

### Chapter Three

- 3.2 The mole is the SI unit for the amount of a substance. A mole is equal in quantity to Avogadro's number ( $6.022 \times 10^{23}$ ) of particles, or the formula mass in grams of a substance.
- 3.4 There are the same number of molecules in 2.5 moles of  $\text{H}_2\text{O}$  and 2.5 moles of  $\text{H}_2$ .
- 3.5 There are 2 moles of iron atoms in 1 mole of  $\text{Fe}_2\text{O}_3$ . The stoichiometric equivalent between Fe and  $\text{Fe}_2\text{O}$  is  $2 \text{ mol Fe} \equiv 1 \text{ mol Fe}_2\text{O}_3$ .  
For the number of iron atoms in 1 mole of  $\text{Fe}_2\text{O}_3$ :
- $$1 \text{ mol Fe}_2\text{O}_3 \left( \frac{2 \text{ mol Fe}}{1 \text{ mole Fe}_2\text{O}_3} \right) \left( \frac{6.022 \times 10^{23} \text{ Fe atoms}}{1 \text{ mol Fe}} \right) = 1.204 \times 10^{24} \text{ atoms Fe}$$
- 3.12 When balancing a chemical equation, changing the subscripts changes the identity of the substance.
- 3.14 There are three distinct empirical formulas represented  $\text{AB}_2$ ,  $\text{AB}_3$ , and  $\text{A}_3\text{B}_8$ . There are two molecules with the empirical formula  $\text{AB}_3$ ;  $\text{AB}_3$  and  $\text{A}_2\text{B}_6$ . There is one  $\text{A}_3\text{B}_8$ , and there are two with the formula  $\text{AB}_2$ ;  $\text{A}_6\text{B}_{12}$  and  $\text{A}_3\text{B}_6$ .
- 3.17 Student B is correct.  
Student A wrote a properly balanced equation. However, by changing the subscript for the product of the reaction from an implied one,  $\text{NaCl}$ , to a two,  $\text{NaCl}_2$ , this student has changed the identity of the product. When balancing chemical equations, never change the values of the subscripts given in the unbalanced equation.
- 3.26 1:4, 1 mol C:4 mol H
- 3.28  $1.80 \times 10^{24} \text{ molecules of I}_2 \left( \frac{1 \text{ mol I}_2}{6.022 \times 10^{23} \text{ molecules I}_2} \right) = 2.99 \text{ mole I}_2$
- 3.30 (a) 2 atom C: 1 atom O  
(b) 2 mole C: 1 mole O  
(c) 1 atom C:2 atom H  
(d) 1 mole C:2 mole H
- 3.34  $\text{mol O} = (4.25 \text{ mol CaCO}_3) \left( \frac{3 \text{ mol O}}{1 \text{ mol CaCO}_3} \right) = 12.8 \text{ mol O}$
- 3.42  $\text{atom H} = (2.31 \text{ mol C}_3\text{H}_8) \left( \frac{8 \text{ mol H}}{1 \text{ mol C}_3\text{H}_8} \right) \left( \frac{6.022 \times 10^{23} \text{ atoms H}}{1 \text{ mol H}} \right) = 1.11 \times 10^{25} \text{ atoms H}$
- 3.48 (a)  $\text{g S} = (0.546 \text{ mol S}) \left( \frac{32.07 \text{ g S}}{1 \text{ mole S}} \right) = 17.5 \text{ g S}$   
(b)  $\text{g N} = (3.29 \text{ mol N}) \left( \frac{14.01 \text{ g N}}{1 \text{ mole N}} \right) = 46.1 \text{ g N}$   
(c)  $\text{g Al} = (8.11 \text{ mol Al}) \left( \frac{26.98 \text{ g N}}{1 \text{ mole N}} \right) = 219 \text{ g Al}$
- 3.50  $\text{g Na} = 4.00 \times 10^{17} \text{ atoms Na} \left( \frac{1 \text{ mol Na}}{6.022 \times 10^{23} \text{ atoms Na}} \right) \left( \frac{22.99 \text{ g Na}}{1 \text{ mol Na}} \right) = 1.53 \times 10^{-5} \text{ g Na}$
- 3.52  $\text{mol Cr} = 85.7 \text{ g Cr} \left( \frac{1 \text{ mol Cr}}{52.00 \text{ g Cr}} \right) = 1.65 \text{ mol Cr}$

