2

MOTION ALONG A STRAIGHT LINE

2.1. **IDENTIFY:** The average velocity is $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$.

SET UP: Let $+x$ be upward.

EXECUTE: **(a)** $v_{\text{av-}x} = \dfrac{1000\ \text{m} - 63\ \text{m}}{4.75\ \text{s}} = 197\ \text{m/s}$

(b) $v_{\text{av-}x} = \dfrac{1000\ \text{m} - 0}{5.90\ \text{s}} = 169\ \text{m/s}$

EVALUATE: For the first 1.15 s of the flight, $v_{\text{av-}x} = \dfrac{63\ \text{m} - 0}{1.15\ \text{s}} = 54.8\ \text{m/s}$. When the velocity isn't constant the average velocity depends on the time interval chosen. In this motion the velocity is increasing.

2.2. **IDENTIFY:** $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$

SET UP: $13.5\ \text{days} = 1.166 \times 10^5\ \text{s}$. At the release point, $x = +5.150 \times 10^6\ \text{m}$.

EXECUTE: **(a)** $v_{\text{av-}x} = \dfrac{x_2 - x_1}{\Delta t} = \dfrac{5.150 \times 10^6\ \text{m}}{1.166 \times 10^6\ \text{s}} = -4.42\ \text{m/s}$

(b) For the round trip, $x_2 = x_1$ and $\Delta x = 0$. The average velocity is zero.

EVALUATE: The average velocity for the trip from the nest to the release point is positive.

2.3. **IDENTIFY:** Target variable is the time Δt it takes to make the trip in heavy traffic. Use Eq.(2.2) that relates the average velocity to the displacement and average time.

SET UP: $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$ so $\Delta x = v_{\text{av-}x}\Delta t$ and $\Delta t = \dfrac{\Delta x}{v_{\text{av-}x}}$.

EXECUTE: Use the information given for normal driving conditions to calculate the distance between the two cities:

$$\Delta x = v_{\text{av-}x}\Delta t = (105\ \text{km/h})(1\ \text{h}/60\ \text{min})(140\ \text{min}) = 245\ \text{km}.$$

Now use $v_{\text{av-}x}$ for heavy traffic to calculate Δt; Δx is the same as before:

$$\Delta t = \frac{\Delta x}{v_{\text{av-}x}} = \frac{245\ \text{km}}{70\ \text{km/h}} = 3.50\ \text{h} = 3\ \text{h}\ \text{ and 30 min.}$$

The trip takes an additional 1 hour and 10 minutes.

EVALUATE: The time is inversely proportional to the average speed, so the time in traffic is $(105/70)(140\ \text{m}) = 210\ \text{min}$.

2.4. **IDENTIFY:** The average velocity is $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$. Use the average speed for each segment to find the time traveled in that segment. The average speed is the distance traveled by the time.

SET UP: The post is 80 m west of the pillar. The total distance traveled is $200\ \text{m} + 280\ \text{m} = 480\ \text{m}$.

EXECUTE: **(a)** The eastward run takes time $\dfrac{200\ \text{m}}{5.0\ \text{m/s}} = 40.0\ \text{s}$ and the westward run takes $\dfrac{280\ \text{m}}{4.0\ \text{m/s}} = 70.0\ \text{s}$. The average speed for the entire trip is $\dfrac{480\ \text{m}}{110.0\ \text{s}} = 4.4\ \text{m/s}$.

(b) $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t} = \dfrac{-80\ \text{m}}{110.0\ \text{s}} = -0.73\ \text{m/s}$. The average velocity is directed westward.

EVALUATE: The displacement is much less than the distance traveled and the magnitude of the average velocity is much less than the average speed. The average speed for the entire trip has a value that lies between the average speed for the two segments.

2.5. **IDENTIFY:** When they first meet the sum of the distances they have run is 200 m.

SET UP: Each runs with constant speed and continues around the track in the same direction, so the distance each runs is given by $d = vt$. Let the two runners be objects A and B.

EXECUTE: **(a)** $d_A + d_B = 200\text{ m}$, so $(6.20\text{ m/s})t + (5.50\text{ m/s})t = 200\text{ m}$ and $t = \dfrac{200\text{ m}}{11.70\text{ m/s}} = 17.1\text{ s}$.

(b) $d_A = v_A t = (6.20\text{ m/s})(17.1\text{ s}) = 106\text{ m}$. $d_B = v_B t = (5.50\text{ m/s})(17.1\text{ s}) = 94\text{ m}$. The faster runner will be 106 m from the starting point and the slower runner will be 94 m from the starting point. These distances are measured around the circular track and are not straight-line distances.

EVALUATE: The faster runner runs farther.

2.6. **IDENTIFY:** To overtake the slower runner the first time the fast runner must run 200 m farther. To overtake the slower runner the second time the faster runner must run 400 m farther.

SET UP: t and x_0 are the same for the two runners.

EXECUTE: **(a)** Apply $x - x_0 = v_{0x}t$ to each runner: $(x - x_0)_\text{f} = (6.20\text{ m/s})t$ and $(x - x_0)_\text{s} = (5.50\text{ m/s})t$.

$(x - x_0)_\text{f} = (x - x_0)_\text{s} + 200\text{ m}$ gives $(6.20\text{ m/s})t = (5.50\text{ m/s})t + 200\text{ m}$ and $t = \dfrac{200\text{ m}}{6.20\text{ m/s} - 5.50\text{ m/s}} = 286\text{ s}$.

$(x - x_0)_\text{f} = 1770\text{ m}$ and $(x - x_0)_\text{s} = 1570\text{ m}$.

(b) Repeat the calculation but now $(x - x_0)_\text{f} = (x - x_0)_\text{s} + 400\text{ m}$. $t = 572\text{ s}$. The fast runner has traveled 3540 m. He has made 17 full laps for 3400 m and 140 m past the starting line in this 18$^\text{th}$ lap.

EVALUATE: In part (a) the fast runner will have run 8 laps for 1600 m and will be 170 m past the starting line in his 9$^\text{th}$ lap.

2.7. **IDENTIFY:** In time t_S the S-waves travel a distance $d = v_\text{S}t_\text{S}$ and in time t_P the P-waves travel a distance $d = v_\text{P}t_\text{P}$.

SET UP: $t_\text{S} = t_\text{P} + 33\text{ s}$

EXECUTE: $\dfrac{d}{v_\text{S}} = \dfrac{d}{v_\text{P}} + 33\text{ s}$. $d\left(\dfrac{1}{3.5\text{ km/s}} - \dfrac{1}{6.5\text{ km/s}}\right) = 33\text{ s}$ and $d = 250\text{ km}$.

EVALUATE: The times of travel for each wave are $t_\text{S} = 71\text{ s}$ and $t_\text{P} = 38\text{ s}$.

2.8. **IDENTIFY:** The average velocity is $v_\text{av-}x = \dfrac{\Delta x}{\Delta t}$. Use $x(t)$ to find x for each t.

SET UP: $x(0) = 0$, $x(2.00\text{ s}) = 5.60\text{ m}$, and $x(4.00\text{ s}) = 20.8\text{ m}$

EXECUTE: **(a)** $v_\text{av-}x = \dfrac{5.60\text{ m} - 0}{2.00\text{ s}} = +2.80\text{ m/s}$

(b) $v_\text{av-}x = \dfrac{20.8\text{ m} - 0}{4.00\text{ s}} = +5.20\text{ m/s}$

(c) $v_\text{av-}x = \dfrac{20.8\text{ m} - 5.60\text{ m}}{2.00\text{ s}} = +7.60\text{ m/s}$

EVALUATE: The average velocity depends on the time interval being considered.

2.9. **(a) IDENTIFY:** Calculate the average velocity using Eq.(2.2).

SET UP: $v_\text{av-}x = \dfrac{\Delta x}{\Delta t}$ so use $x(t)$ to find the displacement Δx for this time interval.

EXECUTE: $t = 0$: $x = 0$

$t = 10.0\text{ s}$: $x = (2.40\text{ m/s}^2)(10.0\text{ s})^2 - (0.120\text{ m/s}^3)(10.0\text{ s})^3 = 240\text{ m} - 120\text{ m} = 120\text{ m}.$

Then $v_\text{av-}x = \dfrac{\Delta x}{\Delta t} = \dfrac{120\text{ m}}{10.0\text{ s}} = 12.0\text{ m/s}.$

(b) IDENTIFY: Use Eq.(2.3) to calculate $v_x(t)$ and evaluate this expression at each specified t.

SET UP: $v_x = \dfrac{dx}{dt} = 2bt - 3ct^2.$

EXECUTE: (i) $t = 0$: $v_x = 0$

(ii) $t = 5.0\text{ s}$: $v_x = 2(2.40\text{ m/s}^2)(5.0\text{ s}) - 3(0.120\text{ m/s}^3)(5.0\text{ s})^2 = 24.0\text{ m/s} - 9.0\text{ m/s} = 15.0\text{ m/s}.$

(iii) $t = 10.0\text{ s}$: $v_x = 2(2.40\text{ m/s}^2)(10.0\text{ s}) - 3(0.120\text{ m/s}^3)(10.0\text{ s})^2 = 48.0\text{ m/s} - 36.0\text{ m/s} = 12.0\text{ m/s}.$

(c) IDENTIFY: Find the value of t when $v_x(t)$ from part (b) is zero.

SET UP: $v_x = 2bt - 3ct^2$

$v_x = 0$ at $t = 0$.

$v_x = 0$ next when $2bt - 3ct^2 = 0$

EXECUTE: $2b = 3ct$ so $t = \dfrac{2b}{3c} = \dfrac{2(2.40\text{ m/s}^2)}{30(.120\text{ m/s}^3)} = 13.3\text{ s}$

EVALUATE: $v_x(t)$ for this motion says the car starts from rest, speeds up, and then slows down again.

2.10. **IDENTIFY** and **SET UP:** The instantaneous velocity is the slope of the tangent to the x versus t graph.
EXECUTE: **(a)** The velocity is zero where the graph is horizontal; point IV.
(b) The velocity is constant and positive where the graph is a straight line with positive slope; point I.
(c) The velocity is constant and negative where the graph is a straight line with negative slope; point V.
(d) The slope is positive and increasing at point II.
(e) The slope is positive and decreasing at point III.
EVALUATE: The sign of the velocity indicates its direction.

