Stoichiometry Review

1. The combustion of propane occurs via the reaction:

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

How many grams of oxygen are required to burn completely 10.0 g of propane?

$$\left(\frac{10.0\text{g } C_3H_8}{44.09652\text{ g/mol}}\right)\left(\frac{5\text{ mol } O_2}{1\text{ mol } C_3H_8}\right)\left(31.9988\text{ g/mol}\right)$$

$$= 36.3\text{ g } O_2$$

2. Small quantities of chlorine can be prepared in the laboratory by the reaction:

$$MnO_2(s) + 4\ HCl(aq) \rightarrow MnCl_2(aq) + Cl_2(g) + 2\ H_2O(l)$$

What volume of chlorine at STP can be prepared from 100.0 g of manganese dioxide?

$$\left(\frac{100.0\text{g } MnO_2}{86.9368\text{ g/mol}}\right)\left(\frac{1\text{ mol } Cl_2}{1\text{ mol } MnO_2}\right)\left(22.4\text{ L/mol}\right) = 25.8\text{ L } Cl_2$$

3. The most common ore of arsenic is mispickel, FeSAs. Upon heating this ore, free arsenic is obtained. How many grams of FeSAs are required to produce 10.0 g of arsenic according to the following reaction?

$$FeSAs(s) \rightarrow FeS(s) + As(s)$$

$$\left(\frac{10.0\text{ g As}}{74.9216\text{ g/mol}}\right)\left(\frac{1\text{ mol FeSAs}}{1\text{ mol As}}\right)\left(162.8346\text{ g/mol}\right)$$

$$= 21.7\text{ g FeSAs}$$

4. Glucose is used as an energy source by the human body. The overall reaction in the body is:

$$C_6H_{12}O_6(aq) + 6\,O_2(g) \rightarrow 6\,CO_2(g) + 5\,H_2O(l)$$

Calculate the volume of oxygen at STP required to convert 28.0 g of glucose to carbon dioxide and water.

$$\left(\frac{28.0\text{ g } C_6H_{12}O_6}{180.157\,68\text{ g/mol}}\right)\left(\frac{6\text{ mol } O_2}{1\text{ mol } C_6H_{12}O_6}\right)\left(22.4\text{ L/mol}\right)$$

$$= 20.9\text{ L } O_2$$

5. Potassium nitrate is widely used as a fertilizer because it provides two essential elements, potassium and nitrogen. It is made by mixing potassium chloride and nitric acid in the presence of oxygen according to the equation

$$4\,KCl(aq) + 4\,HNO_3(aq) + O_2(g) \rightarrow 4\,KNO_3(aq) + 2\,Cl_2(g) + 2\,H_2O(l)$$

How many kilograms of potassium nitrate will be produced from 50.0 kg of potassium chloride and 50.0 kg of nitric acid with excess oxygen?

$$\left(\frac{50\,000\text{ g KCl}}{74.5513\text{ g/mol}}\right)\left(\frac{4\text{ mol } KNO_3}{4\text{ mol KCl}}\right)\left(101.1032\text{ g/mol}\right) = 67\,800\text{ g}$$

$$\left(\frac{50\,000\text{ g } HNO_3}{63.012\,84\text{ g/mol}}\right)\left(\frac{4\text{ mol } KNO_3}{4\text{ mol } HNO_3}\right)\left(101.1032\text{ g/mol}\right) = 80\,200\text{ g}$$

$\therefore$ 67.8 kg KNO_3 produced

6. Bromine can be prepared by adding chlorine to an aqueous solution of sodium bromide. How many grams of bromine are formed if 25.0 g of chlorine and 25.0 g of sodium bromide are reacted according to the reaction below? Which reactant is in excess and how much remains after the reaction is complete?

$$2\,NaBr(aq) + Cl_2(g) \rightarrow Br_2(l) + 2\,NaCl(aq)$$

$$\left(\frac{25.0\,g\ Cl_2}{70.906\,g/mol}\right)\left(\frac{1\,mol\ Br_2}{1\,mol\ Cl_2}\right)\left(159.808\,g/mol\right) = 56.3\,g\ Br_2$$

$$\left(\frac{25.0\,g\ NaBr}{102.89377\,g/mol}\right)\left(\frac{1\,mol\ Br_2}{2\,mol\ NaBr}\right)\left(159.808\,g/mol\right) = 19.4\,g\ Br_2$$

