Stoichiometry

Chapter 9 and 14.6
Importance of Stoichiometry

Stoichiometry: The quantitative relationship between reactants and products in a chemical reaction.

Based on stoichiometry (by balancing the equations and doing some cost study analysis) using excess amounts of costly chemicals is avoided.
Meaning of Chemical Equations

In the reaction of nitrogen monoxide with oxygen, nitrogen dioxide is produced.

\[ 2 \text{ NO}(g) + \text{ O}_2(g) \xrightarrow{\text{UV}} 2 \text{ NO}_2(g) \]

Two molecules of NO gas react with one molecule of O\(_2\) gas to produce 2 molecules of NO\(_2\) gas.
Coefficients

\[ 2 \text{NO}(g) + \text{O}_2(g) \rightarrow 2 \text{NO}_2(g) \]

<table>
<thead>
<tr>
<th>NO (g)</th>
<th>( \text{O}_2(g) )</th>
<th>( \text{NO}_2(g) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 molecules</td>
<td>1 molecule</td>
<td>2 molecules</td>
</tr>
<tr>
<td>2000 molecules</td>
<td>1000 molecules</td>
<td>2000 molecules</td>
</tr>
<tr>
<td>(12.04 \times 10^{23})</td>
<td>(6.02 \times 10^{23})</td>
<td>(12.04 \times 10^{23})</td>
</tr>
<tr>
<td>2 moles</td>
<td>1 mole</td>
<td>2 moles</td>
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</table>
Volume & Equation Coefficients

In the Avogadro’s theory, there are equal numbers of molecules in equal volumes of gas at the same temperature and pressure.

When the number of molecules are increased twice, the volume occupied will also be increased twice.

\[ 2 \text{ NO(g)} + \text{O}_2(\text{g}) \rightarrow 2 \text{ NO}_2(\text{g}) \]

Instead of writing 2 molecules NO, 1 molecule O$_2$, and 2 molecules NO$_2$; we can write: 2 liters of NO react with 1 liter of O$_2$ gas to produce 2 liters of NO$_2$ gas.
Interpretation of Coefficients

A balanced chemical equation shows how many moles of a substance reacted and how many moles of product(s) are produced.

If there are gases, the liters of gas reacted or produced will be obtained.
Conservation of Mass

Mass is neither created nor destroyed during a chemical reaction.

Example:

2 NO(g) + O₂(g) → 2 NO₂(g)

2 mol NO + 1 mol O₂ → 2 mol NO

2 (30.01 g) + 1 (32.00 g) → 2 (46.01 g)

60.02 g + 32.00 g → 92.02 g

92.02 g = 92.02 g

The mass of the reactants is equal to the mass of the product!
Mole - Mole Calculations

Problem: How many moles of oxygen react with 2.25 mol of nitrogen?

\[ \text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{ NO}(\text{g}) \]

Knowing N₂, would like to calculate O₂,

Use 1 mol N₂ = 1 mol O₂.

\[ 2.25 \text{ mol N}_2 \times \frac{1 \text{ mol O}_2}{1 \text{ mol N}_2} = 2.25 \text{ mol O}_2 \]
Types of Stoichiometry Problems

There are three basic types of stoichiometry problems:

- Mass-Mass
- Mass-Volume
- Volume-Volume
Mass - Mass Problems

Convert a given mass of a reactant or product to an unknown mass of reactant or product.

Follow these three steps:

1) Convert the given mass to \( \rightarrow \) moles using the molar mass as a unit factor.

2) Convert the moles of given to \( \rightarrow \) moles of the unknown using the coefficients in the balanced equation.

3) Convert the moles of unknown to \( \rightarrow \) grams using the molar mass as a unit factor.
Mass-Mass Stoichiometry Problem

Problem: What is the mass of mercury produced from the decomposition of 1.25 g of orange mercury (II) oxide (MW = 216.59 g/mol)?

\[ 2 \text{HgO(s)} \rightarrow 2 \text{Hg(l)} + \text{O}_2(\text{g}) \]

1) Convert grams Hg to moles Hg using the molar mass of mercury (200.59 g/mol).

2) Convert moles Hg to moles HgO using the balanced equation.

3) Convert moles HgO to grams HgO using the molar mass.
Cont’d…Problem

\[ 2 \text{HgO}(s) \rightarrow 2 \text{Hg}(l) + \text{O}_2(g) \]

\[ \text{g Hg} \Rightarrow \text{mol Hg} \Rightarrow \text{mol HgO} \Rightarrow \text{g HgO} \]

\[
1.25 \text{ g HgO} \times \frac{1 \text{ mol HgO}}{216.59 \text{ g HgO}} \times \frac{2 \text{ mol Hg}}{2 \text{ mol HgO}} \times \frac{200.59 \text{ g Hg}}{1 \text{ mol Hg}} = 1.16 \text{ g Hg}
\]
Mass-Volume Problems

Convert a given mass of a reactant or product to an unknown volume of reactant or product.

