. If a subway train accelerates at +1.2 m/s² from rest through the first half of the distance and decelerates at −1.2 m/s² through the second half, what are (a) its travel time and (b) its maximum speed? (c) Graph x, v, and a versus t for the trip.

51P. To stop a car, you require first a certain reaction time to begin braking; then the car slows under the constant braking deceleration. Suppose that the total distance moved by your car during these two phases is 186 ft when its initial speed is 50 mi/h, and 80 ft when the initial speed is 30 mi/h. What are (a) your reaction time and (b) the magnitude of the deceleration?

52P. You are driving toward a traffic signal when it turns yellow. Your speed is the legal speed limit of $v_0 = 35$ mi/h; your best deceleration rate is $a = 17$ ft/s². Your best reaction time to begin braking is $T = 0.75$ s. To avoid having the front of your car enter the intersection after the light turns red, should you brake to a stop or continue to move at 35 mi/h if the distance to the intersection and the duration of the yellow light are (a) 40 m and 2.8 s, and (b) 32 m and 1.8 s?

53P. When a driver brings a car to a stop by braking as hard as possible, the stopping distance can be regarded as the sum of a "reaction distance," which is initial speed times the driver's reaction time, and a "braking distance," which is the distance covered during braking. The following table gives typical values:

Initial Speed (m/s)	Reaction Distance (m)	Braking Distance (m)	Stopping Distance (m)
10	7.5	5.0	12.5
20	15	20	35
30	22.5	45	67.5

(a) What reaction time is the driver assumed to have? (b) What is the car's stopping distance if the initial speed is 25 m/s?

54P. (a) If the maximum acceleration that is tolerable for passengers in a subway train is 1.34 m/s², and subway stations are located 806 m apart, what is the maximum speed a subway train can attain between stations? (b) What is the travel time between stations? (c) If the subway train stops for 20 s at each station, what is the maximum average speed of a subway train, from one start-up to the next? (d) Graph x, v, and a versus t.

55P. An elevator cab in the New York Marquis Marriott has a total run of 624 ft. Its maximum speed is 1000 ft/min. Its acceleration and deceleration both have a magnitude of 4.0 ft/s². (a) How far does the cab move while accelerating to full speed from rest? (b) How long does it take to make the nonstop 624 ft run, starting and ending at rest?

56P. At the instant the traffic light turns green, an automobile starts with a constant acceleration a of 2.2 m/s². At the same instant a truck, traveling with a constant speed of 9.5 m/s, overtakes and passes the automobile. (a) How far beyond the traffic signal will the automobile overtake the truck? (b) How fast will the car be traveling at that instant?

57P. When a high-speed passenger train traveling at 100 mi/h rounds a bend, the engineer is shocked to see that a locomotive has improperly entered onto the track from a siding 0.42 mi ahead; see Fig. 2-26. The locomotive is moving at 18 mi/h. The engineer of the passenger train immediately applies the brakes. (a) What must be the magnitude of the resulting constant acceleration if a collision is to be just avoided? (b) Assume that the

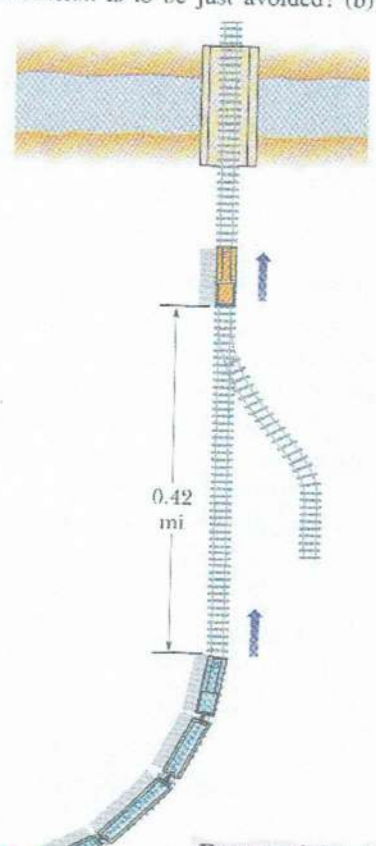


FIGURE 2-26 Problem 57.

engineer is at $x = 0$ when, at $t = 0$, he first spots the locomotive. Sketch the $x(t)$ curves representing the locomotive and passenger train for the situations in which a collision is just avoided and not quite avoided.

58P. Two trains, one traveling at 72 km/h and the other at 144 km/h, are headed toward one another along a straight, level track. When they are 950 m apart, each engineer sees the other's train and applies the brakes. The brakes decelerate each train at the rate of 1.0 m/s². Is there a collision?

59P. Sketch a $v(t)$ graph that would be associated with the $a(t)$ graph shown in Fig. 2-27.

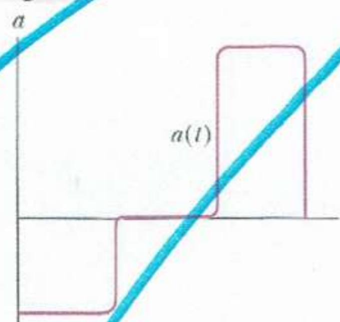


FIGURE 2-27 Problem 59.

SECTION 2-8 Free-Fall Acceleration

60E. At a construction site a pipe wrench strikes the ground with a speed of 24 m/s. (a) From what height was it inadvertently dropped? (b) How long was it falling? (c) Sketch graphs of y, v, and a versus t for the wrench.

