Stoichiometry - Limiting Reactants

1. Hydrogen gas can be produced in the laboratory by the reaction of magnesium metal with hydrochloric acid.
   a) How many grams of hydrogen can be produced when 4.00 g of hydrochloric acid are added to 3.00 g of magnesium?

$$\left(\frac{4.00\text{ g HCl}}{36.461\text{ g/mol}}\right)\left(\frac{1\text{ mol }H_2}{2\text{ mol HCl}}\right)\left(2.01588\,\frac{\text{g}}{\text{mol}}\right) = 0.111\text{ g }H_2$$

$$\left(\frac{3.00\text{ g Mg}}{24.305\text{ g/mol}}\right)\left(\frac{1\text{ mol }H_2}{1\text{ mol Mg}}\right)\left(2.01588\,\frac{\text{g}}{\text{mol}}\right) = 0.249\text{ g }H_2$$

$\therefore$ **0.111g H_2 produced**

   b) What is the volume of this hydrogen at standard conditions?

$$\left(\frac{0.111\text{ g }H_2}{2.01588\text{ g/mol}}\right)\left(22.4\,\frac{\text{L}}{\text{mol}}\right) = 1.23\text{ L }H_2$$

2. 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:

$$4KCl + 4HNO_3 + O_2 \rightarrow 4KNO_3 + 2Cl_2 + 2H_2O$$

How many kilograms of potassium nitrate will be produced from 50.0 kg of potassium chloride and 50.0 kg of nitric acid? An important by-product is chlorine. How many kilograms of chlorine will be produced?

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

$$\left(\frac{50\,000\text{ g }HNO_3}{63.013\text{ g/mol}}\right)\left(\frac{4\text{ mol }KNO_3}{4\text{ mol }HNO_3}\right)\left(101.1032\,\frac{\text{g}}{\text{mol}}\right) = 80\,200\text{ g}$$

KCl is the limiting reactant

$\therefore$ **67.8 kg KNO_3 produced**

$$\left(\frac{50\,000\text{ g KCl}}{74.5513\text{ g/mol}}\right)\left(\frac{2\text{ mol }Cl_2}{4\text{ mol KCl}}\right)\left(70.906\,\frac{\text{g}}{\text{mol}}\right) = 23\,800\text{ g}$$

$\therefore$ **23.8 kg Cl_2 produced**

3. Phosphorus forms a compound similar to ammonia. The compound has the formula PH_3 and is called phosphine. It can be prepared by the reaction:

$$P_4 + 3NaOH + 3H_2O \rightarrow PH_3 + 3NaH_2PO_2$$

If 20.0 g of phosphorus and 50.0 g of sodium hydroxide are reacted with excess water, how many grams of phosphine will be obtained?

$$\left(\frac{20.0\text{ g }P_4}{123.895\text{ g/mol}}\right)\left(\frac{1\text{ mol }PH_3}{1\text{ mol }P_4}\right)\left(33.9976\,\frac{\text{g}}{\text{mol}}\right) = 5.49\text{ g}$$

$$\left(\frac{50.0\text{ g NaOH}}{39.99711\text{ g/mol}}\right)\left(\frac{1\text{ mol }PH_3}{3\text{ mol NaOH}}\right)\left(33.9976\,\frac{\text{g}}{\text{mol}}\right) = 14.2\text{ g}$$

$\therefore$ **5.49 g PH_3 produced**

4. 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 sodium bromide and 25.0 g of chlorine are reacted?

$$Cl_2 + 2NaBr \rightarrow Br_2 + 2NaCl$$

$$\left(\frac{25.0\,g\ NaBr}{102.89\,g/mol}\right)\left(\frac{1\ mol\ Br_2}{2\ mol\ NaBr}\right)\left(159.808\,\frac{g}{mol}\right) = 19.4\,g\ Br_2$$

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

∴ 19.4 g Br_2 produced.

