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

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

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

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

(c) and its volume is

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

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: $1 \text{ gry} = 1/10 \text{ line}$, $1 \text{ line} = 1/12 \text{ inch}$ 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 km = 1×10^3 m and 1 m = 1×10^6 μm,

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

The given measurement is 1.0 km (two significant figures), which implies our result should be written as 1.0×10^9 μm.

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

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

We conclude that the fraction of one centimeter equal to 1.0 μm is 1.0×10^{-4}.

(c) Since 1 yd = (3 ft)(0.3048 m/ft) = 0.9144 m,

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

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

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

(b) With 12 points = 1 pica, we have

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

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 m (meters), the unwanted unit.

ANALYZE Using the above conversion factors, we find

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

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

LEARN Since 4 furlongs is about 800 m, this distance is approximately equal to 160 rods ($1 \text{ rod} \approx 5 \text{ m}$) and 40 chains ($1 \text{ chain} \approx 20 \text{ m}$). 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 fanega = $\frac{1}{12}$ cahiz, or 8.33×10^{-2} cahiz. Similarly, "1 cahiz = 48 cuartilla" (in the already completed part) implies that 1 cuartilla = $\frac{1}{48}$ cahiz, or 2.08×10^{-2} cahiz. Continuing in this way, the remaining entries in the first column are 6.94×10^{-3} and 3.47×10^{-3}.

(b) In the second ("fanega") column, we find 0.250, 8.33×10^{-2}, and 4.17×10^{-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 almude = 6.94×10^{-3} cahiz) found in part (a), we conclude that 7.00 almudes is equivalent to 4.86×10^{-2} cahiz.

(g) Since each decimeter is 0.1 meter, then 55.501 cubic decimeters is equal to 0.055501 m^3 or 55501 cm^3. Thus, 7.00 almudes = $\frac{7.00}{12}$ 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 $V = \frac{\pi}{2}\left(2000\times 10^5\text{ cm}\right)^2\left(3000\times 10^2\text{ cm}\right) = 1.9\times 10^{22}\text{ cm}^3$.

10. Since a change of longitude equal to $360°$ corresponds to a 24 hour change, then one expects to change longitude by $360°/24 = 15°$ 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

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

when $t'_A - t_A = 600$ s.

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

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

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

14. The metric prefixes (micro (μ), pico, nano, …) are given for ready reference on the inside front cover of the textbook (also Table 1–2).

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

(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 $1.21 \times 10^{12}\ \mu$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 3.88×10^8 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 $\pm 3\times10^{-17}$s . We therefore expect that as a result of one million revolutions, the uncertainty should be $(\pm 3\times10^{-17})(1\times10^{6}) = \pm 3\times10^{-11}$ 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

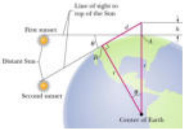
$$(20 \text{ century})(0.001 \text{ s/century}) = 0.02 \text{ s}.$$

The average day during the 20 centuries is (0 + 0.02)/2 = 0.01 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 θ, which is also the angle through which the Sun moves about Earth during the time interval t = 11.1 s. The value of θ can be obtained by using

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

This yields

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

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 θ and h = 1.7 m, we have $r = 5.2\times10^6$ m.

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

$$193\ \text{gal} = (193\ \text{gal})\left(\frac{231\ \text{in}^3}{1\ \text{gal}}\right)\left(\frac{2.54\ \text{cm}}{1\ \text{in}}\right)^3 = 7.31\times10^5\ \text{cm}^3$$

and subtract this from 1×10^6 cm^3 to obtain 2.69×10^5 cm^3. The conversion gal $\rightarrow$ 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 cm/m)^3) to 0.731 m^3, which corresponds to a mass of

$$\left(1000\ \text{kg/m}^3\right)\left(0.731\ \text{m}^2\right) = 731\ \text{kg}$$

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

$$\frac{731\text{kg}}{0.0018\ \text{kg/min}} = 4.06\times10^5\ \text{min} = 0.77\ \text{y}$$

after dividing by the number of minutes in a year (365 days)(24 h/day) (60 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 u = 1.661×10^{-27} 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 $\rho = 19.32$ g/cm^3 and mass $m = 27.63$ 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 $z = 1 \times 10^{-6}$ 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 ℓ is $V = A\ell$ where the cross-section area is that of a circle: $A = \pi r^2$. Therefore, with $r = 2.500 \times 10^{-6}$ m and $V = 1.430 \times 10^{-6}$ 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 g = 1 × 10^{-3} kg and 1 cm^3 = (1 × 10^{-2}m)^3 = 1 × 10^{-6}m^3, the density of water in SI units (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 h)(3600 s/h) = 3.6 × 10^4 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 (μ), 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 μm = 50 × 10^{-6} m is given by $A = 4\pi(50\times 10^{-6})^2 = 3.14\times 10^{-8}$ 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 ρ = 2600 kg/m^3. Thus, using $V = 4\pi r^3/3$, the mass of each grain is

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

We observe that (because a cube has six equal faces) the indicated surface area is 6 m^2. The number of spheres (the grains of sand) N that have a total surface area of 6 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 $M = Nm = \left(1.91\times 10^8\right)\left(1.36\times 10^{-9} \text{ kg}\right) = 0.260 \text{ kg}.$

25. The volume of the section is (2500 m)(800 m)(2.0 m) = 4.0 × 10^6 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 m)(400 m)d. Requiring these two volumes to be equal, we can solve for d. Thus, d = 25 m. The volume of a small part of the mud over a patch of area of 4.0 m^2 is (4.0)d = 100 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 1.9×10^5 kg.

