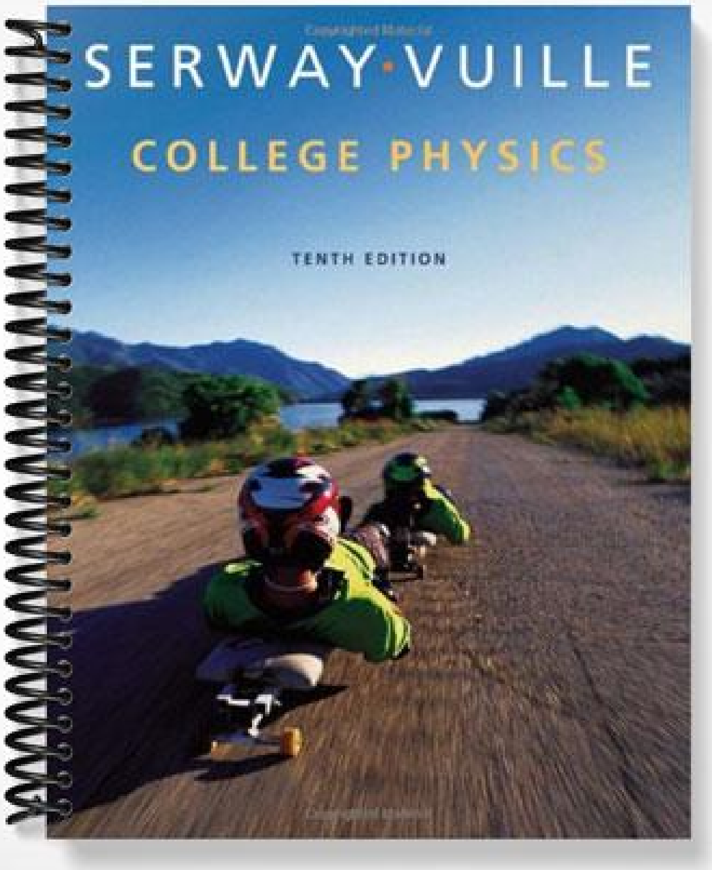
# SOLUTIONS MANUAL



# Instructor Solutions Manual

# College Physics

## TENTH EDITION

**RAYMOND A. SERWAY**
Emeritus, James Madison University

**CHRIS VUILLE**
Embry-Riddle Aeronautical University

Prepared by

**Vahe Peroomian & John Gordon**

Australia • Brazil • Japan • Korea • Mexico • Singapore • Spain • United Kingdom • United States

# 1
# Introduction

## ANSWERS TO WARM-UP EXERCISES

**1.** (a) The number given, 568 017, has six significant figures, which we will retain in converting the number to scientific notation. Moving the decimal five spaces to the left gives us the answer, $\boxed{5.680\ 17 \times 10^5}$.

(b) The number given, 0.000 309, has three significant figures, which we will retain in converting the number to scientific notation. Moving the decimal four spaces to the right gives us the answer, $\boxed{3.09 \times 10^{-4}}$.

**2.** We first collect terms, then simplify:

$$\frac{[M][L]^2}{[T]^3}\cdot\frac{[T]}{[L]}[T]=\frac{[M][L]^2[T]^2}{[T]^3[L]}=\boxed{\frac{[M][L]}{[T]}}$$

As we will see in Chapter 6, these are the units for momentum.

**3.** Examining the expression shows that the units of meters and seconds squared ($s^2$) appear in both the numerator and the denominator, and therefore cancel out. We combine the numbers and units separately, squaring the last term before doing so:

$$\left(7.00\frac{\text{m}}{\text{s}^2}\right)\left(\frac{1.00\,\text{km}}{1.00\times10^3\text{m}}\right)\left(\frac{60.0\,\text{s}}{1.00\,\text{min}}\right)^2$$
$$=(7.00)\left(\frac{1.00}{1.00\times10^3}\right)\left(\frac{3600}{1.00}\right)\left(\frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\right)\left(\frac{\text{km}}{\cancel{\text{m}}}\right)\left(\frac{\cancel{\text{s}^2}}{\text{min}^2}\right)$$
$$=\boxed{25.2\frac{\text{km}}{\text{min}^2}}$$

**4.** The required conversion can be carried out in one step:

$$h=(2.00\ \cancel{\text{m}})\left(\frac{1.00\,\text{cubitus}}{0.445\ \cancel{\text{m}}}\right)=\boxed{4.49\,\text{cubiti}}$$

**5** The area of the house in square feet (1 420 $\text{ft}^2$) contains 3 significant figures. Our answer will therefore also contain three significant figures. Also note that the conversion from feet to meters is squared to account for the $\text{ft}^2$ units in which the area is originally given.

$$A=\left(1\ 420\ \text{ft}^2\right)\left(\frac{1.00\ \text{m}}{3.281\ \text{ft}}\right)^2=131.909\ \text{m}^2=\boxed{132\ \text{m}^2}$$

**6.** Using a calculator to multiply the length by the width gives a raw answer of 6 783 $\text{m}^2$. This answer must be rounded to contain the same number of significant figures as the least accurate factor in the product. The least accurate factor is the length, which contains 2 significant figures, since the trailing zero is not significant (see Section 1.6). The correct answer for the area of the airstrip is $\boxed{6.80 \times 10^3\ \text{m}^2}$.

**7.** Adding the three numbers with a calculator gives 21.4 + 15 + 17.17 + 4.003 = 57.573. However, this answer must be rounded to contain the same number of significant figures as the least accurate number in the sum, which is 15, with two significant figures. The correct answer is therefore $\boxed{58}$.

**8.** The given Cartesian coordinates are $x = -5.00$ and $y = 12.00$. The least accurate of these coordinates contains 3 significant figures, so we will express our answer in three significant figures. The specified point, (–5.00, 12.00), is in the second quadrant since $x < 0$ and $y > 0$. To find the polar coordinates $(r,\ \theta)$ of this point, we use

$$r=\sqrt{x^2+y^2}=\sqrt{(5.00)^2+(12.00)^2}=13.0$$

and

$$\theta = \tan^{-1}\left(\frac{y}{x}\right) = \tan^{-1}\left(\frac{12.00}{-5.00}\right) = -67.3°$$

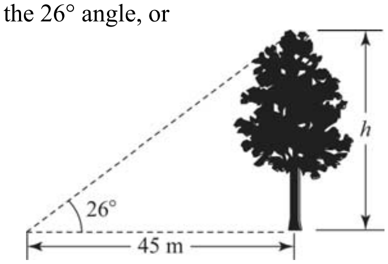
Since the point is in the second quadrant, we add 180° to this angle to obtain $\theta = -67.3° + 180° = 113°$. The polar coordinates of the point are therefore $\boxed{(13.0, 113°)}$.

**9.** Refer to ANS. FIG 9. The height of the tree is described by the tangent of the 26° angle, or

$$\tan 26° = \frac{h}{45 \text{ m}}$$

from which we obtain

$$h = (45 \text{ m})\tan 26° = \boxed{22 \text{ m}}$$



**ANS. FIG 9**

**ANSWERS TO EVEN NUMBERED CONCEPTUAL QUESTIONS**

**2.** Atomic clocks are based on the electromagnetic waves that atoms emit. Also, pulsars are highly regular astronomical clocks.

**4.** **(a)** $\sim 0.5 \text{ lb} \approx 0.25 \text{ kg or} \sim 10^{-1} \text{ kg}$

**(b)** $\sim 4 \text{ lb} \approx 2 \text{ kg or} \sim 10^{0} \text{ kg}$

**(c)** $\sim 4000 \text{ lb} \approx 2000 \text{ kg or} \sim 10^{3} \text{ kg}$

**6.** Let us assume the atoms are solid spheres of diameter $10^{-10}$ m. Then, the volume of each atom is of the order of $10^{-30}$ $m^3$. (More precisely, volume $= 4\pi r^3/3 = \pi d^3/6$.) Therefore, since $1 \text{ cm}^3 = 10^{-6} \text{ m}^3$, the number of atoms in the 1 $cm^3$ solid is on the order of $10^{-6}/10^{-30} = 10^{24}$ atoms. A more precise calculation would require knowledge of the density of the solid and the mass of each atom. However, our estimate agrees with the more precise calculation to within a factor of 10.

**8.** Realistically, the only lengths you might be able to verify are the length of a football field and the length of a housefly. The only time intervals subject to verification would be the length of a day and the time between normal heartbeats.

**10.** In the metric system, units differ by powers of ten, so it's very easy and accurate to convert from one unit to another.

**12.** Both answers (d) and (e) could be physically meaningful. Answers (a), (b), and (c) must be meaningless since quantities can be added or subtracted only if they have the same dimensions.

**ANSWERS TO EVEN NUMBERED PROBLEMS**

**2.** **(a)** $L/T^2$ **(b)** L

**4.** All three equations are dimensionally incorrect.

**6.** **(a)** $\text{kg} \cdot \text{m/s}$ **(b)** $Ft = p$

**8.** **(a)** 22.6 **(b)** 22.7 **(c)** 22.6 is more reliable

**10.** **(a)** $3.00 \times 10^8$ m/s **(b)** $2.997\,9 \times 10^8$ m/s **(c)** $2.997\,925 \times 10^8$ m/s

**12.** **(a)** $346 \text{ m}^2 \pm 13 \text{ m}^2$ **(b)** $66.0 \text{ m} \pm 1.3 \text{ m}$

**14.** **(a)** 797 **(b)** 1.1 **(c)** 17.66

**16.** 3.09 cm/s

**18.** **(a)** $5.60 \times 10^2 \text{ km} = 5.60 \times 10^5 \text{ m} = 5.60 \times 10^7 \text{ cm}$

**(b)** $0.491\,2 \text{ km} = 491.2 \text{ m} = 4.912 \times 10^4 \text{ cm}$

**(c)** $6.192 \text{ km} = 6.192\times10^3 \text{ m} = 6.192\times10^5 \text{ cm}$

**(d)** $2.499 \text{ km} = 2.499\times10^3 \text{ m} = 2.499\times10^5 \text{ cm}$

**20.** $10.6 \text{ km/L}$

**22.** $9.2 \text{ nm/s}$

**24.** $2.9\times10^2 \text{ m}^3 = 2.9\times10^8 \text{ cm}^3$

**26.** $2.57\times10^6 \text{ m}^3$

**28.** $\sim10^8$ steps

**30.** $\sim10^8$ people with colds on any given day

**32.** **(a)** $4.2\times10^{-18} \text{ m}^3$ (b) $\sim10^{-1} \text{ m}^3$ (c) $\sim10^{16}$ cells

**34.** **(a)** $\sim10^{29}$ prokaryotes (b) $\sim10^{14}$ kg

**(c)** The very large mass of prokaryotes implies they are important to the biosphere. They are responsible for fixing carbon, producing oxygen, and breaking up pollutants, among many other biological roles. Humans depend on them!

**36.** 2.2 m

**38.** 8.1 cm

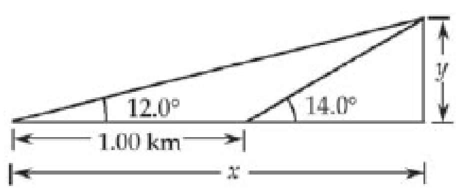
**40.** $\Delta s = \sqrt{r_1^2 + r_2^2 - 2r_1r_2\cos(\theta_1 - \theta_2)}$

**42.** 2.33 m

**44.** **(a)** 1.50 m **(b)** 2.60 m

**46.** 8.60 m

**48.** **(a)** and **(b)**




**(c)** $y/x = \tan 12.0°$, $y/(x - 1.00 \text{ km}) = \tan 14.0°$ **(d)** $1.44\times10^3 \text{ m}$

**50.** $y = \dfrac{d\cdot\tan\theta\cdot\tan\phi}{\tan\phi - \tan\theta}$

**52.** **(a)** $1.609 \text{ km/h}$ **(b)** $88 \text{ km/h}$ **(c)** $16 \text{ km/h}$

**54.** Assumes population of 300 million, average of 1 can/week per person, and 0.5 oz per can.

**(a)** $\sim10^{10}$ cans/yr **(b)** $\sim10^5$ tons/yr

**56.** **(a)** $7.14\times10^{-2} \text{ gal/s}$ **(b)** $2.70\times10^{-4} \text{ m}^3/\text{s}$ **(c)** 1.03 h

**58.** **(a)** $A_2/A_1 = 4$ **(b)** $V_2/V_1 = 8$

**60.** **(a)** 500 yr **(b)** $6.6 \times 10^4$ times

**62.** $\sim10^4$ balls/yr. Assumes 1 lost ball per hitter, 10 hitters per inning, 9 innings per game, and 81 games per year.

**PROBLEM SOLUTIONS**

**1.1** Substituting dimensions into the given equation $T = 2\pi\sqrt{\ell/g}$, and recognizing that $2\pi$ is a dimensionless constant, we have

$$[T] = \sqrt{\frac{[\ell]}{[g]}} \qquad \text{or} \qquad \mathrm{T} = \sqrt{\frac{\mathrm{L}}{\mathrm{L/T^2}}} = \sqrt{\mathrm{T^2}} = \mathrm{T}$$

Thus, the $\boxed{\text{dimensions are consistent}}$.

**1.2** (a) From $x = Bt^2$, we find that $B = \dfrac{x}{t^2}$. Thus, $B$ has units of

$$[B] = \frac{[x]}{[t^2]} = \boxed{\frac{\mathrm{L}}{\mathrm{T^2}}}$$

(b) If $x = A\sin(2\pi ft)$, then $[A] = [x]/[\sin(2\pi ft)]$

But the sine of an angle is a dimensionless ratio.

Therefore, $[A] = [x] = \boxed{\mathrm{L}}$

**1.3** (a) The units of volume, area, and height are:

$[V] = \mathrm{L}^3$, $[A] = \mathrm{L}^2$, and $[h] = \mathrm{L}$

We then observe that $\mathrm{L^3 = L^2 L}$ or $[V] = [A][h]$

Thus, the equation $V = Ah$ is $\boxed{\text{dimensionally correct}}$.

(b) $V_{\text{cylinder}} = \pi R^2 h = (\pi R^2)h = Ah$, where $\boxed{A = \pi R^2}$

$V_{\text{rectangular box}} = \ell wh = (\ell w)h = Ah$, where $\boxed{A = \ell w = length \times width}$

**1.4** (a) In the equation $\frac{1}{2}mv^2 = \frac{1}{2}mv_0^2 + \sqrt{mgh}$, $[mv^2] = [mv_0^2] = \mathrm{M}\left(\dfrac{\mathrm{L}}{\mathrm{T}}\right)^2 = \dfrac{\mathrm{ML^2}}{\mathrm{T^2}}$

while $\left[\sqrt{mgh}\,\right] = \sqrt{\mathrm{M}\left(\dfrac{\mathrm{L}}{\mathrm{T^2}}\right)\mathrm{L}} = \dfrac{\mathrm{M^{\frac{1}{2}}L}}{\mathrm{T}}$. Thus, the equation is $\boxed{\text{dimensionally incorrect}}$.

(b) In $v = v_0 + at^2$, $[v] = [v_0] = \dfrac{\mathrm{L}}{\mathrm{T}}$ but $[at^2] = [a][t^2] = \left(\dfrac{\mathrm{L}}{\mathrm{T^2}}\right)(\mathrm{T^2}) = \mathrm{L}$. Hence, this equation is $\boxed{\text{dimensionally incorrect}}$.

(c) In the equation $ma = v^2$, we see that $[ma] = [m][a] = \mathrm{M}\left(\dfrac{\mathrm{L}}{\mathrm{T^2}}\right) = \dfrac{\mathrm{ML}}{\mathrm{T^2}}$, while $[v^2] = \left(\dfrac{\mathrm{L}}{\mathrm{T}}\right)^2 = \dfrac{\mathrm{L^2}}{\mathrm{T^2}}$. Therefore, this equation is also $\boxed{\text{dimensionally incorrect}}$.

**1.5** From the universal gravitation law, the constant $G$ is $G = Fr^2/Mm$. Its units are then

$$[G] = \frac{[F][r^2]}{[M][m]} = \frac{(\cancel{\mathrm{kg}}\cdot\mathrm{m/s^2})(\mathrm{m^2})}{\cancel{\mathrm{kg}}\cdot\mathrm{kg}} = \boxed{\frac{\mathrm{m^3}}{\mathrm{kg\cdot s^2}}}$$

**1.6** (a) Solving $KE = \dfrac{p^2}{2m}$ for the momentum, $p$, gives $p = \sqrt{2m(KE)}$ where the numeral 2 is a dimensionless constant. Dimensional analysis gives the units of momentum as:

$$[p] = \sqrt{[m][KE]} = \sqrt{\mathrm{M}\left(\mathrm{M}\cdot\mathrm{L}^2/\mathrm{T}^2\right)} = \sqrt{\mathrm{M}^2\cdot\mathrm{L}^2/\mathrm{T}^2} = \mathrm{M}(\mathrm{L}/\mathrm{T})$$

Therefore, in the SI system, the units of momentum are $\boxed{\mathrm{kg}\cdot(\mathrm{m/s})}$.

(b) Note that the units of force are $\mathrm{kg}\cdot\mathrm{m/s^2}$ or $[F] = \mathrm{M}\cdot\mathrm{L}/\mathrm{T}^2$. Then, observe that

$$[F][t] = \left(\mathrm{M}\cdot\mathrm{L}/\mathrm{T}^2\right)\cdot\mathrm{T} = \mathrm{M}(\mathrm{L}/\mathrm{T}) = [p]$$

From this, it follows that force multiplied by time is proportional to momentum: $\boxed{Ft = p}$. (See the impulse–momentum theorem in Chapter 6, $F\cdot\Delta t = \Delta p$, which says that a constant force $F$ multiplied by a duration of time $\Delta t$ equals the change in momentum, $\Delta p$.)

**1.7** $Area = (length)\times(width) = (9.72\ \mathrm{m})(5.3\ \mathrm{m}) = \boxed{52\ \mathrm{m}^2}$

**1.8** (a) Computing $\left(\sqrt{8}\right)^3$ without rounding the intermediate result yields

$\left(\sqrt{8}\right)^3 = \boxed{22.6}$ to three significant figures.

(b) Rounding the intermediate result to three significant figures yields

$\sqrt{8} = 2.8284 \quad\rightarrow\quad 2.83$

Then, we obtain $\left(\sqrt{8}\right)^3 = (2.83)^3 = \boxed{22.7}$ to three significant figures.

(c) $\boxed{\text{The answer 22.6 is more reliable}}$ because rounding in part (b) was carried out too soon.

**1.9** (a) $78.9 \pm 0.2$ has $\boxed{\text{3 significant figures}}$ with the uncertainty in the tenths position.

(b) $3.788\times10^9$ has $\boxed{\text{4 significant figures}}$

(c) $2.46\times10^{-6}$ has $\boxed{\text{3 significant figures}}$

(d) $0.003\,2 = 3.2\times10^{-3}$ has $\boxed{\text{2 significant figures}}$. The two zeros were originally included only to position the decimal.

**1.10** $c = 2.997\,924\,58\times10^8\ \mathrm{m/s}$

(a) Rounded to 3 significant figures: $c = \boxed{3.00\times10^8\ \mathrm{m/s}}$

(b) Rounded to 5 significant figures: $c = \boxed{2.997\,9\times10^8\ \mathrm{m/s}}$

(c) Rounded to 7 significant figures: $c = \boxed{2.997\,925\times10^8\ \mathrm{m/s}}$

**1.11** Observe that the length $\ell = 5.62\ \mathrm{cm}$, the width $w = 6.35$ cm, and the height $h = 2.78$ cm all contain 3 significant figures. Thus, any product of these quantities should contain 3 significant figures.

(a) $\ell w = (5.62\ \mathrm{cm})(6.35\ \mathrm{cm}) = \boxed{35.7\ \mathrm{cm}^2}$

(b) $V = (\ell w)h = \left(35.7\ \mathrm{cm}^2\right)(2.78\ \mathrm{cm}) = \boxed{99.2\ \mathrm{cm}^3}$

(c) $wh = (6.35\ \mathrm{cm})(2.78\ \mathrm{cm}) = \boxed{17.7\ \mathrm{cm}^2}$

$$V = (wh)\ell = (17.7\text{ cm}^2)(5.62\text{ cm}) = \boxed{99.5\text{ cm}^3}$$

(d) In the rounding process, small amounts are either added to or subtracted from an answer to satisfy the rules of signify cant figures. For a given rounding, different small adjustments are made, introducing a certain amount of randomness in the last significant digit of the final answer.

**1.12** (a) $A = \pi r^2 = \pi(10.5\text{ m} \pm 0.2\text{ m})^2 = \pi\left[(10.5\text{ m})^2 \pm 2(10.5\text{ m})(0.2\text{ m}) + (0.2\text{ m})^2\right]$

Recognize that the last term in the brackets is insignificant in comparison to the other two. Thus, we have

$$A = \pi\left[110\text{ m}^2 \pm 4.2\text{ m}^2\right] = \boxed{346\text{ m}^2 \pm 13\text{ m}^2}$$

(b) $C = 2\pi r = 2\pi(10.5\text{ m} \pm 0.2\text{ m}) = \boxed{66.0\text{ m} \pm 1.3\text{ m}}$

**1.13** The least accurate dimension of the box has two significant figures. Thus, the volume (product of the three dimensions) will contain only two significant figures.

$$V = \ell \cdot w \cdot h = (29\text{ cm})(17.8\text{ cm})(11.4\text{ cm}) = \boxed{5.9\times10^3\text{ cm}^3}$$

**1.14** (a) The sum is rounded to $\boxed{797}$ because 756 in the terms to be added has no positions beyond the decimal.

