General Chemistry

Principles and Modern Applications

Petrucci • Harwood • Herring

8th Edition

Chapter 4: Chemical Reactions

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Contents

4-1 Chemical Reactions and Chemical Equations

- A **chemical reaction** is a process in which one set of substances, called **reactants**, is converted to a new set of substances, called **products**.
- In other words, a chemical reaction is the process by which a chemical change occurs.

As reactants are converted to products we observe:

- Color change
- Precipitate formation
- Gas evolution
- Heat absorption or evolution

Chemical evidence may be necessary.

Chemical Reaction

Nitrogen monoxide + oxygen → nitrogen dioxide

Step 1: Write the reaction using chemical symbols.

Step 2: Balance the chemical equation.

$$2\ NO + 1\ O_2 \rightarrow 2\ NO_2$$

Balancing Equations

- Never introduce extraneous atoms to balance.

$$NO + O_2 \rightarrow NO_2 + O$$

- Never change a formula for the purpose of balancing an equation.

$$NO + O_2 \rightarrow NO_3$$

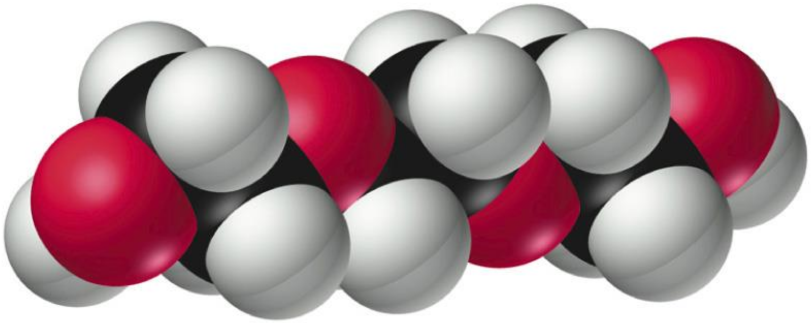
Balancing Equation Strategy

- Balance elements that occur in only one compound on each side first.
- Balance free elements last.
- Balance unchanged polyatomics as groups.
- Fractional coefficients are acceptable and can be cleared at the end by multiplication.

Example 4-2

Writing and Balancing an Equation: The Combustion of a Carbon-Hydrogen-Oxygen Compound.

Liquid triethylene glycol, $C_6H_{14}O_4$, is used a a solvent and plasticizer for vinyl and polyurethane plastics. Write a balanced chemical equation for its complete combustion.



Triethylene glycol

Example 4-2

Chemical Equation:

$$C_6H_{14}O_4 + \frac{15}{2}\ O_2 \rightarrow 6\ CO_2 + 7\ H_2O$$

1. *Balance C.*
2. *Balance H.*
3. *Balance O.*
4. *Multiply by two*

$$2\ C_6H_{14}O_4 + 15\ O_2 \rightarrow 12\ CO_2 + 14\ H_2O$$

and check all elements.

4-2 Chemical Equations and Stoichiometry

- Stoichiometry includes all the *quantitative* relationships involving:
  - atomic and formula masses
  - chemical formulas.

- *Mole ratio* is a central conversion factor.

4-2 Chemical Equations and Stoichiometry

- The coefficients in the chemical equation

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

mean that

$$2x \text{ molecules } H_2 + x \text{ molecules } O_2 \longrightarrow 2x \text{ molecules } H_2O$$

- Suppose we let x= 6.02214×10^{23} (Avogadro s number).

- Then *x* molecules represents *1 mole*. Thus the chemical equation also means that

$$2 \text{ mol } H_2 + 1 \text{ mol } O_2 \longrightarrow 2 \text{ mol } H_2O$$

Example 4-3

Relating the Numbers of Moles of Reactant and Product.

How many moles of H_2O are produced by burning 2.72 mol H_2 in an excess of O_2?

Write the Chemical Equation:

Balance the Chemical Equation:

$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

Use the stoichiometric factor or mole ratio in an equation:

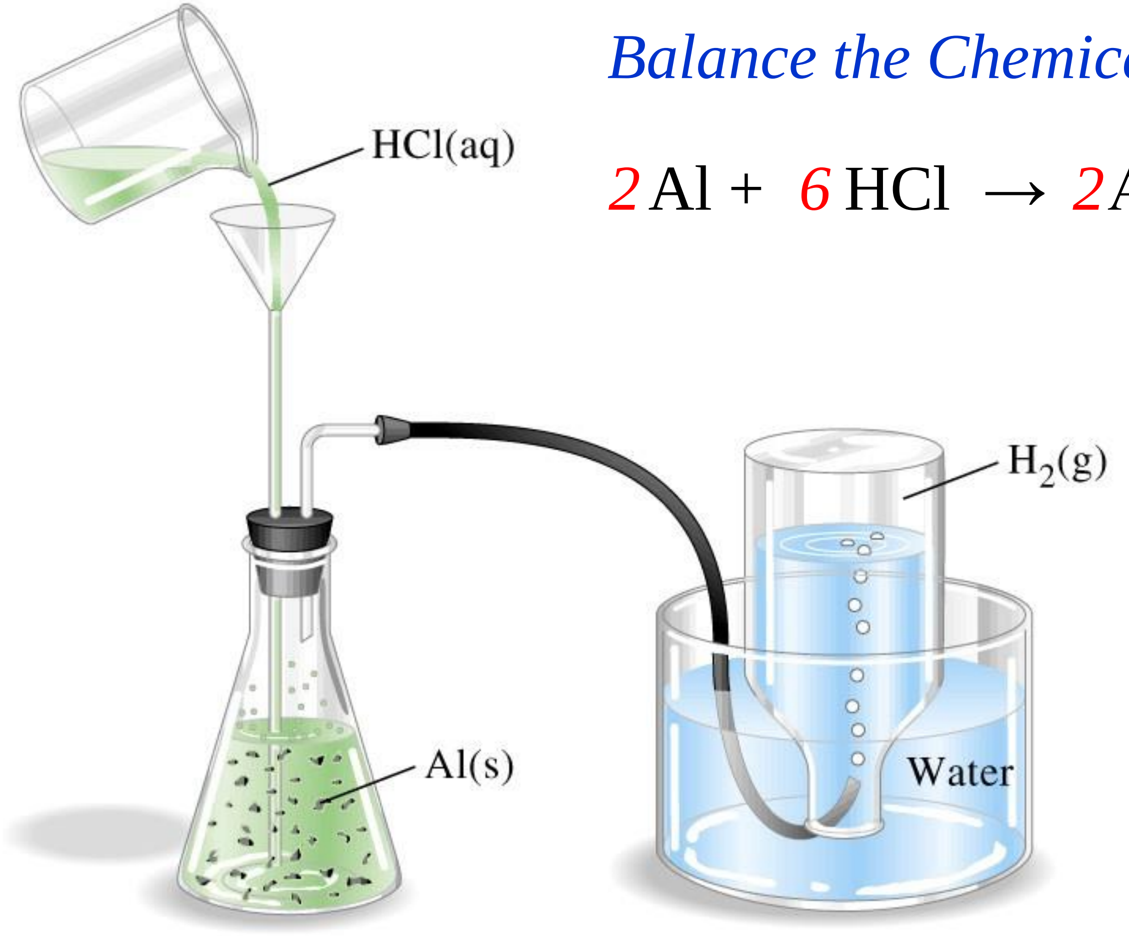
$$n_{H_2O} = 2.72 \text{ mol } H_2 \times \frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2} = 2.72 \text{ mol } H_2O$$

Example 4-6

Additional Conversion Factors in a Stoichiometric Calculation: Volume, Density, and Percent Composition.

The density of 28% (w/w) HCl solution is 1.14 g/mL. How many mL of this solution is required to react with 1.87 g of Al according to the following reaction? (Al: 27; HCl: 36.5 g/mol)

Example 4-6



Write the Chemical Equation:

Balance the Chemical Equation:

$$2\,Al + 6\,HCl \rightarrow 2\,AlCl_3 + 3\,H_2$$

Example 4-6

$$2\ Al + 6\ HCl \rightarrow 2\ AlCl_3 + 3\ H_2$$

$n_{Al} = m/M_{Al} = 1.87/27 = 0.069$ mol

2 mol Al	6 mol HCl	$n_{HCl} = m/M_{HCl}$
0.069 mol	x mol HCl	$0.207 = m/\ 36.5$
x= 0.207 mol HCl		m=7.58 g HCl

100 g HCl	28 g HCl	$d_{HCl} = m/V$
x	7.58 g HCl	$1.14 = 27.05/V$
x= 27.05 g HCl		V= 23.7 mL HCl

4-3 Chemical Reactions in Solution

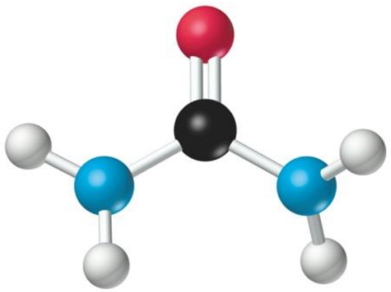
- Close contact between atoms, ions and molecules necessary for a reaction to occur.

- Solvent
  - We will usually use *aqueous* (aq) solution.
- Solute
  - A material dissolved by the solvent.

