CHAPTER 3

Accelerated Motion

Practice Problems

3.1 Acceleration pages 57–64

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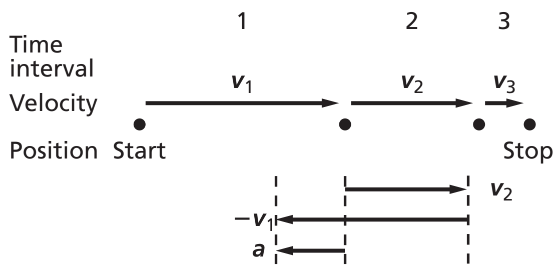
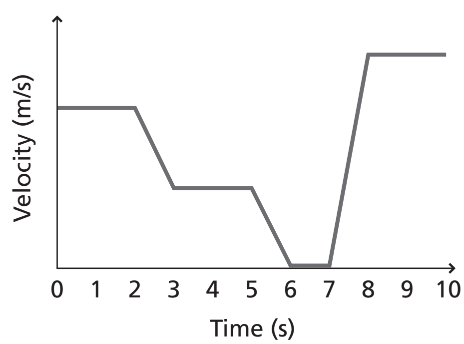
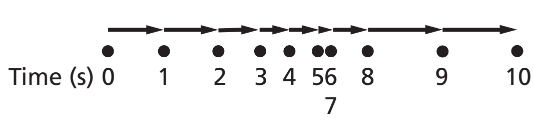
1. A dog runs into a room and sees a cat at the other end of the room. The dog instantly stops running but slides along the wood floor until he stops, by slowing down with a constant acceleration. Sketch a motion diagram for this situation, and use the velocity vectors to find the acceleration vector.



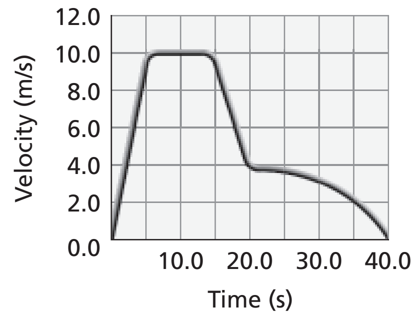
2. **Figure 3-5** is a *v-t* graph for Steven as he walks along the midway at the state fair. Sketch the corresponding motion diagram, complete with velocity vectors.



■ **Figure 3-5**



3. Refer to the *v-t* graph of the toy train in **Figure 3-6** to answer the following questions.



■ **Figure 3-6**

a. When is the train's speed constant?

5.0 to 15.0 s

b. During which time interval is the train's acceleration positive?

0.0 to 5.0 s

c. When is the train's acceleration most negative?

15.0 to 20.0 s

4. Refer to Figure 3-6 to find the average acceleration of the train during the following time intervals.

a. 0.0 s to 5.0 s

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1}$$

$$= \frac{10.0\ \text{m/s} - 0.0\ \text{m/s}}{5.0\ \text{s} - 0.0\ \text{s}}$$

$$= 2.0\ \text{m/s}^2$$

b. 15.0 s to 20.0 s

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1}$$

$$= \frac{4.0\ \text{m/s} - 10.0\ \text{m/s}}{20.0\ \text{s} - 15.0\ \text{s}}$$

$$= -1.2\ \text{m/s}^2$$

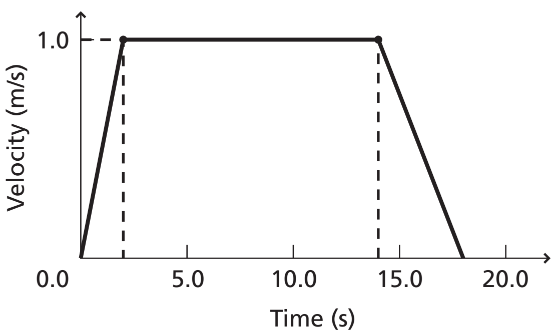
c. 0.0 s to 40.0 s

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1}$$

$$= \frac{0.0\text{ m/s} - 0.0\text{ m/s}}{40.0\text{ s} - 0.0\text{ s}}$$

$$= \mathbf{0.0\ m/s^2}$$

5. Plot a *v-t* graph representing the following motion. An elevator starts at rest from the ground floor of a three-story shopping mall. It accelerates upward for 2.0 s at a rate of 0.5 m/s^2, continues up at a constant velocity of 1.0 m/s for 12.0 s, and then experiences a constant downward acceleration of 0.25 m/s^2 for 4.0 s as it reaches the third floor.



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6. A race car's velocity increases from 4.0 m/s to 36 m/s over a 4.0-s time interval. What is its average acceleration?

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{36\text{ m/s} - 4.0\text{ m/s}}{4.0\text{ s}} = \mathbf{8.0\ m/s^2}$$

7. The race car in the previous problem slows from 36 m/s to 15 m/s over 3.0 s. What is its average acceleration?

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{15\text{ m/s} - 36\text{ m/s}}{3.0\text{ s}} = \mathbf{-7.0\ m/s^2}$$

8. A car is coasting backwards downhill at a speed of 3.0 m/s when the driver gets the engine started. After 2.5 s, the car is moving uphill at 4.5 m/s. If uphill is chosen as the positive direction, what is the car's average acceleration?

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{4.5\text{ m/s} - (-3.0\text{ m/s})}{2.5\text{ s}} = \mathbf{3.0\ m/s^2}$$

9. A bus is moving at 25 m/s when the driver steps on the brakes and brings the bus to a stop in 3.0 s.

a. What is the average acceleration of the bus while braking?

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

$$= \frac{0.0\text{ m/s} - 25\text{ m/s}}{3.0\text{ s}} = \mathbf{-8.3\ m/s^2}$$

b. If the bus took twice as long to stop, how would the acceleration compare with what you found in part **a?**

half as great ($-$4.2 m/s^2)

10. Rohith has been jogging to the bus stop for 2.0 min at 3.5 m/s when he looks at his watch and sees that he has plenty of time before the bus arrives. Over the next 10.0 s, he slows his pace to a leisurely 0.75 m/s. What was his average acceleration during this 10.0 s?

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

$$= \frac{0.75\text{ m/s} - 3.5\text{ m/s}}{10.0\text{ s}}$$

$$= \mathbf{-0.28\ m/s^2}$$

11. If the rate of continental drift were to abruptly slow from 1.0 cm/yr to 0.5 cm/yr over the time interval of a year, what would be the average acceleration?

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{0.5\text{ cm/yr} - 1.0\text{ cm/yr}}{1.0\text{ yr}}$$

$$= \mathbf{-0.5\ cm/yr^2}$$

Section Review

3.1 Acceleration pages 57–64

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12. Velocity-Time Graph What information can you obtain from a velocity-time graph?

The velocity at any time, the time at which the object had a particular velocity, the sign of the velocity, and the displacement.

13. Position-Time and Velocity-Time Graphs Two joggers run at a constant velocity of 7.5 m/s toward the east. At time $t = 0$, one is 15 m east of the origin and the other is 15 m west.

a. What would be the difference(s) in the position-time graphs of their motion?

Both lines would have the same slope, but they would rise from the *d*-axis at different points, +15 m, and −15 m.

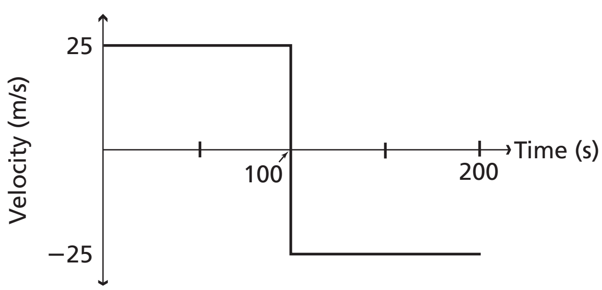
b. What would be the difference(s) in their velocity-time graphs?

Their velocity-time graphs would be identical.

14. **Velocity** Explain how you would use a velocity-time graph to find the time at which an object had a specified velocity.

Draw or imagine a horizontal line at the specified velocity. Find the point where the graph intersects this line. Drop a line straight down to the *t*-axis. This would be the required time.

15. **Velocity-Time Graph** Sketch a velocity-time graph for a car that goes east at 25 m/s for 100 s, then west at 25 m/s for another 100 s.



16. **Average Velocity and Average Acceleration** A canoeist paddles upstream at 2 m/s and then turns around and floats downstream at 4 m/s. The turnaround time is 8 s.

a. What is the average velocity of the canoe?

Choose a coordinate system with the positive direction upstream.

$$\bar{v} = \frac{v_i + v_f}{2}$$

$$= \frac{2\text{ m/s} + (-4\text{ m/s})}{2}$$

$$= -1\text{ m/s}$$

b. What is the average acceleration of the canoe?

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

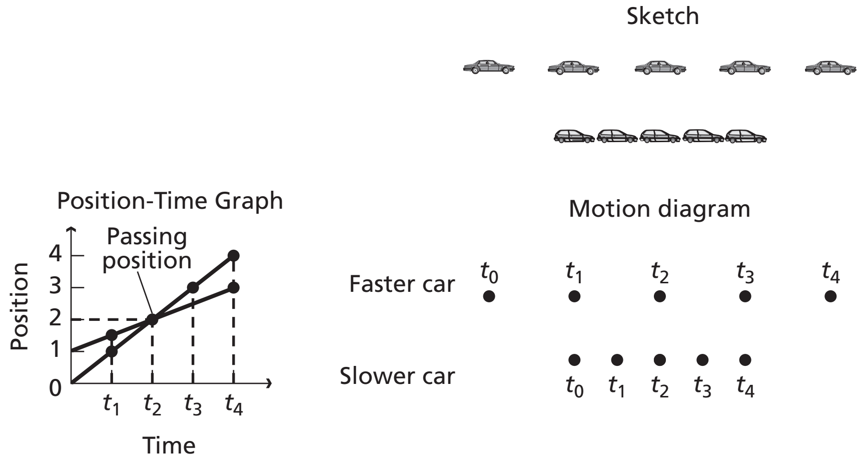
$$= \frac{v_f - v_i}{\Delta t}$$

$$= \frac{(-4\text{ m/s}) - (2\text{ m/s})}{8\text{ s}}$$

$$= 0.8\text{ m/s}^2$$

17. **Critical Thinking** A police officer clocked a driver going 32 km/h over the speed limit just as the driver passed a slower car. Both drivers were issued speeding tickets. The judge agreed with the officer that both were guilty. The judgement was issued based on the assumption that the cars must have been going the same speed because they were observed next to each other. Are the judge and the police officer correct? Explain with a sketch, a motion diagram, and a position-time graph.

No, they had the same position, not velocity. To have the same velocity, they would have had to have the same relative position for a length of time.



Practice Problems

3.2 Motion with Constant Acceleration pages 65–71

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18. A golf ball rolls up a hill toward a miniature-golf hole. Assume that the direction toward the hole is positive.

a. If the golf ball starts with a speed of 2.0 m/s and slows at a constant rate of 0.50 m/s^2, what is its velocity after 2.0 s?

