CHAPTER ONE

CHEMICAL FOUNDATIONS

Questions

16. a. Law versus theory: A law is a concise statement or equation that summarizes observed behavior. A theory is a set of hypotheses that gives an overall explanation of some phenomenon. A law summarizes what happens; a theory (or model) attempts to explain why it happens.

    b. Theory versus experiment: A theory is an explanation of why things behave the way they do, while an experiment is the process of observing that behavior. Theories attempt to explain the results of experiments and are, in turn, tested by further experiments.

    c. Qualitative versus quantitative: A qualitative observation only describes a quality while a quantitative observation attaches a number to the observation. Examples: Qualitative observations: The water was hot to the touch. Mercury was found in the drinking water. Quantitative observations: The temperature of the water was 62°C. The concentration of mercury in the drinking water was 1.5 ppm.

    d. Hypothesis versus theory: Both are explanations of experimental observation. A theory is a set of hypotheses that has been tested over time and found to still be valid, with (perhaps) some modifications.

17. No, it is useful whenever a systematic approach of observation and hypothesis testing can be used.

18. a. No b. Yes c. Yes

    Only statements b and c can be determined from experiment.

19. Volume readings are estimated to one decimal place past the markings on the glassware. The assumed uncertainty is ±1 in the estimated digit. For glassware a, the volume would be estimated to the tenths place since the markings are to the ones place. A sample reading would be 4.2 with an uncertainty of ±0.1. This reading has two significant figures. For glassware b, 10.52 ±0.01 would be a sample reading and the uncertainty; this reading has four significant figures. For glassware c, 18 ±1 would be a sample reading and uncertainty, with the reading having two significant figures.

20. Accuracy: How close a measurement or series of measurements are to an accepted or true value. Precision: How close a series of measurements of the same thing are to each other. The results, average = 14.91 ± 0.03% are precise (close to each other) but are not accurate (not close to the true value).

21. Chemical changes involve the making and breaking of chemical forces (bonds). Physical changes do

not. The identity of a substance changes after a chemical change, but not after a physical change.

22. Many techniques of chemical analysis need to be performed on relatively pure materials. Thus, a separation step often is necessary to remove materials that will interfere with the analytical measurement.

Exercises

Significant Figures and Unit Conversions

23. a. inexact b. exact c. exact

For c, $\frac{36\text{ in}}{\text{yd}} \times \frac{2.54\text{ cm}}{\text{in}} \times \frac{1\text{ m}}{100\text{ cm}} = \frac{0.9144\text{ m}}{\text{yd}}$ (All conversion factors used are exact.)

d. inexact; Although this number appears to be exact, it probably isn't. The announced attendance may be tickets sold but not the number who were actually in the stadium. Some people who paid may not have gone, some may leave early or arrive late, some may sneak in without paying, etc.

e. exact f. inexact

24. a. exact b. inexact; 0.9144 m/yd is exact (see Exercise 1.23c)
Thus, there are 1/0.9144 = 1.093613 ... yd/m.

c. exact d. inexact (π has an infinite number of decimal places.)

25. a. $\underline{12}$; 2 significant figures (S.F.); Nonzero integers always count as significant figures.

b. $\underline{1098}$; 4 S.F.; Captive zeros always count as significant figures.

c. $\underline{2001}$; 4 S.F. d. $\underline{2.001} \times 10^3$; 4 S.F.

e. $0.0000\underline{101}$; 3 S.F.; Leading zeros never count as significant figures.

f. $\underline{1.01} \times 10^{-5}$; 3 S.F.

g. $\underline{1000}$.; 4 S.F.; Trailing zeros are only counted as significant figures if the number contains a decimal point.

h. $\underline{22.04030}$; 7 S.F.; The trailing zero is a significant figure since the number contains a decimal point.

26. a. $\underline{1}00$; 1 S.F. b. $\underline{1.0} \times 10^2$; 2 S.F.

c. $\underline{1.00} \times 10^3$; 3 S.F. d. $\underline{100.}$; 3 S.F.

e. $0.00\underline{48}$; 2 S.F. f. $0.00\underline{480}$; 3 S.F.

g. $\underline{4.80} \times 10^{-3}$; 3 S.F. h. $\underline{4.800} \times 10^{-3}$; 4 S.F.

27. a. 3.13×10^{2} b. 3.13×10^{-4} c. 3.13×10^{7}

d. 3.13×10^{-1} e. 3.13×10^{-2}

28. a. 5×10^{2} b. 4.8×10^{2} c. 4.80×10^{2} d. 4.800×10^{2}

29. For addition and/or subtraction, the result has the same number of decimal places as the number in the calculation with the fewest decimal places. When the result is rounded to the correct number of significant figures, the last significant figure stays the same if the number after this significant figure is less than 5 and increases by one if the number is greater than or equal to 5.

a. $97.381 + 4.2502 + 0.99195 = \underline{102.623}15 = 102.623$; Since 97.381 has only three decimal places, the result should only have three decimal places.

b. $171.5 + 72.915 - 8.23 = \underline{236.1}85 = 236.2$

c. $1.00914 + 0.87104 + 1.2012 = \underline{3.0813}8 = 3.0814$

d. $21.901 - 13.21 - 4.0215 = \underline{4.66}95 = 4.67$

30. For multiplication and/or division, the result has the same number of significant figures as the number in the calculation with the fewest significant figures.

a. $\dfrac{0.102 \times 0.0821 \times 273}{1.01} = \underline{2.26}35 = 2.26$

b. $0.14 \times 6.022 \times 10^{23} = \underline{8.4}31 \times 10^{22} = 8.4 \times 10^{22}$; Since 0.14 only has two significant figures, the result should only have two significant figures.

c. $4.0 \times 10^{4} \times 5.021 \times 10^{-3} \times 7.34993 \times 10^{2} = \underline{1.4}76 \times 10^{5} = 1.5 \times 10^{5}$

d. $\dfrac{2.00 \times 10^{6}}{3.00 \times 10^{-7}} = \underline{6.66}67 \times 10^{12} = 6.67 \times 10^{12}$

