CHAPTER 9

Chemical Quantities

CHAPTER ANSWERS

1. The coefficients of the balanced chemical equation for a reaction give the *relative numbers of molecules* of reactants and products that are involved in the reaction.
2. The coefficients of the balanced chemical equation for a reaction indicate the *relative numbers of moles* of each reactant that combine during the process as well as the number of moles of each product formed.
3. Although we define mass as the "amount of matter in a substance," the *units* in which we measure mass are a human invention. Atoms and molecules react on an individual particle-by-particle basis, and we have to count individual particles when doing chemical calculations.
4. Balanced chemical equations tell us in what molar ratios substances combine to form products; not, in what mass proportions they combine.
5.
   a. $PCl_3(l) + 3H_2O(l) \rightarrow H_3PO_3(aq) + 3HCl(g)$

   One molecule of liquid phosphorus trichloride reacts with three molecules of liquid water, producing one molecule of aqueous phosphorous acid and three molecules of gaseous hydrogen chloride. One mole of phosphorus trichloride reacts with three moles of water to produce one mole of phosphorous acid and three moles of hydrogen chloride.

   b. $2XeF_2(g) + 2H_2O(l) \rightarrow 2Xe(g) + 4HF(g) + O_2(g)$

   Two molecules of gaseous xenon difluoride react with two molecules of liquid water, producing two gaseous xenon atoms, four molecules of gaseous hydrogen fluoride, and one molecule of oxygen gas. Two moles of xenon difluoride react with two moles of water to produce two moles of xenon, four moles of hydrogen fluoride, and one mole of oxygen.

   c. $S(s) + 6HNO_3(aq) \rightarrow H_2SO_4(aq) + 2H_2O(l) + 6NO_2(g)$

   One sulfur atom reacts with six molecules of aqueous nitric acid, producing one molecule of aqueous sulfuric acid, two molecules of water, and six molecules of nitrogen dioxide gas. One mole of sulfur reacts with six moles of nitric acid to produce one mole of sulfuric acid, two moles of water, and six moles of nitrogen dioxide.

   d. $2NaHSO_3(s) \rightarrow Na_2SO_3(s) + SO_2(g) + H_2O(l)$

   Two formula units of solid sodium hydrogen sulfite react to produce one formula unit of solid sodium sulfite, one molecule of gaseous sulfur dioxide, and one molecule of liquid water. Two moles of sodium hydrogen sulfite react to produce one mole of sodium sulfite, one mole of sulfur dioxide, and one mole of water.

6.

a. $(NH_4)_2CO_3(s) \rightarrow 2NH_3(g) + CO_2(g) + H_2O(g)$

One formula unit of solid ammonium carbonate decomposes to produce two molecules of ammonia gas, one molecule of carbon dioxide gas, and one molecule of water vapor. One mole of solid ammonium carbonate decomposes into two moles of gaseous ammonia, one mole of carbon dioxide gas, and one mole of water vapor.

b. $6Mg(s) + P_4(s) \rightarrow 2Mg_3P_2(s)$

Six atoms of magnesium metal react with one molecule of solid phosphorus (P_4) to make two formula units of solid magnesium phosphide. Six moles of magnesium metal react with one mole of phosphorus solid (P_4) to produce two moles of solid magnesium phosphide.

c. $4Si(s) + S_8(s) \rightarrow 2Si_2S_4(l)$

Four atoms of solid silicon react with one molecule of solid sulfur (S_8) to form two molecules of liquid disilicon tetrasulfide. Four moles of solid silicon react with one mole of solid sulfur (S_8) to form two moles of liquid disilicon tetrasulfide.

d. $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$

One molecule of liquid ethanol burns with three molecules of oxygen gas to produce two molecules of carbon dioxide gas and three molecules of water vapor. One mole of liquid ethanol burns with three moles of oxygen gas to produce two moles of gaseous carbon dioxide and three moles of water vapor.

7. False. The coefficients of the balanced chemical equation represent the ratios on a *mole* basis by which potassium hydroxide combines with sulfur dioxide.

8. Balanced chemical equations tell us in what molar ratios substances combine to form products; not in what mass proportions they combine. How could 2 g of reactant produce a total of 3 g of products?

9. For converting from a given number of moles of CH_4 to the number of moles of oxygen needed for reaction, the correct mole ratio is

$$\left(\frac{2 \text{ mol } O_2}{1 \text{ mol } CH_4}\right).$$

For converting from a given number of moles of CH_4 to the number of moles of product produced, the ratios are

$$\left(\frac{1 \text{ mol } CO_2}{1 \text{ mol } CH_4}\right) \text{ and } \left(\frac{2 \text{ mol } H_2O}{1 \text{ mol } CH_4}\right).$$

10. $S(s) + 2H_2SO_4(l) \rightarrow 3SO_2(g) + 2H_2O(l)$

For SO_2, $\left(\frac{3 \text{ mol } SO_2}{1 \text{ mol } S}\right)$.

For H_2O, $\left(\frac{2 \text{ mol } H_2O}{1 \text{ mol } S}\right)$

For H_2SO_4, $\left(\frac{2 \text{ mol } H_2SO_4}{1 \text{ mol } S}\right)$

11.

a. $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

$0.15 \text{ mol Mg} \times \frac{2 \text{ mol MgO}}{2 \text{ mol Mg}} = 0.15 \text{ mol MgO}$

b. $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

$0.15 \text{ mol } O_2 \times \frac{2 \text{ mol MgO}}{1 \text{ mol } O_2} = 0.30 \text{ mol MgO}$

c. $4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

$0.15 \text{ mol Fe} \times \frac{2 \text{ mol } Fe_2O_3}{4 \text{ mol Fe}} = 0.075 \text{ mol } Fe_2O_3$

d. $4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

$0.15 \text{ mol } O_2 \times \frac{2 \text{ mol } Fe_2O_3}{3 \text{ mol } O_2} = 0.10 \text{ mol } Fe_2O_3$

12.

a. $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$

$5.0 \text{ mol } C_2H_6 \times \frac{7 \text{ mol } O_2}{2 \text{ mol } C_2H_6} = 17.5 \text{ mol } O_2$ (18 mol O_2)

b. $P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(g)$

$5.0 \text{ mol } P_4 \times \frac{5 \text{ mol } O_2}{1 \text{ mol } P_4} = 25 \text{ mol } O_2$

c. $CaO(s) + CO_2(g) \rightarrow CaCO_3(s)$

$5.0 \text{ mol CaO} \times \frac{1 \text{ mol } CO_2}{1 \text{ mol CaO}} = 5.0 \text{ mol } CO_2$

d. $4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

$5.0 \text{ mol Fe} \times \frac{3 \text{ mol } O_2}{4 \text{ mol Fe}} = 3.75 \text{ mol } O_2$ (3.8 mol O_2)

13.

a. $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$

$$1.25 \text{ mol } C_2H_5OH \times \frac{2 \text{ mol } CO_2}{1 \text{ mol } C_2H_5OH} = 2.50 \text{ mol } CO_2$$

$$1.25 \text{ mol } C_2H_5OH \times \frac{3 \text{ mol } H_2O}{1 \text{ mol } C_2H_5OH} = 3.75 \text{ mol } H_2O$$

b. $N_2(g) + O_2(g) \rightarrow 2NO(g)$

$$1.25 \text{ mol } N_2 \times \frac{2 \text{ mol NO}}{1 \text{ mol } N_2} = 2.50 \text{ mol NO}$$

c. $2NaClO_2(s) + Cl_2(g) \rightarrow 2ClO_2(g) + 2NaCl(s)$

$$1.25 \text{ mol } NaClO_2 \times \frac{2 \text{ mol } ClO_2}{2 \text{ mol } NaClO_2} = 1.25 \text{ mol } ClO_2$$

$$1.25 \text{ mol } NaClO_2 \times \frac{2 \text{ mol NaCl}}{2 \text{ mol } NaClO_2} = 1.25 \text{ mol NaCl}$$

d. $3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$

$$1.25 \text{ mol } H_2 \times \frac{2 \text{ mol } NH_3}{3 \text{ mol } H_2} = 0.833 \text{ mol } NH_3$$

14.

a. $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$

molar mass of NH_4Cl, 53.49 g

$$0.50 \text{ mol } NH_3 \times \frac{1 \text{ mol } NH_4Cl}{1 \text{ mol } NH_3} = 0.50 \text{ mol } NH_4Cl$$

$$0.50 \text{ mol } NH_4Cl \times \frac{53.49 \text{ g } NH_4Cl}{1 \text{ mol } NH_4Cl} = 27 \text{ g } NH_4Cl$$

b. $CH_4(g) + 4S(g) \rightarrow CS_2(l) + 2H_2S(g)$

molar masses: CS_2, 76.15 g; H_2S, 34.09 g

$$0.50 \text{ mol S} \times \frac{1 \text{ mol } CS_2}{4 \text{ mol S}} = 0.125 \text{ mol } CS_2 \ (= 0.13 \text{ mol } CS_2)$$

$$0.125 \text{ mol } CS_2 \times \frac{76.15 \text{ g } CS_2}{1 \text{ mol } CS_2} = 9.5 \text{ g } CS_2$$

$$0.50 \text{ mol S} \times \frac{2 \text{ mol } H_2S}{4 \text{ mol S}} = 0.25 \text{ mol } H_2S$$

$$0.25 \text{ mol } H_2S \times \frac{34.09 \text{ g } H_2S}{1 \text{ mol } H_2S} = 8.5 \text{ g } H_2S$$

c. $PCl_3(l) + 3H_2O(l) \rightarrow H_3PO_3(aq) + 3HCl(aq)$

molar masses: H_3PO_3, 81.99 g; HCl, 36.46 g

$$0.50 \text{ mol } PCl_3 \times \frac{1 \text{ mol H3PO}_3}{1 \text{ mol } PCl_3} = 0.50 \text{ mol } H_3PO_3$$

$$0.50 \text{ mol } H_3PO_3 \times \frac{81.99 \text{ g } H_3PO_3}{1 \text{ mol } H_3PO_3} = 41 \text{ g } H_3PO_3$$

$$0.50 \text{ mol } PCl_3 \times \frac{3 \text{ mol HCl}}{1 \text{ mol } PCl_3} = 1.5 \text{ mol HCl}$$

$$1.5 \text{ mol HCl} \times \frac{36.46 \text{ g HCl}}{1 \text{ mol HCl}} = 54.7 = 55 \text{ g HCl}$$

d. $NaOH(s) + CO_2(g) \rightarrow NaHCO_3(s)$

molar mass of $NaHCO_3$ = 84.01 g

$$0.50 \text{ mol NaOH} \times \frac{1 \text{ mol } NaHCO_3}{1 \text{ mol NaOH}} = 0.50 \text{ mol } NaHCO_3$$

$$0.50 \text{ mol } NaHCO_3 \times \frac{84.01 \text{ g } NaHCO_3}{1 \text{ mol } NaHCO_3} = 42 \text{ g } NaHCO_3$$

15.

a. $Cl_2(g) + 2KI(aq) \rightarrow 2KCl(aq) + I_2(s)$

$$0.275 \text{ mol } Cl_2 \times \frac{2 \text{ mol KI}}{1 \text{ mol } Cl_2} = 0.550 \text{ mol KI}$$

b. $6Co(s) + P_4(s) \rightarrow 2Co_3P_2(s)$

$$0.275 \text{ mol Co} \times \frac{1 \text{ mol } P_4}{6 \text{ mol Co}} = 0.0458 \text{ mol } P_4$$

c. $Zn(s) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + H_2(g)$

$$0.275 \text{ mol Zn} \times \frac{2 \text{ mol } HNO_3}{1 \text{ mol Zn}} = 0.550 \text{ mol } HNO_3$$

d. $C_5H_{12}(l) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(g)$

$$0.275 \text{ mol } C_5H_{12} \times \frac{8 \text{ mol } O_2}{1 \text{ mol } C_5H_{12}} = 2.20 \text{ mol } O_2$$

16. Before doing the calculations, the equations must be *balanced.*

a. $4KO_2(s) + 2H_2O(l) \rightarrow 3O_2(g) + 4KOH(s)$

$$0.625 \text{ mol KOH} \times \frac{3 \text{ mol } O_2}{4 \text{ mol KOH}} = 0.469 \text{ mol } O_2$$

b. $SeO_2(g) + 2H_2Se(g) \rightarrow 3Se(s) + 2H_2O(g)$

$$0.625 \text{ mol } H_2O \times \frac{3 \text{ mol Se}}{2 \text{ mol } H_2O} = 0.938 \text{ mol Se}$$

c. $2CH_3CH_2OH(l) + O_2(g) \rightarrow 2CH_3CHO(aq) + 2H_2O(l)$

$$0.625 \text{ mol } H_2O \times \frac{2 \text{ mol } CH_3CHO}{2 \text{ mol } H_2O} = 0.625 \text{ mol } CH_3CHO$$

d. $Fe_2O_3(s) + 2Al(s) \rightarrow 2Fe(l) + Al_2O_3(s)$

$$0.625 \text{ mol } Al_2O_3 \times \frac{2 \text{ mol Fe}}{1 \text{ mol } Al_2O_3} = 1.25 \text{ mol Fe}$$

17. the molar mass of the substance

18. Stoichiometry is the process of using a chemical equation to calculate the relative masses of reactants and products involved in a reaction.