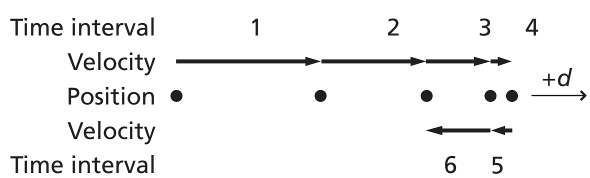
$$\boldsymbol{v_f = v_i + at}$$
$$\mathbf{= 2.0\ m/s + (-0.50\ m/s^2)(2.0\ s)}$$
$$\mathbf{= 1.0\ m/s}$$

b. What is the golf ball's velocity if the constant acceleration continues for 6.0 s?

$$\boldsymbol{v_f = v_i + at}$$
$$\mathbf{= 2.0\ m/s + (-0.50\ m/s^2)(6.0\ s)}$$
$$\mathbf{= -1.0\ m/s}$$

c. Describe the motion of the golf ball in words and with a motion diagram.

The ball's velocity simply decreased in the first case. In the second case, the ball slowed to a stop and then began rolling back down the hill.



19. A bus that is traveling at 30.0 km/h speeds up at a constant rate of 3.5 m/s^2. What velocity does it reach 6.8 s later?

$$\boldsymbol{v_f = v_i + at}$$
$$\mathbf{= 30.0\ km/h + (3.5\ m/s^2)(6.8\ s)\left(\frac{1\ km}{1000\ m}\right)\left(\frac{3600\ s}{1\ h}\right)}$$
$$\mathbf{= 120\ km/h}$$

20. If a car accelerates from rest at a constant $5.5\ m/s^2$, how long will it take for the car to reach a velocity of 28 m/s?

$$v_f = v_i + at$$

$$\text{so } t = \frac{v_f - v_i}{a}$$

$$= \frac{28\ m/s - 0.0\ m/s}{5.5\ m/s^2}$$

$$= 5.1\ s$$

21. A car slows from 22 m/s to 3.0 m/s at a constant rate of $2.1\ m/s^2$. How many seconds are required before the car is traveling at 3.0 m/s?

$$v_f = v_i + at$$

$$\text{so } t = \frac{v_f - v_i}{a}$$

$$= \frac{3.0\ m/s - 22\ m/s}{-2.1\ m/s^2}$$

$$= 9.0\ s$$

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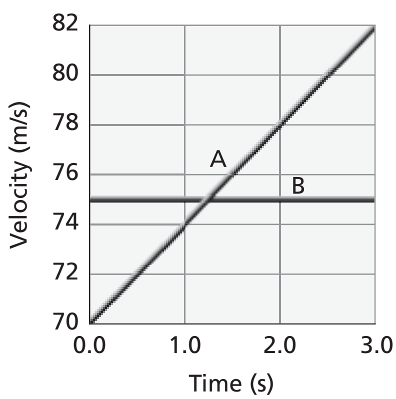
22. Use **Figure 3-11** to determine the velocity of an airplane that is speeding up at each of the following times.



■ **Figure 3-11**

Graph B represents constant speed. So graph A should be used for the following calculations.

a. 1.0 s

At 1.0 s, *v* = 74 m/s

b. 2.0 s

At 2.0 s, *v* = 78 m/s

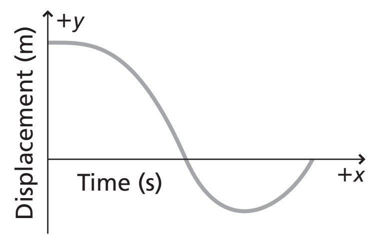
c. 2.5 s

At 2.5 s, *v* = 80 m/s

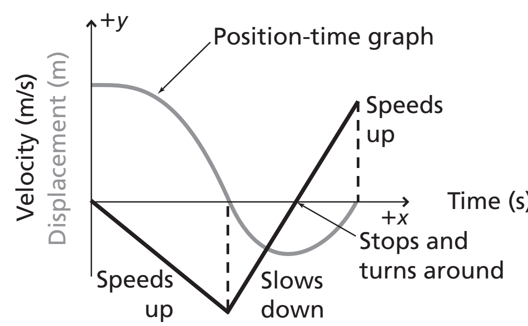
23. Use dimensional analysis to convert an airplane's speed of 75 m/s to km/h.

$$(75\ m/s)\left(\frac{3600\ s}{1\ h}\right)\left(\frac{1\ km}{1000\ m}\right) = 2.7\times10^2\ km/h$$

24. A position-time graph for a pony running in a field is shown in **Figure 3-12.** Draw the corresponding velocity-time graph using the same time scale.

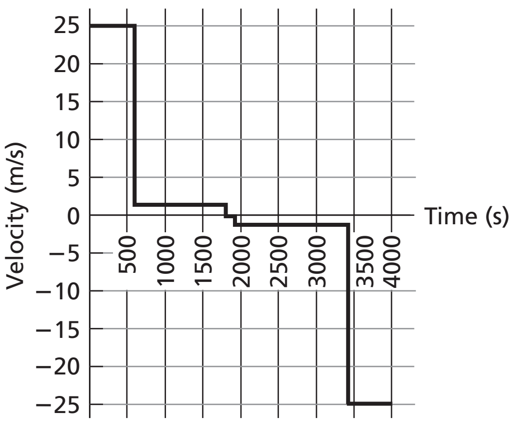


■ **Figure 3-12**



25. A car is driven at a constant velocity of 25 m/s for 10.0 min. The car runs out of gas and the driver walks in the same direction at 1.5 m/s for 20.0 min to the nearest gas station. The driver takes 2.0 min to fill a gasoline can, then walks back to the car at 1.2 m/s and eventually drives home at 25 m/s in the direction opposite that of the original trip.

a. Draw a *v-t* graph using seconds as your time unit. Calculate the distance the driver walked to the gas station to find the time it took him to walk back to the car.



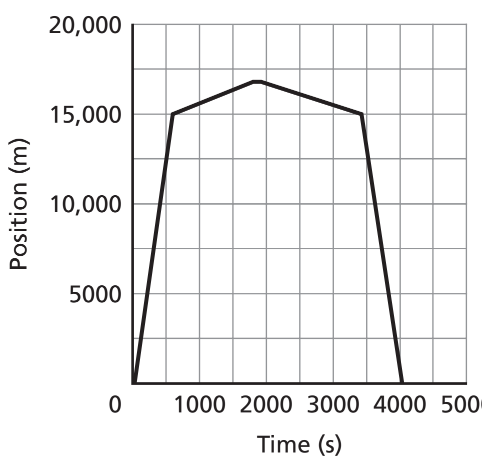
distance the driver walked to the gas station:

$$d = vt$$
$$= (1.5\text{ m/s})(20.0\text{ min})(60\text{ s/min})$$
$$= 1800\text{ m}$$
$$= 1.8\text{ km}$$

time to walk back to the car:

$$t = \frac{d}{v} = \frac{1800\text{ m}}{1.2\text{ m/s}} = 1500\text{ s} = 25\text{ min}$$

b. Draw a position-time graph for the situation using the areas under the velocity-time graph.



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26. A skateboarder is moving at a constant velocity of 1.75 m/s when she starts up an incline that causes her to slow down with a constant acceleration of −0.20 m/s². How much time passes from when she begins to slow down until she begins to move back down the incline?

$$v_f = v_i + at$$

$$t = \frac{v_f - v_i}{a} = \frac{0.0\text{ m/s} - 1.75\text{ m/s}}{-0.20\text{ m/s}^2} = 8.8\text{ s}$$

27. A race car travels on a racetrack at 44 m/s and slows at a constant rate to a velocity of 22 m/s over 11 s. How far does it move during this time?

$$\bar{v} = \frac{\Delta v}{2} = \frac{(v_f - v_i)}{2}$$

$$\Delta d = \bar{v}\Delta t$$
$$= \frac{(v_f - v_i)\Delta t}{2}$$
$$= \frac{(22\text{ m/s} - 44\text{ m/s})(11\text{ s})}{2}$$
$$= -1.2\times10^2\text{ m}$$

28. A car accelerates at a constant rate from 15 m/s to 25 m/s while it travels a distance of 125 m. How long does it take to achieve this speed?

$$\bar{v} = \frac{\Delta v}{2} = \frac{(v_f - v_i)}{2}$$

$$\Delta d = \bar{v}\Delta t$$
$$= \frac{(v_f - v_i)\Delta t}{2}$$

$$\Delta t = \frac{2\Delta d}{(v_f - v_i)}$$
$$= \frac{(2)(125\text{ m})}{25\text{ m/s} - 15\text{ m/s}}$$
$$= 25\text{ s}$$

29. A bike rider pedals with constant acceleration to reach a velocity of 7.5 m/s over a time of 4.5 s. During the period of acceleration, the bike's displacement is 19 m. What was the initial velocity of the bike?

$$\bar{v} = \frac{\Delta v}{2} = \frac{(v_f - v_i)}{2}$$

$$\Delta d = \bar{v}\Delta t = \frac{(v_f - v_i)\Delta t}{2}$$

$$\text{so } v_i = \frac{2\Delta d}{\Delta t} - v_f$$
$$= \frac{(2)(19\text{ m})}{4.5\text{ s} - 7.5\text{ m/s}}$$
$$= 0.94\text{ m/s}$$

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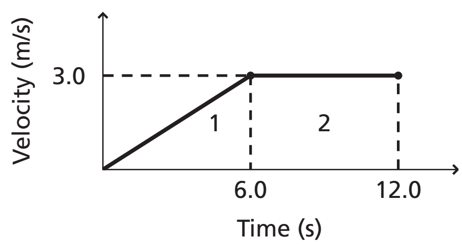
30. A man runs at a velocity of 4.5 m/s for 15.0 min. When going up an increasingly steep hill, he slows down at a constant rate of 0.05 m/s^2 for 90.0 s and comes to a stop. How far did he run?

$$d = v_1 t_1 + \frac{1}{2}(v_{2f} + v_{2i})t_2$$

$$= (4.5\text{ m/s})(15.0\text{ min})(60\text{ s/min}) + \frac{1}{2}(0.0\text{ m/s} + 4.5\text{ m/s})(90.0\text{ s})$$

$$= 4.3\times10^3\text{ m}$$

31. Sekazi is learning to ride a bike without training wheels. His father pushes him with a constant acceleration of 0.50 m/s^2 for 6.0 s, and then Sekazi continues at 3.0 m/s for another 6.0 s before falling. What is Sekazi's displacement? Solve this problem by constructing a velocity-time graph for Sekazi's motion and computing the area underneath the graphed line.



Part 1: Constant acceleration:

$$d_1 = \frac{1}{2}(3.0\text{ m/s})(6.0\text{ s})$$

$$= 9.0\text{ m}$$

Part 2: Constant velocity:

$$d_2 = (3.0\text{ m/s})(12.0\text{ s} - 6.0\text{ s})$$

$$= 18\text{ m}$$

Thus $d = d_1 + d_2 = 9.0\text{ m} + 18\text{ m} = 27\text{ m}$

32. You start your bicycle ride at the top of a hill. You coast down the hill at a constant acceleration of 2.00 m/s^2. When you get to the bottom of the hill, you are moving at 18.0 m/s, and you pedal to maintain that speed. If you continue at this speed for 1.00 min, how far will you have gone from the time you left the hilltop?