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3.54

Note: all masses are in g/mole

- (a)  $\text{Ca}(\text{NO}_3)_2 = 1\text{Ca} + 2\text{N} + 6\text{O}$   
 $= (40.078) + (2 \times 14.0067) + (6 \times 15.9994)$   
 $= 164.0878 \text{ g/mole} = 164.088 \text{ g/mol}$
- (b)  $\text{Pb}(\text{C}_2\text{H}_5)_4 = 1\text{Pb} + 8\text{C} + 20\text{H}$   
 $= (207.2) + (8 \times 12.0107) + (20 \times 1.00794)$   
 $= 323.4 \text{ g/mole}$  (Since the mass of Pb is known exactly.)
- (c)  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O} = 2\text{Na} + 1\text{S} + 14\text{O} + 20\text{H}$   
 $= (2 \times 22.98977) + 32.065 + (14 \times 15.9994) + (20 \times 1.00794)$   
 $= 322.19494 \text{ g/mole} = 322.195 \text{ g/mol}$
- (d)  $\text{Fe}_4[\text{Fe}(\text{CN})_6]_3 = 7\text{Fe} + 18\text{C} + 18\text{N}$   
 $= (7 \times 55.845) + (18 \times 12.0107) + (18 \times 14.0067)$   
 $= 859.2282 \text{ g/mole} = 859.228 \text{ g/mol}$
- (e)  $\text{Mg}_3(\text{PO}_4)_2 = 3\text{Mg} + 2\text{P} + 8\text{O}$   
 $= (3 \times 24.3050) + (2 \times 30.97376) + (8 \times 15.9994)$   
 $= 262.85772 \text{ g/mole} = 262.8577 \text{ g/mol}$

3.56

- (a)  $\text{g ZnCl}_2 = (0.754 \text{ mol ZnCl}_2) \left( \frac{136.31 \text{ g ZnCl}_2}{1 \text{ mol ZnCl}_2} \right) = 103 \text{ g ZnCl}_2$
- (b)  $\mu\text{g KIO}_3 = (0.194 \mu\text{mol KIO}_3) \left( \frac{1 \text{ mol KIO}_3}{10^6 \mu\text{mol KIO}_3} \right) \left( \frac{214.00 \text{ g KIO}_3}{1 \text{ mol KIO}_3} \right) \left( \frac{1000 \mu\text{g KIO}_3}{1 \text{ g KIO}_3} \right)$   
 $= 4.15 \times 10^{-5} \text{ g KIO}_3$
- (c)  $\text{g POCl}_3 = (0.322 \text{ mmol POCl}_3) \left( \frac{1 \text{ mol POCl}_3}{10^3 \text{ mmol POCl}_3} \right) \left( \frac{153.33 \text{ g POCl}_3}{1 \text{ mol POCl}_3} \right) = 0.0494 \text{ g POCl}_3$
- (d)  $\text{g } (\text{NH}_4)_2\text{HPO}_4 = (4.31 \times 10^{-3} \text{ mol } (\text{NH}_4)_2\text{HPO}_4) \left( \frac{132.1 \text{ g } (\text{NH}_4)_2\text{HPO}_4}{1 \text{ mol } (\text{NH}_4)_2\text{HPO}_4} \right)$   
 $= 0.569 \text{ g } (\text{NH}_4)_2\text{HPO}_4$