61E. (a) With what speed must a ball be thrown vertically from ground level to rise to a maximum height of 50 m? (b) How long will it be in the air? (c) Sketch graphs of y, v, and a versus t for the ball. On the first two graphs, indicate the time at which 50 m is reached.

62E. Raindrops fall to Earth from a cloud 1700 m above the Earth's surface. If they were not slowed by air resistance, how fast would the drops be moving when they struck the ground? Would it be safe to walk outside during a rainstorm?

63E. The single cable supporting an unoccupied construction elevator breaks when the elevator is at rest at the top of a 120-m-high building. (a) With what speed does the elevator strike the ground? (b) How long was it falling? (c) What was its speed when it passed the halfway point on the way down? (d) How long had it been falling when it passed the halfway point?

64E. A hoodlum throws a stone vertically downward with an initial speed of 12.0 m/s from the roof of a building, 30.0 m above the ground. (a) How long does it take the stone to reach the ground? (b) What is the speed of the stone at impact?

65E. The Zero Gravity Research Facility at the NASA Lewis Research Center includes a 145 m drop tower. This is an evacuated vertical tower through which, among other possibilities, a 1 m diameter sphere containing an experimental package can be dropped. (a) How long is the sphere in free fall? (b) What is its speed just as it reaches a catching device at the bottom of the tower? (c) When caught, the sphere experiences an average deceleration of $25g$ as its speed is reduced to zero. Through what distance does it travel during the deceleration?

66E. A model rocket, propelled by burning fuel, takes off vertically. Plot qualitatively (numbers not required) graphs of y, v, and a versus t for the rocket's flight. Indicate when the fuel is exhausted, when the rocket reaches maximum height, and when it returns to the ground.

67E. A rock is dropped from a 100-m-high cliff. How long does it take to fall (a) the first 50 m and (b) the second 50 m?

68P. A startled armadillo leaps upward (Fig. 2-28), rising 0.544 m in 0.200 s. (a) What was its initial speed? (b) What is its speed at this height? (c) How much higher does it go?

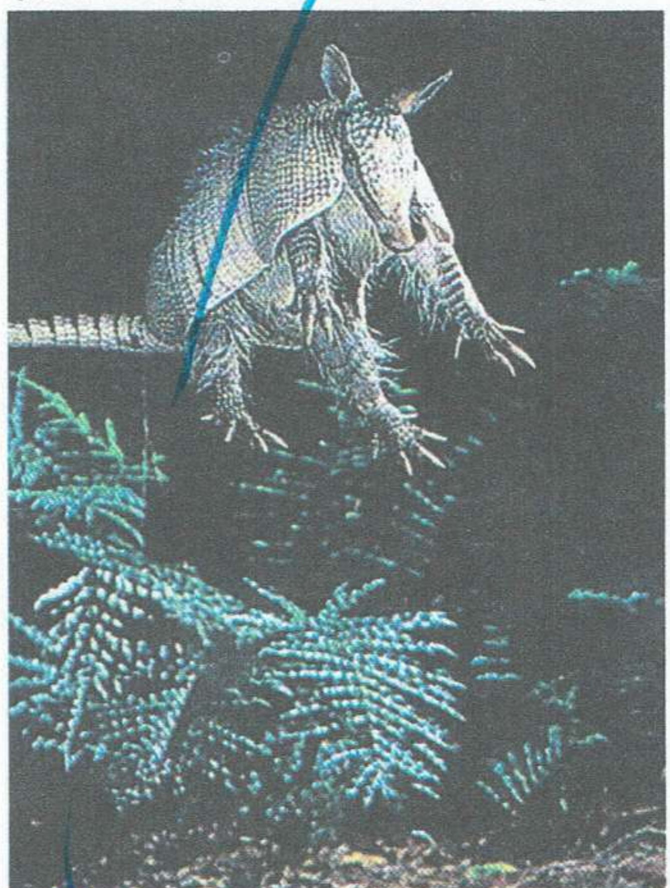


FIGURE 2-28 Problem 68.

69P. An object falls from a bridge that is 45 m above the water. It falls directly into a model boat, moving with constant velocity, that was 12 m from the point of impact when the object was released. What was the speed of the boat?

70P. A model rocket is fired vertically and ascends with a constant vertical acceleration of 4.00 m/s² for 6.00 s. Its fuel is then exhausted and it continues as a free-fall particle. (a) What is the maximum altitude reached? (b) What is the total time elapsed from takeoff until the rocket strikes the Earth?

71P. A basketball player, standing near the basket to grab a rebound, jumps 76.0 cm vertically. How much (total) time does the player spend (a) in the top 15.0 cm of this jump and (b) in the bottom 15.0 cm? Does this help explain why such players seem to hang in the air at the tops of their jumps?

gives their velocities v as functions of time t as the conductors slow the trains. The figure's vertical scaling is set by $v_s = 40.0$ m/s. The slowing processes begin when the trains are 200 m apart. What is their separation when both trains have stopped?

••40 In Fig. 2-28, a red car and a green car, identical except for the color, move toward each other in adjacent lanes and parallel to an x axis. At time $t = 0$, the red car is at $x_r = 0$ and the green car is at $x_g = 220$ m. If the red car has a constant velocity of 20 km/h, the cars pass each other at $x = 44.5$ m, and if it has a constant velocity of 40 km/h, they pass each other at $x = 76.6$ m. What are (a) the initial velocity and (b) the acceleration of the green car?

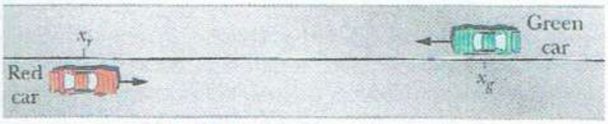


FIG. 2-28 Problems 40 and 41.