19.

a. molar mass He = 4.003 g

$$2.62 \text{ g He} \times \frac{1 \text{ mol He}}{4.003 \text{ g He}} = 0.654 \text{ mol He}$$

b. molar mass H_3BO_3 = 61.83 g

$$4.95 \text{ g } H_3BO_3 \times \frac{1 \text{ mol } H_3BO_3}{61.83 \text{ g } H_3BO_3} = 0.0801 \text{ mol } H_3BO_3$$

c. molar mass CaF_2 = 78.08 g

$$8.31 \text{ g } CaF_2 \times \frac{1 \text{ mol } CaF_2}{78.08 \text{ g } CaF_2} = 0.106 \text{ mol } CaF_2$$

d. molar mass $Mg(C_2H_3O_2)_2$ = 142.4 g

$$0.195 \text{ g } Mg(C_2H_3O_2)_2 \times \frac{1 \text{ mol } Mg(C_2H_3O_2)_2}{142.4 \text{ g } Mg(C_2H_3O_2)_2} = 0.00137 \text{ mol } Mg(C_2H_3O_2)_2$$

e. molar mass NH_3 = 17.03 g

$$9.72 \text{ g } NH_3 \times \frac{1 \text{ mol } NH_3}{17.03 \text{ g } NH_3} = 0.571 \text{ mol } NH_3$$

20.

a. molar mass Li_2CO_3 = 73.89 g; 2.36 mg = 0.00236 g

$$0.00236 \text{ g } Li_2CO_3 \times \frac{1 \text{ mol } Li_2CO_3}{73.89 \text{ g } Li_2CO_3} = 3.19 \times 10^{-5} \text{ mol } Li_2CO_3$$

b. molar mass U = 238.0 g

$$1.92 \times 10^{-3} \text{ g U} \times \frac{1 \text{ mol U}}{238.0 \text{ g U}} = 8.07 \times 10^{-6} \text{ mol U}$$

c. molar mass $PbCl_2$ = 278.1 g; 3.21 kg = 3.21×10^3 g

$$3.21 \times 10^3 \text{ g } PbCl_2 \times \frac{1 \text{ mol}}{278.1 \text{ g}} = 11.5 \text{ mol } PbCl_2$$

d. molar mass $C_6H_{12}O_6$ = 180.2 g

$$4.62 \text{ g } C_6H_{12}O_6 \times \frac{1 \text{ mol } C_6H_{12}O_6}{180.2 \text{ g } C_6H_{12}O_6} = 0.0256 \text{ mol } C_6H_{12}O_6$$

e. molar mass KOH = 56.11 g

$$7.75 \text{ g KOH} \times \frac{1 \text{ mol KOH}}{56.11 \text{ g KOH}} = 0.138 \text{ mol KOH}$$

21.

a. molar mass O_2 = 32.00 g

$$4.25 \text{ mol } O_2 \times \frac{32.00 \text{ g } O_2}{1 \text{ mol } O_2} = 136 \text{ g } O_2$$

b. molar mass Pt = 195.1 g; 1.27 millimol = 0.00127 mol

$$0.00127 \text{ mol Pt} \times \frac{195.1 \text{ g Pt}}{1 \text{ mol Pt}} = 0.248 \text{ g Pt}$$

c. molar mass $FeSO_4$ = 151.92 g

$$0.00101 \text{ mol } FeSO_4 \times \frac{151.92 \text{ g } FeSO_4}{1 \text{ mol } FeSO_4} = 0.153 \text{ g } FeSO_4$$

d. molar mass $CaCO_3$ = 100.09 g

$$75.1 \text{ mol } CaCO_3 \times \frac{100.09 \text{ g } CaCO_3}{1 \text{ mol } CaCO_3} = 7.52 \times 10^3 \text{ g } CaCO_3$$

e. molar mass Au = 197.0 g

$$1.35 \times 10^{-4} \text{ mol Au} \times \frac{197.0 \text{ g Au}}{1 \text{ mol Au}} = 0.0266 \text{ mol Au}$$

f. molar mass H_2O_2 = 34.02 g

$$1.29 \text{ mol } H_2O_2 \times \frac{34.02 \text{ g } H_2O_2}{1 \text{ mol } H_2O_2} = 43.9 \text{ g } H_2O_2$$

g. molar mass CuS = 95.62 g

$$6.14 \text{ mol CuS} \times \frac{95.62 \text{ g CuS}}{1 \text{ mol CuS}} = 587 \text{ g CuS}$$

22.

a. molar mass of CuI = 190.5 g

$$0.624 \text{ mol CuI} \times \frac{190.5 \text{ g CuI}}{1 \text{ mol CuI}} = 119 \text{ g CuI}$$

b. molar mass of Br_2 = 159.8 g

$$4.24 \text{ mol } Br_2 \times \frac{159.8 \text{ g } Br_2}{1 \text{ mol } Br_2} = 678 \text{ g } Br_2$$

c. molar mass of XeF_4 = 207.4 g

$$0.000211 \text{ mol } XeF_4 \times \frac{207.4 \text{ g } XeF_4}{1 \text{ mol } XeF_4} = 0.0438 \text{ g } XeF_4$$

d. molar mass of C_2H_4 = 28.05 g

$$9.11 \text{ mol } C_2H_4 \times \frac{28.05 \text{ g } C_2H_4}{1 \text{ mol } C_2H_4} = 256 \text{ g } C_2H_4$$

e. molar mass of NH_3 = 17.03 g; 1.21 millimol = 0.00121 mol

$$0.00121 \text{ mol } NH_3 \times \frac{17.03 \text{ g } NH_3}{1 \text{ mol } NH_3} = 0.0206 \text{ g } NH_3$$

f. molar mass of NaOH = 40.00 g

$$4.25 \text{ mol NaOH} \times \frac{40.00 \text{ g NaOH}}{1 \text{ mol NaOH}} = 170 \text{ g NaOH}$$

g. molar mass of KI = 166.0 g

$$1.27 \times 10^{-6} \text{ mol KI} \times \frac{166.0 \text{ g KI}}{1 \text{ mol KI}} = 2.11 \times 10^{-4} \text{ g KI}$$

23. Before any calculations are done, the equations must be *balanced*.

a. $CS_2(l) + 3O_2(g) \rightarrow CO_2(g) + 2SO_2(g)$

masses: CS_2, 76.15 g; CO_2, 44.01 g; SO_2, 64.07 g

$$1.55 \text{ g } CS_2 \times \frac{1 \text{ mol } CS_2}{76.15 \text{ g } CS_2} = 0.02035 \text{ mol } CS_2$$

$$0.02035 \text{ mol } CS_2 \times \frac{1 \text{ mol } CO_2}{1 \text{ mol } CS_2} = 0.02035 \text{ mol } CO_2$$

$$0.02035 \text{ mol } CO_2 \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 0.896 \text{ g } CO_2$$

$$0.02035 \text{ mol } CS_2 \times \frac{2 \text{ mol } SO_2}{1 \text{ mol } CS_2} = 0.04071 \text{ mol } SO_2$$

$$0.04071 \text{ mol } SO_2 \times \frac{64.07 \text{ g } SO_2}{1 \text{ mol } SO_2} = 2.61 \text{ g } SO_2$$

b. $2NaNO_3(s) \rightarrow 2NaNO_2(s) + O_2(g)$

molar masses: $NaNO_3$, 85.00 g; $NaNO_2$, 69.00 g; O_2, 32.00 g

$$1.55 \text{ g } NaNO_3 \times \frac{1 \text{ mol } NaNO_3}{85.00 \text{ g } NaNO_3} = 0.01824 \text{ mol } NaNO_3$$

$$0.01824 \text{ mol } NaNO_3 \times \frac{2 \text{ mol } NaNO_2}{2 \text{ mol } NaNO_3} = 0.01824 \text{ mol } NaNO_2$$

$$0.01824 \text{ mol } NaNO_2 \times \frac{69.00 \text{ g } NaNO_2}{1 \text{ mol } NaNO_2} = 1.26 \text{ g } NaNO_2$$

$$0.01824 \text{ mol } NaNO_3 \times \frac{1 \text{ mol } O_2}{2 \text{ mol } NaNO_3} = 0.00912 \text{ mol } O_2$$

$$0.00912 \text{ mol } O_2 \times \frac{32.00 \text{ g } O_2}{1 \text{ mol } O_2} = 0.292 \text{ g } O_2$$

c. $H_2(g) + MnO_2(s) \rightarrow MnO(s) + H_2O(g)$ (already balanced)

molar masses: MnO_2, 86.94 g; MnO, 70.94 g; H_2O, 18.02 g

$$1.55 \text{ g } MnO_2 \times \frac{1 \text{ mol } MnO_2}{86.94 \text{ g } MnO_2} = 0.01783 \text{ mol } MnO_2$$

$$0.01783 \text{ mol } MnO_2 \times \frac{1 \text{ mol } MnO}{1 \text{ mol } MnO_2} = 0.01783 \text{ mol } MnO$$

$$0.01783 \text{ mol } MnO \times \frac{70.94 \text{ g } MnO}{1 \text{ mol } MnO} = 1.26 \text{ g } MnO$$

$$0.01783 \text{ mol } MnO_2 \times \frac{1 \text{ mol } H_2O}{1 \text{ mol } MnO_2} = 0.01783 \text{ mol } H_2O$$

$$0.01783 \text{ mol } H_2O \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 0.321 \text{ g } H_2O$$

d. $Br_2(l) + Cl_2(g) \rightarrow 2BrCl(g)$

molar masses: Br_2, 159.8 g; BrCl, 115.4 g

$$1.55 \text{ g } Br_2 \times \frac{1 \text{ mol } Br_2}{159.8 \text{ g } Br_2} = 0.00970 \text{ mol } Br_2$$

$$0.09700 \text{ mol } Br_2 \times \frac{2 \text{ mol } BrCl}{1 \text{ mol } Br_2} = 0.01940 \text{ mol } BrCl$$

$$0.01940 \text{ mol } BrCl \times \frac{115.4 \text{ g } BrCl}{1 \text{ mol } BrCl} = 2.24 \text{ g } BrCl$$

24. Before any calculations are done, the equations must be *balanced.*

a. $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$

molar mass C_2H_5OH = 46.07 g

$$5.00 \text{ g } C_2H_5OH \times \frac{1 \text{ mol } C_2H_5OH}{46.07 \text{ g } C_2H_5OH} \times \frac{3 \text{ mol } O_2}{1 \text{ mol } C_2H_5OH} = 0.326 \text{ mol } O_2$$

b. $P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(g)$

molar mass P_4 = 123.88 g

$$5.00 \text{ g } P_4 \times \frac{1 \text{ mol } P_4}{123.88 \text{ g}} \times \frac{5 \text{ mol } O_2}{1 \text{ mol } P_4} = 0.202 \text{ mol } O_2$$

c. $MgO(s) + CO_2(g) \rightarrow MgCO_3(s)$

molar mass MgO = 40.31 g

$$5.00 \text{ g MgO} \times \frac{1 \text{ mol MgO}}{40.31 \text{ g MgO}} \times \frac{1 \text{ mol } CO_2}{1 \text{ mol MgO}} = 0.124 \text{ mol } CO_2$$

d. $2Fe(s) + O_2(g) \rightarrow 2FeO(s)$

molar mass Fe = 55.85 g

$$5.00 \text{ g Fe} \times \frac{1 \text{ mol Fe}}{55.85 \text{ g Fe}} \times \frac{1 \text{ mol } O_2}{2 \text{ mol Fe}} = 0.0448 \text{ mol } O_2$$

25. Before any calculations are done, the equations must be *balanced.*

a. $TiBr_4(g) + 2H_2(g) \rightarrow Ti(s) + 4HBr(g)$

molar mass H_2 = 2.016 g; molar mass Ti = 47.90 g; molar mass of HBr = 80.91 g

$$12.5 \text{ g } H_2 \times \frac{1 \text{ mol } H_2}{2.016 \text{ g } H_2} = 6.20 \text{ mol } H_2$$

$$6.20 \text{ mol } H_2 \times \frac{1 \text{ mol Ti}}{2 \text{ mol } H_2} = 3.10 \text{ mol Ti}$$

$$3.10 \text{ mol Ti} \times \frac{47.90 \text{ g Ti}}{1 \text{ mol Ti}} = 148 \text{ g Ti}$$

$$6.20 \text{ mol } H_2 \times \frac{4 \text{ mol HBr}}{2 \text{ mol } H_2} = 12.4 \text{ mol HBr}$$

$$12.4 \text{ mol HBr} \times \frac{80.91 \text{ g HBr}}{1 \text{ mol HBr}} = 1.00 \times 10^3 \text{ g HBr}$$

b. $3SiH_4(g) + 4NH_3(g) \rightarrow Si_3N_4(s) + 12H_2(g)$

molar mass SiH_4 = 32.12 g; molar mass Si_3N_4 = 140.3 g; molar mass H_2 = 2.016 g

$$12.5 \text{ g } SiH_4 \times \frac{1 \text{ mol } SiH_4}{32.12 \text{ g } SiH_4} = 0.389 \text{ mol } SiH_4$$

$$0.389 \text{ mol } SiH_4 \times \frac{1 \text{ mol } Si_3N_4}{3 \text{ mol } SiH_4} = 0.130 \text{ mol } Si_3N_4$$

$$0.130 \text{ mol } Si_3N_4 \times \frac{140.3 \text{ g } Si_3N_4}{1 \text{ mol } Si_3N_4} = 18.2 \text{ g } Si_3N_4$$

$$0.389 \text{ mol } SiH_4 \times \frac{12 \text{ mol } H_2}{3 \text{ mol } SiH_4} = 1.56 \text{ mol } H_2$$

$$1.56 \text{ mol } H_2 \times \frac{2.016 \text{ g } H_2}{1 \text{ mol } H_2} = 3.14 \text{ g } H_2$$

c. $2NO(g) + 2H_2(g) \rightarrow N_2(g) + 2H_2O(l)$

molar mass H_2 = 2.016 g; molar mass N_2 = 28.02 g; molar mass H_2O = 18.02 g

$$12.5 \text{ g } H_2 \times \frac{1 \text{ mol } H_2}{2.016 \text{ g } H_2} = 6.20 \text{ mol } H_2$$

$$6.20 \text{ mol } H_2 \times \frac{1 \text{ mol } N_2}{2 \text{ mol } H_2} = 3.10 \text{ mol } N_2$$

$$3.10 \text{ mol } N_2 \times \frac{28.02 \text{ g } N_2}{1 \text{ mol } N_2} = 86.9 \text{ g } N_2$$

$$6.20 \text{ mol } H_2 \times \frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2} = 6.20 \text{ mol } H_2O$$

$$6.20 \text{ mol } H_2O \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 112 \text{ g } H_2O$$

d. $Cu_2S(s) \rightarrow 2Cu(s) + S(g)$

molar mass Cu_2S = 159.2 g; molar mass Cu = 63.55 g; molar mass S = 32.07 g

$$12.5 \text{ g } Cu_2S \times \frac{1 \text{ mol } Cu_2S}{159.2 \text{ g } Cu_2S} = 0.0785 \text{ mol } Cu_2S$$

$$0.0785 \text{ mol } Cu_2S \times \frac{2 \text{ mol Cu}}{1 \text{ mol } Cu_2S} = 0.157 \text{ mol Cu}$$

$$0.157 \text{ mol Cu} \times \frac{63.55 \text{ g Cu}}{1 \text{ mol Cu}} = 9.98 \text{ g Cu}$$

$$0.0785 \text{ mol } Cu_2S \times \frac{1 \text{ mol S}}{1 \text{ mol } Cu_2S} = 0.0785 \text{ mol S}$$

$$0.0785 \text{ mol S} \times \frac{32.07 \text{ g S}}{1 \text{ mol S}} = 2.52 \text{ g S}$$

