

## Chapter 1

1. **THINK** In this problem we're given the radius of Earth, and asked to compute its circumference, surface area and volume.

**EXPRESS** Assuming Earth to be a sphere of radius

$$R_E = (6.37 \times 10^6 \text{ m})(10^{-3} \text{ km/m}) = 6.37 \times 10^3 \text{ km},$$

the corresponding circumference, surface area and volume are:

$$C = 2\pi R_E, \quad A = 4\pi R_E^2, \quad V = \frac{4\pi}{3} R_E^3.$$

The geometric formulas are given in Appendix E.

**ANALYZE** (a) Using the formulas given above, we find the circumference to be

$$C = 2\pi R_E = 2\pi(6.37 \times 10^3 \text{ km}) = 4.00 \times 10^4 \text{ km}.$$

(b) Similarly, the surface area of Earth is

$$A = 4\pi R_E^2 = 4\pi(6.37 \times 10^3 \text{ km})^2 = 5.10 \times 10^8 \text{ km}^2,$$

(c) and its volume is

$$V = \frac{4\pi}{3} R_E^3 = \frac{4\pi}{3} (6.37 \times 10^3 \text{ km})^3 = 1.08 \times 10^{12} \text{ km}^3.$$

**LEARN** From the formulas given, we see that  $C \sim R_E$ ,  $A \sim R_E^2$ , and  $V \sim R_E^3$ . The ratios of volume to surface area, and surface area to circumference are  $V/A = R_E/3$  and  $A/C = 2R_E$ .

2. The conversion factors are: 1 gry = 1/10 line, 1 line = 1/12 inch and 1 point = 1/72 inch. The factors imply that

$$1 \text{ gry} = (1/10)(1/12)(72 \text{ points}) = 0.60 \text{ point}.$$

Thus,  $1 \text{ gry}^2 = (0.60 \text{ point})^2 = 0.36 \text{ point}^2$ , which means that  $0.50 \text{ gry}^2 = 0.18 \text{ point}^2$ .

3. The metric prefixes (micro, pico, nano, ...) are given for ready reference on the inside front cover of the textbook (see also Table 1-2).

(a) Since  $1 \text{ km} = 1 \times 10^3 \text{ m}$  and  $1 \text{ m} = 1 \times 10^6 \mu\text{m}$ ,

$$1 \text{ km} = 10^3 \text{ m} = (10^3 \text{ m})(10^6 \mu\text{m/m}) = 10^9 \mu\text{m}.$$

The given measurement is  $1.0 \text{ km}$  (two significant figures), which implies our result should be written as  $1.0 \times 10^9 \mu\text{m}$ .

(b) We calculate the number of microns in 1 centimeter. Since  $1 \text{ cm} = 10^{-2} \text{ m}$ ,

$$1 \text{ cm} = 10^{-2} \text{ m} = (10^{-2} \text{ m})(10^6 \mu\text{m/m}) = 10^4 \mu\text{m}.$$

We conclude that the fraction of one centimeter equal to  $1.0 \mu\text{m}$  is  $1.0 \times 10^{-4}$ .

(c) Since  $1 \text{ yd} = (3 \text{ ft})(0.3048 \text{ m/ft}) = 0.9144 \text{ m}$ ,

$$1.0 \text{ yd} = (0.91 \text{ m})(10^6 \mu\text{m/m}) = 9.1 \times 10^5 \mu\text{m}.$$

4. (a) Using the conversion factors  $1 \text{ inch} = 2.54 \text{ cm}$  exactly and  $6 \text{ picas} = 1 \text{ inch}$ , we obtain

$$0.80 \text{ cm} = (0.80 \text{ cm}) \left( \frac{1 \text{ inch}}{2.54 \text{ cm}} \right) \left( \frac{6 \text{ picas}}{1 \text{ inch}} \right) \approx 1.9 \text{ picas}.$$

(b) With  $12 \text{ points} = 1 \text{ pica}$ , we have

$$0.80 \text{ cm} = (0.80 \text{ cm}) \left( \frac{1 \text{ inch}}{2.54 \text{ cm}} \right) \left( \frac{6 \text{ picas}}{1 \text{ inch}} \right) \left( \frac{12 \text{ points}}{1 \text{ pica}} \right) \approx 23 \text{ points}.$$

5. **THINK** This problem deals with conversion of furlongs to rods and chains, all of which are units for distance.

**EXPRESS** Given that  $1 \text{ furlong} = 201.168 \text{ m}$ ,  $1 \text{ rod} = 5.0292 \text{ m}$  and  $1 \text{ chain} = 20.117 \text{ m}$ , the relevant conversion factors are

$$1.0 \text{ furlong} = 201.168 \text{ m} = (201.168 \cancel{\text{m}}) \frac{1 \text{ rod}}{5.0292 \cancel{\text{m}}} = 40 \text{ rods},$$

and

$$1.0 \text{ furlong} = 201.168 \text{ m} = (201.168 \cancel{\text{m}}) \frac{1 \text{ chain}}{20.117 \cancel{\text{m}}} = 10 \text{ chains}.$$

Note the cancellation of  $\text{m}$  (meters), the unwanted unit.

**ANALYZE** Using the above conversion factors, we find

(a) the distance  $d$  in *rods* to be  $d = 4.0 \text{ furlongs} = (4.0 \text{ furlongs}) \frac{40 \text{ rods}}{1 \text{ furlong}} = 160 \text{ rods}$ ,

(b) and in *chains* to be  $d = 4.0 \text{ furlongs} = (4.0 \text{ furlongs}) \frac{10 \text{ chains}}{1 \text{ furlong}} = 40 \text{ chains}$ .

**LEARN** Since 4 furlongs is about 800 m, this distance is approximately equal to 160 rods (1 rod  $\approx$  5 m) and 40 chains (1 chain  $\approx$  20 m). So our results make sense.

6. We make use of Table 1-6.

(a) We look at the first (“cahiz”) column: 1 fanega is equivalent to what amount of cahiz? We note from the already completed part of the table that 1 cahiz equals a dozen fanega. Thus,  $1 \text{ fanega} = \frac{1}{12} \text{ cahiz}$ , or  $8.33 \times 10^{-2} \text{ cahiz}$ . Similarly, “1 cahiz = 48 cuartilla” (in the already completed part) implies that  $1 \text{ cuartilla} = \frac{1}{48} \text{ cahiz}$ , or  $2.08 \times 10^{-2} \text{ cahiz}$ . Continuing in this way, the remaining entries in the first column are  $6.94 \times 10^{-3}$  and  $3.47 \times 10^{-3}$ .

(b) In the second (“fanega”) column, we find 0.250,  $8.33 \times 10^{-2}$ , and  $4.17 \times 10^{-2}$  for the last three entries.

(c) In the third (“cuartilla”) column, we obtain 0.333 and 0.167 for the last two entries.

(d) Finally, in the fourth (“almude”) column, we get  $\frac{1}{2} = 0.500$  for the last entry.

(e) Since the conversion table indicates that 1 almude is equivalent to 2 medios, our amount of 7.00 almudes must be equal to 14.0 medios.

(f) Using the value ( $1 \text{ almude} = 6.94 \times 10^{-3} \text{ cahiz}$ ) found in part (a), we conclude that 7.00 almudes is equivalent to  $4.86 \times 10^{-2} \text{ cahiz}$ .

(g) Since each decimeter is 0.1 meter, then 55.501 cubic decimeters is equal to 0.055501  $\text{m}^3$  or 55501  $\text{cm}^3$ . Thus,  $7.00 \text{ almudes} = \frac{7.00}{12} \text{ fanega} = \frac{7.00}{12} (55501 \text{ cm}^3) = 3.24 \times 10^4 \text{ cm}^3$ .

