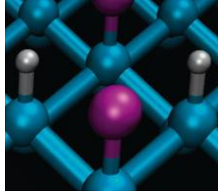

Chapter 4

Stoichiometry

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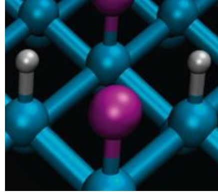
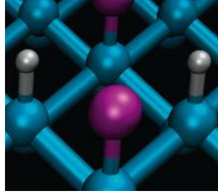
Fundamentals of Stoichiometry



- Stoichiometry: A term used to describe quantitative relationships in chemistry
  - 'How much?' of a particular substance will be consumed or formed in a chemical reaction
  - A balanced chemical equation is needed
  - Conversion between the measured value of a mass or volume and the desired value of a number of moles is needed



Obtaining Ratios from a Balanced Chemical Equation

$$CH_4(g) + 2\,O_2(g) \longrightarrow CO_2(g) + 2\,H_2O(\ell)$$

- Mole ratios are obtained from the coefficients in the balanced chemical reaction
  - 1 mol CH_4 : 2 mol O_2 : 1 mol CO_2 : 2 mol H_2O
- These ratios can be used in solving problems

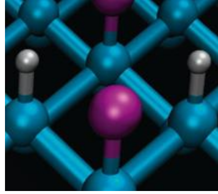
$$\frac{1\text{ mol } CH_4}{2\text{ mol } O_2} \text{ or } \frac{2\text{ mol } H_2O}{1\text{ mol } CH_4}$$

Example Problem 4.1

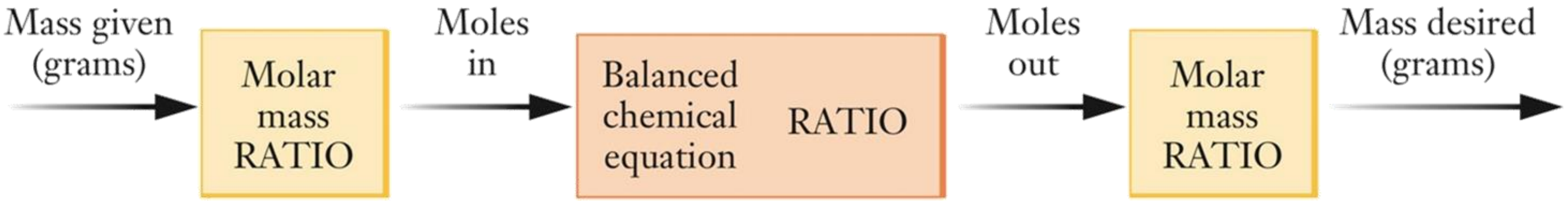
- In the combustion of methane, how many moles of O_2 are required if 6.75 mol of CH_4 is to be completely consumed?

$$CH_4(g) + 2\,O_2(g) \longrightarrow CO_2(g) + 2\,H_2O(\ell)$$

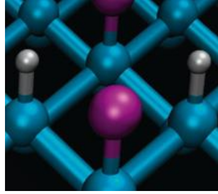
$$\frac{1\text{ mol }CH_4}{2\text{ mol }O_2} \text{ or } \frac{2\text{ mol }H_2O}{1\text{ mol }CH_4}$$



Obtaining Ratios from a Balanced Chemical Equation



- This flow diagram illustrates the various steps involved in solving a typical reaction stoichiometry problem
  - No different than unit conversion
  - Usually more than one conversion is necessary
  - Write all quantities with their complete units



Example Problem 4.2

- How many grams of water can be produced if sufficient hydrogen reacts with 26.0 g of oxygen?

Obtaining Ratios from a Balanced Chemical Equation

- Solution to Problem 4.2 using the stoichiometry problem flow diagram, Figure 4.3

Mass given

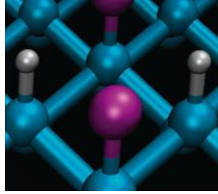
Molar mass ratio for oxygen

Mole ratio from equation

Molar mass ratio for water

$$26.0 \text{ g } O_2 \times \frac{1 \text{ mol } O_2}{32.0 \text{ g } O_2} \times \frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2} \times \frac{18.0 \text{ g } H_2O}{1 \text{ mol } H_2O} = 29.3 \text{ g } H_2O$$

Example Problem 4.3



- If we have 153 g of S_8 and an excess of phosphorus, what mass of P_4S_3 can be produced in the reaction shown?

$$8P_4 + 3S_8 \rightarrow 8P_4S_3$$

$$\frac{153\,g}{32\times 8\,g/mol} \times \frac{8}{3} \times (4\times 31 + 3\times 32)\,g/mol$$