31. a. 467; The difference of $25.27 - 24.16 = 1.11$ has only three significant figures. The answer will only have three significant figures since we have a four significant figure number multiplied by a five significant figure number multiplied by a three significant figure number. For this problem and for subsequent problems, the addition/subtraction rule must be applied separately from the multiplication/division rule.

b. 0.24; The difference of $8.925 - 8.904 = 0.021$ has only 2 significant figures. When a two significant figure number is divided by a four significant figure number, the result is reported to two significant figures (division rule).

c. $(9.04 - 8.23 + 21.954 + 81.0) \div 3.1416 = 103.8 \div 3.1416 = 33.04$

Here, apply the addition/subtraction rule first; then apply the multiplication/division rule to arrive at the four significant figure answer. We will generally round off at intermediate steps in order to show the correct number of significant figures. However, you should round off at the end of all the mathematical operations in order to avoid round-off error. Make sure you keep track of the correct number of significant figures during intermediate steps, but round off at the end.

d. $\dfrac{9.2 \times 100.65}{8.321 + 4.026} = \dfrac{9.2 \times 100.65}{12.347} = 75$

e. $0.1654 + 2.07 - 2.114 = 0.12$

Uncertainty begins to appear in the second decimal place. Numbers were added as written and the answer was rounded off to 2 decimal places at the end. If you round to 2 decimal places and add you get 0.13. Always round off at the end of the operation to avoid round-off error.

f. $8.27(4.987 - 4.962) = 8.27(0.025) = 0.21$

g. $\dfrac{9.5 + 4.1 + 2.8 + 3.175}{4} = \dfrac{19.6}{4} = 4.90 = 4.9$

Uncertainty appears in the first decimal place. The average of several numbers can only be as precise as the least precise number. Averages can be exceptions to the significant figure rules.

h. $\dfrac{9.025 - 9.024}{9.025} \times 100 = \dfrac{0.001}{9.025} \times 100 = 0.01$

32. a. $6.022 \times 10^{23} \times 1.05 \times 10^{2} = 6.32 \times 10^{25}$

b. $\dfrac{6.6262 \times 10^{-34} \times 2.998 \times 10^{8}}{2.54 \times 10^{-9}} = 7.82 \times 10^{-17}$

c. $1.285 \times 10^{-2} + 1.24 \times 10^{-3} + 1.879 \times 10^{-1}$

$= 0.1285 \times 10^{-1} + 0.0124 \times 10^{-1} + 1.879 \times 10^{-1} = 2.020 \times 10^{-1}$

When the exponents are different, it is easiest to apply the addition/subtraction rule when all numbers are based on the same power of 10.

d. $1.285 \times 10^{-2} - 1.24 \times 10^{-3} = 1.285 \times 10^{-2} - 0.124 \times 10^{-2} = 1.161 \times 10^{-2}$

e. $\dfrac{(1.00866 - 1.00728)}{6.02205 \times 10^{23}} = \dfrac{0.00138}{6.02205 \times 10^{23}} = 2.29 \times 10^{-27}$

f. $\dfrac{9.875 \times 10^{2} - 9.795 \times 10^{2}}{9.875 \times 10^{2}} \times 100 = \dfrac{0.080 \times 10^{2}}{9.875 \times 10^{2}} \times 100 = 8.1 \times 10^{-1}$

g. $\dfrac{9.42 \times 10^2 + 8.234 \times 10^2 + 1.625 \times 10^3}{3}$

$$= \frac{0.942 \times 10^3 + 0.8234 \times 10^3 + 1.625 \times 10^3}{3} = 1.130 \times 10^3$$

33. a. $8.43 \text{ cm} \times \dfrac{1 \text{ m}}{100 \text{ cm}} \times \dfrac{1000 \text{ mm}}{\text{m}} = 84.3 \text{ mm}$ b. $2.41 \times 10^2 \text{ cm} \times \dfrac{1 \text{ m}}{100 \text{ cm}} = 2.41 \text{ m}$

c. $294.5 \text{ nm} \times \dfrac{1 \text{ m}}{1 \times 10^9 \text{ nm}} \times \dfrac{100 \text{ cm}}{\text{m}} = 2.945 \times 10^{-5} \text{ cm}$ d. $1.445 \times 10^4 \text{ m} \times \dfrac{1 \text{ km}}{1000 \text{ m}} = 14.45 \text{ km}$

e. $235.3 \text{ m} \times \dfrac{1000 \text{ mm}}{\text{m}} = 2.353 \times 10^5 \text{ mm}$

f. $903.3 \text{ nm} \times \dfrac{1 \text{ m}}{1 \times 10^9 \text{ nm}} \times \dfrac{1 \times 10^6 \text{ µm}}{\text{m}} = 0.9033 \text{ µm}$

34. a. $1 \text{ Tg} \times \dfrac{1 \times 10^{12} \text{ g}}{\text{Tg}} \times \dfrac{1 \text{ kg}}{1000 \text{ g}} = 1 \times 10^9 \text{ kg}$

b. $6.50 \times 10^2 \text{ Tm} \times \dfrac{1 \times 10^{12} \text{ m}}{\text{Tm}} \times \dfrac{1 \times 10^9 \text{ nm}}{\text{m}} = 6.50 \times 10^{23} \text{ nm}$

c. $25 \text{ fg} \times \dfrac{1 \text{ g}}{1 \times 10^{15} \text{ fg}} \times \dfrac{1 \text{ kg}}{1000 \text{ g}} = 25 \times 10^{-18} \text{ kg} = 2.5 \times 10^{-17} \text{ kg}$

d. $8.0 \text{ dm}^3 \times \dfrac{1 \text{ L}}{\text{dm}^3} = 8.0 \text{ L}$ ($1 \text{ L} = 1 \text{ dm}^3 = 1000 \text{ cm}^3 = 1000 \text{ mL}$)

e. $1 \text{ mL} \times \dfrac{1 \text{ L}}{1000 \text{ mL}} \times \dfrac{1 \times 10^6 \text{ µL}}{\text{L}} = 1 \times 10^3 \text{ µL}$

f. $1 \text{ µg} \times \dfrac{1 \text{ g}}{1 \times 10^6 \text{ µg}} \times \dfrac{1 \times 10^{12} \text{ pg}}{\text{g}} = 1 \times 10^6 \text{ pg}$

35. a. Appropriate conversion factors are found in Appendix 6. In general, the number of significant figures we use in the conversion factors will be one more than the number of significant figures from the numbers given in the problem. This is usually sufficient to avoid round-off error.