7. We use the conversion factors found in Appendix D.

$$1 \text{ acre} \cdot \text{ft} = (43,560 \text{ ft}^2) \cdot \text{ft} = 43,560 \text{ ft}^3$$

Since 2 in. = (1/6) ft, the volume of water that fell during the storm is

$$V = (26 \text{ km}^2)(1/6 \text{ ft}) = (26 \text{ km}^2)(3281 \text{ ft/km})^2(1/6 \text{ ft}) = 4.66 \times 10^7 \text{ ft}^3.$$

Thus,

$$V = \frac{4.66 \times 10^7 \text{ ft}^3}{4.3560 \times 10^4 \text{ ft}^3/\text{acre} \cdot \text{ft}} = 1.1 \times 10^3 \text{ acre} \cdot \text{ft}.$$

8. From Fig. 1-4, we see that 212 S is equivalent to 258 W and  $212 - 32 = 180$  S is equivalent to  $216 - 60 = 156$  Z. The information allows us to convert S to W or Z.

(a) In units of W, we have

$$50.0 \text{ S} = (50.0 \text{ S}) \left( \frac{258 \text{ W}}{212 \text{ S}} \right) = 60.8 \text{ W}$$

(b) In units of Z, we have

$$50.0 \text{ S} = (50.0 \text{ S}) \left( \frac{156 \text{ Z}}{180 \text{ S}} \right) = 43.3 \text{ Z}$$

9. The volume of ice is given by the product of the semicircular surface area and the thickness. The area of the semicircle is  $A = \pi r^2/2$ , where  $r$  is the radius. Therefore, the volume is

$$V = \frac{\pi}{2} r^2 z$$

where  $z$  is the ice thickness. Since there are  $10^3$  m in 1 km and  $10^2$  cm in 1 m, we have

$$r = (2000 \text{ km}) \left( \frac{10^3 \text{ m}}{1 \text{ km}} \right) \left( \frac{10^2 \text{ cm}}{1 \text{ m}} \right) = 2000 \times 10^5 \text{ cm}.$$

In these units, the thickness becomes

$$z = 3000 \text{ m} = (3000 \text{ m}) \left( \frac{10^2 \text{ cm}}{1 \text{ m}} \right) = 3000 \times 10^2 \text{ cm}$$

which yields  $V = \frac{\pi}{2} (2000 \times 10^5 \text{ cm})^2 (3000 \times 10^2 \text{ cm}) = 1.9 \times 10^{22} \text{ cm}^3$ .

10. Since a change of longitude equal to  $360^\circ$  corresponds to a 24 hour change, then one expects to change longitude by  $360^\circ/24=15^\circ$  before resetting one's watch by 1.0 h.

11. (a) Presuming that a French decimal day is equivalent to a regular day, then the ratio of weeks is simply  $10/7$  or (to 3 significant figures) 1.43.

(b) In a regular day, there are 86400 seconds, but in the French system described in the problem, there would be  $10^5$  seconds. The ratio is therefore 0.864.

12. A day is equivalent to 86400 seconds and a meter is equivalent to a million micrometers, so

$$\frac{(3.7 \text{ m})(10^6 \mu\text{m/m})}{(14 \text{ day})(86400 \text{ s/day})} = 3.1 \mu\text{m/s}.$$

13. The time on any of these clocks is a straight-line function of that on another, with slopes  $\neq 1$  and y-intercepts  $\neq 0$ . From the data in the figure we deduce

$$t_C = \frac{2}{7}t_B + \frac{594}{7}, \quad t_B = \frac{33}{40}t_A - \frac{662}{5}.$$

These are used in obtaining the following results.

(a) We find

$$t'_B - t_B = \frac{33}{40}(t'_A - t_A) = 495 \text{ s}$$

when  $t'_A - t_A = 600 \text{ s}$ .

(b) We obtain  $t'_C - t_C = \frac{2}{7}(t'_B - t_B) = \frac{2}{7}(495) = 141 \text{ s}$ .

(c) Clock  $B$  reads  $t_B = (33/40)(400) - (662/5) \approx 198 \text{ s}$  when clock  $A$  reads  $t_A = 400 \text{ s}$ .

(d) From  $t_C = 15 = (2/7)t_B + (594/7)$ , we get  $t_B \approx -245 \text{ s}$ .

14. The metric prefixes (micro ( $\mu$ ), pico, nano, ...) are given for ready reference on the inside front cover of the textbook (also Table 1-2).

$$(a) 1 \mu\text{century} = (10^{-6} \text{ century}) \left( \frac{100 \text{ y}}{1 \text{ century}} \right) \left( \frac{365 \text{ day}}{1 \text{ y}} \right) \left( \frac{24 \text{ h}}{1 \text{ day}} \right) \left( \frac{60 \text{ min}}{1 \text{ h}} \right) = 52.6 \text{ min}.$$

(b) The percent difference is therefore

$$\frac{52.6 \text{ min} - 50 \text{ min}}{52.6 \text{ min}} = 4.9\%.$$

15. A week is 7 days, each of which has 24 hours, and an hour is equivalent to 3600 seconds. Thus, two weeks (a fortnight) is 1209600 s. By definition of the micro prefix, this is roughly  $1.21 \times 10^{12} \mu\text{s}$ .

16. We denote the pulsar rotation rate  $f$  (for frequency).

$$f = \frac{1 \text{ rotation}}{1.55780644887275 \times 10^{-3} \text{ s}}$$

(a) Multiplying  $f$  by the time-interval  $t = 7.00$  days (which is equivalent to 604800 s, if we ignore *significant figure* considerations for a moment), we obtain the number of rotations:

$$N = \left( \frac{1 \text{ rotation}}{1.55780644887275 \times 10^{-3} \text{ s}} \right) (604800 \text{ s}) = 388238218.4$$

which should now be rounded to  $3.88 \times 10^8$  rotations since the time-interval was specified in the problem to three significant figures.

(b) We note that the problem specifies the *exact* number of pulsar revolutions (one million). In this case, our unknown is  $t$ , and an equation similar to the one we set up in part (a) takes the form  $N = ft$ , or

$$1 \times 10^6 = \left( \frac{1 \text{ rotation}}{1.55780644887275 \times 10^{-3} \text{ s}} \right) t$$

which yields the result  $t = 1557.80644887275$  s (though students who do this calculation on their calculator might not obtain those last several digits).

(c) Careful reading of the problem shows that the time-uncertainty *per revolution* is  $\pm 3 \times 10^{-17}$  s. We therefore expect that as a result of one million revolutions, the uncertainty should be  $(\pm 3 \times 10^{-17})(1 \times 10^6) = \pm 3 \times 10^{-11}$  s.

**17. THINK** In this problem we are asked to rank 5 clocks, based on their performance as timekeepers.

**EXPRESS** We first note that none of the clocks advance by exactly 24 h in a 24-h period but this is not the most important criterion for judging their quality for measuring time intervals. What is important here is that the clock advance by the same (or nearly the same) amount in each 24-h period. The clock reading can then easily be adjusted to give the correct interval.

**ANALYZE** The chart below gives the corrections (in seconds) that must be applied to the reading on each clock for each 24-h period. The entries were determined by subtracting the clock reading at the end of the interval from the clock reading at the beginning.

Clocks C and D are both good timekeepers in the sense that each is consistent in its daily drift (relative to WWF time); thus, C and D are easily made “perfect” with simple and predictable corrections. The correction for clock C is less than the correction for clock D, so we judge clock C to be the best and clock D to be the next best. The correction that must be applied to clock A is in the range from 15 s to 17s. For clock B it is the range from  $-5$  s to  $+10$  s, for clock E it is in the range from  $-70$  s to  $-2$  s. After C and D, A has

the smallest range of correction, B has the next smallest range, and E has the greatest range. From best to worst, the ranking of the clocks is C, D, A, B, E.