26.

a. $2BCl_3(s) + 3H_2(g) \rightarrow 2B(s) + 6HCl(g)$

molar masses: BCl_3, 117.16 g; B, 10.81 g; HCl, 36.46 g

$$15.0 \text{ g } BCl_3 \times \frac{1 \text{ mol } BCl_3}{117.16 \text{ g } BCl_3} = 0.128 \text{ mol } BCl_3$$

$$0.128 \text{ mol } BCl_3 \times \frac{2 \text{ mol B}}{2 \text{ mol } BCl_3} \times \frac{10.81 \text{ g B}}{1 \text{ mol B}} = 1.38 \text{ g B}$$

$$0.128 \text{ mol } BCl_3 \times \frac{6 \text{ mol HCl}}{2 \text{ mol } BCl_3} \times \frac{36.46 \text{ g HCl}}{1 \text{ mol HCl}} = 14.0 \text{ g HCl}$$

b. $2Cu_2S(s) + 3O_2(g) \rightarrow 2Cu_2O(s) + 2SO_2(g)$

molar masses: Cu_2S, 159.17 g; Cu_2O, 143.1 g; SO_2, 64.07 g

$$15.0 \text{ g } Cu_2S \times \frac{1 \text{ mol } Cu_2S}{159.17 \text{ g } Cu_2S} = 0.09424 \text{ mol } Cu_2S$$

$$0.09424 \text{ mol } Cu_2S \times \frac{2 \text{ mol } Cu_2O}{2 \text{ mol } Cu_2S} \times \frac{143.1 \text{ g } Cu_2O}{1 \text{ mol } Cu_2O} = 13.5 \text{ g } Cu_2O$$

$$0.09424 \text{ mol } Cu_2S \times \frac{2 \text{ mol } SO_2}{2 \text{ mol } Cu_2S} \times \frac{64.07 \text{ g } SO_2}{1 \text{ mol } SO_2} = 6.04 \text{ g } SO_2$$

c. $2Cu_2O(s) + Cu_2S(s) \rightarrow 6Cu(s) + SO_2(g)$

molar masses: Cu_2S, 159.17 g; Cu, 63.55 g; SO_2, 64.07 g

$$15.0 \text{ g } Cu_2S \times \frac{1 \text{ mol } Cu_2S}{159.17 \text{ g } Cu_2S} = 0.09424 \text{ mol } Cu_2S$$

$$0.09424 \text{ mol } Cu_2S \times \frac{6 \text{ mol Cu}}{1 \text{ mol } Cu_2S} \times \frac{63.55 \text{ g Cu}}{1 \text{ mol Cu}} = 35.9 \text{ g Cu}$$

$$0.09424 \text{ mol } Cu_2S \times \frac{1 \text{ mol } SO_2}{1 \text{ mol } Cu_2S} \times \frac{64.07 \text{ g } SO_2}{1 \text{ mol } SO_2} = 6.04 \text{ g } SO_2$$

d. $CaCO_3(s) + SiO_2(s) \rightarrow CaSiO_3(s) + CO_2(g)$

molar masses: SiO_2, 60.09 g; $CaSiO_3$, 116.17 g; CO_2, 44.01 g

$$15.0 \text{ g } SiO_2 \times \frac{1 \text{ mol } SiO_2}{60.09 \text{ g } SiO_2} = 0.2496 \text{ mol } SiO_2$$

$$0.2496 \text{ mol } SiO_2 \times \frac{1 \text{ mol } CaSiO_3}{1 \text{ mol } SiO_2} \times \frac{116.17 \text{ g } CaSiO_3}{1 \text{ mol } CaSiO_3} = 29.0 \text{ g } CaSiO_3$$

$$0.2496 \text{ mol } SiO_2 \times \frac{1 \text{ mol } CO_2}{1 \text{ mol } SiO_2} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 11.0 \text{ g } CO_2$$

27. $C_3H_8(l) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

molar mass H_2O = 18.02 g

$$3.11 \text{ mol } C_3H_8 \times \frac{4 \text{ mol } H_2O}{1 \text{ mol } C_3H_8} = 12.44 \text{ mol } H_2O$$

$$12.44 \text{ mol } H_2O \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 224 \text{ g } H_2O$$

28. $2S(s) + 3O_2(g) \rightarrow 2SO_3(g)$ $\quad$ $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(l)$

It would make things simpler if the first equation were expressed in terms of one mole of SO_3 since the second equation is expressed in terms of 1 mole of SO_3. To do this, divide the first equation by two:

$S(s) + \frac{3}{2}O_2(g) \rightarrow SO_3(g)$ $\quad$ $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(l)$

By doing this, we now have the simpler relationship that one mole of S will produce one mole of H_2SO_4.

molar masses: S, 32.07 g; H_2SO_4, 98.09 g

$$1.25 \text{ g S} \times \frac{1 \text{ mol S}}{32.07 \text{ g S}} = 0.03898 \text{ mol S}$$

$$0.03988 \text{ mol S} \times \frac{1 \text{ mol } H_2SO_4}{1 \text{ mol S}} = 0.03988 \text{ mol } H_2SO_4$$

$$0.03988 \text{ mol } H_2SO_4 \times \frac{98.09 \text{ g } H_2SO_4}{1 \text{ mol } H_2SO_4} = 3.82 \text{ g } H_2SO_4$$

29. molar masses: C, 12.01 g; CO, 28.01 g; CO_2, 44.01 g

$$5.00\text{ g C} \times \frac{1\text{ mol C}}{12.01\text{ g C}} = 0.4163\text{ mol C}$$

carbon dioxide: $C(s) + O_2(g) \rightarrow CO_2(g)$

$$0.4163\text{ mol C} \times \frac{1\text{ mol }CO_2}{1\text{ mol C}} = 0.4163\text{ mol }CO_2$$

$$0.4163\text{ mol }CO_2 \times \frac{44.01\text{ g }CO_2}{1\text{ mol }CO_2} = 18.3\text{ g }CO_2$$

carbon monoxide: $2C(s) + O_2(g) \rightarrow 2CO(g)$

$$0.4163\text{ mol C} \times \frac{2\text{ mol CO}}{2\text{ mol C}} = 0.4163\text{ mol CO}$$

$$0.4163\text{ mol CO} \times \frac{28.01\text{ g CO}}{1\text{ mol CO}} = 11.7\text{ g CO}$$

30. $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + H_2O(g) + CO_2(g)$

molar masses: $NaHCO_3$, 84.01 g; Na_2CO_3, 106.0 g

$$1.52\text{ g }NaHCO_3 \times \frac{1\text{ mol }NaHCO_3}{84.01\text{ g }NaHCO_3} = 0.01809\text{ mol }NaHCO_3$$

$$0.01809\text{ mol }NaHCO_3 \times \frac{1\text{ mol }Na_2CO_3}{2\text{ mol }NaHCO_3} = 0.009047\text{ mol }Na_2CO_3$$

$$0.009047\text{ mol }Na_2CO_3 \times \frac{106.0\text{ g }Na_2CO_3}{1\text{ mol }Na_2CO_3} = 0.959\text{ g }Na_2CO_3$$

31. $2Fe(s) + 3Cl_2(g) \rightarrow 2FeCl_3(s)$

millimolar masses: iron, 55.85 mg; $FeCl_3$, 162.2 mg

$$15.5\text{ mg Fe} \times \frac{1\text{ mmol Fe}}{55.85\text{ mg Fe}} = 0.2775\text{ mmol Fe}$$

$$0.2775\text{ mmol Fe} \times \frac{2\text{ mmol }FeCl_3}{2\text{ mmol Fe}} = 0.2775\text{ mmol }FeCl_3$$

$$0.2775\text{ mmol }FeCl_3 \times \frac{162.2\text{ mg }FeCl_3}{1\text{ mmol }FeCl_3} = 45.0\text{ mg }FeCl_3$$

32. $C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$

molar masses: $C_6H_{12}O_6$, 180.2 g; C_2H_5OH, 46.07 g

$$5.25 \text{ g } C_6H_{12}O_6 \times \frac{1 \text{ mol } C_6H_{12}O_6}{180.2 \text{ g } C_6H_{12}O_6} = 0.02913 \text{ mol } C_6H_{12}O_6$$

$$0.02913 \text{ mol } C_6H_{12}O_6 \times \frac{2 \text{ mol } C_2H_5OH}{1 \text{ mol } C_6H_{12}O_6} = 0.5826 \text{ mol } C_2H_5OH$$

$$0.5286 \text{ mol } C_2H_5OH \times \frac{46.07 \text{ g } C_2H_5OH}{1 \text{ mol } C_2H_5OH} = 2.68 \text{ g ethyl alcohol}$$

33. $H_2SO_3(aq) \rightarrow H_2O(l) + SO_2(g)$

molar masses: H_2SO_3, 82.09 g; SO_2, 64.07 g

$$4.25 \text{ g } H_2SO_3 \times \frac{1 \text{ mol } H_2SO_3}{82.09 \text{ g } H_2SO_3} = 0.05177 \text{ mol } H_2SO_3$$

$$0.05177 \text{ mol } H_2SO_3 \times \frac{1 \text{ mol } SO_2}{1 \text{ mol } H_2SO_3} = 0.05177 \text{ mol } SO_2$$

$$0.05177 \text{ mol } SO_2 \times \frac{64.07 \text{ g } SO_2}{1 \text{ mol } SO_2} = 3.32 \text{ g } SO_2$$

34. $NH_4Cl(s) + NaOH(s) \rightarrow NH_3(g) + NaCl(s) + H_2O(g)$

molar masses: NH_4Cl, 53.49 g; NH_3, 17.03 g

$$1.39 \text{ g } NH_4Cl \times \frac{1 \text{ mol } NH_4Cl}{53.49 \text{ g } NH_4Cl} = 0.02599 \text{ mol } NH_4Cl$$

$$0.02599 \text{ mol } NH_4Cl \times \frac{1 \text{ mol } NH_3}{1 \text{ mol } NH_4Cl} = 0.02599 \text{ mol } NH_3$$

$$0.02599 \text{ mol } NH_3 \times \frac{17.03 \text{ g } NH_3}{1 \text{ mol } NH_3} = 0.443 \text{ g } NH_3$$

35. $P_4(s) + 5O_2(g) \rightarrow 2P_2O_5(s)$

molar masses: P_4, 123.88 g; O_2, 32.00 g

$$4.95 \text{ g } P_4 \times \frac{1 \text{ mol } P_4}{123.88 \text{ g } P_4} = 0.03996 \text{ mol } P_4$$

$$0.03996 \text{ mol } P_4 \times \frac{5 \text{ mol } O_2}{1 \text{ mol } P_4} = 0.1998 \text{ mol } O_2$$

$$0.1998 \text{ mol } O_2 \times \frac{32.00 \text{ g } O_2}{1 \text{ mol } O_2} = 6.39 \text{ g } O_2$$

36. $4HgS(s) + 4CaO(s) \rightarrow 4Hg(l) + 3CaS(s) + CaSO_4(s)$

molar masses: HgS, 232.7 g Hg, 200.6 g; 10.0 kg = 1.00×10^4 g

$$1.00 \times 10^4 \text{ g HgS} \times \frac{1 \text{ mol HgS}}{232.7 \text{ g HgS}} = 42.97 \text{ mol HgS}$$

$$42.97 \text{ mol HgS} \times \frac{4 \text{ mol Hg}}{4 \text{ mol HgS}} = 42.97 \text{ mol Hg}$$

$$42.97 \text{ mol Hg} \times \frac{200.6 \text{ g Hg}}{1 \text{ mol Hg}} = 8.62 \times 10^3 \text{ g Hg} = 8.62 \text{ kg Hg}$$

37. $2NH_4NO_3(s) \rightarrow 2N_2(g) + O_2(g) + 4H_2O(g)$

molar masses: NH_4NO_3, 80.05 g; N_2, 28.02 g; O_2, 32.00 g; H_2O, 18.02 g

$$1.25 \text{ g } NH_4NO_3 \times \frac{1 \text{ mol } NH_4NO_3}{80.05 \text{ g } NH_4NO_3} = 0.0156 \text{ mol } NH_4NO_3$$

$$0.0156 \text{ mol } NH_4NO_3 \times \frac{2 \text{ mol } N_2}{2 \text{ mol } NH_4NO_3} = 0.0156 \text{ mol } N_2$$

$$0.0156 \text{ mol } N_2 \times \frac{28.02 \text{ g } N_2}{1 \text{ mol } N_2} = 0.437 \text{ g } N_2$$

$$0.0156 \text{ mol } NH_4NO_3 \times \frac{1 \text{ mol } O_2}{2 \text{ mol } NH_4NO_3} = 0.00780 \text{ mol } O_2$$

$$0.00780 \text{ mol } O_2 \times \frac{32.00 \text{ g } O_2}{1 \text{ mol } O_2} = 0.250 \text{ g } O_2$$

$$0.0156 \text{ mol } NH_4NO_3 \times \frac{4 \text{ mol } H_2O}{2 \text{ mol } NH_4NO_3} = 0.0312 \text{ mol } H_2O$$

$$0.0312 \text{ mol } H_2O \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 0.562 \text{ g } H_2O$$

As a check, note that 0.437 g + 0.250 g + 0.562 g = 1.249 g = 1.25 g.

