# 3 Mass Relationships in Chemical Reactions

3.1 $3\ A_2 + 2\ B \rightarrow 2\ BA_3$

3.2 reactants, box (d), and products, box (c)

3.3 $4\ NH_3 + Cl_2 \rightarrow N_2H_4 + 2\ NH_4Cl$

3.4 $8\ KClO_3 + C_{12}H_{22}O_{11} \rightarrow 8\ KCl + 12\ CO_2 + 11\ H_2O$

3.5 $H_2SO_4$ $2(1.01) + 1(32.07) + 4(16.00) = 98.1$

3.6 sucrose, $C_{12}H_{22}O_{11}$ $12(12.01) + 22(1.01) + 11(16.00) = 342.3$
molar mass = 342.3 g/mol

3.7 $NaHCO_3$, 84.0

$$5.26\text{ g } NaHCO_3 \times \frac{1\text{ mol } NaHCO_3}{84.0\text{ g } NaHCO_3} = 0.0626\text{ mol } NaHCO_3$$

3.8 glucose, $C_6H_{12}O_6$, 180.0

(a) $$0.0833\text{ mol glucose} \times \frac{180.0\text{ g glucose}}{1\text{ mol glucose}} = 15.0\text{ g glucose}$$

(b) $$15.0\text{ g glucose} \times \frac{1\text{ glucose tablet}}{3.75\text{ g glucose}} = 4\text{ glucose tablets}$$

(c) $$0.0833\text{ mol glucose} \times \frac{6.022 \times 10^{23}\text{ glucose molecules}}{1\text{ mol glucose}} = 5.02 \times 10^{22}\text{ glucose molecules}$$

3.9 salicylic acid, $C_7H_6O_3$, 138.1; acetic anhydride, $C_4H_6O_3$, 102.1

$$4.50\text{ g } C_7H_6O_3 \times \frac{1\text{ mol } C_7H_6O_3}{138.1\text{ g } C_7H_6O_3} \times \frac{1\text{ mol } C_4H_6O_3}{1\text{ mol } C_7H_6O_3} \times \frac{102.1\text{ g } C_4H_6O_3}{1\text{ mol } C_4H_6O_3} = 3.33\text{ g } C_4H_6O_3$$

3.10 salicylic acid, $C_7H_6O_3$, 138.1; acetic anhydride, $C_4H_6O_3$, 102.1
aspirin, $C_9H_8O_4$, 180.2; acetic acid, $CH_3CO_2H$, 60.1

(a) $$10.0\text{ g } C_9H_8O_4 \times \frac{1\text{ mol } C_9H_8O_4}{180.2\text{ g } C_9H_8O_4} \times \frac{1\text{ mol } C_7H_6O_3}{1\text{ mol } C_9H_8O_4} \times \frac{138.1\text{ g } C_7H_6O_3}{1\text{ mol } C_7H_6O_3} = 7.66\text{ g } C_7H_6O_3$$

(b) $$10.0\text{ g } C_9H_8O_4 \times \frac{1\text{ mol } C_9H_8O_4}{180.2\text{ g } C_9H_8O_4} \times \frac{1\text{ mol } CH_3CO_2H}{1\text{ mol } C_9H_8O_4} \times \frac{60.1\text{ g } CH_3CO_2H}{1\text{ mol } CH_3CO_2H} = 3.34\text{ g } CH_3CO_2H$$

3.11 $C_2H_4$, 28.1; $C_2H_6O$, 46.1

$$4.6\text{ g } C_2H_4 \times \frac{1\text{ mol } C_2H_4}{28.1\text{ g } C_2H_4} \times \frac{1\text{ mol } C_2H_6O}{1\text{ mol } C_2H_4} \times \frac{46.1\text{ g } C_2H_6O}{1\text{ mol } C_2H_6O} = 7.5\text{ g } C_2H_6O \text{ (theoretical yield)}$$

$$\text{Percent yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100\% = \frac{4.7\text{ g}}{7.5\text{ g}} \times 100\% = 63\%$$

3.12 $C_2H_6O$, 46.1; $C_4H_{10}O$, 74.1

(a) $$40.0\text{ g } C_2H_6O \times \frac{1\text{ mol } C_2H_6O}{46.1\text{ g } C_2H_6O} \times \frac{1\text{ mol } C_4H_{10}O}{2\text{ mol } C_2H_6O} \times \frac{74.1\text{ g } C_4H_{10}O}{1\text{ mol } C_4H_{10}O} = 32.1\text{ g } C_4H_{10}O \text{ (theoretical yield)}$$

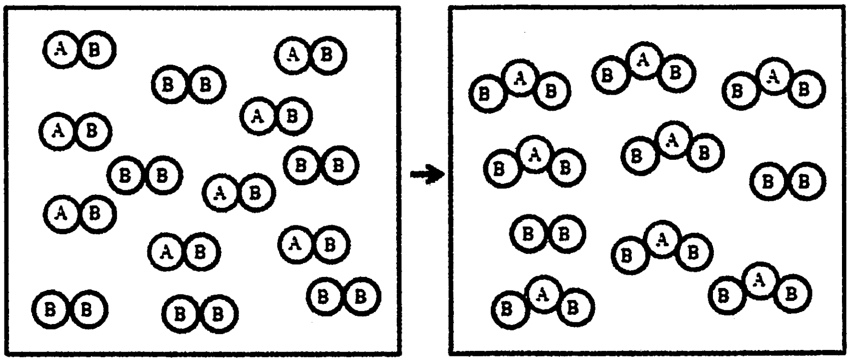
actual yield = (32.1 g)(0.870) = 27.9 g $C_4H_{10}O$

(b) 100.0 g = (theoretical yield)(0.870)
theoretical yield = 100.0 g/0.870 = 115 g $C_4H_{10}O$

$$115\text{ g } C_4H_{10}O \times \frac{1\text{ mol } C_4H_{10}O}{74.1\text{ g } C_4H_{10}O} \times \frac{2\text{ mol } C_2H_6O}{1\text{ mol } C_4H_{10}O} \times \frac{46.1\text{ g } C_2H_6O}{1\text{ mol } C_2H_6O} = 143\text{ g } C_2H_6O$$

3.13 (a) $A + B_2 \rightarrow AB_2$
There is a 1:1 stoichiometry between the two reactants. A is the limiting reactant because there are fewer reactant A's than there are reactant $B_2$'s.
(b) 1.0 mol of $AB_2$ can be made from 1.0 mol of A and 1.0 mol of $B_2$.

3.14



$B_2$ is in excess, AB is the limiting reactant.

3.15 $Li_2O$, 29.9: 65 kg = 65,000 g; $H_2O$, 18.0: 80.0 kg = 80,000 g; LiOH, 23.9

(a) $$65{,}000\text{ g } Li_2O \times \frac{1\text{ mol } Li_2O}{29.9\text{ g } Li_2O} = 2.17 \times 10^3\text{ mol } Li_2O$$

$$80{,}000\text{ g } H_2O \times \frac{1\text{ mol } H_2O}{18.0\text{ g } H_2O} = 4.44 \times 10^3\text{ mol } H_2O$$

The reaction stoichiometry between $Li_2O$ and $H_2O$ is one to one. There are twice as many moles of $H_2O$ as there are moles of $Li_2O$. Therefore, $Li_2O$ is the limiting reactant.

(b) $(4.44 \times 10^3 \text{ mol} - 2.17 \times 10^3 \text{ mol}) = 2.27 \times 10^3 \text{ mol } H_2O$ remaining

$$2.27 \times 10^3 \text{ mol } H_2O \times \frac{18.0 \text{ g } H_2O}{1 \text{ mol } H_2O} = 40{,}860 \text{ g } H_2O = 40.9 \text{ kg} = 41 \text{ kg } H_2O$$

3.16 $LiHCO_3$, 68.0; LiOH, 23.9

$$500.0 \text{ g } LiHCO_3 \times \frac{1 \text{ mol } LiHCO_3}{68.0 \text{ g } LiHCO_3} \times \frac{1 \text{ mol LiOH}}{1 \text{ mol } LiHCO_3} \times \frac{23.9 \text{ g LiOH}}{1 \text{ mol LiOH}} = 175.7 \text{ g LiOH}$$

You start with 400.0 g of LiOH. 500.0 g of $LiHCO_3$ are produced from 175.7 g of LiOH. Over 200 g of LiOH remain. Additional $CO_2$ can be removed.

3.17 Assume a 100.0 g sample. From the percent composition data, a 100.0 g sample contains 14.25 g C, 56.93 g O, and 28.83 g Mg.

$$14.25 \text{ g C} \times \frac{1 \text{ mol C}}{12.011 \text{ g C}} = 1.19 \text{ mol C}$$

$$56.93 \text{ g O} \times \frac{1 \text{ mol O}}{15.999 \text{ g O}} = 3.56 \text{ mol O}$$

$$28.83 \text{ g Mg} \times \frac{1 \text{ mol Mg}}{24.305 \text{ g Mg}} = 1.19 \text{ mol Mg}$$

$Mg_{1.19}C_{1.19}O_{3.56}$; divide each subscript by the smallest, 1.19.

$Mg_{1.19/1.19}C_{1.19/1.19}O_{3.56/1.19}$

The empirical formula is $MgCO_3$.

3.18 glucose, $C_6H_{12}O_6$, 180.0

Divide each subscript by the smallest, 6, to get the empirical formula.

$C_{6/6}H_{12/6}O_{6/6}$

The empirical formula is $CH_2O$.

Percent composition:

$$\%C = \frac{6 \times 12.0 \text{ g}}{180.0 \text{ g}} \times 100\% = 40.0\%$$

$$\%H = \frac{12 \times 1.01 \text{ g}}{180.0 \text{ g}} \times 100\% = 6.7\%$$

$$\%O = \frac{6 \times 16.0 \text{ g}}{180.0 \text{ g}} \times 100\% = 53.3\%$$

3.19 $$1.161 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.0 \text{ g } H_2O} \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.129 \text{ mol H}$$

$$2.818 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.0 \text{ g } CO_2} \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.0640 \text{ mol C}$$

$$0.129 \text{ mol H} \times \frac{1.01 \text{ g H}}{1 \text{ mol H}} = 0.130 \text{ g H}$$

$0.0640 \text{ mol C} \times \dfrac{12.0 \text{ g C}}{1 \text{ mol C}} = 0.768 \text{ g C}$

$1.00 \text{ g total} - (0.130 \text{ g H} + 0.768 \text{ g C}) = 0.102 \text{ g O}$

$0.102 \text{ g O} \times \dfrac{1 \text{ mol O}}{16.0 \text{ g O}} = 0.006\ 38 \text{ mol O}$

$C_{0.0640}H_{0.129}O_{0.006\ 38}$; divide each subscript by the smallest, 0.006 38.

$C_{0.0640 / 0.006\ 38}H_{0.129 / 0.006\ 38}O_{0.006\ 38 / 0.006\ 38}$

$C_{10.03}H_{20.22}O_1$

The empirical formula is $C_{10}H_{20}O$.

3.20 $0.697 \text{ g } H_2O \times \dfrac{1 \text{ mol } H_2O}{18.0 \text{ g } H_2O} \times \dfrac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.0774 \text{ mol H}$

$1.55 \text{ g } CO_2 \times \dfrac{1 \text{ mol } CO_2}{44.0 \text{ g } CO_2} \times \dfrac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.0352 \text{ mol C}$

$C_{0.0352}H_{0.0774}$; divide each subscript by the smaller, 0.0352.

$C_{0.0352 / 0.0352}H_{0.0774 / 0.0352}$

$CH_2$

The empirical formula is $CH_2$, 14.0.

142.0 / 14.0 = 10.1 = 10; molecular formula = $C_{(10 \times 1)}H_{(10 \times 2)} = C_{10}H_{20}$

3.21 The empirical formula is $C_6H_5$, 77.0.

The peak with the largest mass in the mass spectrum occurs near a mass of 154, which would be the molecular weight of the compound.

