Stoichiometry Notes

Unit 7 - STOICHIOMETRY
1. Introduction to Stoichiometry
2. Mole-Mole Stoichiometry
3. Mass-Mole Stoichiometry
4. Mass-Mass Stoichiometry
5. Mass-Volume & Volume-Volume Stoichiometry
6. Excess & Limiting Reactants

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1. Introduction to Stoichiometry

Stoichiometry:

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


Stoichiometry

Derived from the Greek
"*stoicheion*" or element and
"*metron*" or measure.
This is the term we use to refer
to all quanititative aspects of
chemical composition and reaction

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

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$
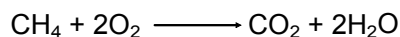
1 methane molecule reacts with two oxygen molecules to produce 1 carbon dioxide molecule and two water molecules
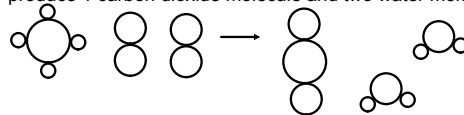
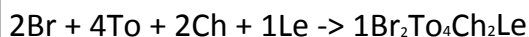The balanced reaction is the ratio or 'recipe' we need for the reaction to occur.

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)
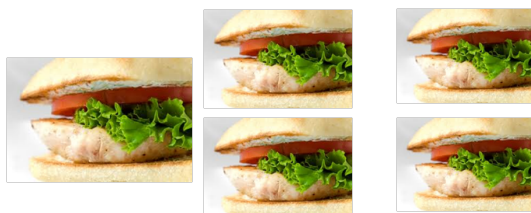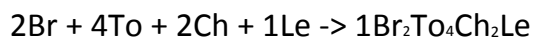- 1 piece of lettuce (Le)
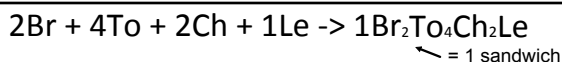- Sandwich equation:

$2Br + 4To + 2Ch + 1Le \rightarrow 1Br_2To_4Ch_2Le$

1 sandwich

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

$2Br + 4To + 2Ch + 1Le \rightarrow 1Br_2To_4Ch_2Le$

$2Br + 4To + 2Ch + 1Le \rightarrow 1Br_2To_4Ch_2Le$

↖ = 1 sandwich

5 sandwiches	2Br	
	1 sandwich	= 10 Bread Slices

5 sandwiches		
		= Tomatoes

		= Chicken Slices

		= Lettuce pieces

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recipe for 1 sandwich:

$2Br + 4To + 2Ch + 1Le \rightarrow 1Br_2To_4Ch_2Le$
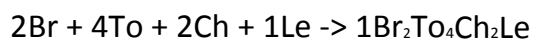
x 5

recipe for 5 sandwiches

$10Br + 20To + 10Ch + 5Le \rightarrow 5Br_2To_4Ch_2Le$
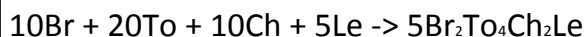
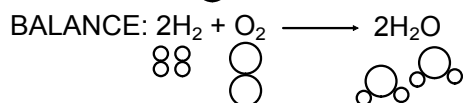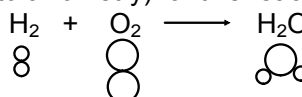**And now for some chemicals!**
Determining the amount of each component of a sandwich is like using moles in a chemical equation.

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?

$$H_2 + O_2 \longrightarrow H_2O$$

BALANCE: $2H_2 + O_2 \longrightarrow 2H_2O$

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

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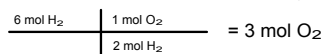The coefficients refer to the amount of molecules which are involved in a reaction.

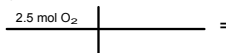The amount of molecules can also be termed as the amount in moles.