38. $C_{12}H_{22}O_{11}(s) \rightarrow 12C(s) + 11H_2O(g)$

molar masses: $C_{12}H_{22}O_{11}$, 342.3 g; C, 12.01

$$1.19 \text{ g } C_{12}H_{22}O_{11} \times \frac{1 \text{ mol } C_{12}H_{22}O_{11}}{342.3 \text{ g } C_{12}H_{22}O_{11}} = 3.476 \times 10^{-3} \text{ mol } C_{12}H_{22}O_{11}$$

$$3.476 \times 10^{-3} \text{ mol } C_{12}H_{22}O_{11} \times \frac{12 \text{ mol C}}{1 \text{ mol } C_{12}H_{22}O_{11}} = 0.04172 \text{ mol C}$$

$$0.04172 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 0.501 \text{ g C}$$

39. $SOCl_2(l) + H_2O(l) \rightarrow SO_2(g) + 2HCl(g)$

molar masses: $SOCl_2$, 119.0 g; H_2O, 18.02 g

$$35.0 \text{ g } SOCl_2 \times \frac{1 \text{ mol } SOCl_2}{119.0 \text{ g } SOCl_2} = 0.294 \text{ mol } SOCl_2$$

$$0.294 \text{ mol } SOCl_2 \times \frac{1 \text{ mol } H_2O}{1 \text{ mol } SOCl_2} = 0.294 \text{ mol } H_2O$$

$$0.294 \text{ mol } H_2O \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 5.30 \text{ g } H_2O$$

40. $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

molar masses: Mg, 24.31 g; MgO, 40.31 g

$$1.25 \text{ g Mg} \times \frac{1 \text{ mol Mg}}{24.31 \text{ g Mg}} = 5.14 \times 10^{-2} \text{ mol Mg}$$

$$5.14 \times 10^{-2} \text{ mol Mg} \times \frac{2 \text{ mol MgO}}{2 \text{ mol Mg}} = 5.14 \times 10^{-2} \text{ mol MgO}$$

$$5.14 \times 10^{-2} \text{ mol MgO} \times \frac{40.31 \text{ g MgO}}{1 \text{ mol MgO}} = 2.07 \text{ g MgO}$$

41. To determine the limiting reactant, first calculate the number of moles of each reactant present. Then determine how these numbers of moles correspond to the stoichiometric ratio indicated by the balanced chemical equation for the reaction. Specific answer depends on student response.

42. To determine the limiting reactant, first calculate the number of moles of each reactant present. Then determine how these numbers of moles correspond to the stoichiometric ratio indicated by the balanced chemical equation for the reaction.

43. The theoretical yield of a reaction represents the stoichiometric amount of product that should form if the limiting reactant for the process is completely consumed.

44. A reactant is present *in excess* if there is more of that reactant present than is needed to combine with the limiting reactant for the process. By definition, the limiting reactant cannot be present in excess. An excess of any reactant does not affect the theoretical yield for a process; the theoretical yield is determined by the limiting reactant.

45.

a. $Na_2B_4O_7(s) + H_2SO_4(aq) + 5H_2O(l) \rightarrow 4H_3BO_3(s) + Na_2SO_4(aq)$

molar masses: $Na_2B_4O_7$, 201.2 g; H_2SO_4, 98.09 g; H_2O, 18.02 g

$$5.00\ \text{g}\ Na_2B_4O_7 \times \frac{1\ \text{mol}}{201.2\ \text{g}} = 0.0249\ \text{mol}\ Na_2B_4O_7$$

$$5.00\ \text{g}\ H_2SO_4 \times \frac{1\ \text{mol}}{98.09\ \text{g}} = 0.0510\ \text{mol}\ H_2SO_4$$

$$5.00\ \text{g}\ H_2O \times \frac{1\ \text{mol}}{18.02\ \text{g}} = 0.277\ \text{mol}\ H_2O$$

$Na_2B_4O_7$ is the limiting reactant.

mol H_2SO_4 remaining unreacted = 0.0510 – 0.0249 = 0.0261 mol

mol H_2O remaining unreacted = 0.277 – 5(0.0249) = 0.153 mol

$$\text{mass of } H_2SO_4 \text{ remaining} = 0.0261\ \text{mol} \times \frac{98.09\ \text{g}}{1\ \text{mol}} = 2.56\ \text{g}\ H_2SO_4$$

$$\text{mass of } H_2O \text{ remaining} = 0.153\ \text{mol} \times \frac{18.02\ \text{g}}{1\ \text{mol}} = 2.76\ \text{g}\ H_2O$$

b. $CaC_2(s) + 2H_2O(l) \rightarrow Ca(OH)_2(s) + C_2H_2(g)$

molar masses: CaC_2, 64.10 g; H_2O, 18.02 g

$$5.00\ \text{g}\ CaC_2 \times \frac{1\ \text{mol}}{64.10\ \text{g}} = 0.0780\ \text{mol}\ CaC_2$$

$$5.00\ \text{g}\ H_2O \times \frac{1\ \text{mol}}{18.02\ \text{g}} = 0.277\ \text{mol}\ H_2O$$

CaC_2 is the limiting reactant; water is present in excess.

mol of H_2O remaining = 0.277 – 2(0.0780) = 0.121 mol H_2O

$$\text{mass of } H_2O \text{ remaining} = 0.121\ \text{mol} \times \frac{18.02\ \text{g}}{1\ \text{mol}} = 2.18\ \text{g}\ H_2O$$

c. $2NaCl(s) + H_2SO_4(l) \rightarrow 2HCl(g) + Na_2SO_4(s)$

molar masses: NaCl, 58.44 g; H_2SO_4, 98.09 g

$$5.00\ \text{g}\ NaCl \times \frac{1\ \text{mol}}{58.44\ \text{g}} = 0.0856\ \text{mol}\ NaCl$$

$$5.00\ \text{g}\ H_2SO_4 \times \frac{1\ \text{mol}}{98.09\ \text{g}} = 0.0510\ \text{mol}\ H_2SO_4$$

NaCl is the limiting reactant; H_2SO_4 is present in excess.

mol H_2SO_4 that reacts = 0.5(0.0856) = 0.0428 mol H_2SO_4

mol H_2SO_4 remaining = 0.0510 – 0.0428 = 0.0082 mol

$$\text{mass of } H_2SO_4 \text{ remaining} = 0.0082 \text{ mol} \times \frac{98.09 \text{ g}}{1 \text{ mol}} = 0.80 \text{ g } H_2SO_4$$

d. $SiO_2(s) + 2C(s) \rightarrow Si(l) + 2CO(g)$

molar masses: SiO_2, 60.09 g; C, 12.01 g

$$5.00 \text{ g } SiO_2 \times \frac{1 \text{ mol}}{60.09 \text{ g}} = 0.0832 \text{ mol } SiO_2$$

$$5.00 \text{ g C} \times \frac{1 \text{ mol}}{12.01 \text{ g}} = 0.416 \text{ mol C}$$

SiO_2 is the limiting reactant; C is present in excess.

mol C remaining = 0.416 – 2(0.0832) = 0.250 mol

$$\text{mass of C remaining} = 0.250 \text{ mol} \times \frac{12.01 \text{ g}}{1 \text{ mol}} = 3.00 \text{ g C}$$

46.

a. $S(s) + 2H_2SO_4(aq) \rightarrow 3SO_2(g) + 2H_2O(l)$

Molar masses: S, 32.07 g; H_2SO_4, 98.09 g; SO_2, 64.07 g; H_2O, 18.02 g

$$5.00 \text{ g S} \times \frac{1 \text{ mol}}{32.07 \text{ g}} = 0.1559 \text{ mol S}$$

$$5.00 \text{ g } H_2SO_4 \times \frac{1 \text{ mol}}{98.09 \text{ g}} = 0.05097 \text{ mol } H_2SO_4$$

According to the balanced chemical equation, we would need twice as much sulfuric acid as sulfur for complete reaction of both reactants. We clearly have much less sulfuric acid present than sulfur; sulfuric acid is the limiting reactant. The calculation of the masses of products produced is based on the number of moles of the sulfuric acid.

$$0.05097 \text{ mol } H_2SO_4 \times \frac{3 \text{ mol } SO_2}{2 \text{ mol } H_2SO_4} \times \frac{64.07 \text{ g } SO_2}{1 \text{ mol } SO_2} = 4.90 \text{ g } SO_2$$

$$0.05097 \text{ mol } H_2SO_4 \times \frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2SO_4} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 0.918 \text{ g } H_2O$$

b. $MnO_2(s) + 2H_2SO_4(aq) \rightarrow Mn(SO_4)_2 + 2H_2O(l)$

molar masses: MnO_2, 86.94 g; H_2SO_4 98.09 g; $Mn(SO_4)_2$, 247.1 g; H_2O, 18.02 g

$$5.00 \text{ g } MnO_2 \times \frac{1 \text{ mol}}{86.94 \text{ g}} = 0.05751 \text{ mol } MnO_2$$

$$5.00 \text{ g } H_2SO_4 \times \frac{1 \text{ mol}}{98.09 \text{ g}} = 0.05097 \text{ mol } H_2SO_4$$

According to the balanced chemical equation, we would need twice as much sulfuric acid as manganese(IV) oxide for complete reaction of both reactants. We do not have this much sulfuric acid, so sulfuric acid must be the limiting reactant. The amount of each product produced will be based on the sulfuric acid reacting completely.

$$0.05097 \text{ mol } H_2SO_4 \times \frac{1 \text{ mol } Mn(SO_4)_2}{2 \text{ mol } H_2SO_4} \times \frac{247.1 \text{ g } Mn(SO_4)_2}{1 \text{ mol } Mn(SO_4)_2} = 6.30 \text{ g } Mn(SO_4)_2$$

$$0.05097 \text{ mol } H_2SO_4 \times \frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2SO_4} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 0.918 \text{ g } H_2O$$

c. $2H_2S(g) + 3O_2(g) \rightarrow 2SO_2(g) + 2H_2O(l)$

Molar masses: H_2S, 34.09 g; O_2, 32.00 g; SO_2, 64.07 g; H_2O, 18.02 g

$$5.00 \text{ g } H_2S \times \frac{1 \text{ mol}}{34.09 \text{ g}} = 0.1467 \text{ mol } H_2S$$

$$5.00 \text{ g } O_2 \times \frac{1 \text{ mol}}{32.00 \text{ g}} = 0.1563 \text{ mol } O_2$$

According to the balanced equation, we would need 1.5 times as much O_2 as H_2S for complete reaction of both reactants. We don't have that much O_2, so O_2 must be the limiting reactant that will control the masses of each product produced.

$$0.1563 \text{ mol } O_2 \times \frac{2 \text{ mol } SO_2}{3 \text{ mol } O_2} \times \frac{64.07 \text{ g } SO_2}{1 \text{ mol } SO_2} = 6.67 \text{ g } SO_2$$

$$0.1563 \text{ mol } O_2 \times \frac{2 \text{ mol } H_2O}{3 \text{ mol } O_2} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 1.88 \text{ g } H_2O$$

d. $3AgNO_3(aq) + Al(s) \rightarrow 3Ag(s) + Al(NO_3)_3(aq)$

Molar masses: $AgNO_3$, 169.9 g; Al, 26.98 g; Ag, 107.9 g; $Al(NO_3)_3$, 213.0 g

$$5.00 \text{ g } AgNO_3 \times \frac{1 \text{ mol}}{169.9 \text{ g}} = 0.02943 \text{ mol } AgNO_3$$

$$5.00 \text{ g Al} \times \frac{1 \text{ mol}}{26.98 \text{ g}} = 0.1853 \text{ mol Al}$$

According to the balanced chemical equation, we would need three moles of $AgNO_3$ for every mole of Al for complete reaction of both reactants. We in fact have fewer moles of $AgNO_3$ than aluminum, so $AgNO_3$ must be the limiting reactant. The amount of product produced is calculated from the number of moles of the limiting reactant present:

$$0.02943 \text{ mol } AgNO_3 \times \frac{3 \text{ mol Ag}}{3 \text{ mol } AgNO_3} \times \frac{107.9 \text{ g Ag}}{1 \text{ mol Ag}} = 3.18 \text{ g Ag}$$

$$0.02943 \text{ mol } AgNO_3 \times \frac{1 \text{ mol } Al(NO_3)_3}{3 \text{ mol } AgNO_3} \times \frac{213.0 \text{ g } Al(NO_3)_3}{1 \text{ mol } Al(NO_3)_3} = 2.09 \text{ g}$$

47. Before any calculations are attempted, the equations must be balanced.

a. $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

molar masses: C_3H_8, 44.09 g; O_2, 32.00 g; CO_2, 44.01 g; H_2O, 18.02 g

$$10.0 \text{ g } C_3H_8 \times \frac{1 \text{ mol}}{44.09 \text{ g}} = 0.2268 \text{ mol } C_3H_8$$

$$10.0 \text{ g } O_2 \times \frac{1 \text{ mol}}{32.00 \text{ g}} = 0.3125 \text{ mol } O_2$$

For 0.2268 mol C_3H_8, the amount of O_2 that would be needed is

$$0.2268 \text{ mol } C_3H_8 \times \frac{5 \text{ mol } O_2}{1 \text{ mol } C_3H_8} = 1.134 \text{ mol } O_2$$