••41 Figure 2-28 shows a red car and a green car that move toward each other. Figure 2-29 is a graph of their motion, showing the positions $x_{g0} = 270$ m and $x_{r0} = -35.0$ m at time $t = 0$. The green car has a constant speed of 20.0 m/s and the red car begins from rest. What is the acceleration magnitude of the red car?

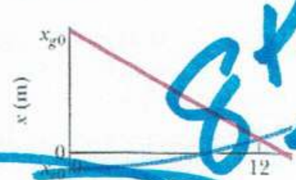


FIG. 2-29 Problem 41.

•••42 When a high-speed passenger train traveling at 161 km/h rounds a bend, the engineer is shocked to see that a locomotive has improperly entered onto the track from a siding and is a distance $D = 676$ m ahead (Fig. 2-30). The locomotive is moving at 29.0 km/h. The engineer of the high-speed train immediately applies the brakes. (a) What must be the magnitude of the resulting constant deceleration if a collision is to be just avoided? (b) Assume that the engineer is at $x = 0$ when, at $t = 0$, he first spots the locomotive. Sketch $x(t)$ curves for the locomotive and high-speed train for the cases in which a collision is just avoided and is not quite avoided. GO

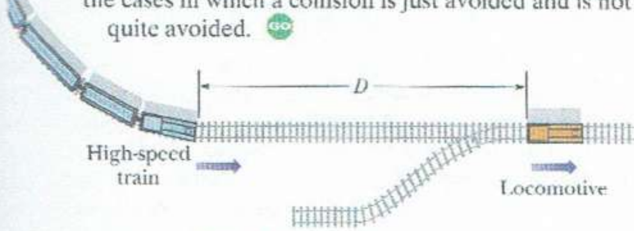


FIG. 2-30 Problem 42.

•••43 You are arguing over a cell phone while trailing an unmarked police car by 25 m; both your car and the police car are traveling at 110 km/h. Your argument diverts your attention from the police car for 2.0 s (long enough for you to look at the phone and yell, "I won't do that!"). At the beginning of that 2.0 s, the police officer begins braking suddenly at 5.0 m/s^2. (a) What is the separation between the two cars when your attention finally returns? Suppose that you take another 0.40 s to realize your danger and begin braking. (b) If you too brake at 5.0 m/s^2, what is your speed when you hit the police car?

sec. 2-9 Free-Fall Acceleration

•44 Raindrops fall 1700 m from a cloud to the ground. (a) If they were not slowed by air resistance, how fast would the drops be moving when they struck the ground? (b) Would it be safe to walk outside during a rainstorm?

•45 At a construction site a pipe wrench struck the ground with a speed of 24 m/s. (a) From what height was it inadvertently dropped? (b) How long was it falling? (c) Sketch graphs of y, v, and a versus t for the wrench. SSM

•46 A hoodlum throws a stone vertically downward with an initial speed of 12.0 m/s from the roof of a building, 30.0 m above the ground. (a) How long does it take the stone to reach the ground? (b) What is the speed of the stone at impact?

•47 (a) With what speed must a ball be thrown vertically from ground level to rise to a maximum height of 50 m? (b) How long will it be in the air? (c) Sketch graphs of y, v, and a versus t for the ball. On the first two graphs, indicate the time at which 50 m is reached. SSM WWW

•48 When startled, an armadillo will leap upward. Suppose it rises 0.544 m in the first 0.200 s. (a) What is its initial speed as it leaves the ground? (b) What is its speed at the height of 0.544 m? (c) How much higher does it go?

•49 A hot-air balloon is ascending at the rate of 12 m/s and is 80 m above the ground when a package is dropped over the side. (a) How long does the package take to reach the ground? (b) With what speed does it hit the ground? SSM

••50 A bolt is dropped from a bridge under construction, falling 90 m to the valley below the bridge. (a) In how much time does it pass through the last 20% of its fall? What is its speed (b) when it begins that last 20% of its fall and (c) when it reaches the valley beneath the bridge?

••51 A key falls from a bridge that is 45 m above the water. It falls directly into a model boat, moving with constant velocity, that is 12 m from the point of impact when the key is released. What is the speed of the boat? SSM ILW

••52 At time $t = 0$, apple 1 is dropped from a bridge onto a roadway beneath the bridge; somewhat later, apple 2 is thrown down from the same height. Figure 2-31 gives the vertical positions y of the apples versus t during the falling, until both apples have hit the roadway. With approximately what speed is apple 2 thrown down?

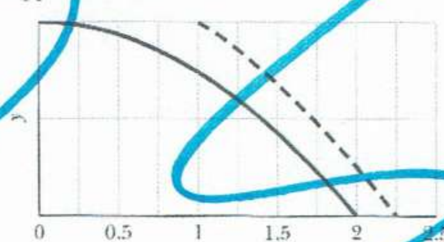


FIG. 2-31 Problem 52.