$3.91 \text{ kg} \times \dfrac{1 \text{ lb}}{0.4536 \text{ kg}} = 8.62 \text{ lb}$; $0.62 \text{ lb} \times \dfrac{16 \text{ oz}}{\text{lb}} = 9.9 \text{ oz}$

Baby's weight = 8 lb and 9.9 oz or to the nearest ounce, 8 lb and 10 oz.

$51.4 \text{ cm} \times \dfrac{1 \text{ in}}{2.54 \text{ cm}} = 20.2 \text{ in} \approx 20\ 1/4 \text{ in}$ = baby's height

b. $25{,}000\text{ mi} \times \dfrac{1.61\text{ km}}{\text{mi}} = 4.0 \times 10^4\text{ km};\ \ 4.0 \times 10^4\text{ km} \times \dfrac{1000\text{ m}}{\text{km}} = 4.0 \times 10^7\text{ m}$

c. $V = 1 \times w \times h = 1.0\text{ m} \times \left(5.6\text{ cm} \times \dfrac{1\text{ m}}{100\text{ cm}}\right) \times \left(2.1\text{ dm} \times \dfrac{1\text{ m}}{10\text{ dm}}\right) = 1.2 \times 10^{-2}\text{ m}^3$

$1.2 \times 10^{-2}\text{ m}^3 \times \left(\dfrac{10\text{ dm}}{\text{m}}\right)^3 \times \dfrac{1\text{ L}}{\text{dm}^3} = 12\text{ L}$

$12\text{ L} \times \dfrac{1000\text{ cm}^3}{\text{L}} \times \left(\dfrac{1\text{ in}}{2.54\text{ cm}}\right)^3 = 730\text{ in}^3;\ \ 730\text{ in}^3 \times \left(\dfrac{1\text{ ft}}{12\text{ in}}\right)^3 = 0.42\text{ ft}^3$

36. a. $908\text{ oz} \times \dfrac{1\text{ lb}}{16\text{ oz}} \times \dfrac{0.4536\text{ kg}}{\text{lb}} = 25.7\text{ kg}$

b. $12.8\text{ L} \times \dfrac{1\text{ qt}}{0.9463\text{ L}} \times \dfrac{1\text{ gal}}{4\text{ qt}} = 3.38\text{ gal}$

c. $125\text{ mL} \times \dfrac{1\text{ L}}{1000\text{ mL}} \times \dfrac{1\text{ qt}}{0.9463\text{ L}} = 0.132\text{ qt}$

d. $2.89\text{ gal} \times \dfrac{4\text{ qt}}{1\text{ gal}} \times \dfrac{1\text{ L}}{1.057\text{ qt}} \times \dfrac{1000\text{ mL}}{1\text{ L}} = 1.09 \times 10^4\text{ mL}$

e. $4.48\text{ lb} \times \dfrac{453.6\text{ g}}{1\text{ lb}} = 2.03 \times 10^3\text{ g}$

f. $550\text{ mL} \times \dfrac{1\text{ L}}{1000\text{ mL}} \times \dfrac{1.06\text{ qt}}{\text{L}} = 0.58\text{ qt}$

37. a. $1.25\text{ mi} \times \dfrac{8\text{ furlongs}}{\text{mi}} = 10.0\text{ furlongs};\ \ 10.0\text{ furlongs} \times \dfrac{40\text{ rods}}{\text{furlong}} = 4.00 \times 10^2\text{ rods}$

$4.00 \times 10^2\text{ rods} \times \dfrac{5.5\text{ yd}}{\text{rod}} \times \dfrac{36\text{ in}}{\text{yd}} \times \dfrac{2.54\text{ cm}}{\text{in}} \times \dfrac{1\text{ m}}{100\text{ cm}} = 2.01 \times 10^3\text{ m}$

$2.01 \times 10^3\text{ m} \times \dfrac{1\text{ km}}{1000\text{ m}} = 2.01\text{ km}$

b. Let's assume we know this distance to ± 1 yard. First convert 26 miles to yards.

$26\text{ mi} \times \dfrac{5280\text{ ft}}{\text{mi}} \times \dfrac{1\text{ yd}}{3\text{ ft}} = 45{,}760.\text{ yd}$

$26\text{ mi} + 385\text{ yd} = 45{,}760.\text{ yd} + 385\text{ yd} = 46{,}145\text{ yards}$

$46{,}145\text{ yard} \times \dfrac{1\text{ rod}}{5.5\text{ yd}} = 8390.0\text{ rods};\ \ 8390.0\text{ rods} \times \dfrac{1\text{ furlong}}{40\text{ rods}} = 209.75\text{ furlongs}$

$46{,}145\text{ yard} \times \dfrac{36\text{ in}}{\text{yd}} \times \dfrac{2.54\text{ cm}}{\text{in}} \times \dfrac{1\text{ m}}{100\text{ cm}} = 42{,}195\text{ m};\ \ 42{,}195\text{ m} \times \dfrac{1\text{ km}}{1000\text{ m}} = 42.195\text{ km}$

38. a. $1\text{ ha} \times \frac{10{,}000\text{ m}^2}{\text{ha}} \times \left(\frac{1\text{ km}}{1000\text{ m}}\right)^2 = 1 \times 10^{-2}\text{ km}^2$

b. $5.5\text{ acre} \times \frac{160\text{ rod}^2}{\text{acre}} \times \left(\frac{5.5\text{ yd}}{\text{rod}} \times \frac{36\text{ in}}{\text{yd}} \times \frac{2.54\text{ cm}}{\text{in}} \times \frac{1\text{ m}}{100\text{ cm}}\right)^2 = 2.2 \times 10^4\text{ m}^2$