2.11. **IDENTIFY:** The average velocity is given by $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t}$. We can find the displacement Δt for each constant velocity time interval. The average speed is the distance traveled divided by the time.
SET UP: For $t = 0$ to $t = 2.0\text{ s}$, $v_x = 2.0\text{ m/s}$. For $t = 2.0\text{ s}$ to $t = 3.0\text{ s}$, $v_x = 3.0\text{ m/s}$. In part (b), $v_x = -3.0\text{ m/s}$ for $t = 2.0\text{ s}$ to $t = 3.0\text{ s}$. When the velocity is constant, $\Delta x = v_x \Delta t$.
EXECUTE: **(a)** For $t = 0$ to $t = 2.0\text{ s}$, $\Delta x = (2.0\text{ m/s})(2.0\text{ s}) = 4.0\text{ m}$. For $t = 2.0\text{ s}$ to $t = 3.0\text{ s}$, $\Delta x = (3.0\text{ m/s})(1.0\text{ s}) = 3.0\text{ m}$. For the first 3.0 s, $\Delta x = 4.0\text{ m} + 3.0\text{ m} = 7.0\text{ m}$. The distance traveled is also 7.0 m.
The average velocity is $v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t} = \dfrac{7.0\text{ m}}{3.0\text{ s}} = 2.33\text{ m/s}$. The average speed is also 2.33 m/s.
(b) For $t = 2.0$ s to 3.0 s, $\Delta x = (-3.0\text{ m/s})(1.0\text{ s}) = -3.0\text{ m}$. For the first 3.0 s, $\Delta x = 4.0\text{ m} + (-3.0\text{ m}) = +1.0\text{ m}$.
The dog runs 4.0 m in the $+x$-direction and then 3.0 m in the $-x$-direction, so the distance traveled is still 7.0 m.
$v_{\text{av-}x} = \dfrac{\Delta x}{\Delta t} = \dfrac{1.0\text{ m}}{3.0\text{ s}} = 0.33\text{ m/s}$. The average speed is $\dfrac{7.00\text{ m}}{3.00\text{ s}} = 2.33\text{ m/s}$.
EVALUATE: When the motion is always in the same direction, the displacement and the distance traveled are equal and the average velocity has the same magnitude as the average speed. When the motion changes direction during the time interval, those quantities are different.

2.12. **IDENTIFY** and **SET UP:** $a_{\text{av},x} = \dfrac{\Delta v_x}{\Delta t}$. The instantaneous acceleration is the slope of the tangent to the v_x versus t graph.
EXECUTE: **(a)** 0 s to 2 s: $a_{\text{av},x} = 0$; 2 s to 4 s: $a_{\text{av},x} = 1.0\text{ m/s}^2$; 4 s to 6 s: $a_{\text{av},x} = 1.5\text{ m/s}^2$; 6 s to 8 s: $a_{\text{av},x} = 2.5\text{ m/s}^2$; 8 s to 10 s: $a_{\text{av},x} = 2.5\text{ m/s}^2$; 10 s to 12 s: $a_{\text{av},x} = 2.5\text{ m/s}^2$; 12 s to 14 s: $a_{\text{av},x} = 1.0\text{ m/s}^2$; 14 s to 16 s: $a_{\text{av},x} = 0$. The acceleration is not constant over the entire 16 s time interval. The acceleration is constant between 6 s and 12 s.
(b) The graph of v_x versus t is given in Fig. 2.12. $t = 9\text{ s}$: $a_x = 2.5\text{ m/s}^2$; $t = 13\text{ s}$: $a_x = 1.0\text{ m/s}^2$; $t = 15\text{ s}$: $a_x = 0$.

EVALUATE: The acceleration is constant when the velocity changes at a constant rate. When the velocity is constant, the acceleration is zero.

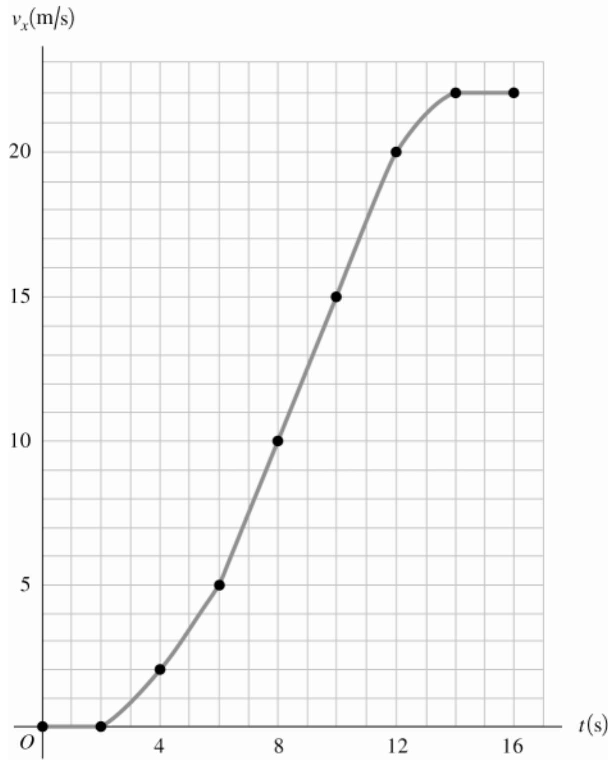


Figure 2.12

2.13. IDENTIFY: The average acceleration for a time interval Δt is given by $a_{\text{av-}x} = \dfrac{\Delta v_x}{\Delta t}$.

SET UP: Assume the car is moving in the $+x$ direction. $1 \text{ mi/h} = 0.447 \text{ m/s}$, so $60 \text{ mi/h} = 26.82 \text{ m/s}$, $200 \text{ mi/h} = 89.40 \text{ m/s}$ and $253 \text{ mi/h} = 113.1 \text{ m/s}$.

EXECUTE: **(a)** The graph of v_x versus t is sketched in Figure 2.13. The graph is not a straight line, so the acceleration is not constant.

(b) (i) $a_{\text{av-}x} = \dfrac{26.82 \text{ m/s} - 0}{2.1 \text{ s}} = 12.8 \text{ m/s}^2$ (ii) $a_{\text{av-}x} = \dfrac{89.40 \text{ m/s} - 26.82 \text{ m/s}}{20.0 \text{ s} - 2.1 \text{ s}} = 3.50 \text{ m/s}^2$ (iii) $a_{\text{av-}x} = \dfrac{113.1 \text{ m/s} - 89.40 \text{ m/s}}{53 \text{ s} - 20.0 \text{ s}} = 0.718 \text{ m/s}^2$. The slope of the graph of v_x versus t decreases as t increases. This is consistent with an average acceleration that decreases in magnitude during each successive time interval.

EVALUATE: The average acceleration depends on the chosen time interval. For the interval between 0 and 53 s, $a_{\text{av-}x} = \dfrac{113.1 \text{ m/s} - 0}{53 \text{ s}} = 2.13 \text{ m/s}^2$.

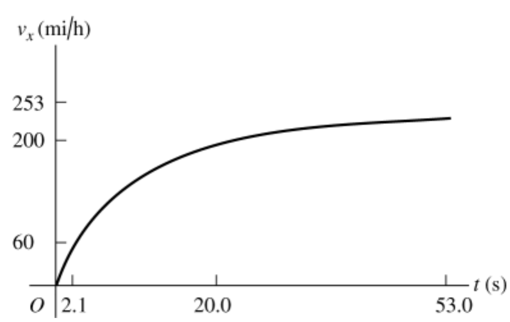


Figure 2.13

2.14. **IDENTIFY:** $a_{\text{av-}x} = \dfrac{\Delta v_x}{\Delta t}$. $a_x(t)$ is the slope of the v_x versus t graph.

SET UP: $60\text{ km/h} = 16.7\text{ m/s}$

EXECUTE: **(a)** (i) $a_{\text{av-}x} = \dfrac{16.7\text{ m/s} - 0}{10\text{ s}} = 1.7\text{ m/s}^2$. (ii) $a_{\text{av-}x} = \dfrac{0 - 16.7\text{ m/s}}{10\text{ s}} = -1.7\text{ m/s}^2$.

(iii) $\Delta v_x = 0$ and $a_{\text{av-}x} = 0$. (iv) $\Delta v_x = 0$ and $a_{\text{av-}x} = 0$.

(b) At $t = 20$ s, v_x is constant and $a_x = 0$. At $t = 35$ s, the graph of v_x versus t is a straight line and $a_x = a_{\text{av-}x} = -1.7\text{ m/s}^2$.

EVALUATE: When $a_{\text{av-}x}$ and v_x have the same sign the speed is increasing. When they have opposite sign the speed is decreasing.

2.15. **IDENTIFY** and **SET UP:** Use $v_x = \dfrac{dx}{dt}$ and $a_x = \dfrac{dv_x}{dt}$ to calculate $v_x(t)$ and $a_x(t)$.

EXECUTE: $v_x = \dfrac{dx}{dt} = 2.00\text{ cm/s} - (0.125\text{ cm/s}^2)t$

$a_x = \dfrac{dv_x}{dt} = -0.125\text{ cm/s}^2$

(a) At $t = 0$, $x = 50.0$ cm, $v_x = 2.00$ cm/s, $a_x = -0.125\text{ cm/s}^2$.

(b) Set $v_x = 0$ and solve for t: $t = 16.0$ s.

(c) Set $x = 50.0$ cm and solve for t. This gives $t = 0$ and $t = 32.0$ s. The turtle returns to the starting point after 32.0 s.

(d) Turtle is 10.0 cm from starting point when $x = 60.0$ cm or $x = 40.0$ cm.
Set $x = 60.0$ cm and solve for t: $t = 6.20$ s and $t = 25.8$ s.

At $t = 6.20$ s, $v_x = +1.23$ cm/s.

At $t = 25.8$ s, $v_x = -1.23$ cm/s.

Set $x = 40.0$ cm and solve for t: $t = 36.4$ s (other root to the quadratic equation is negative and hence nonphysical).

At $t = 36.4$ s, $v_x = -2.55$ cm/s.

(e) The graphs are sketched in Figure 2.15.

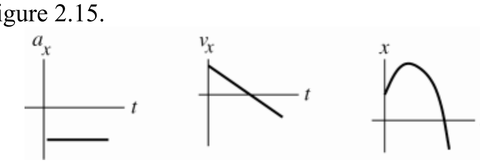


Figure 2.15

EVALUATE: The acceleration is constant and negative. v_x is linear in time. It is initially positive, decreases to zero, and then becomes negative with increasing magnitude. The turtle initially moves farther away from the origin but then stops and moves in the $-x$-direction.

2.16. **IDENTIFY:** Use Eq.(2.4), with $\Delta t = 10$ s in all cases.

SET UP: v_x is negative if the motion is to the right.

EXECUTE: **(a)** $\big((5.0\text{ m/s}) - (15.0\text{ m/s})\big)/(10\text{ s}) = -1.0\text{ m/s}^2$

(b) $\big((-15.0\text{ m/s}) - (-5.0\text{ m/s})\big)/(10\text{ s}) = -1.0\text{ m/s}^2$

(c) $\big((-15.0\text{ m/s}) - (+15.0\text{ m/s})\big)/(10\text{ s}) = -3.0\text{ m/s}^2$

EVALUATE: In all cases, the negative acceleration indicates an acceleration to the left.