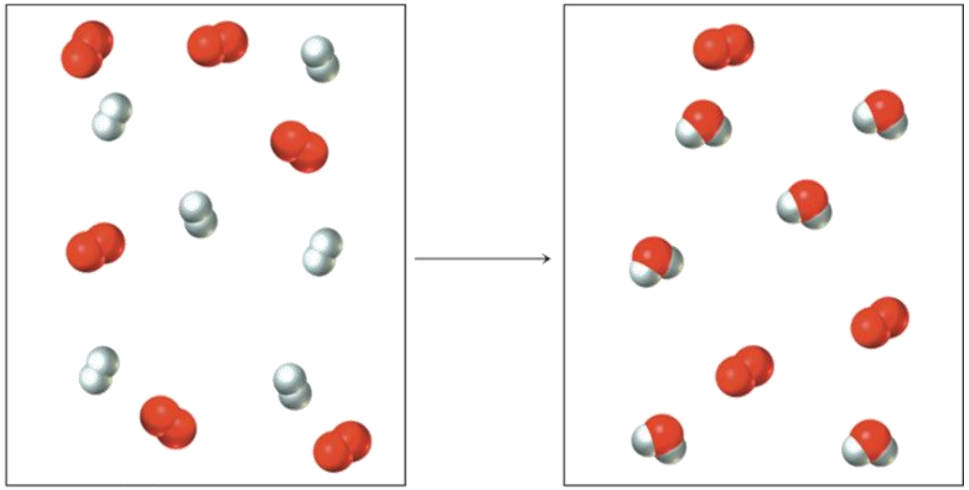
$$= 350.625\,g$$

Limiting Reactants

- In many chemical reactions, the available supply of one reactant is often exhausted before the other reactants
- Limiting reactant: The reactant that is completely consumed in a reaction
  - Limits the quantity of product produced

Limiting Reactants

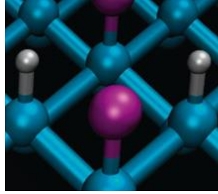
$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$$



- Reaction between 6 H_2 and 6 O_2 will produce 6 H_2O
  - 6 H_2 can produce 6 H_2O
  - 6 O_2 can produce 12 H_2O
  - H_2 is limiting reactant
  - 3 O_2 are left over

Limiting Reactants

- In many cases, we manipulate the amounts of reactants to ensure that one specific compound is the limiting reactant
  - For example, a more expensive or scarce reagent is usually chosen to be the limiting reagent
- Other times, it is best to have a stoichiometric mixture (equal ratio of moles) to prevent waste
  - For example, rocket fuel is designed so that no mass is left over, which would add unnecessary weight to the rocket



Example Problem 4.4

- A solution of hydrochloric acid contains 5.22 g of HCl. When it is allowed to react with 3.25 g of solid K_2CO_3, the products are KCl, CO_2, and H_2O. Which reactant is in excess?

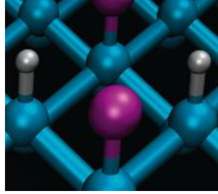
$$2HCl + K_2CO_3 = 2KCl + H_2O + CO_2\uparrow$$

$$n_1 = \frac{5.22}{36.5} = 0.143$$

$$n_2 = \frac{3.25}{138} = 0.023$$

HCl is left

Example Problem 4.5



- If 28.2 g of P_4 is allowed to react with 18.3 g of S_8, which is the limiting reactant?

$$8P_4 + 3S_8 \rightarrow 8P_4S_3$$

$n_1 = \frac{28.2}{124} = 0.227$ 0.0284

$n_2 = \frac{18.3}{256} = 0.0714$ 0.0238 S_8 is the limiting reactant

Theoretical Yield

- The maximum mass of a product that can be obtained in a reaction is determined by the limiting reactant
  - Used to determine which reactant is the limiting reactant
  - Efficiency of a reaction can be rated by calculating how much product would form under perfect or ideal conditions and then comparing the actual measured result with this ideal

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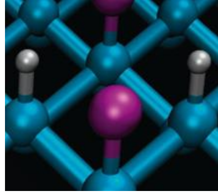
Theoretical and Percentage Yields

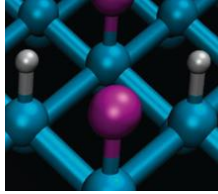
- Many factors determine the amount of desired product actually produced in a reaction
  - Temperature of the reaction
  - Possibility of side reactions
  - Further reaction of the product
  - Time

Theoretical and Percentage Yields (2 of 2)



$$\text{Percentage Yield} = \left(\frac{\text{actual yield}}{\text{theoretical yield}}\right) \times 100\%$$

- Percentage yield: Calculated by comparing the ratio of the actual yield to the theoretical yield
  - Measures reaction efficiency
  - Theoretical yield: Ideal amount of product formed under perfect or ideal conditions
  - Measuring the amount of product formed gives the actual yield



Example Problem 4.8

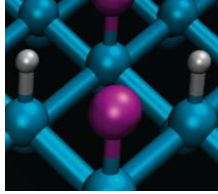
- In a laboratory experiment, a student heats 42.0 g of $NaHCO_3$ and determines that 22.3 g of Na_2CO_3 is formed. What is the percentage yield of this reaction?

