

2.34 Mass-mole-number conversions require the use of masses in grams, molar masses, and/or the Avogadro constant. To determine the number of moles, convert the mass into grams and divide by the molar mass.

$$(a) n = \frac{m}{MM} = 3.67 \text{ kg} \left(\frac{10^3 \text{ g}}{1 \text{ kg}} \right) \left(\frac{1 \text{ mol}}{47.88 \text{ g}} \right) = 76.6 \text{ mol};$$

$$(b) n = \frac{m}{MM} = 7.9 \text{ mg} \left(\frac{10^{-3} \text{ g}}{1 \text{ mg}} \right) \left(\frac{1 \text{ mol}}{40.08 \text{ g}} \right) = 2.0 \times 10^{-4} \text{ mol};$$

$$(c) n = \frac{m}{MM} = 1.56 \text{ g} \left(\frac{1 \text{ mol}}{101.07 \text{ g}} \right) = 1.54 \times 10^{-2} \text{ mol}; \text{ and}$$

$$(d) n = \frac{m}{MM} = 9.63 \text{ pg} \left(\frac{10^{-12} \text{ g}}{1 \text{ pg}} \right) \left(\frac{1 \text{ mol}}{98 \text{ g}} \right) = 9.8 \times 10^{-14} \text{ mol}.$$

3.34 All parts of this question involve mass-mole-number conversions. Moles and mass in grams are related through the equation, $n = \frac{m}{MM}$. Use the Avogadro constant to convert between number and moles. When masses are not given in grams, unit conversions must be made. The chemical formula states the number of atoms of each element per molecule of substance.

$$MM (\text{C}_{20}\text{H}_{24}\text{O}_2) = 20(12.01 \text{ g/mol}) + 24(1.008 \text{ g/mol}) + 2(16.00 \text{ g/mol}) = 296.4 \text{ g/mol};$$

$$n = \frac{m}{MM} = 0.035 \text{ mg} \left(\frac{10^{-3} \text{ g}}{1 \text{ mg}} \right) \left(\frac{1 \text{ mol}}{296.4 \text{ g}} \right) = 1.18 \times 10^{-7} \text{ mol};$$

(note an additional sig. fig. is added here to avoid rounding errors later on)

$$\# = n N_A = (1.2 \times 10^{-7} \text{ mol})(6.022 \times 10^{23} \text{ molecules/mol}) = 7.2 \times 10^{16} \text{ molecules};$$

atoms = (atoms/molecule)(# molecules)

$$\#_{\text{C atoms}} = 7.2 \times 10^{16} \text{ molecules} \left(\frac{20 \text{ atom C}}{1 \text{ molecule C}_{20}\text{H}_{24}\text{O}_2} \right) = 1.4 \times 10^{18} \text{ atoms C};$$

$$m = n MM = 1.18 \times 10^{-7} \text{ mol} \left(\frac{20 \text{ mol C}}{1 \text{ mole C}_{20}\text{H}_{24}\text{O}_2} \right) \left(\frac{12.01 \text{ g}}{1 \text{ mol}} \right) = 2.9 \times 10^{-5} \text{ g}. \text{ (remember there should only be two sig figs here because the number of moles is only known to 2 sig figs)}$$

- 3.38 When working with mass percent compositions, it is convenient to consider 100 g of substance. Divide the mass of each element by its elemental molar mass to obtain relative amounts of each element in the substance.

$$\text{O: } \left(\frac{41.41 \text{ g}}{100 \text{ g}} \right) \left(\frac{1 \text{ mol}}{16.00 \text{ g}} \right) = 2.588 \text{ mol O/100 g};$$

$$\text{P: } \left(\frac{18.50 \text{ g}}{100 \text{ g}} \right) \left(\frac{1 \text{ mol}}{30.97 \text{ g}} \right) = 0.5974 \text{ mol P/100 g};$$

$$\text{H: } \left(\frac{0.20 \text{ g}}{100 \text{ g}} \right) \left(\frac{1 \text{ mol}}{1.008 \text{ g}} \right) = 0.20 \text{ mol H/100 g};$$

$$\text{Ca: } \left(\frac{39.89 \text{ g}}{100 \text{ g}} \right) \left(\frac{1 \text{ mol}}{40.08 \text{ g}} \right) = 0.9953 \text{ mol Ca/100 g};$$