(b) $0.003\,2\times356.3 = (3.2\times10^{-3})\times356.3 = 1.14016$ must be rounded to $\boxed{1.1}$ because $3.2\times10^{-3}$ has only two significant figures.

(c) $5.620\times\pi$ must be rounded to $\boxed{17.66}$ because 5.620 has only four significant figures.

**1.15** $d = (250\,000\text{ mi})\left(\dfrac{5\,280\text{ ft}}{1.000\text{ mi}}\right)\left(\dfrac{1\text{ fathom}}{6\text{ ft}}\right) = \boxed{2\times10^8\text{ fathoms}}$

The answer is limited to one significant figure because of the accuracy to which the conversion from fathoms to feet is given.

**1.16** $v = \dfrac{\ell}{t} = \dfrac{186\text{ furlongs}}{1\text{ fortnight}}\left(\dfrac{1\text{ fortnight}}{14\text{ days}}\right)\left(\dfrac{1\text{ day}}{8.64\times10^4\text{ s}}\right)\left(\dfrac{220\text{ yds}}{1\text{ furlong}}\right)\left(\dfrac{3\text{ ft}}{1\text{ yd}}\right)\left(\dfrac{100\text{ cm}}{3.281\text{ ft}}\right)$

giving $v = \boxed{3.09\text{ cm/s}}$

**1.17** $6.00\text{ firkins} = 6.00\text{ firkins}\left(\dfrac{9\text{ gal}}{1\text{ firkin}}\right)\left(\dfrac{3.786\text{ L}}{1\text{ gal}}\right)\left(\dfrac{10^3\text{ cm}^3}{1\text{ L}}\right)\left(\dfrac{1\text{ m}^3}{10^6\text{ cm}^3}\right) = \boxed{0.204\text{ m}^3}$

**1.18** (a) $\ell = (348\text{ mi})\left(\dfrac{1.609\text{ km}}{1.000\text{ mi}}\right) = \boxed{5.60\times10^2\text{ km}} = \boxed{5.60\times10^5\text{ m}} = \boxed{5.60\times10^7\text{ cm}}$

(b) $h = (1\,612\text{ ft})\left(\dfrac{1.609\text{ km}}{5\,280\text{ ft}}\right) = \boxed{0.491\,2\text{ km}} = \boxed{491.2\text{ m}} = \boxed{4.912\times10^4\text{ cm}}$

(c) $h = (20\,320\text{ ft})\left(\dfrac{1.609\text{ km}}{5\,280\text{ ft}}\right) = \boxed{6.192\text{ km}} = \boxed{6.192\times10^3\text{ m}} = \boxed{6.192\times10^5\text{ cm}}$

(d) $d = (8\,200\text{ ft})\left(\dfrac{1.609\text{ km}}{5\,280\text{ ft}}\right) = \boxed{2.499\text{ km}} = \boxed{2.499\times10^3\text{ m}} = \boxed{2.499\times10^5\text{ cm}}$

In (a), the answer is limited to three significant figures because of the accuracy of the original data value, 348 miles. In (b), (c), and (d), the answers are limited to four significant figures because of the accuracy to which the kilometers-to-feet conversion factor is given.

**1.19** $v = 38.0\ \frac{\text{m}}{\text{s}}\left(\frac{1\ \text{km}}{10^3\ \text{m}}\right)\left(\frac{1\ \text{mi}}{1.609\ \text{km}}\right)\left(\frac{3\,600\ \text{s}}{1\ \text{h}}\right) = 85.0\ \text{mi/h}$

Yes, the driver is exceeding the speed limit by 10.0 mi/h.

**1.20** $\textit{efficiency} = 25.0\ \frac{\text{mi}}{\text{gal}}\left(\frac{1\ \text{km}}{0.621\ \text{mi}}\right)\left(\frac{1\ \text{gal}}{3.786\ \text{L}}\right) = \boxed{10.6\ \text{km/L}}$

**1.21** (a) $r = \frac{\textit{diameter}}{2} = \frac{5.36\ \text{in}}{2}\left(\frac{2.54\ \text{cm}}{1\ \text{in}}\right) = \boxed{6.81\ \text{cm}}$

(b) $A = 4\pi r^2 = 4\pi(6.81\ \text{cm})^2 = \boxed{5.83\times 10^2\ \text{cm}^2}$

(c) $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(6.81\ \text{cm})^3 = \boxed{1.32\times 10^3\ \text{cm}^3}$

**1.22** $\textit{rate} = \left(\frac{1}{32}\ \frac{\text{in}}{\text{day}}\right)\left(\frac{1\ \text{day}}{24\ \text{h}}\right)\left(\frac{1\ \text{h}}{3\,600\ \text{s}}\right)\left(\frac{2.54\ \text{cm}}{1.00\ \text{in}}\right)\left(\frac{10^9\ \text{nm}}{10^2\ \text{cm}}\right) = \boxed{9.2\ \text{nm/s}}$

This means that the proteins are assembled at a rate of many layers of atoms each second!

**1.23** $c = \left(3.00\times 10^8\ \frac{\text{m}}{\text{s}}\right)\left(\frac{3\,600\ \text{s}}{1\ \text{h}}\right)\left(\frac{1\ \text{km}}{10^3\ \text{m}}\right)\left(\frac{1\ \text{mi}}{1.609\ \text{km}}\right) = \boxed{6.71\times 10^8\ \text{mi/h}}$

**1.24** $\text{Volume of house} = (50.0\ \text{ft})(26\ \text{ft})(8.0\ \text{ft})\left(\frac{2.832\times 10^{-2}\ \text{m}^3}{1\ \text{ft}^3}\right)$

$$= \boxed{2.9\times 10^2\ \text{m}^3} = \left(2.9\times 10^2\ \text{m}^3\right)\left(\frac{100\ \text{cm}}{1\ \text{m}}\right)^3 = \boxed{2.9\times 10^8\ \text{cm}^3}$$

**1.25** $\text{Volume} = (25.0\ \text{acre ft})\left(\frac{1\ \text{m}}{3.281\ \text{ft}}\right)\left[\left(\frac{43\,560\ \text{ft}^2}{1\ \text{acre}}\right)\left(\frac{1\ \text{m}}{3.281\ \text{ft}}\right)^2\right] = \boxed{3.08\times 10^4\ \text{m}^3}$

**1.26** $\text{Volume of pyramid} = \frac{1}{3}(\text{area of base})(\text{height})$

$$= \frac{1}{3}\left[(13.0\ \text{acres})\left(43\,560\ \text{ft}^2/\text{acre}\right)\right](481\ \text{ft}) = 9.08\times 10^7\ \text{f}$$

$$= \left(9.08\times 10^7\ \text{ft}^3\right)\left(\frac{2.832\times 10^{-2}\ \text{m}^3}{1\ \text{ft}^3}\right) = \boxed{2.57\times 10^6\ \text{m}^3}$$

**1.27** Volume of cube $= L^3 = 1$ quart (Where $L$ = length of one side of the cube.)

Thus, $L^3 = (1\ \text{quart})\left(\frac{1\ \text{gallon}}{4\ \text{quarts}}\right)\left(\frac{3.786\ \text{liter}}{1\ \text{gallon}}\right)\left(\frac{1000\ \text{cm}^3}{1\ \text{liter}}\right) = 947\ \text{cm}^3$

and $L = \sqrt[3]{947\ \text{cm}^3} = \boxed{9.82\ \text{cm}}$

**1.28** We estimate that the length of a step for an average person is about 18 inches, or roughly 0.5 m.

Then, an estimate for the number of steps required to travel a distance equal to the circumference of the Earth would be

$$N = \frac{\text{Circumference}}{\text{Step Length}} = \frac{2\pi R_E}{\text{Step Length}} \approx \frac{2\pi\left(6.38\times 10^6\ \text{m}\right)}{0.5\ \text{m/step}} \approx 8\times 10^7\ \text{steps}$$

or $\boxed{N \sim 10^8 \text{ steps}}$

**1.29** We assume an average respiration rate of about 10 breaths/minute and a typical life span of 70 years. Then, an estimate of the number of breaths an average person would take in a lifetime is

$$n = \left(10 \ \frac{\text{breaths}}{\cancel{\text{min}}}\right)(70 \ \cancel{\text{yr}})\left(\frac{3.156\times10^7 \ \cancel{\text{s}}}{1 \ \cancel{\text{yr}}}\right)\left(\frac{1 \ \cancel{\text{min}}}{60 \ \cancel{\text{s}}}\right) = 4\times10^8 \text{ breaths}$$

or $\boxed{n \sim 10^8 \text{ breaths}}$

**1.30** We assume that the average person catches a cold twice a year and is sick an average of 7 days (or 1 week) each time. Thus, on average, each person is sick for 2 weeks out of each year (52 weeks). The probability that a particular person will be sick at any given time equals the percentage of time that person is sick, or

$$probability\ of\ sickness = \frac{2 \text{ weeks}}{52 \text{ weeks}} = \frac{1}{26}$$

The population of the Earth is approximately 7 billion. The number of people expected to have a cold on any given day is then

$$Number\ sick = (population)(probability\ of\ sickness) = (7\times10^9)\left(\frac{1}{26}\right) = 3\times10^8 \text{ or } \boxed{10^8}$$

**1.31** (a) Assume that a typical intestinal tract has a length of about 7 m and average diameter of 4 cm. The estimated total intestinal volume is then

$$V_{\text{total}} = A\ell = \left(\frac{\pi d^2}{4}\right)\ell = \frac{\pi(0.04 \text{ m})^2}{4}(7 \text{ m}) = 0.009 \text{ m}^3$$

The approximate volume occupied by a single bacterium is

$$V_{\text{bacteria}} \sim (typical\ length\ scale)^3 = (10^{-6} \text{ m})^3 = 10^{-18} \text{ m}^3$$

If it is assumed that bacteria occupy one hundredth of the total intestinal volume, the estimate of the number of microorganisms in the human intestinal tract is

$$n = \frac{V_{\text{total}}/100}{V_{\text{bacteria}}} = \frac{(0.009 \text{ m}^3)/100}{10^{-18} \text{ m}^3} = 9\times10^{13} \quad \text{or} \quad n \sim \boxed{10^{14}}$$

(b) The large value of the number of bacteria estimated to exist in the intestinal tract means that they are probably not dangerous. Intestinal bacteria help digest food and provide important nutrients. Humans and bacteria enjoy a mutually beneficial symbiotic relationship.

**1.32** (a) $V_{\text{cell}} = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(1.0\times10^{-6} \text{ m})^3 = \boxed{4.2\times10^{-18} \text{ m}^3}$

(b) Consider your body to be a cylinder having a radius of about 6 inches (or 0.15 m) and a height of about 1.5 meters. Then, its volume is

$$V_{\text{body}} = Ah = (\pi r^2)h = \pi(0.15 \text{ m})^2(1.5 \text{ m}) = 0.11 \text{ m}^3 \text{ or } \boxed{\sim 10^{-1} \text{ m}^3}$$

(c) The estimate of the number of cells in the body is then

$$n = \frac{V_{\text{body}}}{V_{\text{cell}}} = \frac{0.11 \text{ m}^3}{4.2\times10^{-18} \text{ m}^3} = 2.6\times10^{16} \text{ or } \boxed{\sim 10^{16}}$$

**1.33** A reasonable guess for the diameter of a tire might be 3 ft, with a circumference ($C = 2\pi r = \pi D$ = distance travels per revolution) of about 9 ft. Thus, the total number of revolutions the tire might make is

$$n = \frac{\textit{total distance traveled}}{\textit{distance per revolution}} = \frac{(50\,000 \text{ mi})(5\,280 \text{ ft/mi})}{9 \text{ ft/rev}} = 3 \times 10^7 \text{ rev, or } \boxed{\sim 10^7 \text{ rev}}$$

**1.34** Answers to this problem will vary, dependent on the assumptions one makes. This solution assumes that bacteria and other prokaryotes occupy approximately one ten-millionth (10–7) of the Earth's volume, and that the density of a prokaryote, like the density of the human body, is approximately equal to that of water (103 kg/m3).

(a) $$\textit{estimated number} = n = \frac{V_{\text{total}}}{V_{\substack{\text{single}\\ \text{prokaryote}}}} \sim \frac{(10^{-7})V_{\text{Earth}}}{V_{\substack{\text{single}\\ \text{prokaryote}}}} \sim \frac{(10^{-7})R^3_{\text{Earth}}}{(\textit{length scale})^3} \sim \frac{(10^{-7})(10^6 \text{ m})^3}{(10^{-6} \text{ m})^3} \sim \boxed{10^{20}}$$

(b) $$m_{\text{total}} = (\textit{density})(\textit{total volume}) \sim \rho_{\text{water}}\left(nV_{\substack{\text{single}\\ \text{prokaryote}}}\right) = \left(10^3 \frac{\text{kg}}{\text{m}^3}\right)(10^{20})(10^{-6} \text{ m})^3 \sim \boxed{10^{14} \text{ kg}}$$

(c) The very large mass of prokaryotes implies they are important to the biosphere. They are responsible for fixing carbon, producing oxygen, and breaking up pollutants, among many other biological roles. Humans depend on them!

**1.35** The x coordinate is found as $x = r\cos\theta = (2.5 \text{ m})\cos 35° = \boxed{2.0 \text{ m}}$

and the y coordinate $y = r\sin\theta = (2.5 \text{ m})\sin 35° = \boxed{1.4 \text{ m}}$

**1.36** The x distance out to the fly is 2.0 m and the y distance up to the fly is 1.0 m. Thus, we can use the Pythagorean theorem to find the distance from the origin to the fly as

$$d = \sqrt{x^2 + y^2} = \sqrt{(2.0 \text{ m})^2 + (1.0 \text{ m})^2} = \boxed{2.2 \text{ m}}$$

**1.37** The distance from the origin to the fly is r in polar coordinates, and this was found to be 2.2 m in Problem 36. The angle θ is the angle between r and the horizontal reference line (the x axis in this case). Thus, the angle can be found as

$$\tan\theta = \frac{y}{x} = \frac{1.0 \text{ m}}{2.0 \text{ m}} = 0.50 \qquad \text{and} \qquad \theta = \tan^{-1}(0.50) = 27°$$

The polar coordinates are $\boxed{r = 2.2 \text{ m and } \theta = 27°}$

**1.38** The x distance between the two points is $|\Delta x| = |x_2 - x_1| = |-3.0 \text{ cm} - 5.0 \text{ cm}| = 8.0 \text{ cm}$ and the y distance between them is $|\Delta y| = |y_2 - y_1| = |3.0 \text{ cm} - 4.0 \text{ cm}| = 1.0 \text{ cm}$. The distance between them is found from the Pythagorean theorem:

$$d = \sqrt{|\Delta x|^2 + |\Delta y|^2} = \sqrt{(8.0 \text{ cm})^2 + (1.0 \text{ cm})^2} = \sqrt{65 \text{ cm}^2} = \boxed{8.1 \text{ cm}}$$

**1.39** Refer to the Figure given in Problem 1.40 below. The Cartesian coordinates for the two given points are:

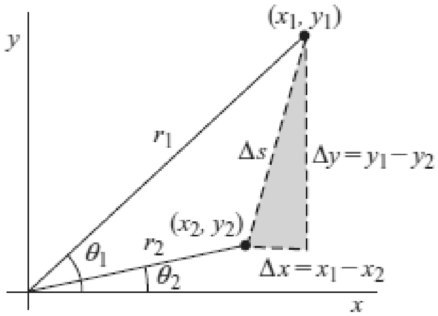
$$x_1 = r_1\cos\theta_1 = (2.00 \text{ m})\cos 50.0° = 1.29 \text{ m} \qquad x_2 = r_2\cos\theta_2 = (5.00 \text{ m})\cos(-50.0°) = 3.21 \text{ m}$$
$$y_1 = r_1\sin\theta_1 = (2.00 \text{ m})\sin 50.0° = 1.53 \text{ m} \qquad y_2 = r_2\sin\theta_2 = (5.00 \text{ m})\sin(-50.0°) = -3.83 \text{ m}$$

The distance between the two points is then:

$$\Delta s = \sqrt{(\Delta x)^2 + (\Delta y)^2} = \sqrt{(1.29 \text{ m} - 3.21 \text{ m})^2 + (1.53 \text{ m} + 3.83 \text{ m})^2} = \boxed{5.69 \text{ m}}$$

**1.40** Consider the Figure shown at the right. The Cartesian coordinates for the two points are:

$$x_1 = r_1\cos\theta_1 \qquad x_2 = r_2\cos\theta_2$$
$$y_1 = r_1\sin\theta_1 \qquad y_2 = r_2\sin\theta_2$$




The distance between the two points is the length of the hypotenuse of the shaded triangle and is given by

$$\Delta s = \sqrt{(\Delta x)^2 + (\Delta y)^2} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

or

$$\Delta s = \sqrt{\left(r_1^2 \cos^2\theta_1 + r_2^2\cos^2\theta_2 - 2r_1r_2\cos\theta_1\cos\theta_2\right) + \left(r_1^2\sin^2\theta_1 + r_2^2\sin^2\theta_2 - 2r_1r_2\sin\theta_1\sin\theta_2\right)}$$

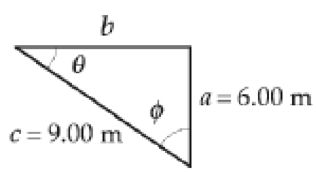
$$= \sqrt{r_1^2\left(\cos^2\theta_1 + \sin^2\theta_1\right) + r_2^2\left(\cos^2\theta_2 + \sin^2\theta_2\right) - 2r_1r_2\left(\cos\theta_1\cos\theta_2 + \sin\theta_1\sin\theta_2\right)}$$

Applying the identities $\cos^2\theta + \sin^2\theta = 1$ and $\cos\theta_1\cos\theta_2 + \sin\theta_1\sin\theta_2 = \cos(\theta_1 - \theta_2)$, this reduces to

$$\boxed{\Delta s = \sqrt{r_1^2 + r_2^2 - 2r_1r_2\left(\cos\theta_1\cos\theta_2 + \sin\theta_1\sin\theta_2\right)}} = \boxed{\sqrt{r_1^2 + r_2^2 - 2r_1r_2\cos(\theta_1 - \theta_2)}}$$

**1.41** (a) With $a = 6.00$ m and b being two sides of this right triangle having hypotenuse $c = 9.00$ m, the Pythagorean theorem gives the unknown side as

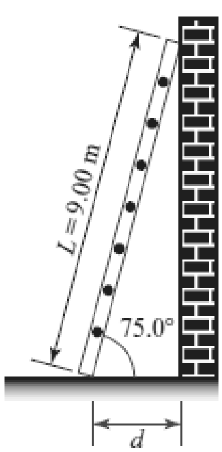
$$b = \sqrt{c^2 - a^2} = \sqrt{(9.00\text{ m})^2 - (6.00\text{ m})^2} = \boxed{6.71\text{ m}}$$




(b) $\tan\theta = \dfrac{a}{b} = \dfrac{6.00\text{ m}}{6.71\text{ m}} = \boxed{0.894}$ (c) $\sin\phi = \dfrac{b}{c} = \dfrac{6.71\text{ m}}{9.00\text{ m}} = \boxed{0.746}$

**1.42** From the diagram, $\cos(75.0°) = d/L$

Thus, $d = L\cos(75.0°) = (9.00\text{ m})\cos(75.0°) = \boxed{2.33\text{ m}}$



**1.43** The circumference of the fountain is $C = 2\pi r$, so the radius is

$$r = \frac{C}{2\pi} = \frac{15.0 \text{ m}}{2\pi} = 2.39 \text{ m}$$


Thus, $\tan(55.0°) = \frac{h}{r} = \frac{h}{2.39 \text{ m}}$ which gives

$$h = (2.39 \text{ m})\tan(55.0°) = \boxed{3.41 \text{ m}}$$

**1.44** (a) $\sin\theta = \frac{\text{opposite side}}{\text{hypotenuse}}$ so, opposite side $= (3.00 \text{ m})\sin(30.0°) = \boxed{1.50 \text{ m}}$

(b) $\cos\theta = \frac{\text{adjacent side}}{\text{hypotenuse}}$ so, adjacent side $= (3.00 \text{ m})\cos(30.0°) = \boxed{2.60 \text{ m}}$

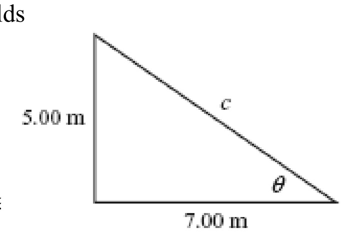
**1.45** (a) The side opposite $\theta = \boxed{3.00}$ (b) The side adjacent to $\phi = \boxed{3.00}$

(c) $\cos\theta = \frac{4.00}{5.00} = \boxed{0.800}$ (d) $\sin\phi = \frac{4.00}{5.00} = \boxed{0.800}$

(e) $\tan\phi = \frac{4.00}{3.00} = \boxed{1.33}$

**1.46** Using the diagram at the right, the Pythagorean theorem yields

$$c = \sqrt{(5.00 \text{ m})^2 + (7.00 \text{ m})^2} = \boxed{8.60 \text{ m}}$$

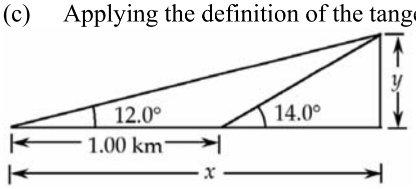



**1.47** From the diagram given in Problem 1.46 above, it is seen tha

$$\tan\theta = \boxed{\frac{5.00}{7.00}} = 0.714 \quad \text{and} \quad \theta = \tan^{-1}(0.714) = \boxed{35.5°}$$