154/77.0 = 2; molecular formula = $C_{(2 \times 6)}H_{(2 \times 5)} = C_{12}H_{10}$

3.22 $0.57 \text{ g } H_2O \times \dfrac{1 \text{ mol } H_2O}{18.0 \text{ g } H_2O} \times \dfrac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.063 \text{ mol H}$

$2.79 \text{ g } CO_2 \times \dfrac{1 \text{ mol } CO_2}{44.0 \text{ g } CO_2} \times \dfrac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.063 \text{ mol C}$

$0.063 \text{ mol H} \times \dfrac{1.01 \text{ g H}}{1 \text{ mol H}} = 0.063 \text{ g H}$; $\quad 0.063 \text{ mol C} \times \dfrac{12.0 \text{ g C}}{1 \text{ mol C}} = 0.76 \text{ g C}$

$1.00 \text{ g total} - (0.063 \text{ g H} + 0.76 \text{ g C}) = 0.18 \text{ g N}$

$0.18 \text{ g N} \times \dfrac{1 \text{ mol N}}{14.0 \text{ g N}} = 0.013 \text{ mol N}$

$C_{0.063}H_{0.063}N_{0.013}$; divide each subscript by the smallest, 0.013.

$C_{0.063 / 0.013}H_{0.063 / 0.013}N_{0.013 / 0.013}$

$C_{4.85}H_{4.85}N$

The empirical formula is $C_5H_5N$, 79.0.

The peak with the largest mass in the mass spectrum occurs near a mass of 79, which would be the molecular weight of the compound, therefore the empirical formula and molecular formula are the same.

3.23 (b) Design safer chemical products and processes that reduce or eliminate the generation of hazardous substances.

3.24 (a) percent yield (b) percent atom economy

3.25 (a) Reaction 1 has the higher % atom economy because all reactant atoms are used.
(b) rxn 1: $C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2$
There are no undesired products, therefore the % Atom Economy = 100%.

rxn 2: $CH_3Cl + Br^- \rightarrow CH_3Br + Cl^-$

| Reactants: | Desired Product: |
|---|---|
| 1 C = (1)(12.0) = 12.0 | 1 C = (1)(12.0) = 12.0 |
| 3 H = (3)(1.0) = 3.0 | 3 H = (3)(1.0) = 3.0 |
| 1 Cl = (1)(35.5) = 35.5 | 1 Br = (1)(80.0) = 80.0 |
| 1 Br = (1)(80.0) = 80.0 | Σ = 93.0 |
| Σ = 130.5 | |

$$\% \text{ Atom Economy} = \frac{\Sigma \text{ Atomic Weight}_{\text{(atoms in desired product)}}}{\Sigma \text{ Atomic Weight}_{\text{(atoms in all reactants)}}} = \frac{93.0}{130.5} \times 100 = 71\%$$

3.26 (a) $C_3H_8O$, 60.1; $C_3H_6$, 42.1

$$23.50 \text{ g } C_3H_8O \times \frac{1 \text{ mol } C_3H_8O}{60.1 \text{ g } C_3H_8O} = 0.39 \text{ mol } C_3H_8O$$

$$\text{theoretical yield} = (0.39 \text{ mol } C_3H_8O)\left(\frac{1 \text{ mol } C_3H_6}{1 \text{ mol } C_3H_8O}\right)\left(\frac{42.1 \text{ g } C_3H_6}{1 \text{ mol } C_3H_6}\right) = 16.4 \text{ g } C_3H_6$$

$$\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\% = \frac{10.15 \text{ g}}{16.4 \text{ g}} \times 100\% = 61.9\%$$

(b) $C_3H_8O \rightarrow C_3H_6 + H_2O$

| Reactants: | Desired Product: |
|---|---|
| 3 C = (3)(12.0) = 36.0 | 3 C = (3)(12.0) = 36.0 |
| 8 H = (8)(1.0) = 8.0 | 6 H = (6)(1.0) = 6.0 |
| 1 O = (1)(16.0) = 16.0 | Σ = 42.0 |
| Σ = 60.0 | |

$$\% \text{ Atom Economy} = \frac{\Sigma \text{ Atomic Weight}_{\text{(atoms in desired product)}}}{\Sigma \text{ Atomic Weight}_{\text{(atoms in all reactants)}}} = \frac{42.0}{60.0} \times 100 = 70\%$$

3.27 (a) Ibuprofen, $C_{13}H_{18}O_2$
(b) (13 x 12.0) + (18 x 1.0) + (2 x 16.0) = 206.0
(c) $\% C = \frac{13 \times 12.0 \text{ g}}{206.0 \text{ g}} \times 100\% = 75.7\%$

$$\%H = \frac{18 \times 1.01\ g}{206.0\ g} \times 100\% = 8.8\%$$

$$\%O = \frac{2 \times 16.0\ g}{206.0\ g} \times 100\% = 15.5\%$$

3.28 (a) $4\ mol\ H \times \frac{1.0\ g\ H}{1\ mol\ H} = 4.0\ g\ H$

$2\ mol\ C \times \frac{12.0\ g\ C}{1\ mol\ C} = 24.0\ g\ C$

$2\ mol\ O \times \frac{16.0\ g\ O}{1\ mol\ O} = 32.0\ g\ O$

4.0 g + 24.0 g + 32.0 g = 60.0 g

(b) Ibuprofen, $C_{13}H_{18}O_2$, 206.0

mass Ibuprofen = $30 \times 10^6\ lbs \times \frac{1\ kg}{2.20\ lbs} \times \frac{1000\ g}{1\ kg} = 1.4 \times 10^{10}$ g Ibuprofen

mol Ibuprofen = $1.4 \times 10^{10}$ g Ibuprofen $\times \frac{1\ mol\ Ibuprofen}{206.0\ g\ Ibuprofen} = 6.6 \times 10^7$ mol Ibuprofen

(c) $6.6 \times 10^7$ mol Ibuprofen $\times \frac{60.0\ g\ waste}{1\ mol\ Ibuprofen} \times \frac{1\ kg}{1000\ g} = 4.0 \times 10^6$ kg waste

## Conceptual Problems

3.29 (c) $2\ A + B_2 \rightarrow A_2B_2$

3.30 $2\ A_5B_2 \rightarrow A_2 + 4\ A_2B$

3.31 $C_{17}H_{18}F_3NO$ 17(12.01) + 18(1.01) + 3(19.00) + 1(14.01) + 1(16.00) = 309.36

3.32 (a) $A_2 + 3\ B_2 \rightarrow 2\ AB_3$; $B_2$ is the limiting reactant because it is completely consumed.
(b) For 1.0 mol of $A_2$, 3.0 mol of $B_2$ are required. Because only 1.0 mol of $B_2$ is available, $B_2$ is the limiting reactant.

$1\ mol\ B_2 \times \frac{2\ mol\ AB_3}{3\ mol\ B_2} = 2/3\ mol\ AB_3$

3.33 $C_3H_7NO_2S$, 121.2

$$\%C = \frac{3 \times 12.0\ g}{121.2\ g} \times 100\% = 29.7\%$$

$$\%H = \frac{7 \times 1.01\ g}{121.2\ g} \times 100\% = 5.83\%$$

$$\%N = \frac{1 \times 14.0\ g}{121.2\ g} \times 100\% = 11.6\%$$

$$\%\,O = \frac{2 \text{ x } 16.0\text{ g}}{121.2\text{ g}} \text{ x } 100\% = 26.4\%$$

$$\%\,S = \frac{1 \text{ x } 32.1\text{ g}}{121.2\text{ g}} \text{ x } 100\% = 26.5\%$$

3.34 The molecular formula for cytosine is $C_4H_5N_3O$.

$$\text{mol } CO_2 = 0.001 \text{ mol cyt x } \frac{4\text{ C}}{\text{cyt}} \text{ x } \frac{1\text{ }CO_2}{\text{C}} = 0.004 \text{ mol } CO_2$$

$$\text{mol } H_2O = 0.001 \text{ mol cyt x } \frac{5\text{ H}}{\text{cyt}} \text{ x } \frac{1\text{ }H_2O}{2\text{ H}} = 0.0025 \text{ mol } H_2O$$

3.35 $C_xH_y \xrightarrow{O_2} 3\,CO_2 + 4\,H_2O$; x is equal to the coefficient for $CO_2$ and y is equal to 2 times the coefficient for $H_2O$. The empirical formula for the hydrocarbon is $C_3H_8$.

**Section Problems**
**Balancing Equations (Section 3.2)**

3.36 Equation (b) is balanced, (a) is not balanced.

3.37 (a) and (c) are not balanced, (b) is balanced.
(a) $2\,Al + Fe_2O_3 \rightarrow Al_2O_3 + 2\,Fe$ (balanced)
(c) $4\,Au + 8\,NaCN + O_2 + 2\,H_2O \rightarrow 4\,NaAu(CN)_2 + 4\,NaOH$ (balanced)

3.38 (a) $Mg + 2\,HNO_3 \rightarrow H_2 + Mg(NO_3)_2$
(b) $CaC_2 + 2\,H_2O \rightarrow Ca(OH)_2 + C_2H_2$
(c) $2\,S + 3\,O_2 \rightarrow 2\,SO_3$
(d) $UO_2 + 4\,HF \rightarrow UF_4 + 2\,H_2O$

3.39 (a) $2\,NH_4NO_3 \rightarrow 2\,N_2 + O_2 + 4\,H_2O$
(b) $C_2H_6O + O_2 \rightarrow C_2H_4O_2 + H_2O$
(c) $C_2H_8N_2 + 2\,N_2O_4 \rightarrow 3\,N_2 + 2\,CO_2 + 4\,H_2O$

3.40 (a) $SiCl_4 + 2\,H_2O \rightarrow SiO_2 + 4\,HCl$
(b) $P_4O_{10} + 6\,H_2O \rightarrow 4\,H_3PO_4$
(c) $CaCN_2 + 3\,H_2O \rightarrow CaCO_3 + 2\,NH_3$
(d) $3\,NO_2 + H_2O \rightarrow 2\,HNO_3 + NO$

3.41 (a) $VCl_3 + 3\,Na + 6\,CO \rightarrow V(CO)_6 + 3\,NaCl$
(b) $RuI_3 + 5\,CO + 3\,Ag \rightarrow Ru(CO)_5 + 3AgI$
(c) $2\,CoS + 8\,CO + 4\,Cu \rightarrow Co_2(CO)_8 + 2\,Cu_2S$

3.42 (a) $4\,C_6H_5NO_2 + 29\,O_2 \rightarrow 24\,CO_2 + 10\,H_2O + 4\,NO_2$
(b) $2\,Au + 6\,H_2SeO_4 \rightarrow Au_2(SeO_4)_3 + 3\,H_2SeO_3 + 3\,H_2O$
(c) $6\,NH_4ClO_4 + 8\,Al \rightarrow 4\,Al_2O_3 + 3\,N_2 + 3\,Cl_2 + 12\,H_2O$

3.43 (a) $CO(NH_2)_2(aq) + 6\ HOCl(aq) \rightarrow 2\ NCl_3(aq) + CO_2(aq) + 5\ H_2O(l)$
(b) $2\ Ca_3(PO_4)_2(s) + 6\ SiO_2(s) + 10\ C(s) \rightarrow P_4(g) + 6\ CaSiO_3(l) + 10\ CO(g)$

**Molecular Weights and Molar Mass (Section 3.3)**

3.44 (a) $Hg_2Cl_2$: 2(200.59) + 2(35.45) = 472.1
(b) $C_4H_8O_2$: 4(12.01) + 8(1.01) + 2(16.00) = 88.1
(c) $CF_2Cl_2$: 1(12.01) + 2(19.00) + 2(35.45) = 120.9

3.45 (a) (1 x 30.97) + (Y x 35.45) = 137.3; Solve for Y; Y = 3.
The formula is $PCl_3$.
(b) (10 x 12.01) + (14 x 1.008) + (Z x 14.01) = 162.2
Solve for Z; Z = 2. The formula is $C_{10}H_{14}N_2$.