To obtain the empirical formula divide each amount by the smallest among them (hydrogen with 0.20 mol/100 g;) and round to whole numbers. This tells us the number of each element relative to one nitrogen atom in the compound:

$$\text{O: } \left(\frac{2.588 \text{ mol O}}{100 \text{ g}} \right) \left(\frac{100 \text{ g}}{0.20 \text{ mol H}} \right) = 13 \text{ mol O/mol H, round to 13 O/H};$$

$$\text{P: } \left(\frac{0.5974 \text{ mol P}}{100 \text{ g}} \right) \left(\frac{100 \text{ g}}{0.20 \text{ mol H}} \right) = 3.0 \text{ mol P/mol H, round to 3 P/H};$$

$$\text{Ca: } \left(\frac{0.9953 \text{ mol Ca}}{100 \text{ g}} \right) \left(\frac{100 \text{ g}}{0.20 \text{ mol H}} \right) = 5.0 \text{ mol Ca/mol H, round to 5 Ca/H};$$

Empirical formula: $\text{Ca}_5\text{HP}_3\text{O}_{13}$, empirical $MM = 502.3 \text{ g/mol}$;

To convert empirical formula to molecular formula, multiply subscripts in the empirical formula by the ratio of the compound's molar mass to its empirical formula mass.

$$MM/\text{empirical } MM = \left(\frac{1004 \text{ g/mol}}{502.3 \text{ g/mol}} \right) = 2; \text{ Molecular formula: } \text{Ca}_{10}\text{H}_2\text{P}_6\text{O}_{26}.$$

- 3.66 The chemical formula of a substance provides all the information needed to compute its molar characteristics.

(a) $MM = 58.69 + 32.07 + 4(16.00) + 6[(2)(1.008) + 16.00] = 262.9 \text{ g/mol}$;

(b) $n = \frac{m}{MM} = 25.0 \text{ g} \left(\frac{1 \text{ mol}}{262.9 \text{ g}} \right) = 9.51 \times 10^{-2} \text{ mol}$;

(c) To determine the percent composition, work with one mole of substance. Take the ratio of the mass of each element that one mole contains to the mass of one mole (molar mass).

$$\% \text{ Ni} = \frac{58.69 \text{ g/mol}}{262.9 \text{ g/mol}} \times 100\% = 22.33 \%$$

$$\% \text{ S} = \frac{32.07 \text{ g/mol}}{262.9 \text{ g/mol}} \times 100\% = 12.20 \%$$

$$\% \text{ O} = \frac{10(16.00 \text{ g/mol})}{262.9 \text{ g/mol}} \times 100\% = 60.87 \%$$

$$\% \text{ H} = \frac{12(1.008 \text{ g/mol})}{262.9 \text{ g/mol}} \times 100\% = 4.601 \%$$

$$(d) 1.00 \text{ mol O} \left(\frac{1 \text{ mol NiSO}_4 \cdot 6\text{H}_2\text{O}}{10 \text{ mol O}} \right) \left(\frac{262.9 \text{ g}}{1 \text{ mol}} \right) = 26.3 \text{ g.}$$

3.40 Since the rxn yields pure lead as one of the product, we can determine the mass of sulfur in the galena sample by taking the difference:

$$m_{\text{S}} = m_{\text{galena}} - m_{\text{Pb}} = 7.85 \text{ g} - 6.80 \text{ g} = 1.05 \text{ g sulfur}$$

$$n_{\text{S}} = \frac{m_{\text{S}}}{MM_{\text{S}}} = 1.05 \text{ g} \left(\frac{1 \text{ mol}}{32.066 \text{ g}} \right) = 0.0327 \text{ mol}$$

$$n_{\text{Pb}} = \frac{m_{\text{Pb}}}{MM_{\text{Pb}}} = 6.80 \text{ g} \left(\frac{1 \text{ mol}}{200.59 \text{ g}} \right) = 0.0339 \text{ mol}$$

Since the ratio (0.0327/0.0339) is approximately 1:1, the empirical formula of galena is PbS.

