

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?

$$\left(\frac{4.00 \text{ g HCl}}{36.461 \text{ g/mol}} \right) \left(\frac{1 \text{ mol H}_2}{2 \text{ mol HCl}} \right) \left(2.01588 \frac{\text{g}}{\text{mol}} \right) = 0.111 \text{ g H}_2$$

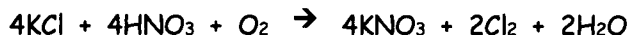
$$\left(\frac{3.00 \text{ g Mg}}{24.305 \text{ g/mol}} \right) \left(\frac{1 \text{ mol H}_2}{1 \text{ mol Mg}} \right) \left(2.01588 \frac{\text{g}}{\text{mol}} \right) = 0.249 \text{ g H}_2$$

∴ **0.111 g H₂ produced**

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

$$\left(\frac{0.111 \text{ g H}_2}{2.01588 \text{ g/mol}} \right) \left(22.4 \frac{\text{L}}{\text{mol}} \right) = \boxed{1.23 \text{ L H}_2}$$

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:



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?

KCl is the limiting reactant

$$\left(\frac{50\,000 \text{ g KCl}}{74.5513 \text{ g/mol}} \right) \left(\frac{4 \text{ mol KNO}_3}{4 \text{ mol KCl}} \right) \left(101.1032 \frac{\text{g}}{\text{mol}} \right) = 67\,800 \text{ g}$$

$$\left(\frac{50\,000 \text{ g HNO}_3}{63.013 \text{ g/mol}} \right) \left(\frac{4 \text{ mol KNO}_3}{4 \text{ mol HNO}_3} \right) \left(101.1032 \frac{\text{g}}{\text{mol}} \right) = 80\,200 \text{ g}$$

∴ **67.8 kg KNO₃ produced**

$$\left(\frac{50\,000 \text{ g KCl}}{74.5513 \text{ g/mol}} \right) \left(\frac{2 \text{ mol Cl}_2}{4 \text{ mol KCl}} \right) \left(70.906 \frac{\text{g}}{\text{mol}} \right) = 23\,800 \text{ g} \therefore \boxed{23.8 \text{ kg Cl}_2 \text{ produced}}$$

3. Phosphorus forms a compound similar to ammonia. The compound has the formula PH₃ and is called phosphine. It can be prepared by the reaction:



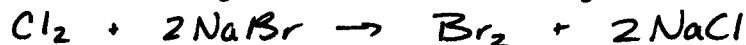
If 20.0 g of phosphorus and 50.0 g of sodium hydroxide are reacted with excess water, how many grams of phosphine will be obtained?

$$\left(\frac{20.0 \text{ g P}_4}{123.895 \text{ g/mol}} \right) \left(\frac{1 \text{ mol PH}_3}{1 \text{ mol P}_4} \right) \left(33.9976 \frac{\text{g}}{\text{mol}} \right) = 5.49 \text{ g}$$

$$\left(\frac{50.0 \text{ g NaOH}}{39.99711 \text{ g/mol}} \right) \left(\frac{1 \text{ mol PH}_3}{3 \text{ mol NaOH}} \right) \left(33.9976 \frac{\text{g}}{\text{mol}} \right) = 14.2 \text{ g}$$

∴ **5.49 g PH₃ 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?

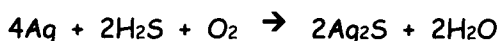


$$\left(\frac{25.0 \text{ g NaBr}}{102.89 \text{ g/mol}} \right) \left(\frac{1 \text{ mol Br}_2}{2 \text{ mol NaBr}} \right) \left(159.808 \frac{\text{g}}{\text{mol}} \right) = 19.4 \text{ g Br}_2$$

$$\left(\frac{25.0 \text{ g Cl}_2}{70.906 \text{ g/mol}} \right) \left(\frac{1 \text{ mol Br}_2}{1 \text{ mol Cl}_2} \right) \left(159.808 \frac{\text{g}}{\text{mol}} \right) = 56.3 \text{ g Br}_2$$

$$\therefore \boxed{19.4 \text{ g Br}_2 \text{ produced.}}$$

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



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?