3.46 (a) $C_{33}H_{35}FN_2O_5$: 33(12.01) + 35(1.01) + 1(19.00) + 2(14.01) + 5(16.00) = 558.7
(b) $C_{22}H_{27}F_3O_4S$: 22(12.01) + 27(1.01) + 3(19.00) + 4(16.00) + 1(32.06) = 444.5
(c) $C_{16}H_{16}ClNO_2S$: 16(12.01) + 16(1.01) + 1(35.45) + 1(14.01) + 2(16.00) + 1(32.06) = 321.8

3.47 (a) $C_6H_6Cl_2O_3$: 6(12.01) + 6(1.01) + 2(35.45) + 3(16.00) = 197.0
(b) $C_{15}H_{22}ClNO_2$: 15(12.01) + 22(1.01) + 1(35.45) + 1(14.01) + 2(16.00) = 283.8
(c) $C_8H_6Cl_2O_3$: 8(12.01) + 6(1.01) + 2(35.45) + 3(16.00) = 221.0

3.48 One mole equals the atomic weight or molecular weight in grams.
(a) Ti, 47.87 g (b) $Br_2$, 159.81 g (c) Hg, 200.59 g (d) $H_2O$, 18.02 g

3.49 (a) $1.00\text{ g Cr} \times \dfrac{1\text{ mol Cr}}{52.0\text{ g Cr}} = 0.0192\text{ mol Cr}$

(b) $1.00\text{ g Cl}_2 \times \dfrac{1\text{ mol Cl}_2}{70.9\text{ g Cl}_2} = 0.0141\text{ mol Cl}_2$

(c) $1.00\text{ g Au} \times \dfrac{1\text{ mol Au}}{197.0\text{ g Au}} = 0.005\ 08\text{ mol Au}$

(d) $1.00\text{ g NH}_3 \times \dfrac{1\text{ mol NH}_3}{17.0\text{ g NH}_3} = 0.0588\text{ mol NH}_3$

3.50 There are 3 ions (one $Mg^{2+}$ and 2 $Cl^-$) per formula unit of $MgCl_2$.
$MgCl_2$, 95.2

$$27.5\text{ g MgCl}_2 \times \frac{1\text{ mol MgCl}_2}{95.2\text{ g MgCl}_2} \times \frac{3\text{ mol ions}}{1\text{ mol MgCl}_2} = 0.867\text{ mol ions}$$

3.51 There are 3 $F^-$ anions per formula unit of $AlF_3$.
$AlF_3$, 84.0

$$35.6\text{ g AlF}_3 \times \frac{1\text{ mol AlF}_3}{84.0\text{ g AlF}_3} \times \frac{3\text{ mol anions}}{1\text{ mol AlF}_3} = 1.27\text{ mol F}^-$$

3.52 Molar mass = $\frac{3.28 \text{ g}}{0.0275 \text{ mol}}$ = 119 g/mol; molecular weight = 119.

3.53 Molar mass = $\frac{221.6 \text{ g}}{0.5731 \text{ mol}}$ = 386.7 g/mol; molecular weight = 386.7.

3.54 $FeSO_4$, 151.9; 300 mg = 0.300 g

$$0.300 \text{ g } FeSO_4 \times \frac{1 \text{ mol } FeSO_4}{151.9 \text{ g } FeSO_4} = 1.97 \times 10^{-3} \text{ mol } FeSO_4$$

$$1.97 \times 10^{-3} \text{ mol } FeSO_4 \times \frac{6.022 \times 10^{23} \text{ Fe(II) atoms}}{1 \text{ mol } FeSO_4} = 1.19 \times 10^{21} \text{ Fe(II) atoms}$$

3.55 $0.0001 \text{ g C} \times \frac{1 \text{ mol C}}{12.0 \text{ g C}} \times \frac{6.02 \times 10^{23} \text{ C atoms}}{1 \text{ mol C}} = 5 \times 10^{18} \text{ C atoms}$

3.56 $C_8H_{10}N_4O_2$, 194.2; 125 mg = 0.125 g

$$0.125 \text{ g caffeine} \times \frac{1 \text{ mol caffeine}}{194.2 \text{ g caffeine}} = 6.44 \times 10^{-4} \text{ mol caffeine}$$

$$0.125 \text{ g caffeine} \times \frac{1 \text{ mol caffeine}}{194.2 \text{ g caffeine}} \times \frac{6.022 \times 10^{23} \text{ molecules}}{1 \text{ mol}} = 3.88 \times 10^{20} \text{ caffeine molecules}$$

3.57 (a) $0.0015 \text{ mol Na} \times \frac{23.0 \text{ g Na}}{1 \text{ mol Na}} = 0.034 \text{ g Na}$

(b) $0.0015 \text{ mol Pb} \times \frac{207.2 \text{ g Pb}}{1 \text{ mol Pb}} = 0.31 \text{ g Pb}$

(c) $C_{16}H_{13}ClN_2O$, 284.7

$$0.0015 \text{ mol diazepam} \times \frac{284.7 \text{ g diazepam}}{1 \text{ mol diazepam}} = 0.43 \text{ g diazepam}$$

3.58 By definition, $6.022 \times 10^{23}$ particles are 1.000 mole of particles.
mol Ar = 0.2500 mol and mol "other" = 0.7500 mol

$$\text{mass Ar} = 0.2500 \text{ mol Ar} \times \frac{39.95 \text{ g Ar}}{1 \text{ mol Ar}} = 9.99 \text{ g Ar}$$

mass "other" = total mass – mass Ar = 25.12 g – 9.99 g = 15.13 g "other"

$$\text{molar mass "other"} = \frac{15.13 \text{ g "other"}}{0.7500 \text{ mol "other"}} = 20.17 \text{ g/mol}$$

The "other" element is neon (Ne).

3.59 He, 4.00; Kr, 83.80; By definition, $6.022 \times 10^{23}$ particles are 1.000 mole of particles.
mass of $6.022 \times 10^{23}$ particles = (0.30)(4.00 g He) + (0.70)(83.80 g Ar) = 60 g

$$\text{number of particles in sample} = 107.75 \text{ g} \times \frac{6.022 \times 10^{23} \text{ particles}}{60 \text{ g}} = 1.1 \times 10^{24} \text{ particles}$$

3.60 $TiO_2$, 79.87; $100.0 \text{ kg Ti} \times \dfrac{79.87 \text{ kg } TiO_2}{47.87 \text{ kg Ti}} = 166.8 \text{ kg } TiO_2$

3.61 $Fe_2O_3$, 159.7; $\% \text{ Fe} = \dfrac{2(55.85 \text{ g}) \text{ Fe}}{159.7 \text{ g } Fe_2O_3} \times 100\% = 69.94\%$

mass Fe = (0.6994)(105 kg) = 73.4 kg

**Stoichiometry (Section 3.4)**

3.62 (a) $2\, Fe_2O_3 + 3\, C \rightarrow 4\, Fe + 3\, CO_2$

(b) $Fe_2O_3$, 159.7; $525 \text{ g } Fe_2O_3 \times \dfrac{1 \text{ mol } Fe_2O_3}{159.7 \text{ g } Fe_2O_3} \times \dfrac{3 \text{ mol C}}{2 \text{ mol } Fe_2O_3} = 4.93 \text{ mol C}$

(c) $4.93 \text{ mol C} \times \dfrac{12.01 \text{ g C}}{1 \text{ mol C}} = 59.2 \text{ g C}$

3.63 (a) $Fe_2O_3 + 3\, CO \rightarrow 2\, Fe + 3\, CO_2$

(b) $Fe_2O_3$, 159.7; CO, 28.01

$$3.02 \text{ g } Fe_2O_3 \times \frac{1 \text{ mol } Fe_2O_3}{159.7 \text{ g } Fe_2O_3} \times \frac{3 \text{ mol CO}}{1 \text{ mol } Fe_2O_3} \times \frac{28.01 \text{ g CO}}{1 \text{ mol CO}} = 1.59 \text{ g CO}$$

(c) $1.68 \text{ mol } Fe_2O_3 \times \dfrac{3 \text{ mol CO}}{1 \text{ mol } Fe_2O_3} \times \dfrac{28.01 \text{ g CO}}{1 \text{ mol CO}} = 141 \text{ g CO}$

3.64 (a) $2\, Mg + O_2 \rightarrow 2\, MgO$

(b) Mg, 24.30; $O_2$, 32.00; MgO, 40.30

$$25.0 \text{ g Mg} \times \frac{1 \text{ mol Mg}}{24.30 \text{ g Mg}} \times \frac{1 \text{ mol } O_2}{2 \text{ mol Mg}} \times \frac{32.00 \text{ g } O_2}{1 \text{ mol } O_2} = 16.5 \text{ g } O_2$$

$$25.0 \text{ g Mg} \times \frac{1 \text{ mol Mg}}{24.30 \text{ g Mg}} \times \frac{2 \text{ mol MgO}}{2 \text{ mol Mg}} \times \frac{40.30 \text{ g MgO}}{1 \text{ mol MgO}} = 41.5 \text{ g MgO}$$

(c) $25.0 \text{ g } O_2 \times \dfrac{1 \text{ mol } O_2}{32.00 \text{ g } O_2} \times \dfrac{2 \text{ mol Mg}}{1 \text{ mol } O_2} \times \dfrac{24.30 \text{ g Mg}}{1 \text{ mol Mg}} = 38.0 \text{ g Mg}$

$$25.0 \text{ g } O_2 \times \frac{1 \text{ mol } O_2}{32.00 \text{ g } O_2} \times \frac{2 \text{ mol MgO}}{1 \text{ mol } O_2} \times \frac{40.30 \text{ g MgO}}{1 \text{ mol MgO}} = 63.0 \text{ g MgO}$$

3.65 $C_2H_4 + H_2O \rightarrow C_2H_6O$; $C_2H_4$, 28.05; $H_2O$, 18.02; $C_2H_6O$, 46.07

(a) $0.133 \text{ mol } H_2O \times \dfrac{1 \text{ mol } C_2H_4}{1 \text{ mol } H_2O} \times \dfrac{28.05 \text{ g } C_2H_4}{1 \text{ mol } C_2H_4} = 3.73 \text{ g } C_2H_4$

$$0.133 \text{ mol } H_2O \times \frac{1 \text{ mol } C_2H_6O}{1 \text{ mol } H_2O} \times \frac{46.07 \text{ g } C_2H_6O}{1 \text{ mol } C_2H_6O} = 6.13 \text{ g } C_2H_6O$$

(b) $0.371 \text{ mol } C_2H_4 \times \frac{1 \text{ mol } H_2O}{1 \text{ mol } C_2H_4} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 6.69 \text{ g } H_2O$

$0.371 \text{ mol } C_2H_4 \times \frac{1 \text{ mol } C_2H_6O}{1 \text{ mol } C_2H_4} \times \frac{46.07 \text{ g } C_2H_6O}{1 \text{ mol } C_2H_6O} = 17.1 \text{ g } C_2H_6O$

3.66 (a) $2\,HgO \rightarrow 2\,Hg + O_2$

(b) HgO, 216.6; Hg, 200.6; $O_2$, 32.0

$45.5 \text{ g HgO} \times \frac{1 \text{ mol HgO}}{216.6 \text{ g HgO}} \times \frac{2 \text{ mol Hg}}{2 \text{ mol HgO}} \times \frac{200.6 \text{ g Hg}}{1 \text{ mol Hg}} = 42.1 \text{ g Hg}$

$45.5 \text{ g HgO} \times \frac{1 \text{ mol HgO}}{216.6 \text{ g HgO}} \times \frac{1 \text{ mol } O_2}{2 \text{ mol HgO}} \times \frac{32.00 \text{ g } O_2}{1 \text{ mol } O_2} = 3.36 \text{ g } O_2$

(c) $33.3 \text{ g } O_2 \times \frac{1 \text{ mol } O_2}{32.00 \text{ g } O_2} \times \frac{2 \text{ mol HgO}}{1 \text{ mol } O_2} \times \frac{216.6 \text{ g HgO}}{1 \text{ mol HgO}} = 451 \text{ g HgO}$

3.67 5.60 kg = 5600 g; $TiCl_4$, 189.7; $TiO_2$, 79.87

$5600 \text{ g } TiCl_4 \times \frac{1 \text{ mol } TiCl_4}{189.7 \text{ g } TiCl_4} \times \frac{1 \text{ mol } TiO_2}{1 \text{ mol } TiCl_4} \times \frac{79.87 \text{ g } TiO_2}{1 \text{ mol } TiO_2} = 2358 \text{ g } TiO_2 = 2.36 \text{ kg } TiO_2$

3.68 $2.00 \text{ g Ag} \times \frac{1 \text{ mol Ag}}{107.9 \text{ g Ag}} = 0.0185 \text{ mol Ag}$; $0.657 \text{ g Cl} \times \frac{1 \text{ mol Cl}}{35.45 \text{ g Cl}} = 0.0185 \text{ mol Cl}$

$Ag_{0.0185}Cl_{0.0185}$; divide both subscripts by 0.0185. The empirical formula is AgCl.

3.69 $5.0 \text{ g Al} \times \frac{1 \text{ mol Al}}{27.0 \text{ g Al}} = 0.19 \text{ mol Al}$; $4.45 \text{ g O} \times \frac{1 \text{ mol O}}{16.0 \text{ g O}} = 0.28 \text{ mol O}$

$Al_{0.19}O_{0.28}$; divide both subscripts by the smaller, 0.19.