CLOCK	Sun. -Mon.	Mon. -Tues.	Tues. -Wed.	Wed. -Thurs.	Thurs. -Fri.	Fri. -Sat.
A	-16	-16	-15	-17	-15	-15
B	-3	+5	-10	+5	+6	-7
C	-58	-58	-58	-58	-58	-58
D	+67	+67	+67	+67	+67	+67
E	+70	+55	+2	+20	+10	+10

**LEARN** Of the five clocks, the readings in clocks A, B and E jump around from one 24-h period to another, making it difficult to correct them.

18. The last day of the 20 centuries is longer than the first day by

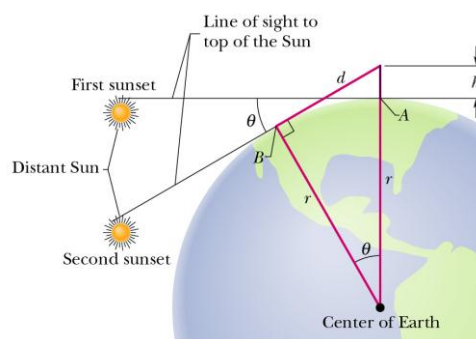
$$(20 \text{ century}) (0.001 \text{ s/century}) = 0.02 \text{ s.}$$

The average day during the 20 centuries is  $(0 + 0.02)/2 = 0.01 \text{ s}$  longer than the first day. Since the increase occurs uniformly, the cumulative effect  $T$  is

$$\begin{aligned} T &= (\text{average increase in length of a day})(\text{number of days}) \\ &= \left( \frac{0.01 \text{ s}}{\text{day}} \right) \left( \frac{365.25 \text{ day}}{\text{y}} \right) (2000 \text{ y}) \\ &= 7305 \text{ s} \end{aligned}$$

or roughly two hours.

19. When the Sun first disappears while lying down, your line of sight to the top of the Sun is tangent to the Earth's surface at point A shown in the figure. As you stand, elevating your eyes by a height  $h$ , the line of sight to the Sun is tangent to the Earth's surface at point B.



Let  $d$  be the distance from point B to your eyes. From the Pythagorean theorem, we have

$$d^2 + r^2 = (r+h)^2 = r^2 + 2rh + h^2$$

or  $d^2 = 2rh + h^2$ , where  $r$  is the radius of the Earth. Since  $r \gg h$ , the second term can be dropped, leading to  $d^2 \approx 2rh$ . Now the angle between the two radii to the two tangent points  $A$  and  $B$  is  $\theta$ , which is also the angle through which the Sun moves about Earth during the time interval  $t = 11.1$  s. The value of  $\theta$  can be obtained by using

$$\frac{\theta}{360^\circ} = \frac{t}{24 \text{ h}}.$$

This yields

$$\theta = \frac{(360^\circ)(11.1 \text{ s})}{(24 \text{ h})(60 \text{ min/h})(60 \text{ s/min})} = 0.04625^\circ.$$

Using  $d = r \tan \theta$ , we have  $d^2 = r^2 \tan^2 \theta = 2rh$ , or

$$r = \frac{2h}{\tan^2 \theta}$$

Using the above value for  $\theta$  and  $h = 1.7$  m, we have  $r = 5.2 \times 10^6$  m.

20. (a) We find the volume in cubic centimeters

$$193 \text{ gal} = (193 \text{ gal}) \left( \frac{231 \text{ in}^3}{1 \text{ gal}} \right) \left( \frac{2.54 \text{ cm}}{1 \text{ in}} \right)^3 = 7.31 \times 10^5 \text{ cm}^3$$

and subtract this from  $1 \times 10^6 \text{ cm}^3$  to obtain  $2.69 \times 10^5 \text{ cm}^3$ . The conversion  $\text{gal} \rightarrow \text{in}^3$  is given in Appendix D (immediately below the table of Volume conversions).

(b) The volume found in part (a) is converted (by dividing by  $(100 \text{ cm/m})^3$ ) to  $0.731 \text{ m}^3$ , which corresponds to a mass of

$$(1000 \text{ kg/m}^3) (0.731 \text{ m}^3) = 731 \text{ kg}$$

using the density given in the problem statement. At a rate of  $0.0018 \text{ kg/min}$ , this can be filled in

$$\frac{731 \text{ kg}}{0.0018 \text{ kg/min}} = 4.06 \times 10^5 \text{ min} = 0.77 \text{ y}$$

after dividing by the number of minutes in a year  $(365 \text{ days})(24 \text{ h/day})(60 \text{ min/h})$ .

21. If  $M_E$  is the mass of Earth,  $m$  is the average mass of an atom in Earth, and  $N$  is the number of atoms, then  $M_E = Nm$  or  $N = M_E/m$ . We convert mass  $m$  to kilograms using Appendix D ( $1 \text{ u} = 1.661 \times 10^{-27} \text{ kg}$ ). Thus,



$$N = \frac{M_E}{m} = \frac{5.98 \times 10^{24} \text{ kg}}{(40 \text{ u})(1.661 \times 10^{-27} \text{ kg/u})} = 9.0 \times 10^{49}.$$

22. The density of gold is

$$\rho = \frac{m}{V} = \frac{19.32 \text{ g}}{1 \text{ cm}^3} = 19.32 \text{ g/cm}^3.$$

(a) We take the volume of the leaf to be its area  $A$  multiplied by its thickness  $z$ . With density  $\rho = 19.32 \text{ g/cm}^3$  and mass  $m = 27.63 \text{ g}$ , the volume of the leaf is found to be

$$V = \frac{m}{\rho} = 1.430 \text{ cm}^3.$$

We convert the volume to SI units:

$$V = (1.430 \text{ cm}^3) \left( \frac{1 \text{ m}}{100 \text{ cm}} \right)^3 = 1.430 \times 10^{-6} \text{ m}^3.$$

Since  $V = Az$  with  $z = 1 \times 10^{-6} \text{ m}$  (metric prefixes can be found in Table 1–2), we obtain

$$A = \frac{1.430 \times 10^{-6} \text{ m}^3}{1 \times 10^{-6} \text{ m}} = 1.430 \text{ m}^2.$$

(b) The volume of a cylinder of length  $\ell$  is  $V = A\ell$  where the cross-section area is that of a circle:  $A = \pi r^2$ . Therefore, with  $r = 2.500 \times 10^{-6} \text{ m}$  and  $V = 1.430 \times 10^{-6} \text{ m}^3$ , we obtain

$$\ell = \frac{V}{\pi r^2} = 7.284 \times 10^4 \text{ m} = 72.84 \text{ km}.$$

23. **THINK** This problem consists of two parts: in the first part, we are asked to find the mass of water, given its volume and density; the second part deals with the mass flow rate of water, which is expressed as kg/s in SI units.

**EXPRESS** From the definition of density:  $\rho = m/V$ , we see that mass can be calculated as  $m = \rho V$ , the product of the volume of water and its density. With  $1 \text{ g} = 1 \times 10^{-3} \text{ kg}$  and  $1 \text{ cm}^3 = (1 \times 10^{-2} \text{ m})^3 = 1 \times 10^{-6} \text{ m}^3$ , the density of water in SI units ( $\text{kg/m}^3$ ) is

$$\rho = 1 \text{ g/cm}^3 = \left( \frac{1 \text{ g}}{\text{cm}^3} \right) \left( \frac{10^{-3} \text{ kg}}{\text{g}} \right) \left( \frac{\text{cm}^3}{10^{-6} \text{ m}^3} \right) = 1 \times 10^3 \text{ kg/m}^3.$$

To obtain the flow rate, we simply divide the total mass of the water by the time taken to drain it.