Part 1: Constant acceleration:

$v_f^2 = v_i^2 + 2a(d_f - d_i)$ **and** $d_i = 0.00\text{ m}$

so $d_f = \dfrac{v_f^2 - v_i^2}{2a}$

since $v_i = 0.00\text{ m/s}$

$$d_f = \frac{v_f^2}{2a}$$

$$= \frac{(18.0\text{ m/s})^2}{(2)(2.00\text{ m/s}^2)}$$

$$= 81.0\text{ m}$$

Part 2: Constant velocity:

$d_2 = vt = (18.0\text{ m/s})(60.0\text{ s}) = 1.08\times10^3\text{ m}$

Thus $d = d_1 + d_2$

$= 81.0\text{ m} + 1.08\times10^3\text{ m}$

$= 1.16\times10^3\text{ m}$

33. Sunee is training for an upcoming 5.0-km race. She starts out her training run by moving at a constant pace of 4.3 m/s for 19 min. Then she accelerates at a constant rate until she crosses the finish line, 19.4 s later. What is her acceleration during the last portion of the training run?

Part 1: Constant velocity:

$d = vt$

$= (4.3\text{ m/s})(19\text{ min})(60\text{ s/min})$

$= 4902\text{ m}$

Part 2: Constant acceleration:

$d_f = d_i + v_i t + \frac{1}{2}at^2$

$$a = \frac{2(d_f - d_i - v_i t)}{t^2} = \frac{(2)(5.0\times10^3\text{ m} - 4902\text{ m} - (4.3\text{ m/s})(19.4\text{ s}))}{(19.4\text{ s})^2}$$

$= 0.077\text{ m/s}^2$

Section Review

3.2 Motion with Constant Acceleration pages 65–71

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34. **Acceleration** A woman driving at a speed of 23 m/s sees a deer on the road ahead and applies the brakes when she is 210 m from the deer. If the deer does not move and the car stops right before it hits the deer, what is the acceleration provided by the car's brakes?

$v_f^2 = v_i^2 + 2a(d_f - d_i)$

$$a = \frac{v_f^2 - v_i^2}{2(d_f - d_i)}$$

$$= \frac{0.0\text{ m/s} - (23\text{ m/s})^2}{(2)(210\text{ m})}$$

$= -1.3\text{ m/s}^2$

35. **Displacement** If you were given initial and final velocities and the constant acceleration of an object, and you were asked to find the displacement, what equation would you use?

$v_f^2 = v_i^2 + 2ad_f$

36. Distance An in-line skater first accelerates from 0.0 m/s to 5.0 m/s in 4.5 s, then continues at this constant speed for another 4.5 s. What is the total distance traveled by the in-line skater?

Accelerating

$$d_f = \bar{v}t_f = \frac{v_i + v_f}{2}(t_f)$$

$$= \left(\frac{0.0\text{ m/s} + 5.0\text{ m/s}}{2}\right)(4.5\text{ s})$$

$$= 11.25\text{ m}$$

Constant speed

$$d_f = v_f t_f$$

$$= (5.0\text{ m/s})(4.5\text{ s})$$

$$= 22.5\text{ m}$$

$$\text{total distance} = 11.25\text{ m} + 22.5\text{ m}$$

$$= 34\text{ m}$$

37. Final Velocity A plane travels a distance of 5.0×10^2 m while being accelerated uniformly from rest at the rate of 5.0 m/s^2. What final velocity does it attain?

$$v_f^2 = v_f^2 + 2a(d_f - d_i) \text{ and } d_i = 0\text{, so}$$

$$v_f^2 = v_f^2 + 2ad_f$$

$$v_f = \sqrt{(0.0\text{ m/s})^2 + 2(5.0\text{ m/s}^2)(5.0\times10^2\text{ m})}$$

$$= 71\text{ m/s}$$

38. Final Velocity An airplane accelerated uniformly from rest at the rate of 5.0 m/s^2 for 14 s. What final velocity did it attain?

$$v_f = v_i + at_f$$

$$= 0 + (5.0\text{ m/s}^2)(14\text{ s}) = 7.0\times10^1\text{ m/s}$$

39. Distance An airplane starts from rest and accelerates at a constant 3.00 m/s^2 for 30.0 s before leaving the ground.

a. How far did it move?

$$d_f = v_i t_f + \frac{1}{2}at_f^2$$

$$= (0.0\text{ m/s})(30.0\text{ s})^2 + \left(\frac{1}{2}\right)(3.00\text{ m/s}^2)(30.0\text{ s})^2$$

$$= 1.35\times10^3\text{ m}$$

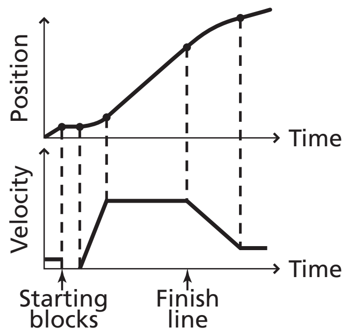
b. How fast was the airplane going when it took off?

$$v_f = v_i + at_f$$

$$= 0.0\text{ m/s} + (3.00\text{ m/s}^2)(30.0\text{ s})$$

$$= 90.0\text{ m/s}$$

40. **Graphs** A sprinter walks up to the starting blocks at a constant speed and positions herself for the start of the race. She waits until she hears the starting pistol go off, and then accelerates rapidly until she attains a constant velocity. She maintains this velocity until she crosses the finish line, and then she slows down to a walk, taking more time to slow down than she did to speed up at the beginning of the race. Sketch a velocity-time and a position-time graph to represent her motion. Draw them one above the other on the same time scale. Indicate on your *p-t* graph where the starting blocks and finish line are.



41. **Critical Thinking** Describe how you could calculate the acceleration of an automobile. Specify the measuring instruments and the procedures that you would use.

One person reads a stopwatch and calls out time intervals. Another person reads the speedometer at each time and records it. Plot speed versus time and find the slope.

Practice Problems

3.3 Free Fall pages 72–75

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42. A construction worker accidentally drops a brick from a high scaffold.

a. What is the velocity of the brick after 4.0 s?

Say upward is the positive direction.

$\boldsymbol{v_f = v_i + at,\ a = -g = -9.80\ \text{m/s}^2}$

$\boldsymbol{v_f = 0.0\ \text{m/s} + (-9.80\ \text{m/s}^2)(4.0\ \text{s})}$

$\boldsymbol{= -39\ \text{m/s}}$ **when the upward direction is positive**

b. How far does the brick fall during this time?

$$\boldsymbol{d = v_i t + \frac{1}{2}at^2}$$

$$\boldsymbol{= 0 + \left(\frac{1}{2}\right)(-9.80\ \text{m/s}^2)(4.0\ \text{s})^2}$$

$$\boldsymbol{= -78\ \text{m}}$$

The brick falls 78 m.

43. Suppose for the previous problem you choose your coordinate system so that the opposite direction is positive.

a. What is the brick's velocity after 4.0 s?

Now the positive direction is downward.

$v_f = v_i + at$, $a = g = 9.80\ \text{m/s}^2$

$v_f = 0.0\ \text{m/s} + (9.80\ \text{m/s}^2)(4.0\ \text{s})$

$= +39\ \text{m/s}$ **when the downward direction is positive**

b. How far does the brick fall during this time?

$d = v_i t + \frac{1}{2}at^2$, $a = g = 9.80\ \text{m/s}^2$

$= (0.0\ \text{m/s})(4.0\ \text{s}) + \left(\frac{1}{2}\right)(9.80\ \text{m/s}^2)(4.0\ \text{s})^2$

$= +78\ \text{m}$

The brick still falls 78 m.

44. A student drops a ball from a window 3.5 m above the sidewalk. How fast is it moving when it hits the sidewalk?

$v_f^2 = v_i^2 + 2ad$, $a = g$ **and** $v_i = 0$

so $v_f = \sqrt{2gd}$

$= \sqrt{(2)(9.80\ \text{m/s}^2)(3.5\ \text{m})}$

$= 8.3\ \text{m/s}$

45. A tennis ball is thrown straight up with an initial speed of 22.5 m/s. It is caught at the same distance above the ground.

a. How high does the ball rise?

$a = -g$, **and at the maximum height,** $v_f = 0$

$v_f^2 = v_i^2 + 2ad$ **becomes**

$v_i^2 = 2gd$

$$d = \frac{v_i^2}{2g} = \frac{(22.5\ \text{m/s})^2}{(2)(9.80\ \text{m/s}^2)} = 25.8\ \text{m}$$

b. How long does the ball remain in the air? *Hint: The time it takes the ball to rise equals the time it takes to fall.*

Calculate time to rise using $v_f = v_i + at$, **with** $a = -g$ **and** $v_f = 0$

$$t = \frac{v_i}{g} = \frac{22.5\ \text{m/s}}{9.80\ \text{m/s}^2} = 2.30\ \text{s}$$

The time to fall equals the time to rise, so the time to remain in the air is

$t_{air} = 2t_{rise} = (2)(2.30\ \text{s}) = 4.60\ \text{s}$

46. You decide to flip a coin to determine whether to do your physics or English homework first. The coin is flipped straight up.

a. If the coin reaches a high point of 0.25 m above where you released it, what was its initial speed?

$$v_f^2 = v_i^2 + 2a\Delta d$$

$$v_i = \sqrt{v_f^2 + 2g\Delta d} \text{ where } a = -g$$

and $v_f = 0$ at the height of the toss, so

$$v_i = \sqrt{(0.0\text{ m/s})^2 + (2)(9.80\text{ m/s}^2)(0.25\text{ m})}$$

$$= 2.2\text{ m/s}$$

b. If you catch it at the same height as you released it, how much time did it spend in the air?

$v_f = v_i + at$ **where** $a = -g$

$v_i = 2.2$ **m/s and**

$v_f = -2.2$ **m/s**

$$t = \frac{v_f - v_i}{-g}$$

$$= \frac{-2.2\text{ m/s} - 2.2\text{ m/s}}{-9.80\text{ m/s}^2}$$

$$= 0.45\text{ s}$$

Section Review

3.3 Free Fall pages 72–75

page 75

47. Maximum Height and Flight Time Acceleration due to gravity on Mars is about one-third that on Earth. Suppose you throw a ball upward with the same velocity on Mars as on Earth.

a. How would the ball's maximum height compare to that on Earth?

At maximum height, $v_f = 0$,

so $d_f = \frac{v_i^2}{2g}$, or three times higher.

b. How would its flight time compare?

Time is found from $d_f = \frac{1}{2}gt_f^2$, or

$t_f = \sqrt{\frac{2d_f}{g}}$. Distance is multiplied by 3 and g is divided by 3,

so the flight time would be three times as long.

48. Velocity and Acceleration Suppose you throw a ball straight up into the air. Describe the changes in the velocity of the ball. Describe the changes in the acceleration of the ball.

Velocity is reduced at a constant rate as the ball travels upward. At its highest point, velocity is zero. As the ball begins to drop, the velocity begins to increase in the negative direction until it reaches the height from which it was initially released. At that point, the ball has the same speed it had upon release. The acceleration is constant throughout the ball's flight.

49. Final Velocity Your sister drops your house keys down to you from the second floor window. If you catch them 4.3 m from where your sister dropped them, what is the velocity of the keys when you catch them?