2.17. **IDENTIFY:** The average acceleration is $a_{\text{av-}x} = \dfrac{\Delta v_x}{\Delta t}$

SET UP: Assume the car goes from rest to 65 mi/h (29 m/s) in 10 s. In braking, assume the car goes from 65 mi/h to zero in 4.0 s. Let $+x$ be in the direction the car is traveling.

EXECUTE: **(a)** $a_{\text{av-}x} = \dfrac{29\text{ m/s} - 0}{10\text{ s}} = 2.9\text{ m/s}^2$

(b) $a_{\text{av-}x} = \dfrac{0 - 29\text{ m/s}}{4.0\text{ s}} = -7.2\text{ m/s}^2$

(c) In part (a) the speed increases so the acceleration is in the same direction as the velocity. If the velocity direction is positive, then the acceleration is positive. In part (b) the speed decreases so the acceleration is in the direction opposite to the direction of the velocity. If the velocity direction is positive then the acceleration is negative, and if the velocity direction is negative then the acceleration direction is positive.

EVALUATE: The sign of the velocity and of the acceleration indicate their direction.

2.18. **IDENTIFY:** The average acceleration is $a_{\text{av-}x} = \frac{\Delta v_x}{\Delta t}$. Use $v_x(t)$ to find v_x at each *t*. The instantaneous acceleration is $a_x = \frac{dv_x}{dt}$.

SET UP: $v_x(0) = 3.00$ m/s and $v_x(5.00\ \text{s}) = 5.50$ m/s.

EXECUTE: **(a)** $a_{\text{av-}x} = \frac{\Delta v_x}{\Delta t} = \frac{5.50\ \text{m/s} - 3.00\ \text{m/s}}{5.00\ \text{s}} = 0.500\ \text{m/s}^2$

(b) $a_x = \frac{dv_x}{dt} = (0.100\ \text{m/s}^3)(2t) = (0.200\ \text{m/s}^3)t$. At $t = 0$, $a_x = 0$. At $t = 5.00$ s, $a_x = 1.00\ \text{m/s}^2$.

(c) Graphs of $v_x(t)$ and $a_x(t)$ are given in Figure 2.18.

EVALUATE: $a_x(t)$ is the slope of $v_x(t)$ and increases at *t* increases. The average acceleration for $t = 0$ to $t = 5.00$ s equals the instantaneous acceleration at the midpoint of the time interval, $t = 2.50$ s, since $a_x(t)$ is a linear function of *t*.

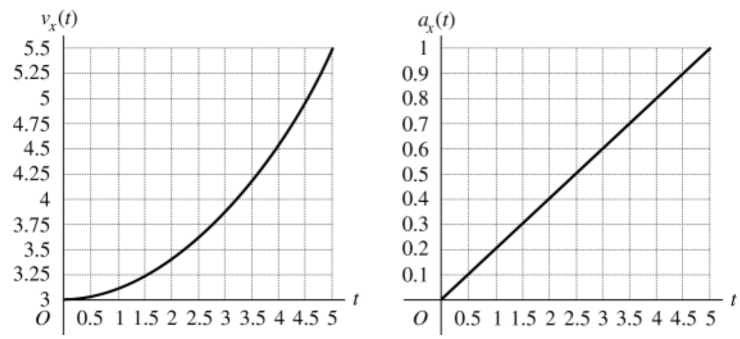


Figure 2.18

2.19. **(a) IDENTIFY** and **SET UP:** v_x is the slope of the *x* versus *t* curve and a_x is the slope of the v_x versus *t* curve.

EXECUTE: $t = 0$ to $t = 5$ s: *x* versus *t* is a parabola so a_x is a constant. The curvature is positive so a_x is positive. v_x versus *t* is a straight line with positive slope. $v_{0x} = 0$.

$t = 5$ s to $t = 15$ s: *x* versus *t* is a straight line so v_x is constant and $a_x = 0$. The slope of *x* versus *t* is positive so v_x is positive.

$t = 15$ s to $t = 25$ s: *x* versus *t* is a parabola with negative curvature, so a_x is constant and negative. v_x versus *t* is a straight line with negative slope. The velocity is zero at 20 s, positive for 15 s to 20 s, and negative for 20 s to 25 s.

$t = 25$ s to $t = 35$ s: *x* versus *t* is a straight line so v_x is constant and $a_x = 0$. The slope of *x* versus *t* is negative so v_x is negative.

$t = 35$ s to $t = 40$ s: *x* versus *t* is a parabola with positive curvature, so a_x is constant and positive. v_x versus *t* is a straight line with positive slope. The velocity reaches zero at $t = 40$ s.

The graphs of $v_x(t)$ and $a_x(t)$ are sketched in Figure 2.19a.

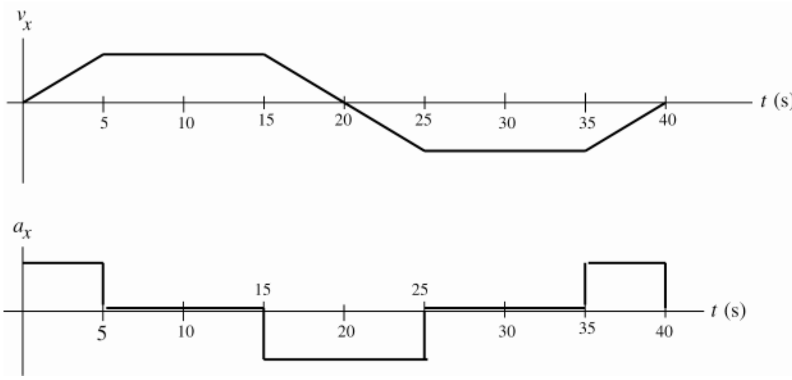


Figure 2.19a

(b) The motions diagrams are sketched in Figure 2.19b.

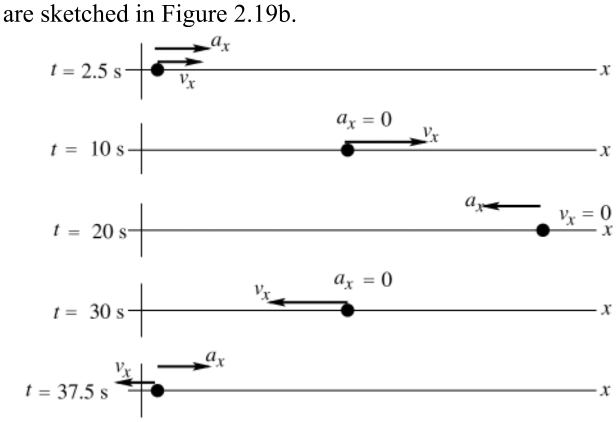


Figure 2.19b

EVALUATE: The spider speeds up for the first 5 s, since v_x and a_x are both positive. Starting at $t = 15$ s the spider starts to slow down, stops momentarily at $t = 20$ s, and then moves in the opposite direction. At $t = 35$ s the spider starts to slow down again and stops at $t = 40$ s.

2.20. IDENTIFY: $v_x(t) = \dfrac{dx}{dt}$ and $a_x(t) = \dfrac{dv_x}{dt}$

SET UP: $\dfrac{d}{dt}(t^n) = nt^{n-1}$ for $n \geq 1$.

EXECUTE: **(a)** $v_x(t) = (9.60\text{ m/s}^2)t - (0.600\text{ m/s}^6)t^5$ and $a_x(t) = 9.60\text{ m/s}^2 - (3.00\text{ m/s}^6)t^4$. Setting $v_x = 0$ gives $t = 0$ and $t = 2.00$ s. At $t = 0$, $x = 2.17$ m and $a_x = 9.60\text{ m/s}^2$. At $t = 2.00$ s, $x = 15.0$ m and $a_x = -38.4\text{ m/s}^2$.

(b) The graphs are given in Figure 2.20.

EVALUATE: For the entire time interval from $t = 0$ to $t = 2.00$ s, the velocity v_x is positive and x increases. While a_x is also positive the speed increases and while a_x is negative the speed decreases.

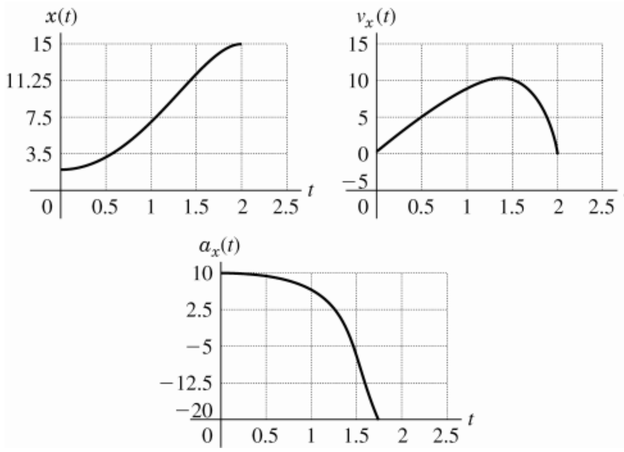
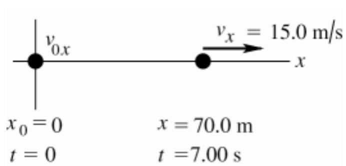


Figure 2.20

2.21. **IDENTIFY:** Use the constant acceleration equations to find v_{0x} and a_x.

(a) SET UP: The situation is sketched in Figure 2.21.



$x - x_0 = 70.0$ m
$t = 7.00$ s
$v_x = 15.0$ m/s
$v_{0x} = ?$

Figure 2.21

EXECUTE: Use $x - x_0 = \left(\dfrac{v_{0x} + v_x}{2}\right)t$, so $v_{0x} = \dfrac{2(x - x_0)}{t} - v_x = \dfrac{2(70.0\text{ m})}{7.00\text{ s}} - 15.0\text{ m/s} = 5.0\text{ m/s}.$

(b) Use $v_x = v_{0x} + a_x t$, so $a_x = \dfrac{v_x - v_{0x}}{t} = \dfrac{15.0\text{ m/s} - 5.0\text{ m/s}}{7.00\text{ s}} = 1.43\text{ m/s}^2.$

EVALUATE: The average velocity is $(70.0\text{ m})/(7.00\text{ s}) = 10.0\text{ m/s}$. The final velocity is larger than this, so the antelope must be speeding up during the time interval; $v_{0x} < v_x$ and $a_x > 0$.

2.22. **IDENTIFY:** Apply the constant acceleration kinematic equations.

SET UP: Let $+x$ be in the direction of the motion of the plane. $173\text{ mi/h} = 77.33\text{ m/s}$. $307\text{ ft} = 93.57\text{ m}$.