**ANALYZE** (a) Using  $m = \rho V$ , the mass of a cubic meter of water is

$$m = \rho V = (1 \times 10^3 \text{ kg/m}^3)(1 \text{ m}^3) = 1000 \text{ kg}.$$

(b) The total mass of water in the container is

$$M = \rho V = (1 \times 10^3 \text{ kg/m}^3)(5700 \text{ m}^3) = 5.70 \times 10^6 \text{ kg},$$

and the time elapsed is  $t = (10 \text{ h})(3600 \text{ s/h}) = 3.6 \times 10^4 \text{ s}$ . Thus, the mass flow rate  $R$  is

$$R = \frac{M}{t} = \frac{5.70 \times 10^6 \text{ kg}}{3.6 \times 10^4 \text{ s}} = 158 \text{ kg/s}.$$

**LEARN** In terms of volume, the drain rate can be expressed as

$$R' = \frac{V}{t} = \frac{5700 \text{ m}^3}{3.6 \times 10^4 \text{ s}} = 0.158 \text{ m}^3/\text{s} \approx 42 \text{ gal/s}.$$

The greater the flow rate, the less time required to drain a given amount of water.

24. The metric prefixes (micro ( $\mu$ ), pico, nano, ...) are given for ready reference on the inside front cover of the textbook (see also Table 1–2). The surface area  $A$  of each grain of sand of radius  $r = 50 \text{ } \mu\text{m} = 50 \times 10^{-6} \text{ m}$  is given by  $A = 4\pi(50 \times 10^{-6})^2 = 3.14 \times 10^{-8} \text{ m}^2$  (Appendix E contains a variety of geometry formulas). We introduce the notion of density,  $\rho = m/V$ , so that the mass can be found from  $m = \rho V$ , where  $\rho = 2600 \text{ kg/m}^3$ . Thus, using  $V = 4\pi r^3/3$ , the mass of each grain is

$$m = \rho V = \rho \left( \frac{4\pi r^3}{3} \right) = \left( 2600 \frac{\text{kg}}{\text{m}^3} \right) \frac{4\pi (50 \times 10^{-6} \text{ m})^3}{3} = 1.36 \times 10^{-9} \text{ kg}.$$

We observe that (because a cube has six equal faces) the indicated surface area is  $6 \text{ m}^2$ . The number of spheres (the grains of sand)  $N$  that have a total surface area of  $6 \text{ m}^2$  is given by

$$N = \frac{6 \text{ m}^2}{3.14 \times 10^{-8} \text{ m}^2} = 1.91 \times 10^8.$$

Therefore, the total mass  $M$  is  $M = Nm = (1.91 \times 10^8) (1.36 \times 10^{-9} \text{ kg}) = 0.260 \text{ kg}$ .

25. The volume of the section is  $(2500 \text{ m})(800 \text{ m})(2.0 \text{ m}) = 4.0 \times 10^6 \text{ m}^3$ . Letting “ $d$ ” stand for the thickness of the mud after it has (uniformly) distributed in the valley, then its volume there would be  $(400 \text{ m})(400 \text{ m})d$ . Requiring these two volumes to be equal, we can solve for  $d$ . Thus,  $d = 25 \text{ m}$ . The volume of a small part of the mud over a patch of area of  $4.0 \text{ m}^2$  is  $(4.0)d = 100 \text{ m}^3$ . Since each cubic meter corresponds to a mass of

1900 kg (stated in the problem), then the mass of that small part of the mud is  $1.9 \times 10^5$  kg.

26. (a) The volume of the cloud is  $(3000 \text{ m})\pi(1000 \text{ m})^2 = 9.4 \times 10^9 \text{ m}^3$ . Since each cubic meter of the cloud contains from  $50 \times 10^6$  to  $500 \times 10^6$  water drops, then we conclude that the entire cloud contains from  $4.7 \times 10^{18}$  to  $4.7 \times 10^{19}$  drops. Since the volume of each drop is  $\frac{4}{3}\pi(10 \times 10^{-6} \text{ m})^3 = 4.2 \times 10^{-15} \text{ m}^3$ , then the total volume of water in a cloud is from  $2 \times 10^3$  to  $2 \times 10^4 \text{ m}^3$ .

(b) Using the fact that  $1 \text{ L} = 1 \times 10^3 \text{ cm}^3 = 1 \times 10^{-3} \text{ m}^3$ , the amount of water estimated in part (a) would fill from  $2 \times 10^6$  to  $2 \times 10^7$  bottles.

(c) At 1000 kg for every cubic meter, the mass of water is from  $2 \times 10^6$  to  $2 \times 10^7$  kg. The coincidence in numbers between the results of parts (b) and (c) of this problem is due to the fact that each liter has a mass of one kilogram when water is at its normal density (under standard conditions).

27. We introduce the notion of density,  $\rho = m/V$ , and convert to SI units:  $1000 \text{ g} = 1 \text{ kg}$ , and  $100 \text{ cm} = 1 \text{ m}$ .

(a) The density  $\rho$  of a sample of iron is

$$\rho = (7.87 \text{ g/cm}^3) \left( \frac{1 \text{ kg}}{1000 \text{ g}} \right) \left( \frac{100 \text{ cm}}{1 \text{ m}} \right)^3 = 7870 \text{ kg/m}^3.$$

If we ignore the empty spaces between the close-packed spheres, then the density of an individual iron atom will be the same as the density of any iron sample. That is, if  $M$  is the mass and  $V$  is the volume of an atom, then

$$V = \frac{M}{\rho} = \frac{9.27 \times 10^{-26} \text{ kg}}{7.87 \times 10^3 \text{ kg/m}^3} = 1.18 \times 10^{-29} \text{ m}^3.$$

(b) We set  $V = 4\pi R^3/3$ , where  $R$  is the radius of an atom (Appendix E contains several geometry formulas). Solving for  $R$ , we find

$$R = \left( \frac{3V}{4\pi} \right)^{1/3} = \left( \frac{3(1.18 \times 10^{-29} \text{ m}^3)}{4\pi} \right)^{1/3} = 1.41 \times 10^{-10} \text{ m}.$$

The center-to-center distance between atoms is twice the radius, or  $2.82 \times 10^{-10} \text{ m}$ .

28. If we estimate the “typical” large domestic cat mass as 10 kg, and the “typical” atom (in the cat) as  $10 \text{ u} \approx 2 \times 10^{-26} \text{ kg}$ , then there are roughly  $(10 \text{ kg}) / (2 \times 10^{-26} \text{ kg}) \approx 5 \times 10^{26}$  atoms. This is close to being a factor of a thousand greater than Avogadro’s number. Thus this is roughly a kilomole of atoms.

29. The mass in kilograms is

$$(28.9 \text{ piculs}) \left( \frac{100 \text{ gin}}{1 \text{ picul}} \right) \left( \frac{16 \text{ tahlil}}{1 \text{ gin}} \right) \left( \frac{10 \text{ chee}}{1 \text{ tahlil}} \right) \left( \frac{10 \text{ hoon}}{1 \text{ chee}} \right) \left( \frac{0.3779 \text{ g}}{1 \text{ hoon}} \right)$$

which yields  $1.747 \times 10^6 \text{ g}$  or roughly  $1.75 \times 10^3 \text{ kg}$ .

30. To solve the problem, we note that the first derivative of the function with respect to time gives the rate. Setting the rate to zero gives the time at which an extreme value of the variable mass occurs; here that extreme value is a maximum.

(a) Differentiating  $m(t) = 5.00t^{0.8} - 3.00t + 20.00$  with respect to  $t$  gives

$$\frac{dm}{dt} = 4.00t^{-0.2} - 3.00.$$

The water mass is the greatest when  $dm/dt = 0$ , or at  $t = (4.00/3.00)^{1/0.2} = 4.21 \text{ s}$ .