••53 As a runaway scientific balloon ascends at 19.6 m/s, one of its instrument packages breaks free of a harness and free-falls. Figure 2-32 gives the vertical velocity of the package versus time, from before it breaks free to when it reaches the ground. (a) What maximum

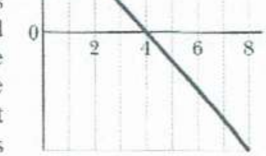


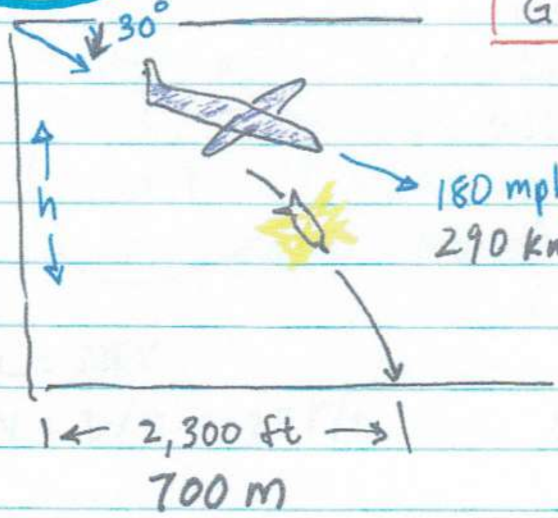
FIG. 2-32 Problem 53.

WHY

5th

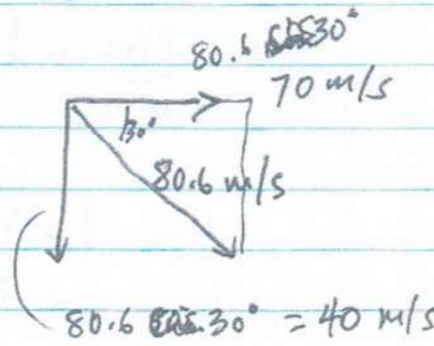
4-48

Go metric!!



h =

Δt =



$y(t) = \frac{9.8}{2} \frac{m}{s} \times t^2 + 40t$

t = 10 s

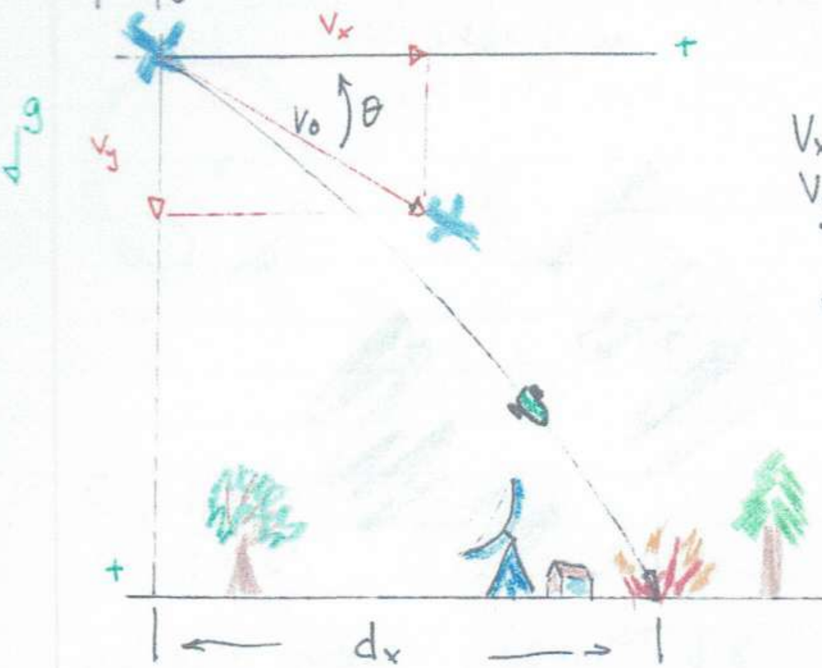
y(10) =

PAST DUE

The evolution of politically correct problems
Physics and war
War and money for research
How did the problem grow easier? 2nd to 5th Eds??
English to SI systems.

HOW

4-48



$V_x = V_0 \cos\theta$

$V_y = V_0 \sin\theta - gt$

$d_x = (V_0 \cos\theta)\, t$

$t = \frac{d_x}{V_x \cos\theta} = \frac{700}{80.6 \times \sqrt{3}/2} = 10$

$y = +g\frac{t^2}{2} + (V_0 \sin\theta)\, t$

$=$

$V_0 = 180 \text{ mph} = 180 \frac{\text{miles}}{\text{hour}} \times 5280 \frac{\text{ft}}{\text{mi}} \times 12 \frac{\text{in}}{\text{ft}} \times \frac{2.54}{100} \frac{\text{m}}{\text{in}} \times \frac{1 \text{ hr}}{3600 \text{ s}}$

$= 80.4 \text{ m/s}$

$V_x = 80.4 \times \cos 30° = 70.0 \text{ m/s}$ $\quad t = \frac{700 \text{ m}}{70 \text{ m/s}} = 10 \text{ s}$

$V_y = 80.4 \times \sin 30° = 40.2 \text{ m/s}$

6. Show that the horizontal range of a projectile having an initial speed v_0 and angle of projection θ_0 is $R = (v_0^2/g) \sin 2\theta_0$. Then show that a projection angle of 45° gives the maximum horizontal range (Fig. 4-13).

7. Find the angle of projection at which the horizontal range and the maximum height of a projectile are equal.

8. In Galileo's *Two New Sciences* the author states that "for elevations (angles of projection) which exceed or fall short of 45° by equal amounts, the ranges are equal . . . ". Prove this statement.