EXECUTE: **(a)** $v_{0x} = 0$, $v_x = 77.33$ m/s and $x - x_0 = 93.57$ m. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

$$a_x = \frac{v_x^2 - v_{0x}^2}{2(x - x_0)} = \frac{(77.33\text{ m/s})^2 - 0}{2(93.57\text{ m})} = 32.0\text{ m/s}^2 .$$

(b) $x - x_0 = \left(\dfrac{v_{0x} + v_x}{2}\right)t$ gives $t = \dfrac{2(x - x_0)}{v_{0x} + v_x} = \dfrac{2(93.57\text{ m})}{0 + 77.33\text{ m/s}} = 2.42\text{ s}$

EVALUATE: Either $v_x = v_{0x} + a_x t$ or $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ could also be used to find t and would give the same result as in part (b).

2.23. **IDENTIFY:** For constant acceleration, Eqs. (2.8), (2.12), (2.13) and (2.14) apply.

SET UP: Assume the ball starts from rest and moves in the $+x$-direction.

EXECUTE: **(a)** $x - x_0 = 1.50$ m, $v_x = 45.0$ m/s and $v_{0x} = 0$. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

$$a_x = \frac{v_x^2 - v_{0x}^2}{2(x - x_0)} = \frac{(45.0\text{ m/s})^2}{2(1.50\text{ m})} = 675\text{ m/s}^2 .$$

(b) $x - x_0 = \left(\dfrac{v_{0x} + v_x}{2}\right)t$ gives $t = \dfrac{2(x - x_0)}{v_{0x} + v_x} = \dfrac{2(1.50\text{ m})}{45.0\text{ m/s}} = 0.0667\text{ s}$

EVALUATE: We could also use $v_x = v_{0x} + a_x t$ to find $t = \dfrac{v_x}{a_x} = \dfrac{45.0\text{ m/s}}{675\text{ m/s}^2} = 0.0667$ s which agrees with our previous result. The acceleration of the ball is very large.

2.24. IDENTIFY: For constant acceleration, Eqs. (2.8), (2.12), (2.13) and (2.14) apply.
SET UP: Assume the ball moves in the $+x$ direction.
EXECUTE: **(a)** $v_x = 73.14\text{ m/s}$, $v_{0x} = 0$ and $t = 30.0\text{ ms}$. $v_x = v_{0x} + a_x t$ gives

$$a_x = \frac{v_x - v_{0x}}{t} = \frac{73.14\text{ m/s} - 0}{30.0\times10^{-3}\text{ s}} = 2440\text{ m/s}^2.$$

(b) $x - x_0 = \left(\frac{v_{0x}+v_x}{2}\right)t = \left(\frac{0+73.14\text{ m/s}}{2}\right)(30.0\times10^{-3}\text{ s}) = 1.10\text{ m}$

EVALUATE: We could also use $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ to calculate $x - x_0$:
$x - x_0 = \frac{1}{2}(2440\text{ m/s}^2)(30.0\times10^{-3}\text{ s})^2 = 1.10\text{ m}$, which agrees with our previous result. The acceleration of the ball is very large.

2.25. IDENTIFY: Assume that the acceleration is constant and apply the constant acceleration kinematic equations. Set $|a_x|$ equal to its maximum allowed value.
SET UP: Let $+x$ be the direction of the initial velocity of the car. $a_x = -250\text{ m/s}^2$. $105\text{ km/h} = 29.17\text{ m/s}$.
EXECUTE: $v_{0x} = +29.17\text{ m/s}$. $v_x = 0$. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives $x - x_0 = \frac{v_x^2 - v_{0x}^2}{2a_x} = \frac{0-(29.17\text{ m/s})^2}{2(-250\text{ m/s}^2)} = 1.70\text{ m}$.
EVALUATE: The car frame stops over a shorter distance and has a larger magnitude of acceleration. Part of your 1.70 m stopping distance is the stopping distance of the car and part is how far you move relative to the car while stopping.

2.26. IDENTIFY: Apply constant acceleration equations to the motion of the car.
SET UP: Let $+x$ be the direction the car is moving.
EXECUTE: **(a)** From Eq. (2.13), with $v_{0x} = 0$, $a_x = \frac{v_x^2}{2(x-x_0)} = \frac{(20\text{ m/s})^2}{2(120\text{ m})} = 1.67\text{ m/s}^2$.
(b) Using Eq. (2.14), $t = 2(x - x_0)/v_x = 2(120\text{ m})/(20\text{ m/s}) = 12\text{ s}$.
(c) $(12\text{ s})(20\text{ m/s}) = 240\text{ m}$.
EVALUATE: The average velocity of the car is half the constant speed of the traffic, so the traffic travels twice as far.

2.27. IDENTIFY: The average acceleration is $a_{\text{av-}x} = \frac{\Delta v_x}{\Delta t}$. For constant acceleration, Eqs. (2.8), (2.12), (2.13) and (2.14) apply.
SET UP: Assume the shuttle travels in the $+x$ direction. $161\text{ km/h} = 44.72\text{ m/s}$ and $1610\text{ km/h} = 447.2\text{ m/s}$. $1.00\text{ min} = 60.0\text{ s}$
EXECUTE: **(a)** (i) $a_{\text{av-}x} = \frac{\Delta v_x}{\Delta t} = \frac{44.72\text{ m/s} - 0}{8.00\text{ s}} = 5.59\text{ m/s}^2$

(ii) $a_{\text{av-}x} = \frac{447.2\text{ m/s} - 44.72\text{ m/s}}{60.0\text{ s} - 8.00\text{ s}} = 7.74\text{ m/s}^2$

(b) (i) $t = 8.00\text{ s}$, $v_{0x} = 0$, and $v_x = 44.72\text{ m/s}$. $x - x_0 = \left(\frac{v_{0x}+v_x}{2}\right)t = \left(\frac{0+44.72\text{ m/s}}{2}\right)(8.00\text{ s}) = 179\text{ m}$.

(ii) $\Delta t = 60.0\text{ s} - 8.00\text{ s} = 52.0\text{ s}$, $v_{0x} = 44.72\text{ m/s}$, and $v_x = 447.2\text{ m/s}$.

$$x - x_0 = \left(\frac{v_{0x}+v_x}{2}\right)t = \left(\frac{44.72\text{ m/s} + 447.2\text{ m/s}}{2}\right)(52.0\text{ s}) = 1.28\times10^4\text{ m}.$$

EVALUATE: When the acceleration is constant the instantaneous acceleration throughout the time interval equals the average acceleration for that time interval. We could have calculated the distance in part (a) as
$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2 = \frac{1}{2}(5.59\text{ m/s}^2)(8.00\text{ s})^2 = 179\text{ m}$, which agrees with our previous calculation.

2.28. IDENTIFY: Apply the constant acceleration kinematic equations to the motion of the car.
SET UP: $0.250\text{ mi} = 1320\text{ ft}$. $60.0\text{ mph} = 88.0\text{ ft/s}$. Let $+x$ be the direction the car is traveling.
EXECUTE: **(a)** braking: $v_{0x} = 88.0\text{ ft/s}$, $x - x_0 = 146\text{ ft}$, $v_x = 0$. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

$$a_x = \frac{v_x^2 - v_{0x}^2}{2(x-x_0)} = \frac{0-(88.0\text{ ft/s})^2}{2(146\text{ ft})} = -26.5\text{ ft/s}^2$$

Speeding up: $v_{0x} = 0$, $x - x_0 = 1320\text{ ft}$, $t = 19.9\text{ s}$. $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ gives

$$a_x = \frac{2(x-x_0)}{t^2} = \frac{2(1320\text{ ft})}{(19.9\text{ s})^2} = 6.67\text{ ft/s}^2$$

(b) $v_x = v_{0x} + a_x t = 0 + (6.67\ \text{ft/s}^2)(19.9\ \text{s}) = 133\ \text{ft/s} = 90.5\ \text{mph}$

(c) $t = \dfrac{v_x - v_{0x}}{a_x} = \dfrac{0 - 88.0\ \text{ft/s}}{-26.5\ \text{ft/s}^2} = 3.32\ \text{s}$

EVALUATE: The magnitude of the acceleration while braking is much larger than when speeding up. That is why it takes much longer to go from 0 to 60 mph than to go from 60 mph to 0.

2.29. **IDENTIFY:** The acceleration a_x is the slope of the graph of v_x versus t.

SET UP: The signs of v_x and of a_x indicate their directions.

EXECUTE: **(a)** Reading from the graph, at $t = 4.0\ \text{s}$, $v_x = 2.7\ \text{cm/s}$, to the right and at $t = 7.0\ \text{s}$, $v_x = 1.3\ \text{cm/s}$, to the left.

(b) v_x versus t is a straight line with slope $-\dfrac{8.0\ \text{cm/s}}{6.0\ \text{s}} = -1.3\ \text{cm/s}^2$. The acceleration is constant and equal to $1.3\ \text{cm/s}^2$, to the left. It has this value at all times.

(c) Since the acceleration is constant, $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$. For $t = 0$ to 4.5 s, $x - x_0 = (8.0\ \text{cm/s})(4.5\ \text{s}) + \frac{1}{2}(-1.3\ \text{cm/s}^2)(4.5\ \text{s})^2 = 22.8\ \text{cm}$. For $t = 0$ to 7.5 s, $x - x_0 = (8.0\ \text{cm/s})(7.5\ \text{s}) + \frac{1}{2}(-1.3\ \text{cm/s}^2)(7.5\ \text{s})^2 = 23.4\ \text{cm}$

(d) The graphs of a_x and x versus t are given in Fig. 2.29.

EVALUATE: In part (c) we could have instead used $x - x_0 = \left(\dfrac{v_{0x} + v_x}{2}\right)t$.

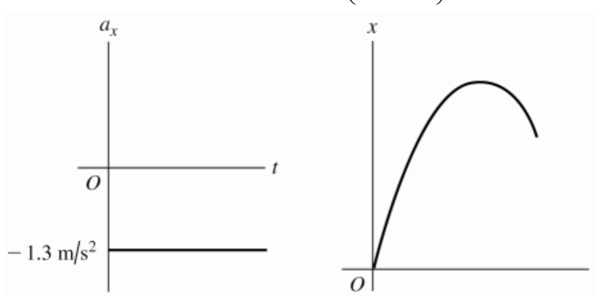


Figure 2.29

2.30. **IDENTIFY:** Use the constant acceleration equations to find x, v_{0x}, v_x and a_x for each constant-acceleration segment of the motion.

SET UP: Let $+x$ be the direction of motion of the car and let $x = 0$ at the first traffic light.

EXECUTE: **(a)** For $t = 0$ to $t = 8\ \text{s}$: $x = \left(\dfrac{v_{0x} + v_x}{2}\right)t = \left(\dfrac{0 + 20\ \text{m/s}}{2}\right)(8\ \text{s}) = 80\ \text{m}$.