**1.48** (a) and (b) See the Figure given at the right.

(c) Applying the definition of the tangent function to the large right triangle containing the 12.0° angle gives:




$$\boxed{y/x = \tan 12.0°} \qquad [1]$$

Also, applying the definition of the tangent function to the smaller right triangle containing the 14.0° angle gives:

$$\boxed{\frac{y}{x - 1.00 \text{ km}} = \tan 14.0°} \qquad [2]$$

(d) From Equation [1] above, observe that $x = y/\tan 12.0°$

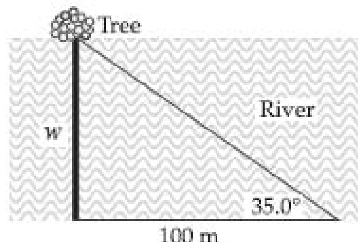
Substituting this result into Equation [2] gives

$$\frac{y \cdot \tan 12.0°}{y - (1.00\text{ km})\tan 12.0°} = \tan 14.0°$$

Then, solving for the height of the mountain, y, yields

$$y = \frac{(1.00\text{ km})\tan 12.0° \tan 14.0°}{\tan 14.0° - \tan 12.0°} = 1.44\text{ km} = \boxed{1.44\times 10^3\text{ m}}$$

**1.49** Using the sketch at the right:

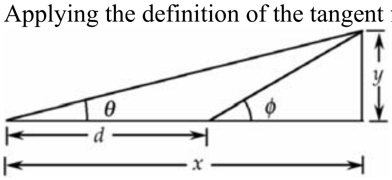



$$\frac{w}{100\text{ m}} = \tan 35.0°\text{ , or}$$

$$w = (100\text{ m})\tan 35.0° = \boxed{70.0\text{ m}}$$

**1.50** The figure at the right shows the situation described in the problem statement.

Applying the definition of the tangent function to the large right triangle containing the angle $\theta$ in the Figure, one obtains




$$y/x = \tan\theta \qquad [1]$$

Also, applying the definition of the tangent function to the small right triangle containing the angle $\phi$ gives

$$\frac{y}{x-d} = \tan\phi \qquad [2]$$

Solving Equation [1] for x and substituting the result into Equation [2] yields

$$\frac{y}{y/\tan\theta - d} = \tan\phi \qquad \text{or} \qquad \frac{y\cdot\tan\theta}{y - d\cdot\tan\theta} = \tan\phi$$

The last result simplifies to $y\cdot\tan\theta = y\cdot\tan\phi - d\cdot\tan\theta\cdot\tan\phi$

Solving for y: $y(\tan\theta - \tan\phi) = -d\cdot\tan\theta\cdot\tan\phi$ or

$$y = -\frac{d\cdot\tan\theta\cdot\tan\phi}{\tan\theta - \tan\phi} = \boxed{\frac{d\cdot\tan\theta\cdot\tan\phi}{\tan\phi - \tan\theta}}$$

**1.51** (a) Given that $a \propto F/m$, we have $F \propto ma$. Therefore, the units of force are those of ma,

$$[F] = [ma] = [m][a] = \text{M}\left(\text{L}/\text{T}^2\right) = \boxed{\text{M L T}^{-2}}$$

(b) $[F] = \text{M}\left(\frac{\text{L}}{\text{T}^2}\right) = \frac{\text{M}\cdot\text{L}}{\text{T}^2}$ so newton = $\boxed{\frac{\text{kg}\cdot\text{m}}{\text{s}^2}}$

**1.52** (a) $1\ \frac{\text{mi}}{\text{h}} = \left(1\ \frac{\text{mi}}{\text{h}}\right)\left(\frac{1.609\text{ km}}{1\text{ mi}}\right) = \boxed{1.609\ \frac{\text{km}}{\text{h}}}$

(b) $v_{max} = 55\ \frac{\text{mi}}{\text{h}} = \left(55\ \frac{\text{mi}}{\text{h}}\right)\left(\frac{1.609\text{ km/h}}{1\text{ mi/h}}\right) = \boxed{88\ \frac{\text{km}}{\text{h}}}$

(c) $\Delta v_{\max} = 65\ \dfrac{\text{mi}}{\text{h}} - 55\ \dfrac{\text{mi}}{\text{h}} = \left(10\ \dfrac{\text{mi}}{\text{h}}\right)\left(\dfrac{1.609\ \text{km/h}}{1\ \text{mi/h}}\right) = \boxed{16\ \dfrac{\text{km}}{\text{h}}}$

**1.53** (a) Since $1\ \text{m} = 10^2\ \text{cm}$, then $1\ \text{m}^3 = (1\ \text{m})^3 = (10^2\ \text{cm})^3 = (10^2)^3\ \text{cm}^3 = 10^6\ \text{cm}^3$, giving

$$\text{mass} = (\text{density})(\text{volume}) = \left(\frac{1.0\times10^{-3}\ \text{kg}}{1.0\ \text{cm}^3}\right)(1.0\ \text{m}^3)$$

$$= \left(1.0\times10^{-3}\ \frac{\text{kg}}{\text{cm}^3}\right)(1.0\ \text{m}^3)\left(\frac{10^6\ \text{cm}^3}{1\ \text{m}^3}\right) = \boxed{1.0\times10^3\ \text{kg}}$$

As a rough calculation, treat each of the following objects as if they were 100% water.

(b) cell: $\text{mass} = \text{density}\times\text{volume} = \left(10^3\ \dfrac{\text{kg}}{\text{m}^3}\right)\dfrac{4}{3}\pi(0.50\times10^{-6}\ \text{m})^3 = \boxed{5.2\times10^{-16}\ \text{kg}}$

(c) kidney: $\text{mass} = \text{density}\times\text{volume} = \rho\left(\dfrac{4}{3}\pi r^3\right) = \left(10^3\ \dfrac{\text{kg}}{\text{m}^3}\right)\dfrac{4}{3}\pi(4.0\times10^{-2}\ \text{m})^3 = \boxed{0.27\ \text{kg}}$

$\text{mass} = \text{density}\times\text{volume} = (\text{density})(\pi r^2 h)$

(d) fly:

$$= \left(10^3\ \frac{\text{kg}}{\text{m}^3}\right)\pi(1.0\times10^{-3}\ \text{m})^2(4.0\times10^{-3}\ \text{m}) = \boxed{1.3\times10^{-5}\ \text{kg}}$$

**1.54** Assume an average of 1 can per person each week and a population of 300 million.

(a) $$\text{number cans/year} = \left(\frac{\text{number cans/person}}{\text{week}}\right)(\text{population})(\text{weeks/year})$$

$$= \left(1\ \frac{\text{can/person}}{\text{week}}\right)(3\times10^8\ \text{people})(52\ \text{weeks/yr})$$

$$= 2\times10^{10}\ \text{cans/yr, or } \boxed{\sim10^{10}\ \text{cans/yr}}$$

(b) $$\text{number of tons} = (\text{weight/can})(\text{number cans /year})$$

$$= \left[\left(0.5\ \frac{\text{oz}}{\text{can}}\right)\left(\frac{1\ \text{lb}}{16\ \text{oz}}\right)\left(\frac{1\ \text{ton}}{2\,000\ \text{lb}}\right)\right]\left(2\times10^{10}\ \frac{\text{can}}{\text{yr}}\right)$$

$$= 3\times10^5\ \text{ton/yr, or } \boxed{\sim10^5\ \text{ton/yr}}$$

Assumes an average weight of 0.5 oz of aluminum per can.

**1.55** The term $s$ has dimensions of L, $a$ has dimensions of LT–2, and $t$ has dimensions of T. Therefore, the equation, $s = k\,a^m t^n$ with $k$ being dimensionless, has dimensions of

$$\text{L} = (\text{LT}^{-2})^m(\text{T})^n \qquad \text{or} \qquad \text{L}^1\text{T}^0 = \text{L}^m\,\text{T}^{n-2m}$$

The powers of L and T must be the same on each side of the equation. Therefore, $\text{L}^1 = \text{L}^m$ and $\boxed{m = 1}$

Likewise, equating powers of T, we see that $n - 2m = 0$, or $\boxed{n = 2m = 2}$

$\boxed{\text{Dimensional analysis cannot determine the value of } k}$, a dimensionless constant.

**1.56** (a) The rate of filling in gallons per second is

$$rate = \frac{30.0 \text{ gal}}{7.00 \text{ min}}\left(\frac{1 \text{ min}}{60 \text{ s}}\right) = \boxed{7.14\times10^{-2} \text{ gal/s}}$$

(b) Note that Note that $1 \text{ m}^3 = \left(10^2 \text{ cm}\right)^3 = \left(10^6 \text{ cm}^3\right)\left(\frac{1 \text{ L}}{10^3 \text{ cm}^3}\right) = 10^3 \text{ L}$. Thus,

$$rate = 7.14\times10^{-2} \frac{\text{gal}}{\text{s}}\left(\frac{3.786 \text{ L}}{1 \text{ gal}}\right)\left(\frac{1 \text{ m}^3}{10^3 \text{ L}}\right) = \boxed{2.70\times10^{-4} \text{ m}^3/\text{s}}$$

(c) $t = \frac{V_{\text{filled}}}{rate} = \frac{1.00 \text{ m}^3}{2.70\times10^{-4} \text{ m}^3/\text{s}} = 3.70\times10^3 \text{ s}\left(\frac{1 \text{ h}}{3\,600 \text{ s}}\right) = \boxed{1.03 \text{ h}}$

**1.57** The volume of paint used is given by $V = Ah$, where $A$ is the area covered and $h$ is the thickness of the layer. Thus,

$$h = \frac{V}{A} = \frac{3.79\times10^{-3} \text{ m}^3}{25.0 \text{ m}^2} = 1.52\times10^{-4} \text{ m} = 152\times10^{-6} \text{ m} = \boxed{152 \ \mu\text{m}}$$

**1.58** (a) For a sphere, $A = 4\pi R^2$. In this case, the radius of the second sphere is twice that of the first, or $R_2 = 2R_1$.

Hence, $\frac{A_2}{A_1} = \frac{4\pi R_2^2}{4\pi R_1^2} = \frac{R_2^2}{R_1^2} = \frac{(2R_1)^2}{R_1^2} = \boxed{4}$

(b) For a sphere, the volume is $V = \frac{4}{3}\pi R^3$

Thus, $\frac{V_2}{V_1} = \frac{(4/3)\pi R_2^3}{(4/3)\pi R_1^3} = \frac{R_2^3}{R_1^3} = \frac{(2R_1)^3}{R_1^3} = \boxed{8}$

**1.59** The estimate of the total distance cars are driven each year is

$$d = (\text{cars in use})(\text{distance traveled per car}) = \left(100\times10^6 \text{ cars}\right)\left(10^4 \text{ mi/car}\right) = 1\times10^{12} \text{ mi}$$

At a rate of 20 mi/gal, the fuel used per year would be

$$V_1 = \frac{d}{rate_1} = \frac{1\times10^{12} \text{ mi}}{20 \text{ mi/gal}} = 5\times10^{10} \text{ gal}$$

If the rate increased to $25 \text{ mi/gal}$, the annual fuel consumption would be

$$V_2 = \frac{d}{rate_2} = \frac{1\times10^{12} \text{ mi}}{25 \text{ mi/gal}} = 4\times10^{10} \text{ gal}$$

and the fuel savings each year would be

$$savings = V_1 - V_2 = 5\times10^{10} \text{ gal} - 4\times10^{10} \text{ gal} = \boxed{1\times10^{10} \text{ gal}}$$

**1.60** (a) The time interval required to repay the debt will be calculated by dividing the total debt by the rate at which it is repaid.

$$T = \frac{\$17 \text{ trillion}}{\$1000/\text{s}} = \frac{\$16\times10^{12}}{(\$1000/\text{s})\left(3.156\times10^7 \text{ s/yr}\right)}$$

$$= 539 \text{ yr} \sim \boxed{500 \text{ yr}}$$

(b) The number of times \$17 trillion in bills encircles the Earth is given by 17 trillion times the length of one dollar bill divided by the circumference of the Earth ($C = 2\pi R_E$).

$$N = \frac{n\ell}{2\pi R_E} = \frac{(17\times 10^{12})(0.155 \text{ m})}{2\pi(6.378\times 10^{6} \text{ m})} = \boxed{6.6\times 10^{4} \text{ times}}$$

**1.61** (a) $$1 \text{ yr} = (1 \text{ yr})\left(\frac{365.2 \text{ days}}{1 \text{ yr}}\right)\left(\frac{8.64\times 10^{4} \text{ s}}{1 \text{ day}}\right) = \boxed{3.16\times 10^{7} \text{ s}}$$

(b) Consider a segment of the surface of the Moon which has an area of 1 m2 and a depth of 1 m. When filled with meteorites, each having a diameter $10^{-6}$ m, the number of meteorites along each edge of this box is

$$n = \frac{\text{length of an edge}}{\text{meteorite diameter}} = \frac{1 \text{ m}}{10^{-6} \text{ m}} = 10^{6}$$

The total number of meteorites in the filled box is then

$$N = n^3 = (10^6)^3 = 10^{18}$$

At the rate of 1 meteorite per second, the time to fill the box is

$$t = 10^{18} \text{ s} = (10^{18} \text{ s})\left(\frac{1 \text{ y}}{3.16\times 10^{7} \text{ s}}\right) = 3\times 10^{10} \text{ yr, or } \boxed{\sim 10^{10} \text{ yr}}$$

**1.62** We will assume that, on average, 1 ball will be lost per hitter, that there will be about 10 hitters per inning, a game has 9 innings, and the team plays 81 home games per season. Our estimate of the number of game balls needed per season is then

$$\begin{aligned}\text{number of balls needed} &= (\text{number lost per hitter})(\text{number hitters/game})(\text{home games/year}) \\ &= (1 \text{ ball per hitter})\left[\left(10 \frac{\text{hitters}}{\text{inning}}\right)\left(9 \frac{\text{innings}}{\text{game}}\right)\right]\left(81 \frac{\text{games}}{\text{year}}\right) \\ &= 7300 \frac{\text{balls}}{\text{year}} \quad \text{or} \quad \boxed{\sim 10^4 \frac{\text{balls}}{\text{year}}}\end{aligned}$$

**1.63** The volume of the Milky Way galaxy is roughly

$$V_G = At = \left(\frac{\pi d^2}{4}\right)t = \frac{\pi}{4}(10^{21} \text{ m})^2(10^{19} \text{ m}) \quad \text{or} \quad V_G \sim 10^{61} \text{ m}^3$$

If, within the Milky Way galaxy, there is typically one neutron star in a spherical volume of radius $r = 3\times 10^{18}$ m, then the galactic volume per neutron star is

$$V_1 = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(3\times 10^{18} \text{ m})^3 = 1\times 10^{56} \text{ m}^3 \quad \text{or} \quad V_1 \sim 10^{56} \text{ m}^3$$

The order of magnitude of the number of neutron stars in the Milky Way is then

$$n = \frac{V_G}{V_1} \sim \frac{10^{61} \text{ m}^3}{10^{56} \text{ m}^3} \quad \text{or} \quad \boxed{n \sim 10^5 \text{ neutron stars}}$$

## 2
## Motion in One Dimension

### QUICK QUIZZES

**1.** (a) 200 yd (b) 0 (c) 0

**2.** (a) False. The car may be slowing down, so that the direction of its acceleration is opposite the direction of its velocity.

(b) True. If the velocity is in the direction chosen as negative, a positive acceleration causes a decrease in speed.

(c) True. For an accelerating particle to stop at all, the velocity and acceleration must have opposite signs, so that the speed is decreasing. If this is the case, the particle will eventually come to rest. If the acceleration remains constant, however, the particle must begin to move again, opposite to the direction of its original velocity. If the particle comes to rest and then stays at rest, the acceleration has become zero at the moment the motion stops. This is the case for a braking car—the acceleration is negative and goes to zero as the car comes to rest.

**3.** The velocity-vs.-time graph (a) has a constant slope, indicating a constant acceleration, which is represented by the acceleration-vs.-time graph (e).

Graph (b) represents an object whose speed always increases, and does so at an ever increasing rate. Thus, the acceleration must be increasing, and the acceleration-vs.-time graph that best indicates this behavior is (d).

Graph (c) depicts an object which first has a velocity that increases at a constant rate, which means that the object's acceleration is constant. The motion then changes to one at constant speed, indicating that the acceleration of the object becomes zero. Thus, the best match to this situation is graph (f).

**4.** Choice (b). According to *graph b*, there are some instants in time when the object is simultaneously at two different $x$-coordinates. This is physically impossible.

**5.** (a) The *blue graph* of Figure 2.14b best shows the puck's position as a function of time. As seen in Figure 2.14a, the distance the puck has traveled grows at an increasing rate for approximately three time intervals, grows at a steady rate for about four time intervals, and then grows at a diminishing rate for the last two intervals.

(b) The *red graph* of Figure 2.14c best illustrates the speed (distance traveled per time interval) of the puck as a function of time. It shows the puck gaining speed for approximately three time intervals, moving at constant speed for about four time intervals, then slowing to rest during the last two intervals.

(c) The *green graph* of Figure 2.14d best shows the puck's acceleration as a function of time. The puck gains velocity (positive acceleration) for approximately three time intervals, moves at constant velocity (zero acceleration) for about four time intervals, and then loses velocity (negative acceleration) for roughly the last two time intervals.

**6.** Choice (e). The acceleration of the ball remains constant while it is in the air. The magnitude of its acceleration is the free-fall acceleration, $g = 9.80 \text{ m/s}^2$.

**7.** Choice (c). As it travels upward, its speed decreases by 9.80 m/s during each second of its motion. When it reaches the peak of its motion, its speed becomes zero. As the ball moves downward, its speed increases by 9.80 m/s each second.

**8.** Choices (a) and (f). The first jumper will always be moving with a higher velocity than the second. Thus, in a given time interval, the first jumper covers more distance than the second, and the separation distance between them *increases*. At any given instant of time, the velocities of the jumpers are definitely different, because one had a head start. In a time interval after this instant, however, each jumper increases his or her velocity by the same amount, because they have the same acceleration. Thus, the difference in velocities *stays the same*.

## ANSWERS TO WARM-UP EXERCISES

**1.** For a quadratic equation in the form of $ax^2 + bx + c = 0$, the quadratic formula gives the answer for $x$ as

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

The quadratic equation given has $a = 2.00$, $b = -6.00$, and $c = -9.00$. Substituting into the quadratic formula gives two solutions for $t$:

$$t = \frac{6.00 \pm \sqrt{(-6.00)^2 - 4(2.00)(-9.00)}}{2(2.00)} = \frac{6.00 \pm \sqrt{108}}{4.00}$$

which gives $t = \boxed{-1.10}$ or $t = \boxed{4.10}$.

**2.** (a) Solving the first equation for the time $t$ (assuming SI units):

$$-9.8t + 49 = 0 \quad \rightarrow \quad -9.8t = -49 \quad \rightarrow \quad t = \boxed{5.0 \text{ s}}$$

(b) Substituting the value of $t$ from above into the equation for $x$:

$$x = -4.9t^2 + 49t + 16 = -4.9(5.00 \text{ s})^2 + 49(5.00 \text{ s}) + 16$$
$$= 138.5 \text{ m} = \boxed{140 \text{ m}}$$

**3.** (a) Setting the two equations for $x$ equal to one another, we obtain

$$3.00t^2 = 24.0t + 72.0$$

Rearranging gives us a quadratic equation,

$$3.00t^2 - 24.0t - 72.0 = 0$$

Dividing out a factor of 3.00,

$$t^2 - 8.00t - 24.0 = 0$$

Substituting into the quadratic formula gives

$$t = \frac{8.00 \pm \sqrt{(-8.00)^2 - 4(1.00)(-24.00)}}{2(1.00)} = \frac{8.00 \pm \sqrt{160}}{2.00}$$
$$= \boxed{10.3 \text{ s}} \text{ or } -2.32 \text{ s}$$

Where we have chosen the positive root for the time $t$.

(b) Substituting the value of $t$ from above into the first equation for $x$:

$$x = 3.00t^2 = 3.00(10.3 \text{ s}) = \boxed{3.20 \times 10^3 \text{ m}}$$

Where the answer has been expressed in three significant figures.