Because we do not have this amount of O_2, then O_2 is the limiting reactant.

$$0.3125 \text{ mol } O_2 \times \frac{3 \text{ mol } CO_2}{5 \text{ mol } O_2} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 8.25 \text{ g } CO_2$$

$$0.3125 \text{ mol } O_2 \times \frac{4 \text{ mol } H_2O}{5 \text{ mol } O_2} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 4.51 \text{ g } H_2O$$

b. $2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s)$

molar masses: Al, 26.98 g; Cl_2, 70.90 g; $AlCl_3$, 133.3 g

$$10.0 \text{ g Al} \times \frac{1 \text{ mol}}{26.98 \text{ g}} = 0.3706 \text{ mol Al}$$

$$10.0 \text{ g } Cl_2 \times \frac{1 \text{ mol}}{70.90 \text{ g}} = 0.1410 \text{ mol } Cl_2$$

For 0.1410 mol $Cl_2(g)$, the amount of $Al(s)$ required is

$$0.1410 \text{ mol } Cl_2 \times \frac{2 \text{ mol Al}}{3 \text{ mol } Cl_2} = 0.09400 \text{ mol Al}$$

We have far more than this amount of Al(s) present, so $Cl_2(g)$ must be the limiting reactant that will control the amount of $AlCl_3$ that forms.

$$0.1410 \text{ mol } Cl_2 \times \frac{2 \text{ mol } AlCl_3}{3 \text{ mol } Cl_2} \times \frac{133.3 \text{ g } AlCl_3}{1 \text{ mol } AlCl_3} = 12.5 \text{ g } AlCl_3$$

c. $2NaOH(s) + CO_2(g) \rightarrow Na_2CO_3(s) + H_2O(l)$

molar masses: NaOH, 40.00 g; CO_2, 44.01 g; Na_2CO_3, 106.0 g; H_2O, 18.02 g

$$10.0 \text{ g NaOH} \times \frac{1 \text{ mol}}{40.00 \text{ g}} = 0.2500 \text{ mol NaOH}$$

$$10.0 \text{ g } CO_2 \times \frac{1 \text{ mol}}{44.01 \text{ g}} = 0.2272 \text{ mol } CO_2$$

Without having to calculate, according to the balanced chemical equation we would need *twice* as many moles of NaOH as CO_2 for complete reaction. For the amounts calculated above, there is not nearly enough NaOH present for the amount of Cl_2 used; NaOH is the limiting reactant.

$$0.2500 \text{ mol NaOH} \times \frac{1 \text{ mol } Na_2CO_3}{2 \text{ mol NaOH}} \times \frac{106.0 \text{ g } Na_2CO_3}{1 \text{ mol } Na_2CO_3} = 13.3 \text{ g } Na_2CO_3$$

$$0.2500 \text{ mol NaOH} \times \frac{1 \text{ mol } H_2O}{2 \text{ mol NaOH}} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 2.25 \text{ g } H_2O$$

d. $NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$

molar masses: $NaHCO_3$, 84.01 g; HCl, 36.46 g; NaCl, 58.44 g; H_2O, 18.02 g; CO_2, 44.01 g

$$10.0 \text{ g } NaHCO_3 \times \frac{1 \text{ mol}}{84.01 \text{ g}} = 0.1190 \text{ mol } NaHCO_3$$

$$10.0 \text{ g HCl} \times \frac{1 \text{ mol}}{36.46 \text{ g}} = 0.2742 \text{ mol HCl}$$

Because the coefficients of $NaHCO_3(s)$ and HCl(aq) are both *one* in the balanced chemical equation for the reaction, there is not enough $NaHCO_3$ present to react with the amount of HCl present: the 0.1190 mol $NaHCO_3$ present is the limiting reactant. Because all the coefficients of the products are also each *one*, then if 0.1190 mol $NaHCO_3$ reacts completely (with 0.1190 mol HCl), 0.1190 mol of each product will form.

$$0.1190 \text{ mol NaCl} \times \frac{58.44 \text{ g}}{1 \text{ mol}} = 6.95 \text{ g NaCl}$$

$$0.1190 \text{ mol } H_2O \times \frac{18.02 \text{ g}}{1 \text{ mol}} = 2.14 \text{ g } H_2O$$

$$0.1190 \text{ mol } CO_2 \times \frac{44.01 \text{ g}}{1 \text{ mol}} = 5.24 \text{ g } CO_2$$

48.

a. $CS_2(l) + 3O_2(g) \rightarrow CO_2(g) + 2SO_2(g)$

Molar masses: CS_2, 76.15 g; O_2, 32.00 g; CO_2, 44.01 g

$$1.00 \text{ g } CS_2 \times \frac{1 \text{ mol}}{76.15 \text{ g}} = 0.01313 \text{ mol } CS_2$$

$$1.00 \text{ g } O_2 \times \frac{1 \text{ mol}}{32.00 \text{ g}} = 0.03125 \text{ mol } O_2$$

From the balanced chemical equation, we would need three times as much oxygen as carbon disulfide for complete reaction of both reactants. We do not have this much oxygen, and so oxygen must be the limiting reactant.

$$0.03125 \text{ mol } O_2 \times \frac{1 \text{ mol } CO_2}{3 \text{ mol } O_2} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 0.458 \text{ g } CO_2$$

b. $2NH_3(g) + CO_2(g) \rightarrow CN_2H_4O(s) + H_2O(l)$

Molar masses: NH_3, 17.03 g; CO_2, 44.01 g; H_2O, 18.02 g

$$1.00 \text{ g } NH_3 \times \frac{1 \text{ mol}}{17.03 \text{ g}} = 0.05872 \text{ mol } NH_3$$

$$1.00 \text{ g } CO_2 \times \frac{1 \text{ mol}}{44.01 \text{ g}} = 0.02272 \text{ mol } CO_2$$

The balanced chemical equation tells us that we would need twice as many moles of ammonia as carbon dioxide for complete reaction of both reactants. We have *more* than this amount of ammonia present, so the reaction will be limited by the amount of carbon dioxide present.

$$0.02272 \text{ mol } CO_2 \times \frac{1 \text{ mol } H_2O}{1 \text{ mol } CO_2} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 0.409 \text{ g } H_2O$$

c. $H_2(g) + MnO_2(s) \rightarrow MnO(s) + H_2O(l)$

Molar masses: H_2, 2.016 g; MnO_2, 86.94 g; H_2O, 18.02 g

$$1.00 \text{ g } H_2 \times \frac{1 \text{ mol}}{2.016 \text{ g}} = 0.496 \text{ mol } H_2$$

$$1.00 \text{ g } MnO_2 \times \frac{1 \text{ mol}}{86.94 \text{ g}} = 0.0115 \text{ mol } MnO_2$$

Because the coefficients of both reactants in the balanced chemical equation are the same, we would need equal amounts of both reactants for complete reaction. Therefore manganese(IV) oxide must be the limiting reactant and controls the amount of product obtained.

$$0.0115 \text{ mol } MnO_2 \times \frac{1 \text{ mol } H_2O}{1 \text{ mol } MnO_2} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 0.207 \text{ g } H_2O$$

d. $I_2(s) + Cl_2(g) \rightarrow 2ICl(g)$

Molar masses: I_2, 253.8 g; Cl_2, 70.90 g; ICl, 162.35 g

$$1.00 \text{ g } I_2 \times \frac{1 \text{ mol}}{253.8 \text{ g}} = 0.00394 \text{ mol } I_2$$

$$1.00 \text{ g } Cl_2 \times \frac{1 \text{ mol}}{70.90 \text{ g}} = 0.0141 \text{ mol } Cl_2$$

From the balanced chemical equation, we would need equal amounts of I_2 and Cl_2 for complete reaction of both reactants. As we have much less iodine than chlorine, iodine must be the limiting reactant.

$$0.00394 \text{ mol } I_2 \times \frac{2 \text{ mol ICl}}{1 \text{ mol } I_2} \times \frac{162.35 \text{ g ICl}}{1 \text{ mol ICl}} = 1.28 \text{ g ICl}$$

49.

a. $UO_2(s) + 4HF(aq) \rightarrow UF_4(aq) + 2H_2O(l)$

UO_2 is the limiting reactant; 1.16 g UF_4, 0.133 g H_2O

b. $(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2HNO_3(aq)$

$NaNO_3$ is the limiting reactant; 0.836 g Na_2SO_4; 0.741 g HNO_3

c. $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

HCl is the limiting reactant; 1.87 g $ZnCl_2$; 0.0276 g H_2

d. $B(OH)_3(s) + 3CH_3OH(l) \rightarrow B(OCH_3)_3(s) + 3H_2O(l)$

CH_3OH is the limiting reactant; 1.08 g $B(OCH_3)_3$; 0.562 g H_2O

50.

a. $CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$

CO is the limiting reactant; 11.4 mg CH_3OH

b. $2Al(s) + 3I_2(s) \rightarrow 2AlI_3(s)$

I_2 is the limiting reactant; 10.7 mg AlI_3

c. $Ca(OH)_2(aq) + 2HBr(aq) \rightarrow CaBr_2(aq) + 2H_2O(l)$

HBr is the limiting reactant; 12.4 mg $CaBr_2$; 2.23 mg H_2O

d. $2Cr(s) + 2H_3PO_4(aq) \rightarrow 2CrPO_4(s) + 3H_2(g)$

H_3PO_4 is the limiting reactant; 15.0 mg $CrPO_4$; 0.309 mg H_2

51. $2KI(aq) + Pb(NO_3)_2(aq) \rightarrow 2KNO_3(aq) + PbI(s)$

molar masses: KI, 166.0 g; $Pb(NO_3)_2$, 331.2 g; PbI, 334.1 g

$$1.25 \text{ g KI} \times \frac{1 \text{ mol}}{166.0 \text{ g}} = 0.007530 \text{ mol KI}$$

$$2.42 \text{ g } Pb(NO_3)_2 \times \frac{1 \text{ mol}}{331.2 \text{ g}} = 0.007306 \text{ mol}$$

KI is the limiting reactant that determines the yield of product.

$$0.007530 \text{ mol KI} \times \frac{1 \text{ mol PbI}}{2 \text{ mol KI}} \times \frac{334.1 \text{ g PbI}}{1 \text{ mol PbI}} = 1.26 \text{ g PbI}$$

52. $2NH_3(g) + CO_2(g) \rightarrow CN_2H_4O(s) + H_2O(l)$

molar masses: NH_3, 17.03 g; CO_2, 44.01 g; CN_2H_4O, 60.06 g

$$100. \text{ g } NH_3 \times \frac{1 \text{ mol}}{17.03 \text{ g}} = 5.872 \text{ mol } NH_3$$

$$100. \text{ g } CO_2 \times \frac{1 \text{ mol}}{44.01 \text{ g}} = 2.272 \text{ mol } CO_2$$

CO_2 is the limiting reactant that determines the yield of product.

$$2.272 \text{ mol } CO_2 \times \frac{1 \text{ mol } CN_2H_4O}{1 \text{ mol } CO_2} \times \frac{60.06 \text{ g } CN_2H_4O}{1 \text{ mol } CN_2H_4O} = 136 \text{ g } CN_2H_4O$$

53. $PbO(s) + C(s) \rightarrow Pb(l) + CO(g)$

molar masses: PbO, 223.2 g; C, 12.01 g; Pb, 207.2 g

$$50.0 \times 10^3 \text{ g PbO} \times \frac{1 \text{ mol}}{223.2 \text{ g}} = 224.0 \text{ mol PbO}$$

$$50.0 \times 10^3 \text{ g C} \times \frac{1 \text{ mol}}{12.01 \text{ g}} = 4163 \text{ mol C}$$

PbO is the limiting reactant.

$$224.0 \text{ mol PbO} \times \frac{1 \text{ mol Pb}}{1 \text{ mol PbO}} \times \frac{207.2 \text{ g Pb}}{1 \text{ mol Pb}} = 4.64 \times 10^4 \text{ g} = 46.4 \text{ kg Pb}$$

54. $4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

Molar masses: Fe, 55.85 g; Fe_2O_3, 159.7 g

$$1.25 \text{ g Fe} \times \frac{1 \text{ mol}}{55.85 \text{ g}} = 0.0224 \text{ mol Fe present}$$

Calculate how many mol of O_2 are required to react with this amount of Fe

$$0.0224 \text{ mol Fe} \times \frac{3 \text{ mol } O_2}{4 \text{ mol Fe}} = 0.0168 \text{ mol } O_2$$

Because we have more O_2 than this, Fe must be the limiting reactant.

$$0.0224 \text{ mol Fe} \times \frac{2 \text{ mol } Fe_2O_3}{4 \text{ mol Fe}} \times \frac{159.7 \text{ g } Fe_2O_3}{1 \text{ mol } Fe_2O_3} = 1.79 \text{ g } Fe_2O_3$$

55. $Ca^{2+}(aq) + Na_2C_2O_4(aq) \rightarrow CaC_2O_4(s) + 2Na^+(aq)$

molar masses: Ca^{2+}, 40.08 g; $Na_2C_2O_4$, 134.0 g

$$15 \text{ g } Ca^{2+} \times \frac{1 \text{ mol}}{40.08 \text{ g}} = 0.37 \text{ mol } Ca^{2+}$$

$$15 \text{ g } Na_2C_2O_4 \times \frac{1 \text{ mol}}{134.0 \text{ g}} = 0.11 \text{ mol } Na_2C_2O_4$$

As the balanced chemical equation tells us that one oxalate ion is needed to precipitate each calcium ion, from the number of moles calculated to be present it should be clear that not nearly enough sodium oxalate ion has been added to precipitate all the calcium ion in the sample.

