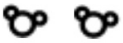
Unit 11 Stoichiometry

The mol and compounds

# of H_2O molecules	# of H atoms	# of O atoms
1 		
2 		
3 		
100		
6.02×10^{23}		

mass:	mass:	mass:

a. molar mass: the mass of one mole of a substance
- Example: Water's molar mass is 18g / 1 mol

Steps to find molar mass:

1. Write out atomic symbols for each element
2. Put how many atoms of each element you have
3. Put the atomic mass of the elements
4. Multiply 2 and 3
5. Add all of the products together

Examples: Find the molar mass of the following substances

Lead (IV) Oxide - PbO_2

Answer:

Nitric Acid - HNO_3

Answer:

Ammonium Phosphate - $(NH_4)_3PO_4$

Answer:

5. <u>Percent Composition</u> - the mass percentage of each element in a compound

$$\% \text{ of element} = \frac{\text{g of element}}{\text{molar mass of compound}} \times 100$$

Example:
Lead (IV) Oxide - PbO_2

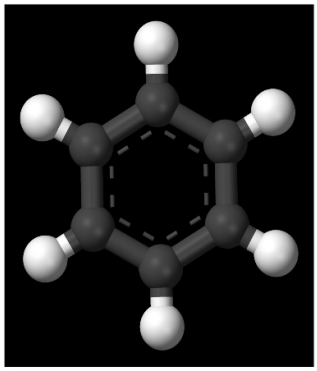
Ammonium Phosphate - $(NH_4)_3PO_4$

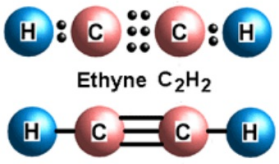
6. **<u>Empirical Formulas</u>** - the smallest ratio of elements that are in a compound

Example: C_6H_6 --> CH (empirical formula)

C_2H_2 --> CH (empirical formula)

Both have the same empirical formula - are not the same compound





How to find an Empirical Formula from Experimental Data

1. Find the number of grams of each element

2. Convert each number of grams to mols

3. Divide each "number of mols" by the smallest "number of mols"

4. Use ratio to find formula
   - the number you come up with tells you how many atoms of each element you have

Example:

A compound is 45.5% yttrium and 54.5% chlorine. Find its empirical formula.

Answer:

Example:

A ruthenium/sulfur compound is 67.7% Ru. Find its empirical formula.

Answer:

Example:

A 17.4g sample of a technetium/oxygen compound contains 11.07g of Tc. Find its empirical formula.

Answer:

Example:

A compound contains 4.63g lead, 0.56g nitrogen, and 1.92g oxygen. Find its empirical formula. Name the compound.

Answer:

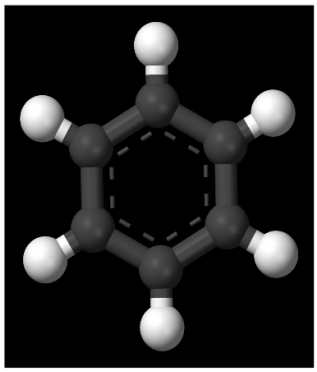
7. **Molecular Formulas** - the actual ratio of elements that are in a compound

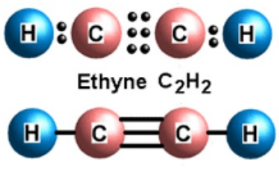
Example: C_6H_6 (molecular formula) --> CH (empirical formula)

C_2H_2 (molecular formula) --> CH (empirical formula)

- Different number of atoms
- Unique molecular formula
- Different molar mass

Both have the same empirical formula - are not the same compound





How to find Molecular Formula from Experimental Data

1. Find empirical formula

2. Find molar mass of empirical formula

3. Find $n = \frac{\text{mm molecular}}{\text{mm empirical}}$

4. Multiply all parts of empirical formula by n

Example:

A carbon/hydrogen compound is 7.7% hydrogen and has a molar mass of 78g. Find its molecular formula.

Answer: [redacted]

Example:

A compound has 26.44g nitrogen, 60.20g oxygen, and a molar mass of 92g. Find the molecular formula.

Answer: [redacted]

Example:

A 60g sample of a compound composed of carbon and hyrdogen was found to be 8.6g hydrogen and has a molar mass of 112 g/mol. What is the molecular formula of this compound?

Answer:

8. **Hydrates and Anhydrous Salts**

a. **anhydrous salt**: an ionic compound (a salt) that attracts water molecules and forms loose chemical bonds with them; symbolized by "MN" (metal-nonmetal)

b. "**anhydrous**" means without water

c. Uses: desiccants in leather goods, electronics, and vitamins (to keep leather dry)

d. **hydrate**: an anhydrous salt with the water attached

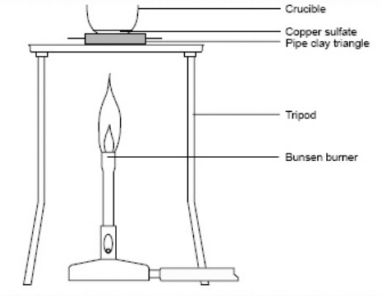
- symbolized by $MN \cdot ? H_2O$

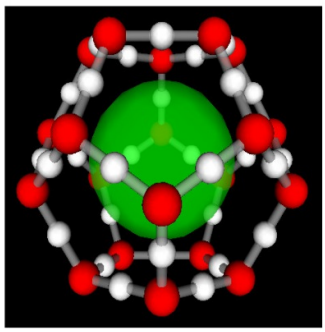
- Examples: $CuSO_4 \cdot 5 H_2O$
  $BaCl_2 \cdot 2 H_2O$
  $FeCl_3 \cdot 6 H_2O$

How do we find the formula of a hydrate?