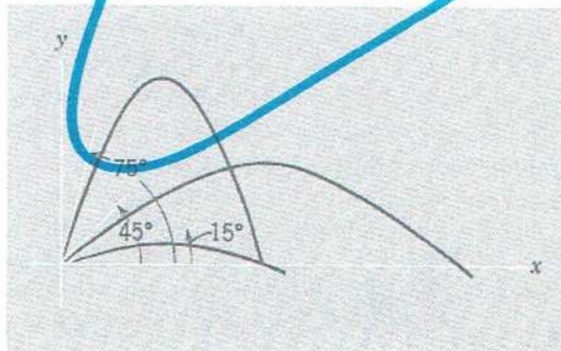


Fig. 4-13

9. A rifle with a muzzle velocity of 1500 ft/sec shoots a bullet at a small target 150 ft away. How high above the target must the gun be aimed so that the bullet will hit the target?

10. A dive bomber, diving at an angle of 53° with the vertical, releases a bomb at an altitude of 2400 ft. The bomb hits the ground 5.0 sec after being released. (*a*) What is the speed of the bomber? (*b*) How far did the bomb travel horizontally during its flight? (*c*) What were the horizontal and vertical components of its velocity just before striking the ground?

11. A batter hits a pitched ball at a height 4.0 ft above ground so that its angle of projection is 45° and its horizontal range is 350 ft. The ball is fair down the left field line where a 24-ft-high fence is located 320 ft from home plate. Will the ball clear the fence?

12. A football is kicked off with an initial speed of 64 ft/sec at a projection angle of 45°. A receiver on the goal line 60 yd away in the direction of the kick starts running to meet the ball at that instant. What must his speed be if he is to catch the ball before it hits the ground?

13. In a cathode-ray tube a beam of electrons is projected horizontally with a speed of 1.0×10^9 cm/sec into the region between a pair of horizontal plates 2.0 cm long. An electric field between the plates exerts a constant downward acceleration on the electrons of magnitude 1.0×10^{17} cm/sec². Find (*a*) the vertical displacement of the beam in passing through the plates and (*b*) the velocity of the beam (direction and magnitude) as it emerges from the plates.

14. (*a*) Show that if the acceleration of gravity changes by an amount dg, the range of a projectile (see Problem 6) of given initial speed v_0 and angle of projection θ_0 changes by dR where $dR/R = -dg/g$. (*b*) If the acceleration of gravity changes by a small amount Δg (say by going from one place to another), the range for a given projectile system will change as well. Let the change in range be ΔR. If Δg, ΔR are small enough, we may write $\Delta R/R = -\Delta g/g$. In 1936, Jesse Owens (United States) established a world's running broad jump record of 8.09 meters at the Olympic games at Berlin ($g = 9.8128$ meters/sec²). By how much would his record have differed if he had competed instead in 1956 at Melbourne ($g = 9.7999$ meters/sec²)? (In this connection see "Bad Physics in Athletic Measurements," by P. Kirkpatrick, *American Journal of Physics*, February 1944.)

15. Electrons, nuclei, atoms and molecules, like all forms of matter, will fall under the influence of gravity. Consider separately a beam of electrons, of nuclei, of atoms, and of molecules traveling a horizontal distance of 1.0 meter. Let the average speed be

of projection θ_0 is $R = (v_0^2/g) \sin 2\theta_0$. Then show that a projection angle of 45° gives the maximum range (Fig. 4-14). (*b*) Show that the maximum height reached by the projectile is $y_{max} = (v_0 \sin \theta_0)^2/2g$. (*c*) Find the angle of projection at which the range and the maximum height of a projectile are equal. *Answer:* (*c*) 76°.

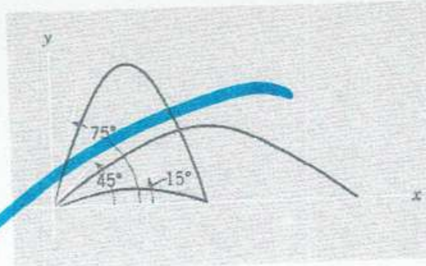


figure 4-14
Problems 7, and 15

8. A projectile is fired horizontally from a gun located 144 ft (44 m) above a horizontal plane with a muzzle speed of 800 ft/s (240 m/s). (*a*) How long does the projectile remain in the air? (*b*) At what horizontal distance does it strike the ground? (*c*) What is the magnitude of the vertical component of its velocity as it strikes the ground?

9. A ball is thrown from the ground into the air. At a height of 9.1 m the velocity is observed to be $\mathbf{v} = 7.6\mathbf{i} + 6.1\mathbf{j}$ in m/s (*x*-axis horizontal, *y*-axis vertical). (*a*) To what maximum height will the ball rise? (*b*) What will be the total horizontal distance traveled by the ball? (*c*) What is the velocity of the ball (magnitude and direction) the instant before it hits the ground? *Answer:* (*a*) 11 m. (*b*) 23 m. (*c*) 17 m/s, 63° below the horizontal.

10. Electrons, nuclei, atoms, and molecules, like all forms of matter, will fall under the influence of gravity. Consider separately a beam of electrons, of nuclei, of atoms, and of molecules traveling a horizontal distance of 1.0 m. Let the average speed be for an electron 3.0×10^7 m/s, for a thermal neutron 2.2×10^3 m/s, for a neon atom 5.8×10^2 m/s, and for an oxygen molecule 4.6×10^2 m/s. Let the beams move through vacuum with initial horizontal velocities and find by how much their paths deviate from a straight line (vertical displacement in 1.0 m) due to gravity. How do these results compare to that for a beam of golf balls (use reasonable data)? What is the controlling factor here?