**4.** (a) The football player covers a total of 150 yards in 18.0 s. His average speed is

$$\text{average speed} = \frac{\text{path length}}{\text{elapsed time}} = \frac{150 \text{ yd}}{18.0 \text{ s}} = \boxed{8.33 \text{ yd/s}}$$

(b) The football player's average velocity is his total displacement divided by the elapsed time. His displacement at the end of the run is 50.0 yards, since he has returned to the fifty-yard line.

$$\overline{v} = \frac{\Delta x}{\Delta t} = \frac{50.0 \text{ yd}}{18.0 \text{ s}} = \boxed{2.78 \text{ yd/s}}$$

**5.** At ground level, the displacement of the rock from its launch point is $\Delta y = -h,$ where $h$ is the height of the tower and upward has been chosen as the positive direction. From Equation 2.10,

$$v^2 = v_0^2 + 2a\Delta y$$

we obtain (with $a = -g$),

$$|v| = \left|\pm\sqrt{v_0^2 + 2(-g)(-h)}\right|$$

$$= \left|\pm\sqrt{(12.0 \text{ m/s})^2 + 2(-9.80 \text{ m/s}^2)(-40.0 \text{ m})}\right| = \boxed{30.5 \text{ m/s}}$$

**6.** Once the arrow has left the bow, it has a constant downward acceleration equal to the free-fall acceleration, $g$. Taking upward as the positive direction, the elapsed time required for the velocity to change from an initial value of 15.0 m/s upward ($v_0 = +15.0 \text{ m/s}$) to a value of 8.00 m/s downward $(v_f = -8.00 \text{ m/s})$ is given by

$$\Delta t = \frac{\Delta v}{a} = \frac{v_f - v_0}{-g} = \frac{-8.00 \text{ m/s} - (+15.0 \text{ m/s})}{-9.80 \text{ m/s}^2} = \boxed{2.35 \text{ s}}$$

**7.** We set the initial position of the blue ball, at a height of 10.0 m, as the origin and take upward as the positive direction. The initial position of the blue ball is then 0, and the initial position of the red ball is 10.0 m – 6.00 m = 4.00 m below the blue ball, or at $y = -4.00$ m. At the instant that the blue ball catches up to the red ball, the $y$ coordinate of both balls will be equal. The displacement of the red ball is given by

$$\Delta y_{\text{red}} = y - y_{0,\text{red}} = v_{0,\text{red}}t + \frac{1}{2}at^2$$

Since the initial velocity of the red ball is zero,

$$y_{\text{red}} = y_{0,\text{red}} - \frac{1}{2}gt^2$$

The displacement of the blue ball is given by

$$\Delta y_{\text{blue}} = y_{\text{blue}} - y_{0,\text{blue}} = v_{0,\text{blue}}t + \frac{1}{2}at^2$$

or

$$y_{\text{blue}} = v_{0,\text{blue}}t - \frac{1}{2}gt^2$$

Setting the two equations equal and substituting $a = -$g gives

$$y_{0,\text{red}} - \frac{1}{2}gt^2 = v_{0,\text{blue}}t - \frac{1}{2}gt^2$$

Simplifying,

$$v_{0,\text{blue}}t = y_{0,\text{red}}$$

or

$$t = \frac{y_{0,\text{red}}}{v_{0,\text{blue}}} = \frac{-4.00\text{ m}}{-4.00\text{ m/s}} = \boxed{1.00\text{ s}}$$

## ANSWERS TO EVEN NUMBERED CONCEPTUAL QUESTIONS

**2.** Yes. The particle may stop at some instant, but still have an acceleration, as when a ball thrown straight up reaches its maximum height.

**4.** (a) No. They can be used only when the acceleration is constant.

(b) Yes. Zero is a constant.

**6.** (a) In Figure (c), the images are farther apart for each successive time interval. The object is moving toward the right and speeding up. This means that the acceleration is positive in Figure (c).

(b) In Figure (a), the first four images show an increasing distance traveled each time interval and therefore a positive acceleration. However, after the fourth image, the spacing is decreasing, showing that the object is now slowing down (or has negative acceleration).

(c) In Figure (b), the images are equally spaced, showing that the object moved the same distance in each time interval. Hence, the velocity is constant in Figure (b).

**8.** (a) At the maximum height, the ball is momentarily at rest (i.e., has zero velocity). The acceleration remains constant, with magnitude equal to the free-fall acceleration $g$ and directed downward. Thus, even though the velocity is momentarily zero, it continues to change, and the ball will begin to gain speed in the downward direction.

(b) The acceleration of the ball remains constant in magnitude and direction throughout the ball's free flight, from the instant it leaves the hand until the instant just before it strikes the ground. The acceleration is directed downward and has a magnitude equal to the freefall acceleration $g$.

**10.** (a) Successive images on the film will be separated by a constant distance if the ball has constant velocity.

(b) Starting at the right-most image, the images will be getting closer together as one moves toward the left.

(c) Starting at the right-most image, the images will be getting farther apart as one moves toward the left.

(d) As one moves from left to right, the balls will first get farther apart in each successive image, then closer together when the ball begins to slow down.

**12.** Once the ball has left the thrower's hand, it is a freely falling body with a constant, nonzero, acceleration of $a = -g$. Since the acceleration of the ball is not zero at any point on its trajectory, choices (a) through (d) are all false and the correct response is (e).

**14.** The initial velocity of the car is $v_0 = 0$ and the velocity at time $t$ is $v$. The constant acceleration is therefore given by

$$a = \frac{\Delta v}{\Delta t} = \frac{v - v_0}{t} = \frac{v - 0}{t} = \frac{v}{t}$$

and the average velocity of the car is

$$\bar{v} = \frac{(v + v_0)}{2} = \frac{(v + 0)}{2} = \frac{v}{2}$$

The distance traveled in time $t$ is $\Delta x = \bar{v}t = vt/2$. In the special case where $a = 0$ (and hence $v = v_0 = 0$), we see that statements (a), (b), (c), and (d) are all correct. However, in the general case ($a \neq 0$, and hence $v \neq 0$) only statements (b) and (c) are true. Statement (e) is not true in either case.

## ANSWERS TO EVEN NUMBERED PROBLEMS

**2.** **(a)** $2 \times 10^4$ mi **(b)** $\Delta x/2R_E = 2.4$

**4.** **(a)** 10.04 m/s **(b)** 7.042 m/s

**6.** **(a)** 5.00 m/s **(b)** 1.25 m/s **(c)** −2.50 m/s

**(d)** −3.33 m/s **(e)** 0

**8.** **(a)** +4.0 m/s **(b)** −0.50 m/s **(c)** −1.0 m/s

**(d)** 0

**10.** **(a)** 2.3 min **(b)** 64 mi

**12.** **(a)** $L/t_1$ **(b)** $-L/t_2$ **(c)** 0

**(d)** $2L/(t_1 + t_2)$

**14.** **(a)** $1.3 \times 10^2$ s **(b)** 13 m

**16.** **(a)** The trailing runner's speed must be greater than that of the leader, and the leader's distance from the finish line must be great enough to give the trailing runner time to make up the deficient distance.

**(b)** $t = d/(v_1 - v_2)$ **(c)** $d_2 = v_2 d/(v_1 - v_2)$

**18.** **(a)** Some data points that can be used to plot the graph are as given below:

| | | | | | | |
|---|---|---|---|---|---|---|
| $x$ (m) | 5.75 | 16.0 | 35.3 | 68.0 | 119 | 192 |
| $t$ (s) | 1.00 | 2.00 | 3.00 | 4.00 | 5.00 | 6.00 |

**(b)** 41.0 m/s, 41.0 m/s, 41.0 m/s

**(c)** 17.0 m/s, much smaller than the instantaneous velocity at $t = 4.00$ s

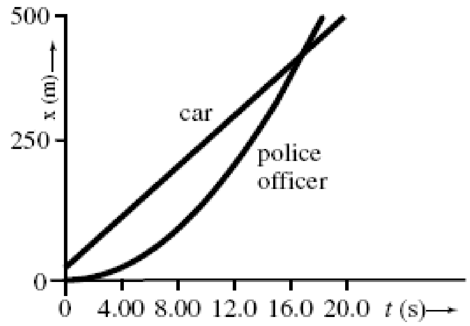
**20.** **(a)** 20.0 m/s, 5.00 m/s **(b)** 263 m

**22.** 0.391 s

**24.** **(i)** (a) 0 (b) $1.6\ \text{m/s}^2$ (c) $0.80\ \text{m/s}^2$

**(ii)** (a) 0 (b) $1.6\ \text{m/s}^2$ (c) 0

**26.** The curves intersect at $t = 16.9$ s.




**28.** $a = 2.74\times10^5\ \text{m/s}^2 = (2.79\times10^4)g$

**30.** **(a)**


**(b)** $v_f^2 = v_i^2 + 2a(\Delta x)$ **(c)** $a = (v_f^2 - v_i^2)/2(\Delta x)$ **(d)** $1.25\ \text{m/s}^2$

**(e)** 8.00 s

**32.** **(a)** 13.5 m **(b)** 13.5 m **(c)** 13.5 m

**(d)** 22.5 m

**34.** **(a)** 20.0 s **(b)** No, it cannot land safely on the 0.800 km runway.

**36.** **(a)** 5.51 km **(b)** $20.8\ \text{m/s}$, $41.6\ \text{m/s}$, $20.8\ \text{m/s}$, $38.7\ \text{m/s}$

**38.** **(a)** 107 m **(b)** $1.49\ \text{m/s}^2$

**40.** **(a)** $v = a_1 t_1$ **(b)** $\Delta x = \frac{1}{2}a_1 t_1^2$

**(c)** $\Delta x_{\text{total}} = \frac{1}{2}a_1 t_1^2 + a_1 t_1 t_2 + \frac{1}{2}a_2 t_2^2$

**42.** 95 m

**44.** 29.1 s

**46.** 1.79 s

**48.** **(a)** Yes. **(b)** $v_{\text{top}} = 3.69\ \text{m/s}$ **(c)** $|\Delta\vec{\mathbf{v}}|_{\text{downward}} = 2.39\ \text{m/s}$

**(d)** No, $|\Delta\vec{\mathbf{v}}|_{\text{upward}} = 3.71\ \text{m/s}$. The two rocks have the same acceleration, but the rock thrown downward has a higher average speed between the two levels, and is accelerated over a smaller time interval.

**50.** **(a)** $21.1\ \text{m/s}$ **(b)** 19.6 m **(c)** $18.1\ \text{m/s}$, $19.6\ \text{m}$

**52.** **(a)** $v = |-v_0 - gt| = |v_0 + gt|$ **(b)** $d = \frac{1}{2}gt^2$

**(c)** $v = |v_0 - gt|$, $d = \frac{1}{2}gt^2$

**54.** **(a)** $29.4 \text{ m/s}$ **(b)** 44.1 m

**56.** **(a)** $-202 \text{ m/s}^2$ **(b)** 198 m

**58.** **(a)** 4.53 s **(b)** $14.1 \text{ m/s}$

**60.** **(a)** $v_i = h/t + gt/2$ **(b)** $v = h/t - gt/2$

**62.** See Solutions Section for Motion Diagrams.

**64.** Yes. The minimum acceleration needed to complete the 1 mile distance in the allotted time is $a_{\min} = 0.032 \text{ m/s}^2$, considerably less than what she is capable of producing.

**66.** **(a)** $y_1 = h - v_0 t - \frac{1}{2}gt^2$, $y_2 = h + v_0 t - \frac{1}{2}gt^2$ **(b)** $t_2 - t_1 = 2v_0/g$

**(c)** $v_{1f} = v_{2f} = -\sqrt{v_0^2 + 2gh}$ **(d)** $y_2 - y_1 = 2v_0 t$ as long as both balls are still in the air.

**68.** $3.10 \text{ m/s}$

**70.** **(a)** 3.00 s **(b)** $v_{0,2} = -15.2 \text{ m/s}$

**(c)** $v_1 = -31.4 \text{ m/s}$, $v_2 = -34.8 \text{ m/s}$

**72.** **(a)** 2.2 s **(b)** $-21 \text{ m/s}$

**74.** **(a)** only if acceleration $= 0$ **(b)** Yes, for all initial velocities and accelerations.

## PROBLEM SOLUTIONS

**2.1** We assume that you are approximately 2 m tall and that the nerve impulse travels at uniform speed. The elapsed time is then

$$\Delta t = \frac{\Delta x}{v} = \frac{2 \text{ m}}{100 \text{ m/s}} = 2\times10^{-2} \text{ s} = \boxed{0.02 \text{ s}}$$

**2.2** (a) At constant speed, $c = 3\times10^8 \text{ m/s}$, the distance light travels in 0.1 s is

$$\Delta x = c(\Delta t) = (3\times10^8 \text{ m/s})(0.1 \text{ s})$$
$$= (3\times10^7 \cancel{\text{m}})\left(\frac{1 \text{ mi}}{1.609 \cancel{\text{km}}}\right)\left(\frac{1 \cancel{\text{km}}}{10^3 \cancel{\text{m}}}\right) = \boxed{2\times10^4 \text{ mi}}$$

(b) Comparing the result of part (a) to the diameter of the Earth, $D_E$, we find

$$\frac{\Delta x}{D_E} = \frac{\Delta x}{2R_E} = \frac{3.0\times10^7 \cancel{\text{m}}}{2(6.38\times10^6 \cancel{\text{m}})} \approx \boxed{2.4} \quad (\text{with } R_E = \text{Earth's radius})$$

**2.3** Distances traveled between pairs of cities are

$$\Delta x_1 = v_1(\Delta t_1) = (80.0 \text{ km/h})(0.500 \text{ h}) = 40.0 \text{ km}$$

$$\Delta x_2 = v_2(\Delta t_2) = (100 \text{ km/h})(0.200 \text{ h}) = 20.0 \text{ km}$$

$$\Delta x_3 = v_3(\Delta t_3) = (40.0 \text{ km/h})(0.750 \text{ h}) = 30.0 \text{ km}$$

Thus, the total distance traveled is $\Delta x = (40.0 + 20.0 + 30.0)\text{ km} = 90.0\text{ km}$, and the elapsed time is $\Delta t = 0.500\text{ h} + 0.200\text{ h} + 0.750\text{ h} + 0.250\text{ h} = 1.70\text{ h}$.

(a) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{90.0\text{ km}}{1.70\text{ h}} = \boxed{52.9\text{ km/h}}$

(b) $\Delta x = \boxed{90.0\text{ km}}$ (see above)

**2.4** (a) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{2.000\times 10^2\text{ m}}{19.92\text{ s}} = \boxed{10.04\text{ m/s}}$

(b) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{1.000\text{ mi}}{228.5\text{ s}}\left(\dfrac{1.609\text{ km}}{1\text{ mi}}\right)\left(\dfrac{10^3\text{ m}}{1\text{ km}}\right) = \boxed{7.042\text{ m/s}}$

**2.5** (a) Boat A requires 1.0 h to cross the lake and 1.0 h to return, total time 2.0 h. Boat B requires 2.0 h to cross the lake at which time the race is over. $\boxed{\text{Boat A wins, being 60 km ahead of B}}$ when the race ends.

(b) Average velocity is the net displacement of the boat divided by the total elapsed time. The winning boat is back where it started, its displacement thus being zero, yielding an average velocity of $\boxed{\text{zero}}$.

**2.6** The average velocity over any time interval is

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

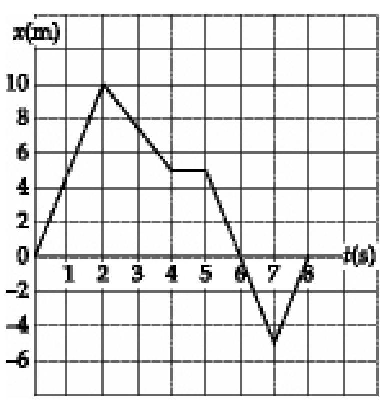
(a) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{10.0\text{ m} - 0}{2.00\text{ s} - 0} = \boxed{5.00\text{ m/s}}$

(b) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{5.00\text{ m} - 0}{4.00\text{ s} - 0} = \boxed{1.25\text{ m/s}}$

(c) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{5.00\text{ m} - 10.0\text{ m}}{4.00\text{ s} - 2.00\text{ s}} = \boxed{-2.50\text{ m/s}}$

(d) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{-5.00\text{ m} - 5.00\text{ m}}{7.00\text{ s} - 4.00\text{ s}} = \boxed{-3.33\text{ m/s}}$

(e) $\bar{v} = \dfrac{\Delta x}{\Delta t} = \dfrac{x_2 - x_1}{t_2 - t_1} = \dfrac{0 - 0}{8.00\text{ s} - 0} = \boxed{0}$




**2.7** (a) $\text{Displacement} = \Delta x = (85.0\text{ km/h})(35.0\text{ min})\left(\dfrac{1\text{ h}}{60.0\text{ min}}\right) + 130\text{ km} = \boxed{180\text{ km}}$

(b) The total elapsed time is $\Delta t = (35.0\text{ min} + 15.0\text{ min})\left(\dfrac{1\text{ h}}{60.0\text{ min}}\right) + 2.00\text{ h} = 2.83\text{ h}$

so, $\bar{v} = \frac{\Delta x}{\Delta t} = \frac{180 \text{ km}}{2.84 \text{ h}} = \boxed{63.6 \text{ km/h}}$

**2.8** The average velocity over any time interval is

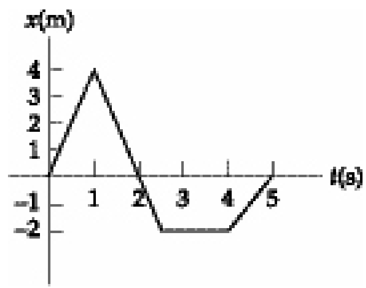
$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

(a) $\bar{v} = \frac{\Delta x}{\Delta t} = \frac{4.0 \text{ m} - 0}{1.0 \text{ s} - 0} = \boxed{+4.0 \text{ m/s}}$

(b) $\bar{v} = \frac{\Delta x}{\Delta t} = \frac{-2.0 \text{ m} - 0}{4.0 \text{ s} - 0} = \boxed{-0.50 \text{ m/s}}$

(c) $\bar{v} = \frac{\Delta x}{\Delta t} = \frac{0 - 4.0 \text{ m}}{5.0 \text{ s} - 1.0 \text{ s}} = \boxed{-1.0 \text{ m/s}}$

(d) $\bar{v} = \frac{\Delta x}{\Delta t} = \frac{0 - 0}{5.0 \text{ s} - 0} = \boxed{0}$




**2.9** The plane starts from rest $(v_0 = 0)$ and maintains a constant acceleration of $a = +1.3 \text{ m/s}^2$. Thus, we find the distance it will travel before reaching the required takeoff speed $(v = 75 \text{ m/s})$, from $v^2 = v_0^2 + 2a(\Delta x)$, as

$$\Delta x = \frac{v^2 - v_0^2}{2a} = \frac{(75 \text{ m/s})^2 - 0}{2(1.3 \text{ m/s}^2)} = 2.2 \times 10^3 \text{ m} = 2.2 \text{ km}$$

Since this distance is less than the length of the runway, $\boxed{\text{the plane takes off safely.}}$

**2.10** (a) The time for a car to make the trip is $t = \frac{\Delta x}{v}$. Thus, the difference in the times for the two cars to complete the same 10 mile trip is

$$\Delta t = t_1 - t_2 = \frac{\Delta x}{v_1} - \frac{\Delta x}{v_2} = \left(\frac{10 \text{ mi}}{55 \text{ mi/h}} - \frac{10 \text{ mi}}{70 \text{ mi/h}}\right)\left(\frac{60 \text{ min}}{1 \text{ h}}\right) = \boxed{2.3 \text{ min}}$$

(b) When the faster car has a 15.0 min lead, it is ahead by a distance equal to that traveled by the slower car in a time of 15.0 min. This distance is given by $\Delta x_1 = v_1(\Delta t) = (55 \text{ mi/h})(15 \text{ min})$.