$\therefore$ 19.4 g Br_2 is produced

Cl_2 is in excess

$$\left(\frac{25.0\,g\ NaBr}{102.89377\,g/mol}\right)\left(\frac{1\,mol\ Cl_2}{2\,mol\ NaBr}\right)\left(70.906\,g/mol\right) = 8.61\,g\ Cl_2 \text{ required}$$

$$25.0\,g - 8.61\,g = 16.4\,g\ Cl_2 \text{ in excess}$$

7. How many millilitres of 2.00 M hydrochloric acid are required to react with 2.55 g of zinc according to the following reaction:

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

$$\left(\frac{2.55\,g\ Zn}{65.38\,g/mol}\right)\left(\frac{2\,mol\ HCl}{1\,mol\ Zn}\right) = 0.0780\,mol\ HCl$$

$$V = \frac{n}{C} = \frac{0.0780\,mol}{2.00\,mol/L} = 0.0390\,L \text{ or } 39.0\,mL$$

8. A 0.473 g sample of phosphorus is reacted with an excess of chlorine. Calculate the mass of phosphorus pentachloride produced. $2P + 5Cl_2 \rightarrow 2PCl_5$

$$\left(\frac{0.473\,g\ P}{30.97376\,g/mol}\right)\left(\frac{2\,mol\ PCl_5}{2\,mol\ P}\right)\left(208.23876\,g/mol\right)$$

$$= 3.18\,g\ PCl_5$$

9. How many grams of oxygen can be prepared by the decomposition of 25.0 g of mercury(II) oxide?

$$\left(\frac{25.0\ g\ HgO}{216.5894\ g/mol}\right)\left(\frac{1\ mol\ O_2}{2\ mol\ HgO}\right)\left(31.9988\ g/mol\right) = \underline{1.84\ g\ O_2}$$

$$2\ HgO \rightarrow 2\ Hg + O_2$$

10. What volume of oxygen gas at STP can be prepared by the decomposition of 25.0 g of potassium chlorate? $2\ KClO_3 \rightarrow 2\ KCl + 3O_2$

$$\left(\frac{25.0\ g\ KClO_3}{122.5495\ g/mol}\right)\left(\frac{3\ mol\ O_2}{2\ mol\ KClO_3}\right)\left(22.4\ L/mol\right)$$

$$= \underline{6.85\ L\ O_2}$$

11. How many grams of zinc are required for the replacement of 0.100 g of hydrogen from sulfuric acid? $Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$

$$\left(\frac{0.100\ g\ H_2}{2.01528\ g/mol}\right)\left(\frac{1\ mol\ Zn}{1\ mol\ H_2}\right)\left(65.38\ g/mol\right)$$

$$= \underline{3.24\ g\ Zn}$$

12. What mass of magnesium chloride is required to react with 10.0 g of silver nitrate?

$$MgCl_2 + 2\ AgNO_3 \rightarrow Mg(NO_3)_2 + 2\ AgCl$$

$$\left(\frac{10.0\ g\ AgNO_3}{169.8731\ g/mol}\right)\left(\frac{1\ mol\ MgCl_2}{2\ mol\ AgNO_3}\right)\left(95.211\ g/mol\right)$$

$$= \underline{2.80\ g\ MgCl_2}$$

13. **Determine the volume of hydrogen gas at STP that can be produced by the reaction of 130.0 g of zinc with 100.0 g of hydrochloric acid. Which reactant is in excess, and how much remains unreacted?** $Zn + 2HCl \rightarrow ZnCl_2 + H_2$

$$\left(\frac{130.0\ g\ Zn}{65.38\ g/mol}\right)\left(\frac{1\ mol\ H_2}{1\ mol\ Zn}\right)\left(22.4\ L/mol\right) = 44.5\ L\ H_2$$

$$\left(\frac{100.0\ g\ HCl}{36.46094\ g/mol}\right)\left(\frac{1\ mol\ H_2}{2\ mol\ HCl}\right)\left(22.4\ L/mol\right) = 30.7\ L\ H_2$$

$\therefore$ 30.7 L H_2 is produced

Zn is in excess

$$\left(\frac{100.0\ g\ HCl}{36.46094\ g/mol}\right)\left(\frac{1\ mol\ Zn}{2\ mol\ HCl}\right)\left(65.38\ g/mol\right) = 89.7\ g\ Zn\ \text{needed}$$

$130.0\ g - 89.7\ g = 40.3\ g$ Zn in excess

14. **29.6 mL of 0.350 M sodium hydroxide are required to titrate 20.0 mL of phosphoric acid. Calculate the molarity of the phosphoric acid.** $3NaOH + H_3PO_4 \rightarrow Na_3PO_4 + 3H_2O$ (B) (A)