Molarity

$$\text{Molarity } (M) = \frac{\text{Amount of solute } (\textit{mol solute})}{\text{Volume of solution (L)}}$$

If 0.444 mol of urea is dissolved in enough water to make 1.000 L of solution the concentration is:



Urea

$$c_{\text{urea}} = \frac{0.444 \text{ mol urea}}{1.000 \text{ L}} = 0.444 \text{ M } CO(NH_2)_2$$

Example 4-6

Calculating the mass of Solute in a solution of Known Molarity.

We want to prepare exactly 250 mL of an 0.250 M K_2CrO_4 solution in water. What mass of K_2CrO_4 should we use?

K_2CrO_4=194.02 g/mol

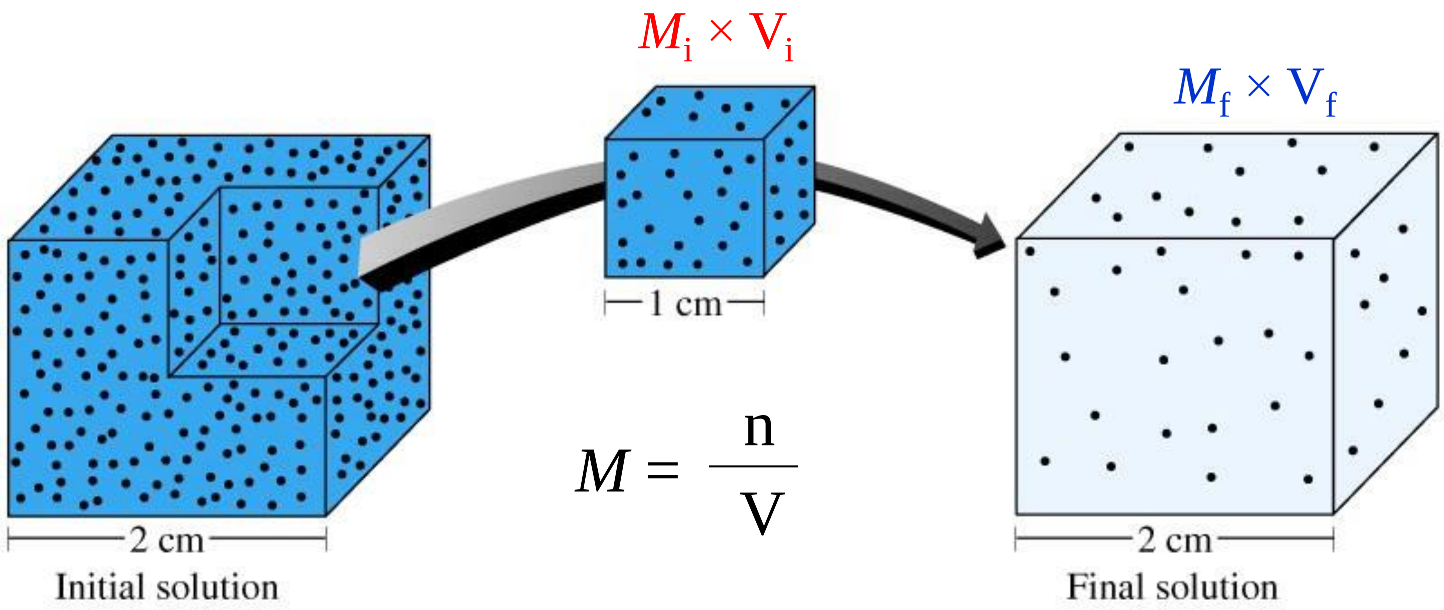
$$\text{Molarity } (M) = \frac{\text{Amount of solute } (\textit{mol solute})}{\text{Volume of solution (L)}}$$

$M_{\text{K2Cro4}} = n / V$

0.250 = n / 0.250 n= 0.0625 mol

n= m/M $\rightarrow$ 0.0625=m/194.02 m=12.1 g K_2CrO_4

Solution Dilution



$$M = \frac{n}{V}$$

$$M_i \times V_i = n_i \;=\; n_f = M_f \times V_f$$

$$M_f = \frac{M_i \times V_i}{V_f} = M_i \frac{V_i}{V_f}$$

Example 4-10

Preparing a solution by dilution.

A particular analytical chemistry procedure requires 0.0100 M K_2CrO_4. What volume of 0.250 M K_2CrO_4 should we use to prepare 0.250 L of 0.0100 M K_2CrO_4?