The faster car pulls ahead of the slower car at a rate of

$$v_{\text{relative}} = 70 \text{ mi/h} - 55 \text{ mi/h} = 15 \text{ mi/h}$$

Thus, the time required for it to get distance $\Delta x_1$ ahead is

$$\Delta t = \frac{\Delta x_1}{v_{\text{relative}}} = \frac{(55 \text{ mi/h})(15 \text{ min})}{15.0 \text{ mi/h}} = 55 \text{ min}$$

Finally, the distance the faster car has traveled during this time is

$$\Delta x_2 = v_2(\Delta t) = (70\ \text{mi/h})(55\ \text{min})\left(\frac{1\ \text{h}}{60\ \text{min}}\right) = \boxed{64\ \text{mi}}$$

**2.11** (a) From $v_f^2 = v_i^2 + 2a(\Delta x)$, with $v_i = 0$, $v_f = 72\ \text{km/h}$, and $\Delta x = 45$ m, the acceleration of the cheetah is found to be

$$a = \frac{v_f^2 - v_i^2}{2(\Delta x)} = \frac{\left[\left(72\ \frac{\text{km}}{\text{h}}\right)\left(\frac{10^3\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3\,600\ \text{s}}\right)\right]^2 - 0}{2(45\ \text{m})} = \boxed{4.4\ \text{m/s}^2}$$

(b) The cheetah's displacement 3.5 s after starting from rest is

$$\Delta x = v_i t + \frac{1}{2}at^2 = 0 + \frac{1}{2}\left(4.4\ \text{m/s}^2\right)(3.5\ \text{s})^2 = \boxed{27\ \text{m}}$$

**2.12** (a) $\bar{v}_1 = \dfrac{(\Delta x)_1}{(\Delta t)_1} = \dfrac{+L}{t_1} = \boxed{+L/t_1}$

(b) $\bar{v}_2 = \dfrac{(\Delta x)_2}{(\Delta t)_2} = \dfrac{-L}{t_2} = \boxed{-L/t_2}$

(c) $\bar{v}_{\text{total}} = \dfrac{(\Delta x)_{\text{total}}}{(\Delta t)_{\text{total}}} = \dfrac{(\Delta x)_1 + (\Delta x)_2}{t_1 + t_2} = \dfrac{+L - L}{t_1 + t_2} = \dfrac{0}{t_1 + t_2} = \boxed{0}$

(d) $(\textit{ave. speed})_{\text{trip}} = \dfrac{\textit{total distance traveled}}{(\Delta t)_{\text{total}}} = \dfrac{|(\Delta x)_1| + |(\Delta x)_2|}{t_1 + t_2} = \dfrac{|+L| + |-L|}{t_1 + t_2} = \boxed{\dfrac{2L}{t_1 + t_2}}$

**2.13** (a) The total time for the trip is $t_{\text{total}} = t_1 + 22.0\ \text{min} = t_1 + 0.367\ \text{h}$, where $t_1$ is the time spent traveling at $v_1 = 89.5\ \text{km/h}$. Thus, the distance traveled is $\Delta x = v_1 t_1 = \bar{v}t_{\text{total}}$, which gives

$$(89.5\ \text{km/h})t_1 = (77.8\ \text{km/h})(t_1 + 0.367\ \text{h}) = (77.8\ \text{km/h})t_1 + 28.5\ \text{km}$$

or, $(89.5\ \text{km/h} - 77.8\ \text{km/h})t_1 = 28.5\ \text{km}$

From which, $t_1 = 2.44\ \text{h}$ for a total time of $t_{\text{total}} = t_1 + 0.367\ \text{h} = \boxed{2.81\ \text{h}}$

(b) The distance traveled during the trip is $\Delta x = v_1 t_1 = \bar{v}t_{\text{total}}$, giving

$$\Delta x = \bar{v}t_{\text{total}} = (77.8\ \text{km/h})(2.81\ \text{h}) = \boxed{219\ \text{km}}$$

**2.14** (a) At the end of the race, the tortoise has been moving for time $t$ and the hare for a time $t - 2.0\ \text{min} = t - 120\ \text{s}$. The speed of the tortoise is $v_t = 0.100\ \text{m/s}$, and the speed of the hare is $v_h = 20v_t = 2.0\ \text{m/s}$. The tortoise travels distance $x_t$, which is 0.20 m larger than the distance $x_h$ traveled by the hare. Hence,

$$x_t = x_h + 0.20\ \text{m}$$

which becomes $v_t t = v_h(t - 120\ \text{s}) + 0.20\ \text{m}$

or $(0.100\ \text{m/s})t = (2.0\ \text{m/s})(t - 120\ \text{s}) + 0.20\ \text{m}$

This gives the time of the race as $t = \boxed{1.3\times 10^2\ \text{s}}$

(b) $x_t = v_t t = (0.100\ \text{m/s})(1.3\times 10^2\ \text{s}) = \boxed{13\ \text{m}}$

**2.15** The maximum allowed time to complete the trip is

$$t_{\text{total}} = \frac{\text{total distance}}{\text{required average speed}} = \frac{1600\text{ m}}{250\text{ km/h}}\left(\frac{1\text{ km/h}}{0.278\text{ m/s}}\right) = 23.0\text{ s}$$

The time spent in the first half of the trip is

$$t_1 = \frac{\text{half distance}}{\bar{v}_1} = \frac{800\text{ m}}{230\text{ km/h}}\left(\frac{1\text{ km/h}}{0.278\text{ m/s}}\right) = 12.5\text{ s}$$

Thus, the maximum time that can be spent on the second half of the trip is

$$t_2 = t_{\text{total}} - t_1 = 23.0\text{ s} - 12.5\text{ s} = 10.5\text{ s}$$

and the required average speed on the second half is

$$\bar{v}_2 = \frac{\text{half distance}}{t_2} = \frac{800\text{ m}}{10.5\text{ s}} = 76.2\text{ m/s}\left(\frac{1\text{ km/h}}{0.278\text{ m/s}}\right) = \boxed{274\text{ km/h}}$$

**2.16** (a) In order for the trailing athlete to be able to catch the leader, his speed ($v_1$) must be greater than that of the leading athlete ($v_2$), and the distance between the leading athlete and the finish line must be great enough to give the trailing athlete sufficient time to make up the deficient distance, *d*.

(b) During a time *t* the leading athlete will travel a distance $d_2 = v_2 t$ and the trailing athlete will travel a distance $d_1 = v_1 t$. Only when $d_1 = d_2 + d$ (where *d* is the initial distance the trailing athlete was behind the leader) will the trailing athlete have caught the leader. Requiring that this condition be satisfied gives the elapsed time required for the second athlete to overtake the first:

$$d_1 = d_2 + d \quad \text{or} \quad v_1 t = v_2 t + d$$

giving $v_1 t - v_2 t = d$ or $t = \boxed{d/(v_1 - v_2)}$

(c) In order for the trailing athlete to be able to at least tie for first place, the initial distance *D* between the leader and the finish line must be greater than or equal to the distance the leader can travel in the time *t* calculated above (i.e., the time required to overtake the leader). That is, we must require that

$$D \geq d_2 = v_2 t = v_2\left[d/(v_1 - v_2)\right] \quad \text{or} \quad \boxed{D \geq \frac{v_2 d}{v_1 - v_2}}$$

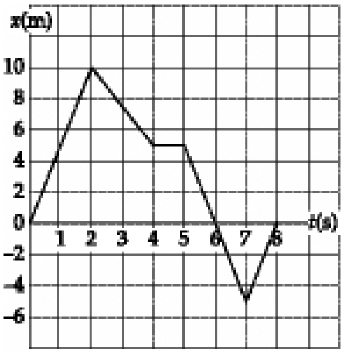
**2.17** The instantaneous velocity at any time is the slope of the *x* vs. *t* graph at that time. We compute this slope by using two points on a straight segment of the curve, one point on each side of the point of interest.

(a) $v_{t=1.00\text{ s}} = \frac{10.0\text{ m} - 0}{2.00\text{ s} - 0} = \boxed{5.00\text{ m/s}}$

(b) $v_{t=3.00\text{ s}} = \frac{(5.00 - 10.0)\text{ m}}{(4.00 - 2.00)\text{ s}} = \boxed{-2.50\text{ m/s}}$

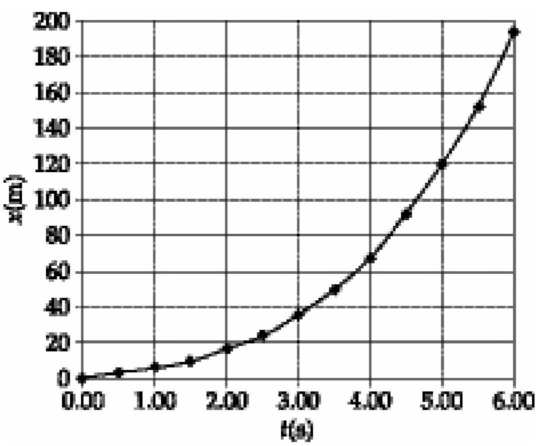
(c) $v_{t=4.50\text{ s}} = \frac{(5.00 - 5.00)\text{ m}}{(5.00 - 4.00)\text{ s}} = \boxed{0}$

(d) $v_{t=7.50\text{ s}} = \frac{0 - (-5.00\text{ m})}{(8.00 - 7.00)\text{ s}} = \boxed{5.00\text{ m/s}}$




**2.18** (a) A few typical values are

| $t$ (s) | $x$ (m) |
|---|---|
| 1.00 | 5.75 |
| 2.00 | 16.0 |
| 3.00 | 35.3 |
| 4.00 | 68.0 |
| 5.00 | 119 |
| 6.00 | 192 |




(b) We will use a 0.400 s interval centered at $t$ = 400 s. We find at $t$ = 3.80 s, $x$ = 60.2 m and at $t$ = 4.20 s, $x$ = 76.6 m. Therefore,

$$v = \frac{\Delta x}{\Delta t} = \frac{16.4\ \text{m}}{0.400\ \text{s}} = \boxed{41.0\ \text{m/s}}$$

Using a time interval of 0.200 s, we find the corresponding values to be: at $t$ = 3.90 s, $x$ = 64.0 m and at $t$ = 4.10 s, $x$ = 72.2 m. Thus,

$$v = \frac{\Delta x}{\Delta t} = \frac{8.20\ \text{m}}{0.200\ \text{s}} = \boxed{41.0\ \text{m/s}}$$

For a time interval of 0.100 s, the values are: at $t$ = 3.95 s, $x$ = 66.0 m, and at $t$ = 4.05 s, $x$ = 70.1 m. Therefore,

$$v = \frac{\Delta x}{\Delta t} = \frac{4.10\ \text{m}}{0.100\ \text{s}} = \boxed{41.0\ \text{m/s}}$$

(c) At $t$ = 4.00 s, $x$ = 68.0 m. Thus, for the first 4.00 s,

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{68.0\ \text{m} - 0}{4.00\ \text{s} - 0} = \boxed{17.0\ \text{m/s}}$$

This value is $\boxed{\text{much less}}$ than the instantaneous velocity at $t$ = 4.00 s.

**2.19** Choose a coordinate axis with the origin at the flagpole and east as the positive direction. Then, using $x = x_0 + v_0 t + \frac{1}{2}at^2$ with $a = 0$ for each runner, the $x$-coordinate of each runner at time $t$ is

$$x_A = -4.0 \text{ mi} + (6.0 \text{ mi/h})t \quad \text{and} \quad x_B = 3.0 \text{ mi} + (-5.0 \text{ mi/h})t$$

When the runners meet, $x_A = x_B$

giving $$-4.0 \text{ mi} + (6.0 \text{ mi/h})t = 3.0 \text{ mi} + (-5.0 \text{ mi/h})t$$

or $(6.0 \text{ mi/h} + 5.0 \text{ mi/h})t = 3.0 \text{ mi} + 4.0 \text{ mi}$

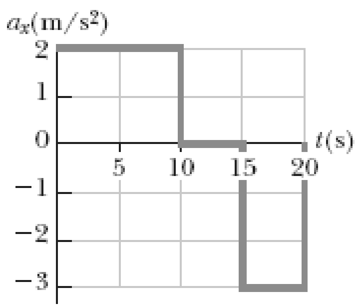
This gives the elapsed time when they meet as $t = (7.0 \text{ mi})/(11.0 \text{ mi/h}) = 0.64 \text{ h}$. At this time,

$x_A = x_B = -0.18 \text{ mi}$. Thus, they meet $\boxed{\text{0.18 mi west of the flagpole}}$.

**2.20** From the figure at the right, observe that the motion of this particle can be broken into three distinct time intervals, during each of which the particle has a constant acceleration. These intervals and the associated accelerations are

$0 \le t < 10.0 \text{ s}, \; a = a_1 = +2.00 \text{ m/s}^2$

$10 \le t < 15.0 \text{ s}, \; a = a_2 = 0$




and $15.0 \le t < 20.0 \text{ s}, \; a = a_3 = -3.00 \text{ m/s}^2$

(a) Applying $v_f = v_i + a(\Delta t)$ to each of the three time intervals gives

for $0 \le t < 10.0$ s, $$v_{10} = v_0 + a_1(\Delta t_1) = 0 + (2.00 \text{ m/s}^2)(10.0 \text{ s}) = \boxed{20.0 \text{ m/s}}$$

for $10.0 \text{ s} \le t < 15.0$ s, $$v_{15} = v_{10} + a_2(\Delta t_2) = 20.0 \text{ m/s} + 0 = 20.0 \text{ m/s}$$

for $15.0 \text{ s} \le t < 20.0$ s, $$v_{20} = v_{15} + a_3(\Delta t_3) = 20.0 \text{ m/s} + (-3.00 \text{ m/s}^2)(5.00 \text{ s}) = \boxed{5.00 \text{ m/s}}$$

(b) Applying $\Delta x = v_i(\Delta t) + \frac{1}{2}a(\Delta t)^2$ to each of the time intervals gives

for $0 \le t < 10.0$ s,

$$\Delta x_1 = v_0 \Delta t_1 + \frac{1}{2}a_1(\Delta t_1)^2 = 0 + \frac{1}{2}(2.00 \text{ m/s}^2)(10.0 \text{ s})^2 = 1.00 \times 10^2 \text{ m}$$

for $10.0 \text{ s} \le t < 15.0$ s,

$$\Delta x_2 = v_{10} \Delta t_2 + \frac{1}{2}a_2(\Delta t_2)^2 = (20.0 \text{ m/s})(5.00 \text{ s}) + 0 = 1.00 \times 10^2 \text{ m}$$

for $15.0 \text{ s} \le t < 20.0$ s,

$$\Delta x_3 = v_{15}\Delta t_3 + \frac{1}{2}a_3(\Delta t_3)^2$$

$$= (20.0\ \text{m/s})(5.00\ \text{s}) + \frac{1}{2}(-3.00\ \text{m/s}^2)(5.00\ \text{s})^2 = 62.5\ \text{m}$$

Thus, the total distance traveled in the first 20.0 s is

$$\Delta x_{\text{total}} = \Delta x_1 + \Delta x_2 + \Delta x_3 = 100\ \text{m} + 100\ \text{m} + 62.5\ \text{m} = \boxed{263\ \text{m}}$$

**2.21** We choose the positive direction to point away from the wall. Then, the initial velocity of the ball is $v_i = -25.0\ \text{m/s}$ and the final velocity is $v_f = +22.0\ \text{m/s}$. If this change in velocity occurs over a time interval of $\Delta t = 3.50\ \text{ms}$ (i.e., the interval during which the ball is in contact with the wall), the average acceleration is

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{\Delta t} = \frac{+22.0\ \text{m/s} - (-25.0\ \text{m/s})}{3.50\times10^{-3}\ \text{s}} = \boxed{1.34\times10^4\ \text{m/s}^2}$$

**2.22** From $a = \Delta v/\Delta t$, the required time is

$$\Delta t = \frac{\Delta v}{a} = \left(\frac{60.0\ \text{mi/h} - 0}{7g}\right)\left(\frac{1g}{9.80\ \text{m/s}^2}\right)\left(\frac{0.447\ \text{m/s}}{1\ \text{mi/h}}\right) = \boxed{0.391\ \text{s}}$$

**2.23** From $a = \dfrac{\Delta v}{\Delta t}$, we have $\Delta t = \dfrac{\Delta v}{a} = \dfrac{(60-55)\ \text{mi/h}}{0.60\ \text{m/s}^2}\left(\dfrac{0.447\ \text{m/s}}{1\ \text{mi/h}}\right) = \boxed{3.7\ \text{s}}$

**2.24** **(i)** (a) From $t = 0$ to $t = 5.0$ s,

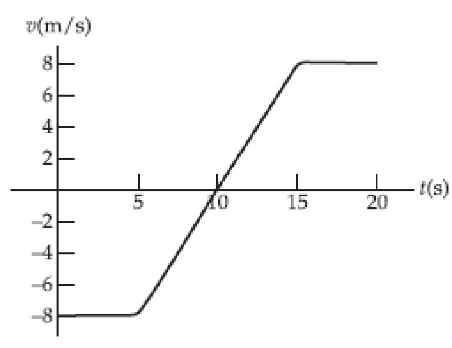
$$\bar{a} = \frac{v_f - v_i}{t_f - t_i} = \frac{-8.0\ \text{m/s} - (-8.0\ \text{m/s})}{5.0\ \text{s} - 0} = \boxed{0}$$

(b) From $t = 5.0$ s to $t = 15$ s,

$$\bar{a} = \frac{8.0\ \text{m/s} - (-8.0\ \text{m/s})}{15\ \text{s} - 5.0\ \text{s}} = \boxed{1.6\ \text{m/s}^2}$$

(c) From $t = 0$ to $t = 20$ s,

$$\bar{a} = \frac{8.0\ \text{m/s} - (-8.0\ \text{m/s})}{20\ \text{s} - 0} = \boxed{0.80\ \text{m/s}^2}$$




**(ii)** At any instant, the instantaneous acceleration equals the slope of the line tangent to the *v* vs. *t* graph at that point in time.

(a) At $t = 2.0$ s, the slope of the tangent line to the curve is $\boxed{0}$.

(b) At $t$ = 10 s, the slope of the tangent line is $\boxed{1.6\ \text{m/s}^2}$.

(c) At $t$ = 18 s, the slope of the tangent line is $\boxed{0}$.

**2.25** (a) $\bar{a} = \dfrac{\Delta v}{\Delta t} = \dfrac{175\ \text{mi/h} - 0}{2.5\ \text{s}} = \boxed{70.0\ \text{mi/h}\cdot\text{s}}$

or $\bar{a} = \left(70.0\ \dfrac{\text{mi}}{\text{h}\cdot\text{s}}\right)\left(\dfrac{1609\ \text{m}}{1\ \text{mi}}\right)\left(\dfrac{1\ \text{h}}{3600\ \text{s}}\right) = \boxed{31.3\ \text{m/s}^2}$

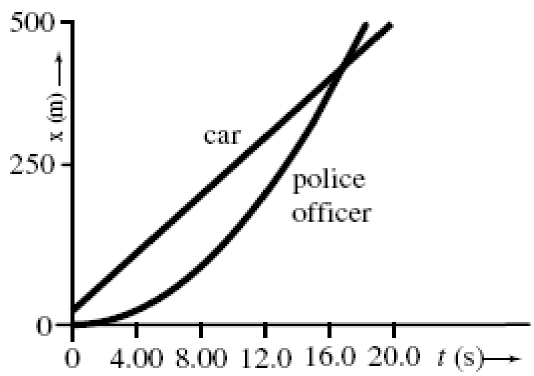
Alternatively, $\bar{a} = \left(31.3\ \dfrac{\text{m}}{s^2}\right)\left(\dfrac{1\ g}{9.80\ \text{m/s}^2}\right) = \boxed{3.19g}$

(b) If the acceleration is constant, $\Delta x = v_0 t + \frac{1}{2}at^2$

$$\Delta x = 0 + \frac{1}{2}\left(31.3\ \frac{\text{m}}{\text{s}^2}\right)(2.50\ \text{s})^2 = \boxed{97.8\ \text{m}}$$

or $\Delta x = (\,97.8\ \text{m}\,)\left(\dfrac{3.281\ \text{ft}}{1\ \text{m}}\right) = \boxed{321\ \text{ft}}$

**2.26** As in the algebraic solution to Example 2.5, we let $t$ represent the time the trooper has been moving.




We graph

$$x_{\text{car}} = 24.0\ \text{m} + (24.0\ \text{m/s})t$$

and

$$x_{\text{trooper}} = (1.50\ \text{m/s}^2)t^2$$

The curves intersect at $t = \boxed{16.9\ \text{s}}$

**2.27** Apply $\Delta x = v_0 + \frac{1}{2}at^2$ to the 2.00-second time interval during which the object moves from $x_i = 3.00$ cm to $x_f = -5.00$ cm. With $v_0 = 12.0$ cm/s, this yields an acceleration of

$$a = \frac{2\left[\left(x_f - x_i\right) - v_0 t\right]}{t^2} = \frac{2\left[(-5.00 - 3.00)\ \text{cm} - (12.0\ \text{cm/s})(2.00\ \text{s})\right]}{(2.00\ \text{s})^2}$$

or $a = \boxed{-16.0\ \text{cm/s}^2}$

**2.28** From $v^2 = v_0^2 + 2a(\Delta x)$, we have $\left(10.97\times10^3 \text{ m/s}\right)^2 = 0 + 2a(220 \text{ m})$ so that

$$a = \frac{v^2 - v_0^2}{2(\Delta x)} = \frac{\left(10.97\times10^3 \text{ m/s}\right)^2 - 0}{2(220 \text{ m})} = \boxed{2.74\times10^5 \text{ m/s}^2}$$

$$= \left(2.74\times10^5 \text{ m/s}^2\right)\left(\frac{1\ g}{9.80 \text{ m/s}^2}\right) = \boxed{2.79\times10^4 \text{ times } g!}$$

**2.29** (a) $\Delta x = \bar{v}(\Delta t) = \left[(v + v_0)/2\right]\Delta t$ becomes

$$40.0 \text{ m} = \left(\frac{2.80 \text{ m/s} + v_0}{2}\right)(8.50 \text{ s})$$

which yields $v_0 = \dfrac{2}{8.50 \text{ s}}(40.0 \text{ m}) - 2.80 \text{ m/s} = \boxed{6.61 \text{ m/s}}$

(b) $a = \dfrac{v - v_0}{\Delta t} = \dfrac{2.80 \text{ m/s} - 6.61 \text{ m/s}}{8.50 \text{ s}} = \boxed{-0.448 \text{ m/s}^2}$

**2.30** (a)


(b) The known quantities are initial velocity, final velocity, and displacement. The kinematics equation that relates these quantities to acceleration is $\boxed{v_f^2 = v_i^2 + 2a(\Delta x)}$

(c) $a = \boxed{\dfrac{v_f^2 - v_i^2}{2(\Delta x)}}$

(d) $a = \dfrac{v_f^2 - v_i^2}{2(\Delta x)} = \dfrac{(30.0 \text{ m/s})^2 - (20.0 \text{ m/s})^2}{2\left(2.00\times10^2 \text{ m}\right)} = \boxed{1.25 \text{ m/s}^2}$

(e) Using $a = \Delta v/\Delta t$, we find that $\Delta t = \dfrac{\Delta v}{a} = \dfrac{v_f - v_i}{a} = \dfrac{30.0 \text{ m/s} - 20.0 \text{ m/s}}{1.25 \text{ m/s}^2} = \boxed{8.00 \text{ s}}$

**2.31** (a) With $v = 120$ km/h, $v^2 = v_0^2 + 2a(\Delta x)$ yields

$$a = \frac{v^2 - v_0^2}{2(\Delta x)} = \frac{\left[(120 \text{ km/h})^2 - 0\right]}{2(240 \text{ m})}\left(\frac{0.278 \text{ m/s}}{1 \text{ km/h}}\right)^2 = \boxed{2.32 \text{ m/s}^2}$$

(b) The required time is $\Delta t = \dfrac{v - v_0}{a} = \dfrac{(120 \text{ km/h} - 0)}{2.32 \text{ m/s}^2}\left(\dfrac{0.278 \text{ m/s}}{1 \text{ km/h}}\right) = \boxed{14.4 \text{ s}}$

**2.32** (a) From $v_f^2 = v_i^2 + 2a(\Delta x)$, with $v_i = 6.00$ m/s and $v_f = 12.0$ m/s, we find

$$\Delta x = \frac{v_f^2 - v_i^2}{2a} = \frac{(12.0 \text{ m/s})^2 - (6.00 \text{ m/s})^2}{2\left(4.00 \text{ m/s}^2\right)} = \boxed{13.5 \text{ m}}$$

(b) In this case, the object moves in the same direction for the entire time interval and the total distance traveled is simply the magnitude or absolute value of the displacement. That is,

$$d = |\Delta x| = \boxed{13.5 \text{ m}}$$

(c) Here, $v_i = -6.00\ \text{m/s}$ and $v_f = 12.0\ \text{m/s}$, and we find

$$\Delta x = \frac{v_f^2 - v_i^2}{2a} = \boxed{13.5\ \text{m}}$$ [the same as in part (a)]

(d) In this case, the object initially slows down as it travels in the negative $x$-direction, stops momentarily, and then gains speed as it begins traveling in the positive $x$-direction. We find the total distance traveled by first finding the displacement during each phase of this motion.