$Al_{0.19/0.19}O_{0.28/0.19}$

$Al_1O_{1.5}$; multiply both subscripts by 2 to obtain integers.

The empirical formula is $Al_2O_3$.

3.70 $N_2H_4$, 32.05; $I_2$, 253.8; HI, 127.9

(a) $36.7 \text{ g } N_2H_4 \times \frac{1 \text{ mol } N_2H_4}{32.05 \text{ g } N_2H_4} \times \frac{2 \text{ mol } I_2}{1 \text{ mol } N_2H_4} \times \frac{253.8 \text{ g } I_2}{1 \text{ mol } I_2} = 581 \text{ g } I_2$

(b) $115.7 \text{ g } N_2H_4 \times \frac{1 \text{ mol } N_2H_4}{32.05 \text{ g } N_2H_4} \times \frac{4 \text{ mol HI}}{1 \text{ mol } N_2H_4} \times \frac{127.9 \text{ g HI}}{1 \text{ mol HI}} = 1847 \text{ g HI}$

3.71 $H_2S$, 34.08; $I_2$, 253.8; HI, 127.9

(a) $49.2 \text{ g } H_2S \times \frac{1 \text{ mol } H_2S}{34.08 \text{ g } H_2S} \times \frac{1 \text{ mol } I_2}{1 \text{ mol } H_2S} \times \frac{253.8 \text{ g } I_2}{1 \text{ mol } I_2} = 366 \text{ g } I_2$

(b) $95.4\text{ g }H_2S \times \frac{1\text{ mol }H_2S}{34.08\text{ g }H_2S} \times \frac{2\text{ mol HI}}{1\text{ mol }H_2S} \times \frac{127.9\text{ g HI}}{1\text{ mol HI}} = 716\text{ g HI}$

**Reaction Yield and Limiting Reactants (Sections 3.5–3.6)**

3.72 $H_2SO_4$, 98.08; $NiCO_3$, 118.7; $NiSO_4$, 154.8

(a) $14.5\text{ g }NiCO_3 \times \frac{1\text{ mol }NiCO_3}{118.7\text{ g }NiCO_3} \times \frac{1\text{ mol }H_2SO_4}{1\text{ mol }NiCO_3} \times \frac{98.08\text{ g }H_2SO_4}{1\text{ mol }H_2SO_4} = 12.0\text{ g }H_2SO_4$

(b) $14.5\text{ g }NiCO_3 \times \frac{1\text{ mol }NiCO_3}{118.7\text{ g }NiCO_3} \times \frac{1\text{ mol }NiSO_4}{1\text{ mol }NiCO_3} \times \frac{154.8\text{ g }NiSO_4}{1\text{ mol }NiSO_4} \times 0.789 = 14.9\text{ g }NiSO_4$

3.73 $O_2$, 32.00; $N_2$, 28.01; $N_2H_4$, 32.05

(a) $50.0\text{ g }N_2H_4 \times \frac{1\text{ mol }N_2H_4}{32.05\text{ g }N_2H_4} \times \frac{1\text{ mol }O_2}{1\text{ mol }N_2H_4} \times \frac{32.00\text{ g }O_2}{1\text{ mol }O_2} = 49.9\text{ g }O_2$

(b) $50.0\text{ g }N_2H_4 \times \frac{1\text{ mol }N_2H_4}{32.05\text{ g }N_2H_4} \times \frac{1\text{ mol }N_2}{1\text{ mol }N_2H_4} \times \frac{28.01\text{ g }N_2}{1\text{ mol }N_2} \times 0.855 = 37.4\text{ g }N_2$

3.74 $3.44\text{ mol }N_2 \times \frac{3\text{ mol }H_2}{1\text{ mol }N_2} = 10.3\text{ mol }H_2$ required.

Because there is only 1.39 mol $H_2$, $H_2$ is the limiting reactant.

$1.39\text{ mol }H_2 \times \frac{2\text{ mol }NH_3}{3\text{ mol }H_2} \times \frac{17.03\text{ g }NH_3}{1\text{ mol }NH_3} = 15.8\text{ g }NH_3$

$1.39\text{ mol }H_2 \times \frac{1\text{ mol }N_2}{3\text{ mol }H_2} \times \frac{28.01\text{ g }N_2}{1\text{ mol }N_2} = 13.0\text{ g }N_2$ reacted

$3.44\text{ mol }N_2 \times \frac{28.01\text{ g }N_2}{1\text{ mol }N_2} = 96.3\text{ g }N_2$ initially

(96.3 g – 13.0 g) = 83.3 g $N_2$ left over

3.75 $H_2$, 2.016; $Cl_2$, 70.91; HCl 36.46

$3.56\text{ g }H_2 \times \frac{1\text{ mol }H_2}{2.016\text{ g }H_2} = 1.77\text{ mol }H_2$

$8.94\text{ g }Cl_2 \times \frac{1\text{ mol }Cl_2}{70.91\text{ g }Cl_2} = 0.126\text{ mol }Cl_2$

Because the reaction stoichiometry between $H_2$ and $Cl_2$ is one to one, $Cl_2$ is the limiting reactant.

$0.126\text{ mol }Cl_2 \times \frac{2\text{ mol HCl}}{1\text{ mol }Cl_2} \times \frac{36.46\text{ g HCl}}{1\text{ mol HCl}} = 9.19\text{ g HCl}$

$$0.134 \text{ mol } K_2PtCl_4 \times \frac{1 \text{ mol } Pt(NH_3)_2Cl_2}{1 \text{ mol } K_2PtCl_4} \times \frac{300.0 \text{ g } Pt(NH_3)_2Cl_2}{1 \text{ mol } Pt(NH_3)_2Cl_2} = 40.2 \text{ g } Pt(NH_3)_2Cl_2$$

40.2 g $Pt(NH_3)_2Cl_2$ is the theoretical yield.
Actual yield = (40.2 g)(0.95) = 38 g $Pt(NH_3)_2Cl_2$.

3.82 $CH_3CO_2H + C_5H_{12}O \rightarrow C_7H_{14}O_2 + H_2O$

$CH_3CO_2H$, 60.05; $C_5H_{12}O$, 88.15; $C_7H_{14}O_2$, 130.19

$$1.87 \text{ g } CH_3CO_2H \times \frac{1 \text{ mol } CH_3CO_2H}{60.05 \text{ g } CH_3CO_2H} = 0.0311 \text{ mol } CH_3CO_2H$$

$$2.31 \text{ g } C_5H_{12}O \times \frac{1 \text{ mol } C_5H_{12}O}{88.15 \text{ g } C_5H_{12}O} = 0.0262 \text{ mol } C_5H_{12}O$$

Because the reaction stoichiometry between $CH_3CO_2H$ and $C_5H_{12}O$ is one to one, isopentyl alcohol ($C_5H_{12}O$) is the limiting reactant.

$$0.0262 \text{ mol } C_5H_{12}O \times \frac{1 \text{ mol } C_7H_{14}O_2}{1 \text{ mol } C_5H_{12}O} \times \frac{130.19 \text{ g } C_7H_{14}O_2}{1 \text{ mol } C_7H_{14}O_2} = 3.41 \text{ g } C_7H_{14}O_2$$

3.41 g $C_7H_{14}O_2$ is the theoretical yield.

$$\% \text{ Yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100\% = \frac{2.96 \text{ g}}{3.41 \text{ g}} \times 100\% = 86.8\%$$

3.83 $K_2PtCl_4 + 2\,NH_3 \rightarrow 2\,KCl + Pt(NH_3)_2Cl_2$

$K_2PtCl_4$, 415.1; $NH_3$, 17.03; $Pt(NH_3)_2Cl_2$, 300.0

$$3.42 \text{ g } K_2PtCl_4 \times \frac{1 \text{ mol } K_2PtCl_4}{415.1 \text{ g } K_2PtCl_4} = 0.008\ 24 \text{ mol } K_2PtCl_4$$

$$1.61 \text{ g } NH_3 \times \frac{1 \text{ mol } NH_3}{17.03 \text{ g } NH_3} = 0.0945 \text{ mol } NH_3$$

Only 2 x (0.008 24) = 0.0165 mol of $NH_3$ are needed to react with 0.008 24 mol $K_2PtCl_4$. Therefore, the $NH_3$ is in excess and $K_2PtCl_4$ is the limiting reactant.

$$0.008\ 24 \text{ mol } K_2PtCl_4 \times \frac{1 \text{ mol } Pt(NH_3)_2Cl_2}{1 \text{ mol } K_2PtCl_4} \times \frac{300.0 \text{ g } Pt(NH_3)_2Cl_2}{1 \text{ mol } Pt(NH_3)_2Cl_2} = 2.47 \text{ g } Pt(NH_3)_2Cl_2$$

2.47 g $Pt(NH_3)_2Cl_2$ is the theoretical yield. 2.08 g $Pt(NH_3)_2Cl_2$ is the actual yield.

$$\% \text{ Yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100\% = \frac{2.08 \text{ g}}{2.47 \text{ g}} \times 100\% = 84.2\%$$

3.84 $WCl_6$, 396.6; $W_6Cl_{12}$, 1528

(a) $6\,WCl_6 + 8\,Bi \rightarrow W_6Cl_{12} + 8\,BiCl_3$

(b) $$150.0 \text{ g } WCl_6 \times \frac{1 \text{ mol } WCl_6}{396.6 \text{ g } WCl_6} \times \frac{8 \text{ mol Bi}}{6 \text{ mol } WCl_6} \times \frac{209.0 \text{ g Bi}}{1 \text{ mol Bi}} = 105.4 \text{ g Bi}$$

(c) Compute the theoretical yield for $W_6Cl_{12}$ from each reactant to determine the limiting reactant.

$$228 \text{ g } WCl_6 \times \frac{1 \text{ mol } WCl_6}{396.6 \text{ g } WCl_6} \times \frac{1 \text{ mol } W_6Cl_{12}}{6 \text{ mol } WCl_6} \times \frac{1528 \text{ g } W_6Cl_{12}}{1 \text{ mol } W_6Cl_{12}} = 146 \text{ g } W_6Cl_{12}$$

$$175 \text{ g Bi} \times \frac{1 \text{ mol Bi}}{209.0 \text{ g Bi}} \times \frac{1 \text{ mol } W_6Cl_{12}}{8 \text{ mol Bi}} \times \frac{1528 \text{ g } W_6Cl_{12}}{1 \text{ mol } W_6Cl_{12}} = 160 \text{ g } W_6Cl_{12}$$

The smaller theoretical yield (146 g) means that $WCl_6$ is the limiting reactant and 146 g $W_6Cl_{12}$ are produced.

3.85 NaH, 24.00; $B_2H_6$, 27.67; $NaBH_4$, 37.83

(a) $2\,NaH + B_2H_6 \rightarrow 2\,NaBH_4$

$$8.55 \text{ g NaH} \times \frac{1 \text{ mol NaH}}{24.00 \text{ g NaH}} = 0.356 \text{ mol NaH}$$

$$6.75 \text{ g } B_2H_6 \times \frac{1 \text{ mol } B_2H_6}{27.67 \text{ g } B_2H_6} = 0.244 \text{ mol } B_2H_6$$

For 0.244 mol $B_2H_6$, 2 x (0.244) = 0.488 mol NaH are needed. Because only 0.356 mol of NaH is available, NaH is the limiting reactant.

$$0.356 \text{ mol NaH} \times \frac{2 \text{ mol } NaBH_4}{2 \text{ mol NaH}} \times \frac{37.83 \text{ g } NaBH_4}{1 \text{ mol } NaBH_4} = 13.5 \text{ g } NaBH_4 \text{ produced}$$

(b) $$0.356 \text{ mol NaH} \times \frac{1 \text{ mol } B_2H_6}{2 \text{ mol NaH}} \times \frac{27.67 \text{ g } B_2H_6}{1 \text{ mol } B_2H_6} = 4.93 \text{ g } B_2H_6 \text{ reacted}$$