3.58

- (a)  $\text{mol Ca}(\text{OH})_2 = (9.36 \text{ g Ca}(\text{OH})_2) \left( \frac{1 \text{ mole Ca}(\text{OH})_2}{74.10 \text{ g Ca}(\text{OH})_2} \right) = 0.126 \text{ mol Ca}(\text{OH})_2$
- (b)  $\text{mol PbSO}_4 = (38.2 \text{ kg PbSO}_4) \left( \frac{1000 \text{ g PbSO}_4}{1 \text{ kg PbSO}_4} \right) \left( \frac{1 \text{ mole PbSO}_4}{303.3 \text{ g PbSO}_4} \right) = 126 \text{ mol PbSO}_4$
- (c)  $\text{mol H}_2\text{O}_2 = (4.29 \text{ g H}_2\text{O}_2) \left( \frac{1 \text{ mole H}_2\text{O}_2}{34.01 \text{ g H}_2\text{O}_2} \right) = 0.126 \text{ mol H}_2\text{O}_2$
- (d)  $\text{mol NaAuCl}_4 = (4.65 \text{ mg NaAuCl}_4) \left( \frac{1 \text{ g NaAuCl}_4}{1000 \text{ mg NaAuCl}_4} \right) \left( \frac{1 \text{ mol NaAuCl}_4}{361.8 \text{ g NaAuCl}_4} \right)$   
 $= 1.29 \times 10^{-5} \text{ mol NaAuCl}_4$

3.66

- (a) The molar mass of  $(\text{CH}_3)_2\text{N}_2\text{H}_2$  is 60.12 g/mol.

$$\% \text{ C} = \frac{24.02 \text{ g C}}{60.12 \text{ g } (\text{CH}_3)_2\text{N}_2\text{H}_2} \times 100\% = 40.0\%$$

$$\% \text{ H} = \frac{8.06 \text{ g H}}{60.12 \text{ g } (\text{CH}_3)_2\text{N}_2\text{H}_2} \times 100\% = 13.4\%$$

$$\% \text{ N} = \frac{28.0 \text{ g N}}{60.12 \text{ g } (\text{CH}_3)_2\text{N}_2\text{H}_2} \times 100\% = 46.6\%$$

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(b) The molar mass of  $\text{CaCO}_3$  is 100.1 g/mol.

$$\% \text{ Ca} = \frac{40.08 \text{ g Ca}}{100.1 \text{ g CaCO}_3} \times 100\% = 40.0\%$$

$$\% \text{ C} = \frac{12.01 \text{ g C}}{100.1 \text{ g CaCO}_3} \times 100\% = 12.0\%$$

$$\% \text{ O} = \frac{48.00 \text{ g O}}{100.1 \text{ g CaCO}_3} \times 100\% = 48.0\%$$

(c) The molar mass of  $\text{Fe}(\text{NO}_3)_3$  is 241.9 g/mol.

$$\% \text{ Fe} = \frac{55.85 \text{ g Fe}}{241.9 \text{ g Fe}(\text{NO}_3)_3} \times 100\% = 23.1\%$$

$$\% \text{ N} = \frac{42.03 \text{ g N}}{241.9 \text{ g Fe}(\text{NO}_3)_3} \times 100\% = 17.4\%$$

$$\% \text{ O} = \frac{144.00 \text{ g O}}{241.9 \text{ g Fe}(\text{NO}_3)_3} \times 100\% = 59.5\%$$

(d) The molar mass of  $\text{C}_3\text{H}_8$  is 44.11 g/mol.

$$\% \text{ C} = \frac{36.03 \text{ g C}}{44.11 \text{ g C}_3\text{H}_8} \times 100\% = 81.7\%$$

$$\% \text{ H} = \frac{8.08 \text{ g H}}{44.11 \text{ g C}_3\text{H}_8} \times 100\% = 18.3\%$$

(e) The molar mass of  $\text{Al}_2(\text{SO}_4)_3$  is 342.2 g/mol.