11. A dive bomber, diving at an angle of 53° with the vertical, releases a bomb at an altitude of 730 m. The bomb hits the ground 5.0 s after being released. (*a*) What is the speed of the bomber? (*b*) How far did the bomb travel horizontally during its flight? (*c*) What were the horizontal and vertical components of its velocity just before striking the ground? *Answer:* (*a*) 200 m/s. (*b*) 810 m. (*c*) $v_h = 160$ m/s, $v_v = 170$ m/s.

12. A football is kicked off with an initial speed of 64 ft/s at a projection angle of 45°. A receiver on the goal line 60 yd away in the direction of the kick starts running to meet the ball at that instant. What must be his minimum speed if he is to catch the ball before it hits the ground? (See, in this connection, "Catching a Baseball" by Seville Chapman in *American Journal of Physics*, October 1968.)

13. In a cathode-ray tube a beam of electrons is projected horizontally with a speed of 1.0×10^9 cm/s into the region between a pair of horizontal plates 2.0 cm long. An electric field between the plates exerts a constant downward acceleration on the electrons of magnitude 1.0×10^{17} cm/s². Find (*a*) the vertical displacement of the beam in passing through the plates and (*b*) the velocity of the beam (direction and magnitude) as it emerges from the plates. *Answer:* (*a*) 2.0 mm. (*b*) $v_x = 1.0 \times 10^9$ cm/s, $v_y = 0.2 \times 10^9$ cm/s down.

14. A batter hits a pitched ball at a height of 4.0 ft above the ground so that its angle of projection is 45° and its initial speed is 110 ft/s. The ball is hit fair down the left field line where a 24-ft high fence is located 320 ft from home plate. Will the ball clear the fence?

15. Galileo, in his *Two New Sciences*, states that "for elevations (angles of projection) which exceed or fall short of 45° by equal amounts, the ranges are equal. . . ." Prove this statement. See Fig. 4-14.

16. A ball rolls off the top of a stairway with a horizontal velocity of magnitude 5.0 ft/s. The steps are 8.0 in. high and 8.0 in. wide. Which step will the ball hit first?

17. (*a*) Show that if the acceleration due to gravity changes by an amount dg, the range of a projectile (see Problem 7) of given initial speed v_0 and angle

ning broad jump record of 8.09 m at the Olympic Games at Berlin ($g = 9.8128$ m/s^2). Assuming the same values of v_0 and θ_0, by how much would his record have differed if he had competed instead in 1956 at Melbourne ($g = 9.7999$ m/s^2)?

41P. A third baseman wishes to throw to first base, 127 ft distant. His best throwing speed is 85 mi/h. (a) If he throws the ball horizontally 3.0 ft above the ground, how far from first base will it hit the ground? (b) At what upward angle must the third baseman throw the ball if the first baseman is to catch it 3.0 ft above the ground? (c) What will be the time of flight in that case?

42P. During volcanic eruptions, chunks of solid rock can be blasted out of the volcano; these projectiles are called *volcanic bombs*. Figure 4-35 shows a cross section of Mt. Fuji, in Japan. (a) At what initial speed would a bomb have to be ejected, at 35° to the horizontal, from the vent at A in order to fall at the foot of the volcano at B? Ignore, for the moment, the effects of air on the bomb's travel. (b) What would be the time of flight? (c) Would the effect of the air increase or decrease your answer in (a)?

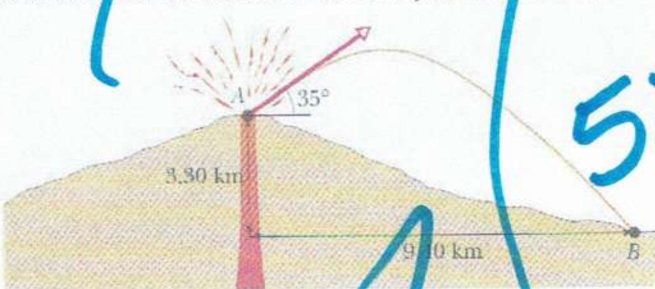


FIGURE 4-35 Problem 42.

43P. At what initial speed must the basketball player throw the ball, at 55° above the horizontal, to make the foul shot, as shown in Fig. 4-36?

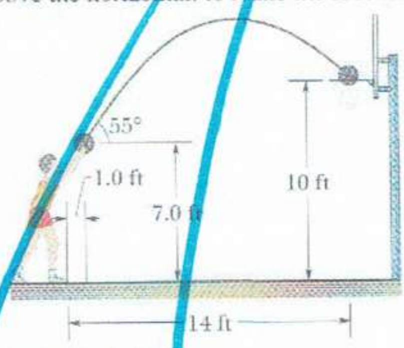


FIGURE 4-36 Problem 43.

44P. A football player punts the football so that it will have a "hang time" (time of flight) of 4.5 s and land 50 yd away. If the ball leaves the player's foot 5.0 ft above the ground, what initial velocity (magnitude and direction) must the ball have?

45P. A golfer tees off from the top of a rise, giving the golf ball an initial velocity of 43 m/s at an angle of 30° above the horizontal. The ball strikes the fairway a horizontal distance of 180 m from the tee. Assume the fairway is level. (a) How high is the rise above the fairway? (b) What is the speed of the ball as it strikes the fairway?

46P. A projectile is fired with an initial speed $v_0 = 30.0$ m/s from the level ground at a target on the ground a distance $R = 20.0$ m away (Fig. 4-37). Find the two projection angles.

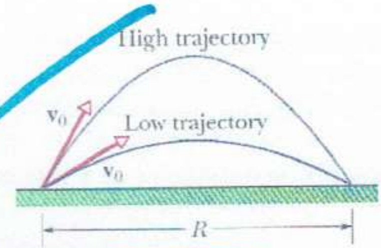


FIGURE 4-37 Problem 46.