5. Silver tarnishes in the presence of hydrogen sulfide, a gas that originate from the decay of food, because of the reaction:

$$4Ag + 2H_2S + O_2 \rightarrow 2Ag_2S + 2H_2O$$

The black product, silver sulfide, is the "tarnish". If 25.00 g of silver, 5.00 g of hydrogen sulfide, and 4.00 g of oxygen are present in a reaction mixture, which one is the limiting reactant, and what mass of silver sulfide is produced?

$$\left(\frac{25.00\,g\ Ag}{107.8682\,g/mol}\right)\left(\frac{2\ mol\ Ag_2S}{4\ mol\ Ag}\right)\left(247.80\,\frac{g}{mol}\right) = 28.72\,g\ Ag_2S$$

$$\left(\frac{5.00\,g\ H_2S}{34.082\,g/mol}\right)\left(\frac{2\ mol\ Ag_2S}{2\ mol\ H_2S}\right)\left(247.80\,\frac{g}{mol}\right) = 36.4\,g\ Ag_2S$$

$$\left(\frac{4.00\,g\ O_2}{31.9988\,g/mol}\right)\left(\frac{2\ mol\ Ag_2S}{2\ mol\ H_2S}\right)\left(247.80\,\frac{g}{mol}\right) = 62.0\,g\ Ag_2S$$

∴ Ag is the limiting reactant and 28.72 g Ag_2S produced

6. Sulfur dioxide can be produced from the reaction of hydrogen sulfide and oxygen as shown by the following reaction: $2H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O$

   a) How many grams of sulfur dioxide can be produced from 70.0 g of hydrogen sulfide and 125 g of oxygen.

$$\left(\frac{70.0\,g\ H_2S}{34.082\,g/mol}\right)\left(\frac{2\ mol\ SO_2}{2\ mol\ H_2S}\right)\left(64.065\,\frac{g}{mol}\right) = 132\,g\ SO_2$$

$$\left(\frac{125\,g\ O_2}{31.9988\,g/mol}\right)\left(\frac{2\ mol\ SO_2}{3\ mol\ O_2}\right)\left(64.065\,g/mol\right) = 167\,g\ SO_2$$

∴ 132 g SO_2 produced

   b) How many grams of excess reactant are left over after the reaction is complete?

$$\left(\frac{70.0\,g\ H_2S}{34.082\,g/mol}\right)\left(\frac{3\ mol\ O_2}{2\ mol\ H_2S}\right)\left(31.9988\,\frac{g}{mol}\right) = 98.6\,g\ O_2 \text{ needed}$$

$$125\,g - 98.6\,g = 26\,g\ O_2 \text{ left over}$$

7. What mass of carbon disulfide is produced when 17.5 g of carbon are reacted with 39.5 g of sulfur dioxide according to the equation:

$$5C(s) + 2SO_2(g) \rightarrow CS_2(s) + 4CO(g)$$

$$\left(\frac{17.5\text{ g C}}{12.011\text{ g/mol}}\right)\left(\frac{1\text{ mol } CS_2}{5\text{ mol C}}\right)\left(76.143\ \frac{\text{g}}{\text{mol}}\right) = 22.2\text{ g } CS_2$$

$$\left(\frac{39.5\text{ g } SO_2}{64.0648\text{ g/mol}}\right)\left(\frac{1\text{ mol } CS_2}{2\text{ mol } SO_2}\right)\left(76.143\ \frac{\text{g}}{\text{mol}}\right) = 23.5\text{ g } CS_2$$

$\therefore$ 22.2 g CS_2 produced

8. What mass of P_4 is produced when 41.5 g of $Ca_3(PO_4)_2$, 26.5 g of SiO_2 and 7.80 g of C are reacted according to the equation:

$$2Ca_3(PO_4)_2 + 6SiO_2 + 10C \rightarrow P_4 + 6CaSiO_3 + 10CO$$

$$\left(\frac{41.5\text{ g } Ca_3(PO_4)_2}{310.17672\text{ g/mol}}\right)\left(\frac{1\text{ mol } P_4}{2\text{ mol } Ca_3(PO_4)_2}\right)\left(123.89504\ \frac{\text{g}}{\text{mol}}\right) = 8.29\text{ g } P_4$$

$$\left(\frac{26.5\text{ g } SiO_2}{60.0843\text{ g/mol}}\right)\left(\frac{1\text{ mol } P_4}{6\text{ mol } SiO_2}\right)\left(123.89504\ \frac{\text{g}}{\text{mol}}\right) = 9.11\text{ g } P_4$$

$$\left(\frac{7.80\text{ g C}}{12.011\text{ g/mol}}\right)\left(\frac{1\text{ mol } P_4}{10\text{ mol C}}\right)\left(123.89504\ \frac{\text{g}}{\text{mol}}\right) = 8.05\text{ g } P_4$$