(b) At  $t = 4.21 \text{ s}$ , the water mass is

$$m(t = 4.21 \text{ s}) = 5.00(4.21)^{0.8} - 3.00(4.21) + 20.00 = 23.2 \text{ g}.$$

(c) The rate of mass change at  $t = 2.00 \text{ s}$  is

$$\begin{aligned} \left. \frac{dm}{dt} \right|_{t=2.00 \text{ s}} &= [4.00(2.00)^{-0.2} - 3.00] \text{ g/s} = 0.48 \text{ g/s} = 0.48 \frac{\text{g}}{\text{s}} \cdot \frac{1 \text{ kg}}{1000 \text{ g}} \cdot \frac{60 \text{ s}}{1 \text{ min}} \\ &= 2.89 \times 10^{-2} \text{ kg/min.} \end{aligned}$$

(d) Similarly, the rate of mass change at  $t = 5.00 \text{ s}$  is

$$\begin{aligned} \left. \frac{dm}{dt} \right|_{t=5.00 \text{ s}} &= [4.00(5.00)^{-0.2} - 3.00] \text{ g/s} = -0.101 \text{ g/s} = -0.101 \frac{\text{g}}{\text{s}} \cdot \frac{1 \text{ kg}}{1000 \text{ g}} \cdot \frac{60 \text{ s}}{1 \text{ min}} \\ &= -6.05 \times 10^{-3} \text{ kg/min.} \end{aligned}$$

31. The mass density of the candy is

$$\rho = \frac{m}{V} = \frac{0.0200 \text{ g}}{50.0 \text{ mm}^3} = 4.00 \times 10^{-4} \text{ g/mm}^3 = 4.00 \times 10^{-4} \text{ kg/cm}^3.$$

If we neglect the volume of the empty spaces between the candies, then the total mass of the candies in the container when filled to height  $h$  is  $M = \rho Ah$ , where  $A = (14.0 \text{ cm})(17.0 \text{ cm}) = 238 \text{ cm}^2$  is the base area of the container that remains unchanged. Thus, the rate of mass change is given by

$$\begin{aligned} \frac{dM}{dt} &= \frac{d(\rho Ah)}{dt} = \rho A \frac{dh}{dt} = (4.00 \times 10^{-4} \text{ kg/cm}^3)(238 \text{ cm}^2)(0.250 \text{ cm/s}) \\ &= 0.0238 \text{ kg/s} = 1.43 \text{ kg/min}. \end{aligned}$$

32. The total volume  $V$  of the real house is that of a triangular prism (of height  $h = 3.0 \text{ m}$  and base area  $A = 20 \times 12 = 240 \text{ m}^2$ ) in addition to a rectangular box (height  $h' = 6.0 \text{ m}$  and same base). Therefore,

$$V = \frac{1}{2} hA + h'A = \left( \frac{h}{2} + h' \right) A = 1800 \text{ m}^3.$$

(a) Each dimension is reduced by a factor of  $1/12$ , and we find

$$V_{\text{doll}} = (1800 \text{ m}^3) \left( \frac{1}{12} \right)^3 \approx 1.0 \text{ m}^3.$$

(b) In this case, each dimension (relative to the real house) is reduced by a factor of  $1/144$ . Therefore,

$$V_{\text{miniature}} = (1800 \text{ m}^3) \left( \frac{1}{144} \right)^3 \approx 6.0 \times 10^{-4} \text{ m}^3.$$

33. **THINK** In this problem we are asked to differentiate between three types of tons: *displacement* ton, *freight* ton and *register* ton, all of which are units of volume.

**EXPRESS** The three different tons are defined in terms of *barrel bulk*, with  $1 \text{ barrel bulk} = 0.1415 \text{ m}^3 = 4.0155 \text{ U.S. bushels}$  (using  $1 \text{ m}^3 = 28.378 \text{ U.S. bushels}$ ). Thus, in terms of U.S. bushels, we have

$$1 \text{ displacement ton} = (7 \text{ barrels bulk}) \times \left( \frac{4.0155 \text{ U.S. bushels}}{1 \text{ barrel bulk}} \right) = 28.108 \text{ U.S. bushels}$$

$$1 \text{ freight ton} = (8 \text{ barrels bulk}) \times \left( \frac{4.0155 \text{ U.S. bushels}}{1 \text{ barrel bulk}} \right) = 32.124 \text{ U.S. bushels}$$

$$1 \text{ register ton} = (20 \text{ barrels bulk}) \times \left( \frac{4.0155 \text{ U.S. bushels}}{1 \text{ barrel bulk}} \right) = 80.31 \text{ U.S. bushels}$$

**ANALYZE** (a) The difference between 73 “freight” tons and 73 “displacement” tons is

$$\Delta V = 73(\text{freight tons} - \text{displacement tons}) = 73(32.124 \text{ U.S. bushels} - 28.108 \text{ U.S. bushels}) \\ = 293.168 \text{ U.S. bushels} \approx 293 \text{ U.S. bushels}$$

(b) Similarly, the difference between 73 “register” tons and 73 “displacement” tons is

$$\Delta V = 73(\text{register tons} - \text{displacement tons}) = 73(80.31 \text{ U.S. bushels} - 28.108 \text{ U.S. bushels}) \\ = 3810.746 \text{ U.S. bushels} \approx 3.81 \times 10^3 \text{ U.S. bushels}$$

**LEARN** With 1 register ton > 1 freight ton > 1 displacement ton, we expect the difference found in (b) to be greater than that in (a). This is indeed the case.

34. The customer expects a volume  $V_1 = 20 \times 7056 \text{ in}^3$  and receives  $V_2 = 20 \times 5826 \text{ in}^3$ , the difference being  $\Delta V = V_1 - V_2 = 24600 \text{ in}^3$ , or

$$\Delta V = (24600 \text{ in}^3) \left( \frac{2.54 \text{ cm}}{1 \text{ inch}} \right)^3 \left( \frac{1 \text{ L}}{1000 \text{ cm}^3} \right) = 403 \text{ L}$$

where Appendix D has been used.

35. The first two conversions are easy enough that a *formal* conversion is not especially called for, but in the interest of *practice makes perfect* we go ahead and proceed formally:

$$(a) 11 \text{ tuffets} = (11 \text{ tuffets}) \left( \frac{2 \text{ peck}}{1 \text{ tuffet}} \right) = 22 \text{ pecks}.$$

$$(b) 11 \text{ tuffets} = (11 \text{ tuffets}) \left( \frac{0.50 \text{ Imperial bushel}}{1 \text{ tuffet}} \right) = 5.5 \text{ Imperial bushels}.$$

$$(c) 11 \text{ tuffets} = (5.5 \text{ Imperial bushel}) \left( \frac{36.3687 \text{ L}}{1 \text{ Imperial bushel}} \right) \approx 200 \text{ L}.$$

36. Table 7 can be completed as follows:

(a) It should be clear that the first column (under “wey”) is the reciprocal of the first row – so that  $\frac{9}{10} = 0.900$ ,  $\frac{3}{40} = 7.50 \times 10^{-2}$ , and so forth. Thus, 1 pottle =  $1.56 \times 10^{-3}$  wey and 1 gill =  $8.32 \times 10^{-6}$  wey are the last two entries in the first column.

(b) In the second column (under “chaldron”), clearly we have 1 chaldron = 1 chaldron (that is, the entries along the “diagonal” in the table must be 1’s). To find out how many

chaldron are equal to one bag, we note that  $1 \text{ wey} = 10/9 \text{ chaldron} = 40/3 \text{ bag}$  so that  $\frac{1}{12} \text{ chaldron} = 1 \text{ bag}$ . Thus, the next entry in that second column is  $\frac{1}{12} = 8.33 \times 10^{-2}$ . Similarly,  $1 \text{ pottle} = 1.74 \times 10^{-3} \text{ chaldron}$  and  $1 \text{ gill} = 9.24 \times 10^{-6} \text{ chaldron}$ .