Plan strategy:

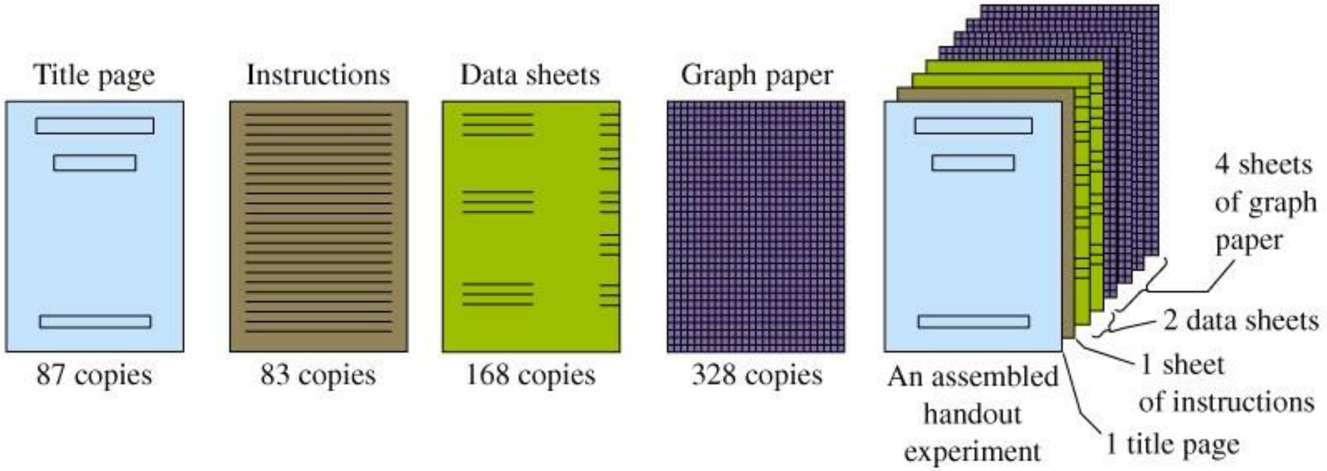
$$M_f = M_i \frac{V_i}{V_f} \qquad V_i = V_f \frac{M_f}{M_i}$$

Calculate:

$$V_{K_2CrO_4} = 0.2500 \text{ L} \times \frac{0.0100 \text{ mol}}{1.00 \text{ L}} \times \frac{1.000 \text{ L}}{0.250 \text{ mol}} = 0.0100 \text{ L}$$

4-4 Determining Limiting Reagent

- The reactant that is completely consumed determines the quantities of the products formed.



Example 4-12

Determining the Limiting Reactant in a Reaction.

Phosphorus trichloride , PCl_3, is a commercially important compound used in the manufacture of pesticides, gasoline additives, and a number of other products. It is made by the direct combination of phosphorus and chlorine

$$P_4\,(s) + 6\,Cl_2\,(g) \rightarrow 4\,PCl_3\,(l)$$

What mass of PCl_3 forms in the reaction of 125 g P_4 with 323 g Cl_2?

Strategy: Compare the actual mole ratio to the required mole ratio.

Example 4-12

$$n_{Cl_2} = 323 \text{ g } Cl_2 \times \frac{1 \text{ mol } Cl_2}{70.91 \text{ g } Cl_2} = 4.56 \text{ mol } Cl_2$$

$$n_{P_4} = 125 \text{ g } P_4 \times \frac{1 \text{ mol } P_4}{123.9 \text{ g } P_4} = 1.01 \text{ mol } P_4$$

$$\chi = \frac{n_{Cl_2}}{n_{P_4}}$$

$$\chi_{actual} = 4.55 \text{ mol } Cl_2/\text{mol } P_4$$

$$\chi_{theoretical} = 6.00 \text{ mol } Cl_2/\text{mol } P_4$$

Chlorine gas is the limiting reagent.

Example 4-12

$1 \text{ mol } P_4 \qquad 6 \text{ mol } Cl_2$

$x \text{ mol} \qquad 4.56 \text{ mol } Cl_2$

$x = 0.76 \text{ mol } P_4$

$n_{P4} = m/M_{P4}$

$0.76 = m/ \ 123.9$

$m = 94.1 \text{ g } P_4$

125-94.1=30.9 g P4 artar

$1 \text{ mol } P_4 \qquad 4 \text{ mol } PCl_3$

$0.76 \text{ mol} \qquad x \text{ mol } PCl_3$

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x= 3.04 mol PCl3

$n_{PCl3} = m/M_{PCl3}$

$3.04 = m/ \ 137$

$m = 416.5 \text{ g } PCl_3$

4-5 Other Practical Matters in Reaction Stoichiometry

Theoretical yield is the expected yield from a reactant.

Actual yield is the amount of product actually produced.

$$\text{Percent yield} = \frac{\text{Actual yield}}{\text{Theoretical Yield}} \times 100\%$$

Theoretical, Actual and Percent Yield

- When actual yield = % yield the reaction is said to be quantitative.
- Side reactions reduce the percent yield.
- By-products are formed by side reactions.