$B_2H_6$ left over = 6.75 g – 4.93 g = 1.82 g $B_2H_6$

**Percent Composition and Empirical Formulas (Section 3.7)**

3.86 $CH_4N_2O$, 60.1

$$\%C = \frac{12.0 \text{ g C}}{60.1 \text{ g}} \times 100\% = 20.0\%$$

$$\%H = \frac{4 \times 1.01 \text{ g H}}{60.1 \text{ g}} \times 100\% = 6.72\%$$

$$\%N = \frac{2 \times 14.0 \text{ g N}}{60.1 \text{ g}} \times 100\% = 46.6\%$$

$$\%O = \frac{16.0 \text{ g O}}{60.1 \text{ g}} \times 100\% = 26.6\%$$

3.87 (a) $Cu_2(OH)_2CO_3$, 221.1

$$\%Cu = \frac{2 \times 63.5 \text{ g Cu}}{221.1 \text{ g}} \times 100\% = 57.4\%$$

$$\%O = \frac{5 \times 16.0 \text{ g O}}{221.1 \text{ g}} \times 100\% = 36.2\%$$

$$\%C = \frac{12.0 \text{ g C}}{221.1 \text{ g}} \times 100\% = 5.43\%$$

3.76 $C_2H_4$, 28.05; $Cl_2$, 70.91; $C_2H_4Cl_2$, 98.96

$$15.4\text{ g } C_2H_4 \times \frac{1\text{ mol } C_2H_4}{28.05\text{ g } C_2H_4} = 0.549\text{ mol } C_2H_4$$

$$3.74\text{ g } Cl_2 \times \frac{1\text{ mol } Cl_2}{70.91\text{ g } Cl_2} = 0.0527\text{ mol } Cl_2$$

Because the reaction stoichiometry between $C_2H_4$ and $Cl_2$ is one to one, $Cl_2$ is the limiting reactant.

$$0.0527\text{ mol } Cl_2 \times \frac{1\text{ mol } C_2H_4Cl_2}{1\text{ mol } Cl_2} \times \frac{98.96\text{ g } C_2H_4Cl_2}{1\text{ mol } C_2H_4Cl_2} = 5.22\text{ g } C_2H_4Cl_2$$

3.77 (a) NaCl, 58.44; $AgNO_3$, 169.9; AgCl, 143.3; $NaNO_3$, 85.00

$NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$

$$1.3\text{ g NaCl} \times \frac{1\text{ mol NaCl}}{58.44\text{ g NaCl}} = 0.022\text{ mol NaCl}$$

$$3.5\text{ g } AgNO_3 \times \frac{1\text{ mol } AgNO_3}{169.9\text{ g } AgNO_3} = 0.021\text{ mol } AgNO_3$$

Because the reaction stoichiometry between NaCl and $AgNO_3$ is one to one, $AgNO_3$ is the limiting reactant.

$$0.021\text{ mol } AgNO_3 \times \frac{1\text{ mol AgCl}}{1\text{ mol } AgNO_3} \times \frac{143.3\text{ g AgCl}}{1\text{ mol AgCl}} = 3.0\text{ g AgCl}$$

$$0.021\text{ mol } AgNO_3 \times \frac{1\text{ mol } NaNO_3}{1\text{ mol } AgNO_3} \times \frac{85.00\text{ g } NaNO_3}{1\text{ mol } NaNO_3} = 1.8\text{ g } NaNO_3$$

$$0.021\text{ mol } AgNO_3 \times \frac{1\text{ mol NaCl}}{1\text{ mol } AgNO_3} \times \frac{58.44\text{ g NaCl}}{1\text{ mol NaCl}} = 1.2\text{ g NaCl reacted}$$

(1.3 g – 1.2 g) = 0.1 g NaCl left over

(b) $BaCl_2$, 208.2; $H_2SO_4$, 98.08; $BaSO_4$, 233.4; HCl, 36.46

$BaCl_2 + H_2SO_4 \rightarrow BaSO_4 + 2\text{ HCl}$

$$2.65\text{ g } BaCl_2 \times \frac{1\text{ mol } BaCl_2}{208.2\text{ g } BaCl_2} = 0.0127\text{ mol } BaCl_2$$

$$6.78\text{ g } H_2SO_4 \times \frac{1\text{ mol } H_2SO_4}{98.08\text{ g } H_2SO_4} = 0.0691\text{ mol } H_2SO_4$$

Because the reaction stoichiometry between $BaCl_2$ and $H_2SO_4$ is one to one, $BaCl_2$ is the limiting reactant.

$$0.0127\text{ mol } BaCl_2 \times \frac{1\text{ mol } BaSO_4}{1\text{ mol } BaCl_2} \times \frac{233.4\text{ g } BaSO_4}{1\text{ mol } BaSO_4} = 2.96\text{ g } BaSO_4$$

$$0.0127\text{ mol } BaCl_2 \times \frac{2\text{ mol HCl}}{1\text{ mol } BaCl_2} \times \frac{36.46\text{ g HCl}}{1\text{ mol HCl}} = 0.926\text{ g HCl}$$

$$0.0127 \text{ mol } BaCl_2 \times \frac{1 \text{ mol } H_2SO_4}{1 \text{ mol } BaCl_2} \times \frac{98.1 \text{ g } H_2SO_4}{1 \text{ mol } H_2SO_4} = 1.25 \text{ g } H_2SO_4 \text{ reacted}$$

$(6.78 \text{ g} - 1.25 \text{ g}) = 5.53 \text{ g } H_2SO_4$ left over

3.78 $CaCO_3$, 100.1; HCl, 36.46

$$CaCO_3 + 2\,HCl \rightarrow CaCl_2 + H_2O + CO_2$$

$$2.35 \text{ g } CaCO_3 \times \frac{1 \text{ mol } CaCO_3}{100.1 \text{ g } CaCO_3} = 0.0235 \text{ mol } CaCO_3$$

$$2.35 \text{ g HCl} \times \frac{1 \text{ mol HCl}}{36.46 \text{ g HCl}} = 0.0645 \text{ mol HCl}$$

The reaction stoichiometry is 1 mole of $CaCO_3$ for every 2 moles of HCl. For 0.0235 mol $CaCO_3$, we only need 2(0.0235 mol) = 0.0470 mol HCl. We have 0.0645 mol HCl, therefore $CaCO_3$ is the limiting reactant.

$$0.0235 \text{ mol } CaCO_3 \times \frac{1 \text{ mol } CO_2}{1 \text{ mol } CaCO_3} \times \frac{22.4 \text{ L}}{1 \text{ mol } CO_2} = 0.526 \text{ L } CO_2$$

3.79 $2\,NaN_3 \rightarrow 3\,N_2 + 2\,Na$; $NaN_3$, 65.01; $N_2$, 28.01

$$38.5 \text{ g } NaN_3 \times \frac{1 \text{ mol } NaN_3}{65.01 \text{ g } NaN_3} \times \frac{3 \text{ mol } N_2}{2 \text{ mol } NaN_3} \times \frac{47.0 \text{ L}}{1.00 \text{ mol } N_2} = 41.8 \text{ L}$$

3.80 $CH_3CO_2H + C_5H_{12}O \rightarrow C_7H_{14}O_2 + H_2O$

$CH_3CO_2H$, 60.05; $C_5H_{12}O$, 88.15; $C_7H_{14}O_2$, 130.19

$$3.58 \text{ g } CH_3CO_2H \times \frac{1 \text{ mol } CH_3CO_2H}{60.05 \text{ g } CH_3CO_2H} = 0.0596 \text{ mol } CH_3CO_2H$$

$$4.75 \text{ g } C_5H_{12}O \times \frac{1 \text{ mol } C_5H_{12}O}{88.15 \text{ g } C_5H_{12}O} = 0.0539 \text{ mol } C_5H_{12}O$$

Because the reaction stoichiometry between $CH_3CO_2H$ and $C_5H_{12}O$ is one to one, isopentyl alcohol ($C_5H_{12}O$) is the limiting reactant.

$$0.0539 \text{ mol } C_5H_{12}O \times \frac{1 \text{ mol } C_7H_{14}O_2}{1 \text{ mol } C_5H_{12}O} \times \frac{130.19 \text{ g } C_7H_{14}O_2}{1 \text{ mol } C_7H_{14}O_2} = 7.02 \text{ g } C_7H_{14}O_2$$

7.02 g $C_7H_{14}O_2$ is the theoretical yield. Actual yield = (7.02 g)(0.45) = 3.2 g.

3.81 $K_2PtCl_4 + 2\,NH_3 \rightarrow 2\,KCl + Pt(NH_3)_2Cl_2$

$K_2PtCl_4$, 415.1; $NH_3$, 17.03; $Pt(NH_3)_2Cl_2$, 300.0

$$55.8 \text{ g } K_2PtCl_4 \times \frac{1 \text{ mol } K_2PtCl_4}{415.1 \text{ g } K_2PtCl_4} = 0.134 \text{ mol } K_2PtCl_4$$

$$35.6 \text{ g } NH_3 \times \frac{1 \text{ mol } NH_3}{17.03 \text{ g } NH_3} = 2.09 \text{ mol } NH_3$$

Only 2(0.134) = 0.268 mol $NH_3$ are needed to react with 0.134 mol $K_2PtCl_4$. Therefore, the $NH_3$ is in excess and $K_2PtCl_4$ is the limiting reactant.

$$\% H = \frac{2 \times 1.01 \text{ g H}}{221.1 \text{ g}} \times 100\% = 0.914\%$$

(b) $C_8H_9NO_2$, 151.2

$$\% C = \frac{8 \times 12.0 \text{ g C}}{151.2 \text{ g}} \times 100\% = 63.5\%$$

$$\% H = \frac{9 \times 1.01 \text{ g H}}{151.2 \text{ g}} \times 100\% = 6.01\%$$

$$\% N = \frac{14.0 \text{ g N}}{151.2 \text{ g}} \times 100\% = 9.26\%$$

$$\% O = \frac{2 \times 16.0 \text{ g O}}{151.2 \text{ g}} \times 100\% = 21.2\%$$

(c) $Fe_4[Fe(CN)_6]_3$, 859.2

$$\% Fe = \frac{7 \times 55.85 \text{ g Fe}}{859.2 \text{ g}} \times 100\% = 45.50\%$$

$$\% C = \frac{18 \times 12.01 \text{ g C}}{859.2 \text{ g}} \times 100\% = 25.16\%$$

$$\% N = \frac{18 \times 14.01 \text{ g N}}{859.2 \text{ g}} \times 100\% = 29.35\%$$

3.88 (a) Assume a 100.0 g sample of aspirin. From the percent composition data, a 100.0 g sample contains 60.00 g C, 35.52 g O, and 4.48 g H.

$$60.00 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 4.996 \text{ mol C}$$

$$35.52 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 2.220 \text{ mol O}$$

$$4.48 \text{ g H} \times \frac{1 \text{ mol H}}{1.01 \text{ g H}} = 4.44 \text{ mol H}$$

$C_{4.996}H_{4.44}O_{2.220}$; divide each subscript by the smallest, 2.220.

$C_{4.996/2.220}H_{4.44/2.220}O_{2.220/2.220}$

$C_{2.25}H_2O_1$; multiply each subscript by 4 to obtain integers.

The empirical formula is $C_9H_8O_4$.

(b) Assume a 100.0 g sample of ilmenite. From the percent composition data, a 100.0 g sample contains 31.63 g O, 31.56 g Ti, and 36.81 g Fe.

$$31.63 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 1.977 \text{ mol O}$$

$$31.56 \text{ g Ti} \times \frac{1 \text{ mol Ti}}{47.87 \text{ g Ti}} = 0.6593 \text{ mol Ti}$$

$$36.81 \text{ g Fe} \times \frac{1 \text{ mol Fe}}{55.85 \text{ g Fe}} = 0.6591 \text{ mol Fe}$$

$Fe_{0.6591}Ti_{0.6593}O_{1.977}$; divide each subscript by the smallest, 0.6591.

$Fe_{0.6591 / 0.6591}Ti_{0.6593 / 0.6591}O_{1.977 / 0.6591}$
The empirical formula is $FeTiO_3$.
(c) Assume a 100.0 g sample of sodium thiosulfate. From the percent composition data, a 100.0 g sample contains 30.36 g O, 29.08 g Na, and 40.56 g S.

$$30.36 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 1.897 \text{ mol O}$$

$$29.08 \text{ g Na} \times \frac{1 \text{ mol Na}}{22.99 \text{ g Na}} = 1.265 \text{ mol Na}$$

$$40.56 \text{ g S} \times \frac{1 \text{ mol S}}{32.07 \text{ g S}} = 1.265 \text{ mol S}$$

$Na_{1.265}S_{1.265}O_{1.897}$; divide each subscript by the smallest, 1.265.
$Na_{1.265 / 1.265}S_{1.265 / 1.265}O_{1.897 / 1.265}$
$NaSO_{1.5}$; multiply each subscript by 2 to obtain integers.
The empirical formula is $Na_2S_2O_3$.