Upward is positive

$v^2 = v_i^2 + 2a\Delta d$ where $a = -g$

$v = \sqrt{v_i^2 - 2g\Delta d}$

$= \sqrt{(0.0 \text{ m/s})^2 - (2)(9.80 \text{ m/s}^2)(-4.3 \text{ m})}$

$= 9.2 \text{ m/s}$

50. Initial Velocity A student trying out for the football team kicks the football straight up in the air. The ball hits him on the way back down. If it took 3.0 s from the time when the student punted the ball until he gets hit by the ball, what was the football's initial velocity?

Choose a coordinate system with up as the positive direction and the origin at the punter. Choose the initial time at the punt and the final time at the top of the football's flight.

$v_f = v_i + at_f$ where $a = -g$

$v_i = v_f + gt_f$

$= 0.0 \text{ m/s} + (9.80 \text{ m/s}^2)(1.5 \text{ s})$

$= 15 \text{ m/s}$

51. Maximum Height When the student in the previous problem kicked the football, approximately how high did the football travel?

$v_f^2 = v_i^2 + 2a(\Delta d)$ where $a = -g$

$\Delta d = \frac{v_f^2 - v_i^2}{-2g}$

$= \frac{(0.0 \text{ m/s})^2 - (15 \text{ m/s})^2}{(-2)(9.80 \text{ m/s}^2)}$

$= 11 \text{ m}$

52. Critical Thinking When a ball is thrown vertically upward, it continues upward until it reaches a certain position, and then it falls downward. At that highest point, its velocity is instantaneously zero. Is the ball accelerating at the highest point? Devise an experiment to prove or disprove your answer.

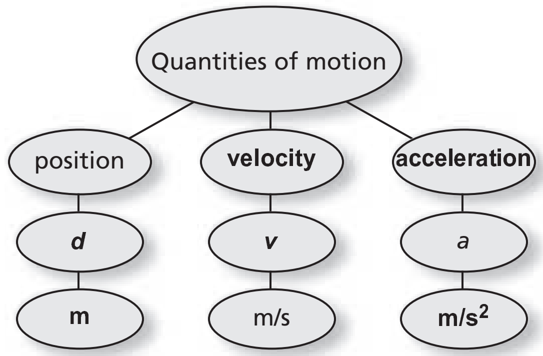
The ball is accelerating; its velocity is changing. Take a strobe photo to measure its position. From photos, calculate the ball's velocity.

Chapter Assessment

Concept Mapping

page 80

53. Complete the following concept map using the following symbols or terms: *d, velocity, m/s²*, *v, m, acceleration.*



Mastering Concepts

page 80

54. How are velocity and acceleration related? (3.1)

Acceleration is the change in velocity divided by the time interval in which it occurs: it is the rate of change of velocity.

55. Give an example of each of the following. (3.1)

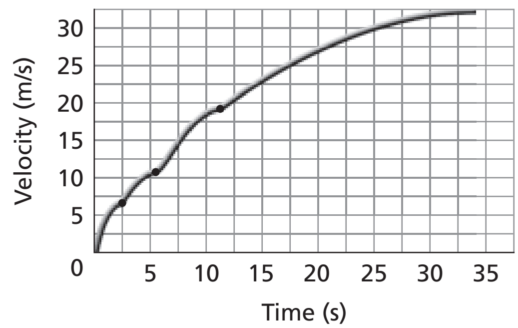
a. an object that is slowing down, but has a positive acceleration

if forward is the positive direction, a car moving backward at decreasing speed

b. an object that is speeding up, but has a negative acceleration

in the same coordinate system, a car moving backward at increasing speed

56. **Figure 3-16** shows the velocity-time graph for an automobile on a test track. Describe how the velocity changes with time. (3.1)



■ **Figure 3-16**

The car starts from rest and increases its speed. As the car's speed increases, the driver shifts gears.

57. What does the slope of the tangent to the curve on a velocity-time graph measure? (3.1)

instantaneous acceleration

58. Can a car traveling on an interstate highway have a negative velocity and a positive acceleration at the same time? Explain. Can the car's velocity change signs while it is traveling with constant acceleration? Explain. (3.1)

Yes, a car's velocity is positive or negative with respect to its direction of motion from some point of reference. One direction of motion is defined as positive, and velocities in that direction are considered positive. The opposite direction of motion is considered negative; all velocities in that direction are negative. An object undergoing positive acceleration is either increasing its velocity in the positive direction or reducing its velocity in the negative direction. A car's velocity can change signs when experiencing constant acceleration. For example, it can be traveling right, while the acceleration is to the left. The car slows down, stops, and then starts accelerating to the left.

59. Can the velocity of an object change when its acceleration is constant? If so, give an example. If not, explain. (3.1)

Yes, the velocity of an object can change when its acceleration is constant. Example: dropping a book. The

longer it drops, the faster it goes, but the acceleration is constant at *g*.

60. If an object's velocity-time graph is a straight line parallel to the *t*-axis, what can you conclude about the object's acceleration? (3.1)

When the velocity-time graph is a line parallel to the *t*-axis, the acceleration is zero.

61. What quantity is represented by the area under a velocity-time graph? (3.2)

the change in displacement

62. Write a summary of the equations for position, velocity, and time for an object experiencing motion with uniform acceleration. (3.2)

$$t_f = \frac{(v_f - v_i)}{a}$$

$$v_f = v_i + at_f$$

$$\bar{v} = \frac{\Delta v}{2} = \frac{v_f - v_i}{2}$$

$$\Delta d = \bar{v}\Delta t$$

$$= \frac{v_f - v_i}{2}\Delta t$$

assuming $t_i = 0$, then

$$\Delta t = t_f$$

$$\Delta d = \left(\frac{v_f - v_i}{2}\right)t_f$$

63. Explain why an aluminum ball and a steel ball of similar size and shape, dropped from the same height, reach the ground at the same time. (3.3)

All objects accelerate toward the ground at the same rate.

64. Give some examples of falling objects for which air resistance cannot be ignored. (3.3)

Student answers will vary. Some examples are sheets of paper, parachutes, leaves, and feathers.

65. Give some examples of falling objects for which air resistance can be ignored. (3.3)

Student answers will vary. Some examples are a steel ball, a rock, and a person falling through small distances.

Applying Concepts

pages 80–81

66. Does a car that is slowing down always have a negative acceleration? Explain.

No, if the positive axis points in the direction opposite the velocity, the acceleration will be positive.

67. **Croquet** A croquet ball, after being hit by a mallet, slows down and stops. Do the velocity and acceleration of the ball have the same signs?

No, they have opposite signs.

68. If an object has zero acceleration, does it mean its velocity is zero? Give an example.

No, $a = 0$ when velocity is constant.

69. If an object has zero velocity at some instant, is its acceleration zero? Give an example.

No, a ball rolling uphill has zero velocity at the instant it changes direction, but its acceleration is nonzero.

70. If you were given a table of velocities of an object at various times, how would you find out whether the acceleration was constant?

Draw a velocity-time graph and see whether the curve is a straight line or calculate accelerations using $\bar{a} = \frac{\Delta v}{\Delta t}$ and compare the answers to see if they are the same.

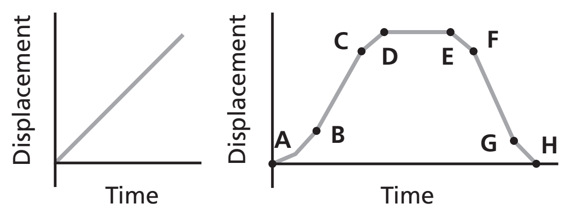
71. The three notches in the graph in Figure 3-16 occur where the driver changed gears. Describe the changes in velocity and acceleration of the car while in first gear. Is the acceleration just before a gear change larger or smaller than the acceleration just after the change? Explain your answer.

Velocity increases rapidly at first, then more slowly. Acceleration is greatest at the beginning but is reduced as velocity increases. Eventually, it is necessary for the driver to shift into second gear. The acceleration is smaller just before the gear change because the slope is less at that point on the graph. Once the driver shifts and the gears engage, acceleration and the slope of the curve increase.

72. Use the graph in Figure 3-16 and determine the time interval during which the acceleration is largest and the time interval during which the acceleration is smallest.

The acceleration is largest during an interval starting at $t = 0$ and lasting about $\frac{1}{2}$ s. It is smallest beyond 33 s.

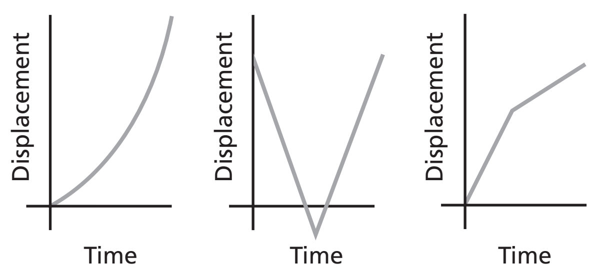
73. Explain how you would walk to produce each of the position-time graphs in **Figure 3-17.**



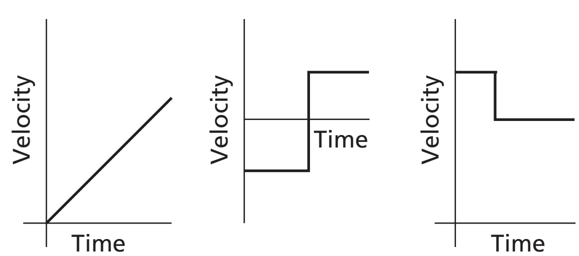
■ **Figure 3-17**

Walk in the positive direction at a constant speed. Walk in the positive direction at an increasing speed for a short time; keep walking at a moderate speed for twice that amount of time; slow down over a short time and stop; remain stopped; and turn around and repeat the procedure until the original position is reached.

74. Draw a velocity-time graph for each of the graphs in **Figure 3-18.**



■ **Figure 3-18**



75. An object shot straight up rises for 7.0 s before it reaches its maximum height. A second object falling from rest takes 7.0 s to reach the ground. Compare the displacements of the two objects during this time interval.

Both objects traveled the same distance. The object that is shot straight upward rises to the same height from which the other object fell.

76. **The Moon** The value of g on the Moon is one-sixth of its value on Earth.

a. Would a ball that is dropped by an astronaut hit the surface of the Moon with a greater, equal, or lesser speed than that of a ball dropped from the same height to Earth?

The ball will hit the Moon with a lesser speed because the acceleration due to gravity is less on the Moon.

b. Would it take the ball more, less, or equal time to fall?

The ball will take more time to fall.

77. **Jupiter** The planet Jupiter has about three times the gravitational acceleration of Earth. Suppose a ball is thrown vertically upward with the same initial velocity on Earth and on Jupiter. Neglect the effects of Jupiter's atmospheric resistance and assume that gravity is the only force on the ball.

a. How does the maximum height reached by the ball on Jupiter compare to the maximum height reached on Earth?

The relationship between d and g is an inverse one: $d_f = \frac{(v_f^2 - v_i^2)}{2g}$.

If g increases by three times, or $d_f = \frac{(v_f^2 - v_i^2)}{2(3g)}$, d_f changes by $\frac{1}{3}$.