$$\left(\frac{25.00 \text{ g Ag}}{107.8682 \text{ g/mol}} \right) \left(\frac{2 \text{ mol Ag}_2\text{S}}{4 \text{ mol Ag}} \right) \left(247.80 \frac{\text{g}}{\text{mol}} \right) = 28.72 \text{ g Ag}_2\text{S}$$

$$\left(\frac{5.00 \text{ g H}_2\text{S}}{34.082 \text{ g/mol}} \right) \left(\frac{2 \text{ mol Ag}_2\text{S}}{2 \text{ mol H}_2\text{S}} \right) \left(247.80 \frac{\text{g}}{\text{mol}} \right) = 36.4 \text{ g Ag}_2\text{S}$$

$$\left(\frac{4.00 \text{ g O}_2}{31.9988 \text{ g/mol}} \right) \left(\frac{2 \text{ mol Ag}_2\text{S}}{2 \text{ mol H}_2\text{S}} \right) \left(247.80 \frac{\text{g}}{\text{mol}} \right) = 62.0 \text{ g Ag}_2\text{S}$$

$$\therefore \boxed{\text{Ag is the limiting reactant and } 28.72 \text{ g Ag}_2\text{S produced}}$$

6. Sulfur dioxide can be produced from the reaction of hydrogen sulfide and oxygen as shown by the following reaction: $2\text{H}_2\text{S} + 3\text{O}_2 \rightarrow 2\text{SO}_2 + 2\text{H}_2\text{O}$

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

$$\left(\frac{70.0 \text{ g H}_2\text{S}}{34.082 \text{ g/mol}} \right) \left(\frac{2 \text{ mol SO}_2}{2 \text{ mol H}_2\text{S}} \right) \left(64.065 \frac{\text{g}}{\text{mol}} \right) = 132 \text{ g SO}_2$$

$$\left(\frac{125 \text{ g O}_2}{31.9988 \text{ g/mol}} \right) \left(\frac{2 \text{ mol SO}_2}{3 \text{ mol O}_2} \right) \left(64.065 \frac{\text{g}}{\text{mol}} \right) = 167 \text{ g SO}_2$$

$$\therefore \boxed{132 \text{ g SO}_2 \text{ produced}}$$

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

$$\left(\frac{70.0 \text{ g H}_2\text{S}}{34.082 \text{ g/mol}} \right) \left(\frac{3 \text{ mol O}_2}{2 \text{ mol H}_2\text{S}} \right) \left(31.9988 \frac{\text{g}}{\text{mol}} \right) = 98.6 \text{ g O}_2 \text{ needed}$$

$$125 \text{ g} - 98.6 \text{ g} = \boxed{26 \text{ g O}_2 \text{ left over}}$$

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:

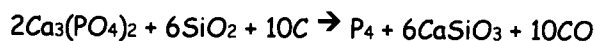


$$\left(\frac{17.5 \text{ g C}}{12.011 \text{ g/mol}} \right) \left(\frac{1 \text{ mol CS}_2}{5 \text{ mol C}} \right) \left(\frac{76.143 \text{ g}}{\text{mol}} \right) = 22.2 \text{ g CS}_2$$

$$\left(\frac{39.5 \text{ g SO}_2}{64.0648 \text{ g/mol}} \right) \left(\frac{1 \text{ mol CS}_2}{2 \text{ mol SO}_2} \right) \left(\frac{76.143 \text{ g}}{\text{mol}} \right) = 23.5 \text{ g CS}_2$$

$$\therefore 22.2 \text{ g CS}_2 \text{ produced}$$

8. What mass of P₄ is produced when 41.5 g of Ca₃(PO₄)₂, 26.5 g of SiO₂ and 7.80 g of C are reacted according to the equation:



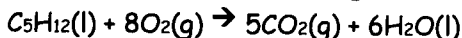
$$\left(\frac{41.5 \text{ g Ca}_3(\text{PO}_4)_2}{310.17672 \text{ g/mol}} \right) \left(\frac{1 \text{ mol P}_4}{2 \text{ mol Ca}_3(\text{PO}_4)_2} \right) \left(\frac{123.89504 \text{ g}}{\text{mol}} \right) = 8.29 \text{ g P}_4$$

$$\left(\frac{26.5 \text{ g SiO}_2}{60.0843 \text{ g/mol}} \right) \left(\frac{1 \text{ mol P}_4}{6 \text{ mol SiO}_2} \right) \left(\frac{123.89504 \text{ g}}{\text{mol}} \right) = 9.11 \text{ g P}_4$$

$$\left(\frac{7.80 \text{ g C}}{12.011 \text{ g/mol}} \right) \left(\frac{1 \text{ mol P}_4}{10 \text{ mol C}} \right) \left(\frac{123.89504 \text{ g}}{\text{mol}} \right) = 8.05 \text{ g P}_4$$

$$\therefore 8.05 \text{ g P}_4 \text{ produced}$$

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:



$$\left(\frac{15.65 \text{ g C}_5\text{H}_{12}}{72.15028 \text{ g/mol}} \right) \left(\frac{5 \text{ mol CO}_2}{1 \text{ mol C}_5\text{H}_{12}} \right) \left(\frac{22.4 \text{ L}}{\text{mol}} \right) = 24.3 \text{ L CO}_2$$

$$\left(\frac{40.0 \text{ L O}_2}{22.4 \text{ L/mol}} \right) \left(\frac{5 \text{ mol CO}_2}{8 \text{ mol O}_2} \right) \left(\frac{22.4 \text{ L}}{\text{mol}} \right) = 25.0 \text{ L CO}_2$$

$$\therefore 24.3 \text{ L CO}_2 \text{ produced}$$

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?



$$\left(\frac{4.50 \text{ g H}_2}{2.01588 \text{ g/mol}} \right) \left(\frac{2 \text{ mol HCl}}{1 \text{ mol H}_2} \right) \left(36.46094 \frac{\text{g}}{\text{mol}} \right) = 163 \text{ g HCl}$$

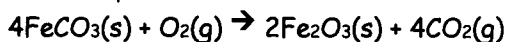
$$\left(\frac{140.0 \text{ g Cl}_2}{70.906 \text{ g/mol}} \right) \left(\frac{2 \text{ mol HCl}}{1 \text{ mol Cl}_2} \right) \left(36.46094 \frac{\text{g}}{\text{mol}} \right) = 144.0 \text{ g HCl}$$

∴ 144.0 g HCl produced, H₂ is in excess

$$\left(\frac{140.0 \text{ g Cl}_2}{70.906 \text{ g/mol}} \right) \left(\frac{1 \text{ mol H}_2}{1 \text{ mol Cl}_2} \right) \left(2.01588 \frac{\text{g}}{\text{mol}} \right) = 3.980 \text{ g H}_2 \text{ needed}$$

$$4.50 \text{ g available} - 3.980 \text{ g needed} = 0.52 \text{ g H}_2 \text{ remains unreacted}$$

11. The roasting of siderite ore, FeCO₃, produces ferric oxide:



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?

$$\left(\frac{55.0 \text{ g FeCO}_3}{115.8562 \text{ g/mol}} \right) \left(\frac{2 \text{ mol Fe}_2\text{O}_3}{4 \text{ mol FeCO}_3} \right) \left(159.6922 \frac{\text{g}}{\text{mol}} \right) = 37.9 \text{ g Fe}_2\text{O}_3$$

$$\left(\frac{40.0 \text{ L O}_2}{22.4 \text{ L/mol}} \right) \left(\frac{2 \text{ mol Fe}_2\text{O}_3}{1 \text{ mol O}_2} \right) \left(159.6922 \frac{\text{g}}{\text{mol}} \right) = 570. \text{ g Fe}_2\text{O}_3$$