3.89 Assume a 100.0 g sample of ferrocene. From the percent composition data, a 100.0 g sample contains 5.42 g H, 64.56 g C, and 30.02 g Fe.

$$5.42 \text{ g H} \times \frac{1 \text{ mol H}}{1.01 \text{ g H}} = 5.37 \text{ mol H}$$

$$64.56 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 5.376 \text{ mol C}$$

$$30.02 \text{ g Fe} \times \frac{1 \text{ mol Fe}}{55.85 \text{ g Fe}} = 0.5375 \text{ mol Fe}$$

$C_{5.376}H_{5.37}Fe_{0.5375}$; divide each subscript by the smallest, 0.5375.
$C_{5.376 / 0.5375}H_{5.37 / 0.5375}Fe_{0.5375 / 0.5375}$
The empirical formula is $C_{10}H_{10}Fe$.

3.90 Assume a 100.0 g sample. From the percent composition data, a 100.0 g sample contains 24.25 g F and 75.75 g Sn.

$$24.25 \text{ g F} \times \frac{1 \text{ mol F}}{19.00 \text{ g F}} = 1.276 \text{ mol F}$$

$$75.75 \text{ g Sn} \times \frac{1 \text{ mol Sn}}{118.7 \text{ g Sn}} = 0.6382 \text{ mol Sn}$$

$Sn_{0.6382}F_{1.276}$; divide each subscript by the smaller, 0.6382.
$Sn_{0.6382 / 0.6382}F_{1.276 / 0.6382}$
The empirical formula is $SnF_2$.

3.91 (a) Assume a 100.0 g sample. From the percent composition data, a 100.0 g sample contains 75.69 g C, 15.51 g O, and 8.80 g H.

$$75.69 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 6.302 \text{ mol C}$$

$$8.80 \text{ g H} \times \frac{1 \text{ mol H}}{1.01 \text{ g H}} = 8.71 \text{ mol H}$$

$15.51 \text{ g O x } \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.9694 \text{ mol O}$

$C_{6.302}H_{8.71}O_{0.9694}$; divide each subscript by the smallest, 0.9694.
$C_{6.302 / 0.9694}H_{8.71 / 0.9694}O_{0.9694 / 0.9694}$
$C_{6.5}H_9O$; multiply each subscript by 2 to obtain integers.
The empirical formula is $C_{13}H_{18}O_2$.
(b) Assume a 100.0 g sample. From the percent composition data, a 100.0 g sample contains 72.36 g Fe, and 27.64 g O.

$72.36 \text{ g Fe x } \frac{1 \text{ mol Fe}}{55.85 \text{ g Fe}} = 1.296 \text{ mol Fe}$

$27.64 \text{ g O x } \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 1.727 \text{ mol O}$

$Fe_{1.296}O_{1.727}$; divide each subscript by the smaller, 1.296.
$Fe_{1.296 / 1.296}O_{1.727 / 1.296}$
$FeO_{1.333}$; multiply each subscript by 3 to obtain integers.
The empirical formula is $Fe_3O_4$.
(c) Assume a 100.0 g sample. From the percent composition data, a 100.0 g sample contains 34.91 g O, 15.32 g Si, and 49.77 g Zr.

$49.77 \text{ g Zr x } \frac{1 \text{ mol Zr}}{91.22 \text{ g Zr}} = 0.5456 \text{ mol Zr}$

$15.32 \text{ g Si x } \frac{1 \text{ mol Si}}{28.09 \text{ g Si}} = 0.5454 \text{ mol Si}$

$34.91 \text{ g O x } \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 2.182 \text{ mol O}$

$Zr_{0.5456}Si_{0.5454}O_{2.182}$; divide each subscript by the smallest, 0.5454.
$Zr_{0.5456 / 0.5454}Si_{0.5454/ 0.5454}O_{2.182 / 0.5454}$
The empirical formula is $ZrSiO_4$.

## Formulas and Elemental Analysis (Section 3.8)

3.92 Assume a 100.0 g sample of liquid. From the percent composition data, a 100.0 g sample of liquid contains 5.57 g H, 28.01 g Cl, and 66.42 g C.

$66.42 \text{ g C x } \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 5.530 \text{ mol C}$

$5.57 \text{ g H x } \frac{1 \text{ mol H}}{1.01 \text{ g H}} = 5.51 \text{ mol H}$

$28.01 \text{ g Cl x } \frac{1 \text{ mol Cl}}{35.45 \text{ g Cl}} = 0.7901 \text{ mol Cl}$

$C_{5.530}H_{5.51}Cl_{0.7901}$; divide each subscript by the smallest, 0.7901.
$C_{5.530 / 0.7901}H_{5.51 / 0.7901}Cl_{0.7901 / 0.7901}$
$C_7H_7Cl$
The empirical formula is $C_7H_7Cl$, 126.59.
Because the molecular weight equals the empirical formula weight, the empirical formula is also the molecular formula.

3.93 Assume a 100.0 g sample of liquid. From the percent composition data, a 100.0 g sample of liquid contains 34.31 g C, 5.28 g H, and 60.41 g I.

$$34.31 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 2.857 \text{ mol C}$$

$$5.28 \text{ g H} \times \frac{1 \text{ mol H}}{1.01 \text{ g H}} = 5.23 \text{ mol H}$$

$$60.41 \text{ g I} \times \frac{1 \text{ mol I}}{126.9 \text{ g I}} = 0.4760 \text{ mol I}$$

$C_{2.857}H_{5.23}I_{0.4760}$; divide each subscript by the smallest, 0.4760.

$C_{2.857/0.4760}H_{5.23/0.4760}I_{0.4760/0.4760}$

$C_6H_{11}I$

The empirical formula is $C_6H_{11}I$, 210.07.

Because the molecular weight equals the empirical formula weight, the empirical formula is also the molecular formula.

3.94 Mass of toluene sample = 45.62 mg = 0.045 62 g; mass of $CO_2$ = 152.5 mg = 0.1525 g; mass of $H_2O$ = 35.67 mg = 0.035 67 g

$$0.1525 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2} \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.003\ 465 \text{ mol C}$$

$$\text{mass C} = 0.003\ 465 \text{ mol C} \times \frac{12.011 \text{ g C}}{1 \text{ mol C}} = 0.041\ 62 \text{ g C}$$

$$0.035\ 67 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.003\ 959 \text{ mol H}$$

$$\text{mass H} = 0.003\ 959 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 0.003\ 991 \text{ g H}$$

The (mass C + mass H) = 0.041 62 g + 0.003 991 g = 0.045 61 g. The calculated mass of (C + H) essentially equals the mass of the toluene sample, this means that toluene contains only C and H and no other elements.

$C_{0.003\ 465}H_{0.003\ 959}$; divide each subscript by the smaller, 0.003 465.

$C_{0.003\ 465/0.003\ 465}H_{0.003\ 959/0.003\ 465}$

$CH_{1.14}$; multiply each subscript by 7 to obtain integers.

The empirical formula is $C_7H_8$.

3.95 5.024 mg = 0.005 024 g; 13.90 mg = 0.013 90 g; 6.048 mg = 0.006 048 g

$$0.013\ 90 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2} \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 3.158 \times 10^{-4} \text{ mol C}$$

$$0.006\ 048 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 6.713 \times 10^{-4} \text{ mol H}$$

$$3.158 \times 10^{-4} \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 0.003\ 793 \text{ g C}$$

$$6.713 \times 10^{-4} \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 0.000\ 676\ 7 \text{ g H}$$

mass N = 0.005 024 g – (0.003 793 g + 0.000 676 7 g) = 0.000 554 g N

$0.000\ 554\ \text{g N} \times \dfrac{1\ \text{mol N}}{14.01\ \text{g N}} = 3.95 \times 10^{-5}\ \text{mol N}$

Scale each mol quantity to eliminate exponents.

$C_{3.158}H_{6.713}N_{0.395}$; divide each subscript by the smallest, 0.395.

$C_{3.158/0.395}H_{6.713/0.395}N_{0.395/0.395}$

The empirical formula is $C_8H_{17}N$.

3.96 Let X equal the molecular weight of cytochrome c.

$0.0043 = \dfrac{55.847\ \text{u}}{X}; \quad X = \dfrac{55.847\ \text{u}}{0.0043} = 13{,}000\ \text{u}$

3.97 Let X equal the molecular weight of nitrogenase.

$0.000\ 872 = \dfrac{2 \times 95.94\ \text{u}}{X}; \quad X = \dfrac{2 \times 95.94\ \text{u}}{0.000\ 872} = 220{,}000\ \text{u}$

3.98 Let X equal the molecular weight of disilane.

$0.9028 = \dfrac{2 \times 28.09\ \text{u}}{X}; \quad X = \dfrac{2 \times 28.09\ \text{u}}{0.9028} = 62.23\ \text{u}$

62.23 – 2(Si atomic weight) = 62.23 – 2(28.09) = 6.05

6.05 is the total mass of H atoms.

$6.05\ \text{u} \times \dfrac{1\ \text{H atom}}{1.01\ \text{u}} = 6\ \text{H atoms}$; Disilane is $Si_2H_6$.

3.99 Let X equal the molecular weight of $MS_2$.

$0.4006 = \dfrac{2 \times 32.07\ \text{u}}{X}; \quad X = \dfrac{2 \times 32.07\ \text{u}}{0.4006} = 160.1\ \text{u}$

Atomic weight of M = 160.1 – 2(S atomic weight)
= 160.1 – 2(32.07) = 95.96

M is Mo.

3.100 $C_{12}Br_{10}$, 943.2; $C_{12}Br_{10}O$, 959.2; 17.33 mg = 0.017 33 g

For $C_{12}Br_{10}$, $\%\ C = \dfrac{12 \times 12.01\ \text{g C}}{943.2\ \text{g}} \times 100\% = 15.28\%$

For $C_{12}Br_{10}O$, $\%\ C = \dfrac{12 \times 12.01\ \text{g C}}{959.2\ \text{g}} \times 100\% = 15.03\%$

Calculate the mass of C in 17.33 mg of $CO_2$.

$0.017\ 33\ \text{g}\ CO_2 \times \dfrac{1\ \text{mol}\ CO_2}{44.01\ \text{g}\ CO_2} \times \dfrac{1\ \text{mol C}}{1\ \text{mol}\ CO_2} \times \dfrac{12.01\ \text{g C}}{1\ \text{mol C}} = 0.004\ 729\ \text{g} = 4.729\ \text{mg C}$

Calculate the %C in the 31.472 mg sample.

$\%C = \dfrac{4.729\ \text{mg C}}{31.472\ \text{mg}} \times 100\% = 15.03\%$

Decabrom is $C_{12}Br_{10}O$.

3.101 Mass of amphetamine sample = 42.92 mg = 0.042 92 g;
mass of $CO_2$ = 125.75 mg = 0.125 75;
mass of $H_2O$ = 37.187 mg = 0.037 187 g

$$0.125\ 75\text{g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2} \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.002\ 857 \text{ mol C}$$

$$\text{mass C} = 0.002\ 857 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 0.034\ 32 \text{ g} = 34.32 \text{ mg C}$$

$$0.037\ 187 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.004\ 127 \text{ mol H}$$

$$\text{mass H} = 0.004\ 127 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 0.004\ 160 \text{ g} = 4.160 \text{ mg H}$$

mass N = 42.92 mg – mass H – mass C = 42.92 mg – 4.16 mg – 34.32 mg = 4.44 mg = 0.004 44 g N

$$0.004\ 44 \text{ g N} \times \frac{1 \text{ mol N}}{14.01 \text{ g N}} = 0.000\ 317 \text{ mol N}$$

$C_{0.002\,857}H_{0.004\,127}N_{0.000\,317}$; divide each subscript by the smallest, 0.000 317.

$C_{0.002\,857\,/\,0.000\,317}H_{0.004\,127\,/\,0.000\,317}N_{0.000\,317\,/\,0.000\,317}$

$C_9H_{13}N$

The empirical formula is $C_9H_{13}N$, 135.20.
Because the molecular weight is less than 160 g/mol, the empirical formula is also the molecular formula.

**Mass Spectrometry (Section 3.9)**

3.102 A neutral molecule will travel in a straight, undeflected, path in a mass spectrometer. Ionization is necessary as electric and magnetic fields will only exert a force on a charged species, not a neutral molecule. Ions of different masses are then accelerated by an electric field and passed between the poles of a strong magnet, which deflects them through a curved, evacuated pipe. The radius of deflection of a charged ion, $M^+$, as it passes between the magnet poles depends on its mass, with lighter ions deflected more strongly than heavier ones.