Therefore, a ball on Jupiter would rise to a height of $\frac{1}{3}$ that on Earth.

b. If the ball on Jupiter were thrown with an initial velocity that is three times greater, how would this affect your answer to part **a?**

With $v_f = 0$, the value d_f is directly proportional to the square of initial velocity, v_i. That is, $d_f = v_f^2 - \frac{(3v_i)^2}{2g}$.

On Earth, an initial velocity three times greater results in a ball rising nine times higher. On Jupiter, however, the height of nine times higher would be reduced to only three times higher because of d_f's inverse relationship to a g that is three times greater.

78. Rock A is dropped from a cliff and rock B is thrown upward from the same position.

a. When they reach the ground at the bottom of the cliff, which rock has a greater velocity?

Rock B hits the ground with a greater velocity.

b. Which has a greater acceleration?

They have the same acceleration, the acceleration due to gravity.

c. Which arrives first?

rock A

Mastering Problems

3.1 Acceleration

pages 81–82

Level 1

79. A car is driven for 2.0 h at 40.0 km/h, then for another 2.0 h at 60.0 km/h in the same direction.

a. What is the car's average velocity?

Total distance:
80.0 km + 120.0 km = 200.0 km
total time is 4.0 hours, so,
$$\bar{v} = \frac{\Delta d}{\Delta t} = \frac{200.0\text{ km}}{4.0\text{ h}} = 5.0\times10^1\text{ km/h}$$

b. What is the car's average velocity if it is driven 1.0×10^2 km at each of the two speeds?

Total distance is 2.03102 km;

$$\text{total time} = \frac{1.0\times10^2 \text{ km}}{40.0 \text{ km/h}} + \frac{1.0\times10^2 \text{ km}}{60.0 \text{ km/h}}$$

$$= 4.2 \text{ h}$$

$$\text{so } \bar{v} = \frac{\Delta d}{\Delta t} = \frac{2.0\times10^2 \text{ km}}{4.2 \text{ h}}$$

$$= 48 \text{ km/h}$$

80. Find the uniform acceleration that causes a car's velocity to change from 32 m/s to 96 m/s in an 8.0-s period.

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

$$= \frac{v_2 - v_1}{\Delta t}$$

$$= \frac{96 \text{ m/s} - 32 \text{ m/s}}{8.0 \text{ s}} = 8.0 \text{ m/s}^2$$

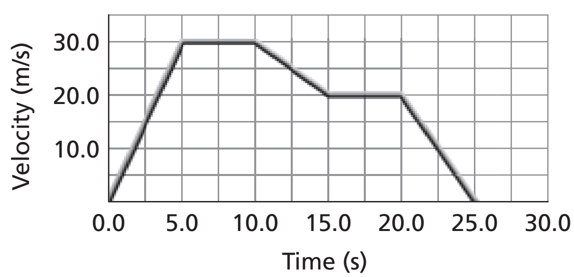
81. A car with a velocity of 22 m/s is accelerated uniformly at the rate of 1.6 m/s^2 for 6.8 s. What is its final velocity?

$$v_f = v_i + at_f$$

$$= 22 \text{ m/s} + (1.6 \text{ m/s}^2)(6.8 \text{ s})$$

$$= 33 \text{ m/s}$$

82. Refer to **Figure 3-19** to find the acceleration of the moving object at each of the following times.



■ **Figure 3-19**

a. during the first 5.0 s of travel

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

$$= \frac{30.0 \text{ m/s} - 0.0 \text{ m/s}}{5.0 \text{ s}}$$

$$= 6.0 \text{ m/s}^2$$

b. between 5.0 s and 10.0 s

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

$$= \frac{30.0 \text{ m/s} - 30.0 \text{ m/s}}{5.0 \text{ s}}$$

$$= 0.0 \text{ m/s}^2$$

c. between 10.0 s and 15.0 s

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

$$= \frac{20.0 \text{ m/s} - 30.0 \text{ m/s}}{5.0 \text{ s}}$$

$$= -2.0 \text{ m/s}^2$$

d. between 20.0 s and 25.0 s

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

$$= \frac{0.0 \text{ m/s} - 20.0 \text{ m/s}}{5.0 \text{ s}}$$

$$= -4.0 \text{ m/s}^2$$

Level 2

83. Plot a velocity-time graph using the information in **Table 3-4,** and answer the following questions.

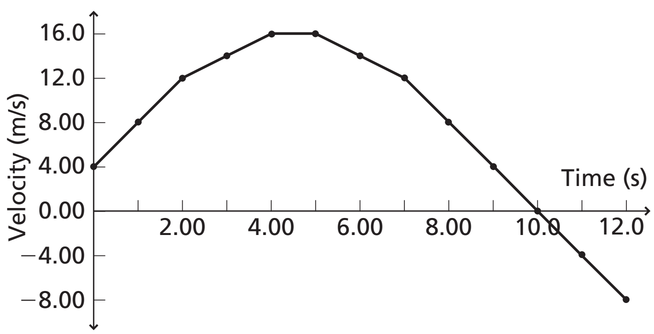


Table 3-4	
Velocity v. Time	
Time (s)	**Velocity (m/s)**
0.00	4.00
1.00	8.00
2.00	12.0
3.00	14.0
4.00	16.0
5.00	16.0
6.00	14.0
7.00	12.0
8.00	8.00
9.00	4.00
10.0	0.00
11.0	−4.00
12.0	−8.00

a. During what time interval is the object speeding up? Slowing down?

speeding up from 0.0 s to 4.0 s; slowing down from 5.0 s to 10.0 s

b. At what time does the object reverse direction?

at 10.0 s

c. How does the average acceleration of the object in the interval between 0.0 s and 2.0 s differ from the average acceleration in the interval between 7.0 s and 12.0 s?

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

between 0.0 s and 2.0 s:

$$\bar{a} = \frac{12.0 \text{ m/s} - 4.0 \text{ m/s}}{2.0 \text{ s} - 0.0 \text{ s}} = 4.0 \text{ m/s}^2$$

between 7.0 s and 12.0 s:

$$\bar{a} = \frac{-8.0 \text{ m/s} - 12.0 \text{ m/s}}{12.0 \text{ s} - 7.0 \text{ s}} = -4.0 \text{ m/s}^2$$

84. Determine the final velocity of a proton that has an initial velocity of 2.35×10^5 m/s and then is accelerated uniformly in an electric field at the rate of -1.10×10^{12} m/s^2 for 1.50×10^{-7} s.

$$\boldsymbol{v_f = v_i + at_f}$$
$$\mathbf{= 2.35\times10^5\ m/s + (-1.10\times10^{12}\ m/s^2)(1.50\times10^{-7}\ s)}$$
$$\mathbf{= 7.0\times10^4\ m/s}$$

Level 3

85. Sports Cars Marco is looking for a used sports car. He wants to buy the one with the greatest acceleration. Car A can go from 0 m/s to 17.9 m/s in 4.0 s; car B can accelerate from 0 m/s to 22.4 m/s in 3.5 s; and car C can go from 0 to 26.8 m/s in 6.0 s. Rank the three cars from greatest acceleration to least, specifically indicating any ties.

Car A:

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{17.9\ \text{m/s} - 0\ \text{m/s}}{4.0\ \text{s} - 0.0\ \text{s}} = 4.5\ \text{m/s}^2$$

Car B:

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{22.4\ \text{m/s} - 0\ \text{m/s}}{3.5\ \text{s} - 0.0\ \text{s}} = 6.4\ \text{m/s}^2$$

Car C:

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{26.8\ \text{m/s} - 0\ \text{m/s}}{6.0\ \text{s} - 0.0\ \text{s}} = 4.5\ \text{m/s}^2$$

Car B has the greatest acceleration of 6.4 m/s^2. Using significant digits, car A and car C tied at 4.5 m/s^2.

86. Supersonic Jet A supersonic jet flying at 145 m/s experiences uniform acceleration at the rate of 23.1 m/s^2 for 20.0 s.

a. What is its final velocity?

$$\boldsymbol{v_f = v_i + at_f}$$
$$\mathbf{= 145\ m/s + (23.1\ m/s^2)(20.0\ s)}$$
$$\mathbf{= 607\ m/s}$$

b. The speed of sound in air is 331 m/s. What is the plane's speed in terms of the speed of sound?

$$N = \frac{607\ \text{m/s}}{331\ \text{m/s}}$$

= 1.83 times the speed of sound

3.2 Motion with Constant Acceleration

page 82

Level 1

87. Refer to **Figure 3-19** to find the distance traveled during the following time intervals.

a. $t = 0.0$ s and $t = 5.0$ s

$$\text{Area I} = \tfrac{1}{2}bh$$
$$= \left(\tfrac{1}{2}\right)(5.0\ \text{s})(30.0\ \text{m/s})$$
$$= 75\ \text{m}$$

b. $t = 5.0$ s and $t = 10.0$ s

$$\text{Area II} = bh$$
$$= (10.0\ \text{s} - 5.0\ \text{s})(30.0\ \text{m/s})$$
$$= 150\ \text{m}$$

c. $t = 10.0$ s and $t = 15.0$ s

$$\text{Area III} + \text{Area IV} = bh + \tfrac{1}{2}bh$$
$$= (15.0\ \text{s} - 10.0\ \text{s})(20.0\ \text{m/s}) + \left(\tfrac{1}{2}\right)(15.0\ \text{s} - 10.0\ \text{s})(10.0\ \text{m/s})$$
$$= 125\ \text{m}$$

d. $t = 0.0$ s and $t = 25.0$ s

$$\text{Area I} + \text{Area II} + (\text{Area III} + \text{Area IV}) + \text{Area V} + \text{IV}$$
$$= 75\ \text{m} + 150\ \text{m} + 125\ \text{m} + bh + \tfrac{1}{2}bh$$
$$= 75\ \text{m} + 150\ \text{m} + 125\ \text{m} + (20.0\ \text{s} - 15.0\ \text{s})(20.0\ \text{m/s}) + \left(\tfrac{1}{2}\right)(25.0\ \text{s} - 20.0\ \text{s})$$
$$= 5.0\times10^2\ \text{m}$$

Level 2

88. A dragster starting from rest accelerates at 49 m/s^2. How fast is it going when it has traveled 325 m?

$$v_f^2 = v_i^2 + 2a(d_f - d_i)$$
$$v_f = \sqrt{v_i^2 + 2a(d_f - d_i)}$$

$= \sqrt{(0.0\ \text{m/s})^2 + (2)(49\ \text{m/s}^2)(325\ \text{m} - 0.0\ \text{m})}$

$= 180\ \text{m/s}$

89. A car moves at 12 m/s and coasts up a hill with a uniform acceleration of -1.6 m/s^2.

a. What is its displacement after 6.0 s?

$d_f = v_i t_f + \frac{1}{2} a t_f^2$

$= (12\ \text{m/s})(6.0\ \text{s}) + \left(\frac{1}{2}\right)(-1.6\ \text{m/s}^2)(6.0\ \text{s})^2$

$= 43\ \text{m}$

b. What is its displacement after 9.0 s?

$d_f = v_i t_f + \frac{1}{2} a t_f^2$

$= (12\ \text{m/s})(9.0\ \text{s}) + \left(\frac{1}{2}\right)(-1.6\ \text{m/s}^2)(9.0\ \text{s})^2$

$= 43\ \text{m}$

The car is on the way back down the hill. The odometer will show that the car traveled 45 m up the hill + 2 m back down = 47 m.