$C_a = ?$
$V_a = 20.0\ mL$
$R_a = 1$
$C_b = 0.350\ M$
$V_b = 29.6\ mL$
$R_b = 3$

$$C_a = \frac{C_b V_b R_a}{V_a R_b} = \frac{(0.350\ M)(0.0296\ L)(1)}{(0.0200\ L)(3)}$$

$$= 0.173\ mol/L\ H_3PO_4$$

15. **What mass of copper(II) hydroxide is precipitated by the reaction of 2.67 g of potassium hydroxide with copper(II) nitrate?** $2KOH + Cu(NO_3)_2 \rightarrow Cu(OH)_2 + 2KNO_3$

$$\left(\frac{2.67\ g\ KOH}{56.10564\ g/mol}\right)\left(\frac{1\ mol\ Cu(OH)_2}{2\ mol\ KOH}\right)\left(97.56068\ g/mol\right)$$

$$= 2.32\ g\ Cu(OH)_2$$

16. Ammonium sulfate fertilizer is manufactured by having sulfuric acid react with ammonia. In a laboratory study of this process, 50.0 mL of sulfuric acid reacts with 24.4 mL of a 2.20 mol/L ammonium hydroxide solution. From this evidence, calculate the concentration of the sulfuric acid at this stage in the process.

$$\underset{(A)}{H_2SO_4} + \underset{(B)}{2\,NH_4OH} \rightarrow (NH_4)_2SO_4 + 2\,H_2O$$

$$C_a = \frac{C_b V_b R_a}{V_a R_b} = \frac{(2.20\ \text{mol/L})(0.0244\ \text{L})(1)}{(0.0500\ \text{L})(2)}$$

$$= \underline{0.537\ \text{mol/L}}$$

17. Slaked lime can be added to an aluminum sulfate solution in a water treatment plant to clarify the water. Fine particles in the water stick to the precipitate produced. Calculate the volume of 0.0250 mol/L calcium hydroxide solution required to react completely with 25.0 mL of 0.125 mol/L aluminum sulfate solution.

$$\underset{(A)}{3\,Ca(OH)_2} + \underset{(B)}{Al_2(SO_4)_3} \rightarrow 2\,Al(OH)_3 + 3\,CaSO_4$$

$$V_a = \frac{C_b V_b R_a}{C_a R_b} = \frac{(0.125\ \text{mol/L})(0.0250\ \text{L})(3)}{(0.0250\ \text{mol/L})(1)}$$

$$= \underline{0.375\ \text{L or } 375\ \text{mL}}$$

18. Some antacid products contain aluminum hydroxide to neutralize excess stomach acid. Determine the volume of 0.100 mol/L stomach acid (assumed to be HCl) that can be neutralized by 912 mg of aluminum hydroxide in an antacid tablet.

$$3\ HCl + Al(OH)_3 \rightarrow AlCl_3 + 3\,H_2O$$

$$\left(\frac{0.912\ \text{g}\ Al(OH)_3}{78.00356\ \text{g/mol}}\right)\left(\frac{3\ \text{mol HCl}}{1\ \text{mol}\ Al(OH)_3}\right) = 0.0351\ \text{mol HCl}$$

$$C = \frac{n}{V} \qquad V = \frac{n}{C} = \frac{0.0351\ \text{mol}}{0.100\ \text{mol/L}} = 0.351\ \text{L}$$

$$\underline{\text{or } 351\ \text{mL HCl}}$$

19. Iron(II) sulfide reacts with oxygen gas to produce iron(III) oxide and sulfur dioxide. What mass of iron(III) oxide is produced from the reaction of 20.0 g of iron(II) sulfide and 14.1 g of oxygen? Which reactant is in excess, and how much remains unreacted?

$$4\,FeS + 7\,O_2 \rightarrow 2\,Fe_2O_3 + 4\,SO_2$$

$$\left(\frac{20.0\text{ g FeS}}{87.913\text{ g/mol}}\right)\left(\frac{2\text{ mol }Fe_2O_3}{4\text{ mol FeS}}\right)\left(159.6922\text{ g/mol}\right) = 18.2\text{ g}$$

$$\left(\frac{14.1\text{ g }O_2}{31.9988\text{ g/mol}}\right)\left(\frac{2\text{ mol }Fe_2O_3}{7\text{ mol }O_2}\right)\left(159.6922\text{ g/mol}\right) = 20.1\text{ g}$$