Eg. $2 H_2 + O_2 \rightarrow 2H_2O$
Is the same as:
   $2 \text{ mol } H_2 + 1 \text{ mol } O_2 \rightarrow 2 \text{ mol } H_2O$
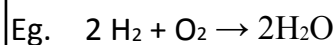
So how many moles of oxygen are needed to react with 6 moles of hydrogen?

$$\frac{6 \text{ mol } H_2}{} \times \frac{1 \text{ mol } O_2}{2 \text{ mol } H_2} = 3 \text{ mol } O_2$$

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

$$\frac{2.5 \text{ mol } O_2}{} \quad\Big|\quad =$$

If 0.5 moles of water are produced, how many moles of hydrogen reacted? oxygen?

$$\underline{\quad\quad}\Big|\underline{\quad\quad} = \quad \underline{\quad\quad}\Big|\underline{\quad\quad}$$

Stoichiometry Notes

2. Mole - Mole Stoichiometry

Moles of Chemical #1	The Moles Bridge	Moles of Chemical #2
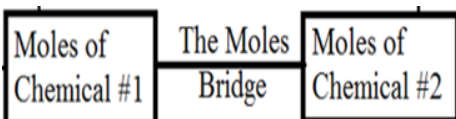
Example:
How many moles of water are produced if you react 2.5 moles of oxygen?

$$\frac{\quad\quad}{\quad\quad} \Big| \frac{\quad\quad}{\quad\quad} = $$

Can ask how much reactant is needed:
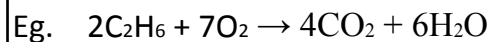
Eg. $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$
- How many moles of O_2 react with 6 moles of C_2H_6?

Can ask how much product is formed:

- $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$
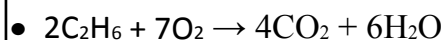
How many moles of H_2O are produced when 12 moles of C_2H_6 react?

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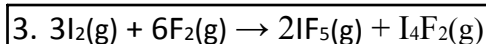
3. $3I_2(g) + 6F_2(g) \rightarrow 2IF_5(g) + I_4F_2(g)$
- How many moles of $I_4F_2(g)$ are produced by 5.40 mol of $F_2(g)$?

- How many moles of $F_2(g)$ are required to produce 4.50 mol of $IF_5(g)$?

HOMEWORK:
Stoichiometry Worksheet 1 -
Mole-Mole Conversions
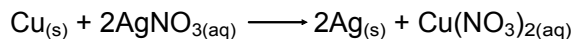
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3. Mass - Mole Stoichiometry

Stoichiometry Notes
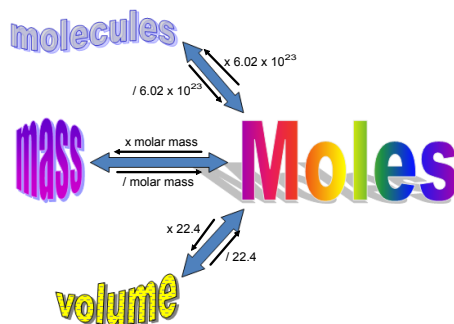
What if a quantity other than moles is used?

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?
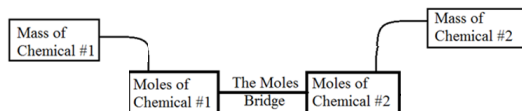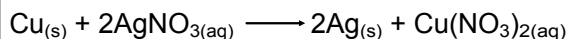
$Cu_{(s)} + 2AgNO_{3(aq)} \longrightarrow 2Ag_{(s)} + Cu(NO_3)_{2(aq)}$

Mole Unit:

Example:
How many moles of silver metal are produced if 85.0g of copper metal react?

$Cu_{(s)} + 2AgNO_{3(aq)} \longrightarrow 2Ag_{(s)} + Cu(NO_3)_{2(aq)}$

Step 1: mass of chemical #1 (Cu) to moles of chemical #1 (Cu)
Step 2: moles of chemical #1 (Cu) to moles of chemical #2 (Ag)

From mass of chemical #1 to moles of chemical #2, there are two steps:
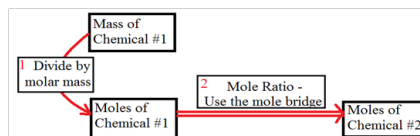• Convert mass of chemical #1 to moles of chemical #1 by dividing by the molar mass:

85.0g Cu	1 mol Cu
	63.5g Cu

= <u>1.33</u>86 mol Cu

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

<u>1.33</u>86 mol Cu	2 mol Ag
	1 mol Cu

= 2.68 mol Ag

This entire calculation can be done in one table:

mass chemical #1	1 mol chemical #1	Moles chemical #2
	molar mass chemical #1	Moles chemical #1

Mass given

Step 1 – divide by molar mass

Step 2 – multiply by mole ratio (mole bridge OR coefficient ratio)
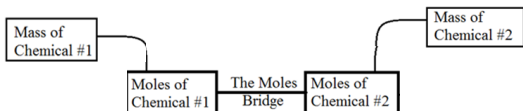
= moles of chemical #2

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

Step 1   Step 2

Stoichiometry Notes

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

- In the reaction $2Na_2CO_3 \rightarrow 4Na + 2CO_2 + O_2$, there are 4.50 mol of oxygen produced. How many grams of CO_2 does it produce?

Try these two questions with the person sitting next to you. Write your answer in the next square using a calculation table:
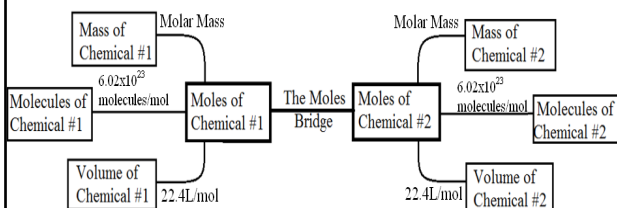
- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- In this reaction, there were 3.00×10^{-3} mol of carbon dioxide produced. How many grams of CH_4 were used?

- $1\ Fe_2O_3 + 3\ CO \rightarrow 2\ Fe + 3CO_2$
- In this reaction, 5.00g of iron (III) oxide were reacted. How many moles of CO react?
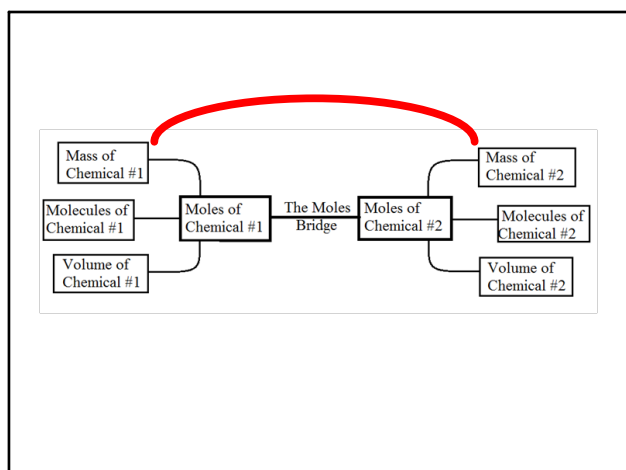
4. Mass - Mass Stoichiometry

Stoichiometry Map

Stoichiometry Notes

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:

mass compound 1	1 mol compound 1	Mole compound 2	Molar mass compound 2
	molar mass compound 1	Moles compound 1	1 mol compound **2**
Mass given	molar mass	mole ratio (mole bridge)	molar mass

= mass (in g) of compound 2

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?
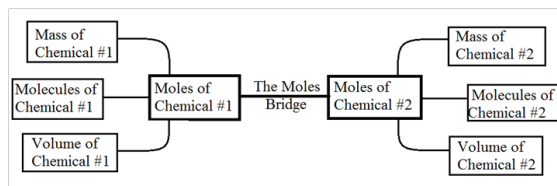
An example:

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

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

<u>HOMEWORK:</u>
Stoichiometry Worksheet #3

### 5. Mass–Volume and Volume-Volume Stoichiometry

- **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:
- $3NO_{2(g)} + H_2O_{(l)} \rightarrow 2HNO_{3(aq)} + NO_{(g)}$
- At STP, what mass of water is needed to react with 15.5L of nitrogen dioxide?

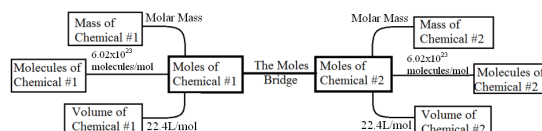- At STP, what volume of nitrogen monoxide would be produced from 100.0g of water?
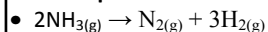
An example:
- $2NH_{3(g)} \rightarrow N_{2(g)} + 3H_{2(g)}$
At STP, what volume of H_2 is produced when 20.0L of NH_3 react?

