Stoichiometry Notes

1. Introduction to Stoichiometry

Stoichiometry:

The chemical 'recipe' necessary to combine substances to make new substances.

Stoichiometry is the relationship between the amount of reactants used and the amount of products produced in a chemical reaction.

\[ CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \]

1 methane molecule reacts with two oxygen molecules to produce 1 carbon dioxide molecule and two water molecules.

The balanced reaction is the ratio or 'recipe' we need for the reaction to occur.

An analogy:

Consider making sandwiches. In each sandwich I’d like to have:

- 2 pieces of bread (Br)
- 4 tomato slices (To)
- 2 pieces of chicken (Ch)
- 1 piece of lettuce (Le)

Sandwich equation:

\[ 2Br + 4To + 2Ch + 1Le \rightarrow 1Br\cdotTo\cdotCh\cdotLe \]

But what if I wanted to make 5 sandwiches for some friends? How much of each component would I need?

\[ 2Br + 4To + 2Ch + 1Le \rightarrow 1Br\cdotTo\cdotCh\cdotLe \]
Stoichiometry Notes

\[ 2\text{Br} + 4\text{To} + 2\text{Ch} + 1\text{Le} \rightarrow \text{1Br:To:Ch:Le} \]

<table>
<thead>
<tr>
<th>5 sandwiches</th>
<th>Br</th>
<th>=</th>
<th>1 sandwich</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 sandwich</td>
<td></td>
<td>=</td>
<td>Tomatoes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>=</td>
<td>Chicken Slices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>=</td>
<td>Lettuce pieces</td>
</tr>
</tbody>
</table>

recipe for 1 sandwich:
\[ 2\text{Br} + 4\text{To} + 2\text{Ch} + 1\text{Le} \rightarrow \text{1Br:To:Ch:Le} \]

x 5

recipe for 5 sandwiches
\[ 10\text{Br} + 20\text{To} + 10\text{Ch} + 5\text{Le} \rightarrow 5\text{Br:To:Ch:Le} \]

And now for some chemicals!
Determining the amount of each component of a sandwich is like using moles in a chemical equation.

In chemistry, you can only use moles to compare one chemical to another within a reaction.

When hydrogen gas reacts with oxygen gas, water is formed. What is the chemical recipe (the stoichiometry) for this reaction?

\[ \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O} \]

BALANCE: \[ 2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} \]

2 hydrogen molecules react with one oxygen molecule to make two water molecules. OR
2 dozen hydrogen molecules react with one dozen oxygen molecules to make two dozen water molecules. OR
2 MOLES of hydrogen react with one MOLE of oxygen to make two MOLES of water.

The coefficients refer to the amount of molecules which are involved in a reaction.

The amount of molecules can also be termed as the amount in moles.

Eg. \[ 2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} \]
Is the same as:
\[ 2 \text{ mol H}_2 + 1 \text{ mol O}_2 \rightarrow 2 \text{ mol H}_2\text{O} \]

So how many moles of oxygen are needed to react with 6 moles of hydrogen?
\[ \frac{6 \text{ mol H}_2}{2 \text{ mol H}_2} = 3 \text{ mol O}_2 \]

How many moles of water are produced if you react 2.5 moles of oxygen?
\[ \frac{2.5 \text{ mol O}_2}{1 \text{ mol O}_2} = \]

If 0.5 moles of water are produced, how many moles of hydrogen reacted? oxygen?
\[ \frac{0.5 \text{ mol H}_2}{2 \text{ mol H}_2} = \]

2
2. Mole - Mole Stoichiometry

Example:
How many moles of water are produced if you react 2.5 moles of oxygen?

\[
\text{Moles of Chemical #1} \quad \text{The Bridge} \quad \text{Moles of Chemical #2}
\]

Can ask how much reactant is needed:
Eg. \(2\text{C}_2\text{H}_6 + 7\text{O}_2 \rightarrow 4\text{CO}_2 + 6\text{H}_2\text{O}\)
- How many moles of \(\text{O}_2\) react with 6 moles of \(\text{C}_2\text{H}_6\)?

Can ask how much product is formed:
- \(2\text{C}_2\text{H}_6 + 7\text{O}_2 \rightarrow 4\text{CO}_2 + 6\text{H}_2\text{O}\)
How many moles of \(\text{H}_2\text{O}\) are produced when 12 moles of \(\text{C}_2\text{H}_6\) react?