While coming to rest $\left(v_i = -6.00\ \text{m/s},\ v_f = 0\right)$,

$$\Delta x_1 = \frac{v_f^2 - v_i^2}{2a} = \frac{(0)^2 - (-6.00\ \text{m/s})^2}{2\left(4.00\ \text{m/s}^2\right)} = -4.50\ \text{m}$$

After reversing direction $\left(v_i = 0,\ v_f = 12.0\ \text{m/s}\right)$,

$$\Delta x_2 = \frac{v_f^2 - v_i^2}{2a} = \frac{(12.0\ \text{m/s})^2 - (0)^2}{2\left(4.00\ \text{m/s}^2\right)} = 18.0\ \text{m}$$

Note that the net displacement is $\Delta x = \Delta x_1 + \Delta x_2 = -4.50\ \text{m} + 18.0\ \text{m} = 13.5\ \text{m}$, as found in part (c) above. However, the total distance traveled in this case is

$$d = |\Delta x_1| + |\Delta x_2| = |-4.50\ \text{m}| + |18.0\ \text{m}| = \boxed{22.5\ \text{m}}$$

**2.33** (a) $a = \dfrac{v - v_0}{\Delta t} = \dfrac{24.0\ \text{m/s}^2 - 0}{2.95\ \text{s}} = \boxed{8.14\ \text{m/s}^2}$

(b) From $a = \Delta v/\Delta t$, the required time is $\Delta t = \dfrac{v_f - v_i}{a} = \dfrac{20.0\ \text{m/s} - 10.0\ \text{m/s}}{8.14\ \text{m/s}^2} = \boxed{1.23\ \text{s}}$

(c) $\boxed{\text{Yes.}}$ For uniform acceleration, the change in velocity $\Delta v$ generated in time $\Delta t$ is given by $\Delta v = a(\Delta t)$. From this, it is seen that doubling the length of the time interval $\Delta t$ will always double the change in velocity $\Delta v$. A more precise way of stating this is: "When acceleration is constant, velocity is a linear function of time."

**2.34** (a) The time required to stop the plane is $t = \dfrac{v - v_0}{a} = \dfrac{0 - 100\ \text{m/s}}{-5.00\ \text{m/s}^2} = \boxed{20.0\ \text{s}}$

(b) The minimum distance needed to stop is

$$\Delta x = \bar{v}t = \left(\frac{v + v_0}{2}\right)t = \left(\frac{0 + 100\ \text{m/s}}{2}\right)(20.0\ \text{s}) = 1000\ \text{m} = 1.00\ \text{km}$$

Thus, the plane requires a minimum runway length of 1.00 km. $\boxed{\text{It cannot land safely on a 0.800 km runway.}}$

**2.35** We choose $x = 0$ and $t = 0$ at the location of Sue's car when she first spots the van and applies the brakes. Then, the initial conditions for Sue's car are $x_{0S} = 0$ and $v_{0S} = 30.0\ \text{m/s}$. Her constant acceleration for $t \geq 0$ is $a_S = -2.00\ \text{m/s}^2$. The initial conditions for the van are $x_{0V} = 155\ \text{m}$, $v_{0V} = 5.00\ \text{m/s}$, and its constant acceleration is $a_V = 0$. We then use $\Delta x = x - x_0 = v_0 t + \frac{1}{2}at^2$ to write an equation for the $x$-coordinate of each vehicle for $t \geq 0$. This gives

Sue's Car: $x_S - 0 = (30.0\ \text{m/s})t + \dfrac{1}{2}\left(-2.00\ \text{m/s}^2\right)t^2$ or $x_S = (30.0\ \text{m/s})t - \left(1.00\ \text{m/s}^2\right)t^2$

Van: $x_V - 155\ \text{m} = (5.00\ \text{m/s})t + \dfrac{1}{2}(0)t^2$ or $x_V = 155\ \text{m} + (5.00\ \text{m/s})t$

In order for a collision to occur, the two vehicles must be at the same location $(\text{i.e., } x_S = x_V)$. Thus, we test for a collision by equating the two equations for the *x*-coordinates and see if the resulting equation has any real solutions.

$$x_S = x_V \qquad \Rightarrow \qquad (30.0\ \text{m/s})t - (1.00\ \text{m/s}^2)t^2 = 155\ \text{m} + (5.00\ \text{m/s})t$$

$$\text{or} \qquad (1.00\ \text{m/s}^2)t^2 - (25.00\ \text{m/s}) + 155\ \text{m} = 0$$

Using the quadratic formula yields

$$t = \frac{-(-25.00\ \text{m/s}) \pm \sqrt{(-25.00\ \text{m/s})^2 - 4(1.00\ \text{m/s}^2)(155\ \text{m})}}{2(1.00\ \text{m/s}^2)} = 13.6\ \text{s} \quad \text{or} \quad \boxed{11.4\ \text{s}}$$

The solutions are real, not imaginary, so $\boxed{\text{a collision will occur}}$. The smaller of the two solutions is the collision time. (The larger solution tells when the van would pull ahead of the car again if the vehicles could pass harmlessly through each other.) The *x*-coordinate where the collision occurs is given by

$$x_{\text{collision}} = x_S\big|_{t=11.4\ \text{s}} = x_V\big|_{t=11.4\ \text{s}} = 155\ \text{m} + (5.00\ \text{m/s})(11.4\ \text{s}) = \boxed{212\ \text{m}}$$

**2.36** The velocity at the end of the first interval is

$$v = v_0 + at = 0 + (2.77\ \text{m/s})(15.0\ \text{s}) = 41.6\ \text{m/s}$$

This is also the constant velocity during the second interval and the initial velocity for the third interval. Also, note that the duration of the second interval is $t_2 = (2.05\ \text{min})(60.0\ \text{s}/1\ \text{min}) = 123\ \text{s}$.

(a) From $\Delta x = v_0 t + \frac{1}{2}at^2$, the total displacement is

$$(\Delta x)_{\text{total}} = (\Delta x)_1 + (\Delta x)_2 + (\Delta x)_3$$

$$= \left[0 + \frac{1}{2}(2.77\ \text{m/s}^2)(15.0\ \text{s})^2\right] + \left[(41.6\ \text{m/s})(123\ \text{s}) + 0\right]$$

$$+ \left[(41.6\ \text{m/s})(4.39\ \text{s}) + \frac{1}{2}(-9.47\ \text{m/s}^2)(4.39\ \text{s})^2\right]$$

or $(\Delta x)_{\text{total}} = 312\ \text{m} + 5.12\times 10^3\ \text{m} + 91.4\ \text{m} = 5.52\times 10^3\text{m} = \boxed{5.52\ \text{km}}$

(b) $\bar{v}_1 = \dfrac{(\Delta x)_1}{t_1} = \dfrac{312\ \text{m}}{15.0\ \text{s}} = \boxed{20.8\ \text{m/s}}$

$\bar{v}_2 = \dfrac{(\Delta x)_2}{t_2} = \dfrac{5.12\times 10^3\ \text{m}}{123\ \text{s}} = \boxed{41.6\ \text{m/s}}$

$\bar{v}_3 = \dfrac{(\Delta x)_3}{t_3} = \dfrac{91.4\ \text{m}}{4.39\ \text{s}} = \boxed{20.8\ \text{m/s}}$, and the average velocity for the

total trip is $\bar{v}_{\text{total}} = \dfrac{(\Delta x)_{\text{total}}}{t_{\text{total}}} = \dfrac{5.52\times 10^3\ \text{m}}{(15.0+123+4.39)\ \text{s}} = \boxed{38.8\ \text{m/s}}$

**2.37** Using the uniformly accelerated motion equation $\Delta x = v_0 t + \frac{1}{2}at^2$ for the full 40 s interval yields $\Delta x = (20\ \text{m/s})(40\ \text{s}) + \frac{1}{2}(-1.0\ \text{m/s}^2)(40\ \text{s})^2 = 0$, which is obviously wrong. The source of the error is found by computing the time required for the train to come to rest. This time is

$$t = \frac{v - v_0}{a} = \frac{0 - 20\ \text{m/s}}{-1.0\ \text{m/s}^2} = 20\ \text{s}$$

Thus, the train is slowing down for the first 20 s and is at rest for the last 20 s of the 40 s interval.

The acceleration is not constant during the full 40 s. It is, however, constant during the first 20 s as the train slows to rest. Application of $\Delta x = v_0 t + \frac{1}{2}at^2$ to this interval gives the stopping distance as

$$\Delta x = (20\ \text{m/s})(20\ \text{s}) + \frac{1}{2}(-1.0\ \text{m/s}^2)(20\ \text{s})^2 = \boxed{200\ \text{m}}$$

**2.38** $v_0 = 0$ and $v_f = \left(40.0\ \frac{\text{mi}}{\text{h}}\right)\left(\frac{0.447\ \text{m/s}}{1\ \text{mi/h}}\right) = 17.9\ \text{m/s}$

(a) To find the distance traveled, we use

$$\Delta x = \bar{v}t = \left(\frac{v_f + v_0}{2}\right)t = \left(\frac{17.9\ \text{m/s} + 0}{2}\right)(12.0\ \text{s}) = \boxed{107\ \text{m}}$$

(b) The constant acceleration is $a = \frac{v_f - v_0}{t} = \frac{17.9\ \text{m/s} - 0}{12.0\ \text{s}} = \boxed{1.49\ \text{m/s}^2}$

**2.39** At the end of the acceleration period, the velocity is

$$v = v_0 + at_{\text{accel}} = 0 + (1.5\ \text{m/s}^2)(5.0\ \text{s}) = 7.5\ \text{m/s}$$

This is also the initial velocity for the braking period.

(a) After braking, $v_f = v + at_{\text{brake}} = 7.5\ \text{m/s} + (-2.0\ \text{m/s}^2)(3.0\ \text{s}) = \boxed{1.5\ \text{m/s}}$

(b) The total distance traveled is

$$\Delta x_{\text{total}} = (\Delta x)_{\text{accel}} + (\Delta x)_{\text{brake}} = (\bar{v}t)_{\text{accel}} + (\bar{v}t)_{\text{brake}} = \left(\frac{v + v_0}{2}\right)t_{\text{accel}} + \left(\frac{v_f + v}{2}\right)t_{\text{brake}}$$

$$\Delta x_{\text{total}} = \left(\frac{7.5\ \text{m/s} + 0}{2}\right)(5.0\ \text{s}) + \left(\frac{1.5\ \text{m/s} + 7.5\ \text{m/s}}{2}\right)(3.0\ \text{s}) = \boxed{32\ \text{m}}$$

**2.40** For the acceleration period, the parameters for the car are: initial velocity $= v_{ia} = 0$, acceleration $= a_a = a_1$, elapsed time $= (\Delta t)_a = t_1$, and final velocity $= v_{fa}$. For the braking period, the parameters are: initial velocity $= v_{ib} =$ final velocity of acceleration period $= v_{fa}$, acceleration $= a_b = a_2$, and elapsed time $= (\Delta t)_b = t_2$.

(a) To determine the velocity of the car just before the brakes are engaged, we apply $v_f = v_i + a(\Delta t)$ to the acceleration period and find

$$v_{ib} = v_{fa} = v_{ia} + a_a(\Delta t)_a = 0 + a_1 t_1 \quad \text{or} \quad v_{ib} = \boxed{a_1 t_1}$$

(b) We may use $\Delta x = v_i(\Delta t) + \frac{1}{2}a(\Delta t)^2$ to determine the distance traveled during the acceleration period (i.e., before the driver begins to brake). This gives

$$(\Delta x)_a = v_{ia}(\Delta t)_a + \tfrac{1}{2}a_a(\Delta t)_a^2 = 0 + \frac{1}{2}a_1 t_1^2 \quad \text{or} \quad (\Delta x)_a = \boxed{\frac{1}{2}a_1 t_1^2}$$

(c) The displacement occurring during the braking period is

$$(\Delta x)_b = v_{ib}(\Delta t)_b + \tfrac{1}{2}a_b(\Delta t)_b^2 = (a_1 t_1)t_2 + \frac{1}{2}a_2 t_2^2$$

Thus, the total displacement of the car during the two intervals combined is

$$(\Delta x)_{\text{total}} = (\Delta x)_a + (\Delta x)_b = \boxed{\frac{1}{2}a_1t_1^2 + a_1t_1t_2 + \frac{1}{2}a_2t_2^2}$$

**2.41** The time the Thunderbird spends slowing down is

$$\Delta t_1 = \frac{\Delta x_1}{\bar{v}_1} = \frac{2(\Delta x_1)}{v+v_0} = \frac{2(250 \text{ m})}{0+71.5 \text{ m/s}} = 6.99 \text{ s}$$

The time required to regain speed after the pit stop is

$$\Delta t_2 = \frac{\Delta x_2}{\bar{v}_2} = \frac{2(\Delta x_2)}{v+v_0} = \frac{2(350 \text{ m})}{71.5 \text{ m/s}+0} = 9.79 \text{ s}$$

Thus, the total elapsed time before the Thunderbird is back up to speed is

$$\Delta t = \Delta t_1 + 5.00 \text{ s} + \Delta t_2 = 6.99 \text{ s} + 5.00 \text{ s} + 9.79 \text{ s} = 21.8 \text{ s}$$

During this time, the Mercedes has traveled (at constant speed) a distance

$$\Delta x_M = v_0(\Delta t) = (71.5 \text{ m/s})(21.8 \text{ s}) = 1\ 559 \text{ m}$$

and the Thunderbird has fallen behind a distance

$$d = \Delta x_M - \Delta x_1 - \Delta x_2 = 1\ 559 \text{ m} - 250 \text{ m} - 350 \text{ m} = \boxed{959 \text{ m}}$$

**2.42** The car is distance $d$ from the dog and has initial velocity $v_0$ when the brakes are applied, giving it a constant acceleration $a$.

Apply $\bar{v} = \Delta x/\Delta t = (v_f + v_0)/2$ to the entire trip (for which $\Delta x = d + 4.0 \text{ m}$, $\Delta t = 10 \text{ s}$, and $v_f = 0$) ) to obtain

$$\frac{d+4.0 \text{ m}}{10 \text{ s}} = \frac{0+v_0}{2} \qquad \text{or} \qquad v_0 = \frac{d+4.0 \text{ m}}{5.0 \text{ s}} \qquad \textbf{[1]}$$

Then, applying $v_f^2 = v_0^2 + 2a(\Delta x)$ to the entire trip yields $0 = v_0^2 + 2a(d+4.0 \text{ m})$.

Substitute for $v_0$ from Equation [1] to find that

$$0 = \frac{(d+4.0 \text{ m})^2}{25 \text{ s}^2} + 2a(d+4.0 \text{ m}) \qquad \text{and} \qquad a = -\frac{d+4.0 \text{ m}}{50 \text{ s}^2} \qquad \textbf{[2]}$$

Finally, apply $\Delta x = v_0 t + \frac{1}{2}at^2$ to the first 8.0 s of the trip (for which $\Delta x = d$).

This gives $d = v_0(8.0 \text{ s}) + \frac{1}{2}a(64 \text{ s}^2)$ **[3]**

Substitute Equations [1] and [2] into Equation [3] to obtain

$$d = \left(\frac{d+4.0 \text{ m}}{5.0 \text{ s}}\right)(8.0 \text{ s}) + \frac{1}{2}\left(-\frac{d+4.0 \text{ m}}{50 \text{ s}^2}\right)(64 \text{ s}^2) = 0.96d + 3.8 \text{ m}$$

which yields $d = 3.8 \text{ m}/0.04 = \boxed{95 \text{ m}}$

**2.43** (a) Take $t = 0$ at the time when the player starts to chase his opponent. At this time, the opponent is distance $d = (12 \text{ m/s})(3.0 \text{ s}) = 36 \text{ m}$ in front of the player. At time $t > 0$, the displacements of the players from their initial positions are

$$\Delta x_{\text{player}} = (v_0)_{\text{player}} t + \frac{1}{2} a_{\text{player}} t^2 = 0 + \frac{1}{2}(4.0 \text{ m/s}^2) t^2 \quad [1]$$

and $$\Delta x_{\text{opponent}} = (v_0)_{\text{opponent}} t + \frac{1}{2} a_{\text{opponent}} t^2 = (12 \text{ m/s}) t + 0 \quad [2]$$

When the players are side-by-side, $\Delta x_{\text{player}} = \Delta x_{\text{opponent}} + 36 \text{ m}$ [3]

Substituting Equations [1] and [2] into Equation [3] gives

$$\frac{1}{2}(4.0 \text{ m/s}^2) t^2 = (12 \text{ m/s}) t + 36 \text{ m} \qquad \text{or} \qquad t^2 + (-6.0 \text{ s}) t + (-18 \text{ s}^2) = 0$$

Applying the quadratic formula to this result gives

$$t = \frac{-(-6.0 \text{ s}) \pm \sqrt{(-6.0 \text{ s})^2 - 4(1)(-18 \text{ s}^2)}}{2(1)}$$

which has solutions of $t = -2.2$ s and $t = +8.2$ s. Since the time must be greater than zero, we must choose $t = \boxed{8.2 \text{ s}}$ as the proper answer.

(b) $$\Delta x_{\text{player}} = (v_0)_{\text{player}} t + \frac{1}{2} a_{\text{player}} t^2 = 0 + \frac{1}{2}(4.0 \text{ m/s}^2)(8.2 \text{ s})^2 = \boxed{1.3 \times 10^2 \text{ m}}$$

**2.44** The initial velocity of the train is $v_0 = 82.4 \text{ km/h}$ and the final velocity is $v = 16.4 \text{ km/h}$. The time required for the 400 m train to pass the crossing is found from $\Delta x = \bar{v} t = [(v + v_0)/2] t$ as

$$t = \frac{2(\Delta x)}{v + v_0} = \frac{2(0.400 \text{ km})}{(82.4 + 16.4) \text{ km/h}} = (8.10 \times 10^{-3} \text{ h})\left(\frac{3600 \text{ s}}{1 \text{ h}}\right) = \boxed{29.1 \text{ s}}$$

**2.45** (a) From $v^2 = v_0^2 + 2a(\Delta y)$ with $v = 0$, we have

$$(\Delta y)_{\max} = \frac{v^2 - v_0^2}{2a} = \frac{0 - (25.0 \text{ m/s})^2}{2(-9.80 \text{ m/s}^2)} = \boxed{31.9 \text{ m}}$$

(b) The time to reach the highest point is

$$t_{\text{up}} = \frac{v - v_0}{a} = \frac{0 - 25.0 \text{ m/s}}{-9.80 \text{ m/s}^2} = \boxed{2.55 \text{ s}}$$

(c) The time required for the ball to fall 31.9 m, starting from rest, is found from

$$\Delta y = (0)t + \frac{1}{2}at^2 \text{ as } t = \sqrt{\frac{2(\Delta y)}{a}} = \sqrt{\frac{2(-31.9 \text{ m})}{-9.80 \text{ m/s}^2}} = \boxed{2.55 \text{ s}}$$

(d) The velocity of the ball when it returns to the original level (2.55 s after it starts to fall from rest) is

$$v = v_0 + at = 0 + (-9.80 \text{ m/s}^2)(2.55 \text{ s}) = \boxed{-25.0 \text{ m/s}}$$

**2.46** We take upward as the positive $y$-direction and $y = 0$ at the point where the ball is released. Then, $v_{0y} = -8.00 \text{ m/s}$, $a_y = -g = -9.80 \text{ m/s}^2$, and $\Delta y = -30.0 \text{ m}$ when the ball reaches the ground.