(c) In the third column (under “bag”), we have  $1 \text{ chaldron} = 12.0 \text{ bag}$ ,  $1 \text{ bag} = 1 \text{ bag}$ ,  $1 \text{ pottle} = 2.08 \times 10^{-2} \text{ bag}$ , and  $1 \text{ gill} = 1.11 \times 10^{-4} \text{ bag}$ .

(d) In the fourth column (under “pottle”), we find  $1 \text{ chaldron} = 576 \text{ pottle}$ ,  $1 \text{ bag} = 48 \text{ pottle}$ ,  $1 \text{ pottle} = 1 \text{ pottle}$ , and  $1 \text{ gill} = 5.32 \times 10^{-3} \text{ pottle}$ .

(e) In the last column (under “gill”), we obtain  $1 \text{ chaldron} = 1.08 \times 10^5 \text{ gill}$ ,  $1 \text{ bag} = 9.02 \times 10^3 \text{ gill}$ ,  $1 \text{ pottle} = 188 \text{ gill}$ , and, of course,  $1 \text{ gill} = 1 \text{ gill}$ .

(f) Using the information from part (c),  $1.5 \text{ chaldron} = (1.5)(12.0) = 18.0 \text{ bag}$ . And since each bag is  $0.1091 \text{ m}^3$  we conclude  $1.5 \text{ chaldron} = (18.0)(0.1091) = 1.96 \text{ m}^3$ .

37. The volume of one unit is  $1 \text{ cm}^3 = 1 \times 10^{-6} \text{ m}^3$ , so the volume of a mole of them is  $6.02 \times 10^{23} \text{ cm}^3 = 6.02 \times 10^{17} \text{ m}^3$ . The cube root of this number gives the edge length:  $8.4 \times 10^5 \text{ m}^3$ . This is equivalent to roughly  $8 \times 10^2 \text{ km}$ .

38. (a) Using the fact that the area  $A$  of a rectangle is (width)  $\times$  (length), we find

$$\begin{aligned} A_{\text{total}} &= (3.00 \text{ acre}) + (25.0 \text{ perch})(4.00 \text{ perch}) \\ &= (3.00 \text{ acre}) \left( \frac{(40 \text{ perch})(4 \text{ perch})}{1 \text{ acre}} \right) + 100 \text{ perch}^2 \\ &= 580 \text{ perch}^2. \end{aligned}$$

We multiply this by the  $\text{perch}^2 \rightarrow \text{rood}$  conversion factor ( $1 \text{ rood}/40 \text{ perch}^2$ ) to obtain the answer:  $A_{\text{total}} = 14.5 \text{ roods}$ .

(b) We convert our intermediate result in part (a):

$$A_{\text{total}} = (580 \text{ perch}^2) \left( \frac{16.5 \text{ ft}}{1 \text{ perch}} \right)^2 = 1.58 \times 10^5 \text{ ft}^2.$$

Now, we use the feet  $\rightarrow$  meters conversion given in Appendix D to obtain

$$A_{\text{total}} = (1.58 \times 10^5 \text{ ft}^2) \left( \frac{1 \text{ m}}{3.281 \text{ ft}} \right)^2 = 1.47 \times 10^4 \text{ m}^2.$$

39. **THINK** This problem compares the U.K. gallon with U.S. gallon, two non-SI units for volume. The interpretation of the type of gallons, whether U.K. or U.S., affects the amount of gasoline one calculates for traveling a given distance.

**EXPRESS** If the fuel consumption rate is  $R$  (in miles/gallon), then the amount of gasoline (in gallons) needed for a trip of distance  $d$  (in miles) would be

$$V(\text{gallon}) = \frac{d \text{ (miles)}}{R \text{ (miles/gallon)}}$$

Since the car was manufactured in U.K., the fuel consumption rate is calibrated based on U.K. gallon, and the correct interpretation should be “40 miles per U.K. gallon.” In U.K., one would think of gallon as U.K. gallon; however, in the U.S., the word “gallon” would naturally be interpreted as U.S. gallon. Note also that since 1 U.K. gallon = 4.5460900 L and 1 U.S. gallon = 3.7854118 L, the relationship between the two is

$$1 \text{ U.K. gallon} = (4.5460900 \text{ L}) \left( \frac{1 \text{ U.S. gallon}}{3.7854118 \text{ L}} \right) = 1.20095 \text{ U.S. gallons}$$

**ANALYZE** (a) The amount of gasoline actually required is

$$V' = \frac{750 \text{ miles}}{40 \text{ miles/U.K. gallon}} = 18.75 \text{ U.K. gallons} \approx 18.8 \text{ U.K. gallons}$$

This means that the driver mistakenly believes that the car should need 18.8 U.S. gallons.

(b) Using the conversion factor found above, this is equivalent to

$$V' = (18.75 \text{ U.K. gallons}) \times \left( \frac{1.20095 \text{ U.S. gallons}}{1 \text{ U.K. gallon}} \right) \approx 22.5 \text{ U.S. gallons}$$

**LEARN** One U.K. gallon is greater than one U.S. gallon by roughly a factor of 1.2 in volume. Therefore, 40 mi/U.K. gallon is less fuel-efficient than 40 mi/U.S. gallon.

40. Equation 1-9 gives (to very high precision!) the conversion from atomic mass units to kilograms. Since this problem deals with the ratio of total mass (1.0 kg) divided by the mass of one atom (1.0 u, but converted to kilograms), then the computation reduces to simply taking the reciprocal of the number given in Eq. 1-9 and rounding off appropriately. Thus, the answer is  $6.0 \times 10^{26}$ .

41. **THINK** This problem involves converting *cord*, a non-SI unit for volume, to SI unit.

**EXPRESS** Using the (exact) conversion 1 in. = 2.54 cm = 0.0254 m for length, we have



$$1 \text{ ft} = 12 \text{ in} = (12 \text{ in.}) \times \left( \frac{0.0254 \text{ m}}{1 \text{ in}} \right) = 0.3048 \text{ m}.$$

Thus,  $1 \text{ ft}^3 = (0.3048 \text{ m})^3 = 0.0283 \text{ m}^3$  for volume (these results also can be found in Appendix D).

**ANALYZE** The volume of a cord of wood is  $V = (8 \text{ ft}) \times (4 \text{ ft}) \times (4 \text{ ft}) = 128 \text{ ft}^3$ . Using the conversion factor found above, we obtain

$$V = 1 \text{ cord} = 128 \text{ ft}^3 = (128 \text{ ft}^3) \times \left( \frac{0.0283 \text{ m}^3}{1 \text{ ft}^3} \right) = 3.625 \text{ m}^3$$

which implies that  $1 \text{ m}^3 = \left( \frac{1}{3.625} \right) \text{ cord} = 0.276 \text{ cord} \approx 0.3 \text{ cord}$ .

**LEARN** The unwanted units  $\text{ft}^3$  all cancel out, as they should. In conversions, units obey the same algebraic rules as variables and numbers.

42. (a) In atomic mass units, the mass of one molecule is  $(16 + 1 + 1)\text{u} = 18 \text{ u}$ . Using Eq. 1-9, we find

$$18 \text{ u} = (18 \text{ u}) \left( \frac{1.6605402 \times 10^{-27} \text{ kg}}{1 \text{ u}} \right) = 3.0 \times 10^{-26} \text{ kg}.$$

(b) We divide the total mass by the mass of each molecule and obtain the (approximate) number of water molecules:

$$N \approx \frac{1.4 \times 10^{21}}{3.0 \times 10^{-26}} \approx 5 \times 10^{46}.$$

43. A million milligrams comprise a kilogram, so  $2.3 \text{ kg/week}$  is  $2.3 \times 10^6 \text{ mg/week}$ . Figuring 7 days a week, 24 hours per day, 3600 second per hour, we find 604800 seconds are equivalent to one week. Thus,  $(2.3 \times 10^6 \text{ mg/week}) / (604800 \text{ s/week}) = 3.8 \text{ mg/s}$ .