$2.2 \times 10^4\text{ m}^2 \times \frac{1\text{ ha}}{1 \times 10^4\text{ m}^2} = 2.2\text{ ha}$; $2.2 \times 10^4\text{ m}^2 \times \left(\frac{1\text{ km}}{1000\text{ m}}\right)^2 = 0.022\text{ km}^2$

c. Area of lot = 120 ft × 75 ft = $9.0 \times 10^3\text{ ft}^2$

$9.0 \times 10^3\text{ ft}^2 \times \left(\frac{1\text{ yd}}{3\text{ ft}} \times \frac{1\text{ rod}}{5.5\text{ yd}}\right)^2 \times \frac{1\text{ acre}}{160\text{ rod}^2} = 0.21\text{ acre}$; $\frac{\$6{,}500}{0.21\text{ acre}} = \frac{\$31{,}000}{\text{acre}}$

We can use our result from (b) to get the conversion factor between acres and ha (5.5 acre = 2.2 ha.). Thus, 1 ha = 2.5 acre.

$0.21\text{ acre} \times \frac{1\text{ ha}}{2.5\text{ acre}} = 0.084\text{ ha}$; The price is: $\frac{\$6{,}500}{0.084\text{ ha}} = \frac{\$77{,}000}{\text{ha}}$

39. a. $1\text{ troy lb} \times \frac{12\text{ troy oz}}{\text{troy lb}} \times \frac{20\text{ pw}}{\text{troy oz}} \times \frac{24\text{ grains}}{\text{pw}} \times \frac{0.0648\text{ g}}{\text{grain}} \times \frac{1\text{ kg}}{1000\text{ g}} = 0.373\text{ kg}$

$1\text{ troy lb} = 0.373\text{ kg} \times \frac{2.205\text{ lb}}{\text{kg}} = 0.822\text{ lb}$

b. $1\text{ troy oz} \times \frac{20\text{ pw}}{\text{troy oz}} \times \frac{24\text{ grains}}{\text{pw}} \times \frac{0.0648\text{ g}}{\text{grain}} = 31.1\text{ g}$

$1\text{ troy oz} = 31.1\text{ g} \times \frac{1\text{ carat}}{0.200\text{ g}} = 156\text{ carats}$

c. 1 troy lb = 0.373 kg; $0.373\text{ kg} \times \frac{1000\text{ g}}{\text{kg}} \times \frac{1\text{ cm}^3}{19.3\text{ g}} = 19.3\text{ cm}^3$

40. a. $1\text{ grain ap} \times \frac{1\text{ scruple}}{20\text{ grain ap}} \times \frac{1\text{ dram ap}}{3\text{ scruples}} \times \frac{3.888\text{ g}}{\text{dram ap}} = 0.06480\text{ g}$

From the previous question, we are given that 1 grain troy = 0.0648 g = 1 grain ap. So, the two are the same.

b. $1\text{ oz ap} \times \frac{8\text{ dram ap}}{\text{oz ap}} \times \frac{3.888\text{ g}}{\text{dram ap}} \times \frac{1\text{ oz troy}*}{31.1\text{ g}} = 1.00\text{ oz troy}$ *See Exercise 39b.

c. $5.00 \times 10^2 \text{ mg} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ dram ap}}{3.888 \text{ g}} \times \frac{3 \text{ scruples}}{\text{dram ap}} = 0.386 \text{ scruple}$

$0.386 \text{ scruple} \times \frac{20 \text{ grains ap}}{\text{scruple}} = 7.72 \text{ grains ap}$

d. $1 \text{ scruple} \times \frac{1 \text{ dram ap}}{3 \text{ scruples}} \times \frac{3.888 \text{ g}}{\text{dram ap}} = 1.296 \text{ g}$

41. $1.71 \text{ warp factor} = \left(5.00 \times \frac{3.00 \times 10^8 \text{ m}}{\text{s}}\right) \times \frac{1.094 \text{ yd}}{\text{m}} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{1 \text{ knot}}{2000 \text{ yd/hr}} = 2.95 \times 10^9 \text{ knots}$

42. $\frac{100. \text{ m}}{9.79 \text{ s}} = 10.2 \text{ m/s}$; $\frac{100. \text{ m}}{9.79 \text{ s}} \times \frac{1 \text{ km}}{1000 \text{ m}} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} = 36.8 \text{ km/hr}$

$\frac{100. \text{ m}}{9.79 \text{ s}} \times \frac{1.0936 \text{ yd}}{\text{m}} \times \frac{3 \text{ ft}}{\text{yd}} = 33.5 \text{ ft/s}$; $\frac{33.5 \text{ ft}}{\text{s}} \times \frac{1 \text{ mi}}{5280 \text{ ft}} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} = 22.8 \text{ mi/hr}$

$1.00 \times 10^2 \text{ yd} \times \frac{1 \text{ m}}{1.0936 \text{ yd}} \times \frac{9.79 \text{ s}}{100. \text{ m}} = 8.95 \text{ s}$

43. $\frac{14 \text{ km}}{\text{L}} \times \frac{1 \text{ mi}}{1.61 \text{ km}} \times \frac{3.79 \text{ L}}{\text{gal}} = 33 \text{ mi/gal}$; The spouse's car has the better gas mileage.

44. $112 \text{ km} \times \frac{0.6214 \text{ mi}}{\text{km}} \times \frac{1 \text{ hr}}{65 \text{ mi}} = 1.1 \text{ hr} = 1 \text{ hr and } 6 \text{ min}$

$112 \text{ km} \times \frac{0.6214 \text{ mi}}{\text{km}} \times \frac{1 \text{ gal}}{28 \text{ mi}} \times \frac{3.785 \text{ L}}{\text{gal}} = 9.4 \text{ L of gasoline}$

45. $1.00 \text{ lb} \times \frac{0.4536 \text{ kg}}{\text{lb}} \times \frac{4.00 \text{ euros}}{\text{kg}} \times \frac{\$1.00}{1.14 \text{ euros}} = \$1.59$

46. $1.5 \text{ teaspoons} \times \frac{80. \text{ mg acet}}{0.50 \text{ teaspoon}} = 240 \text{ mg acetaminophen}$

$\frac{240 \text{ mg acet}}{24 \text{ lb}} \times \frac{1 \text{ lb}}{0.454 \text{ kg}} = 22 \text{ mg acetaminophen/kg}$

$\frac{240 \text{ mg acet}}{35 \text{ lb}} \times \frac{1 \text{ lb}}{0.454 \text{ kg}} = 15 \text{ mg acetaminophen/kg}$

The range is from 15 mg to 22 mg acetaminophen per kg of body weight.