47P. What is the maximum vertical height to which a baseball player can throw a ball if his maximum throwing *range* is 60 m?

48P. A certain airplane has a speed of 180 mi/h and is diving at an angle of 30.0° below the horizontal when a radar decoy is released. (See Fig. 4-38.) The horizontal distance between the release point and the point where the decoy strikes the ground is 2300 ft. (a) How high was the plane when the decoy was released? (b) How long was the decoy in the air?

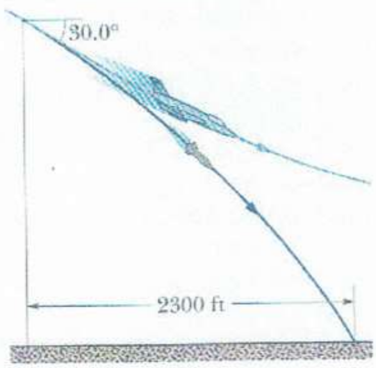


FIGURE 4-38 Problem 48.

49P. A football is kicked off with an initial speed of 64 ft/s at a projection angle of 45°. A receiver 60 yd away in the direction of the kick starts running to meet the ball at that instant. What must be his average speed if he is to catch the ball just before it hits the ground? Neglect air resistance.

50P. A ball rolls horizontally off the top of a stairway with a speed of 5.0 ft/s. The steps are 8.0 in. high and 8.0 in. wide. Which step will the ball hit first?

51P. An airplane, diving at an angle of 53.0° with the vertical, releases a projectile at an altitude of 730 m. The projectile hits the ground 5.00 s after being released. (a) What is the speed of the aircraft? (b) How far did the projectile travel horizontally during its flight? (c) What were the horizontal and vertical components of its velocity just before striking the ground?

52P. A ball is thrown horizontally from a height of 20 m and hits the ground with a speed that is three times its initial speed. What was the initial speed?

53P. (a) During a tennis match, a player serves at 23.6 m/s, the ball leaving the racquet horizontally 2.37 m above the court surface. By how much does the ball clear the net, which is 12 m away and 0.90 m high? (b) Suppose the player serves the ball as before except that the ball leaves the racquet at 5.00° below the horizontal. Does the ball clear the net now?

54P. In Sample Problem 4-8, suppose that a second identical harbor defense cannon is emplaced 30 m above sea level, rather that at sea level. How much longer is the horizontal distance from

sec. 4-4 Average Acceleration and Instantaneous Acceleration

•**11** A particle moves so that its position (in meters) as a function of time (in seconds) is $\vec{r} = \hat{i} + 4t^2\hat{j} + t\hat{k}$. Write expressions for (a) its velocity and (b) its acceleration as functions of time. **SSM**

•**12** A proton initially has $\vec{v} = 4.0\hat{i} - 2.0\hat{j} + 3.0\hat{k}$ and then 4.0 s later has $\vec{v} = -2.0\hat{i} - 2.0\hat{j} + 5.0\hat{k}$ (in meters per second). For that 4.0 s, what are (a) the proton's average acceleration $\vec{a}_{avg}$ in unit-vector notation, (b) the magnitude of $\vec{a}_{avg}$, and (c) the angle between $\vec{a}_{avg}$ and the positive direction of the x axis?

•**13** The position $\vec{r}$ of a particle moving in an xy plane is given by $\vec{r} = (2.00t^3 - 5.00t)\hat{i} + (6.00 - 7.00t^4)\hat{j}$, with $\vec{r}$ in meters and t in seconds. In unit-vector notation, calculate (a) $\vec{r}$, (b) $\vec{v}$, and (c) $\vec{a}$ for $t = 2.00$ s. (d) What is the angle between the positive direction of the x axis and a line tangent to the particle's path at $t = 2.00$ s? **GO**

•**14** At one instant a bicyclist is 40.0 m due east of a park's flagpole, going due south with a speed of 10.0 m/s. Then 30.0 s later, the cyclist is 40.0 m due north of the flagpole, going due east with a speed of 10.0 m/s. For the cyclist in this 30.0 s interval, what are the (a) magnitude and (b) direction of the displacement, the (c) magnitude and (d) direction of the average velocity, and the (e) magnitude and (f) direction of the average acceleration?

••**15** A cart is propelled over an xy plane with acceleration components $a_x = 4.0\text{ m/s}^2$ and $a_y = -2.0\text{ m/s}^2$. Its initial velocity has components $v_{0x} = 8.0$ m/s and $v_{0y} = 12$ m/s. In unit-vector notation, what is the velocity of the cart when it reaches its greatest y coordinate?

••**16** A moderate wind accelerates a pebble over a horizontal xy plane with a constant acceleration $\vec{a} = (5.00\text{ m/s}^2)\hat{i} + (7.00\text{ m/s}^2)\hat{j}$. At time $t = 0$, the velocity is $(4.00\text{ m/s})\hat{i}$. What are the (a) magnitude and (b) angle of its velocity when it has been displaced by 12.0 m parallel to the x axis?

••**17** A particle leaves the origin with an initial velocity $\vec{v} = (3.00\hat{i})$ m/s and a constant acceleration $\vec{a} = (-1.00\hat{i} - 0.500\hat{j})\text{ m/s}^2$. When it reaches its maximum x coordinate, what are its (a) velocity and (b) position vector? **SSM ILW**

••**18** The velocity $\vec{v}$ of a particle moving in the xy plane is given by $\vec{v} = (6.0t - 4.0t^2)\hat{i} + 8.0\hat{j}$, with $\vec{v}$ in meters per second and t (> 0) in seconds. (a) What is the acceleration when $t = 3.0$ s? (b) When (if ever) is the acceleration zero? (c) When (if ever) is the velocity zero? (d) When (if ever) does the speed equal 10 m/s?