56. $2CuSO_4(aq) + 5KI(aq) \rightarrow 2CuI(s) + KI_3(aq) + 2K_2SO_4(aq)$

molar masses: $CuSO_4$, 159.6 g; KI, 166.0 g; CuI, 190.5 g; KI_3, 419.8 g; K_2SO_4, 174.3 g

$$0.525 \text{ g } CuSO_4 \times \frac{1 \text{ mol}}{159.6 \text{ g}} = 3.29 \times 10^{-3} \text{ mol } CuSO_4$$

$$2.00 \text{ g KI} \times \frac{1 \text{ mol}}{166.0 \text{ g}} = 0.0120 \text{ mol KI}$$

To determine the limiting reactant, let's calculate what amount of KI would be needed to react with the given amount of $CuSO_4$ present.

$$3.29 \times 10^{-3} \text{ mol } CuSO_4 \times \frac{5 \text{ mol KI}}{2 \text{ mol } CuSO_4} = 8.23 \times 10^{-3} \text{ mol KI}$$

As we have more KI present than the amount required to react with the $CuSO_4$ present, $CuSO_4$ must be the limiting reactant that will control the amount of products produced.

$$3.29 \times 10^{-3} \text{ mol } CuSO_4 \times \frac{2 \text{ mol CuI}}{2 \text{ mol } CuSO_4} \times \frac{190.5 \text{ g CuI}}{1 \text{ mol CuI}} = 0.627 \text{ g CuI}$$

$$3.29 \times 10^{-3} \text{ mol } CuSO_4 \times \frac{1 \text{ mol } KI_3}{2 \text{ mol } CuSO_4} \times \frac{419.8 \text{ g } KI_3}{1 \text{ mol } KI_3} = 0.691 \text{ g } KI_3$$

$$3.29 \times 10^{-3} \text{ mol } CuSO_4 \times \frac{2 \text{ mol } K_2SO_4}{2 \text{ mol } CuSO_4} \times \frac{174.3 \text{ g } K_2SO_4}{1 \text{ mol } K_2SO_4} = 0.573 \text{ g } K_2SO_4$$

57. $BaO_2(s) + 2HCl(aq) \rightarrow H_2O_2(aq) + BaCl_2(aq)$

molar masses: BaO_2, 169.3 g; HCl, 36.46 g; H_2O_2, 34.02 g

$$1.50 \text{ g } BaO_2 \times \frac{1 \text{ mol}}{169.3 \text{ g}} = 8.860 \times 10^{-3} \text{ mol } BaO_2$$

$$25.0 \text{ mL solution} \times \frac{0.0272 \text{ g HCl}}{1 \text{ mL solution}} = 0.680 \text{ g HCl}$$

$$0.680 \text{ g HCl} \times \frac{1 \text{ mol}}{36.46 \text{ g}} = 1.865 \times 10^{-2} \text{ mol HCl}$$

BaO_2 is the limiting reactant.

$$8.860 \times 10^{-3} \text{ mol } BaO_2 \times \frac{1 \text{ mol } H_2O_2}{1 \text{ mol BaO2}} \times \frac{34.02 \text{ g } H_2O_2}{1 \text{ mol } H_2O_2} = 0.301 \text{ g } H_2O_2$$

58. $SiO_2(s) + 3C(s) \rightarrow 2CO(g) + SiC(s)$

molar masses: SiO_2, 60.09 g; SiC, 40.10 g; 1.0 kg = 1.0×10^3 g

$$1.0 \times 10^3 \text{ g } SiO_2 \times \frac{1 \text{ mol}}{60.09 \text{ g}} = 16.64 \text{ mol } SiO_2$$

From the balanced chemical equation, if 16.64 mol of SiO_2 were to react completely (an excess of carbon is present), then 16.64 mol of SiC should be produced (the coefficients of SiO_2 and SiC are the same).

$$16.64 \text{ mol SiC} \times \frac{40.01 \text{ g}}{1 \text{ mol}} = 6.7 \times 10^2 \text{ g SiC} = 0.67 \text{ kg SiC}$$

59. The *theoretical yield* represents the yield we calculate from the stoichiometry of the reaction and the masses of reactants taken for the experiment. The *actual yield* is what is actually obtained in an experiment. The *percent yield* is the ratio of what is actually obtained to the theoretical amount that could be obtained, converted to a percent basis.

60. If the reaction is performed in a solvent, the product may have substantial solubility in the solvent and the reaction may come to equilibrium before the full yield of product is achieved (See Chapter 17.). Loss of product may occur through operator error.

61. $$\text{Percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{1.23 \text{ g}}{1.44 \text{ g}} \times 100 = 85.4\%$$

62. $2HgO(s) \rightarrow 2Hg(l) + O_2(g)$

molar masses: HgO, 216.6 g; Hg, 200.6 g

$$1.25 \text{ g HgO} \times \frac{1 \text{ mol}}{216.6 \text{ g}} = 0.005771 \text{ mol HgO}$$

$$0.005771 \text{ mol HgO} \times \frac{2 \text{ mol Hg}}{2 \text{ mol HgO}} \times \frac{200.6 \text{ g Hg}}{1 \text{ mol Hg}} = 1.16 \text{ g (theoretical yield)}$$

$$\% \text{ yield} = \frac{1.09 \text{ g actual}}{1.16 \text{ g theoretical}} \times 100 = 94.0\% \text{ of theory}$$

63. $S_8(s) + 8Na_2SO_3(aq) + 40H_2O(l) \rightarrow 8Na_2S_2O_3{=}5H_2O$

molar masses: S_8, 256.6 g; Na_2SO_3, 126.1 g; $Na_2S_2O_3{=}5H_2O$, 248.2 g

$$3.25 \text{ g } S_8 \times \frac{1 \text{ mol}}{256.6 \text{ g}} = 0.01267 \text{ mol } S_8$$

$$13.1 \text{ g } Na_2SO_3 \times \frac{1 \text{ mol}}{126.1 \text{ g}} = 0.1039 \text{ mol } Na_2SO_3$$

S_8 is the limiting reactant.

$$0.01267 \text{ mol } S_8 \times \frac{8 \text{ mol } Na_2S_2O_3 \cdot 5H_2O}{1 \text{ mol } S_8} = 0.1014 \text{ mol } Na_2S_2O_3 \cdot 5H_2O$$

$$0.1014 \text{ mol } Na_2S_2O_3 = 5H_2O \times \frac{248.2 \text{ g } Na_2S_2O_3 \cdot 5H_2O}{1 \text{ mol } Na_2S_2O_3 \cdot 5H_2O} = 25.2 \text{ g } Na_2S_2O_3 \cdot 5H_2O$$

$$\text{Percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{5.26 \text{ g}}{25.2 \text{ g}} \times 100 = 20.9\%$$

64. $2LiOH(s) + CO_2(g) \rightarrow Li_2CO_3(s) + H_2O(g)$

molar masses: LiOH, 23.95 g; CO_2, 44.01 g

$$155 \text{ g LiOH} \times \frac{1 \text{ mol LiOH}}{23.95 \text{ g LiOH}} \times \frac{1 \text{ mol } CO_2}{2 \text{ mol LiOH}} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 142 \text{ g } CO_2$$

As the cartridge has only absorbed 102 g CO_2 out of a total capacity of 142 g CO_2, the cartridge has absorbed

$$\frac{102 \text{ g}}{142 \text{ g}} \times 100 = 71.8\% \text{ of its capacity.}$$

65. $Xe(g) + 2F_2(g) \rightarrow XeF_4(s)$

molar masses: Xe, 131.3 g; F_2, 38.00 g; XeF_4, 207.3 g

$$130. \text{ g Xe} \times \frac{1 \text{ mol}}{131.3 \text{ g}} = 0.9901 \text{ mol Xe}$$

$$100. \text{ g } F_2 \times \frac{1 \text{ mol}}{38.00 \text{ g}} = 2.632 \text{ mol } F_2$$

Xe is the limiting reactant.

$$0.9901 \text{ mol Xe} \times \frac{1 \text{ mol } XeF_4}{1 \text{ mol Xe}} \times \frac{207.3 \text{ g } XeF_4}{1 \text{ mol } XeF_4} = 205 \text{ g } XeF_4$$

$$\text{Percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{145 \text{ g}}{205 \text{ g}} \times 100 = 70.7\ \% \text{ of theory}$$

66. $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

molar masses: SO_4^{2-}, 96.07 g; $BaCl_2$, 208.2 g; $BaSO_4$, 233.4 g

$$1.12 \text{ g } SO_4^{2-} \times \frac{1 \text{ mol}}{96.07 \text{ g}} = 0.01166 \text{ mol } SO_4^{2-}$$

$$5.02 \text{ g } BaCl_2 \times \frac{1 \text{ mol}}{208.2 \text{ g}} = 0.02411 \text{ mol } BaCl_2 = 0.02411 \text{ mol } Ba^{2+}$$

SO_4^{2-} is the limiting reactant.

$$0.01166 \text{ mol } SO_4^{2-} \times \frac{1 \text{ mol } BaSO_4}{1 \text{ mol } SO_4^{2-}} \times \frac{233.4 \text{ g } BaSO_4}{1 \text{ mol } BaSO_4} = 2.72 \text{ g } BaSO_4$$

$$\text{Percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{2.02 \text{ g}}{2.72 \text{ g}} \times 100 = 74.3\%$$

67. $Ca(HCO_3)_2(aq) \rightarrow CaCO_3(s) + CO_2(g) + H_2O(l)$

millimolar masses: $Ca(HCO_3)_2$, 162.1 mg; $CaCO_3$, 100.1 mg

$$2.0 \times 10^{-3} \text{ mg } Ca(HCO_3)_2 \times \frac{1 \text{ mmol}}{162.1 \text{ mg}} = 1.23 \times 10^{-5} \text{ mmol } Ca(HCO_3)_2$$

$$1.23 \times 10^{-5} \text{ mmol } Ca(HCO_3)_2 \times \frac{1 \text{ mmol } CaCO_3}{1 \text{ mmol } Ca(HCO_3)_2} = 1.23 \times 10^{-5} \text{ mmol } CaCO_3$$

$$1.23 \times 10^{-5} \text{ mmol} \times \frac{100.1 \text{ mg}}{1 \text{ mmol}} = 1.2 \times 10^{-3} \text{ mg} = 1.2 \times 10^{-6} \text{ g } CaCO_3$$

68. $NaCl(aq) + NH_3(aq) + H_2O(l) + CO_2(s) \rightarrow NH_4Cl(aq) + NaHCO_3(s)$

molar masses: NH_3, 17.03 g; CO_2, 44.01 g; $NaHCO_3$, 84.01 g

$$10.0 \text{ g } NH_3 \times \frac{1 \text{ mol}}{17.03 \text{ g}} = 0.5872 \text{ mol } NH_3$$

$$15.0 \text{ g } CO_2 \times \frac{1 \text{ mol}}{44.01 \text{ g}} = 0.3408 \text{ mol } CO_2$$

CO_2 is the limiting reactant.

$$0.3408 \text{ mol } CO_2 \times \frac{1 \text{ mol } NaHCO_3}{1 \text{ mol } CO_2} = 0.3408 \text{ mol } NaHCO_3$$

$$0.3408 \text{ mol } NaHCO_3 \times \frac{84.01 \text{ g}}{1 \text{ mol}} = 28.6 \text{ g } NaHCO_3$$

69. $Fe(s) + S(s) \rightarrow FeS(s)$

molar masses: Fe, 55.85 g; S, 32.07 g; FeS, 87.92 g

$$5.25 \text{ g Fe} \times \frac{1 \text{ mol}}{55.85 \text{ g}} = 0.0940 \text{ mol Fe}$$

$$12.7 \text{ g S} \times \frac{1 \text{ mol}}{32.07 \text{ g}} = 0.396 \text{ mol S}$$

Fe is the limiting reactant.

$$0.0940 \text{ mol Fe} \times \frac{1 \text{ mol FeS}}{1 \text{ mol Fe}} \times \frac{87.92 \text{ g FeS}}{1 \text{ mol FeS}} = 8.26 \text{ g FeS produced}$$

70. $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(g)$

molar masses: glucose, 180.2 g; CO_2, 44.01 g

1.00 g glucose × = 5.549×10^{-3} mol glucose

$$5.549 \times 10^{-3} \text{ mol glucose} \times \frac{6 \text{ mol } CO_2}{1 \text{ mol glucose}} = 3.33 \times 10^{-2} \text{ mol } CO_2$$

$$3.33 \times 10^{-2} \text{ mol } CO_2 \times \frac{44.01 \text{ g}}{1 \text{ mol}} = 1.47 \text{ g } CO_2$$

71. $Cu(s) + S(s) \rightarrow CuS(s)$

molar masses: Cu, 63.55 g; S, 32.07 g; CuS, 95.62 g

$$31.8 \text{ g Cu} \times \frac{1 \text{ mol}}{63.55 \text{ g}} = 0.5004 \text{ mol Cu}$$

$$50.0 \text{ g S} \times \frac{1 \text{ mol}}{32.07 \text{ g}} = 1.559 \text{ mol S}$$

Cu is the limiting reactant.

$$0.5004 \text{ mol Cu} \times \frac{1 \text{ mol CuS}}{1 \text{ mol Cu}} = 0.5004 \text{ mol CuS}$$

$$0.5004 \text{ mol CuS} \times \frac{95.62 \text{ g}}{1 \text{ mol}} = 47.8 \text{ g CuS}$$

$$\% \text{ yield} = \frac{40.0 \text{ g}}{47.8 \text{ g}} \times 100 = 83.7\%$$

72. $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

millimolar ionic masses: Ba^{2+}, 137.3 mg; SO_4^{2-}, 96.07 mg; $BaCl_2$, 208.2 mg

$$150 \text{ mg } SO_4^{2-} \times \frac{1 \text{ mmol}}{96.07 \text{ mg}} = 1.56 \text{ millimol } SO_4^{2-}$$

As barium ion and sulfate ion react on a 1:1 stoichiometric basis, then 1.56 millimol of barium ion is needed, which corresponds to 1.56 millimol of $BaCl_2$.

$$1.56 \text{ millimol } BaCl_2 \times \frac{208.2 \text{ mg}}{1 \text{ mmol}} = 325 \text{ milligrams } BaCl_2 \text{ needed}$$