3.103 High mass accuracy is often needed to make an identification of a compound. For example, two compounds with different molecular formulas can have very similar masses, $C_5H_8O$ = 84.0570 and $C_6H_{12}$ = 84.0934. Highly accurate mass measurements are used to confirm the identity of molecules.

3.104 Mass of the sample is 70.042 11.
For $C_5H_{10}$, mass = 5(12.000 000) + 10(1.007 825) = 70.078 250
For $C_4H_6O$, mass = 4(12.000 000) + 6(1.007 825) + 1(15.994 915) = 70.041 865
For $C_3H_6N_2$, mass = 3(12.000 000) + 6(1.007 825) + 2(14.003 074) = 70.053 098
The sample is $C_4H_6O$.

3.105 Mass of the sample is 58.077 46.
For $C_4H_{10}$, mass = 4(12.000 000) + 10(1.007 825) = 58.078 250
For $C_3H_6O$, mass = 3(12.000 000) + 6(1.007 825) + 1(15.994 915) = 58.041 865

For $C_2H_6N_2$, mass = 2(12.000 000) + 6(1.007 825) + 2(14.003 074) = 58.053 098
The sample is $C_4H_{10}$.

3.106 mass of $CO_2$ = 169.2 mg = 0.1692 g; mass of $H_2O$ = 34.6 mg = 0.0346 g

$$0.1692 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2} \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.003\ 845 \text{ mol C}$$

$$0.0346 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.003\ 84 \text{ mol H}$$

$C_{0.003\ 845}H_{0.003\ 84}$; divide each subscript by the smaller, 0.003 84.
$C_{0.003\ 845\ /\ 0.003\ 84}H_{0.003\ 84\ /\ 0.003\ 84}$
The empirical formula is CH, 13.0.
The peak with the largest mass in the mass spectrum occurs near a mass of 78, which would be the molecular weight of the compound.
78/13.0 = 6; molecular formula = $C_{(6 \times 1)}H_{(6 \times 1)} = C_6H_6$

3.107 mass of 1,2,3-benzenetriol = 150.0 mg = 0.1500 g;
mass of $CO_2$ = 314.2 mg = 0.3142 g; mass of $H_2O$ = 64.3 mg = 0.0643 g

$$0.3142 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2} \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.007\ 139 \text{ mol C}$$

$$0.0643 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.007\ 14 \text{ mol H}$$

$$0.007\ 139 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 0.085\ 74 \text{ g C}$$

$$0.007\ 14 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 0.007\ 20 \text{ g H}$$

mass O = 0.1500 g – (0.085 74 g + 0.007 20 g) = 0.0571 g O

$$0.0571 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.003\ 57 \text{ mol O}$$

$C_{0.007\ 139}H_{0.007\ 14}O_{0.003\ 57}$; divide each subscript by the smallest, 0.003 57.
$C_{0.007\ 139\ /\ 0.003\ 57}H_{0.007\ 14\ /\ 0.003\ 57}O_{0.003\ 57\ /\ 0.003\ 57}$
The empirical formula is $C_2H_2O$, 42.0.
The peak with the largest mass in the mass spectrum occurs near a mass of 125, which would be the molecular weight of the compound.
125/42.0 = 2.97 = 3; molecular formula = $C_{(3 \times 2)}H_{(3 \times 2)}O_{(3 \times 1)} = C_6H_6O_3$

## Multiconcept Problems

3.108 High-resolution mass spectrometry is capable of measuring the mass of molecules with a particular isotopic composition.

3.109 Mass of 1 HCl molecule = $(36.5 \frac{u}{\text{molecule}})(1.6605 \times 10^{-24} \frac{g}{u}) = 6.06 \times 10^{-23}$ g/molecule

$$\text{Avogadro's number} = \left(\frac{36.5 \text{ g/mol}}{6.06 \times 10^{-23} \text{ g/molecule}}\right) = 6.02 \times 10^{23} \text{ molecules/mol}$$

3.110 The combustion reaction is: $2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$

$C_8H_{18}$, 114.23; $CO_2$, 44.01

$$\text{pounds } CO_2 = 1.00 \text{ gal} \times \frac{3.7854 \text{ L}}{1 \text{ gal}} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{0.703 \text{ g } C_8H_{18}}{1 \text{ mL}} \times \frac{1 \text{ mol } C_8H_{18}}{114.23 \text{ g } C_8H_{18}} \times$$

$$\frac{16 \text{ mol } CO_2}{2 \text{ mol } C_8H_{18}} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} \times \frac{1 \text{ lb}}{453.59 \text{ g}} = 18.1 \text{ lb } CO_2$$

3.111 AgCl, 143.32; $CO_2$, 44.01; $H_2O$, 18.02

$$\text{mol Cl in 1.00 g of X} = 1.95 \text{ g AgCl} \times \frac{1 \text{ mol AgCl}}{143.32 \text{ g AgCl}} \times \frac{1 \text{ mol Cl}}{1 \text{ mol AgCl}} = 0.0136 \text{ mol Cl}$$

$$\text{mass Cl} = 0.0136 \text{ mol Cl} \times \frac{35.453 \text{ g Cl}}{1 \text{ mol Cl}} = 0.482 \text{ g Cl}$$

$$\text{mol C in 1.00 g of X} = 0.900 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2} \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.0204 \text{ mol C}$$

$$\text{mass C} = 0.0204 \text{ mol C} \times \frac{12.011 \text{ g C}}{1 \text{ mol C}} = 0.245 \text{ g C}$$

$$\text{mol H in 1.00 g of X} = 0.735 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.0816 \text{ mol H}$$

$$\text{mass H} = 0.0816 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 0.0823 \text{ g H}$$

mass N = 1.00 g – mass Cl – mass C – mass H = 1.00 – 0.482 g – 0.245 g – 0.0823 g = 0.19 g N

$$\text{mol N in 1.00 g of X} = 0.19 \text{ g N} \times \frac{1 \text{ mol N}}{14.01 \text{ g N}} = 0.014 \text{ mol N}$$

Determine empirical formula.

$C_{0.0204}H_{0.0816}N_{0.014}Cl_{0.0136}$; divide each subscript by the smallest, 0.0136.

$C_{0.0204/0.0136}H_{0.0816/0.0136}N_{0.014/0.0136}Cl_{0.0136/0.0136}$

$C_{1.5}H_6NCl$, multiply each subscript by 2 to get integers.

The empirical formula is $C_3H_{12}N_2Cl_2$.

3.112 $CaCO_3$, 100.09

$$\% \text{ Ca} = \frac{40.08 \text{ g Ca}}{100.09 \text{ g}} \times 100\% = 40.04\%$$

$$\% \text{ C} = \frac{12.01 \text{ g C}}{100.09 \text{ g}} \times 100\% = 12.00\%$$

$$\% \text{ O} = \frac{3 \text{ x } 16.00 \text{ g O}}{100.09 \text{ g}} \text{ x } 100\% = 47.96\%$$

Because the mass %'s for the pulverized rock are different from the mass %'s for pure $CaCO_3$ calculated here, the pulverized rock cannot be pure $CaCO_3$.

3.113 $C_2H_6O$, 46.07; $H_2O$, 18.02

Let X = mass of $H_2O$ in the 10.00 g sample.

Let Y = mass of ethanol ($C_2H_6O$) in the 10.00 g sample.

X + Y = 10.00 g and Y = 10.00 g – X

mass of collected $H_2O$ = 11.27 g

$$\text{mass of collected } H_2O = X + \left( Y \text{ x } \frac{1 \text{ mol } C_2H_6O}{46.07 \text{ g } C_2H_6O} \text{ x } \frac{3 \text{ mol } H_2O}{1 \text{ mol } C_2H_6O} \text{ x } \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} \right)$$

Substitute for Y.

$$11.27 \text{ g} = X + \left( (10.00 \text{ g} - X) \text{ x } \frac{1 \text{ mol } C_2H_6O}{46.07 \text{ g } C_2H_6O} \text{ x } \frac{3 \text{ mol } H_2O}{1 \text{ mol } C_2H_6O} \text{ x } \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} \right)$$

11.27 g = X + (10.00 g – X)(1.173)

11.27 g = X + 11.73 g – 1.173 X

0.173 X = 11.73 g – 11.27 g = 0.46 g

$$X = \frac{0.46 \text{ g}}{0.173} = 2.7 \text{ g } H_2O$$

Y = 10.00 g – X = 10.00 g – 2.7 g = 7.3 g $C_2H_6O$

3.114 FeO, 71.85; $Fe_2O_3$, 159.7

Let X equal the mass of FeO and Y the mass of $Fe_2O_3$ in the 10.0 g mixture. Therefore, X + Y = 10.0 g.

$$\text{mol Fe} = 7.43 \text{ g x } \frac{1 \text{ mol Fe}}{55.85 \text{ g Fe}} = 0.133 \text{ mol Fe}$$

mol FeO + 2 x mol $Fe_2O_3$ = 0.133 mol Fe

$$X \text{ x } \frac{1 \text{ mol FeO}}{71.85 \text{ g FeO}} + 2 \text{ x } \left( Y \text{ x } \frac{1 \text{ mol } Fe_2O_3}{159.7 \text{ g } Fe_2O_3} \right) = 0.133 \text{ mol Fe}$$

Rearrange to get X = 10.0 g – Y and then substitute it into the equation above to solve for Y.

$$(10.0 \text{ g} - Y) \text{ x } \frac{1 \text{ mol FeO}}{71.85 \text{ g FeO}} + 2 \text{ x } \left( Y \text{ x } \frac{1 \text{ mol } Fe_2O_3}{159.7 \text{ g } Fe_2O_3} \right) = 0.133 \text{ mol Fe}$$

$$\frac{10.0 \text{ mol}}{71.85} - \frac{Y \text{ mol}}{71.85 \text{ g}} + \frac{2 Y \text{ mol}}{159.7 \text{ g}} = 0.133 \text{ mol}$$

$$-\frac{Y \text{ mol}}{71.85 \text{ g}} + \frac{2 Y \text{ mol}}{159.7 \text{ g}} = 0.133 \text{ mol} - \frac{10.0 \text{ mol}}{71.85} = -0.0062 \text{ mol}$$

$$\frac{(-Y \text{ mol})(159.7 \text{ g}) + (2 Y \text{ mol})(71.85 \text{ g})}{(71.85 \text{ g})(159.7 \text{ g})} = -0.0062 \text{ mol}$$

$$\frac{-16.0\text{ Y mol}}{11474\text{ g}} = -0.0062\text{ mol}; \quad \frac{16.0\text{ Y}}{11474\text{ g}} = 0.0062$$

Y = (0.0062)(11474 g)/16.0 = 4.44 g = 4.4 g $Fe_2O_3$
X = 10.0 g – Y = 10.0 g – 4.4 g = 5.6 g FeO

3.115 AgCl, 143.32
Find the mass of Cl in 1.68 g of AgCl.

$$\text{mol Cl in 1.68 g of AgCl} = 1.68\text{ g AgCl} \times \frac{1\text{ mol AgCl}}{143.32\text{ g AgCl}} \times \frac{1\text{ mol Cl}}{1\text{ mol AgCl}} = 0.0117\text{ mol Cl}$$

$$\text{mass Cl} = 0.0117\text{ mol Cl} \times \frac{35.453\text{ g Cl}}{1\text{ mol Cl}} = 0.415\text{ g Cl}$$

All of the Cl in AgCl came from $XCl_3$.
Find the mass of X in 0.634 g of $XCl_3$.
Mass of X = 0.634 g – 0.415 g = 0.219 g X

$$0.0117\text{ mol Cl} \times \frac{1\text{ mol X}}{3\text{ mol Cl}} = 0.00390\text{ mol X}$$

$$\text{molar mass of X} = \frac{0.219\text{ g}}{0.00390\text{ mol}} = 56.2\text{ g/mol}; \quad X = Fe$$

3.116 $C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$; $C_6H_{12}O_6$, 180.16; $CO_2$, 44.01

$$66.3\text{ g }C_6H_{12}O_6 \times \frac{1\text{ mol }C_6H_{12}O_6}{180.16\text{ g }C_6H_{12}O_6} \times \frac{6\text{ mol }CO_2}{1\text{ mol }C_6H_{12}O_6} \times \frac{44.01\text{ g }CO_2}{1\text{ mol }CO_2} = 97.2\text{ g }CO_2$$

$$66.3\text{ g }C_6H_{12}O_6 \times \frac{1\text{ mol }C_6H_{12}O_6}{180.16\text{ g }C_6H_{12}O_6} \times \frac{6\text{ mol }CO_2}{1\text{ mol }C_6H_{12}O_6} \times \frac{25.4\text{ L }CO_2}{1\text{ mol }CO_2} = 56.1\text{ L }CO_2$$

3.117 Mass of Cu = 2.196 g; mass of S = 2.748 g – 2.196 g = 0.552 g S

(a) $$\%Cu = \frac{2.196\text{ g}}{2.748\text{ g}} \times 100\% = 79.91\%$$

$$\%S = \frac{0.552\text{ g}}{2.748\text{ g}} \times 100\% = 20.1\%$$

(b) $$2.196\text{ g Cu} \times \frac{1\text{ mol Cu}}{63.55\text{ g Cu}} = 0.034\,55\text{ mol Cu}$$

$$0.552\text{ g S} \times \frac{1\text{ mol S}}{32.07\text{ g S}} = 0.0172\text{ mol S}$$

$Cu_{0.03455}S_{0.0172}$; divide each subscript by the smaller, 0.0172.
$Cu_{0.03455\,/\,0.0172}S_{0.0172\,/\,0.0172}$
The empirical formula is $Cu_2S$.

