Lesson 14: Stoichiometry

References:
- OpenStax General Chemistry Textbook: Chapter 4 Section 3 (p.203)
- Modern Chemistry (2012) Textbook: Chapter 9
- https://www.khanacademy.org/science/chemistry/chemical-reactions-stoichiometry

Box 1:
1. How many grams are there in 2 moles of NaCl?

2. Write the total ionic equation for the balanced molecular equation below:

   \[ 2 \text{Li}_3\text{PO}_4(\text{aq}) + 3 \text{MgCl}_2(\text{aq}) \rightarrow 6 \text{LiCl}(\text{aq}) + \text{Mg}_3(\text{PO}_4)_2(\text{s}) \]

3. What is the mass in grams of \(1.5 \times 10^{17}\) formula units (compound units) of NaCl?

Intro to Stoichiometry:
A balanced equation tells us a lot of information – the identity of the reactants and products, the type of reaction, and the relative numbers of each substance. Coefficients give us the relative amounts of each reactant and product, allowing us to have a quantitative assessment of the relationships between each chemical species in the reaction.

The _________________________________ in a chemical reaction are known as the reaction’s stoichiometry.
**Example:** A baker needs to bake cupcakes for an upcoming birthday party. Below is the recipe for 1 dozen cupcakes:

$$1.5 \text{ cups flour} + 2 \text{ eggs} + \frac{2}{3} \text{ cup sugar} + 1.5 \text{ sticks butter} \rightarrow 12 \text{ cupcakes}$$

If the baker needs to make 48 cupcakes, how many eggs are required?

$$\frac{\text{cupcakes}}{} \times \frac{\text{eggs}}{\text{cupcake}} = \frac{\text{eggs}}{}$$

We will use balanced chemical equations in a similar manner to determine the amount of a reactant needed to react with a given amount of another reactant, yield an amount of product, etc.

The _____________________________ in a balanced equation will allow us to determine these amounts.

**Example:** Below is the equation representing the reaction of hydrogen and oxygen to yield water.

$$2 \text{ H}_2(g) + \text{ O}_2(g) \rightarrow 2 \text{ H}_2\text{O} (l)$$

The equation shows that water molecules are produced from oxygen molecules in a ______________ ratio.

$$\frac{\text{molec O}_2}{\text{molec H}_2\text{O}} \text{ or } \frac{\text{dozen H}_2\text{O}}{\text{dozen O}_2} \text{ or } \frac{\text{mol H}_2}{\text{mol O}_2}$$

*The top must be equivalent to the bottom.*

You can use these ratios to compute the number of water molecules produced from any number of hydrogen molecules. You can also compute the number of hydrogen molecules required to react to form any number of water molecules.

Aerobic respiration takes place in the mitochondria and requires oxygen and glucose, and produces carbon dioxide, water, and energy. The equation for respiration is

$$\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$$

What are the mole ratios of each pair of substance?

$$\frac{\text{mol C}_6\text{H}_{12}\text{O}_6}{\text{mol O}_2} \quad \frac{\text{mol CO}_2}{\text{mol C}_6\text{H}_{12}\text{O}_6} \quad \frac{\text{mol C}_6\text{H}_{12}\text{O}_6}{\text{mol H}_2\text{O}} \quad \frac{\text{mol H}_2\text{O}}{\text{mol O}_2} \quad \frac{\text{mol CO}_2}{\text{mol O}_2}$$
Box 2:
Solutions of barium chloride and potassium sulfate were mixed and solid barium sulfate in a solution of potassium chloride was produced. Write a balanced molecular and total ionic equation to describe this reaction.

\[ \text{Box 2:} \]

Ratios in Chemical Equations:
Coefficients can refer to the __________________________ OR __________________________ OR __________________________ of a compound or element.

\[ \text{Na}_2\text{CO}_3 (s) + 2\text{HCl} (\text{aq}) \rightarrow \text{CO}_2 (g) + \text{H}_2\text{O} (\text{l}) + 2\text{NaCl} (\text{aq}) \]

- According to the balanced equation above, for every ____ mol of Na\textsubscript{2}CO\textsubscript{3} that reacts with ____ mol of HCl, ____ mol of CO\textsubscript{2}, ____ mol of H\textsubscript{2}O, and ____ mol of NaCl are produced.
- This is true because balanced equations obey the __________________________

From the balanced equation above, what are the ratios per pair of substance?

\[ \frac{1 \text{ mol Na}_2\text{CO}_3}{1 \text{ mol CO}_2} \quad \frac{1 \text{ mol Na}_2\text{CO}_3}{\text{mol NaCl}} \quad \frac{\text{mol HCl}}{\text{mol H}_2\text{O}} \]

- Define mole ratio: the __________________________ of any two compounds involved in a chemical reaction.
- You cannot calculate the mole ratio for an unbalanced equation.
- Use these as __________________________ when you need to convert between amounts of different substances in a chemical reaction (reactant to reactant, reactant to product, etc.)