$\therefore$ 18.2 g Fe_2O_3 is produced

FeS is limiting, O_2 is in excess

$$\left(\frac{20.0\text{ g FeS}}{87.913\text{ g/mol}}\right)\left(\frac{7\text{ mol }O_2}{4\text{ mol FeS}}\right)\left(31.9988\text{ g/mol}\right) = 12.7\text{ g }O_2\text{ needed}$$

$$\underset{\text{available}}{14.1\text{ g}} - \underset{\text{needed}}{12.7\text{ g}} = \underset{\text{in excess}}{1.4\text{ g }O_2}$$

20. The chemical equation below describes what happens when a match is struck against a rough surface to produce light and heat.

$$P_4S_3(s) + O_2(g) \rightarrow P_4O_{10}(g) + SO_2(g)$$

a) Balance this chemical equation

$$P_4S_3(s) + 8O_2(g) \rightarrow P_4O_{10}(g) + 3SO_2(g)$$

b) If 5.3 L of oxygen gas at STP were consumed, what volume of sulfur dioxide at STP would be produced?

$$\left(\frac{5.3\ L\ O_2}{22.4\ L/mol}\right)\left(\frac{3\ mol\ SO_2}{8\ mol\ O_2}\right)\left(22.4\ \frac{L}{mol}\right) = 1.9875$$

$$= 2.0\ L\ SO_2$$

c) What mass of P_4S_3 would be consumed in the same reaction described in (b)?

$$\left(\frac{5.3\ L\ O_2}{22.4\ L/mol}\right)\left(\frac{1\ mol\ P_4S_3}{8\ mol\ O_2}\right)\left(220.09304\ \frac{g}{mol}\right) = 6.5094$$

$$= 6.5\ g\ P_4S_3$$

21. Titanium(IV) chloride reacts violently with water vapour to produce titanium(IV) oxide and hydrogen chloride gas. Titanium(IV) oxide, when finely powdered, is extensively used in paint as a white pigment.

$$TiCl_4(s) + H_2O(l) \rightarrow TiO_2(s) + 4HCl(g)$$

The reaction has been used to create smoke screens. In moist air, the titanium(IV) chloride reacts to produce a thick smoke of suspended titanium(IV) oxide particles. What mass of titanium(IV) oxide can be expected when 85.6 g of titanium(IV) chloride is reacted with excess water vapour?

$$\left(\frac{85.6\ g\ TiCl_4}{189.692\ g/mol}\right)\left(\frac{1\ mol\ TiO_2}{1\ mol\ TiCl_4}\right)\left(79.8788\ \frac{g}{mol}\right)$$

$$= 36.0459$$

$$= 33.0\ g\ TiO_2$$

22. 1.56 g of As_2S_3, 0.140 g of H_2O, 1.23 g of HNO_3, and 3.50 g of $NaNO_3$ are reacted according to the equation below:

$$3As_2S_3(s) + 4H_2O(l) + 10HNO_3(aq) + 18NaNO_3(aq) \rightarrow 9Na_2SO_4(aq) + 6H_3AsO_4(aq) + 28NO(g)$$

a) What mass of H_3AsO_4 is produced?

$$\left(\frac{1.56\ g\ As_2S_3}{246.0412\ g/mol}\right)\left(\frac{6\ mol\ H_3AsO_4}{3\ mol\ As_2S_3}\right)\left(141.94302\ \frac{g}{mol}\right) = 1.80\ g$$

$$\left(\frac{0.140\ g\ H_2O}{18.01528\ g/mol}\right)\left(\frac{6\ mol\ H_3AsO_4}{4\ mol\ H_2O}\right)\left(141.94302\ \frac{g}{mol}\right) = 1.65\ g$$

$$\left(\frac{1.23\ g\ HNO_3}{63.01284\ g/mol}\right)\left(\frac{6\ mol\ H_3AsO_4}{10\ mol\ HNO_3}\right)\left(141.94302\ \frac{g}{mol}\right) = 1.66\ g$$

$$\left(\frac{3.50\ g\ NaNO_3}{84.99467\ g/mol}\right)\left(\frac{6\ mol\ H_3AsO_4}{18\ mol\ NaNO_3}\right)\left(141.94302\ \frac{g}{mol}\right) = 1.95\ g$$

∴ H_2O is the limiting reactant and 1.65 g H_3AsO_4 is produced

b) What volume (at STP) of NO is produced?

$$\left(\frac{0.140\ g\ H_2O}{18.01528\ g/mol}\right)\left(\frac{28\ mol\ NO}{4\ mol\ H_2O}\right)\left(22.4\ L/mol\right) = 1.22\ L\ of\ NO$$