$\therefore$ 8.05 g P_4 produced

9. What volume of carbon dioxide, measured at STP, can be produced when 15.65 g of pentane is reacted with 40.0 L of oxygen, measured at STP, according to the equation:

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

$$\left(\frac{15.65\text{ g } C_5H_{12}}{72.15028\text{ g/mol}}\right)\left(\frac{5\text{ mol } CO_2}{1\text{ mol } C_5H_{12}}\right)\left(22.4\ \frac{\text{L}}{\text{mol}}\right) = 24.3\text{ L } CO_2$$

$$\left(\frac{40.0\text{ L } O_2}{22.4\text{ L/mol}}\right)\left(\frac{5\text{ mol } CO_2}{8\text{ mol } O_2}\right)\left(22.4\text{ L/mol}\right) = 25.0\text{ L } CO_2$$

$\therefore$ 24.3 L CO_2 produced

10. What mass of hydrogen chloride gas is produced when 4.50 g of hydrogen and 140.0 g of chlorine are reacted. Which reactant is in excess and how much remains unreacted?

$$H_2 + Cl_2 \rightarrow 2\,HCl$$

$$\left(\frac{4.50\text{ g } H_2}{2.01588\text{ g/mol}}\right)\left(\frac{2\text{ mol } HCl}{1\text{ mol } H_2}\right)\left(36.46094\ \frac{\text{g}}{\text{mol}}\right) = 163\text{ g } HCl$$

$$\left(\frac{140.0\text{ g } Cl_2}{70.906\text{ g/mol}}\right)\left(\frac{2\text{ mol } HCl}{1\text{ mol } Cl_2}\right)\left(36.46094\text{ g/mol}\right) = 144.0\text{ g } HCl$$

∴ 144.0 g HCl produced, H_2 is in excess

$$\left(\frac{140.0\text{ g } Cl_2}{70.906\text{ g/mol}}\right)\left(\frac{1\text{ mol } H_2}{1\text{ mol } Cl_2}\right)\left(2.01588\ \frac{\text{g}}{\text{mol}}\right) = 3.980\text{ g } H_2 \text{ needed}$$

$\underset{\text{available}}{4.50\text{ g}} - \underset{\text{needed}}{3.980\text{ g}} =$ 0.52 g H_2 remains unreacted

11. The roasting of siderite ore, $FeCO_3$, produces ferric oxide:

$$4FeCO_3(s) + O_2(g) \rightarrow 2Fe_2O_3(s) + 4CO_2(g)$$

What mass of ferric oxide is produced when 55.0 g of siderite is reacted with 40.0 L of oxygen gas? Which reactant is in excess and how much remains unreacted?

$$\left(\frac{55.0\text{ g } FeCO_3}{115.8562\text{ g/mol}}\right)\left(\frac{2\text{ mol } Fe_2O_3}{4\text{ mol } FeCO_3}\right)\left(159.6922\ \frac{\text{g}}{\text{mol}}\right) = 37.9\text{ g } Fe_2O_3$$

$$\left(\frac{40.0\text{ L } O_2}{22.4\text{ L/mol}}\right)\left(\frac{2\text{ mol } Fe_2O_3}{1\text{ mol } O_2}\right)\left(159.6922\ \frac{\text{g}}{\text{mol}}\right) = 570.\text{ g } Fe_2O_3$$

∴ 37.9 g Fe_2O_3 produced, O_2 is in excess

$$\left(\frac{55.0\text{ g } FeCO_3}{115.8562\text{ g/mol}}\right)\left(\frac{1\text{ mol } O_2}{4\text{ mol } FeCO_3}\right)\left(22.4\ \frac{\text{L}}{\text{mol}}\right) = 2.66\text{ L } O_2 \text{ needed}$$

$\underset{\text{available}}{40.0\text{ L}} - \underset{\text{needed}}{2.66\text{ L}} =$ 37.3 L O_2 remains unreacted

12. A manufacturer of bicycles has 5050 wheels, 3013 frames, and 2455 handlebars.

a) How many bicycles can be manufactured using these parts?