Temperature

47. $T_C = \frac{5}{9}(T_F - 32) = \frac{5}{9}(102.5 - 32) = 39.2°C$; $T_K = T_C + 273.2 = 312.4$ K (Note: 32 is exact)

48. $T_C = \frac{5}{9}(74 - 32) = 23°C$; $T_K = 23 + 273 = 296$ K

49. a. $T_F = \frac{9}{5} \times T_C + 32 = \frac{9}{5} \times 78.1°C + 32 = 173°F$

$T_K = T_C + 273.2 = 78.1 + 273.2 = 351.3$ K

b. $T_F = \frac{9}{5} \times (-25) + 32 = -13°F$; $T_K = -25 + 273 = 248$ K

c. $T_F = \frac{9}{5} \times (-273) + 32 = -459°F$; $T_K = -273 + 273 = 0$ K

d. $T_F = \frac{9}{5} \times 801 + 32 = 1470°F$; $T_K = 801 + 273 = 1074$ K

50. a. $T_C = T_K - 273 = 233 - 273 = -40.°C$

$T_F = \frac{9}{5} \times T_C + 32 = \frac{9}{5} \times (-40.) + 32 = -40.°F$

b. $T_C = 4 - 273 = -269°C$; $T_F = \frac{9}{5} \times (-269) + 32 = -452°F$

c. $T_C = 298 - 273 = 25°C$; $T_F = \frac{9}{5} \times 25 + 32 = 77°F$

d. $T_C = 3680 - 273 = 3410°C$; $T_F = \frac{9}{5} \times 3410 + 32 = 6170°F$

51. We can do this two ways. One way is to calculate the high and low temperature and get the uncertainty from the range. 20.6°C ± 0.1°C means the temperature can range from 20.5°C to 20.7°C.

$T_F = \frac{9}{5} \times T_c + 32 \leftarrow$ (exact); $T_F = \frac{9}{5} \times 20.6 + 32 = 69.1°F$

$T_F\,(\text{min}) = \frac{9}{5} \times 20.5 + 32 = 68.9°F$; $T_F\,(\text{max}) = \frac{9}{5} \times 20.7 + 32 = 69.3°F$

So the temperature ranges from 68.9°F to 69.3°F which we can express as 69.1 ± 0.2°F.

An alternative way is to treat the uncertainty and the temperature in °C separately.

$$T_F = \frac{9}{5} \times T_C + 32 = \frac{9}{5} \times 20.6 + 32 = 69.1°F; \quad \pm 0.1°C \times \frac{9°F}{5°C} = \pm 0.18°F \approx \pm 0.2°F$$

Combining the two calculations: $T_F = 69.1 \pm 0.2°F$

52. $96.1°F \pm 0.2°F$; First, convert 96.1°F to °C. $T_C = \frac{5}{9}(T_F - 32) = \frac{5}{9}(96.1 - 32) = 35.6°C$

A change in temperature of 9°F is equal to a change in temperature of 5°C. So the uncertainty is:

$$\pm 0.2°F \times \frac{5°C}{9°F} = \pm 0.1°C. \text{ Thus, } 96.1 \pm 0.2°F = 35.6 \pm 0.1°C$$

Density

53. $$\frac{2.70 \text{ g}}{\text{cm}^3} \times \frac{1 \text{ kg}}{1000 \text{ g}} \times \left(\frac{100 \text{ cm}}{\text{m}}\right)^3 = \frac{2.70 \times 10^3 \text{ kg}}{\text{m}^3}$$

$$\frac{2.70 \text{ g}}{\text{cm}^3} \times \frac{1 \text{ lb}}{453.6 \text{ g}} \times \left(\frac{2.54 \text{ cm}}{\text{in}}\right)^3 \times \left(\frac{12 \text{ in}}{\text{ft}}\right)^3 = \frac{169 \text{ lb}}{\text{ft}^3}$$

54. $$\text{mass} = 350 \text{ lb} \times \frac{453.6 \text{ g}}{\text{lb}} = 1.6 \times 10^5 \text{ g}; \quad V = 1.2 \times 10^4 \text{ in}^3 \times \left(\frac{2.54 \text{ cm}}{\text{in}}\right)^3 = 2.0 \times 10^5 \text{ cm}^3$$

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{1.6 \times 10^5 \text{ g}}{2.0 \times 10^5 \text{ cm}^3} = 0.80 \text{ g/cm}^3$$

Since the material has a density less than water, it will float in water.

55. $$V = \frac{4}{3}\pi r^3 = \frac{4}{3} \times 3.14 \times \left(7.0 \times 10^5 \text{ km} \times \frac{1000 \text{ m}}{\text{km}} \times \frac{100 \text{ cm}}{\text{m}}\right)^3 = 1.4 \times 10^{33} \text{ cm}^3$$

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{2 \times 10^{36} \text{ kg} \times \frac{1000 \text{ g}}{\text{kg}}}{1.4 \times 10^{33} \text{ cm}^3} = 1.4 \times 10^6 \text{ g/cm}^3 = 1 \times 10^6 \text{ g/cm}^3$$

56. $V = l \times w \times h = 2.9 \text{ cm} \times 3.5 \text{ cm} \times 10.0 \text{ cm} = 1.0 \times 10^2 \text{ cm}^3$

$$d = \text{density} = \frac{615.0 \text{ g}}{1.0 \times 10^2 \text{ cm}^3} = \frac{6.2 \text{ g}}{\text{cm}^3}$$