26. (a) The volume of the cloud is (3000 m)π(1000 m)^2 = 9.4 × 10^9 m^3. Since each cubic meter of the cloud contains from 50 × 10^6 to 500 × 10^6 water drops, then we conclude that the entire cloud contains from 4.7 × 10^{18} to 4.7 × 10^{19} drops. Since the volume of each drop is $\frac{4}{3}\pi(10\times10^{-6}\text{ m})^3 = 4.2\times10^{-15}\text{ m}^3$, then the total volume of water in a cloud is from 2×10^3 to 2×10^4 m^3.

(b) Using the fact that $1\text{ L} = 1\times10^3\text{cm}^3 = 1\times10^{-3}\text{m}^3$, the amount of water estimated in part (a) would fill from 2×10^6 to 2×10^7 bottles.

(c) At 1000 kg for every cubic meter, the mass of water is from 2×10^6 to 2×10^7 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 g = 1 kg, and 100 cm = 1 m.

(a) The density ρ of a sample of iron is

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

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

$$V = \frac{M}{\rho} = \frac{9.27\times10^{-26}\text{ kg}}{7.87\times10^3\text{ kg/m}^3} = 1.18\times10^{-29}\text{ m}^3.$$

(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

$$R = \left(\frac{3V}{4\pi}\right)^{1/3} = \left(\frac{3\left(1.18\times10^{-29}\text{ m}^3\right)}{4\pi}\right)^{1/3} = 1.41\times10^{-10}\text{ m}.$$

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

28. If we estimate the "typical" large domestic cat mass as 10 kg, and the "typical" atom (in the cat) as 10 u ≈ 2 × 10^{-26} kg, then there are roughly (10 kg)/(2 × 10^{-26} kg) ≈ 5 × 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

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

which yields 1.747 × 10^6 g or roughly 1.75× 10^3 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

$$\left.\frac{dm}{dt}\right|_{t=2.00\,\text{s}} = \left[4.00(2.00)^{-0.2} - 3.00\right]\text{g/s} = 0.48\text{ g/s} = 0.48\frac{\text{g}}{\text{s}}\cdot\frac{1\,\text{kg}}{1000\text{ g}}\cdot\frac{60\text{ s}}{1\text{ min}}$$
$$= 2.89\times10^{-2}\text{ kg/min}.$$

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

$$\left.\frac{dm}{dt}\right|_{t=2.00\,\text{s}} = \left[4.00(5.00)^{-0.2} - 3.00\right]\text{g/s} = -0.101\text{ g/s} = -0.101\frac{\text{g}}{\text{s}}\cdot\frac{1\,\text{kg}}{1000\text{ g}}\cdot\frac{60\text{ s}}{1\text{ min}}$$
$$= -6.05\times10^{-3}\text{ kg/min}.$$

31. The mass density of the candy is

$$\rho = \frac{m}{V} = \frac{0.0200\text{ g}}{50.0\text{ mm}^3} = 4.00\times10^{-4}\text{ g/mm}^3 = 4.00\times10^{-4}\text{ kg/cm}^3.$$

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

$$\frac{dM}{dt} = \frac{d(\rho Ah)}{dt} = \rho A\frac{dh}{dt} = (4.00\times10^{-4}\text{ kg/cm}^3)(238\text{ cm}^2)(0.250\text{ cm/s})$$
$$= 0.0238\text{ kg/s} = 1.43\text{ kg/min}.$$

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

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

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

$$V_{\text{miniature}} = \left(1800\text{ m}^3\right)\left(\frac{1}{144}\right)^3 \approx 6.0\times10^{-4}\text{ m}^3.$$

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

$$1\text{ displacement ton} = (7\text{ barrels bulk})\times\left(\frac{4.0155\text{ U.S. bushels}}{1\text{ barrel bulk}}\right) = 28.108\text{ U.S. bushels}$$
$$1\text{ freight ton} = (8\text{ barrels bulk})\times\left(\frac{4.0155\text{ U.S. bushels}}{1\text{ barrel bulk}}\right) = 32.124\text{ U.S. bushels}$$
$$1\text{ register ton} = (20\text{ barrels bulk})\times\left(\frac{4.0155\text{ U.S. bushels}}{1\text{ barrel bulk}}\right) = 80.31\text{ U.S. bushels}$$