44. The volume of the water that fell is

$$\begin{aligned} V &= (26 \text{ km}^2) (2.0 \text{ in.}) = (26 \text{ km}^2) \left( \frac{1000 \text{ m}}{1 \text{ km}} \right)^2 (2.0 \text{ in.}) \left( \frac{0.0254 \text{ m}}{1 \text{ in.}} \right) \\ &= (26 \times 10^6 \text{ m}^2) (0.0508 \text{ m}) \\ &= 1.3 \times 10^6 \text{ m}^3. \end{aligned}$$

We write the mass-per-unit-volume (density) of the water as:  $\rho = \frac{m}{V} = 1 \times 10^3 \text{ kg/m}^3$ .

The mass of the water that fell is therefore given by  $m = \rho V$ :

$$m = (1 \times 10^3 \text{ kg/m}^3) (1.3 \times 10^6 \text{ m}^3) = 1.3 \times 10^9 \text{ kg}.$$

45. The number of seconds in a year is  $3.156 \times 10^7$ . This is listed in Appendix D and results from the product

$$(365.25 \text{ day/y}) (24 \text{ h/day}) (60 \text{ min/h}) (60 \text{ s/min}).$$

(a) The number of shakes in a second is  $10^8$ ; therefore, there are indeed more shakes per second than there are seconds per year.

(b) Denoting the age of the universe as 1 u-day (or 86400 u-sec), then the time during which humans have existed is given by

$$\frac{10^6}{10^{10}} = 10^{-4} \text{ u-day},$$

which may also be expressed as  $(10^{-4} \text{ u-day}) \left( \frac{86400 \text{ u-sec}}{1 \text{ u-day}} \right) = 8.6 \text{ u-sec}.$

46. The volume removed in one year is  $V = (75 \times 10^4 \text{ m}^2) (26 \text{ m}) \approx 2 \times 10^7 \text{ m}^3$ , which we convert to cubic kilometers:  $V = (2 \times 10^7 \text{ m}^3) \left( \frac{1 \text{ km}}{1000 \text{ m}} \right)^3 = 0.020 \text{ km}^3.$

47. **THINK** This problem involves expressing the speed of light in astronomical units per minute.

**EXPRESS** We first convert meters to astronomical units (AU), and seconds to minutes, using

$$1000 \text{ m} = 1 \text{ km}, \quad 1 \text{ AU} = 1.50 \times 10^8 \text{ km}, \quad 60 \text{ s} = 1 \text{ min}.$$

**ANALYZE** Using the conversion factors above, the speed of light can be rewritten as

$$c = 3.0 \times 10^8 \text{ m/s} = \left( \frac{3.0 \times 10^8 \text{ m}}{\text{s}} \right) \left( \frac{1 \text{ km}}{1000 \text{ m}} \right) \left( \frac{\text{AU}}{1.50 \times 10^8 \text{ km}} \right) \left( \frac{60 \text{ s}}{\text{min}} \right) = 0.12 \text{ AU/min}.$$

**LEARN** When expressed the speed of light  $c$  in AU/min, we readily see that it takes about 8.3 ( $= 1/0.12$ ) minutes for sunlight to reach the Earth (i.e., to travel a distance of 1 AU).

48. Since one atomic mass unit is  $1 \text{ u} = 1.66 \times 10^{-24} \text{ g}$  (see Appendix D), the mass of one mole of atoms is about  $m = (1.66 \times 10^{-24} \text{ g})(6.02 \times 10^{23}) = 1 \text{ g}$ . On the other hand, the mass of one mole of atoms in the common Eastern mole is

$$m' = \frac{75 \text{ g}}{7.5} = 10 \text{ g}$$

Therefore, in atomic mass units, the average mass of one atom in the common Eastern mole is

$$\frac{m'}{N_A} = \frac{10 \text{ g}}{6.02 \times 10^{23}} = 1.66 \times 10^{-23} \text{ g} = 10 \text{ u.}$$

49. (a) Squaring the relation  $1 \text{ ken} = 1.97 \text{ m}$ , and setting up the ratio, we obtain

$$\frac{1 \text{ ken}^2}{1 \text{ m}^2} = \frac{1.97^2 \text{ m}^2}{1 \text{ m}^2} = 3.88.$$

(b) Similarly, we find

$$\frac{1 \text{ ken}^3}{1 \text{ m}^3} = \frac{1.97^3 \text{ m}^3}{1 \text{ m}^3} = 7.65.$$

(c) The volume of a cylinder is the circular area of its base multiplied by its height. Thus,

$$\pi r^2 h = \pi (3.00)^2 (5.50) = 156 \text{ ken}^3.$$

(d) If we multiply this by the result of part (b), we determine the volume in cubic meters:  $(155.5)(7.65) = 1.19 \times 10^3 \text{ m}^3$ .

50. According to Appendix D, a nautical mile is 1.852 km, so 24.5 nautical miles would be 45.374 km. Also, according to Appendix D, a mile is 1.609 km, so 24.5 miles is 39.4205 km. The difference is 5.95 km.

51. (a) For the minimum (43 cm) case, 9 cubits converts as follows:

$$9 \text{ cubits} = (9 \text{ cubits}) \left( \frac{0.43 \text{ m}}{1 \text{ cubit}} \right) = 3.9 \text{ m.}$$

And for the maximum (53 cm) case we have  $9 \text{ cubits} = (9 \text{ cubits}) \left( \frac{0.53 \text{ m}}{1 \text{ cubit}} \right) = 4.8 \text{ m.}$

(b) Similarly, with  $0.43 \text{ m} \rightarrow 430 \text{ mm}$  and  $0.53 \text{ m} \rightarrow 530 \text{ mm}$ , we find  $3.9 \times 10^3 \text{ mm}$  and  $4.8 \times 10^3 \text{ mm}$ , respectively.

(c) We can convert length and diameter first and then compute the volume, or first compute the volume and then convert. We proceed using the latter approach (where  $d$  is diameter and  $\ell$  is length).

$$V_{\text{cylinder, min}} = \frac{\pi}{4} \ell d^2 = 28 \text{ cubit}^3 = (28 \text{ cubit}^3) \left( \frac{0.43 \text{ m}}{1 \text{ cubit}} \right)^3 = 2.2 \text{ m}^3.$$

Similarly, with 0.43 m replaced by 0.53 m, we obtain  $V_{\text{cylinder, max}} = 4.2 \text{ m}^3$ .

52. Abbreviating wapentake as “wp” and assuming a hide to be 110 acres, we set up the ratio 25 wp/11 barn along with appropriate conversion factors:

$$\frac{(25 \text{ wp}) \left( \frac{100 \text{ hide}}{1 \text{ wp}} \right) \left( \frac{110 \text{ acre}}{1 \text{ hide}} \right) \left( \frac{4047 \text{ m}^2}{1 \text{ acre}} \right)}{(11 \text{ barn}) \left( \frac{1 \times 10^{-28} \text{ m}^2}{1 \text{ barn}} \right)} \approx 1 \times 10^{36}.$$

53. **THINK** The objective of this problem is to convert the Earth-Sun distance (1 AU) to parsecs and light-years.