57. $$5.0 \text{ carat} \times \frac{0.200 \text{ g}}{\text{carat}} \times \frac{1 \text{ cm}^3}{3.51 \text{ g}} = 0.28 \text{ cm}^3$$

58. $$2.8 \text{ mL} \times \frac{1 \text{ cm}^3}{\text{mL}} \times \frac{3.51 \text{ g}}{\text{cm}^3} \times \frac{1 \text{ carat}}{0.200 \text{ g}} = 49 \text{ carats}$$

59. $$V = 21.6 \text{ mL} - 12.7 \text{ mL} = 8.9 \text{ mL}; \quad \text{density} = \frac{33.42 \text{ g}}{8.9 \text{ mL}} = 3.8 \text{ g/mL} = 3.8 \text{ g/cm}^3$$

60. $5.25\text{ g} \times \dfrac{1\text{ cm}^3}{10.5\text{ g}} = 0.500\text{ cm}^3 = 0.500\text{ mL}$

The volume in the cylinder will rise to 11.7 mL (11.2 mL + 0.500 mL = 11.7 mL).

61. a. Both have the same mass of 1.0 kg.

b. 1.0 mL of mercury; Mercury has a greater density than water. Note: 1 mL = 1 cm^3

$1.0\text{ mL} \times \dfrac{13.6\text{ g}}{\text{mL}} = 14\text{ g of mercury}$; $1.0\text{ mL} \times \dfrac{0.998\text{ g}}{\text{mL}} = 1.0\text{ g of water}$

c. Same; Both represent 19.3 g of substance.

$19.3\text{ mL} \times \dfrac{0.9982\text{ g}}{\text{mL}} = 19.3\text{ g of water}$; $1.00\text{ mL} \times \dfrac{19.32\text{ g}}{\text{mL}} = 19.3\text{ g of gold}$

d. 1.0 L of benzene (880 g vs 670 g)

$75\text{ mL} \times \dfrac{8.96\text{ g}}{\text{mL}} = 670\text{ g of copper}$; $1.0\text{ L} \times \dfrac{1000\text{ mL}}{\text{L}} \times \dfrac{0.880\text{ g}}{\text{mL}} = 880\text{ g of benzene}$

62. a. 1.0 kg feather; Feathers are less dense than lead.

b. 100 g water since water is less dense than gold.

c. Same; Both volumes are 1.0 L.

63. $V = 1.00 \times 10^3\text{ g} \times \dfrac{1\text{ cm}^3}{22.57\text{ g}} = 44.3\text{ cm}^3$

$44.3\text{ cm}^3 = 1 \times w \times h = 4.00\text{ cm} \times 4.00\text{ cm} \times h$, $h = 2.77\text{ cm}$

64. $V = 22\text{ g} \times \dfrac{1\text{ cm}^3}{8.96\text{ g}} = 2.5\text{ cm}^3$; $V = \pi r^2 \times l$ where l = length of the wire

$2.5\text{ cm}^3 = \pi \times \left(\dfrac{0.25\text{ mm}}{2}\right)^2 \times \left(\dfrac{1\text{ cm}}{10\text{ mm}}\right)^2 \times l$, $l = 5.1 \times 10^3\text{ cm} = 170\text{ ft}$

Classification and Separation of Matter

65. Solid: own volume, own shape, does not flow; Liquid: own volume, takes shape of container, flows; Gas: takes volume and shape of container, flows

66. Homogeneous: Having visibly indistinguishable parts (the same throughout). Heterogeneous: Having visibly distinguishable parts (not uniform throughout).

a. heterogeneous (Due to mulch, water, roots, etc., which can all be present.)

b. heterogeneous: There is usually a fair amount of particulate matter present in the atmosphere (dirt, smog) in addition to condensed water (rain, clouds). However, an atmosphere consisting of only clean air can be considered homogeneous.

c. heterogeneous (due to bubbles)

d. homogeneous

e. homogeneous

f. homogeneous

67. A gas has molecules that are very far apart from each other while a solid or liquid has molecules that are very close together. An element has the same type of atom, whereas a compound contains two or more different elements. Picture i represents an element that exists as two atoms bonded together (like H_2 or O_2 or N_2). Picture iv represents a compound (like CO, NO, or HF). Pictures iii and iv contain representations of elements that exist as individual atoms (like Ar, Ne, or He).

a. Picture iv represents a gaseous compound. Note that pictures ii and iii also contain a gaseous compound, but they also both have a gaseous element present.

b. Picture vi represents a mixture of two gaseous elements.

c. Picture v represents a solid element.

d. Pictures ii and iii both represent a mixture of a gaseous element and a gaseous compound.

68. a. pure b. mixture c. mixture d. pure e. mixture (copper and zinc)

f. pure g. mixture h. mixture i. pure

Iron and uranium are elements. Water and table salt are compounds. Water is H_2O and table salt is NaCl. Compounds are composed of two or more elements.

69. A physical change is a change in the state of a substance (solid, liquid and gas are the three states of matter); a physical change does not change the chemical composition of the substance. A chemical change is a change in which a given substance is converted into another substance having a different formula (composition).

a. Vaporization refers to a liquid converting to a gas, so this is a physical change. The formula (composition) of the moth ball does not change.

b. This is a chemical change since hydrofluoric acid (HF) is reacting with glass (SiO_2) to form new compounds which wash away.

c. This is a physical change since all that is happening is the conversion of liquid alcohol to gaseous alcohol. The alcohol formula (C_2H_5OH) does not change.

d. This is a chemical change since the acid is reacting with cotton to form new compounds.

70. a. Distillation separates components of a mixture, so the orange liquid is a mixture (has an average color of the yellow liquid and the red solid). Distillation utilizes boiling point differences to separate out the components of a mixture. Distillation is a physical change since the components of the mixture do not become different compounds or elements.

b. Decomposition is a type of chemical reaction. The crystalline solid is a compound, and decomposition is a chemical change where new substances are formed.

c. Tea is a mixture of tea compounds dissolved in water. The process of mixing sugar into tea is a physical change. Sugar doesn't react with the tea compounds, it just makes the solution sweeter.