∴ 37.9 g Fe₂O₃ produced, O₂ is in excess

$$\left(\frac{55.0 \text{ g FeCO}_3}{115.8562 \text{ g/mol}} \right) \left(\frac{1 \text{ mol O}_2}{4 \text{ mol FeCO}_3} \right) \left(22.4 \frac{\text{L}}{\text{mol}} \right) = 2.66 \text{ L O}_2 \text{ needed}$$

$$40.0 \text{ L available} - 2.66 \text{ L needed} = 37.3 \text{ L O}_2 \text{ remains unreacted}$$

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

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

$$2 \text{ wheels} + 1 \text{ frame} + 1 \text{ handlebar} \Rightarrow 1 \text{ bike}$$

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

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

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

$\therefore 2455 \text{ bikes can be manufactured}$

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

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

$$5050 - 4910 = 140 \text{ wheels left over}$$

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

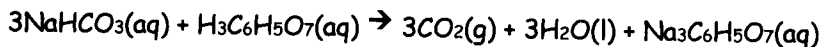
$$3013 - 2455 = 558 \text{ frames left over}$$

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:



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?

$$\left(\frac{1.00 \text{ g NaHCO}_3}{84.00691 \text{ g/mol}} \right) \left(\frac{3 \text{ mol CO}_2}{3 \text{ mol NaHCO}_3} \right) \left(\frac{22.4 \text{ L}}{\text{mol}} \right) = 0.267 \text{ L CO}_2$$

$$\left(\frac{1.00 \text{ g H}_3\text{C}_6\text{H}_5\text{O}_7}{192.12532 \text{ g/mol}} \right) \left(\frac{3 \text{ mol CO}_2}{1 \text{ mol H}_3\text{C}_6\text{H}_5\text{O}_7} \right) \left(\frac{22.4 \text{ L}}{\text{mol}} \right) = 0.350 \text{ L CO}_2$$

$$\boxed{\therefore 0.267 \text{ L CO}_2 \text{ is formed}}$$

- b) Which reactant is the limiting reactant?

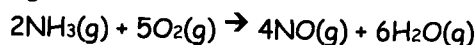
NaHCO₃ is the limiting reactant

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

$$\left(\frac{1.00 \text{ g NaHCO}_3}{84.00691 \text{ g/mol}} \right) \left(\frac{1 \text{ mol H}_3\text{C}_6\text{H}_5\text{O}_7}{3 \text{ mol NaHCO}_3} \right) \left(192.12532 \frac{\text{g}}{\text{mol}} \right) = 0.762 \text{ g needed}$$

$$1.00 \text{ g available} - 0.762 \text{ g needed} = \boxed{0.24 \text{ g H}_3\text{C}_6\text{H}_5\text{O}_7 \text{ remains}}$$

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



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

- a) What mass of nitrogen monoxide is formed?

$$\left(\frac{2.50 \text{ g NH}_3}{17.03052 \text{ g/mol}} \right) \left(\frac{4 \text{ mol NO}}{2 \text{ mol NH}_3} \right) \left(\frac{30.0061 \text{ g}}{\text{mol}} \right) = 8.81 \text{ g NO}$$

$$\left(\frac{2.85 \text{ g O}_2}{31.9988 \text{ g/mol}} \right) \left(\frac{4 \text{ mol NO}}{5 \text{ mol O}_2} \right) \left(\frac{30.0061 \text{ g}}{\text{mol}} \right) = 2.14 \text{ g NO}$$

$$\boxed{\therefore 2.14 \text{ g NO is formed}}$$

- b) Which reactant is the limiting reactant?

O₂ is the limiting reactant

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

$$\left(\frac{2.85 \text{ g O}_2}{31.9988 \text{ g/mol}} \right) \left(\frac{2 \text{ mol NH}_3}{5 \text{ mol O}_2} \right) \left(\frac{17.03052 \text{ g}}{\text{mol}} \right) = 0.607 \text{ g needed}$$

$$2.50 \text{ g available} - 0.607 \text{ g needed} = \boxed{1.89 \text{ g NH}_3 \text{ remains}}$$