$a_x = \dfrac{v_x - v_{0x}}{t} = \dfrac{20\ \text{m/s}}{8\ \text{s}} = +2.50\ \text{m/s}^2$. The car moves from $x = 0$ to $x = 80\ \text{m}$. The velocity v_x increases linearly from zero to 20 m/s. The acceleration is a constant $2.50\ \text{m/s}^2$.

Constant speed for 60 m: The car moves from $x = 80\ \text{m}$ to $x = 140\ \text{m}$. v_x is a constant 20 m/s. $a_x = 0$. This interval starts at $t = 8\ \text{s}$ and continues until $t = \dfrac{60\ \text{m}}{20\ \text{m/s}} + 8\ \text{s} = 11\ \text{s}$.

Slowing from 20 m/s until stopped: The car moves from $x = 140\ \text{m}$ to $x = 180\ \text{m}$. The velocity decreases linearly from 20 m/s to zero. $x - x_0 = \left(\dfrac{v_{0x} + v_x}{2}\right)t$ gives $t = \dfrac{2(40\ \text{m})}{20\ \text{m/s} + 0} = 4\ \text{s}$. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

$a_x = \dfrac{-(20.0\ \text{m/s})^2}{2(40\ \text{m})} = -5.00\ \text{m/s}^2$ This segment is from $t = 11\ \text{s}$ to $t = 15\ \text{s}$. The acceleration is a constant $-5.00\ \text{m/s}^2$.

The graphs are drawn in Figure 2.30a.

(b) The motion diagram is sketched in Figure 2.30b.

EVALUATE: When $\vec{a}$ and $\vec{v}$ are in the same direction, the speed increases ($t = 0$ to $t = 8$ s). When $\vec{a}$ and $\vec{v}$ are in opposite directions, the speed decreases ($t = 11$ s to $t = 15$ s). When $a = 0$ the speed is constant $t = 8$ s to $t = 11$ s.

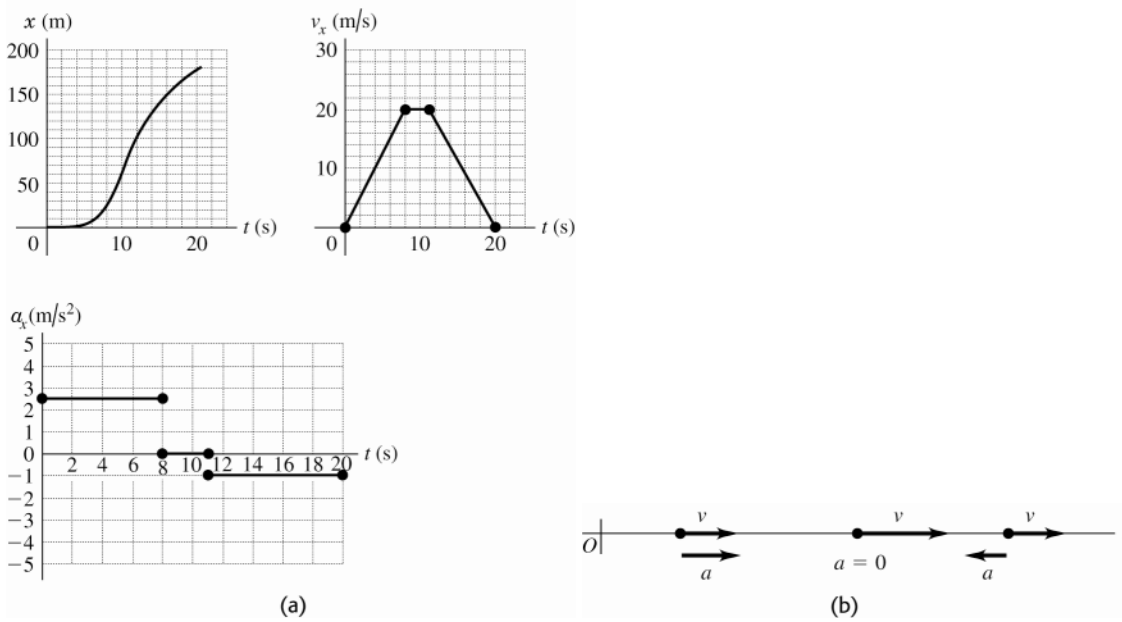


Figure 2.30a-b

2.31. **(a) IDENTIFY** and **SET UP:** The acceleration a_x at time t is the slope of the tangent to the v_x versus t curve at time t.

EXECUTE: At $t = 3$ s, the v_x versus t curve is a horizontal straight line, with zero slope. Thus $a_x = 0$.

At $t = 7$ s, the v_x versus t curve is a straight-line segment with slope $\dfrac{45\text{ m/s} - 20\text{ m/s}}{9\text{ s} - 5\text{ s}} = 6.3\text{ m/s}^2$.

Thus $a_x = 6.3\text{ m/s}^2$.

At $t = 11$ s the curve is again a straight-line segment, now with slope $\dfrac{-0 - 45\text{ m/s}}{13\text{ s} - 9\text{ s}} = -11.2\text{ m/s}^2$.

Thus $a_x = -11.2\text{ m/s}^2$.

EVALUATE: $a_x = 0$ when v_x is constant, $a_x > 0$ when v_x is positive and the speed is increasing, and $a_x < 0$ when v_x is positive and the speed is decreasing.

(b) IDENTIFY: Calculate the displacement during the specified time interval.

SET UP: We can use the constant acceleration equations only for time intervals during which the acceleration is constant. If necessary, break the motion up into constant acceleration segments and apply the constant acceleration equations for each segment. For the time interval $t = 0$ to $t = 5$ s the acceleration is constant and equal to zero. For the time interval $t = 5$ s to $t = 9$ s the acceleration is constant and equal to 6.25 m/s^2. For the interval $t = 9$ s to $t = 13$ s the acceleration is constant and equal to -11.2 m/s^2.

EXECUTE: During the first 5 seconds the acceleration is constant, so the constant acceleration kinematic formulas can be used.

$v_{0x} = 20\text{ m/s}$ $\quad a_x = 0$ $\quad t = 5\text{ s}$ $\quad x - x_0 = ?$

$x - x_0 = v_{0x}t$ $\quad (a_x = 0$ so no $\tfrac{1}{2}a_x t^2$ term)

$x - x_0 = (20\text{ m/s})(5\text{ s}) = 100\text{ m}$; this is the distance the officer travels in the first 5 seconds.

During the interval $t = 5$ s to 9 s the acceleration is again constant. The constant acceleration formulas can be applied to this 4 second interval. It is convenient to restart our clock so the interval starts at time $t = 0$ and ends at time $t = 5$ s. (Note that the acceleration is *not* constant over the entire $t = 0$ to $t = 9$ s interval.)

$v_{0x} = 20\text{ m/s}$ $\quad a_x = 6.25\text{ m/s}^2$ $\quad t = 4\text{ s}$ $\quad x_0 = 100\text{ m}$ $\quad x - x_0 = ?$

$x - x_0 = v_{0x}t + \tfrac{1}{2}a_x t^2$

$x - x_0 = (20\text{ m/s})(4\text{ s}) + \tfrac{1}{2}(6.25\text{ m/s}^2)(4\text{ s})^2 = 80\text{ m} + 50\text{ m} = 130\text{ m}.$

Thus $x - x_0 + 130\text{ m} = 100\text{ m} + 130\text{ m} = 230\text{ m}.$

At $t = 9$ s the officer is at $x = 230$ m, so she has traveled 230 m in the first 9 seconds.

During the interval $t = 9$ s to $t = 13$ s the acceleration is again constant. The constant acceleration formulas can be applied for this 4 second interval but *not* for the whole $t = 0$ to $t = 13$ s interval. To use the equations restart our clock so this interval begins at time $t = 0$ and ends at time $t = 4$ s.

$v_{0x} = 45$ m/s (at the start of this time interval)

$a_x = -11.2\text{ m/s}^2$ $t = 4$ s $x_0 = 230$ m $x - x_0 = ?$

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$

$x - x_0 = (45\text{ m/s})(4\text{ s}) + \frac{1}{2}(-11.2\text{ m/s}^2)(4\text{ s})^2 = 180\text{ m} - 89.6\text{ m} = 90.4\text{ m}.$

Thus $x = x_0 + 90.4\text{ m} = 230\text{ m} + 90.4\text{ m} = 320\text{ m}.$

At $t = 13$ s the officer is at $x = 320$ m, so she has traveled 320 m in the first 13 seconds.

EVALUATE: The velocity v_x is always positive so the displacement is always positive and displacement and distance traveled are the same. The average velocity for time interval Δt is $v_{\text{av-}x} = \Delta x/\Delta t$. For $t = 0$ to 5 s, $v_{\text{av-}x} = 20$ m/s. For $t = 0$ to 9 s, $v_{\text{av-}x} = 26$ m/s. For $t = 0$ to 13 s, $v_{\text{av-}x} = 25$ m/s. These results are consistent with Fig. 2.33.

2.32. **IDENTIFY:** In each constant acceleration interval, the constant acceleration equations apply.

SET UP: When a_x is constant, the graph of v_x versus t is a straight line and the graph of x versus t is a parabola. When $a_x = 0$, v_x is constant and x versus t is a straight line.

EXECUTE: The graphs are given in Figure 2.32.

EVALUATE: The slope of the x versus t graph is $v_x(t)$ and the slope of the v_x versus t graph is $a_x(t)$.

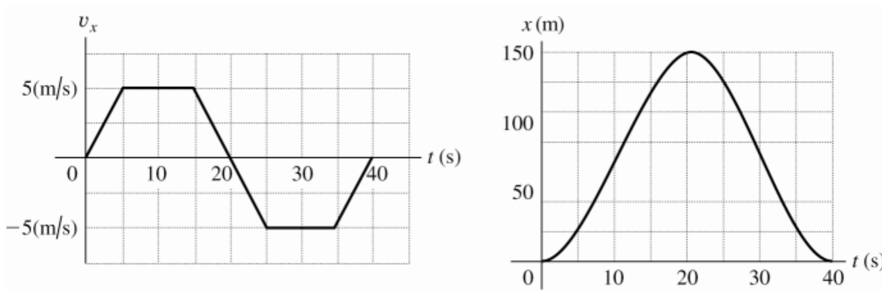


Figure 2.32

2.33. **(a) IDENTIFY:** The maximum speed occurs at the end of the initial acceleration period.