73. mass of Cl^- present = 1.054 g sample × $\frac{10.3 \text{ g } Cl^-}{100.0 \text{ g sample}}$ = 0.1086 g Cl^-

molar masses: Cl^-, 35.45 g; $AgNO_3$, 169.9 g; AgCl, 143.4 g

$$0.1086 \text{ g } Cl^- \times \frac{1 \text{ mol}}{35.45 \text{ g}} = 3.063 \times 10^{-3} \text{ mol } Cl^-$$

$$3.063 \times 10^{-3} \text{ mol } Cl^- \times \frac{1 \text{ mol } AgNO_3}{1 \text{ mol } Cl^-} = 3.063 \times 10^{-3} \text{ mol } AgNO_3$$

$$3.063 \times 10^{-3} \text{ mol } AgNO_3 \times \frac{169.9 \text{ g}}{1 \text{ mol}} = 0.520 \text{ g } AgNO_3 \text{ required}$$

$$3.063 \times 10^{-3} \text{ mol } Cl^- \times \frac{1 \text{ mol AgCl}}{1 \text{ mol } Cl^-} = 3.063 \times 10^{-3} \text{ mol AgCl}$$

$$3.063 \times 10^{-3} \text{ mol AgCl} \times \frac{143.4 \text{ g}}{1 \text{ mol}} = 0.439 \text{ g AgCl produced}$$

74.

a. $UO_2(s) + 4HF(aq) \rightarrow UF_4(aq) + 2H_2O(l)$

One molecule (formula unit) of uranium(IV) oxide will combine with four molecules of hydrofluoric acid, producing one uranium(IV) fluoride molecule and two water molecules. One mole of uranium(IV) oxide will combine with four moles of hydrofluoric acid to produce one mole of uranium(IV) fluoride and two moles of water.

b. $2NaC_2H_3O_2(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2HC_2H_3O_2(aq)$

Two molecules (formula units) of sodium acetate react exactly with one molecule of sulfuric acid, producing one molecule (formula unit) of sodium sulfate and two molecules of acetic acid. Two moles of sodium acetate will combine with one mole of sulfuric acid, producing one mole of sodium sulfate and two moles of acetic acid.

c. $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

One magnesium atom will react with two hydrochloric acid molecules (formula units) to produce one molecule (formula unit) of magnesium chloride and one molecule of hydrogen gas. One mole of magnesium will combine with two moles of hydrochloric acid, producing one mole of magnesium chloride and one mole of gaseous hydrogen.

d. $B_2O_3(s) + 3H_2O(l) \rightarrow 2B(OH)_3(aq)$

One molecule of diboron trioxide will react exactly with three molecules of water, producing two molecules of boron trihydroxide (boric acid). One mole of diboron trioxide will combine with three moles of water to produce two moles of boron trihydroxide (boric acid).

75. False. For 0.40 mol of $Mg(OH)_2$ to react, 0.80 mol of HCl will be needed. According to the balanced equation, for a given amount of $Mg(OH)_2$, *twice* as many moles of HCl is needed.

76. For O_2: $\left(\frac{5 \text{ mol } O_2}{1 \text{ mol } C_3H_8}\right)$ For CO_2: $\left(\frac{3 \text{ mol } CO_2}{1 \text{ mol } C_3H_8}\right)$ For H_2O: $\left(\frac{4 \text{ mol } H_2O}{1 \text{ mol } C_3H_8}\right)$

77.

a. $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$

$$0.50 \text{ mol } H_2O_2 \times \frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2O_2} = 0.50 \text{ mol } H_2O$$

$$0.50 \text{ mol } H_2O_2 \times \frac{1 \text{ mol } O_2}{2 \text{ mol } H_2O_2} = 0.25 \text{ mol } O_2$$

b. $2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$

$$0.50 \text{ mol } KClO_3 \times \frac{2 \text{ mol KCl}}{2 \text{ mol } KClO_3} = 0.50 \text{ mol KCl}$$

$$0.50 \text{ mol } KClO_3 \times \frac{3 \text{ mol } O_2}{2 \text{ mol } KClO_3} = 0.75 \text{ mol } O_2$$

c. $2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$

$$0.50 \text{ mol Al} \times \frac{2 \text{ mol } AlCl_3}{2 \text{ mol Al}} = 0.50 \text{ mol } AlCl_3$$

$$0.50 \text{ mol Al} \times \frac{3 \text{ mol } H_2}{2 \text{ mol Al}} = 0.75 \text{ mol } H_2$$

d. $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$

$$0.50 \text{ mol } C_3H_8 \times \frac{3 \text{ mol } CO_2}{1 \text{ mol } C_3H_8} = 1.5 \text{ mol } CO_2$$

$$0.50 \text{ mol } C_3H_8 \times \frac{4 \text{ mol } H_2O}{1 \text{ mol } C_3H_8} = 2.0 \text{ mol } H_2O$$

78.

a. $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$

molar mass of NH_3 = 17.01 g

$$1.00 \text{ g } NH_3 \times \frac{1 \text{ mol}}{17.01 \text{ g}} = 0.0588 \text{ mol } NH_3$$

$$0.0588 \text{ mol } NH_3 \times \frac{1 \text{ mol } NH_4Cl}{1 \text{ mol } NH_3} = 0.0588 \text{ mol } NH_4Cl$$

b. $CaO(s) + CO_2(g) \rightarrow CaCO_3(s)$

molar mass CaO = 56.08 g

$$1.00 \text{ g CaO} \times \frac{1 \text{ mol}}{56.08 \text{ g}} = 0.0178 \text{ mol CaO}$$

$$0.0178 \text{ mol CaO} \times \frac{1 \text{ mol } CaCO_3}{1 \text{ mol CaO}} = 0.0178 \text{ mol } CaCO_3$$

c. $4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$

molar mass Na = 22.99 g

$$1.00 \text{ g Na} \times \frac{1 \text{ mol}}{22.99 \text{ g}} = 0.0435 \text{ mol Na}$$

$$0.0435 \text{ mol Na} \times \frac{2 \text{ mol } Na_2O}{4 \text{ mol Na}} = 0.0217 \text{ mol } Na_2O$$

d. $2P(s) + 3Cl_2(g) \rightarrow 2PCl_3(l)$

molar mass P = 30.97 g

$$1.00 \text{ g P} \times \frac{1 \text{ mol}}{30.97 \text{ g}} = 0.0323 \text{ mol P}$$

$$0.0323 \text{ mol P} \times \frac{2 \text{ mol } PCl_3}{2 \text{ mol P}} = 0.0323 \text{ mol } PCl_3$$

79.

a. molar mass $CuSO_4$ = 159.6 g

$$4.21 \text{ g } CuSO_4 \times \frac{1 \text{ mol}}{159.6 \text{ g}} = 0.0264 \text{ mol } CuSO_4$$

b. molar mass $Ba(NO_3)_2$ = 261.3 g

$$7.94 \text{ g } Ba(NO_3)_2 \times \frac{1 \text{ mol}}{261.3 \text{ g}} = 0.0304 \text{ mol } Ba(NO_3)_2$$

c. molar mass water = 18.02 g; 1.24 mg = 0.00124 g.

$$0.00124 \text{ g} \times \frac{1 \text{ mol}}{18.02 \text{ g}} = 6.88 \times 10^{-5} \text{ mol } H_2O$$

d. molar mass W = 183.9 g

$$9.79 \text{ g W} \times \frac{1 \text{ mol}}{183.9 \text{ g}} = 5.32 \times 10^{-2} \text{ mol W}$$

e. molar mass S = 32.07 g; 1.45 lb = 1.45(454) = 658 g

$$658 \text{ g S} \times \frac{1 \text{ mol}}{32.07 \text{ g}} = 20.5 \text{ mol S}$$

f. molar mass C_2H_5OH = 46.07 g

$$4.65 \text{ g } C_2H_5OH \times \frac{1 \text{ mol}}{46.07 \text{ g}} = 0.101 \text{ mol } C_2H_5OH$$

g. molar mass C = 12.01 g

$$12.01 \text{ g C} \times \frac{1 \text{ mol}}{12.01 \text{ g}} = 1.00 \text{ mol C}$$

80.

a. molar mass HNO_3 = 63.0 g

$$5.0 \text{ mol } HNO_3 \times \frac{63.0 \text{ g}}{1 \text{ mol}} = 3.2 \times 10^2 \text{ g } HNO_3$$

b. molar mass Hg = 200.6 g

$$0.000305 \text{ mol Hg} \times \frac{200.6 \text{ g}}{1 \text{ mol}} = 0.0612 \text{ g Hg}$$

c. molar mass K_2CrO_4 = 194.2 g

$$2.31 \times 10^{-5} \text{ mol } K_2CrO_4 \times \frac{194.2 \text{ g}}{1 \text{ mol}} = 4.49 \times 10^{-3} \text{ g } K_2CrO_4$$

d. molar mass $AlCl_3$ = 133.3 g

$$10.5 \text{ mol } AlCl_3 \times \frac{133.3 \text{ g}}{1 \text{ mol}} = 1.40 \times 10^3 \text{ g } AlCl_3$$

e. molar mass SF_6 = 146.1 g

$$4.9 \times 10^4 \text{ mol } SF_6 \times \frac{146.1 \text{ g}}{1 \text{ mol}} = 7.2 \times 10^6 \text{ g } SF_6$$

f. molar mass NH_3 = 17.01 g

$$125 \text{ mol } NH_3 \times \frac{17.01 \text{ g}}{1 \text{ mol}} = 2.13 \times 10^3 \text{ g } NH_3$$

g. molar mass Na_2O_2 = 77.98 g

$$0.01205 \text{ mol } Na_2O_2 \times \frac{77.98 \text{ g}}{1 \text{ mol}} = 0.9397 \text{ g } Na_2O_2$$

81. Before any calculations are done, the equations must be *balanced*.

a. $BaCl_2(aq) + H_2SO_4(aq) \rightarrow BaSO_4(s) + 2HCl(aq)$

$$0.145 \text{ mol } BaCl_2 \times \frac{1 \text{ mol } H_2SO_4}{1 \text{ mol } BaCl_2} = 0.145 \text{ mol } H_2SO_4$$

b. $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$

$$0.145 \text{ mol } AgNO_3 \times \frac{1 \text{ mol NaCl}}{1 \text{ mol } AgNO_3} = 0.145 \text{ mol NaCl}$$

c. $Pb(NO_3)_2(aq) + Na_2CO_3(aq) \rightarrow PbCO_3(s) + 2NaNO_3(aq)$

$$0.145 \text{ mol } Pb(NO_3)_2 \times \frac{1 \text{ mol } Na_2CO_3}{1 \text{ mol } Pb(NO_3)_2} = 0.145 \text{ mol } Na_2CO_3$$

d. $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

$$0.145 \text{ mol } C_3H_8 \times \frac{5 \text{ mol } O_2}{1 \text{ mol } C_3H_8} = 0.725 \text{ mol } O_2$$

82. $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$

molar masses: SO_2, 64.07 g; SO_3, 80.07 g; 150 kg = 1.5×10^5 g

$$1.5 \times 10^5 \text{ g } SO_2 \times \frac{1 \text{ mol}}{64.07 \text{ g}} = 2.34 \times 10^3 \text{ mol } SO_2$$

$$2.34 \times 10^3 \text{ mol } SO_2 \times \frac{2 \text{ mol } SO_3}{2 \text{ mol } SO_2} = 2.34 \times 10^3 \text{ mol } SO_3$$

$$2.34 \times 10^3 \text{ mol } SO_3 \times \frac{80.07 \text{ g}}{1 \text{ mol}} = 1.9 \times 10^5 \text{ g } SO_3 = 1.9 \times 10^2 \text{ kg } SO_3$$

83. $2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$

molar masses: ZnS, 97.45 g; SO_2, 64.07 g; 1.0×10^2 kg = 1.0×10^5 g

$$1.0 \times 10^5 \text{ g ZnS} \times \frac{1 \text{ mol}}{97.45 \text{ g}} = 1.026 \times 10^3 \text{ mol ZnS}$$

$$1.026 \times 10^3 \text{ mol ZnS} \times \frac{2 \text{ mol } SO_2}{2 \text{ mol ZnS}} = 1.026 \times 10^3 \text{ mol } SO_2$$

$$1.026 \times 10^3 \text{ mol } SO_2 \times \frac{64.07 \text{ g}}{1 \text{ mol}} = 6.6 \times 10^4 \text{ g } SO_2 = 66 \text{ kg } SO_2$$

84. $2Na_2O_2(s) + 2H_2O(l) \rightarrow 4NaOH(aq) + O_2(g)$

molar masses: Na_2O_2, 77.98 g; O_2, 32.00 g

$$3.25 \text{ g } Na_2O_2 \times \frac{1 \text{ mol}}{77.98 \text{ g}} = 0.0417 \text{ mol } Na_2O_2$$

$$0.0417 \text{ mol } Na_2O_2 \times \frac{1 \text{ mol } O_2}{2 \text{ mol } Na_2O_2} = 0.0209 \text{ mol } O_2$$

$$0.0209 \text{ mol } O_2 \times \frac{32.00 \text{ g}}{1 \text{ mol}} = 0.669 \text{ g } O_2$$

85. $Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$

millimolar masses: Cu, 63.55 mg; $AgNO_3$, 169.9 mg

$$1.95 \text{ mg } AgNO_3 \times \frac{1 \text{ mmol}}{169.9 \text{ mg}} = 0.01148 \text{ mmol } AgNO_3$$

$$0.01148 \text{ mmol } AgNO_3 \times \frac{1 \text{ mmol Cu}}{2 \text{ mmol } AgNO_3} = 0.005740 \text{ mmol Cu}$$

$$0.005740 \text{ mmol Cu} \times \frac{63.55 \text{ g}}{1 \text{ mol}} = 0.365 \text{ mg Cu}$$