90. Race Car A race car can be slowed with a constant acceleration of -11 m/s^2.

a. If the car is going 55 m/s, how many meters will it travel before it stops?

$v_f^2 = v_i^2 + 2ad_f$

$d_f = \frac{v_f^2 - v_i^2}{2a}$

$= \frac{(0.0\ \text{m/s})^2 - (+55\ \text{m/s})^2}{(2)(-11\ \text{m/s}^2)}$

$= 1.4 \times 10^2\ \text{m}$

b. How many meters will it take to stop a car going twice as fast?

$v_f^2 = v_i^2 + 2ad_f$

$d_f = \frac{v_f^2 - v_i^2}{2a}$

$= \frac{(0.0\ \text{m/s})^2 - (110\ \text{m/s})^2}{(2)(-11\ \text{m/s}^2)} = 550\ \text{m},$

which is about 4 times longer than when going half the speed.

91. A car is traveling 20.0 m/s when the driver sees a child standing on the road. She takes 0.80 s to react, then steps on the brakes and slows at 7.0 m/s^2. How far does the car go before it stops?

reaction displacement $d_r = (20.0\ \text{m/s})(0.80\ \text{s}) = 16\ \text{m}$

$$d_f = \frac{v_f^2 - v_i^2}{2a}$$

braking displacement

$$d_b = \frac{(0.0\text{ m/s})^2 - (20.0\text{ m/s})^2}{(2)(-7.0\text{ m/s}^2)}$$

$$= 29\text{ m}$$

total displacement is

$$d_r + d_b = 16\text{ m} + 29\text{ m} = 45\text{ m}$$

Level 3

92. Airplane Determine the displacement of a plane that experiences uniform acceleration from 66 m/s to 88 m/s in 12 s.

$$d_f = \bar{v}t = \frac{(v_f + v_i)t}{2}$$

$$= \frac{(88\text{ m/s} + 66\text{ m/s})(12\text{ s})}{2}$$

$$= 9.2\times10^2\text{ m}$$

93. How far does a plane fly in 15 s while its velocity is changing from 145 m/s to 75 m/s at a uniform rate of acceleration?

$$d = \bar{v}t = \frac{(v_f + v_i)t}{2}$$

$$= \frac{(75\text{ m/s} + 145\text{ m/s})(15\text{ m/s})}{2}$$

$$= 1.6\times10^3\text{ m}$$

94. Police Car A speeding car is traveling at a constant speed of 30.0 m/s when it passes a stopped police car. The police car accelerates at 7.0 m/s^2. How fast will it be going when it catches up with the speeding car?

$$d_{speeder} = v_{speeder}t$$

$$d_{police} = v_{i\text{ police}}t + \frac{1}{2}a_{police}t^2$$

$$v_{speeder}t = v_{i\text{ police}}t + \frac{1}{2}a_{police}t^2$$

since $v_{i\text{ police}} = 0$ then

$$v_{speeder}t = \frac{1}{2}a_{police}t^2$$

$$0 = \frac{1}{2}a_{police}t^2 - v_{speeder}t$$

$$0 = t\left(\frac{1}{2}a_{police}t - v_{speeder}\right)$$

therefore

$$t = 0 \text{ and } \frac{1}{2}a_{police}t - v_{speeder} = 0$$

$$t = \frac{2v_{speeder}}{a_{police}}$$

$$= \frac{(2)(30.0\text{ m/s})}{7.0\text{ m/s}^2}$$

$$= 8.6\text{ s}$$

After $t = 8.6$ s, the police car's velocity was

$$v_f = v_i + at$$

$$= 0.0\text{ m/s} + (7.0\text{ m/s}^2)(8.6\text{ s})$$

$$= 6.0\times10^1\text{ m/s}$$

95. Road Barrier The driver of a car going 90.0 km/h suddenly sees the lights of a barrier 40.0 m ahead. It takes the driver 0.75 s to apply the brakes, and the average acceleration during braking is −10.0 m/s^2.

a. Determine whether the car hits the barrier.

The car will travel
$d = vt = (25.0\text{ m/s})(0.75\text{ s})$
$= 18.8$ m (Round off at the end.)
before the driver applies the brakes.

Convert km/h to m/s.

$$v_i = \frac{(90.0\text{ km/h})(1000\text{ m/km})}{3600\text{ s/h}}$$

$$= 25.0\text{ m/s}$$

$$v_f^2 = v_i^2 + 2a(d_f - d_i)$$

$$d_f = \frac{v_f^2 - v_i^2}{2a} + d_i$$

$$= \frac{(0.0\text{ m/s})^2 - (25.0\text{ m/s})^2}{(2)(-10.0\text{ m/s}^2)} + 18.8\text{ m}$$

$$= 5.0\times10^1\text{ m, yes it hits the barrier}$$

b. What is the maximum speed at which the car could be moving and not hit the barrier 40.0 m ahead? Assume that the acceleration doesn't change.

$d_{total} = d_{constant} + d_{decelerating}$

$= 40.0$ m

$d_c = vt = (0.75\text{ s})v$

$d_d = \frac{0^2 - v^2}{2a} = \frac{-v^2}{2(-10.0\text{ m/s}^2)}$

$= \frac{v^2}{20.0\text{ m/s}^2}$

$40\text{ m} = (0.75\text{ s})v + \frac{v^2}{20.0\text{ m/s}^2}$

$v^2 + (15\text{ m/s})v - 800\text{ m}^2/\text{s}^2 = 0$

Using the quadratic equation:
$v = 22$ **m/s (The sense of the problem excludes the negative value.)**

3.3 Free Fall

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Level 1

96. A student drops a penny from the top of a tower and decides that she will establish a coordinate system in which the direction of the penny's motion is positive. What is the sign of the acceleration of the penny?

The direction of the velocity is positive, and velocity is increasing. Therefore, the acceleration is also positive.

97. Suppose an astronaut drops a feather from 1.2 m above the surface of the Moon. If the acceleration due to gravity on the Moon is 1.62 m/s^2 downward, how long does it take the feather to hit the Moon's surface?

$d_f = v_i t_f + a t_f^2 = (0\text{ m/s})t_f + a t_f^2$

$t_f = \sqrt{\frac{2d_f}{a}} = \sqrt{\frac{(2)(1.2\text{ m})}{(1.62\text{ m/s}^2)}} = 1.2\text{ s}$

98. A stone that starts at rest is in free fall for 8.0 s.

a. Calculate the stone's velocity after 8.0 s.

$v_f = v_i + a t_f$ **where** $a = -g$

$= v_i - g t_f$

$= 0.0\text{ m/s} - (9.80\text{ m/s}^2)(8.0\text{ s})$

$= -78$ **m/s (downward)**

b. What is the stone's displacement during this time?

Choose the coordinate system to have the origin where the stone is at rest and positive to be upward.

$d_f = v_i t + \frac{1}{2} a t_f^2$ **where** $a = -g$

$= v_i t - \frac{1}{2} g t_f^2$

$= 0.0\text{ m} - \left(\frac{1}{2}\right)(9.80\text{ m/s}^2)(8.0\text{ s})^2$

$= -3.1\times10^2$ m

99. A bag is dropped from a hovering helicopter. The bag has fallen for 2.0 s. What is the bag's velocity? How far has the bag fallen?

Velocity:

$v_f = v_i + a t_f$ **where** $a = -g$

$= v_i - g t_f$

$= 0.0\text{ m/s} - (9.80\text{ m/s}^2)(2.0\text{ s})$

$= -2.0\times10^1$ m/s

Displacement:

$d_f = v_i t_f + \frac{1}{2} a t_f^2$ **where** $a = -g$

$= v_i t_f - \frac{1}{2} g t^2$

$= 0.0\text{ m} - \left(\frac{1}{2}\right)(9.80\text{ m/s}^2)(2.0\text{ s})^2$

$= -2.0\times10^1$ m

Level 2

100. You throw a ball downward from a window at a speed of 2.0 m/s. How fast will it be moving when it hits the sidewalk 2.5 m below?

Choose a coordinate system with the positive direction downward and the origin at the point where the ball leaves your hand.

$v_f^2 = v_i^2 + 2ad_f$ where $a = g$

$v_f = \sqrt{v_i^2 + 2gd_f}$

$= \sqrt{(2.0\ \text{m/s})^2 + (2)(9.80\ \text{m/s}^2)(2.5\ \text{m})}$

$= 7.3$ m/s

101. If you throw the ball in the previous problem up instead of down, how fast will it be moving when it hits the sidewalk?

Choose the same coordinate system.

$v_f^2 = v_i^2 + 2ad_f$ where $a = g$

$v_f = \sqrt{v_i^2 + 2gd_f}$

$= \sqrt{(2.0\ \text{m/s})^2 + (2)(9.80\ \text{m/s}^2)(2.5\ \text{m})}$

$= 7.3$ m/s

(d_f is the displacement, not the total distance traveled.)

Level 3

102. Beanbag You throw a beanbag in the air and catch it 2.2 s later.

a. How high did it go?

Choose a coordinate system with the upward direction positive and the origin at the point where the beanbag left your hand. Assume that you catch the beanbag at the same place where you threw it. Therefore, the time to reach the maximum height is half of the time in the air. Choose t_i to be the time when the beanbag left your hand and t_f to be the time at the maximum height. Each formula that you know includes v_i, so you will have to calculate that first.

$v_f = v_i + at_f$ where $a = -g$

$v_i = v_f + gt_f$

$= 0.0\ \text{m/s} + (9.80\ \text{m/s}^2)(1.1\ \text{s})$

$= 11$ m/s

Now you can use an equation that includes the displacement.

$d_f = d_i + v_it_f + \frac{1}{2}at_f^2$ where $a = -g$

$= d_i + v_it_f - \frac{1}{2}gt_f^2$

$= 0.0\ \text{m} + (11\ \text{m/s})(1.1\ \text{s}) - \left(\frac{1}{2}\right)(9.80\ \text{m/s}^2)(1.1\ \text{s})^2$

$= 6.2$ m

b. What was its initial velocity?

$v_i = 11$ m/s

Mixed Review

pages 82–84

Level 1

103. A spaceship far from any star or planet experiences uniform acceleration from 65.0 m/s to 162.0 m/s in 10.0 s. How far does it move?

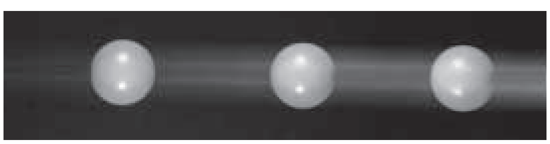
Choosing a coordinate system with the origin at the point where the speed is 65.0 m/s and given $v_i = 65.0$ m/s, $v_f = 162.0$ m/s, and $t_f = 10.0$ s and needing d_f, we use the formula with the average velocity.

$$d_f = d_i + \frac{1}{2}(v_i + v_f)t_f$$

$$d_f = 0 + \frac{1}{2}(65.0\text{ m/s} + 162.0\text{ m/s})(10.0\text{ s})$$

$$= 1.14\times10^3\text{ m}$$

104. **Figure 3-20** is a strobe photo of a horizontally moving ball. What information about the photo would you need and what measurements would you make to estimate the acceleration?