$$\% \text{ Al} = \frac{54.0 \text{ g Al}}{342.2 \text{ g Al}_2(\text{SO}_4)_3} \times 100\% = 15.8\%$$

$$\% \text{ S} = \frac{96.2 \text{ g S}}{342.2 \text{ g Al}_2(\text{SO}_4)_3} \times 100\% = 28.1\%$$

$$\% \text{ O} = \frac{192.0 \text{ g O}}{342.2 \text{ g Al}_2(\text{SO}_4)_3} \times 100\% = 56.1\%$$

$$3.68 \quad \% \text{ N in carbamazepine} = \frac{28.02 \text{ g N}}{236.29 \text{ g C}_{15}\text{H}_{12}\text{N}_2\text{O}} \times 100\% = 11.9\% \text{ N}$$

$$\% \text{ N in carbetapentane} = \frac{14.01 \text{ g N}}{333.52 \text{ g C}_{20}\text{H}_{31}\text{NO}_3} \times 100\% = 4.20\% \text{ N}$$

Therefore, carbamazepine has a higher percentage of nitrogen.

3.78 (a)  $\text{CH}_3\text{O}$  (b)  $\text{HSO}_4$  (c)  $\text{C}_2\text{H}_5$  (d)  $\text{BH}_3$  (e)  $\text{C}_2\text{H}_6\text{O}$

$$3.80 \quad \text{mol C} = (0.423 \text{ g C}) \left( \frac{1 \text{ mol C}}{12.01 \text{ g C}} \right) = 0.0352 \text{ mol C}$$

$$\text{mol Cl} = (2.50 \text{ g Cl}) \left( \frac{1 \text{ mol Cl}}{35.45 \text{ g Cl}} \right) = 0.0705 \text{ mol Cl}$$

$$\text{mol F} = (1.34 \text{ g F}) \left( \frac{1 \text{ mol F}}{19.00 \text{ g F}} \right) = 0.0705 \text{ mol F}$$

Now we divide each of these numbers of moles by the smallest of the three numbers, in order to obtain the simplest mole ratio among the three elements in the compound:

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for C, 0.0352 moles / 0.0352 moles = 1.00  
 for Cl, 0.0705 moles / 0.0352 moles = 2.000  
 for F, 0.0705 moles / 0.0352 moles = 2.00

These relative mole amounts give us the empirical formula  $\text{CCl}_2\text{F}_2$

3.84 Assume a 100 g sample:

$$\text{mol C} = (63.2 \text{ g C}) \left( \frac{1 \text{ mol C}}{12.01 \text{ g C}} \right) = 5.26 \text{ mol C}$$

$$\text{mol H} = (5.26 \text{ g H}) \left( \frac{1 \text{ mol H}}{1.008 \text{ g H}} \right) = 5.22 \text{ mol H}$$

$$\text{mol O} = (31.6 \text{ g O}) \left( \frac{1 \text{ mol O}}{16.00 \text{ g O}} \right) = 1.98 \text{ mol O}$$

Now we divide each of these numbers of moles by the smallest of the three numbers, in order to obtain the simplest mole ratio among the three elements in the compound:

for C, 5.26 moles / 1.98 moles = 2.66

for H, 5.22 moles / 1.98 moles = 2.64

for O, 1.98 moles / 1.98 moles = 1.00

$\text{C}_{2.66}\text{H}_{2.64}\text{O}_1 \times 2 = \text{C}_{5.32}\text{H}_{5.28}\text{O}_2$ , not whole numbers so 2 doesn't work, let's try 3

$\text{C}_{2.66}\text{H}_{2.64}\text{O}_1 \times 3 = \text{C}_8\text{H}_8\text{O}_3$