86. $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

molar masses: Zn, 65.38 g; H_2, 2.016 g

$$2.50 \text{ g Zn} \times \frac{1 \text{ mol}}{65.38 \text{ g}} = 0.03824 \text{ mol Zn}$$

$$0.03824 \text{ mol Zn} \times \frac{1 \text{ mol } H_2}{1 \text{ mol Zn}} = 0.03824 \text{ mol } H_2$$

$$0.03824 \text{ mol } H_2 \times \frac{2.016 \text{ g}}{1 \text{ mol}} = 0.0771 \text{ g } H_2$$

87. $2C_2H_2(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(g)$

molar masses: C_2H_2, 26.04 g; O_2, 32.00 g; 150 g = 1.5×10^2 g

$$1.5 \times 10^2 \text{ g } C_2H_2 \times \frac{1 \text{ mol}}{26.04 \text{ g}} = 5.760 \text{ mol } C_2H_2$$

$$5.760 \text{ mol } C_2H_2 \times \frac{5 \text{ mol } O_2}{2 \text{ mol } C_2H_2} = 14.40 \text{ mol } O_2$$

$$14.40 \text{ mol } O_2 \times \frac{32.00 \text{ g}}{1 \text{ mol}} = 4.6 \times 10^2 \text{ g } O_2$$

88.

a. $2Na(s) + Br_2(l) \rightarrow 2NaBr(s)$

molar masses: Na, 22.99 g; Br_2, 159.8 g; NaBr, 102.9 g

$$5.0 \text{ g Na} \times \frac{1 \text{ mol}}{22.99 \text{ g}} = 0.2175 \text{ mol Na}$$

$$5.0 \text{ g } Br_2 \times \frac{1 \text{ mol}}{159.8 \text{ g}} = 0.03129 \text{ mol } Br_2$$

Intuitively, we would suspect that Br_2 is the limiting reactant because there is much less Br_2 than Na on a mole basis. To *prove* that Br_2 is the limiting reactant, the following calculation is needed:

$$0.03129 \text{ mol } Br_2 \times \frac{2 \text{ mol Na}}{1 \text{ mol } Br_2} = 0.06258 \text{ mol Na.}$$

Clearly there is more Na than this present, so Br_2 limits the reaction extent and the amount of NaBr formed.

$$0.03129 \text{ mol } Br_2 \times \frac{2 \text{ mol NaBr}}{1 \text{ mol } Br_2} = 0.06258 \text{ mol NaBr}$$

$$0.06258 \text{ mol NaBr} \times \frac{102.9 \text{ g}}{1 \text{ mol}} = 6.4 \text{ g NaBr}$$

b. $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$

molar masses: Zn, 65.38 g; Cu, 63.55 g; $ZnSO_4$, 161.5 g; $CuSO_4$, 159.6 g

$$5.0 \text{ g Zn} \times \frac{1 \text{ mol}}{65.38 \text{ g}} = 0.07648 \text{ mol Zn}$$

$$5.0 \text{ g } CuSO_4 \times \frac{1 \text{ mol}}{159.6 \text{ g}} = 0.03132 \text{ mol } CuSO_4$$

As the coefficients of Zn and $CuSO_4$ are the *same* in the balanced chemical equation, an equal number of moles of Zn and $CuSO_4$ would be needed for complete reaction. There is less $CuSO_4$ present, so $CuSO_4$ must be the limiting reactant.

$$0.03132 \text{ mol } CuSO_4 \times \frac{1 \text{ mol } ZnSO_4}{1 \text{ mol } CuSO_4} = 0.03132 \text{ mol } ZnSO_4$$

$$0.03132 \text{ mol } ZnSO_4 \times \frac{161.5 \text{ g}}{1 \text{ mol}} = 5.1 \text{ g } ZnSO_4$$

$$0.03132 \text{ mol } CuSO_4 \times \frac{1 \text{ mol Cu}}{1 \text{ mol } CuSO_4} = 0.03132 \text{ mol Cu}$$

$$0.03132 \text{ mol Cu} \times \frac{63.55 \text{ g}}{1 \text{ mol}} = 2.0 \text{ g Cu}$$

c. $NH_4Cl(aq) + NaOH(aq) \rightarrow NH_3(g) + H_2O(l) + NaCl(aq)$

molar masses: NH_4Cl, 53.49 g; NaOH, 40.00 g; NH_3, 17.03 g; H_2O, 18.02 g; NaCl, 58.44 g

$$5.0 \text{ g } NH_4Cl \times \frac{1 \text{ mol}}{53.49 \text{ g}} = 0.09348 \text{ mol } NH_4Cl$$

$$5.0 \text{ g NaOH} \times \frac{1 \text{ mol}}{40.00 \text{ g}} = 0.1250 \text{ mol NaOH}$$

As the coefficients of NH_4Cl and NaOH are both *one* in the balanced chemical equation for the reaction, an equal number of moles of NH_4Cl and NaOH would be needed for complete reaction. There is less NH_4Cl present, so NH_4Cl must be the limiting reactant.

As the coefficients of the products in the balanced chemical equation are also all *one*, if 0.09348 mol of NH_4Cl (the limiting reactant) reacts completely, then 0.09348 mol of each product will be formed.

$$0.09348 \text{ mol } NH_3 \times \frac{17.03 \text{ g}}{1 \text{ mol}} = 1.6 \text{ g } NH_3$$

$$0.09348 \text{ mol } H_2O \times \frac{18.02 \text{ g}}{1 \text{ mol}} = 1.7 \text{ g } H_2O$$

$$0.09348 \text{ mol NaCl} \times \frac{58.44 \text{ g}}{1 \text{ mol}} = 5.5 \text{ g NaCl}$$

d. $Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$

molar masses: Fe_2O_3, 159.7 g; CO, 28.01 g; Fe, 55.85 g; CO_2, 44.01 g

$$5.0 \text{ g } Fe_2O_3 \times \frac{1 \text{ mol}}{159.7 \text{ g}} = 0.03131 \text{ mol } Fe_2O_3$$

$$5.0 \text{ g CO} \times \frac{1 \text{ mol}}{28.01 \text{ g}} = 0.1785 \text{ mol CO}$$

Because there is considerably less Fe_2O_3 than CO on a mole basis, let's see if Fe_2O_3 is the limiting reactant.

$$0.03131 \text{ mol } Fe_2O_3 \times \frac{3 \text{ mol CO}}{1 \text{ mol } Fe_2O_3} = 0.09393 \text{ mol CO}$$

There is 0.1785 mol of CO present, but we have determined that only 0.09393 mol CO would be needed to react with all the Fe_2O_3 present, so Fe_2O_3 must be the limiting reactant. CO is present in excess.

$$0.03131 \text{ mol } Fe_2O_3 \times \frac{2 \text{ mol Fe}}{1 \text{ mol } Fe_2O_3} \times \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 3.5 \text{ g Fe}$$

$$0.03131 \text{ mol } Fe_2O_3 \times \frac{3 \text{ mol } CO_2}{1 \text{ mol } Fe_2O_3} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 4.1 \text{ g } CO_2$$

89.

a. $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

molar masses: C_2H_5OH, 46.07 g; O_2, 32.00 g; CO_2, 44.01 g

$$25.0 \text{ g } C_2H_5OH \times \frac{1 \text{ mol}}{46.07 \text{ g}} = 0.5427 \text{ mol } C_2H_5OH$$

$$25.0 \text{ g } O_2 \times \frac{1 \text{ mol}}{32.00 \text{ g}} = 0.7813 \text{ mol } O_2$$

As there is less C_2H_5OH present on a mole basis, see if this substance is the limiting reactant.

$$0.5427 \text{ mol } C_2H_5OH \times \frac{3 \text{ mol } O_2}{1 \text{ mol } C_2H_5OH} = 1.6281 \text{ mol } O_2.$$

From the above calculation, C_2H_5OH must *not* be the limiting reactant (even though there is a smaller number of moles of C_2H_5OH present) because more oxygen than is present would be required to react completely with the C_2H_5OH present. Oxygen is the limiting reactant.

$$0.7813 \text{ mol } O_2 \times \frac{2 \text{ mol } CO_2}{3 \text{ mol } O_2} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 22.9 \text{ g } CO_2$$

b. $N_2(g) + O_2(g) \rightarrow 2NO(g)$

molar masses: N_2, 28.02 g; O_2, 32.00 g; NO, 30.01 g

$$25.0 \text{ g } N_2 \times \frac{1 \text{ mol}}{28.02 \text{ g}} = 0.8922 \text{ mol } N_2$$

$$25.0 \text{ g } O_2 \times \frac{1 \text{ mol}}{32.00 \text{ g}} = 0.7813 \text{ mol } O_2$$

As the coefficients of N_2 and O_2 are the *same* in the balanced chemical equation for the reaction, an equal number of moles of each substance would be necessary for complete reaction. There is less O_2 present on a mole basis, so O_2 must be the limiting reactant.

$$0.7813 \text{ mol } O_2 \times \frac{2 \text{ mol NO}}{1 \text{ mol } O_2} \times \frac{30.01 \text{ g NO}}{1 \text{ mol NO}} = 46.9 \text{ g NO}$$

c. $2NaClO_2(aq) + Cl_2(g) \rightarrow 2ClO_2(g) + 2NaCl(aq)$

molar masses: $NaClO_2$, 90.44 g; Cl_2, 70.90 g; NaCl, 58.44 g

$$25.0 \text{ g } NaClO_2 \times \frac{1 \text{ mol}}{90.44 \text{ g}} = 0.2764 \text{ mol } NaClO_2$$

$$25.0 \text{ g } Cl_2 \times \frac{1 \text{ mol}}{70.90 \text{ g}} = 0.3526 \text{ mol } Cl_2$$

See if $NaClO_2$ is the limiting reactant.

$$0.2764 \text{ mol } NaClO_2 \times \frac{1 \text{ mol } Cl_2}{2 \text{ mol } NaClO_2} = 0.1382 \text{ mol } Cl_2$$

As 0.2764 mol of $NaClO_2$ would require only 0.1382 mol Cl_2 to react completely (and since we have more than this amount of Cl_2), then $NaClO_2$ must indeed be the limiting reactant.

$$0.2764 \text{ mol } NaClO_2 \times \frac{2 \text{ mol NaCl}}{2 \text{ mol } NaClO_2} \times \frac{58.44 \text{ g NaCl}}{1 \text{ mol NaCl}} = 16.2 \text{ g NaCl}$$

d. $3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$

molar masses: H_2, 2.016 g; N_2, 28.02 g; NH_3, 17.03 g

$$25.0 \text{ g } H_2 \times \frac{1 \text{ mol}}{2.016 \text{ g}} = 12.40 \text{ mol } H_2$$

$$25.0 \text{ g } N_2 \times \frac{1 \text{ mol}}{28.02 \text{ g}} = 0.8922 \text{ mol } N_2$$

See if N_2 is the limiting reactant.

$$0.8922 \text{ mol } N_2 \times \frac{3 \text{ mol } H_2}{1 \text{ mol } N_2} = 2.677 \text{ mol } H_2$$

N_2 is clearly the limiting reactant because there is 12.40 mol H_2 present (a large excess).

$$0.8922 \text{ mol } N_2 \times \frac{2 \text{ mol } NH_3}{1 \text{ mol } N_2} \times \frac{17.03 \text{ g } NH_3}{1 \text{ mol } NH_3} = 30.4 \text{ g } NH_3$$

90. $N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2H_2O(g)$

molar masses: N_2H_4, 32.05 g; O_2, 32.00 g; N_2, 28.02 g; H_2O, 18.02 g

$$20.0 \text{ g } N_2H_4 \times \frac{1 \text{ mol}}{32.05 \text{ g}} = 0.624 \text{ mol } N_2H_4$$

$$20.0 \text{ g } O_2 \times \frac{1 \text{ mol}}{32.00 \text{ g}} = 0.625 \text{ mol } O_2$$

The two reactants are present in nearly the required ratio for complete reaction (due to the 1:1 stoichiometry of the reaction and the very similar molar masses of the substances). We will consider N_2H_4 as the limiting reactant in the following calculations.

$$0.624 \text{ mol } N_2H_4 \times \frac{1 \text{ mol } N_2}{1 \text{ mol } N_2H_4} \times \frac{28.02 \text{ g } N_2}{1 \text{ mol } N_2} = 17.5 \text{ g } N_2$$

$$0.624 \text{ mol } N_2H_4 \times \frac{2 \text{ mol } H_2O}{1 \text{ mol } N_2H_4} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 22.5 \text{ g } H_2O$$

91. Total quantity of H_2S = 50. L $\times \frac{1.5 \times 10^{-5} \text{ g}}{1 \text{ L}} = 7.5 \times 10^{-4}$ g H_2S

$8H_2S(aq) + 8Cl_2(aq) \rightarrow 16HCl(aq) + S_8(s)$

molar masses: H_2S, 34.09 g; Cl_2, 70.90 g; S_8, 256.6 g

$$7.5 \times 10^{-4} \text{ g } H_2S \times \frac{1 \text{ mol}}{34.09 \text{ g}} = 2.20 \times 10^{-5} \text{ mol } H_2S$$

$$1.0 \text{ g } Cl_2 \times \frac{1 \text{ mol}}{70.90 \text{ g}} = 1.41 \times 10^{-2} \text{ mol } Cl_2$$

There is a large excess of chlorine present compared to the amount of Cl_2 that would be needed to react with all the H_2S present in the water sample: H_2S is the limiting reactant for the process.

$$2.20 \times 10^{-5} \text{ mol } H_2S \times \frac{1 \text{ mol } S_8}{8 \text{ mol } H_2S} \times \frac{256.6 \text{ g } S_8}{1 \text{ mol } S_8} = 7.1 \times 10^{-4} \text{ g } S_8 \text{ removed}$$

92. $12.5 \text{ g theory} \times \frac{40 \text{ g actual}}{100 \text{ g theory}} = 5.0 \text{ g}$