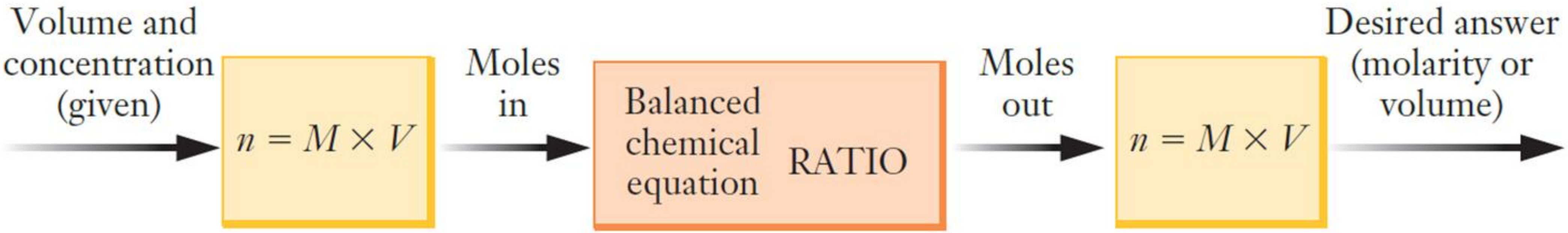
$$2NaHCO_3(s) \xrightarrow{\text{heat}} Na_2CO_3(s) + CO_2(g) + H_2O(g)$$

$$M_T = \frac{42}{84 \times 2} \times 106$$

$$P = 0.8415$$

Solution Stoichiometry (1 of 3)





- For reactions occurring in solution, the amount of a solution is typically measured as a volume rather than a mass
  - Balanced chemical equations provide the critical ratios among numbers of moles of various species in reactions
  - n = number of moles; M = mol/L; V = L

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Example Problem 4.9

- If 750.0 mL of 0.806 M NaClO is mixed with excess ammonia, how many moles of hydrazine can be formed?

$$NaClO(aq) + 2NH_3(aq) \rightarrow N_2H_4(aq) + NaCl(aq) + H_2O(\ell)$$

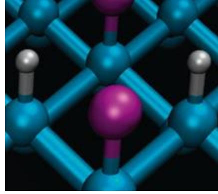
- If the final volume of the resulting solution is 1.25 L, what will be the molarity of hydrazine?

$0.75 \times 0.806 = 0.605$

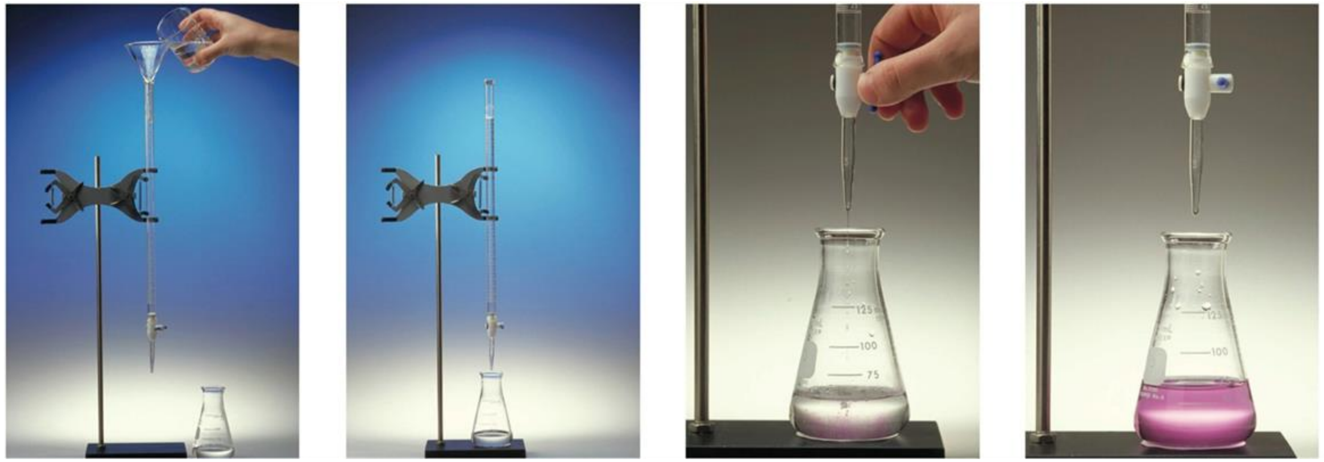
molarity $= 0.484$

Solution Stoichiometry

- Titration: A common laboratory technique that requires understanding solution stoichiometry
  - A solution-phase reaction is carried out under controlled conditions so that the amount of one reactant can be determined with high precision
  - Indicator: A dye used during titration that changes color to indicate when the reaction is complete



Solution Stoichiometry (3 of 3)



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- A solution of one of the reactants (A) is added to a burette
- The burette is positioned above a flask containing the second reactant (B)
- Using the burette, A is added to the flask in a controlled manner
  - Volume is determined from initial and final burette readings
- The reaction is complete when the indicator changes color

Example Problem 4.10

- If 24.75 mL of 0.503 M NaOH solution is used to titrate a 15.00-mL sample of sulfuric acid, H_2SO_4, what is the concentration of the acid?

$$\frac{24.75 \times 0.503}{2 \times 15} = 0.415$$