(c) $Cu_2S$, 159.16

$$\frac{5.6\text{ g }Cu_2S}{1\text{ cm}^3} \times \frac{1\text{ mol }Cu_2S}{159.16\text{ g }Cu_2S} \times \frac{2\text{ mol }Cu^+\text{ ions}}{1\text{ mol }Cu_2S} \times \frac{6.022 \times 10^{23}\text{ }Cu^+\text{ ions}}{1\text{ mol }Cu^+\text{ ions}}$$

$$= 4.2 \times 10^{22}\text{ }Cu^+\text{ ions/cm}^3$$

3.118 Mass of added Cl = mass of $XCl_5$ – mass of $XCl_3$ = 13.233 g – 8.729 g = 4.504 g

mass of Cl in $XCl_5$ = 5 Cl's x $\frac{4.504\ g}{2\ Cl's}$ = 11.26 g Cl

mass of X in $XCl_5$ = 13.233 g – 11.26 g = 1.973 g X

$11.26\ g\ Cl \times \frac{1\ mol\ Cl}{35.45\ g\ Cl} = 0.3176\ mol\ Cl$

$0.3176\ mol\ Cl \times \frac{1\ mol\ X}{5\ mol\ Cl} = 0.063\ 52\ mol\ X$

molar mass of X = $\frac{1.973\ g\ X}{0.063\ 52\ mol\ X}$ = 31.1 g/mol; atomic weight =31.1, X = P

3.119 $PCl_3$, 137.33; $PCl_5$, 208.24

Let Y = mass of $PCl_3$ in the mixture, and (10.00 – Y) = mass of $PCl_5$ in the mixture.

fraction Cl in $PCl_3$ = $\frac{(3)(35.453\ g/mol)}{137.33\ g/mol}$ = 0.774 48

fraction Cl in $PCl_5$ = $\frac{(5)(35.453\ g/mol)}{208.24\ g/mol}$ = 0.851 25

(mass of Cl in $PCl_3$) + (mass of Cl in $PCl_5$) = mass of Cl in the mixture

0.774 48Y + 0.851 25(10.00 g – Y) = (0.8104)(10.00 g)

Y = 5.32 g $PCl_3$ and 10.00 – Y = 4.68 g $PCl_5$

3.120 $NH_4NO_3$, 80.04; $(NH_4)_2HPO_4$, 132.06

Assume you have a 100.0 g sample of the mixture.

Let X = grams of $NH_4NO_3$ and (100.0 – X) = grams of $(NH_4)_2HPO_4$.

Both compounds contain 2 nitrogen atoms per formula unit.

Because the mass % N in the sample is 30.43%, the 100.0 g sample contains 30.43 g N.

mol $NH_4NO_3$ = $(X) \times \frac{1\ mol\ NH_4NO_3}{80.04\ g}$

mol $(NH_4)_2HPO_4$ = $(100.0 - X) \times \frac{1\ mol\ (NH_4)_2HPO_4}{132.06\ g}$

$$\text{mass N} = \left(\left((X) \times \frac{1\ mol\ NH_4NO_3}{80.04\ g}\right) + \left((100.0 - X) \times \frac{1\ mol\ (NH_4)_2HPO_4}{132.06\ g}\right)\right) \times \left(\frac{2\ mol\ N}{1\ mol\ ammonium\ cmpds}\right) \times \left(\frac{14.0067\ g\ N}{1\ mol\ N}\right) = 30.43\ g$$

Solve for X.

$$\left(\frac{X}{80.04} + \frac{100.0 - X}{132.06}\right)(2)(14.0067) = 30.43$$

$$\left(\frac{X}{80.04} + \frac{100.0 - X}{132.06}\right) = 1.08627$$

$$\frac{(132.06)(X) + (100.0 - X)(80.04)}{(80.04)(132.06)} = 1.08627$$

$(132.06)(X) + (100.0 - X)(80.04) = (1.08627)(80.04)(132.06)$
$132.06X + 8004 - 80.04X = 11481.96$
$132.06X - 80.04X = 11481.96 - 8004$
$52.02X = 3477.96$

$$X = \frac{3477.96}{52.02} = 66.86 \text{ g } NH_4NO_3$$

$(100.0 - X) = (100.0 - 66.86) = 33.14 \text{ g } (NH_4)_2HPO_4$

$$\frac{\text{mass}_{NH_4NO_3}}{\text{mass}_{(NH_4)_2HPO_4}} = \frac{66.86 \text{ g}}{33.14 \text{ g}} = 2.018$$

The mass ratio of $NH_4NO_3$ to $(NH_4)_2HPO_4$ in the mixture is 2 to 1.

3.121 $Na_2CO_3 \rightarrow Na_2O + CO_2$; $Na_2CO_3$, 106; $Na_2O$, 62
$CaCO_3 \rightarrow CaO + CO_2$; $CaCO_3$, 100; CaO, 56
In a 0.35 kg sample of glass there would be:
0.12 x 0.35 kg = 0.042 kg = 42 g of $Na_2O$
0.13 x 0.35 kg = 0.045 kg = 45 g of CaO
350 g – 42 g – 45 g = 263 g of $SiO_2$

$$\text{mass } Na_2CO_3 = 42 \text{ g } Na_2O \times \frac{1 \text{ mol } Na_2O}{62 \text{ g } Na_2O} \times \frac{1 \text{ mol } Na_2CO_3}{1 \text{ mol } Na_2O} \times \frac{106 \text{ g } Na_2CO_3}{1 \text{ mol } Na_2CO_3} = 72 \text{ g } Na_2CO_3$$

$$\text{mass } CaCO_3 = 45 \text{ g CaO} \times \frac{1 \text{ mol CaO}}{56 \text{ g CaO}} \times \frac{1 \text{ mol } CaCO_3}{1 \text{ mol CaO}} \times \frac{100 \text{ g } CaCO_3}{1 \text{ mol } CaCO_3} = 80 \text{ g } CaCO_3$$

To make 0.35 kg of glass, start with 72 g $Na_2CO_3$, 80 g $CaCO_3$, and 263 g $SiO_2$.

3.122 (a) 56.0 mL = 0.0560 L

$$\text{mol } X_2 = (0.0560 \text{ L } X_2)\left(\frac{1 \text{ mol}}{22.41 \text{ L}}\right) = 0.00250 \text{ mol } X_2$$

mass $X_2$ = 1.12 g $MX_2$ – 0.720 g MX = 0.40 g $X_2$

$$\text{molar mass } X_2 = \frac{0.40 \text{ g}}{0.00250 \text{ mol}} = 160 \text{ g/mol}$$

atomic weight of X = 160/2 = 80; X is Br.

(b)
$$\text{mol MX} = 0.00250 \text{ mol } X_2 \times \frac{2 \text{ mol MX}}{1 \text{ mol } X_2} = 0.00500 \text{ mol MX}$$

$$\text{mass of X in MX} = 0.00500 \text{ mol MX} \times \frac{1 \text{ mol X}}{1 \text{ mol MX}} \times \frac{80 \text{ g X}}{1 \text{ mol X}} = 0.40 \text{ g X}$$

mass of M in MX = 0.720 g MX – 0.40 g X = 0.32 g M

$$\text{molar mass M} = \frac{0.32 \text{ g}}{0.00500 \text{ mol}} = 64 \text{ g/mol}$$

atomic weight of X = 64; M is Cu.

3.123 23.46 mg = 0.023 46 g; 20.42 mg = 0.02042 g; 33.27 mg = 0.033 27 g

$$0.033\ 27\ \text{g}\ CO_2 \times \frac{1\ \text{mol}\ CO_2}{44.01\ \text{g}\ CO_2} \times \frac{1\ \text{mol C}}{1\ \text{mol}\ CO_2} = 7.560 \times 10^{-4}\ \text{mol C}$$

$$0.020\ 42\ \text{g}\ H_2O \times \frac{1\ \text{mol}\ H_2O}{18.02\ \text{g}\ H_2O} \times \frac{2\ \text{mol H}}{1\ \text{mol}\ H_2O} = 2.266 \times 10^{-3}\ \text{mol H}$$

$$7.560 \times 10^{-4}\ \text{mol C} \times \frac{12.01\ \text{g C}}{1\ \text{mol C}} = 0.009\ 080\ \text{g C}$$

$$2.266 \times 10^{-3}\ \text{mol H} \times \frac{1.008\ \text{g H}}{1\ \text{mol H}} = 0.002\ 284\ \text{g H}$$

mass O = 0.023 46 g – (0.009 080 g + 0.002 284 g) = 0.012 10 g O

$$0.012\ 10\ \text{g O} \times \frac{1\ \text{mol O}}{16.00\ \text{g O}} = 7.563 \times 10^{-4}\ \text{mol O}$$

Scale each mol quantity to eliminate exponents.

$C_{0.7560}H_{2.266}O_{0.7563}$; divide each subscript by the smallest, 0.7560.

$C_{0.7560\,/\,0.7560}H_{2.266\,/\,0.7560}O_{0.7563\,/\,0.7560}$

The empirical formula is $CH_3O$, 31.0.

62.0 / 31.0 = 2; molecular formula = $C_{(2 \times 1)}H_{(2 \times 3)}O_{(2 \times 1)} = C_2H_6O_2$

3.124 (a) $$0.138\ \text{g}\ H_2O \times \frac{1\ \text{mol}\ H_2O}{18.0\ \text{g}\ H_2O} \times \frac{2\ \text{mol H}}{1\ \text{mol}\ H_2O} = 0.0153\ \text{mol H}$$

$$1.617\ \text{g}\ CO_2 \times \frac{1\ \text{mol}\ CO_2}{44.0\ \text{g}\ CO_2} \times \frac{1\ \text{mol C}}{1\ \text{mol}\ CO_2} = 0.0368\ \text{mol C}$$

$$0.0153\ \text{mol H} \times \frac{1.01\ \text{g H}}{1\ \text{mol H}} = 0.016\ \text{g H}$$

$$0.0368\ \text{mol C} \times \frac{12.0\ \text{g C}}{1\ \text{mol C}} = 0.442\ \text{g C}$$

1.0 g total – (0.016 g H + 0.442 g C) = 0.542 g Cl

$$0.542\ \text{g Cl} \times \frac{1\ \text{mol Cl}}{35.5\ \text{g Cl}} = 0.0153\ \text{mol Cl}$$

$C_{0.0368}H_{0.0153}Cl_{0.0153}$; divide each subscript by the smallest, 0.0153.

$C_{0.0368\,/\,0.0153}H_{0.0153\,/\,0.0153}Cl_{0.0153\,/\,0.0153}$

$C_{2.5}HCl$

Multiply each subscript by 2 to get all integer subscripts.

$C_{(2 \times 2.5)}H_{(2 \times 1)}Cl_{(2 \times 1)}$

The empirical formula is $C_5H_2Cl_2$, 133.0.

(b) 326.26/133.0 = 2.45 = 2.5; molecular formula = $C_{(2.5 \times 5)}H_{(2.5 \times 2)}Cl_{(2.5 \times 2)} = C_{12}H_5Cl_5$

(c) No, because Cl does not form a useful oxide, so both O and Cl would have to be obtained by mass difference but that is impossible. You can only determine one element by mass difference.