Therefore the empirical formula is  $\text{C}_8\text{H}_8\text{O}_3$

3.90 (a) Formula mass = 122.1 g

$$\frac{732.6 \text{ g/mol}}{122.1 \text{ g/mol}} = 6.000$$

The molecular formula is  $\text{Na}_{12}\text{Si}_6\text{O}_{18}$

(b) Formula mass = 102.0 g

$$\frac{305.9 \text{ g/mol}}{102.0 \text{ g/mol}} = 2.999$$

The molecular formula is  $\text{Na}_3\text{P}_3\text{O}_9$

(c) Formula mass = 31.03 g

$$\frac{62.1 \text{ g/mol}}{31.03 \text{ g/mol}} = 2.00$$

The molecular formula is  $\text{C}_2\text{H}_6\text{O}_2$

3.94 From the information provided, the mass of sulfur is the difference between the total mass and the mass of antimony:

$$\text{g S} = 0.6662 \text{ g compound} - 0.4017 \text{ g Sb} = 0.2645 \text{ g S}$$

To determine the empirical formula, first convert the two masses to a number of moles.

$$\text{mol S} = (0.2645 \text{ g S}) \left( \frac{1 \text{ mole S}}{32.065 \text{ g S}} \right) = 8.249 \times 10^{-3} \text{ mol S}$$

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$$\text{mol Sb} = (0.4017 \text{ g Sb}) \left( \frac{1 \text{ mole Sb}}{121.76 \text{ g Sb}} \right) = 3.299 \times 10^{-3} \text{ mol Sb}$$

Now, divide each of these values by the smaller quantity to determine the simplest mole ratio between the two elements:

$$\text{For Sb: } 3.299 \times 10^{-3} \text{ moles} / 3.299 \times 10^{-3} \text{ moles} = 1.000 \text{ mol Sb}$$

$$\text{For S: } 8.249 \times 10^{-3} \text{ moles} / 3.299 \times 10^{-3} \text{ moles} = 2.500 \text{ mol S}$$

Hence the empirical formula is  $\text{Sb}_2\text{S}_5$ , and the empirical mass is  $(2 \times \text{Sb}) + (5 \times \text{S}) = 403.85 \text{ g/mol}$ . Since the molecular mass reported in the problem is the same as the calculated empirical mass, the empirical formula is the same as the molecular formula.

$$3.108 \quad (\text{a}) \quad \text{mol O}_2 = (6 \text{ mol C}_8\text{H}_{18}) \left( \frac{25 \text{ mole O}_2}{2 \text{ mole C}_8\text{H}_{18}} \right) = 80 \text{ mol O}_2$$

(Note: This calculation is limited due to sig figs.)

$$(\text{b}) \quad \text{mol CO}_2 = (0.5 \text{ mol C}_8\text{H}_{18}) \left( \frac{16 \text{ mole CO}_2}{2 \text{ mole C}_8\text{H}_{18}} \right) = 4 \text{ mol CO}_2$$

$$(\text{c}) \quad \text{mol H}_2\text{O} = (8 \text{ mol C}_8\text{H}_{18}) \left( \frac{18 \text{ mole H}_2\text{O}}{2 \text{ mole C}_8\text{H}_{18}} \right) = 70 \text{ mol H}_2\text{O}$$

$$(\text{d}) \quad \text{mol O}_2 = (6.00 \text{ mol CO}_2) \left( \frac{25 \text{ mole O}_2}{16 \text{ mole CO}_2} \right) = 9.38 \text{ mol O}_2$$

$$\text{mol C}_8\text{H}_{18} = (6.00 \text{ mol CO}_2) \left( \frac{2 \text{ mole C}_8\text{H}_{18}}{16 \text{ mole CO}_2} \right) = 0.750 \text{ mol C}_8\text{H}_{18}$$

$$3.110 \quad (\text{a}) \quad 3 \text{ mol C}_3\text{H}_8 \left( \frac{5 \text{ mol O}_2}{1 \text{ mol C}_3\text{H}_8} \right) \left( \frac{32.00 \text{ g O}_2}{1 \text{ mol O}_2} \right) = 500 \text{ g O}_2$$