From $v_y^2 = v_{0y}^2 + 2a_y(\Delta y)$,, the velocity of the ball just before it hits the ground is

$$v_y = -\sqrt{v_{0y}^2 + 2a_y(\Delta y)} = -\sqrt{(8.00 \text{ m/s})^2 + 2(-9.80 \text{ m/s}^2)(-30.0 \text{ m})} = -25.5 \text{ m/s}$$

Then, $v_y = v_{0y} + a_y t$ gives the elapsed time as

$$t = \frac{v_y - v_{0y}}{a_y} = \frac{-25.5 \text{ m/s} - (-8.00 \text{ m/s})}{-9.80 \text{ m/s}^2} = \boxed{1.79 \text{ s}}$$

**2.47** (a) The velocity of the object when it was 30.0 m above the ground can be determined by applying $\Delta y = v_0 t + \frac{1}{2}at^2$ to the last 1.50 s of the fall. This gives

$$-30.0 \text{ m} = v_0(1.50 \text{ s}) + \frac{1}{2}\left(-9.80 \frac{\text{m}}{\text{s}^2}\right)(1.50 \text{ s})^2 \qquad \text{or} \qquad v_0 = \boxed{-12.7 \text{ m/s}}$$

(b) The displacement the object must have undergone, starting from rest, to achieve this velocity at a point 30.0 m above the ground is given by $v^2 = v_0^2 + 2a(\Delta y)$ as

$$(\Delta y)_1 = \frac{v^2 - v_0^2}{2a} = \frac{(-12.7 \text{ m/s})^2 - 0}{2(-9.80 \text{ m/s}^2)} = -8.23 \text{ m}$$

The total distance the object drops during the fall is then

$$\left|(\Delta y)_{total}\right| = \left|(-8.23 \text{ m}) + (-30.0 \text{ m})\right| = \boxed{38.2 \text{ m}}$$

**2.48** (a) Consider the rock's entire upward flight, for which $v_0 = +7.40 \text{ m/s}$, $v_f = 0$, $a = -g = -9.80 \text{ m/s}^2$, $y_i = 1.55 \text{ m}$ (taking $y = 0$ at ground level), and $y_f = h_{max} = \text{maximum}$ altitude reached b. Then applying $v_f^2 = v_i^2 + 2a(\Delta y)$ to this upward flight gives

$$0 = (7.40 \text{ m/s})^2 + 2(-9.80 \text{ m/s}^2)(h_{max} - 1.55 \text{ m})$$

Solving for the maximum altitude of the rock gives

$$h_{max} = 1.55\ \text{m} + \frac{(7.40\ \text{m/s})^2}{2(9.80\ \text{m/s}^2)} = 4.34\ \text{m}$$

Since $h_{max} > 3.65\ \text{m}$ (height of the wall), $\boxed{\text{the rock does reach the top of the wall}}$.

(b) To find the velocity of the rock when it reaches the top of the wall, we use $v_f^2 = v_i^2 + 2a(\Delta y)$ and solve for $v_f$ when $y_f = 3.65\ \text{m}$ (starting with $v_i = +7.40\ \text{m/s}$ at $y_i = 1.55\ \text{m}$). This yields

$$v_f = \sqrt{v_i^2 + 2a(y_f - y_i)} = \sqrt{(7.40\ \text{m/s})^2 + 2(-9.80\ \text{m/s}^2)(3.65\ \text{m} - 1.55\ \text{m})} = \boxed{3.69\ \text{m/s}}$$

(c) A rock thrown *downward* at a speed of 7.40 m/s $(v_i = -7.40\ \text{m/s})$ from the top of the wall undergoes a displacement of $(\Delta y) = y_f - y_i = 1.55\ \text{m} - 3.65\ \text{m} = -2.10\ \text{m}$ before reaching the level of the attacker. Its velocity when it reaches the attacker is

$$v_f = -\sqrt{v_i^2 + 2a(\Delta y)} = -\sqrt{(-7.40\ \text{m/s})^2 + 2(-9.80\ \text{m/s}^2)(-2.10\ \text{m})} = -9.79\ \text{m/s}$$

so the change in speed of this rock as it goes between the 2 points located at the top of the wall and the attacker is given by

$$\Delta(speed)_{down} = \left||v_f| - |v_i|\right| = \left||-9.79\ \text{m/s}| - |-7.40\ \text{m/s}|\right| = \boxed{2.39\ \text{m/s}}$$

(d) Observe that the change in speed of the ball thrown upward as it went from the attacker to the top of the wall was

$$\Delta(speed)_{up} = \left||v_f| - |v_i|\right| = |3.69\ \text{m/s} - 7.40\ \text{m/s}| = 3.71\ \text{m/s}$$

$\boxed{\text{The two rocks do not undergo the same magnitude speed change.}}$ The rocks have the same acceleration, but the rock thrown downward has a higher average speed between the two levels, and is accelerated over a smaller time interval.

**2.49** The velocity of the child's head just before impact (after falling a distance of 0.40 m, starting from rest) is given by $v^2 = v_0^2 + 2a(\Delta y)$ as

$$v_I = -\sqrt{v_0^2 + 2a(\Delta y)} = -\sqrt{0 + 2(-9.8\ \text{m/s}^2)(-0.40\ \text{m})} = -2.8\ \text{m/s}$$

If, upon impact, the child's head undergoes an additional displacement $\Delta y = -h$ before coming to rest, the acceleration during the impact can be found from $v^2 = v_0^2 + 2a(\Delta y)$ to be $a = (0 - v_I^2)/2(-h) = v_I^2/2h$. The duration of the impact is found from $v = v_0 + at$ as $t = \Delta v/a = -v_I/(v_I^2/2h)$, or $t = -2h/v_I$.

Applying these results to the two cases yields

Hardwood Floor $(h = 2.0\times10^{-3}\ \text{m})$: $a = \dfrac{v_I^2}{2h} = \dfrac{(-2.8\ \text{m/s})^2}{2(2.0\times10^{-3}\ \text{m})} = \boxed{2.0\times10^3\ \text{m/s}^2}$

and $t = \dfrac{-2h}{v_I} = \dfrac{-2\left(2.0\times10^{-3}\ \text{m}\right)}{-2.8\ \text{m/s}} = 1.4\times10^{-3}\ \text{s} = \boxed{1.4\ \text{ms}}$

Carpeted Floor $(h = 1.0\times10^{-2}\ \text{m})$: $a = \dfrac{v_I^2}{2h} = \dfrac{(-2.8\ \text{m/s})^2}{2\left(1.0\times10^{-2}\ \text{m}\right)} = \boxed{3.9\times10^2\ \text{m/s}^2}$

and $t = \dfrac{-2h}{v_I} = \dfrac{-2\left(1.0\times10^{-2}\ \text{m}\right)}{-2.8\ \text{m/s}} = 7.1\times10^{-3}\ \text{s} = \boxed{7.1\ \text{ms}}$

**2.50** (a) After 2.00 s, the velocity of the mailbag is

$$v_{\text{bag}} = v_0 + at = -1.50\ \text{m/s} + \left(-9.80\ \text{m/s}^2\right)(2.00\ \text{s}) = -21.1\ \text{m/s}$$

The negative sign tells us that the bag is moving downward and the magnitude of the velocity gives the speed as $\boxed{21.1\ \text{m/s}}$.

(b) The displacement of the mailbag after 2.00 s is

$$(\Delta y)_{\text{bag}} = \left(\frac{v+v_0}{2}\right)t = \left[\frac{-21.1\ \text{m/s} + (-1.50\ \text{m/s})}{2}\right](2.00\ \text{s}) = -22.6\ \text{m}$$

During this time, the helicopter, moving downward with constant velocity, undergoes a displacement of

$$(\Delta y)_{\text{copter}} = v_0 t + \frac{1}{2}at^2 = (-1.5\ \text{m/s})(2.00\ \text{s}) + 0 = -3.00\ \text{m}$$

The distance separating the package and the helicopter at this time is then

$$d = \left|(\Delta y)_p - (\Delta y)_h\right| = \left|-22.6\ \text{m} - (-3.00\ \text{m})\right| = \left|-19.6\ \text{m}\right| = \boxed{19.6\ \text{m}}$$

(c) Here, $(v_0)_{\text{bag}} = (v_0)_{\text{copter}} = +1.50\ \text{m/s}$ and $a_{bag} = -9.80\ \text{m/s}^2$ while $a_{\text{copter}} = 0$. After 2.00 s, the velocity of the mailbag is

$$v_{\text{bag}} = 1.50\ \frac{\text{m}}{\text{s}} + \left(-9.80\ \frac{\text{m}}{\text{s}^2}\right)(2.00\ \text{s}) = -18.1\ \frac{\text{m}}{\text{s}} \text{ and its speed is } \left|v_{\text{bag}}\right| = \boxed{18.1\ \frac{\text{m}}{\text{s}}}$$

In this case, the displacement of the helicopter during the 2.00 s interval is

$$\Delta y_{\text{copter}} = (+1.50\ \text{m/s})(2.00\ \text{s}) + 0 = +3.00\ \text{m}$$

Meanwhile, the mailbag has a displacement of

$$(\Delta y)_{\text{bag}} = \left(\frac{v_{\text{bag}} + v_0}{2}\right)t = \left[\frac{-18.1\ \text{m/s} + 1.50\ \text{m/s}}{2}\right](2.00\ \text{s}) = -16.6\ \text{m}$$

The distance separating the package and the helicopter at this time is then

$$d = \left|(\Delta y)_p - (\Delta y)_h\right| = \left|-16.6\text{ m} - (+3.00\text{ m})\right| = \left|-19.6\text{ m}\right| = \boxed{19.6\text{ m}}$$

**2.51** (a) From the instant the ball leaves the player's hand until it is caught, the ball is a freely falling body with an acceleration of

$$a = -g = -9.80\ \text{m/s}^2 = \boxed{9.80\ \text{m/s}^2\ \text{(downward)}}$$

(b) At its maximum height, the ball comes to rest momentarily and then begins to fall back downward. Thus,

$$v_{\substack{\text{max}\\\text{height}}} = \boxed{0}.$$

(c) Consider the relation $\Delta y = v_0 t + \frac{1}{2}at^2$ with $a = -g$. When the ball is at the thrower's hand, the displacement is $\Delta y = 0$, giving

$$0 = v_0 t - \tfrac{1}{2}gt^2$$

This equation has two solutions, $t = 0$, which corresponds to when the ball was thrown, and $t = 2v_0/g$, corresponding to when the ball is caught. Therefore, if the ball is caught at $t = 2.00$ s, the initial velocity must have been

$$v_0 = \frac{gt}{2} = \frac{(9.80\ \text{m/s}^2)(2.00\ \text{s})}{2} = \boxed{9.80\ \text{m/s}}$$

(d) From $v^2 = v_0^2 + 2a(\Delta y)$, with $v = 0$ at the maximum height,

$$(\Delta y)_{\text{max}} = \frac{v^2 - v_0^2}{2a} = \frac{0 - (9.80\ \text{m/s})^2}{2(-9.80\ \text{m/s}^2)} = \boxed{4.90\ \text{m}}$$

**2.52** (a) Let $t = 0$ be the instant the package leaves the helicopter, so the package and the helicopter have a common initial velocity of $v_i = -v_0$ (choosing upward as positive).

At times $t > 0$, the velocity of the package (in free-fall with constant acceleration $a_p = -g$) is given by $v = v_i + at$ as $v_p = -v_0 - gt = -(v_0 + gt)$ and $speed = \boxed{\left|v_p\right| = v_0 + gt}$.

(b) After an elapsed time $t$, the downward displacement of the package from its point of release will be

$$(\Delta y)_p = v_i t + \frac{1}{2}a_p t^2 = -v_0 t - \frac{1}{2}gt^2 = -\left(v_0 t + \frac{1}{2}gt^2\right)$$

and the downward displacement of the helicopter (moving with constant velocity, or acceleration $a_h = 0$) from the release point at this time is

$$(\Delta y)_h = v_i t + \frac{1}{2}a_h t^2 = -v_0 t + 0 = -v_0 t$$

The distance separating the package and the helicopter at this time is then

$$d = \left|(\Delta y)_p - (\Delta y)_h\right| = \left|-\left(v_0 t + \frac{1}{2}gt^2\right) - (-v_0 t)\right| = \boxed{\frac{1}{2}gt^2}$$

(c) If the helicopter and package are moving upward at the instant of release, then the common initial velocity is $v_i = +v_0$. The accelerations of the helicopter (moving with constant velocity) and the package (a freely falling object) remain unchanged from the previous case $(a_p = -g \text{ and } a_h = 0)$.

In this case, the package speed at time $t > 0$ is $\left|v_p\right| = \left|v_i + a_p t\right| = \boxed{\left|v_0 - gt\right|}$.

At this time, the displacements from the release point of the package and the helicopter are given by

$$(\Delta y)_p = v_i t + \frac{1}{2}a_p t^2 = v_0 t - \frac{1}{2}gt^2 \quad \text{and} \quad (\Delta y)_h = v_i t + \frac{1}{2}a_h t^2 = v_0 t + 0 = +v_0 t$$

The distance separating the package and helicopter at time $t$ is now given by

$$d = \left|(\Delta y)_p - (\Delta y)_h\right| = \left|v_0 t - \frac{1}{2}gt^2 - v_0 t\right| = \boxed{\frac{1}{2}gt^2} \quad \text{(the same as earlier!)}$$

**2.53** (a) After its engines stop, the rocket is a freely falling body. It continues upward, slowing under the influence of gravity until it comes to rest momentarily at its maximum altitude. Then it falls back to Earth, gaining speed as it falls.

(b) When it reaches a height of 150 m, the speed of the rocket is

$$v = \sqrt{v_0^2 + 2a(\Delta y)} = \sqrt{(50.0 \text{ m/s})^2 + 2(2.00 \text{ m/s}^2)(150 \text{ m})} = 55.7 \text{ m/s}$$

After the engines stop, the rocket continues moving upward with an initial velocity of $v_0 = 55.7$ m/s and acceleration $a = -g = -9.80$ m/s$^2$. When the rocket reaches maximum height, $v = 0$. The displacement of the rocket above the point where the engines stopped (that is, above the 150 m level) is

$$\Delta y = \frac{v^2 - v_0^2}{2a} = \frac{0 - (55.7 \text{ m/s})^2}{2(-9.80 \text{ m/s}^2)} = 158 \text{ m}$$

The maximum height above ground that the rocket reaches is then given by $h_{max} = 150 \text{ m} + 158 \text{ m} = \boxed{308 \text{ m}}$

(c) The total time of the upward motion of the rocket is the sum of two intervals. The first is the time for the rocket to go from $v_0 = 50.0$ m/s at the ground to a velocity of $v = 55.7$ m/s at an altitude of 150 m. This time is given by

$$t_1 = \frac{(\Delta y)_1}{\bar{v}_1} = \frac{(\Delta y)_1}{(v + v_0)/2} = \frac{2(150 \text{ m})}{(55.7 + 50.0) \text{ m/s}} = 2.84 \text{ s}$$

The second interval is the time to rise 158 m starting with $v_0 = 55.7$ m/s and ending with $v = 0$. This time is

$$t_2 = \frac{(\Delta y)_2}{\bar{v}_2} = \frac{(\Delta y)_2}{(v+v_0)/2} = \frac{2(158\text{ m})}{0+55.7\text{ m/s}} = 5.67\text{ s}$$

The total time of the upward flight is then $t_{up} = t_1 + t_2 = (2.84+5.67)\text{ s} = \boxed{8.51\text{ s}}$

(d) The time for the rocket to fall 308 m back to the ground, with $v_0 = 0$ and acceleration $a = -g = -9.80\text{ m/s}^2$, is found from $\Delta y = v_0 t + \frac{1}{2}at^2$ as

$$t_{down} = \sqrt{\frac{2(\Delta y)}{a}} = \sqrt{\frac{2(-308\text{ m})}{-9.80\text{ m/s}^2}} = 7.93\text{ s}$$

so the total time of the flight is $t_{flight} = t_{up} + t_{down} = (8.51+7.93)\text{ s} = \boxed{16.4\text{ s}}$

**2.54** (a) For the upward flight of the ball, we have $v_i = v_0$, $v_f = 0$, $a = -g$, and $\Delta t = 3.00\text{ s}$. Thus, $v_f = v_i + a(\Delta t)$ gives the initial velocity as

$$v_i = v_f - a(\Delta t) = v_f + g(\Delta t) \text{ or } v_0 = 0 + (9.80\text{ m/s}^2)(3.00\text{ s}) = \boxed{+29.4\text{ m/s}}$$

(b) The vertical displacement of the ball during this 3.00-s upward flight is

$$(\Delta y)_{max} = h = \bar{v}(\Delta t) = \left(\frac{v_i + v_f}{2}\right)(\Delta t) = \left(\frac{29.4\text{ m/s}+0}{2}\right)(3.00\text{ s}) = \boxed{44.1\text{ m}}$$

**2.55** During the 0.600 s required for the rig to pass completely onto the bridge, the front bumper of the tractor moves a distance equal to the length of the rig at constant velocity of $v = 100\text{ km/h}$. Therefore the length of the rig is

$$L_{rig} = vt = \left[100\ \frac{\text{km}}{\text{h}}\left(\frac{0.278\text{ m/s}}{1\text{ km/h}}\right)\right](0.600\text{ s}) = 16.7\text{ m}$$

While some part of the rig is on the bridge, the front bumper moves a distance $\Delta x = L_{bridge} + L_{rig} = 400\text{ m} + 16.7\text{ m}$. With a constant velocity of $v = 100\text{ km/h}$, the time for this to occur is

$$t = \frac{L_{bridge} + L_{rig}}{v} = \frac{400\text{ m} + 16.7\text{ m}}{100\text{ km/h}}\left(\frac{1\text{ km/h}}{0.278\text{ m/s}}\right) = \boxed{15.0\text{ s}}$$

**2.56** (a) The acceleration experienced as he came to rest is given by $v = v_0 + at$ as

$$a = \frac{v - v_0}{t} = \frac{0 - \left(632\ \frac{\text{mi}}{\text{h}}\right)\left(\frac{0.447\text{ m/s}}{1\text{ mi/h}}\right)}{1.40\text{ s}} = \boxed{-202\text{ m/s}^2}$$

(b) The distance traveled while stopping is found from

$$\Delta x = \overline{v}t = \left(\frac{v+v_0}{2}\right)t = \frac{\left[0+\left(632\ \frac{\text{mi}}{\text{h}}\right)\left(\frac{0.447\ \text{m/s}}{1\ \text{mi/h}}\right)\right]}{2}(1.40\ \text{s}) = \boxed{198\ \text{m}}$$

**2.57** (a) The acceleration of the bullet is

$$a = \frac{v^2 - v_0^2}{2(\Delta x)} = \frac{(300\ \text{m/s})^2 - (400\ \text{m/s})^2}{2(0.100\ \text{m})} = \boxed{-3.50\times10^5\ \text{m/s}^2}$$

(b) The time of contact with the board is

$$t = \frac{v - v_0}{a} = \frac{(300-400)\ \text{m/s}}{-3.50\times10^5\ \text{m/s}^2} = \boxed{2.86\times10^{-4}\ \text{s}}$$

**2.58** (a) From $\Delta x = v_0 t + \frac{1}{2}at^2$, we have

$$100\ \text{m} = (30.0\ \text{m/s})t + \frac{1}{2}(-3.50\ \text{m/s}^2)t^2$$

This reduces to $3.50t^2 + (-60.0\ \text{s})t + (200\ \text{s}^2) = 0$, and the quadratic formula gives

$$t = \frac{-(-60.0\ \text{s}) \pm \sqrt{(-60.0\ \text{s})^2 - 4(3.50)(200\ \text{s}^2)}}{2(3.50)}$$

The desired time is the smaller solution of $t = \boxed{4.53\ \text{s}}$. The larger solution of $t$ = 12.6 s is the time when the boat would pass the buoy moving backwards, assuming it maintained a constant acceleration.

(b) The velocity of the boat when it first reaches the buoy is

$$v = v_0 + at = 30.0\ \text{m/s} + (-3.50\ \text{m/s}^2)(4.53\ \text{s}) = \boxed{14.1\ \text{m/s}}$$

**2.59** (a) The keys have acceleration $a = -g = -9.80\ \text{m/s}^2$ from the release point until they are caught 1.50 s later. Thus, $\Delta y = v_0 t + \frac{1}{2}at^2$ gives

$$v_0 = \frac{\Delta y - at^2/2}{t} = \frac{(+4.00\ \text{m}) - (-9.80\ \text{m/s}^2)(1.50\ \text{s})^2/2}{1.50\ \text{s}} = +10.0\ \text{m/s}$$

or $v_0 = \boxed{10.0\ \text{m/s upward}}$

(b) The velocity of the keys just before the catch was

$$v = v_0 + at = 10.0\ \text{m/s} + \left(-9.80\ \text{m/s}^2\right)(1.50\ \text{s}) = -4.70\ \text{m/s}$$

or $v = \boxed{4.70\ \text{m/s downward}}$

**2.60** (a) The keys, moving freely under the influence of gravity $(a = -g)$, undergo a vertical displacement of $\Delta y = +h$ in time $t$. We use $\Delta y = v_i t + \frac{1}{2}at^2$ to find the initial velocity as

$$h = v_i t + \frac{1}{2}(-g)t^2 \qquad \text{giving} \qquad v_i = \frac{h + gt^2/2}{t} = \boxed{\frac{h}{t} + \frac{gt}{2}}$$

(b) The velocity of the keys just before they were caught (at time $t$) is given by $v = v_i + at$ as

$$v = \left(\frac{h}{t} + \frac{gt}{2}\right) + (-g)t = \frac{h}{t} + \frac{gt}{2} - gt = \boxed{\frac{h}{t} - \frac{gt}{2}}$$

**2.61** (a) From $v^2 = v_0^2 + 2a(\Delta y)$, the insect's velocity after straightening its legs is

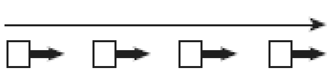
$$v = \sqrt{v_0^2 + 2a(\Delta y)} = \sqrt{0 + 2\left(4\,000\ \text{m/s}^2\right)\left(2.0\times10^{-3}\ \text{m}\right)} = \boxed{4.0\ \text{m/s}}$$

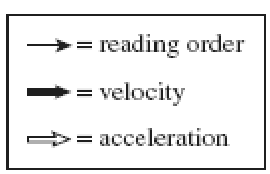
(b) The time to reach this velocity is

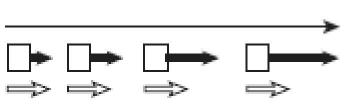
$$t = \frac{v - v_0}{a} = \frac{4.0\ \text{m/s} - 0}{4\,000\ \text{m/s}^2} = 1.0\times10^{-3}\ \text{s} = \boxed{1.0\ \text{ms}}$$

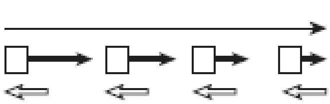
(c) The upward displacement of the insect between when its feet leave the ground and it comes to rest momentarily at maximum altitude is

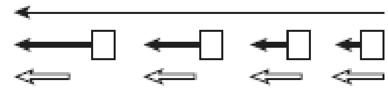
$$\Delta y = \frac{v^2 - v_0^2}{2a} = \frac{0 - v_0^2}{2(-g)} = \frac{-(4.0\ \text{m/s})^2}{2\left(-9.8\ \text{m/s}^2\right)} = \boxed{0.82\ \text{m}}$$

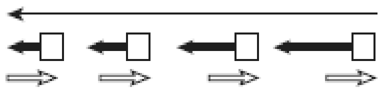
**2.62** (a) 




(b) 

(c) 

(d) 

(e) 

(f) If the speed did not change at a constant rate, the drawings would have less regularity than those given above.