2 wheels + 1 frame + 1 handlebar ⇒ 1 bike

$$5050 \text{ wheels} \left(\frac{1 \text{ bike}}{2 \text{ wheels}}\right) = 2525 \text{ bikes}$$

$$3013 \text{ frames} \left(\frac{1 \text{ bike}}{1 \text{ frame}}\right) = 3013$$

$$2455 \text{ handlebars} \left(\frac{1 \text{ bike}}{1 \text{ handlebar}}\right) = 2455 \text{ bikes}$$

∴ 2455 bikes can be manufactured

b) How many parts of each kind are left over?

$$2455 \text{ bikes} \left(\frac{2 \text{ wheels}}{1 \text{ bike}}\right) = 4910 \text{ wheels needed}$$

5050 − 4910 = 140 wheels left over

$$2455 \text{ bikes} \left(\frac{1 \text{ frame}}{1 \text{ bike}}\right) = 2455 \text{ frames needed}$$

3013 − 2455 = 558 frames left over

0 handlebars left over

c) Which part is like a limiting reactant in that it limits the production of bicycles?

The handlebars ran out first, they are the limiting reactant.

13. The fizz produced when an Alka-Seltzer tablet is dissolved in water is due to the reaction between sodium bicarbonate and citric acid:

$$3NaHCO_3(aq) + H_3C_6H_5O_7(aq) \rightarrow 3CO_2(g) + 3H_2O(l) + Na_3C_6H_5O_7(aq)$$

In a certain experiment 1.00 g of sodium bicarbonate and 1.00 g of citric acid are allowed to react.

a) What volume of carbon dioxide is formed?

$$\left(\frac{1.00\text{ g } NaHCO_3}{84.00691\text{ g/mol}}\right)\left(\frac{3\text{ mol } CO_2}{3\text{ mol } NaHCO_3}\right)\left(\frac{22.4\text{ L}}{\text{mol}}\right) = 0.267\text{ L } CO_2$$

$$\left(\frac{1.00\text{ g } H_3C_6H_5O_7}{192.12532\text{ g/mol}}\right)\left(\frac{3\text{ mol } CO_2}{1\text{ mol } H_3C_6H_5O_7}\right)\left(\frac{22.4\text{ L}}{\text{mol}}\right) = 0.350\text{ L } CO_2$$

∴ 0.267 L CO_2 is formed

b) Which reactant is the limiting reactant?

$NaHCO_3$ is the limiting reactant

c) How much of the excess reactant remains after the limiting reactant is completely consumed?

$$\left(\frac{1.00\text{ g } NaHCO_3}{84.00691\text{ g/mol}}\right)\left(\frac{1\text{ mol } H_3C_6H_5O_7}{3\text{ mol } NaHCO_3}\right)\left(\frac{192.12532\text{ g}}{\text{mol}}\right) = 0.762\text{ g needed}$$

1.00 g available − 0.762 g needed = 0.24 g $H_3C_6H_6O_7$ remains

14. One of the steps in the commercial process for converting ammonia to nitric acid involves the conversion of ammonia to nitrogen monoxide:

$$2NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$$

In a certain experiment 2.50 g of ammonia reacts with 2.85 g of oxygen.

a) What mass of nitrogen monoxide is formed?

$$\left(\frac{2.50\text{ g } NH_3}{17.03052\text{ g/mol}}\right)\left(\frac{4\text{ mol } NO}{2\text{ mol } NH_3}\right)\left(\frac{30.0061\text{ g}}{\text{mol}}\right) = 8.81\text{ g } NO$$

$$\left(\frac{2.85\text{ g } O_2}{31.9988\text{ g/mol}}\right)\left(\frac{4\text{ mol } NO}{5\text{ mol } O_2}\right)\left(\frac{30.0061\text{ g}}{\text{mol}}\right) = 2.14\text{ g } NO$$

∴ 2.14 g NO is formed

b) Which reactant is the limiting reactant?

O_2 is the limiting reactant

c) How much of the excess reactant remains after the limiting reactant is completely consumed?

$$\left(\frac{2.85\text{ g } O_2}{31.9988\text{ g/mol}}\right)\left(\frac{2\text{ mol } NH_3}{5\text{ mol } O_2}\right)\left(\frac{17.03052\text{ g}}{\text{mol}}\right) = 0.607\text{ g needed}$$

2.50 g available − 0.607 g needed = 1.89 g NH_3 remains