Additional Exercises

71. $1\ \mu\text{mol} \times \dfrac{1\ \text{mol}}{1 \times 10^6\ \mu\text{mol}} \times \dfrac{6.02 \times 10^{23}\ \text{atoms}}{\text{mol}} = 6.02 \times 10^{17}$ atoms of helium

$1.25 \times 10^{20}\ \text{atoms} \times \dfrac{1\ \text{mol}}{6.02 \times 10^{23}\ \text{atoms}} = 2.08 \times 10^{-4}$ mol helium

72. $126\ \text{gal} \times \dfrac{4\ \text{qt}}{\text{gal}} \times \dfrac{1\ \text{L}}{1.057\ \text{qt}} = 477\ \text{L}$

73. $\text{Total volume} = \left(200.\ \text{m} \times \dfrac{100\ \text{cm}}{\text{m}}\right) \times \left(300.\ \text{m} \times \dfrac{100\ \text{cm}}{\text{m}}\right) \times 4.0\ \text{cm} = 2.4 \times 10^9\ \text{cm}^3$

$\text{Vol. of topsoil covered by 1 bag} = \left[10.\ \text{ft}^2 \times \left(\dfrac{12\ \text{in}}{\text{ft}}\right)^2 \times \left(\dfrac{2.54\ \text{cm}}{\text{in}}\right)^2\right] \times \left(1.0\ \text{in} \times \dfrac{2.54\ \text{cm}}{\text{in}}\right)$

$= 2.4 \times 10^4\ \text{cm}^3$

$2.4 \times 10^9\ \text{cm}^3 \times \dfrac{1\ \text{bag}}{2.4 \times 10^4\ \text{cm}^3} = 1.0 \times 10^5$ bags topsoil

74. a. No; If the volumes were the same, then the gold idol would have a much greater mass because gold is much more dense than sand.

b. $\text{Mass} = 1.0\ \text{L} \times \dfrac{1000\ \text{cm}^3}{\text{L}} \times \dfrac{19.32\ \text{g}}{\text{cm}^3} \times \dfrac{1\ \text{kg}}{1000\ \text{g}} = 19.32\ \text{kg}\ (= 42.59\ \text{lb})$

It wouldn't be easy to play catch with the idol since it would have a mass of over 40 pounds.

75. $\text{Volume of lake} = 100\ \text{mi}^2 \times \left(\dfrac{5280\ \text{ft}}{\text{mi}}\right)^2 \times 20\ \text{ft} = 6 \times 10^{10}\ \text{ft}^3$

$6 \times 10^{10}\ \text{ft}^3 \times \left(\dfrac{12\ \text{in}}{\text{ft}} \times \dfrac{2.54\ \text{cm}}{\text{in}}\right)^3 \times \dfrac{1\ \text{mL}}{\text{cm}^3} \times \dfrac{0.4\ \mu\text{g}}{\text{mL}} = 7 \times 10^{14}\ \mu\text{g}$ mercury

$7 \times 10^{14}\ \mu\text{g} \times \dfrac{1\ \text{g}}{10^6\ \mu\text{g}} \times \dfrac{1\ \text{kg}}{10^3\ \text{g}} = 7 \times 10^5$ kg of mercury

76. $mass_{benzene}$ = 58.80 g - 25.00 g = 33.80 g; $V_{benzene} = 33.80\text{ g} \times \dfrac{1\text{ cm}^3}{0.880\text{ g}} = 38.4\text{ cm}^3$

$V_{solid} = 50.0\text{ cm}^3 - 38.4\text{ cm}^3 = 11.6\text{ cm}^3$; density $= \dfrac{25.00\text{ g}}{11.6\text{ cm}^3} = 2.16\text{ g/cm}^3$

77. a. Volume × density = mass; the orange block is more dense. Since mass (orange) > mass (blue) and since volume (orange) < volume (blue), the density of the orange block must be greater to account for the larger mass of the orange block.

b. Which block is more dense cannot be determined. Since mass (orange) > mass (blue) and since volume (orange) > volume (blue), the density of the orange block may or may not be larger than the blue block. If the blue block is more dense, its density cannot be so large that its mass is larger than the orange block's mass.

c. The blue block is more dense. Since mass (blue) = mass (orange) and since volume (blue) < volume (orange), the density of the blue block must be larger in order to equate the masses.

d. The blue block is more dense. Since mass (blue) > mass (orange) and since the volumes are equal, the density of the blue block must be larger in order to give the blue block the larger mass.

78. Circumference = c = 2πr; $V = \dfrac{4\pi r^3}{3} = \dfrac{4\pi}{3}\left(\dfrac{c}{2\pi}\right)^3 = \dfrac{c^3}{6\pi^2}$

Largest density $= \dfrac{5.25\text{ oz}}{\dfrac{(9.00\text{ in})^3}{6\pi^2}} = \dfrac{5.25\text{ oz}}{12.3\text{ in}^3} = \dfrac{0.427\text{ oz}}{\text{in}^3}$

Smallest density $= \dfrac{5.00\text{ oz}}{\dfrac{(9.25\text{ in})^3}{6\pi^2}} = \dfrac{5.00\text{ oz}}{13.4\text{ in}^3} = \dfrac{0.373\text{ oz}}{\text{in}^3}$

Maximum range is: $\dfrac{(0.373 - 0.427)\text{ oz}}{\text{in}^3}$ or 0.40 ± 0.03 oz/in^3 (Uncertainty in 2nd decimal place.)

79. $V = V_{final} - V_{initial}$; $d = \dfrac{28.90\text{ g}}{9.8\text{ cm}^3 - 6.4\text{ cm}^3} = \dfrac{28.90\text{ g}}{3.4\text{ cm}^3} = 8.5\text{ g/cm}^3$

$d_{max} = \dfrac{mass_{max}}{V_{min}}$; We get V_{min} from 9.7 cm^3 - 6.5 cm^3 = 3.2 cm^3.

$d_{max} = \dfrac{28.93\text{ g}}{3.2\text{ cm}^3} = \dfrac{9.0\text{ g}}{\text{cm}^3}$; $d_{min} = \dfrac{mass_{min}}{V_{max}} = \dfrac{28.87\text{ g}}{9.9\text{ cm}^3 - 6.3\text{ cm}^3} = \dfrac{8.0\text{ g}}{\text{cm}^3}$

The density is: 8.5 ± 0.5 g/cm^3.