3. Mass - Mole Stoichiometry

\[
3\text{I}_2(\text{g}) + 6\text{F}_2(\text{g}) \rightarrow 2\text{IF}_5(\text{g}) + \text{I}_4\text{F}_2(\text{g})
\]
- How many moles of \(\text{I}_4\text{F}_2(\text{g})\) are produced by 5.40 mol of \(\text{F}_2(\text{g})\)?

- How many moles of \(\text{F}_2(\text{g})\) are required to produce 4.50 mol of \(\text{IF}_5(\text{g})\)?

HOMEWORK:
Stoichiometry Worksheet 1 - Mole-Mole Conversions
Stoichiometry Notes

What if a quantity other than moles is used?
Commonly, in the laboratory, quantities are measured in grams using the balance.

Example:
How many moles of silver metal are produced if 85.0g of copper metal react?
\[ \text{Cu(s)} + 2\text{AgNO}_3(aq) \rightarrow 2\text{Ag(s)} + \text{Cu(NO}_3)_2(aq) \]

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Mole Unit:

From mass of chemical #1 to moles of chemical #2, there are two steps:

- Convert mass of chemical #1 to moles of chemical #1 by dividing by the molar mass:

\[
\frac{85.0\text{g Cu}}{63.5\text{g Cu/mol}} = 1.336\text{ mol Cu}
\]

- Convert moles of chemical #1 to moles of chemical #2 using the mole ratio (coefficient ratio).

\[
\frac{1.336\text{ mol Cu}}{2 \text{ mol Ag}} = 2.68\text{ mol Ag}
\]

This entire calculation can be done in one table:

<table>
<thead>
<tr>
<th>Mass of Chemical #1</th>
<th>1 mol Chemical #1</th>
<th>Moles Chemical #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molar Mass Chemical #1</td>
<td>Moles Chemical #1</td>
<td></td>
</tr>
</tbody>
</table>

Step 1 – divide by molar mass
Step 2 – multiply by mole ratio (mole bridge or coefficient ratio)

- In the reaction \(2\text{Na}_2\text{CO}_3 \rightarrow 4\text{Na} + 2\text{CO}_2 + \text{O}_2\), there are 0.50g of sodium carbonate reacting. How many moles of Na does it produce?

Step 1

Step 2
In the reaction \(2\text{Na}_2\text{CO}_3 \rightarrow 4\text{Na} + 2\text{CO}_2 + \text{O}_2\), there are 4.50 mol of oxygen produced. How many grams of \(\text{CO}_2\) does it produce?

<table>
<thead>
<tr>
<th>Mass of Chemical #1</th>
<th>Moles of Chemical #1</th>
<th>The Mole Bridge</th>
<th>Moles of Chemical #2</th>
<th>Mass of Chemical #2</th>
</tr>
</thead>
</table>

If the amount of moles is given, and the mass needs to be found, reverse the order of operations:

- \(\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}\)
- In this reaction, there were \(3.00 \times 10^{-3}\) mol of carbon dioxide produced. How many grams of \(\text{CH}_4\) were used?
- \(\text{1 Fe}_2\text{O}_3 + 3 \text{CO} \rightarrow 2 \text{Fe} + 3\text{CO}_2\)
- In this reaction, 5.00g of iron (III) oxide were reacted. How many moles of \(\text{CO}\) react?

Try these two questions with the person sitting next to you. Write your answer in the next square using a calculation table:

HOMEWORK:
Stoichiometry Worksheet #2


Stoichiometry Map
From mass of chemical #1 to mass of chemical #2, there are three steps:
• Convert chemical #1 from mass to moles by dividing by the molar mass
• Convert moles of chemical #1 to moles of chemical #2 using the mole ratio (coefficients).
• Convert chemical #2 from moles to mass by multiplying by the molar mass

This is usually shown in one step:

<table>
<thead>
<tr>
<th>Mass (in g) of compound 2</th>
<th>mass of compound 1</th>
<th>1 mol of compound 1</th>
<th>molar mass of compound 1</th>
<th>Mole of compound 2</th>
<th>Molar mass of compound 2</th>
<th>Mole ratio (mol/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass given</td>
<td>molar mass</td>
<td>mole ratio (mol/mol)</td>
<td>molar mass</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An example:
• In the reaction $2Na_2CO_3 \rightarrow 4Na + 2CO_2 + O_2$, there are 0.50g of sodium carbonate reacting. How many grams of CO$_2$ does it produce?

An example:
• $2Al + 3 CuO \rightarrow Al_2O_3 + 3Cu$
• What mass of Aluminum would react with 120g of CuO?

• What mass of Copper would be produced from 15.5g of Aluminum?