•••**19** The acceleration of a particle moving only on a horizontal xy plane is given by $\vec{a} = 3t\hat{i} + 4t\hat{j}$, where $\vec{a}$ is in meters per second-squared and t is in seconds. At $t = 0$, the position vector $\vec{r} = (20.0\text{ m})\hat{i} + (40.0\text{ m})\hat{j}$ locates the particle, which then has the velocity vector $\vec{v} = (5.00\text{ m/s})\hat{i} + (2.00\text{ m/s})\hat{j}$. At $t = 4.00$ s, what are (a) its position vector in unit-vector notation and (b) the angle between its direction of travel and the positive direction of the x axis?

•••**20** In Fig. 4-35, particle A moves along the line $y = 30$ m with a constant velocity $\vec{v}$ of magnitude 3.0 m/s and parallel to the x axis. At the instant particle A passes the y axis, particle B leaves the origin with zero initial speed and constant acceleration $\vec{a}$ of magnitude 0.40 m/s². What angle θ between $\vec{a}$ and the positive direction of the y axis would result in a collision?

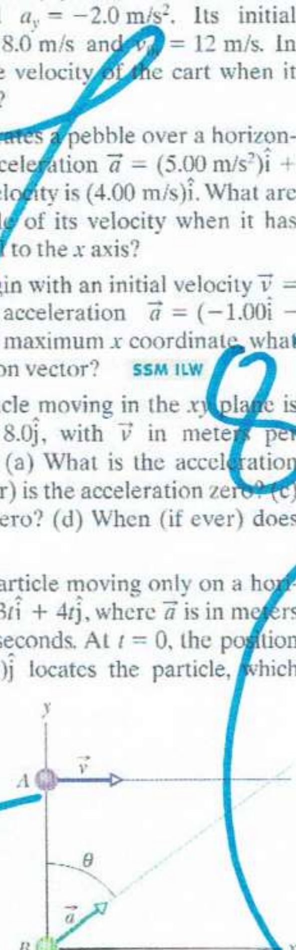


FIG. 4-35 Problem 20.

sec. 4-6 Projectile Motion Analyzed

•**21** A projectile is fired horizontally from a gun that is 45.0 m above flat ground, emerging from the gun with a speed of 250 m/s. (a) How long does the projectile remain in the air? (b) At what horizontal distance from the firing point does it strike the ground? (c) What is the magnitude of the vertical component of its velocity as it strikes the ground?

•**22** In the 1991 World Track and Field Championships in Tokyo, Mike Powell jumped 8.95 m, breaking by a full 5 cm the 23-year long-jump record set by Bob Beamon. Assume that Powell's speed on takeoff was 9.5 m/s (about equal to that of a sprinter) and that $g = 9.80\text{ m/s}^2$ in Tokyo. How much less was Powell's range than the maximum possible range for a particle launched at the same speed?

•**23** The current world-record motorcycle jump is 77.0 m, set by Jason Renie. Assume that he left the take-off ramp at 12.0° to the horizontal and that the take-off and landing heights are the same. Neglecting air drag, determine his take-off speed.

•**24** A small ball rolls horizontally off the edge of a tabletop that is 1.20 m high. It strikes the floor at a point 1.52 m horizontally from the table edge. (a) How long is the ball in the air? (b) What is its speed at the instant it leaves the table?

•**25** A dart is thrown horizontally with an initial speed of 10 m/s toward point P, the bull's-eye on a dart board. It hits at point Q on the rim, vertically below P, 0.19 s later. (a) What is the distance PQ? (b) How far away from the dart board is the dart released?

•**26** In Fig. 4-36, a stone is projected at a cliff of height h with an initial speed of 42.0 m/s directed at angle $\theta_0 = 60.0°$ above the horizontal. The stone strikes at A, 5.50 s after launching. Find (a) the height h of the cliff, (b) the speed of the stone just before impact at A, and (c) the maximum height H reached above the ground.

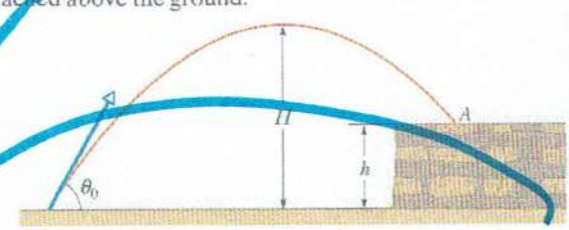


FIG. 4-36 Problem 26.

•**27** A certain airplane has a speed of 290.0 km/h and is diving at an angle of $\theta = 30.0°$ below the horizontal when the pilot releases a radar decoy (Fig. 4-37). The horizontal distance between the release point and the point where the decoy strikes the ground is $d = 700$ m. (a) How long is the decoy in the air? (b) How high was the release point? **ILW**

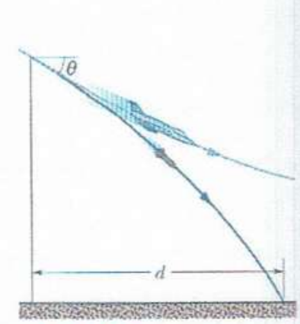


FIG. 4-37 Problem 27.