$$(\text{b}) \quad 0.1 \text{ mol C}_3\text{H}_8 \left( \frac{3 \text{ mol CO}_2}{1 \text{ mol C}_3\text{H}_8} \right) \left( \frac{44.01 \text{ g CO}_2}{1 \text{ mol CO}_2} \right) = 13 \text{ g CO}_2$$

$$(\text{c}) \quad 4 \text{ mol C}_3\text{H}_8 \left( \frac{4 \text{ mol H}_2\text{O}}{1 \text{ mol C}_3\text{H}_8} \right) \left( \frac{18.01 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} \right) = 300 \text{ g H}_2\text{O}$$

$$3.114 \quad \text{g H}_2\text{O}_2 = (852 \text{ g N}_2\text{H}_4) \left( \frac{1 \text{ mol N}_2\text{H}_4}{32.05 \text{ g N}_2\text{H}_4} \right) \left( \frac{7 \text{ mol H}_2\text{O}_2}{1 \text{ mol N}_2\text{H}_4} \right) \left( \frac{34.02 \text{ g H}_2\text{O}_2}{1 \text{ mol H}_2\text{O}_2} \right) = 6330 \text{ g H}_2\text{O}_2$$

3.118 Determine how much ethanol is produced starting with each reactant.

$$1.0 \text{ kg C}_2\text{H}_4 \times \frac{1000 \text{ g C}_2\text{H}_4}{1 \text{ kg C}_2\text{H}_4} \times \frac{1 \text{ mol C}_2\text{H}_4}{28.05 \text{ g C}_2\text{H}_4} \times \frac{1 \text{ mol C}_2\text{H}_5\text{OH}}{1 \text{ mol C}_2\text{H}_4} \times \frac{46.08 \text{ g C}_2\text{H}_5\text{OH}}{1 \text{ mol C}_2\text{H}_5\text{OH}} = 1.64 \times 10^3 \text{ g C}_2\text{H}_5\text{OH}$$

$$0.010 \text{ kg H}_2\text{O} \times \frac{1000 \text{ g H}_2\text{O}}{1 \text{ kg H}_2\text{O}} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} \times \frac{1 \text{ mol C}_2\text{H}_5\text{OH}}{1 \text{ mol H}_2\text{O}} \times \frac{46.08 \text{ g C}_2\text{H}_5\text{OH}}{1 \text{ mol C}_2\text{H}_5\text{OH}} = 25.6 \text{ g C}_2\text{H}_5\text{OH}$$

Because water makes the least amount of ethanol, it is the limiting reactant. Only 25.6 g of ethanol are made. After that, all the water runs out and the reaction cannot proceed.

3.122

$$0.360 \text{ mol } PCl_5 \times \frac{5 \text{ mol } HCl}{1 \text{ mol } PCl_5} \times \frac{36.461 \text{ g } HCl}{1 \text{ mol } HCl} = 65.6 \text{ g } HCl$$

$$2.88 \text{ mol } H_2O \times \frac{5 \text{ mol } HCl}{4 \text{ mol } H_2O} \times \frac{36.461 \text{ g } HCl}{1 \text{ mol } HCl} = 131 \text{ g } HCl$$

$PCl_5$  is the limiting reactant and 65.6 g of HCl are produced.

3.126 Assume there is excess oxygen present and determine the theoretical yield of carbon dioxide.

$$\text{g } CO_2 = (6.40 \text{ g } CH_3OH) \left( \frac{1 \text{ mol } CH_3OH}{32.04 \text{ g } CH_3OH} \right) \left( \frac{2 \text{ mol } CO_2}{2 \text{ mol } CH_3OH} \right) \left( \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} \right) = 8.79 \text{ g } CO_2$$

$$\% \text{ yield} = \frac{6.12 \text{ g}}{8.79 \text{ g}} \times 100\% = 69.6\%$$