Balance this equation: _____ O\textsubscript{3} \rightarrow _____ O\textsubscript{2} 

What is the mole ratio of O\textsubscript{3} to O\textsubscript{2}? ________  Is mass conserved? Show your work to support your answer.
Aqueous solutions of potassium iodide and lead (II) nitrate are mixed and the chemical reaction yields lead (II) iodide in a solution of potassium nitrate. Write balanced molecular and total ionic equations to describe this reaction.

Example: Moles of Reactant Required in a Reaction.

How many moles of I₂ are required to react with 0.429 mol of Al according to the following equation?

\[ 2Al + 3I₂ \rightarrow 2AlI₃ \]

Solution:

\[
\begin{align*}
\text{Moles of Reactant} & \quad \text{Ratio from balanced equation} \quad \text{Moles of Product} \\
\text{Moles of Al} & \quad \text{Ratio from balanced equation} \quad \text{Moles of I₂}
\end{align*}
\]

Your turn:
How many moles of Ca(OH)₂ are required to react with 1.36 mol of H₃PO₄ to produce Ca₃(PO₄)₂ according to the equation below?

\[ 3Ca(OH)₂ + 2H₃PO₄ \rightarrow Ca₃(PO₄)₂ + 6H₂O \]
Practice:

1. \( \text{_____ H}_2\text{SO}_4(aq) + \text{_____ NaOH(aq)} \rightarrow \text{_____ Na}_2\text{SO}_4(aq) + \text{_____ H}_2\text{O(l)} \)

   a. How many moles of Na\(_2\)SO\(_4\) are produced from reacting 8.9 mol of H\(_2\)SO\(_4\)?

   b. How many moles of NaOH are required to form 4.2 mol of H\(_2\)O?

2. \( \text{_____ Fe(s) + _____ Al}_2\text{O}_3(s) \rightarrow \text{_____ Al(s) + _____ Fe}_2\text{O}_3(s) \)

   a. How many moles of Fe\(_2\)O\(_3\) are produced from reacting 2.5 mol of Fe?

   b. How many moles of Al\(_2\)O\(_3\) are required to form 4.0 mol of Al?

3. \( \text{_____ Ca(s) + _____ H}_2\text{O(l)} \rightarrow \text{_____ Ca(OH)}_2(aq) + \text{_____ H}_2(g) \)

   a. How many moles of Ca(OH)\(_2\) are produced from reacting 3.5 mol of Ca?

   b. How many moles of H\(_2\)O are required to form 6.0 mol of H\(_2\)?
**Example: Number of Product Molecules Generated by a Reaction.**

How many carbon dioxide molecules are produced when 1.50 mol of propane is combusted according to this equation?

\[ C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \]

Solution:

Your turn:

How many NH\(_3\) molecules are produced by the reaction of 6.0 mol of Ca(OH)\(_2\) according to the following equation:

\[ (NH_4)_2SO_4 + Ca(OH)_2 \rightarrow 2NH_3 + CaSO_4 + 2H_2O \]
Practice: Balance the equations, then solve.

1. _____ Na₂CO₃(s) + _____ HCl (aq) ➔ _____ CO₂(g) + _____ H₂O (l) + _____ NaCl (aq)

   a. How many moles of H₂O are produced if 4.00 moles of HCl are reacted?

   b. How many molecules of Na₂CO₃ are required to produce 68,800 compounds of NaCl?

2. _____ FrI₂O₃ (s) ➔ _____ FrI (s) + _____ O₂ (g)

   a. How many molecules of O₂ are produced from reacting 185 molecules of FrI₂O₃?

   b. How many moles of FrI are produced if 8.0 mol of O₂ are produced?
Box 4. Balance the equation, then solve.

\[ \text{_____ CO}_2 + \text{_____ Na}_2\text{S} \rightarrow \text{_____ CS}_2 + \text{_____ Na}_2\text{O} \]

a. How many molecules of CO\(_2\) are required to produce 5,045 molecules of Na\(_2\)O?

b. How many moles of CS\(_2\) are produced if 0.553 mol of Na\(_2\)S are reacted?

Example: Relating Masses of Reactants and Products

What mass of sodium hydroxide, NaOH, would be required to produce 20 g of the antacid milk of magnesia \([\text{magnesium hydroxide, Mg(OH)}_2]\) by the following reaction?

\[ \text{MgCl}_2(aq) + 2\text{NaOH}(aq) \rightarrow \text{Mg(OH)}_2(s) + 2\text{NaCl}(aq) \]

Solution:
Your turn:

What mass of gallium oxide, Ga₂O₃, can be prepared from 58.0 g of gallium metal? The equation for the reaction is 4Ga + 3O₂ → 2Ga₂O₃.