HOMEWORK:
Stoichiometry Worksheet #3

- If you start and end with a quantity other than moles, there are three steps:
  - Convert quantity given to moles for chemical #1 (using its molar mass, Avogadro’s number, or molar volume of 22.4L/mol of gas)
  - Use the mole ratio (from coefficients) to convert from moles of chemical #1 to moles of chemical #2.
  - Change moles of chemical #2 to the quantity required by using molar mass, Avogadro’s number, or molar volume of 22.4L/mol of gas.

An example:

- $3\text{NO}_2(g) + \text{H}_2\text{O}(l) \rightarrow 2\text{HNO}_3(aq) + \text{NO}(g)$

At STP, what mass of water is needed to react with 15.5L of nitrogen dioxide?

At STP, what volume of nitrogen monoxide would be produced from 100.0g of water?

Stoichiometry Map

An example:

- $2\text{NH}_3(g) \rightarrow \text{N}_2(g) + 3\text{H}_2(g)$

At STP, what volume of H₂ is produced when 20.0L of NH₃ react?

Notice that when volume-volume calculations are done, the molar volume cancels out. The above calculations could be written like a mole-mole problem:

$\frac{20.0\text{L NH}_3}{2\text{ mol NH}_3} \cdot \frac{3\text{ mol H}_2}{1\text{ mol NH}_3} = 30.0\text{ mol H}_2$
An example:

3. $2C_6H_{14}(s) + 19O_2(g) \rightarrow 12CO_2(g) + 14H_2O(l)$

a) At STP, what volume of CO$_2$ is produced when $2.45 \times 10^{23}$ molecules of C$_6$H$_{14}$ react?

b) What volume of oxygen is required to produce 18.93L of liquid H$_2$O (density of 0.97g/cm$^3$) at 60 degrees C?

*** Note that 1L = 1000cm$^3$

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

18.93L H$_2$O

HOMEWORK:
Stoichiometry Worksheet #4

6. Excess and Limiting Reactants

Excess and Limiting Reactant Definitions

Limiting reactant:

Excess reactant:

Since the limiting reactant is what determines when the reaction is over, it is this quantity that we use for stoichiometric calculation.

An analogy:
Consider making a sandwich. In each sandwich I’d like to have:
- 2 pieces of bread (Br)
- 4 tomato slices (To)
- 2 pieces of chicken (Ch)

$2Br + 4To + 2Ch \rightarrow 1Br:To:Ch$

2Br + 4To + 2Ch

But what if I had 10 bread, 26 tomatoes, and 12 chicken slices?

<table>
<thead>
<tr>
<th>10 Br</th>
<th>1 sandwich</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Br</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>26 To</th>
<th>1 sandwich</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 To</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>12 Ch</th>
<th>1 sandwich</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Ch</td>
<td></td>
</tr>
</tbody>
</table>

1 sandwich

is the limiting reactant, as we can only make sandwiches, and then we are sandwiches.
Stoichiometry Notes

Excess tomatoes and cheese:

<table>
<thead>
<tr>
<th>Sandwiches</th>
<th>Cheese</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4 To</td>
</tr>
<tr>
<td>1</td>
<td>2 Ch</td>
</tr>
</tbody>
</table>

There will be tomatoes in excess

There will be pieces of cheese in excess

Example

2Al + 3 CuO → Al₂O₃ + 3Cu

Calculate the grams of Al₂O₃ produced when 54.0g Al reacts with 124g of CuO?

1. Calculate moles of both potential product amounts.

<table>
<thead>
<tr>
<th>54.0g Al</th>
<th>124g CuO</th>
</tr>
</thead>
</table>

2. Pick the smallest answer. This reactant will be the limiting reactant and this is the moles of product formed.

Al: can potentially make mol Al₂O₃
CuO: can potentially make mol Al₂O₃

Therefore,

is the limiting reactant, as it produces the least amount of product!

Al₂O₃ are produced. is in excess.

Example:

2Ca₃(PO₄)₂ + 6SiO₂ + 10C ⇒ P₄ + 6CaSiO₃ + 10CO

A) What mass of P₄ is produced when 41.5g of Ca₃(PO₄)₂, 26.5g of SiO₂, and 7.80g of C are reacted?

B) How many grams of each excess reactant will remain unreacted?
1. Potential moles of product: 

3. Mass of $P_4$ produced: 

4. Mass of $\text{in excess}$: 

4. Mass of $\text{in excess}$: 

**HOMEWORK:** 
Limiting Reactant Worksheet