**2.63** The falling ball moves a distance of $(15\text{ m}-h)$ before they meet, where $h$ is the height above the ground where they meet. Apply $\Delta y = v_0 t + \frac{1}{2}at^2$, with $a=-g$, to obtain

$$-(15\text{ m}-h)=0-\frac{1}{2}gt^2 \qquad \text{or} \qquad h=15\text{ m}-\frac{1}{2}gt^2 \qquad [1]$$

Applying $\Delta y = v_0 t + \dfrac{1}{2}at^2$ to the rising ball gives

$$h=(25\text{ m/s})t-\frac{1}{2}gt^2 \qquad [2]$$

Combining Equations [1] and [2] gives

$$(25\text{ m/s})t-\cancel{\frac{1}{2}gt^2}=15\text{ m}-\cancel{\frac{1}{2}gt^2}$$

or $$t=\frac{15\text{ m}}{25\text{ m/s}}=\boxed{0.60\text{ s}}$$

**2.64** The constant speed the student has maintained for the first 10 minutes, and hence her initial speed for the final 500 yard dash, is

$$v_0=\frac{\Delta x_{10}}{\Delta t}=\frac{1.0\text{ mi}-500\text{ yards}}{10\text{ min}}=\frac{(5280\text{ ft}-1500\text{ ft})}{600\text{ s}}\left(\frac{1\text{ m}}{3.281\text{ ft}}\right)=1.9\text{ m/s}$$

With an initial speed of $v_0=1.9\text{ m/s}$, the minimum constant acceleration that would be needed to complete the last 500 yards $(1\,500\text{ ft})$ in the remaining 2.0 min (120 s) of her allotted time is found from $\Delta x = v_i t + \frac{1}{2}at^2$ as

$$a_{\min}=\frac{2[\Delta x - v_0 t]}{t^2}=\frac{2[(1\,500\text{ ft})(1\text{ m}/3.281\text{ ft})-(1.9\text{ m/s})(120\text{ s})]}{(120\text{ s})^2}=0.032\text{ m/s}^2$$

Since this acceleration is considerably smaller than the acceleration of $0.15\text{ m/s}^2$ that she is capable of producing, she should be able to $\boxed{\text{easily meet the requirement}}$ of running 1.0 mile in 12 minutes.

**2.65** Once the gymnast's feet leave the ground, she is a freely falling body with constant acceleration $a=-g=-9.80\text{ m/s}^2$. Starting with an initial upward velocity of $v_0=2.80\text{ m/s}$, the vertical displacement of the gymnast's center of mass from its starting point is given as a function of time by $\Delta y = v_0 t + \frac{1}{2}at^2$.

(a) At $t=0.100\text{ s}$, $\Delta y=(2.80\text{ m/s})(0.100\text{ s})-(4.90\text{ m/s}^2)(0.100\text{ s})^2=\boxed{0.231\text{ m}}$

(b) At $t = 0.200$ s, $\Delta y = (2.80\ \text{m/s})(0.200\ \text{s}) - (4.90\ \text{m/s}^2)(0.200\ \text{s})^2 = \boxed{0.364\ \text{m}}$

(c) At $t = 0.300$ s, $\Delta y = (2.80\ \text{m/s})(0.300\ \text{s}) - (4.90\ \text{m/s}^2)(0.300\ \text{s})^2 = \boxed{0.399\ \text{m}}$

(d) At $t = 0.500$ s, $\Delta y = (2.80\ \text{m/s})(0.500\ \text{s}) - (4.90\ \text{m/s}^2)(0.500\ \text{s})^2 = \boxed{0.175\ \text{m}}$

**2.66** (a) While in the air, both balls have acceleration $a_1 = a_2 = -g$ (where upward is taken as positive). Ball 1 (thrown downward) has initial velocity $v_{01} = -v_0$, while ball 2 (thrown upward) has initial velocity $v_{02} = +v_0$. Taking $y = 0$ at ground level, the initial $y$-coordinate of each ball is $y_{01} = y_{02} = +h$. Applying $\Delta y = y - y_i = v_i t + \frac{1}{2}at^2$ to each ball gives their $y$-coordinates at time $t$ as:

Ball 1: $y_1 - h = -v_0 t + \frac{1}{2}(-g)t^2$ or $\boxed{y_1 = h - v_0 t - \frac{1}{2}gt^2}$

Ball 2: $y_2 - h = +v_0 t + \frac{1}{2}(-g)t^2$ or $\boxed{y_2 = h + v_0 t - \frac{1}{2}gt^2}$

(b) At ground level, $y = 0$. Thus, we equate each of the equations found above to zero and use the quadratic formula to solve for the times when each ball reaches the ground. This gives:

Ball 1: $0 = h - v_0 t_1 - \frac{1}{2}gt_1^2 \quad \rightarrow \quad gt_1^2 + (2v_0)t_1 + (-2h) = 0$

$$\text{so} \quad t_1 = \frac{-2v_0 \pm \sqrt{(2v_0)^2 - 4(g)(-2h)}}{2g} = -\frac{v_0}{g} \pm \sqrt{\left(\frac{v_0}{g}\right)^2 + \frac{2h}{g}}$$

Using only the *positive* solution gives $t_1 = -\frac{v_0}{g} + \sqrt{\left(\frac{v_0}{g}\right)^2 + \frac{2h}{g}}$

Ball 2: $0 = h + v_0 t_2 - \frac{1}{2}gt_2^2 \quad \rightarrow \quad gt_2^2 + (-2v_0)t_2 + (-2h) = 0$

$$\text{and} \quad t_2 = \frac{-(-2v_0) \pm \sqrt{(-2v_0)^2 - 4(g)(-2h)}}{2g} = +\frac{v_0}{g} \pm \sqrt{\left(\frac{v_0}{g}\right)^2 + \frac{2h}{g}}$$

Again, using only the *positive* solution $t_2 = \frac{v_0}{g} + \sqrt{\left(\frac{v_0}{g}\right)^2 + \frac{2h}{g}}$

Thus, the difference in the times of flight of the two balls is

$$\Delta t = t_2 - t_1 = \frac{v_0}{g} + \sqrt{\left(\frac{v_0}{g}\right)^2 + \frac{2h}{g}} - \left(-\frac{v_0}{g} + \sqrt{\left(\frac{v_0}{g}\right)^2 + \frac{2h}{g}}\right) = \boxed{\frac{2v_0}{g}}$$

(c) Realizing that the balls are going *downward* $(v < 0)$ as they near the ground, we use $v_f^2 = v_i^2 + 2a(\Delta y)$ with $\Delta y = -h$ to find the velocity of each ball just before it strikes the ground:

Ball 1: $v_{1f} = -\sqrt{v_{1i}^2 + 2a_1(-h)} = -\sqrt{(-v_0)^2 + 2(-g)(-h)} = \boxed{-\sqrt{v_0^2 + 2gh}}$

Ball 2: $v_{2f} = -\sqrt{v_{2i}^2 + 2a_2(-h)} = -\sqrt{(+v_0)^2 + 2(-g)(-h)} = \boxed{-\sqrt{v_0^2 + 2gh}}$

(d) While both balls are still in the air, the distance separating them is

$$d = y_2 - y_1 = \left(h + v_0 t - \frac{1}{2}gt^2\right) - \left(h - v_0 t - \frac{1}{2}gt^2\right) = \boxed{2v_0 t}$$

**2.67** (a) The first ball is dropped from rest $(v_{01} = 0)$ from the height $h$ of the window. Thus, $v_f^2 = v_0^2 + 2a(\Delta y)$ gives the speed of this ball as it reaches the ground (and hence the initial velocity of the second ball) as $|v_f| = \sqrt{v_{01}^2 + 2a_1(\Delta y_1)} = \sqrt{0 + 2(-g)(-h)} = \sqrt{2gh}$.

When ball 2 is thrown upward at the same time that ball 1 is dropped, their $y$-coordinates at time $t$ during the flights are given by $y - y_o = v_0 t + \frac{1}{2}at^2$ as:

Ball 1: $y_1 - h = (0)t + \frac{1}{2}(-g)t^2$ or $y_1 = h - \frac{1}{2}gt^2$

Ball 2: $y_2 - 0 = \left(\sqrt{2gh}\right)t + \frac{1}{2}(-g)t^2$ or $y_2 = \left(\sqrt{2gh}\right)t - \frac{1}{2}gt^2$

When the two balls pass, $y_1 = y_2$, or $h - \cancel{\frac{1}{2}gt^2} = \left(\sqrt{2gh}\right)t - \cancel{\frac{1}{2}gt^2}$

giving $t = \dfrac{h}{\sqrt{2gh}} = \sqrt{\dfrac{h}{2g}} = \sqrt{\dfrac{28.7\text{ m}}{2(9.80\text{ m/s}^2)}} = \boxed{1.21\text{ s}}$

(b) When the balls meet,

$$t = \sqrt{\frac{h}{2g}} \quad \text{and} \quad y_1 = h - \frac{1}{2}g\left(\sqrt{\frac{h}{2g}}\right)^2 = h - \frac{h}{4} = \frac{3h}{4}$$

Thus, the distance below the window where this event occurs is

$$d = h - y_1 = h - \frac{3h}{4} = \frac{h}{4} = \frac{28.7\text{ m}}{4} = \boxed{7.18\text{ m}}$$

**2.68** We do not know either the initial velocity or the final velocity (that is, velocity just before impact) for the truck. What we do know is that the truck skids 62.4 m in 4.20 s while accelerating at $-5.60\text{ m/s}^2$.

We have $v = v_0 + at$ and $\Delta x = \bar{v}t = [(v + v_0)/2]t$. Applied to the motion of the truck, these yield

$$v - v_0 = at = (-5.60\text{ m/s}^2)(4.20\text{ s}) \quad \text{or} \quad v - v_0 = -23.5\text{ m/s} \qquad \textbf{[1]}$$

and

$$v + v_0 = \frac{2(\Delta x)}{t} = \frac{2(62.4\text{ m})}{4.20\text{ s}} \quad \text{or} \quad v + v_0 = 29.7\text{ m/s} \qquad \textbf{[2]}$$

Adding Equations [1] and [2] gives the velocity just before impact as

$$2v = (-23.5 + 29.7)\text{ m/s} \quad \text{or} \quad v = \boxed{3.10\text{ m/s}}$$

**2.69** When released from rest $(v_0 = 0)$, the bill falls freely with a downward acceleration due to gravity $(a = -g = -9.80\text{ m/s}^2)$. Thus, the magnitude of its downward displacement during David's 0.2 s reaction time will be

$$|\Delta y| = \left|v_0 t + \frac{1}{2}at^2\right| = \left|0 + \frac{1}{2}(-9.80\text{ m/s}^2)(0.2\text{ s})^2\right| = 0.2\text{ m} = 20\text{ cm}$$

This is over twice the distance from the center of the bill to its top edge $(\approx 8\text{ cm})$, so $\boxed{\text{David will be unsuccessful}}$.

**2.70** (a) The velocity with which the first stone hits the water is

$$v_1 = -\sqrt{v_{01}^2 + 2a(\Delta y)} = -\sqrt{\left(-2.00\ \frac{\text{m}}{\text{s}}\right)^2 + 2\left(-9.80\ \frac{\text{m}}{\text{s}^2}\right)(-50.0\ \text{m})} = -31.4\ \frac{\text{m}}{\text{s}}$$

The time for this stone to hit the water is

$$t_1 = \frac{v_1 - v_{01}}{a} = \frac{[-31.4\ \text{m/s} - (-2.00\ \text{m/s})]}{-9.80\ \text{m/s}^2} = \boxed{3.00\ \text{s}}$$

(b) Since they hit simultaneously, the second stone, which is released 1.00 s later, will hit the water after an flight time of 2.00 s. Thus,

$$v_{02} = \frac{\Delta y - a t_2^2/2}{t_2} = \frac{-50.0\ \text{m} - (-9.80\ \text{m/s}^2)(2.00\ \text{s})^2/2}{2.00\ \text{s}} = \boxed{-15.2\ \text{m/s}}$$

(c) From part (a), the final velocity of the first stone is $v_1 = \boxed{-31.4\ \text{m/s}}$.

The final velocity of the second stone is

$$v_2 = v_{02} + a t_2 = -15.2\ \text{m/s} + (-9.80\ \text{m/s}^2)(2.00\ \text{s}) = \boxed{-34.8\ \text{m/s}}$$

**2.71** (a) The sled's displacement, $\Delta x_1$, after accelerating at $a_1 = +40\ \text{ft/s}^2$ for time $t_1$, is

$$\Delta x_1 = (0)t_1 + \tfrac{1}{2}a_1 t_1^2 = (20\ \text{ft/s}^2)t_1^2 \quad \text{or} \quad \Delta x_1 = (20\ \text{ft/s}^2)t_1^2 \qquad \textbf{[1]}$$

At the end of time $t_1$, the sled had achieved a velocity of

$$v = v_0 + a_1 t_1 = 0 + (40\ \text{ft/s}^2)t_1 \quad \text{or} \quad v = (40\ \text{ft/s}^2)t_1 \qquad \textbf{[2]}$$

The displacement of the sled while moving at constant velocity $v$ for time $t_2$ is

$$\Delta x_2 = v t_2 = \left[(40\ \text{ft/s}^2)t_1\right]t_2 \quad \text{or} \quad \Delta x_2 = (40\ \text{ft/s}^2)t_1 t_2 \qquad \textbf{[3]}$$

It is known that $\Delta x_1 + \Delta x_2 = 17\ 500\ \text{ft}$, and substitutions from Equations [1] and [3] give

$$(20\ \text{ft/s}^2)t_1^2 + (40\ \text{ft/s}^2)t_1 t_2 = 17\ 500\ \text{ft} \quad \text{or} \quad t_1^2 + 2t_1 t_2 = 875\ \text{s}^2 \qquad \textbf{[4]}$$

Also, it is known that $t_1 + t_2 = 90\ \text{s}$ **[5]**

Solving Equations [4] and [5] simultaneously yields

$$t_1^2 + 2t_1(90\ \text{s} - t_1) = 875\ \text{s}^2 \quad \text{or} \quad t_1^2 + (-180\ \text{s})t_1 + 875\ \text{s}^2 = 0$$

The quadratic formula then gives $t_1 = \dfrac{-(-180\ \text{s}) \pm \sqrt{(-180\ \text{s})^2 - 4(1)(875\ \text{s}^2)}}{2(1)}$

with solutions $t_1 = 5.00\ \text{s}$ $(\text{and } t_2 = 90\ \text{s} - 5.0\ \text{s} = 85\ \text{s})$ or $t_1 = 175\ \text{s}$ $(\text{and } t_2 = -85\ \text{s})$

Since it is necessary that $t_2 > 0$, the valid solutions are $\boxed{t_1 = 5.0\ \text{s and } t_2 = 85\ \text{s}}$.

(b) From Equation [2] above, $v = (40\ \text{ft/s}^2)t_1 = (40\ \text{ft/s}^2)(5.0\ \text{s}) = \boxed{200\ \text{ft/s}}$

(c) The displacement $\Delta x_3$ of the sled as it comes to rest (with acceleration $a_3 = -20\ \text{ft/s}^2$) is

$$\Delta x_3 = \frac{0 - v^2}{2a_3} = \frac{-(200 \text{ ft/s})^2}{2(-20 \text{ ft/s}^2)} = 1\,000 \text{ ft}$$

Thus, the total displacement for the trip (measured from the starting point) is

$$\Delta x_{\text{total}} = (\Delta x_1 + \Delta x_2) + \Delta x_3 = 17\,500 \text{ ft} + 1\,000 \text{ ft} = \boxed{18\,500 \text{ ft}}$$

(d) The time required to come to rest from velocity υ (with acceleration $a_3$) is

$$t_3 = \frac{0 - v}{a_3} = \frac{-200 \text{ ft/s}}{-20 \text{ ft/s}^2} = \boxed{10 \text{ s}}$$

so the duration of the entire trip is

$$t_{\text{total}} = t_1 + t_2 + t_3 = 5.0 \text{ s} + 85 \text{ s} + 10 \text{ s} = \boxed{100 \text{ s}}$$

**2.72** (a) From $\Delta y = v_0 t + \frac{1}{2}at^2$ with $v_0 = 0$, we have

$$t = \sqrt{\frac{2(\Delta y)}{a}} = \sqrt{\frac{2(-23 \text{ m})}{-9.80 \text{ m/s}^2}} = \boxed{2.2 \text{ s}}$$

(b) The final velocity is $v = 0 + (-9.80 \text{ m/s}^2)(2.2\text{s}) = -22 \text{ m/s}$

(c) The time it takes for the sound of the impact to reach the spectator is

$$t_{\text{sound}} = \frac{\Delta y}{v_{\text{sound}}} = \frac{23 \text{ m}}{340 \text{ m/s}} = 6.8 \times 10^{-2} \text{ s}$$

so the total elapsed time is $t_{\text{total}} = 2.2 \text{ s} + 6.8 \times 10^{-2} \text{ s} \approx \boxed{2.3 \text{ s}}$.

**2.73** (a) Since the sound has constant velocity, the distance it traveled is

$$\Delta x = v_{\text{sound}}\, t = (1\,100 \text{ ft/s})(5.0 \text{ s}) = \boxed{5.5 \times 10^3 \text{ ft}}$$

(b) The plane travels this distance in a time of $5.0 \text{ s} + 10 \text{ s} = 15 \text{ s}$, so its velocity must be

$$v_{\text{plane}} = \frac{\Delta x}{t} = \frac{5.5 \times 10^3 \text{ ft}}{15 \text{ s}} = \boxed{3.7 \times 10^2 \text{ ft/s}}$$

(c) The time the light took to reach the observer was

$$t_{\text{light}} = \frac{\Delta x}{v_{\text{light}}} = \frac{5.5 \times 10^3 \text{ ft}}{3.00 \times 10^8 \text{ m/s}} \left( \frac{1 \text{ m/s}}{3.281 \text{ ft/s}} \right) = 5.6 \times 10^{-6} \text{ s}$$

| During this time the plane would only travel a distance of 0.002 ft. |
|---|

**2.74** The distance the glider moves during the time $\Delta t_d$ is given by $\Delta x = \ell = v_0(\Delta t_d) + \frac{1}{2}a(\Delta t_d)^2$, where $v_0$ is the glider's velocity when the flag first enters the photogate and $a$ is the glider's acceleration. Thus, the average velocity is

$$v_d = \frac{\ell}{\Delta t_d} = \frac{v_0(\Delta t_d) + \frac{1}{2}a(\Delta t_d)^2}{\Delta t_d} = v_0 + \frac{1}{2}a(\Delta t_d)$$

(a) The glider's velocity when it is halfway through the photogate in space (i.e., when $\Delta x = \ell/2$) is found from $v^2 = v_0^2 + 2a(\Delta x)$ as

$$v_1 = \sqrt{v_0^2 + 2a(\ell/2)} = \sqrt{v_0^2 + a\ell} = \sqrt{v_0^2 + a\left[v_d(\Delta t_d)\right]} = \sqrt{v_0^2 + av_d(\Delta t_d)}$$

Note that this is $\boxed{\text{not equal to } v_d \text{ unless } a = 0}$, in which case $v_1 = v_d = v_0$.

(b) The speed $v_2$ when the glider is halfway through the photogate in time (i.e., when the elapsed time is $t_2 = \Delta t_d/2$) is given by $v = v_0 + at$ as

$$v = v_0 + at_2 = v_0 + a(\Delta t_d/2) = v_0 + \frac{1}{2}a(\Delta t_d)$$

which $\boxed{\text{is equal to } v_d}$ for all possible values of $v_0$ and $a$.

**2.75** The time required for the stuntman to fall 3.00 m, starting from rest, is found from $\Delta y = v_0 t + \frac{1}{2}at^2$ as

$$-3.00 \text{ m} = 0 + \frac{1}{2}(-9.80 \text{ m/s}^2)t^2 \quad \text{so} \quad t = \sqrt{\frac{2(3.00 \text{ m})}{9.80 \text{ m/s}^2}} = 0.782 \text{ s}$$

(a) With the horse moving with constant velocity of $10.0 \text{ m/s}$, the horizontal distance is

$$\Delta x = v_{\text{horse}} t = (10.0 \text{ m/s})(0.782 \text{ s}) = \boxed{7.82 \text{ m}}$$

(b) The required time is $t = \boxed{0.782 \text{ s}}$ as calculated above.