SET UP: $a_x = 20.0\text{ m/s}^2$ $t = 15.0\text{ min} = 900\text{ s}$ $v_{0x} = 0$ $v_x = ?$

$v_x = v_{0x} + a_x t$

EXECUTE: $v_x = 0 + (20.0\text{ m/s}^2)(900\text{ s}) = 1.80 \times 10^4\text{ m/s}$

(b) IDENTIFY: Use constant acceleration formulas to find the displacement Δx. The motion consists of three constant acceleration intervals. In the middle segment of the trip $a_x = 0$ and $v_x = 1.80 \times 10^4$ m/s, but we can't directly find the distance traveled during this part of the trip because we don't know the time. Instead, find the distance traveled in the first part of the trip (where $a_x = +20.0\text{ m/s}^2$) and in the last part of the trip (where $a_x = -20.0\text{ m/s}^2$). Subtract these two distances from the total distance of 3.84×10^8 m to find the distance traveled in the middle part of the trip (where $a_x = 0$).

first segment

SET UP: $x - x_0 = ?$ $t = 15.0\text{ min} = 900\text{ s}$ $a_x = +20.0\text{ m/s}^2$ $v_{0x} = 0$

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$

EXECUTE: $x - x_0 = 0 + \frac{1}{2}(20.0\text{ m/s}^2)(900\text{ s})^2 = 8.10 \times 10^6\text{ m} = 8.10 \times 10^3\text{ km}$

second segment

SET UP: $x - x_0 = ?$ $t = 15.0\text{ min} = 900\text{ s}$ $a_x = -20.0\text{ m/s}^2$

$v_{0x} = 1.80 \times 10^4$ m/s

$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$

EXECUTE: $x - x_0 = (1.80 \times 10^4\text{ s})(900\text{ s}) + \frac{1}{2}(-20.0\text{ m/s}^2)(900\text{ s})^2 = 8.10 \times 10^6\text{ m} = 8.10 \times 10^3\text{ km}$ (The same distance as traveled as in the first segment.)

Therefore, the distance traveled at constant speed is
$3.84\times10^8\ \text{m} - 8.10\times10^6\ \text{m} - 8.10\times10^6\ \text{m} = 3.678\times10^8\ \text{m} = 3.678\times10^5\ \text{km}.$

The fraction this is of the total distance is $\dfrac{3.678\times10^8\ \text{m}}{3.84\times10^8\ \text{m}} = 0.958.$

(c) IDENTIFY: We know the time for each acceleration period, so find the time for the constant speed segment.

SET UP: $x - x_0 = 3.678\times10^8\ \text{m}$ $v_x = 1.80\times10^4\ \text{m/s}$ $a_x = 0$ $t = ?$

$x - x_0 = v_{0x}t + \tfrac{1}{2}a_x t^2$

EXECUTE: $t = \dfrac{x - x_0}{v_{0x}} = \dfrac{3.678\times10^8\ \text{m}}{1.80\times10^4\ \text{m/s}} = 2.043\times10^4\ \text{s} = 340.5\ \text{min}.$

The total time for the whole trip is thus $15.0\ \text{min} + 340.5\ \text{min} + 15.0\ \text{min} = 370\,\text{min}$.

EVALUATE: If the speed was a constant $1.80\times10^4\ \text{m/s}$ for the entire trip, the trip would take $(3.84\times10^8\ \text{m})/(1.80\times10^4\ \text{m/s}) = 356\ \text{min}.$ The trip actually takes a bit longer than this since the average velocity is less than $1.80\times10^8\ \text{m/s}$ during the relatively brief acceleration phases.

2.34. **IDENTIFY:** Use constant acceleration equations to find $x - x_0$ for each segment of the motion.

SET UP: Let $+x$ be the direction the train is traveling.

EXECUTE: $t = 0$ to 14.0 s: $x - x_0 = v_{0x}t + \tfrac{1}{2}a_x t^2 = \tfrac{1}{2}(1.60\ \text{m/s}^2)(14.0\ \text{s})^2 = 157\ \text{m}$.

At $t = 14.0\ \text{s}$, the speed is $v_x = v_{0x} + a_x t = (1.60\ \text{m/s}^2)(14.0\ \text{s}) = 22.4\ \text{m/s}$. In the next 70.0 s, $a_x = 0$ and $x - x_0 = v_{0x}t = (22.4\ \text{m/s})(70.0\ \text{s}) = 1568\ \text{m}$.

For the interval during which the train is slowing down, $v_{0x} = 22.4\ \text{m/s}$, $a_x = -3.50\ \text{m/s}^2$ and $v_x = 0$.

$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives $x - x_0 = \dfrac{v_x^2 - v_{0x}^2}{2a_x} = \dfrac{0 - (22.4\ \text{m/s})^2}{2(-3.50\ \text{m/s}^2)} = 72\ \text{m}$.

The total distance traveled is $157\ \text{m} + 1568\ \text{m} + 72\ \text{m} = 1800\ \text{m}$.

EVALUATE: The acceleration is not constant for the entire motion but it does consist of constant acceleration segments and we can use constant acceleration equations for each segment.

2.35 **IDENTIFY:** $v_x(t)$ is the slope of the *x* versus *t* graph. Car *B* moves with constant speed and zero acceleration. Car *A* moves with positive acceleration; assume the acceleration is constant.

SET UP: For car *B*, v_x is positive and $a_x = 0$. For car *A*, a_x is positive and v_x increases with *t*.

EXECUTE: **(a)** The motion diagrams for the cars are given in Figure 2.35a.

(b) The two cars have the same position at times when their *x*-*t* graphs cross. The figure in the problem shows this occurs at approximately $t = 1\ \text{s}$ and $t = 3\ \text{s}$.

(c) The graphs of v_x versus *t* for each car are sketched in Figure 2.35b.

(d) The cars have the same velocity when their *x*-*t* graphs have the same slope. This occurs at approximately $t = 2\ \text{s}$.

(e) Car *A* passes car *B* when x_A moves above x_B in the *x*-*t* graph. This happens at $t = 3\ \text{s}$.

(f) Car *B* passes car *A* when x_B moves above x_A in the *x*-*t* graph. This happens at $t = 1\ \text{s}$.

EVALUATE: When $a_x = 0$, the graph of v_x versus *t* is a horizontal line. When a_x is positive, the graph of v_x versus *t* is a straight line with positive slope.

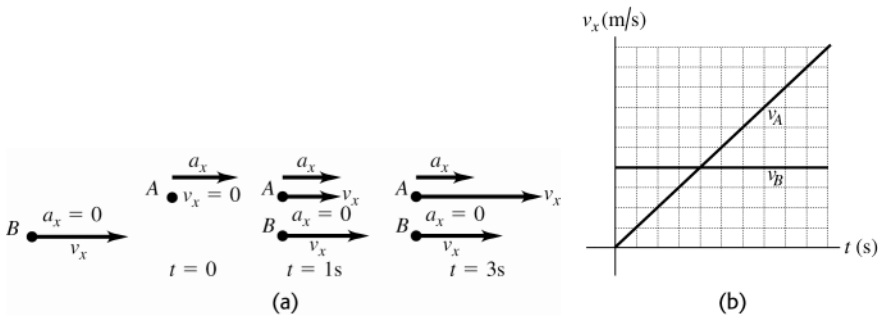


Figure 2.35a-b

2.36. **IDENTIFY:** Apply the constant acceleration equations to the motion of each vehicle. The truck passes the car when they are at the same *x* at the same $t > 0$.

SET UP: The truck has $a_x = 0$. The car has $v_{0x} = 0$. Let $+x$ be in the direction of motion of the vehicles. Both vehicles start at $x_0 = 0$. The car has $a_C = 3.20\ \text{m/s}^2$. The truck has $v_x = 20.0\ \text{m/s}$.

EXECUTE: **(a)** $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2$ gives $x_T = v_{0T}t$ and $x_C = \frac{1}{2}a_C t^2$. Setting $x_T = x_C$ gives $t = 0$ and $v_{0T} = \frac{1}{2}a_C t$, so $t = \dfrac{2v_{0T}}{a_C} = \dfrac{2(20.0\ \text{m/s})}{3.20\ \text{m/s}^2} = 12.5\ \text{s}$. At this t, $x_T = (20.0\ \text{m/s})(12.5\ \text{s}) = 250\ \text{m}$ and $x = \frac{1}{2}(3.20\ \text{m/s}^2)(12.5\ \text{s})^2 = 250\ \text{m}$.

The car and truck have each traveled 250 m.

(b) At $t = 12.5\ \text{s}$, the car has $v_x = v_{0x} + a_x t = (3.20\ \text{m/s}^2)(12.5\ \text{s}) = 40\ \text{m/s}$.

(c) $x_T = v_{0T}t$ and $x_C = \frac{1}{2}a_C t^2$. The *x*-*t* graph of the motion for each vehicle is sketched in Figure 2.36a.

(d) $v_T = v_{0T}$. $v_C = a_C t$. The v_x-t graph for each vehicle is sketched in Figure 2.36b.

EVALUATE: When the car overtakes the truck its speed is twice that of the truck.

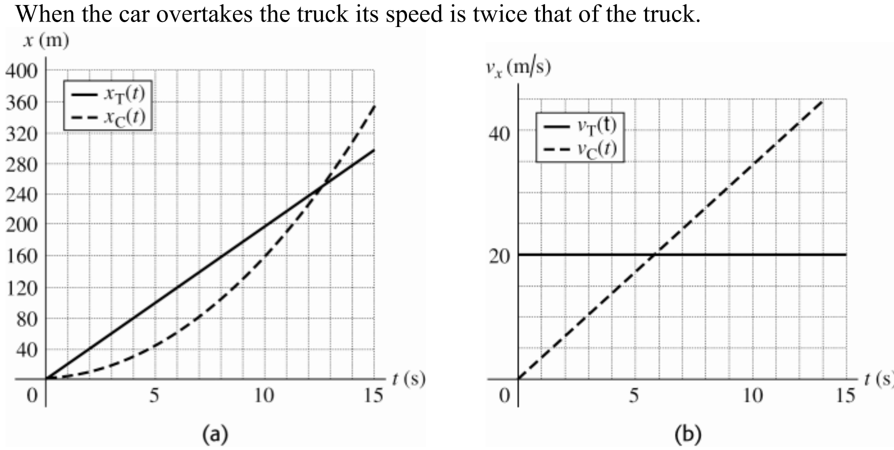


Figure 2.36a-b

2.37. **IDENTIFY:** For constant acceleration, Eqs. (2.8), (2.12), (2.13) and (2.14) apply.

SET UP: Take $+y$ to be downward, so the motion is in the $+y$ direction. $19{,}300\ \text{km/h} = 5361\ \text{m/s}$, $1600\ \text{km/h} = 444.4\ \text{m/s}$, and $321\ \text{km/h} = 89.2\ \text{m/s}$. $4.0\ \text{min} = 240\ \text{s}$.