Challenge Problems

80. a. $\frac{2.70 - 2.64}{2.70} \times 100 = 2\%$ b. $\frac{|16.12 - 16.48|}{16.12} \times 100 = 2.2\%$

c. $\frac{1.000 - 0.9981}{1.000} \times 100 = \frac{0.002}{1.000} \times 100 = 0.2\%$

81. In subtraction, the result gets smaller but the uncertainties add. If the two numbers are very close together, the uncertainty may be larger than the result. For example, let us assume we want to take the difference of the following two measured quantities: 999,999 ± 2 and 999,996 ± 2. The difference is 3 ± 4. Because of the uncertainty, subtracting two similar numbers is bad practice.

82. a. At some point in 1982, the composition of the metal used in minting pennies was changed since the mass changed during this year (assuming the volume of the pennies were constant).

b. It should be expressed as 3.08 ± 0.05 g. The uncertainty in the second decimal place will swamp any effect of the next decimal places.

83. Heavy pennies (old): mean mass = 3.08 ± 0.05 g

Light pennies (new): mean mass $= \frac{(2.467 + 2.545 + 2.518)}{3} = 2.51 \pm 0.04$ g

Since we are assuming that the volume is additive, let's calculate the volume of 100. g of each type of penny then calculate the density of the alloy. For 100. g of the old pennies, 95 g will be Cu and 5 g will be Zn.

$V = 95 \text{ g Cu} \times \frac{1 \text{ cm}^3}{8.96 \text{ g}} + 5 \text{ g Zn} \times \frac{1 \text{ cm}^3}{7.14 \text{ g}} = 11.3 \text{ cm}^3$ (carrying one extra sig. fig.)

Density of old pennies $= \frac{100. \text{ g}}{11.3 \text{ cm}^3} = 8.8 \text{ g/cm}^3$

For 100. g of new pennies, 97.6 g will be Zn and 2.4 g will be copper.

$V = 2.4 \text{ g Cu} \times \frac{1 \text{ cm}^3}{8.96 \text{ g}} + 97.6 \text{ g Zn} \times \frac{1 \text{ cm}^3}{7.14 \text{ g}} = 13.94 \text{ cm}^3$ (carrying one extra sig. fig.)

Density of new pennies $= \frac{100. \text{ g}}{13.94 \text{ cm}^3} = 7.17 \text{ g/cm}^3$

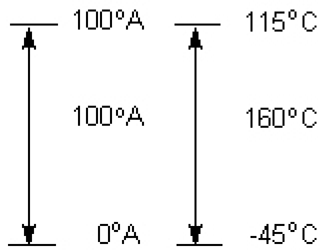
Since $d = \frac{\text{mass}}{\text{volume}}$ and since the volume of both types of pennies are assumed equal, then:

$$\frac{d_{new}}{d_{old}} = \frac{mass_{new}}{mass_{old}} = \frac{7.17\ g/cm^3}{8.8\ g/cm^3} = 0.81$$

The calculated average mass ratio is: $\dfrac{mass_{new}}{mass_{old}} = \dfrac{2.51\ g}{3.08\ g} = 0.815$

To the first two decimal places, the ratios are the same. If the assumptions are correct, then we can reasonably conclude that the difference in mass is accounted for by the difference in alloy used.

84. a.



A change in temperature of 160°C equals a change in temperature of 100°A.

So, $\dfrac{160\ °C}{100\ °C}$ is our unit conversion for a degree change in temperature.

At the freezing point: 0°A = -45°C

Combining the two pieces of information:

$$T_A = (T_C + 45°C) \times \frac{100°A}{160°C} = (T_C + 45°C) \times \frac{5°A}{8°C} \text{ or } T_C = T_A \times \frac{8°C}{5°A} - 45°C$$

b. $T_C = (T_F - 32) \times \dfrac{5}{9}$; $T_C = T_A \times \dfrac{8}{5} - 45 = (T_F - 32) \times \dfrac{5}{9}$

$$T_F - 32 = \frac{9}{5} \times \left[T_A \times \frac{8}{5} - 45\right] = T_A \times \frac{72}{25} - 81, \quad T_F = T_A \times \frac{72°F}{25°A} - 49°F$$

c. $T_C = T_A \times \dfrac{8}{5} - 45$ and $T_C = T_A$; So, $T_C = T_C \times \dfrac{8}{5} - 45$, $\dfrac{3 \times T_C}{5} = 45$, $T_C = 75°C = 75°A$

d. $T_C = 86°A \times \dfrac{8°C}{5°A} - 45°C = 93°C$; $T_F = 86°A \times \dfrac{72°F}{25°A} - 49°F = 199°F = 2.0 \times 10^2 °F$

e. $T_A = (45°C + 45°C) \times \dfrac{5°A}{8°C} = 56°A$

85. a. One possibility is that rope B is not attached to anything and rope A and rope C are connected via a pair of pulleys and/or gears.

b. Try to pull rope B out of the box. Measure the distance moved by C for a given movement of A. Hold either A or C firmly while pulling on the other.

86. The bubbles of gas is air in the sand that is escaping; methanol and sand are not reacting. We will assume that the mass of trapped air is insignificant.

mass of dry sand = 37.3488 g - 22.8317 g = 14.5171 g

mass of methanol = 45.2613 g - 37.3488 g = 7.9125 g

Volume of sand particles (air absent) = volume of sand and methanol - volume of methanol

Volume of sand particles (air absent) = 17.6 mL - 10.00 mL = 7.6 mL

density of dry sand (air present) = $\frac{14.5171\text{ g}}{10.0\text{ mL}}$ = 1.45 g/mL

density of methanol = $\frac{7.9125\text{ g}}{10.00\text{ mL}}$ = 0.7913 g/mL

density of sand particles (air absent) = $\frac{14.5171\text{ g}}{7.6\text{ mL}}$ = 1.9 g/mL