■ **Figure 3-20**

You need to know the time between flashes and the distance between the first two images and the distance between the last two. From these, you get two velocities. Between these two velocities, a time interval of *t* seconds occurred. Divide the difference between the two velocities by *t*.

105. **Bicycle** A bicycle accelerates from 0.0 m/s to 4.0 m/s in 4.0 s. What distance does it travel?

$$d_f = \bar{v}t_f = \frac{v_i + v_f}{2}t_f$$

$$= \left(\frac{0.0\text{ m/s} + 4.0\text{ m/s}}{2}\right)(4.0\text{ s})$$

$$= 8.0\text{ m}$$

106. A weather balloon is floating at a constant height above Earth when it releases a pack of instruments.

a. If the pack hits the ground with a velocity of −73.5 m/s, how far did the pack fall?

$$v_f^2 = v_i^2 + 2ad_f$$

$$d_f = \frac{v_f^2 - v_i^2}{2a}$$

$$= \frac{(-73.5\text{ m/s})^2 - (0.00\text{ m/s})^2}{(2)(-9.80\text{ m/s}^2)}$$

$$= -276\text{ m}$$

b. How long did it take for the pack to fall?

$v_f = v_i + at_f$ **where** $a = -g$

$$t_f = \frac{v_f - v_i}{-g}$$

$$= \frac{-73.5\text{ m/s} - 0.00\text{ m/s}}{-9.80\text{ m/s}^2}$$

$$= 7.50\text{ s}$$

Level 2

107. **Baseball** A baseball pitcher throws a fastball at a speed of 44 m/s. The acceleration occurs as the pitcher holds the ball in his hand and moves it through an almost straight-line distance of 3.5 m. Calculate the acceleration, assuming that it is constant and uniform. Compare this acceleration to the acceleration due to gravity.

$$v_f^2 = v_i^2 + 2ad_f$$

$$a = \frac{v_f^2 - v_i^2}{2d_f}$$

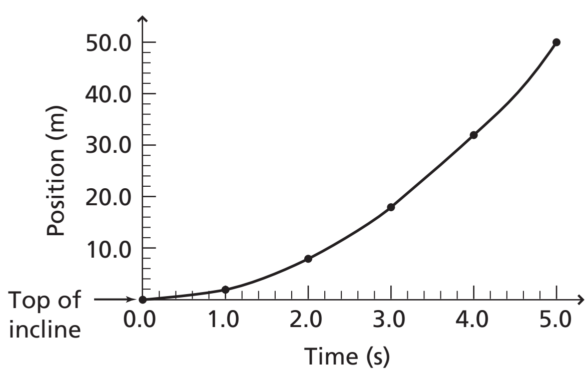
$$= \frac{(44\text{ m/s})^2 - 0}{(2)(3.5\text{ m})} = 2.8\times10^2\text{ m/s}^2$$

$$\frac{2.8\times10^2\text{ m/s}^2}{9.80\text{ m/s}^2} = 29\text{, or 29 times } g$$

108. The total distance a steel ball rolls down an incline at various times is given in **Table 3-5.**

Table 3-5	
Distance v. Time	
Time (s)	**Distance (m)**
0.0	0.0
1.0	2.0
2.0	8.0
3.0	18.0
4.0	32.0
5.0	50.0

a. Draw a position-time graph of the motion of the ball. When setting up the axes, use five divisions for each 10 m of travel on the *d*-axis. Use five divisions for 1 s of time on the *t*-axis.



b. Calculate the distance the ball has rolled at the end of 2.2 s.

After 2.2 seconds the ball has rolled approximately 10 m.

109. Engineers are developing new types of guns that might someday be used to launch satellites as if they were bullets. One such gun can give a small object a velocity of 3.5 km/s while moving it through a distance of only 2.0 cm.

a. What acceleration does the gun give this object?

$$v_f^2 = v_i^2 + 2ad_f$$

or $v_f^2 = 2ad_f$

$$a = \frac{v_f^2}{2d_f} = \frac{(3.5\times10^3 \text{ m/s})^2}{(2)(0.020 \text{ m})}$$

$$= 3.1\times10^8 \text{ m/s}^2$$

b. Over what time interval does the acceleration take place?

$$d = \frac{(v_f + v_i)t}{2}$$

$$t = \frac{2d_f}{v_f + v_i} = \frac{(2)(0.020 \text{ m})}{3.5\times10^3 \text{ m/s} + 0.0 \text{ m/s}}$$

$$= 11\times10^{-6} \text{ s}$$

$$= 11 \text{ microseconds}$$

110. Sleds Rocket-powered sleds are used to test the responses of humans to acceleration. Starting from rest, one sled can reach a speed of 444 m/s in 1.80 s and can be brought to a stop again in 2.15 s.

a. Calculate the acceleration of the sled when starting, and compare it to the magnitude of the acceleration due to gravity, 9.80 m/s^2.

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{\Delta t}$$

$$= \frac{444 \text{ m/s} - 0.00 \text{ m/s}}{1.80 \text{ s}}$$

$$= 247 \text{ m/s}^2$$

$$\frac{247 \text{ m/s}^2}{9.80 \text{ m/s}^2} = 25 \text{ times } g$$

b. Find the acceleration of the sled as it is braking and compare it to the magnitude of the acceleration due to gravity.

$$a = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{\Delta t}$$

$$= \frac{0.00 \text{ m/s} - 444 \text{ m/s}}{2.15 \text{ s}}$$

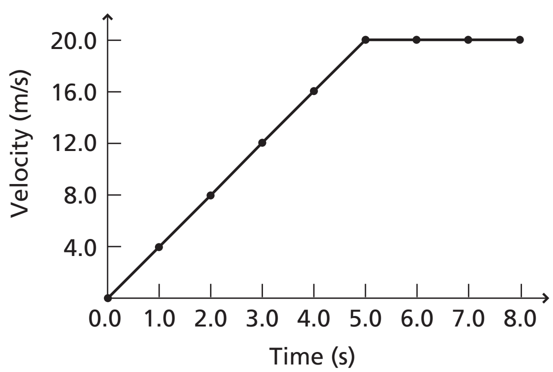
$$= -207 \text{ m/s}^2$$

$$\frac{207 \text{ m/s}^2}{9.80 \text{ m/s}^2} = 21 \text{ times } g$$

111. The velocity of a car changes over an 8.0-s time period, as shown in **Table 3-6.**

Table 3-6	
Velocity v. Time	
Time (s)	Velocity (m/s)
0.0	0.0
1.0	4.0
2.0	8.0
3.0	12.0
4.0	16.0
5.0	20.0
6.0	20.0
7.0	20.0
8.0	20.0

a. Plot the velocity-time graph of the motion.



b. Determine the displacement of the car during the first 2.0 s.

Find the area under the *v-t* curve.

$$d = \frac{1}{2}bh$$

$$= \left(\frac{1}{2}\right)(2.0\ \text{s})(8.0\ \text{m/s} - 0.0\ \text{m/s})$$

$$= 8.0\ \text{m}$$

c. What displacement does the car have during the first 4.0 s?

Find the area under the *v-t* curve.

$$d = \frac{1}{2}bh$$

$$= \left(\frac{1}{2}\right)(4.0\ \text{s})(16.0\ \text{m/s} - 0.0\ \text{m/s})$$

$$= 32\ \text{m}$$

d. What is the displacement of the car during the entire 8.0 s?

Find the area under the *v-t* curve.

$$d = \frac{1}{2}bh + bh$$

$$= \left(\frac{1}{2}\right)(5.0\ \text{s})(20.0\ \text{m/s} - 0.0\ \text{m/s}) + (8.0\ \text{s} - 5.0\ \text{s})(20.0\ \text{m/s})$$

$$= 110\ \text{m}$$

e. Find the slope of the line between $t = 0.0$ s and $t = 4.0$ s. What does this slope represent?

$$a = \frac{\Delta v}{\Delta t} = \frac{16.0\ \text{m/s} - 0.00\ \text{m/s}}{4.0\ \text{s} - 0.0\ \text{s}}$$

$$= 4.0\ \text{m/s}^2\text{, acceleration}$$

f. Find the slope of the line between $t = 5.0$ s and $t = 7.0$ s. What does this slope indicate?

$$a = \frac{\Delta v}{\Delta t} = \frac{20.0\ \text{m/s} - 20.0\ \text{m/s}}{7.0\ \text{s} - 5.0\ \text{s}}$$

$$= 0.0\ \text{m/s}^2\text{, constant velocity}$$

Level 3

112. A truck is stopped at a stoplight. When the light turns green, the truck accelerates at 2.5 m/s^2. At the same instant, a car passes the truck going 15 m/s. Where and when does the truck catch up with the car?

Car:

$$d_f = d_i + vt_f$$

$$d_{car} = d_i + v_{car}t_f = v_{car}t_f$$

$$= 0 + (15\ \text{m/s})t_f$$

Truck:

$$d_f = d_i + v_i t_f + \frac{1}{2}at_f^2$$

$$d_{truck} = \frac{1}{2}a_{truck}t_f^2$$

$$= 0 + 0 + \left(\frac{1}{2}\right)(2.5\ \text{m/s}^2)t_f^2$$

When the truck catches up, the displacements are equal.

$$v_{car}t_f = \frac{1}{2}a_{truck}t_f^2$$

$$0 = \frac{1}{2}a_{truck}t_f^2 - v_{car}t_f$$

$$0 = t_f\left(\frac{1}{2}a_{truck}t_f - v_{car}\right)$$

therefore

$$t_f = 0 \text{ and } \frac{1}{2}a_{truck}t_f - v_{car} = 0$$

$$t_f = \frac{2v_{car}}{a_{truck}} = \frac{(2)(15 \text{ m/s})}{2.5 \text{ m/s}} = 12 \text{ s}$$

$$d_f = (15 \text{ m/s})t_f = (15 \text{ m/s})(12 \text{ s}) = 180 \text{ m}$$

113. Safety Barriers Highway safety engineers build soft barriers, such as the one shown in **Figure 3-21,** so that cars hitting them will slow down at a safe rate. A person wearing a safety belt can withstand an acceleration of -3.0×10^2 m/s^2. How thick should barriers be to safely stop a car that hits a barrier at 110 km/h?

■ **Figure 3-21**

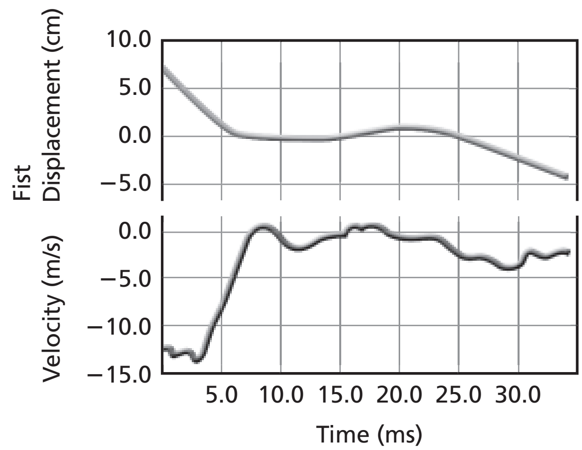
$$v_i = \frac{(110 \text{ km/h})(1000 \text{ m/km})}{3600 \text{ s/h}} = 31 \text{ m/s}$$

$$v_f^2 = v_i^2 + 2ad_f$$

with $v_f = 0$ m/s, $v_i^2 = -2ad_f$, or

$$d_f = \frac{-v_i^2}{2a} = \frac{-(31 \text{ m/s})^2}{(2)(-3.0\times10^2 \text{ m/s}^2)} = 1.6 \text{ m thick}$$

114. Karate The position-time and velocity-time graphs of George's fist breaking a wooden board during karate practice are shown in **Figure 3-22.**



■ **Figure 3-22**

a. Use the velocity-time graph to describe the motion of George's fist during the first 10 ms.