EXECUTE: **(a)** Stage *A*: $t = 240\ \text{s}$, $v_{0y} = 5361\ \text{m/s}$, $v_y = 444.4\ \text{m/s}$. $v_y = v_{0y} + a_y t$ gives

$$a_y = \frac{v_y - v_{0y}}{t} = \frac{444.4\ \text{m/s} - 5361\ \text{m/s}}{240\ \text{s}} = -20.5\ \text{m/s}^2.$$

Stage *B*: $t = 94\ \text{s}$, $v_{0y} = 444.4\ \text{m/s}$, $v_y = 89.2\ \text{m/s}$. $v_y = v_{0y} + a_y t$ gives

$$a_y = \frac{v_y - v_{0y}}{t} = \frac{89.2\ \text{m/s} - 444.4\ \text{m/s}}{94\ \text{s}} = -3.8\ \text{m/s}^2.$$

Stage *C*: $y - y_0 = 75\ \text{m}$, $v_{0y} = 89.2\ \text{m/s}$, $v_y = 0$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$a_y = \dfrac{v_y^2 - v_{0y}^2}{2(y - y_0)} = \dfrac{0 - (89.2\ \text{m/s})^2}{2(75\ \text{m})} = -53.0\ \text{m/s}^2$. In each case the negative sign means that the acceleration is upward.

(b) Stage *A*: $y - y_0 = \left(\dfrac{v_{0y} + v_y}{2}\right)t = \left(\dfrac{5361\ \text{m/s} + 444.4\ \text{m/s}}{2}\right)(240\ \text{s}) = 697\ \text{km}$.

Stage *B*: $y - y_0 = \left(\dfrac{444.4\ \text{m/s} + 89.2\ \text{m/s}}{2}\right)(94\ \text{s}) = 25\ \text{km}$.

Stage *C*: The problem states that $y - y_0 = 75\ \text{m} = 0.075\ \text{km}$.

The total distance traveled during all three stages is $697\ \text{km} + 25\ \text{km} + 0.075\ \text{km} = 722\ \text{km}$.

EVALUATE: The upward acceleration produced by friction in stage *A* is calculated to be greater than the upward acceleration due to the parachute in stage *B*. The effects of air resistance increase with increasing speed and in reality the acceleration was probably not constant during stages *A* and *B*.

2.38. **IDENTIFY:** Assume an initial height of 200 m and a constant acceleration of $9.80\ \text{m/s}^2$.

SET UP: Let $+y$ be downward. $1\ \text{km/h} = 0.2778\ \text{m/s}$ and $1\ \text{mi/h} = 0.4470\ \text{m/s}$.

EXECUTE: **(a)** $y - y_0 = 200\text{ m}$, $a_y = 9.80\text{ m/s}^2$, $v_{0y} = 0$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$v_y = \sqrt{2(9.80\text{ m/s}^2)(200\text{ m})} = 60\text{ m/s} = 200\text{ km/h} = 140\text{ mi/h}$.

(b) Raindrops actually have a speed of about 1 m/s as they strike the ground.

(c) The actual speed at the ground is much less than the speed calculated assuming free-fall, so neglect of air resistance is a very poor approximation for falling raindrops.

EVALUATE: In the absence of air resistance raindrops would land with speeds that would make them very dangerous.

2.39. **IDENTIFY:** Apply the constant acceleration equations to the motion of the flea. After the flea leaves the ground, $a_y = g$, downward. Take the origin at the ground and the positive direction to be upward.

(a) SET UP: At the maximum height $v_y = 0$.

$v_y = 0 \quad y - y_0 = 0.440\text{ m} \quad a_y = -9.80\text{ m/s}^2 \quad v_{0y} = ?$

$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$

EXECUTE: $v_{0y} = \sqrt{-2a_y(y - y_0)} = \sqrt{-2(-9.80\text{ m/s}^2)(0.440\text{ m})} = 2.94\text{ m/s}$

(b) SET UP: When the flea has returned to the ground $y - y_0 = 0$.

$y - y_0 = 0 \quad v_{0y} = +2.94\text{ m/s} \quad a_y = -9.80\text{ m/s}^2 \quad t = ?$

$y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$

EXECUTE: With $y - y_0 = 0$ this gives $t = -\dfrac{2v_{0y}}{a_y} = -\dfrac{2(2.94\text{ m/s})}{-9.80\text{ m/s}^2} = 0.600\text{ s}.$

EVALUATE: We can use $v_y = v_{0y} + a_y t$ to show that with $v_{0y} = 2.94\text{ m/s}$, $v_y = 0$ after 0.300 s.

2.40. **IDENTIFY:** Apply constant acceleration equations to the motion of the lander.

SET UP: Let $+y$ be positive. Since the lander is in free-fall, $a_y = +1.6\text{ m/s}^2$.

EXECUTE: $v_{0y} = 0.8\text{ m/s}$, $y - y_0 = 5.0\text{ m}$, $a_y = +1.6\text{ m/s}^2$ in $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$v_y = \sqrt{v_{0y}^2 + 2a_y(y - y_0)} = \sqrt{(0.8\text{ m/s})^2 + 2(1.6\text{ m/s}^2)(5.0\text{ m})} = 4.1\text{ m/s}$.

EVALUATE: The same descent on earth would result in a final speed of 9.9 m/s, since the acceleration due to gravity on earth is much larger than on the moon.

2.41. **IDENTIFY:** Apply constant acceleration equations to the motion of the meterstick. The time the meterstick falls is your reaction time.

SET UP: Let $+y$ be downward. The meter stick has $v_{0y} = 0$ and $a_y = 9.80\text{ m/s}^2$. Let d be the distance the meterstick falls.

EXECUTE: **(a)** $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives $d = (4.90\text{ m/s}^2)t^2$ and $t = \sqrt{\dfrac{d}{4.90\text{ m/s}^2}}$.

(b) $t = \sqrt{\dfrac{0.176\text{ m}}{4.90\text{ m/s}^2}} = 0.190\text{ s}$

EVALUATE: The reaction time is proportional to the square of the distance the stick falls.

2.42. **IDENTIFY:** Apply constant acceleration equations to the vertical motion of the brick.

SET UP: Let $+y$ be downward. $a_y = 9.80\text{ m/s}^2$

EXECUTE: **(a)** $v_{0y} = 0$, $t = 2.50\text{ s}$, $a_y = 9.80\text{ m/s}^2$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2 = \frac{1}{2}(9.80\text{ m/s}^2)(2.50\text{ s})^2 = 30.6\text{ m}$. The building is 30.6 m tall.

(b) $v_y = v_{0y} + a_y t = 0 + (9.80\text{ m/s}^2)(2.50\text{ s}) = 24.5\text{ m/s}$

(c) The graphs of a_y, v_y and y versus t are given in Fig. 2.42. Take $y = 0$ at the ground.

EVALUATE: We could use either $y - y_0 = \left(\frac{v_{0y} + v_y}{2}\right)t$ or $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ to check our results.

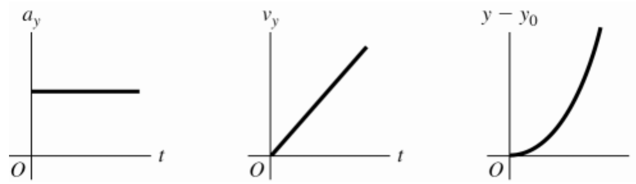


Figure 2.42

2.43. **IDENTIFY:** When the only force is gravity the acceleration is $9.80\ \text{m/s}^2$, downward. There are two intervals of constant acceleration and the constant acceleration equations apply during each of these intervals.

SET UP: Let $+y$ be upward. Let $y = 0$ at the launch pad. The final velocity for the first phase of the motion is the initial velocity for the free-fall phase.

EXECUTE: **(a)** Find the velocity when the engines cut off. $y - y_0 = 525\ \text{m}$, $a_y = +2.25\ \text{m/s}^2$, $v_{0y} = 0$.

$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $v_y = \sqrt{2(2.25\ \text{m/s}^2)(525\ \text{m})} = 48.6\ \text{m/s}$.

Now consider the motion from engine cut off to maximum height: $y_0 = 525\ \text{m}$, $v_{0y} = +48.6\ \text{m/s}$, $v_y = 0$ (at the maximum height), $a_y = -9.80\ \text{m/s}^2$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives $y - y_0 = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{0 - (48.6\ \text{m/s})^2}{2(-9.80\ \text{m/s}^2)} = 121\ \text{m}$ and

$y = 121\ \text{m} + 525\ \text{m} = 646\ \text{m}$.

(b) Consider the motion from engine failure until just before the rocket strikes the ground: $y - y_0 = -525\ \text{m}$, $a_y = -9.80\ \text{m/s}^2$, $v_{0y} = +48.6\ \text{m/s}$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$v_y = -\sqrt{(48.6\ \text{m/s})^2 + 2(-9.80\ \text{m/s}^2)(-525\ \text{m})} = -112\ \text{m/s}$. Then $v_y = v_{0y} + a_y t$ gives

$t = \frac{v_y - v_{0y}}{a_y} = \frac{-112\ \text{m/s} - 48.6\ \text{m/s}}{-9.80\ \text{m/s}^2} = 16.4\ \text{s}$.

(c) Find the time from blast-off until engine failure: $y - y_0 = 525\ \text{m}$, $v_{0y} = 0$, $a_y = +2.25\ \text{m/s}^2$.

$y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives $t = \sqrt{\frac{2(y - y_0)}{a_y}} = \sqrt{\frac{2(525\ \text{m})}{2.25\ \text{m/s}^2}} = 21.6\ \text{s}$. The rocket strikes the launch pad $21.6\ \text{s} + 16.4\ \text{s} = 38.0\ \text{s}$ after blast off. The acceleration a_y is $+2.25\ \text{m/s}^2$ from $t = 0$ to $t = 21.6\ \text{s}$. It is $-9.80\ \text{m/s}^2$ from $t = 21.6\ \text{s}$ to $38.0\ \text{s}$. $v_y = v_{0y} + a_y t$ applies during each constant acceleration segment, so the graph of v_y versus t is a straight line with positive slope of $2.25\ \text{m/s}^2$ during the blast-off phase and with negative slope of $-9.80\ \text{m/s}^2$ after engine failure. During each phase $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$. The sign of a_y determines the curvature of $y(t)$. At $t = 38.0\ \text{s}$ the rocket has returned to $y = 0$. The graphs are sketched in Figure 2.43.

EVALUATE: In part (b) we could have found the time from $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$, finding v_y first allows us to avoid solving for t from a quadratic equation.