**EXPRESS** To relate parsec (pc) to AU, we note that when  $\theta$  is measured in radians, it is equal to the arc length  $s$  divided by the radius  $R$ . For a very large radius circle and small value of  $\theta$ , the arc may be approximated as the straight line-segment of length 1 AU. Thus,

$$\theta = 1 \text{ arcsec} = (1 \text{ arcsec}) \left( \frac{1 \text{ arcmin}}{60 \text{ arcsec}} \right) \left( \frac{1^\circ}{60 \text{ arcmin}} \right) \left( \frac{2\pi \text{ radian}}{360^\circ} \right) = 4.85 \times 10^{-6} \text{ rad}.$$

Therefore, one parsec is

$$1 \text{ pc} = \frac{s}{\theta} = \frac{1 \text{ AU}}{4.85 \times 10^{-6}} = 2.06 \times 10^5 \text{ AU}.$$

Next, we relate AU to light-year (ly). Since a year is about  $3.16 \times 10^7 \text{ s}$ ,

$$1 \text{ ly} = (186,000 \text{ mi/s}) (3.16 \times 10^7 \text{ s}) = 5.9 \times 10^{12} \text{ mi}.$$

**ANALYZE** (a) Since  $1 \text{ pc} = 2.06 \times 10^5 \text{ AU}$ , inverting the relation gives

$$1 \text{ AU} = (1 \text{ AU}) \left( \frac{1 \text{ pc}}{2.06 \times 10^5 \text{ AU}} \right) = 4.9 \times 10^{-6} \text{ pc}.$$

(b) Given that  $1 \text{ AU} = 92.9 \times 10^6 \text{ mi}$  and  $1 \text{ ly} = 5.9 \times 10^{12} \text{ mi}$ , the two expressions together lead to

$$1 \text{ AU} = 92.9 \times 10^6 \text{ mi} = (92.9 \times 10^6 \text{ mi}) \left( \frac{1 \text{ ly}}{5.9 \times 10^{12} \text{ mi}} \right) = 1.57 \times 10^{-5} \text{ ly}.$$

**LEARN** Our results can be further combined to give  $1 \text{ pc} = 3.2 \text{ ly}$ . From the above expression, we readily see that it takes  $1.57 \times 10^{-5} \text{ y}$ , or about 8.3 min, for Sunlight to travel a distance of 1 AU to reach the Earth.

54. (a) Using Appendix D, we have  $1 \text{ ft} = 0.3048 \text{ m}$ ,  $1 \text{ gal} = 231 \text{ in.}^3$ , and  $1 \text{ in.}^3 = 1.639 \times 10^{-2} \text{ L}$ . From the latter two items, we find that  $1 \text{ gal} = 3.79 \text{ L}$ . Thus, the quantity  $460 \text{ ft}^2/\text{gal}$  becomes

$$460 \text{ ft}^2/\text{gal} = \left( \frac{460 \text{ ft}^2}{\text{gal}} \right) \left( \frac{1 \text{ m}}{3.28 \text{ ft}} \right)^2 \left( \frac{1 \text{ gal}}{3.79 \text{ L}} \right) = 11.3 \text{ m}^2/\text{L}.$$

(b) Also, since  $1 \text{ m}^3$  is equivalent to 1000 L, our result from part (a) becomes

$$11.3 \text{ m}^2/\text{L} = \left( \frac{11.3 \text{ m}^2}{\text{L}} \right) \left( \frac{1000 \text{ L}}{1 \text{ m}^3} \right) = 1.13 \times 10^4 \text{ m}^{-1}.$$

(c) The inverse of the original quantity is  $(460 \text{ ft}^2/\text{gal})^{-1} = 2.17 \times 10^{-3} \text{ gal/ft}^2$ .

(d) The answer in (c) represents the volume of the paint (in gallons) needed to cover a square foot of area. From this, we could also figure the paint thickness [it turns out to be about a tenth of a millimeter, as one sees by taking the reciprocal of the answer in part (b)].

55. (a) The receptacle is a volume of  $(40 \text{ cm})(40 \text{ cm})(30 \text{ cm}) = 48000 \text{ cm}^3 = 48 \text{ L} = (48)(16)/11.356 = 67.63$  standard bottles, which is a little more than 3 nebuchadnezzars (the largest bottle indicated). The remainder, 7.63 standard bottles, is just a little less than 1 methuselah. Thus, the answer to part (a) is 3 nebuchadnezzars and 1 methuselah.

(b) Since  $1 \text{ methuselah} = 8$  standard bottles, then the extra amount is  $8 - 7.63 = 0.37$  standard bottle.

(c) Using the conversion factor  $16 \text{ standard bottles} = 11.356 \text{ L}$ , we have

$$0.37 \text{ standard bottle} = (0.37 \text{ standard bottle}) \left( \frac{11.356 \text{ L}}{16 \text{ standard bottles}} \right) = 0.26 \text{ L}.$$

56. The mass of the pig is 3.108 slugs, or  $(3.108)(14.59) = 45.346 \text{ kg}$ . Referring now to the corn, a U.S. bushel is 35.238 liters. Thus, a value of 1 for the *corn-hog ratio* would be equivalent to  $35.238/45.346 = 0.7766$  in the indicated metric units. Therefore, a value of 5.7 for the *ratio* corresponds to  $5.7(0.777) \approx 4.4$  in the indicated metric units.

57. Two jalapeño peppers have spiciness = 8000 SHU, and this amount multiplied by 400 (the number of people) is  $3.2 \times 10^6 \text{ SHU}$ , which is roughly ten times the SHU value for a

single habanero pepper. More precisely, 10.7 habanero peppers will provide that total required SHU value.

58. In the simplest approach, we set up a ratio for the total increase in *horizontal depth*  $x$  (where  $\Delta x = 0.05$  m is the increase in horizontal depth per step)

$$x = N_{\text{steps}} \Delta x = \left( \frac{4.57}{0.19} \right) (0.05 \text{ m}) = 1.2 \text{ m}.$$

However, we can approach this more carefully by noting that if there are  $N = 4.57/.19 \approx 24$  rises then under normal circumstances we would expect  $N - 1 = 23$  runs (horizontal pieces) in that staircase. This would yield  $(23)(0.05 \text{ m}) = 1.15 \text{ m}$ , which - to two significant figures - agrees with our first result.

59. The volume of the filled container is  $24000 \text{ cm}^3 = 24$  liters, which (using the conversion given in the problem) is equivalent to 50.7 pints (U.S). The expected number is therefore in the range from 1317 to 1927 Atlantic oysters. Instead, the number received is in the range from 406 to 609 Pacific oysters. This represents a shortage in the range of roughly 700 to 1500 oysters (the answer to the problem). Note that the minimum value in our answer corresponds to the minimum Atlantic minus the maximum Pacific, and the maximum value corresponds to the maximum Atlantic minus the minimum Pacific.

60. (a) We reduce the stock amount to British teaspoons:

$$1 \text{ breakfastcup} = 2 \times 8 \times 2 \times 2 = 64 \text{ teaspoons}$$

$$1 \text{ teacup} = 8 \times 2 \times 2 = 32 \text{ teaspoons}$$

$$6 \text{ tablespoons} = 6 \times 2 \times 2 = 24 \text{ teaspoons}$$

$$1 \text{ dessertspoon} = 2 \text{ teaspoons}$$

which totals to 122 British teaspoons, or 122 U.S. teaspoons since liquid measure is being used. Now with one U.S cup equal to 48 teaspoons, upon dividing  $122/48 \approx 2.54$ , we find this amount corresponds to 2.5 U.S. cups plus a remainder of precisely 2 teaspoons. In other words,

$$122 \text{ U.S. teaspoons} = 2.5 \text{ U.S. cups} + 2 \text{ U.S. teaspoons}.$$

(b) For the nettle tops, one-half quart is still one-half quart.

(c) For the rice, one British tablespoon is 4 British teaspoons which (since dry-goods measure is being used) corresponds to 2 U.S. teaspoons.

(d) A British saltspoon is  $\frac{1}{2}$  British teaspoon which corresponds (since dry-goods measure is again being used) to 1 U.S. teaspoon.