Follow these three steps:

1) Convert the given mass to \( \rightarrow \) moles using the molar mass as a unit factor.

2) Convert the moles of the given to \( \rightarrow \) moles of the unknown using the coefficients in the balanced equation.

3) Convert the moles of unknown to \( \rightarrow \) liters using the molar volume of a gas as a unit factor.
Mass-Volume Stoichiometry Problem

Problem: How many liters of hydrogen are produced from the reaction of 0.165 g of aluminum metal with dilute hydrochloric acid?

\[
2 \text{Al(s)} + 6 \text{HCl(aq)} \rightarrow 2 \text{AlCl}_3(aq) + 3 \text{H}_2(g)
\]

1) Convert grams Al to moles Al using the molar mass of aluminum (26.98 g/mol).

2) Convert moles Al to moles H\(_2\) using the balanced equation.

3) Convert moles H\(_2\) to liters using the molar volume at STP.
Cont’d…Problem

2 Al(s) + 6 HCl(aq) → 2 AlCl₃(aq) + 3 H₂(g)

g Al ⇒ mol Al ⇒ mol H₂ ⇒ L H₂

\[\begin{align*}
0.165 \text{ g Al} \times \frac{1 \text{ mol Al}}{26.98 \text{ g Al}} \times \frac{3 \text{ mol H₂}}{2 \text{ mol Al}} \times \frac{22.4 \text{ L H₂}}{1 \text{ mol H₂}}
\end{align*}\]

= 0.205 L H₂
Volume-Volume Stoichiometry

The law of combining volumes: Volumes of gases under similar conditions, combine in small whole number ratios (Gay-Lussac).

Example:

\[
\text{H}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightarrow 2 \text{HCl}(\text{g})
\]

10 mL of H₂ reacts with 10 mL of Cl₂ to produce 20 mL of HCl.

The ratio of volumes is 1:1:2, small whole numbers.
Law of Combining Volumes

The whole number ratio (1:1:2) is the same as the mole ratio in the balanced chemical equation:

\[ \text{H}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightarrow 2 \text{HCl}(\text{g}) \]
Volume-Volume Problems

Convert a given volume of a gas to an unknown volume of gaseous reactant or product.

Balance the equation and then, follow this step:

Convert the given volume to the unknown volume using the mole ratio (therefore the volume ratio) from the balanced chemical equation.
Volume-Volume Problem

Problem: How many liters of oxygen react with 37.5 L of sulfur dioxide in the production of sulfur trioxide gas?

\[
\text{Pt } \Delta \\
2 \text{ SO}_2(g) + \text{ O}_2(g) \rightarrow 2 \text{ SO}_3(g)
\]

1 mol of oxygen reacts with 2 mol sulfur dioxide.

1 L of O$_2$ reacts with 2 L of SO$_2$. 
Cont’d…Problem

\[ 2 \text{SO}_2(g) + \text{O}_2(g) \xrightarrow{\text{Pt} \Delta} 2 \text{SO}_3(g) \]

\[ \text{L SO}_2 \Rightarrow \text{L O}_2 \]

\[ 37.5 \text{L SO}_2 \times \frac{1 \text{L O}_2}{2 \text{L SO}_2} = 18.8 \text{L O}_2 \]

How many L of \text{SO}_3 are produced?

\[ 37.5 \text{L SO}_2 \times \frac{2 \text{L SO}_3}{2 \text{L SO}_2} = 37.5 \text{L SO}_3 \]
Review

- The coefficients in a balanced chemical reaction are the mole ratio of the reactants and products.

- The coefficients in a balanced chemical reaction are the volume ratio of gaseous reactants and products.
Cont’d...Review

Flow chart of Stoichiometry

(a) Apply molar mass as a unit factor: 1 mol = ? g (refer to Periodical Table).
(b) Apply mole ratio as a unit factor (refer to balanced equation coefficients).
(c) Apply molar mass as a unit factor: 1 mol = ? g (refer to Periodical Table).
(d) Apply molar volume as a unit factor: 1 mol = 22.4 L at STP.
(e) Apply molar volume as a unit factor: 1 mol = 22.4 L at STP.
(f) Apply volume ratio as a unit factor (refer to balanced equation coefficients).