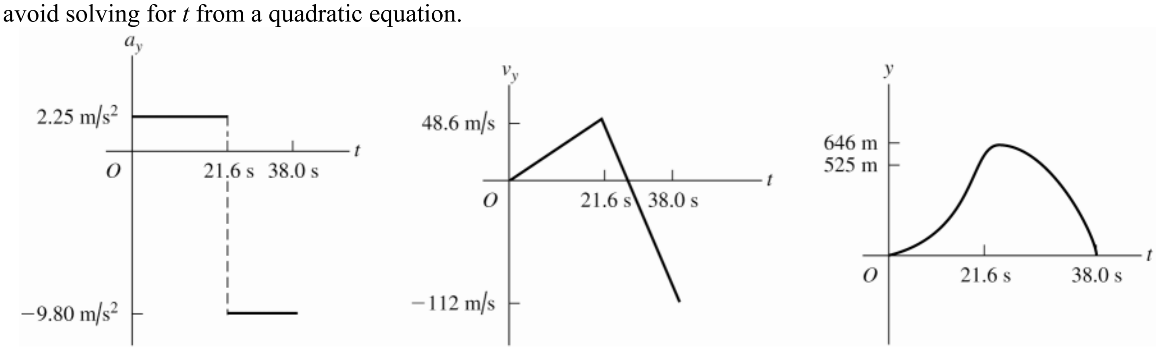


Figure 2.43

2.44. **IDENTIFY:** Apply constant acceleration equations to the vertical motion of the sandbag.

SET UP: Take $+y$ upward. $a_y = -9.80\text{ m/s}^2$. The initial velocity of the sandbag equals the velocity of the balloon, so $v_{0y} = +5.00\text{ m/s}$. When the balloon reaches the ground, $y - y_0 = -40.0\text{ m}$. At its maximum height the sandbag has $v_y = 0$.

EXECUTE: **(a)** $t = 0.250\text{ s}$: $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2 = (5.00\text{ m/s})(0.250\text{ s}) + \frac{1}{2}(-9.80\text{ m/s}^2)(0.250\text{ s})^2 = 0.94\text{ m}$. The sandbag is 40.9 m above the ground. $v_y = v_{0y} + a_y t = +5.00\text{ m/s} + (-9.80\text{ m/s}^2)(0.250\text{ s}) = 2.55\text{ m/s}$.

$t = 1.00\text{ s}$: $y - y_0 = (5.00\text{ m/s})(1.00\text{ s}) + \frac{1}{2}(-9.80\text{ m/s}^2)(1.00\text{ s})^2 = 0.10\text{ m}$. The sandbag is 40.1 m above the ground. $v_y = v_{0y} + a_y t = +5.00\text{ m/s} + (-9.80\text{ m/s}^2)(1.00\text{ s}) = -4.80\text{ m/s}$.

(b) $y - y_0 = -40.0\text{ m}$, $v_{0y} = 5.00\text{ m/s}$, $a_y = -9.80\text{ m/s}^2$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives

$-40.0\text{ m} = (5.00\text{ m/s})t - (4.90\text{ m/s}^2)t^2$. $(4.90\text{ m/s}^2)t^2 - (5.00\text{ m/s})t - 40.0\text{ m} = 0$ and

$t = \frac{1}{9.80}\left(5.00 \pm \sqrt{(-5.00)^2 - 4(4.90)(-40.0)}\right)\text{ s} = (0.51 \pm 2.90)\text{ s}$. t must be positive, so $t = 3.41\text{ s}$.

(c) $v_y = v_{0y} + a_y t = +5.00\text{ m/s} + (-9.80\text{ m/s}^2)(3.41\text{ s}) = -28.4\text{ m/s}$

(d) $v_{0y} = 5.00\text{ m/s}$, $a_y = -9.80\text{ m/s}^2$, $v_y = 0$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$y - y_0 = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{0 - (5.00\text{ m/s})^2}{2(-9.80\text{ m/s}^2)} = 1.28\text{ m}$. The maximum height is 41.3 m above the ground.

(e) The graphs of a_y, v_y, and y versus t are given in Fig. 2.44. Take $y = 0$ at the ground.

EVALUATE: The sandbag initially travels upward with decreasing velocity and then moves downward with increasing speed.

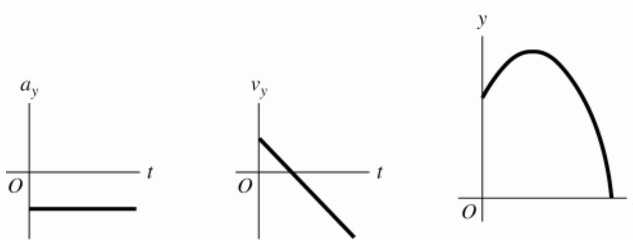


Figure 2.44

2.45. **IDENTIFY:** The balloon has constant acceleration $a_y = g$, downward.

(a) SET UP: Take the $+y$ direction to be upward.

$t = 2.00\text{ s}$, $v_{0y} = -6.00\text{ m/s}$, $a_y = -9.80\text{ m/s}^2$, $v_y = ?$

EXECUTE: $v_y = v_{0y} + a_y t = -6.00\text{ m/s} + (-9.80\text{ m/s}^2)(2.00\text{ s}) = -25.5\text{ m/s}$

(b) SET UP: $y - y_0 = ?$

EXECUTE: $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2 = (-6.00\text{ m/s})(2.00\text{ s}) + \frac{1}{2}(-9.80\text{ m/s}^2)(2.00\text{ s})^2 = -31.6\text{ m}$

(c) SET UP: $y - y_0 = -10.0\text{ m}$, $v_{0y} = -6.00\text{ m/s}$, $a_y = -9.80\text{ m/s}^2$, $v_y = ?$

$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$

EXECUTE: $v_y = -\sqrt{v_{0y}^2 + 2a_y(y - y_0)} = -\sqrt{(-6.00\text{ m/s})^2 + 2(-9.80\text{ m/s}^2)(-10.0\text{ m})} = -15.2\text{ m/s}$

(d) The graphs are sketched in Figure 2.45.

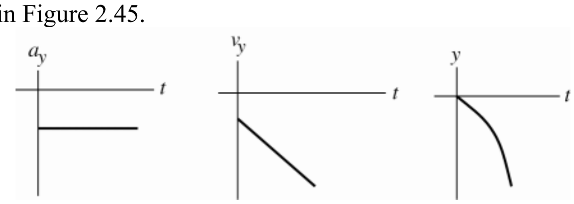


Figure 2.45

EVALUATE: The speed of the balloon increases steadily since the acceleration and velocity are in the same direction. $|v_y| = 25.5\text{ m/s}$ when $|y - y_0| = 31.6\text{ m}$, so $|v_y|$ is less than this (15.2 m/s) when $|y - y_0|$ is less (10.0 m).

2.46. **IDENTIFY:** Since air resistance is ignored, the egg is in free-fall and has a constant downward acceleration of magnitude $9.80\ \text{m/s}^2$. Apply the constant acceleration equations to the motion of the egg.

SET UP: Take $+y$ to be upward. At the maximum height, $v_y = 0$.

EXECUTE: **(a)** $y - y_0 = -50.0\ \text{m}$, $t = 5.00\ \text{s}$, $a_y = -9.80\ \text{m/s}^2$. $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ gives

$$v_{0y} = \frac{y - y_0}{t} - \tfrac{1}{2}a_y t = \frac{-50.0\ \text{m}}{5.00\ \text{s}} - \tfrac{1}{2}(-9.80\ \text{m/s}^2)(5.00\ \text{s}) = +14.5\ \text{m/s}.$$

(b) $v_{0y} = +14.5\ \text{m/s}$, $v_y = 0$ (at the maximum height), $a_y = -9.80\ \text{m/s}^2$. $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$ gives

$$y - y_0 = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{0 - (14.5\ \text{m/s})^2}{2(-9.80\ \text{m/s}^2)} = 10.7\ \text{m}.$$

(c) At the maximum height $v_y = 0$.

(d) The acceleration is constant and equal to $9.80\ \text{m/s}^2$, downward, at all points in the motion, including at the maximum height.

(e) The graphs are sketched in Figure 2.46.

EVALUATE: The time for the egg to reach its maximum height is $t = \frac{v_y - v_{0y}}{a_y} = \frac{-14.5\ \text{m/s}}{-9.8\ \text{m/s}^2} = 1.48\ \text{s}$. The egg has returned to the level of the cornice after 2.96 s and after 5.00 s it has traveled downward from the cornice for 2.04 s.

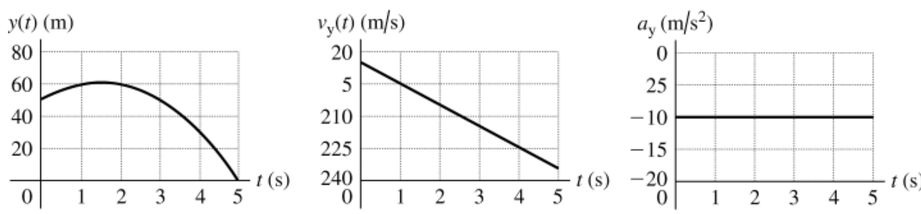


Figure 2.46

2.47. **IDENTIFY:** Use the constant acceleration equations to calculate a_x and $x - x_0$.

(a) SET UP: $v_x = 224\ \text{m/s}$, $v_{0x} = 0$, $t = 0.900\ \text{s}$, $a_x = ?$

$v_x = v_{0x} + a_x t$

EXECUTE: $a_x = \frac{v_x - v_{0x}}{t} = \frac{224\ \text{m/s} - 0}{0.900\ \text{s}} = 249\ \text{m/s}^2$

(b) $a_x / g = (249\ \text{m/s}^2)/(9.80\ \text{m/s}^2) = 25.4$

(c) $x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2 = 0 + \frac{1}{2}(249\ \text{m/s}^2)(0.900\ \text{s})^2 = 101\ \text{m}$

(d) SET UP: Calculate the acceleration, assuming it is constant:

$t = 1.40\ \text{s}$, $v_{0x} = 283\ \text{m/s}$, $v_x = 0$ (stops), $a_x = ?$

$v_x = v_{0x} + a_x t$

EXECUTE: $a_x = \frac{v_x - v_{0x}}{t} = \frac{0 - 283\ \text{m/s}}{1.40\ \text{s}} = -202\ \text{m/s}^2$

$a_x / g = (-202\ \text{m/s}^2)/(9.80\ \text{m/s}^2) = -20.6$; $a_x = -20.6g$

If the acceleration while the sled is stopping is constant then the magnitude of the acceleration is only 20.6*g*. But if the acceleration is not constant it is certainly possible that at some point the instantaneous acceleration could be as large as 40*g*.

EVALUATE: It is reasonable that for this motion the acceleration is much larger than *g*.

2.48. **IDENTIFY:** Since air resistance is ignored, the boulder is in free-fall and has a constant downward acceleration of magnitude $9.80\ \text{m/s}^2$. Apply the constant acceleration equations to the motion of the boulder.

SET UP: Take $+y$ to be upward.

EXECUTE: **(a)** $v_{0y} = +40.0\ \text{m/s}$, $v_y = +20.0\ \text{m/s}$, $a_y = -9.80\ \text{m/s}^2$. $v_y = v_{0y} + a_y t$ gives

$$t = \frac{v_y - v_{0y}}{a_y} = \frac{20.0\ \text{m/s} - 40.0\ \text{m/s}}{-9.80\ \text{m/s}^2} = +2.04\ \text{s}.$$