Example: Relating Masses of Reactants

What mass of oxygen gas, O₂, from the air is consumed in the combustion of 351 g of octane, C₈H₁₈, one of the principal components of gasoline?

\[ 2C₈H₁₈ + 25O₂ \rightarrow 16CO₂ + 18H₂O \]

Solution:

Your turn:

What mass of CO is required to react with 25.13 g of Fe₂O₃ according to the equation below?

\[ Fe₂O₃ + 3CO \rightarrow 2Fe + 3CO₂ \]
FOLLOWING YOUR UNITS:

2 AgI + Na₂S → Ag₂S + 2 NaI

If “X” grams of AgI are reacted completely, how many grams of Ag₂S will be formed?

Set-up the formula using units only. Then, label each conversion.

\[
\begin{array}{c}
\text{1} \\
\times \\
\times \\
\times \\
\text{=}
\end{array}
\]

If 473.2 grams of AgI are reacted completely, how many grams of Ag₂S will be formed? Set up the solution based on the model above.

\[
\begin{array}{c}
\text{1} \\
\times \\
\times \\
\times \\
\text{=}
\end{array}
\]

C₉H₂₀ (l) + 14 O₂ (g) → 9 CO₂ (g) + 10 H₂O (g)

If “X” grams of CO₂ are produced, how many grams of C₉H₂₀ was burned?

Set-up the formula using units only. Then, label each conversion.

\[
\begin{array}{c}
\text{1} \\
\times \\
\times \\
\times \\
\times \\
\times \\
\text{=}
\end{array}
\]

If 500.0 grams of CO₂ are produced, how many grams of C₉H₂₀ was burned?
Mass to Mass Conversion Practice:

1. \[ \text{____ Sr(s) + ____ H}_2\text{O(l) } \rightarrow \text{____ Sr(OH)}_\text{2(aq) + ____ H}_2\text{(g)} \]

a. How many moles of \( \text{Sr(OH)}_\text{2} \) are produced from reacting 1.25g Sr?

b. How many grams of \( \text{H}_2\text{O} \) are required to form 0.254 mol of \( \text{H}_2 \)?

c. How many grams of water are reacted if 48.2g of strontium hydroxide are produced?

Box 5: Write the balanced equation, then outline the steps necessary to determine the information requested.

The number of moles and the mass of chlorine, \( \text{Cl}_\text{2} \), required to react with 10.0 g of sodium metal, Na, to produce sodium chloride, \( \text{NaCl} \).
Box 6: Write the balanced equation, then outline the steps necessary to determine the information requested.

The number of moles and the mass of oxygen formed by the decomposition of 1.252 g of mercury (II) oxide.

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

Mass to Mass Conversion Practice Continued:

2. \[
\text{CO}_2 \quad + \quad \text{Na}_2\text{S} \quad \rightarrow \quad \text{CS}_2 \quad + \quad \text{Na}_2\text{O}
\]

a. How many moles of sodium sulfide are reacted if 164g of carbon dioxide are reacted?

b. How many grams of CO\textsubscript{2} are required to produce 1.33 mol Na\textsubscript{2}O?

c. How many grams of CS\textsubscript{2} are produced if 0.553g Na\textsubscript{2}S are reacted?
Extra Practice:

1. Combustion of hydrocarbons always yields carbon dioxide and water. What mass of oxygen is required to completely combust 67.1 g of propane (C\(_3\)H\(_8\))? 

2. Solid lithium hydroxide is used by NASA as a carbon dioxide absorbent. The products of the reaction are solid lithium carbonate and water. What mass of gaseous carbon dioxide can be absorbed by 5000 g of lithium hydroxide?
Definitions:

Balanced equation: Chemical equation with equal numbers of atoms for each element in the reactant and product.

Chemical equation: Symbolic representation of a chemical reaction.

Coefficient: Number placed in front of symbols or formulas in a chemical equation to indicate their relative amount.

Complete ionic equation: Chemical equation in which all dissolved ionic reactants and products, including spectator ions, are explicitly represented by formulas for their dissociated ions.

Excess reagent: Reactant present in an amount greater than required by the reaction stoichiometry.

Insoluble: Of relatively low solubility; dissolving only to a slight extent.

Limiting reagent: Reactant present in an amount lower than required by the reaction stoichiometry, thus limiting the amount of product generated.

Molecular equation: Chemical equation in which all reactants and products are represented as neutral substances.

Precipitate: Insoluble product that forms from reaction of soluble reactants.

Product: Substance formed by a chemical or physical change; shown on the right side of the arrow in a chemical equation.

Reactant: Substance undergoing a chemical or physical change; shown on the left side of the arrow in a chemical equation.

Stoichiometric factor: Ratio of coefficients in a balanced chemical equation, used in computations relating amounts of reactants and products.

Stoichiometry: Relationships between the amounts of reactants and products of a chemical reaction.