Notice that when volume-volume calculations are done, the molar volume cancels out. The above calculations could be written like a mole-mole problem:
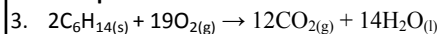
20.0L NH_3	3 mol H_2	
	2 mol NH_3	= 30.0 mol H_2

Stoichiometry Map

Stoichiometry Notes

An example:
3. $2C_6H_{14(s)} + 19O_{2(g)} \rightarrow 12CO_{2(g)} + 14H_2O_{(l)}$
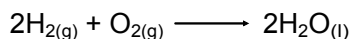a) At STP, what volume of CO_2 is produced when 2.45×10^{23} molecules of C_6H_{14} react?

b) What volume of oxygen is required to produce 18.93L of liquid H_2O (density of $0.97g/cm^3$) at 60 degrees C?
*** Note that $1L = 1000cm^3$

$$2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(l)}$$

18.93L H_2O				

=

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)

$$2Br + 4To + 2Ch \rightarrow 1Br_2To_4Ch_2$$

1 sandwich

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

10 Br	1 sandwich	= sandwiches
	2 Br	

26 To	1 sandwich	= sandwiches
	4 To	

12 Ch	1 sandwich	= sandwiches
	2 Ch	

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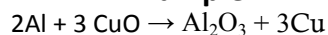
Stoichiometry Notes

Excess tomatoes and cheese:

5 sandwiches	4 To
	1 sandwich

= tomatoes

There will be **tomatoes in excess**

5 sandwiches	2 Ch
	1 sandwich

= cheese

There will be **pieces of cheese in excess**

Example
$$2Al + 3\ CuO \rightarrow Al_2O_3 + 3Cu$$
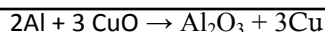
Calculate the grams of Al_2O_3 produced when 54.0g Al reacts with 124g of CuO?

1. Calculate moles of both potential product amounts.

54.0g Al		

$$2Al + 3\ CuO \rightarrow Al_2O_3 + 3Cu$$

Calculate the grams of Al_2O_3 produced when 54.0g Al reacts with 124g of CuO?

2. Pick the smallest answer. This reactant will be the limiting reactant and this is the moles of product formed.
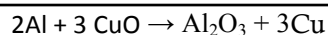
Al: can potentially make _____ mol Al_2O_3

CuO: can potentially make _____ mol Al_2O_3

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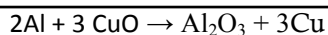_____ is the limiting reactant, as it produces the least amount of product!

_____ is the **limiting reactant**. Therefore,

Al_2O_3 are produced. _____ is in **excess.**

$$2Al + 3\ CuO \rightarrow Al_2O_3 + 3Cu$$

Calculate the grams of Al_2O_3 produced when 54.0g Al reacts with 124g of CuO?

3. Convert the limiting reactant moles to grams.

$$2Al + 3\ CuO \rightarrow Al_2O_3 + 3Cu$$

Calculate the grams of Al_2O_3 produced when 54.0g Al reacts with 124g of CuO?

4. To find the mass of excess reactant left over, use moles of product formed to determine mass of reactant. Then subtract from the original amount.

Example:

$$2Ca_3(PO_4)_2 + 6SiO_2 + 10C \Rightarrow P_4 + 6CaSiO_3 + 10CO$$
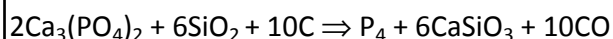
A) What mass of P_4 is produced when 41.5g of $Ca_3(PO_4)_2$, 26.5g of SiO_2, and 7.80g of C are reacted?

B) How many grams of each excess reactant will remain unreacted?

Stoichiometry Notes

1. Potential moles of product:

3. Mass of P_4 produced:

4. Mass of _____ in excess:

4. Mass of _____ in excess:

HOMEWORK:
Limiting Reactant Worksheet