3.42 The problem statement identifies this as an empirical formula problem. Use the combustion data to determine the mass percent composition of the compound, then use elemental molar masses to find the empirical formula.

$$m_{\text{C}} = 3.83 \text{ g CO}_2 \left(\frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} \right) \left(\frac{1 \text{ mol C}}{1 \text{ mol CO}_2} \right) \left(\frac{12.01 \text{ g C}}{1 \text{ mol C}} \right) = 1.045 \text{ g;}$$

$$\% \text{ C} = \frac{1.045 \text{ g}}{1.45 \text{ g}} \times 100\% = 72.1 \%$$

$$m_{\text{H}} = 1.56 \text{ g H}_2\text{O} \left(\frac{1 \text{ mol}}{18.02 \text{ g}} \right) \left(\frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} \right) \left(\frac{1.008 \text{ g}}{1 \text{ mol}} \right) = 0.1745 \text{ g;}$$

$$\% \text{ H} = \frac{0.1745 \text{ g}}{1.45 \text{ g}} \times 100\% = 12.0 \%$$

Mass percent of O can be determined by subtracting the other percentages from 100%

$$\% \text{ O} = 100 \% - (72.1 \% + 12.0 \%) = 15.9 \%$$

$$\text{C: } 72.1 \text{ g} \left(\frac{1 \text{ mol}}{12.01 \text{ g}} \right) = 6.00 \text{ mol C; H: } 12.0 \text{ g} \left(\frac{1 \text{ mol}}{1.008 \text{ g}} \right) = 11.9 \text{ mol H;}$$

$$\text{O: } 15.9 \text{ g} \left(\frac{1 \text{ mol}}{16.00 \text{ g}} \right) = 0.994 \text{ mol O;}$$

Divide each by the smallest among them, 0.994 mol O:

$$\frac{6.00 \text{ mol C}}{0.994 \text{ mol O}} = 6.04 \text{ C/O, round to 6}; \quad \frac{11.9 \text{ mol H}}{0.994 \text{ mol O}} = 12.0 \text{ H/O, round to 12};$$

The empirical formula is $\text{C}_6\text{H}_{12}\text{O}$.

- 3.86 This is an empirical formula problem involving combustion analysis. Do a mass analysis of the combustion data to obtain the mass percent composition of the compound. Determine the mass percent oxygen by difference. Once the mass percentages are known, use elemental molar masses to determine relative amounts of the elements. % N = 3.8 % (stated in the problem);

$$m \text{ C} = 97.46 \text{ mg CO}_2 \left(\frac{1 \text{ mol}}{44.01 \text{ g}} \right) \left(\frac{1 \text{ mol C}}{1 \text{ mol CO}_2} \right) \left(\frac{12.01 \text{ g}}{1 \text{ mol}} \right) = 26.60 \text{ mg};$$

$$\% \text{ C} = \frac{26.60 \text{ mg}}{38.70 \text{ mg}} \times 100\% = 68.73 \%;$$

$$m \text{ H} = 20.81 \text{ mg H}_2\text{O} \left(\frac{1 \text{ mol}}{18.02 \text{ g}} \right) \left(\frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} \right) \left(\frac{1.008 \text{ g}}{1 \text{ mol}} \right) = 2.328 \text{ mg};$$

$$\% \text{ H} = \frac{2.328 \text{ mg}}{38.70 \text{ mg}} \times 100\% = 6.016 \%;$$

$$\% \text{ O} = 100 \% - (3.8 \% + 68.73 \% + 6.016 \%) = 21.5 \%;$$

$$\text{C: } 68.73 \text{ g} \left(\frac{1 \text{ mol}}{12.01 \text{ g}} \right) = 5.723 \text{ mol C}; \quad \text{H: } 6.016 \text{ g} \left(\frac{1 \text{ mol}}{1.008 \text{ g}} \right) = 5.968 \text{ mol H};$$

$$\text{N: } 3.8 \text{ g} \left(\frac{1 \text{ mol}}{14.01 \text{ g}} \right) = 0.27 \text{ mol N}; \quad \text{O: } 21.5 \text{ g} \left(\frac{1 \text{ mol}}{16.00 \text{ g}} \right) = 1.34 \text{ mol O};$$

Divide each by the smallest among them, 0.27 mol N, to determine the relative amounts of each element in the compound:

$$\frac{5.723 \text{ mol C}}{0.27 \text{ mol N}} = 21 \text{ C/N};$$

$$\frac{5.968 \text{ mol H}}{0.27 \text{ mol N}} = 22 \text{ H/N};$$

$$\frac{1.34 \text{ mol O}}{0.27 \text{ mol N}} = 5.0 \text{ O/N};$$

These values match those for heroin, $\text{C}_{21}\text{H}_{22}\text{O}_5\text{N}$.