The fist moves downward at about −13 m/s for about 4 ms. It then suddenly comes to a halt (accelerates).

b. Estimate the slope of the velocity-time graph to determine the acceleration of his fist when it suddenly stops.

$$a = \frac{\Delta v}{\Delta t} = \frac{0 \text{ m/s} - (-13 \text{ m/s})}{7.5 \text{ ms} - 4.0 \text{ ms}} = 3.7\times10^3 \text{ m/s}^2$$

c. Express the acceleration as a multiple of the gravitational acceleration, $g = 9.80$ m/s^2.

$$\frac{3.7\times10^3 \text{ m/s}^2}{9.80 \text{ m/s}^2} = 3.8\times10^2$$

The acceleration is about 380*g*.

d. Determine the area under the velocity-time curve to find the displacement of the fist in the first 6 ms. Compare this with the position-time graph.

The area can be approximated by a rectangle:

$(-13 \text{ m/s})(0.006 \text{ s}) = -8$ cm

This is in agreement with the position-time graph where the hand moves from +8 cm to 0 cm, for a net displacement of −8 cm.

115. Cargo A helicopter is rising at 5.0 m/s when a bag of its cargo is dropped. The bag falls for 2.0 s.

a. What is the bag's velocity?

$v_f = v_i + at_f$ **where** $a = -g$

$= v_i - gt_f$

$= 5.0\ \text{m/s} - (9.80\ \text{m/s}^2)(2.0\ \text{s})$

$= -15\ \text{m/s}$

b. How far has the bag fallen?

$d_f = v_it_f + \frac{1}{2}at_f^2$ **where** $a = -g$

$= v_it_f - \frac{1}{2}gt_f^2$

$= (5.0\ \text{m/s})(2.0\ \text{s}) - \left(\frac{1}{2}\right)(9.80\ \text{m/s}^2)(2.0\ \text{s})^2$

$= -1.0\times10^1\ \text{m}$

The bag has fallen 1.0×10^1 m

c. How far below the helicopter is the bag?

The helicopter has risen

$d_f = v_it_f = (5.0\ \text{m/s}^2)(2.0\ \text{s})$

$= 1.0\times10^1\ \text{m}$

The bag is 1.0×10^1 m below the origin and 2.0×10^1 m below the helicopter.

Thinking Critically

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116. Apply CBLs Design a lab to measure the distance an accelerated object moves over time. Use equal time intervals so that you can plot velocity over time as well as distance. A pulley at the edge of a table with a mass attached is a good way to achieve uniform acceleration. Suggested materials include a motion detector, CBL, lab cart, string, pulley, C-clamp, and masses. Generate distance-time and velocity-time graphs using different masses on the pulley. How does the change in mass affect your graphs?

Students' labs will vary. Students should find that a change in the mass over the edge of the table will not change the distance the cart moves, because the acceleration is always the same: *g*.

117. Analyze and Conclude Which has the greater acceleration: a car that increases its speed from 50 km/h to 60 km/h, or a bike that goes from 0 km/h to 10 km/h in the same time? Explain.

$a = \frac{v_f - v_i}{\Delta t}$

For car, $a = \frac{60\ \text{km/h} - 50\ \text{km/h}}{\Delta t}$

$= \frac{10\ \text{km/h}}{\Delta t}$

For bike, $a = \frac{10\ \text{km/h} - 0\ \text{km/h}}{\Delta t}$

$= \frac{10\ \text{km/h}}{\Delta t}$

The change in velocity is the same.

118. Analyze and Conclude An express train, traveling at 36.0 m/s, is accidentally side-tracked onto a local train track. The express engineer spots a local train exactly 1.00×10^2 m ahead on the same track and traveling in the same direction. The local engineer is unaware of the situation. The express engineer jams on the brakes and slows the express train at a constant rate of 3.00 m/s^2. If the speed of the local train is 11.0 m/s, will the express train be able to stop in time, or will there be a collision? To solve this problem, take the position of the express train when the engineer first sights the local train as a point of origin. Next, keeping in mind that the local train has exactly a 1.00×10^2 m lead, calculate how far each train is from the origin at the end of the 12.0 s it would take the express train to stop (accelerate at -3.00 m/s^2 from 36 m/s to 0 m/s).

a. On the basis of your calculations, would you conclude that a collision will occur?

Express:

$d_f = v_it_f + \frac{1}{2}at_f^2$

$= (36.0\ \text{m/s})(12.0\ \text{s}) +$

$$\left(\frac{1}{2}\right)(-3.00\ \text{m/s}^2)(12.0\ \text{s})^2$$

$$= 432\ \text{m} - 216\ \text{m} = 216\ \text{m}$$

Local:

$$d_f = d_i + v_i t_f + a t_f^2$$

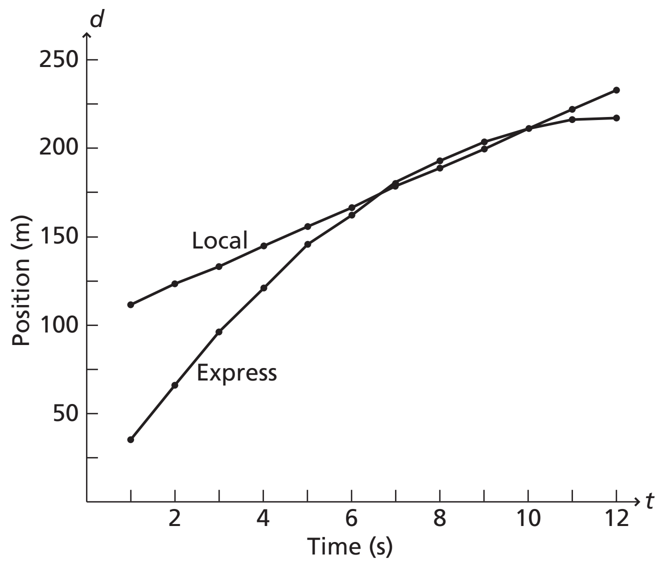
$$= 100\ \text{m} + (11.0\ \text{m/s})(12.0\ \text{s}) + 0$$

$$= 232\ \text{m}$$

On this basis, no collision will occur.

b. The calculations that you made do not allow for the possibility that a collision might take place before the end of the 12 s required for the express train to come to a halt. To check this, take the position of the express train when the engineer first sights the local train as the point of origin and calculate the position of each train at the end of each second after the sighting. Make a table showing the distance of each train from the origin at the end of each second. Plot these positions on the same graph and draw two lines. Use your graph to check your answer to part **a.**

t (s)	*d* (Local) (m)	*d* (Express) (m)
1	111	35
2	122	66
3	133	95
4	144	120
5	155	145
6	166	162
7	177	179
8	188	192
9	199	203
10	210	210
11	221	215
12	232	216



They collide between 6 and 7 s.

Writing in Physics

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119. Research and describe Galileo's contributions to physics.

Student answers will vary. Answers should include Galileo's experiments demonstrating how objects accelerate as they fall. Answers might include his use of a telescope to discover the moons of Jupiter and the rings of Saturn, and his reliance on experimental results rather than authority.

120. Research the maximum acceleration a human body can withstand without blacking out. Discuss how this impacts the design of three common entertainment or transportation devices.

Answers will vary. Because humans can experience negative effects, like blackouts, the designers of roller coasters need to structure the downward slopes in such a way that the coaster does not reach accelerations that cause blackouts. Likewise, engineers working on bullet trains, elevators, or airplanes need to design the system in such a way that allows the object to rapidly accelerate to high speeds, without causing the passengers to black out.

Cumulative Review

page 84

121. Solve the following problems. Express your answers in scientific notation. (Chapter 1)

a. 6.2×10^{-4} m + 5.7×10^{-3} m

6.3×10^{-3} m

b. 8.7×10^{8} km − 3.4×10^{7} m

8.4×10^{8} km

c. $(9.21\times10^{-5}$ cm$)(1.83\times10^{8}$ cm$)$

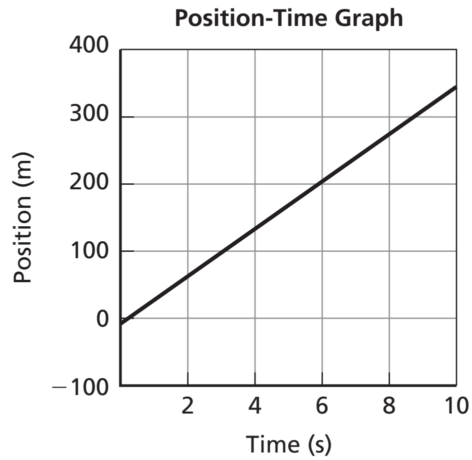
1.69×10^{4} cm^2

d. $(2.63\times10^{-6}$ m$)/(4.08\times10^{6}$ s$)$

6.45×10^{-13} m/s

122. The equation below describes the motion of an object. Create the corresponding position-time graph and motion diagram. Then write a physics problem that could be solved using that equation. Be creative. $d = (35.0\text{ m/s})\,t - 5.0\text{ m}$ (Chapter 2)

Graph and motion diagram indicate constant velocity motion with a velocity of 35.0 m/s and initial position of −5.0 m. Answers will vary for the create-a-problem part.



Challenge Problem

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You notice a water balloon fall past your classroom window. You estimate that it took the balloon about t seconds to fall the length of the window and that the window is about y meters high. Suppose the balloon started from rest, approximately how high above the top of the window was it released? Your answer should be in terms of t, y, g, and numerical constants.

Down is positive. Work this problem in two stages. Stage 1 is falling the distance *D* to the top of the window. Stage 2 is falling the distance *y* from the top of the window to the bottom of the window.

Stage 1: the origin is at the top of the fall.

$$v_{f1}^2 = v_{i1}^2 + 2a(d_{f1} - d_{i1})$$
$$= 0 + 2g(D - 0)$$
$$v_{f1} = \sqrt{2gD}$$

Stage 2: the origin is at the top of the window.

$$d_{f2} = d_{i1} + v_{i1}t_{f2} + \tfrac{1}{2}at_{f2}^2$$
$$y = 0 + v_{f1}t + \tfrac{1}{2}gt^2$$
$$= 0 + \left(\sqrt{2gD}\right)(t) + \tfrac{1}{2}gt^2$$
$$\sqrt{2gD} = \frac{y}{t} - \frac{gt}{2}$$
$$D = \frac{1}{2g}\left(\frac{y}{t} - \frac{gt}{2}\right)^2$$