- 3.50 This is a dilution type problem. Begin by deriving the expression to solve for the volume:

$$M_i V_i = M_f V_f, \text{ or } V_i = \frac{M_f V_f}{M_i}$$

$$V_i = \frac{(0.500 \text{ M})(1.25 \text{ L})}{14.8 \text{ M}} = 0.0422 \text{ L or } 42.2 \text{ mL}$$

- 3.52 In each of the following, remember that concentration is $M = \frac{n}{V}$. Begin each problem by identifying the major ionic species present.

(b) Major ionic species: Fe^{3+} , Cl^-

Determine the number of moles in 1.44 mg of the salt and use stoichiometric ratios to determine the number of moles of each ion:

$$MM(\text{FeCl}_3) = 55.85 \text{ g/mol} + 3(35.45 \text{ g/mol}) = 162.2 \text{ g/mol}$$

$$n(\text{FeCl}_3) = 1.44 \text{ mg} \left(\frac{10^{-3} \text{ g}}{1 \text{ mg}} \right) \left(\frac{1 \text{ mol}}{162.2 \text{ g}} \right) = 8.88 \times 10^{-6} \text{ mol}$$

$$n(\text{Fe}^{3+}) = 8.88 \times 10^{-6} \text{ mol FeCl}_3 \left(\frac{1 \text{ mol Fe}^{3+}}{1 \text{ mol FeCl}_3} \right) = 8.88 \times 10^{-6} \text{ mol}$$

$$n(\text{Cl}^-) = 8.88 \times 10^{-6} \text{ mol FeCl}_3 \left(\frac{3 \text{ mol Cl}^-}{1 \text{ mol FeCl}_3} \right) = 2.66 \times 10^{-5} \text{ mol}$$

Obtain the molarities by dividing the number of moles of each ion by the volume:

$$V = 2.75 \text{ mL} \left(\frac{10^{-3} \text{ L}}{1 \text{ mL}} \right) = 2.75 \times 10^{-3} \text{ L};$$

$$[\text{Fe}^{3+}] = \left(\frac{8.88 \times 10^{-6} \text{ mol}}{0.00275 \text{ L}} \right) = 3.23 \times 10^{-3} \text{ M}$$

$$[\text{Cl}^-] = \left(\frac{2.66 \times 10^{-5} \text{ mol}}{0.00275 \text{ L}} \right) = 9.69 \times 10^{-3} \text{ M}$$

(c) KNO_3 contains both a Group 1 metal ion and a polyatomic ion. The major ionic species are: K^+ , NO_3^-

Since all stoichiometric ratios are 1 for this compound, the moles of each ion equal the moles of the compound:

$$MM = 39.10 \text{ g/mol} + 14.01 \text{ g/mol} + 3(16.00 \text{ g/mol}) = 101.1 \text{ g/mol}$$

$$n(\text{K}^+) = n(\text{NO}_3^-) = n(\text{KNO}_3) = 8.75 \text{ kg} \left(\frac{10^3 \text{ g}}{1 \text{ kg}} \right) \left(\frac{1 \text{ mol}}{101.1 \text{ g}} \right) = 86.5 \text{ mol};$$

Determine the molarities by dividing the number of moles by the volume:

$$[\text{K}^+] = [\text{NO}_3^-] = \frac{86.5 \text{ mol}}{235 \text{ L}} = 0.368 \text{ M}$$

3.84 (a) $MM = 3(22.99 \text{ g/mol Na}) + 30.97 \text{ g/mol P} + 4(16.00 \text{ g/mol O}) = 163.94 \text{ g/mol}$

$$n = 90.0 \text{ g} \left(\frac{1 \text{ mol}}{163.94 \text{ g}} \right) = 0.549 \text{ mol}$$

$$M = \left(\frac{0.549 \text{ mol}}{1.5 \text{ L}} \right) = 0.37 \text{ M Na}_3\text{PO}_4 \text{ (use 0.366 M in b and c to avoid round off error)}$$

$$(b) 2.50 \text{ g} \left(\frac{1 \text{ mol}}{163.94 \text{ g}} \right) = 1.52 \times 10^{-2} \text{ mol}$$

$$\text{volume} = \frac{n}{M} = 1.52 \times 10^{-2} \text{ mol} \left(\frac{1 \text{ L}}{0.366 \text{ mol}} \right) = 4.2 \times 10^{-2} \text{ L or 42 mL}$$

$$(c) 2(0.705 \text{ M}) \left(\frac{50.0 \text{ mL}}{125 \text{ mL}} \right) + 3(0.366 \text{ M}) \left(\frac{75.0 \text{ mL}}{125 \text{ mL}} \right) = 1.22 \text{ M}$$