$$\begin{matrix} H_2O & H_2O \\ H_2O & MN & H_2O \\ H_2O & H_2O \end{matrix} \xrightarrow{\text{Heat}} MN + \begin{matrix} H_2O \\ H_2O \quad H_2O \quad H_2O \\ H_2O \quad H_2O \end{matrix}$$

Hydrate — Anhydrous Salt — Water





Finding the Formula of Hydrate

1. Find the number of grams of MN and number of grams of H_2O

2. Convert grams to mols

3. Divide each number of mols by the smallest number of mols.

4. Use the ratio to find the hydrate's formula.

Examples:

Find the formula of the hydrate from the following information:

sample's mass before heating = 4.38g ($MN \cdot H_2O$)

sample's mass after heating = 1.93g (MN)

molar mass of anhydrous salt = 85g

Answer:

Examples:

Find the formula of the hydrate from the following information:

beaker = 46.82g

beaker + sample before heating = 54.35g

beaker + sample after heating = 50.39g

molar mass of anhydrous salt = 129.9g

Answer:

Examples:

Find the formula of the hydrate from the following information:

beaker = 47.28g

beaker + sample before heating = 53.84g

beaker + sample after heating = 51.48g

molar mass of anhydrous salt = 128g

Answer:

Find the % compostion of water and MN.

Answer:

Examples:

Washing soda, Na_2CO_3, is actually a hydrate that is composed of 62.93% water. What is the formula of this hydrate?

Answer:

1. **Stoichiometry** involves finding the amount of reactants and/or products in a chemical reaction.

2. Why is Stoichiometry important? Consider the following examples:

Internal Combustion Engine:

Balance the following equation:

$$\_\_\_\_C_8H_{18} + \_\_\_\_O_2 \text{ -----> } \_\_\_\_CO_2 + \_\_\_\_H_2O$$

Now, try this equation:

$$\_\_\_\_C_8H_{18} + \_\_\_\_O_2 \text{ -----> } \_\_\_\_C + \_\_\_\_H_2O$$

What is the difference?

Another example:

Balance the following equations:

____C_3H_8 + ____O_2 -----> ____CO_2 + ____H_2O + energy

____C_3H_8 + ____O_2 -----> ____CO + ____H_2O + energy

____C_3H_8 + ____O_2 -----> ____C + ____H_2O + energy

3. Basic Chemical Equation:

$R_A + R_B \rightarrow P_1 + P_2$

If we know the:	One can find the...
Amount of R_A (or R_B)	The amount of the other reactant needed to react
Amount of R_A or R_B	Amount of P_1 or P_2 that will be produced
Amount of P_1 or P_2 you need to produce	Amount of R_A and/or R_B you must use

Example: Big Mac

___ patties + 3 buns

4 patties + 6 buns --> ____ Big Macs

___ patties + ____ buns ----> 25 Big Macs

So how does this work? Let's look at a similar type of situation.

Proportional Relationships

2 1/4 c. flour	3/4 c. brown sugar
1 tsp. baking soda	1 tsp vanilla extract
1 tsp. salt	2 eggs
1 c. butter	2 c. chocolate chips
3/4 c. sugar	Makes 5 dozen cookies.

I have 5 eggs. How many cookies can I make?

4. Calculations in Stoichiometry - Mol Island

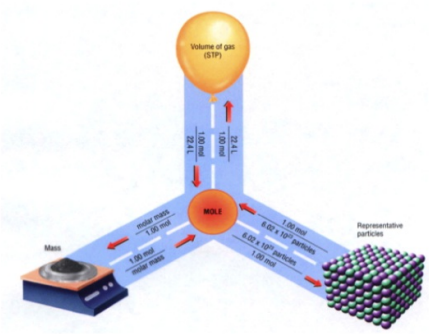
- There are four conversion you will need to know

    1. molar mass (g/mol)

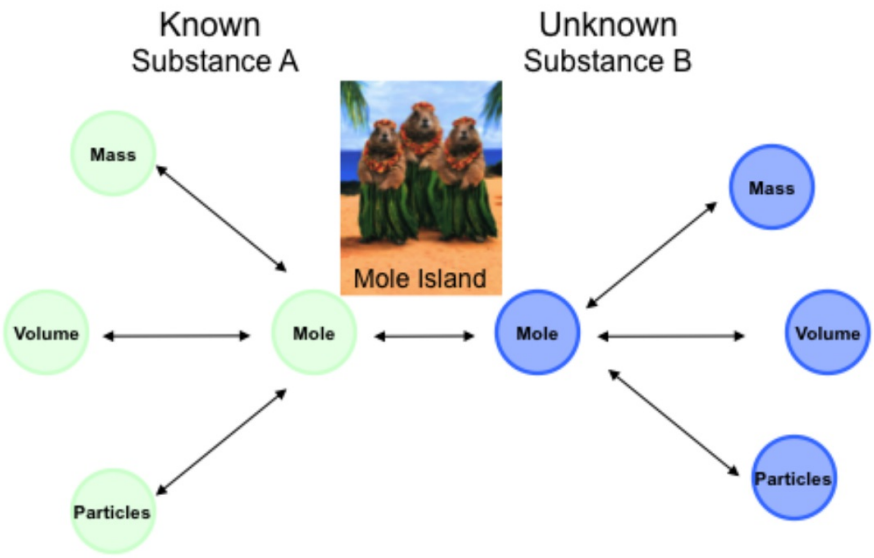
    2. Avogadro's Number (6.02×10^{23} particles/mol)

    3. Volume (22.4 L/mol @ STP)

    4. Mol-Mol Ratio (between reactants and/or products)
        - This comes from the balanced chemical equation



Stoichiometry Island Diagram



Stoichiometry Island Diagram

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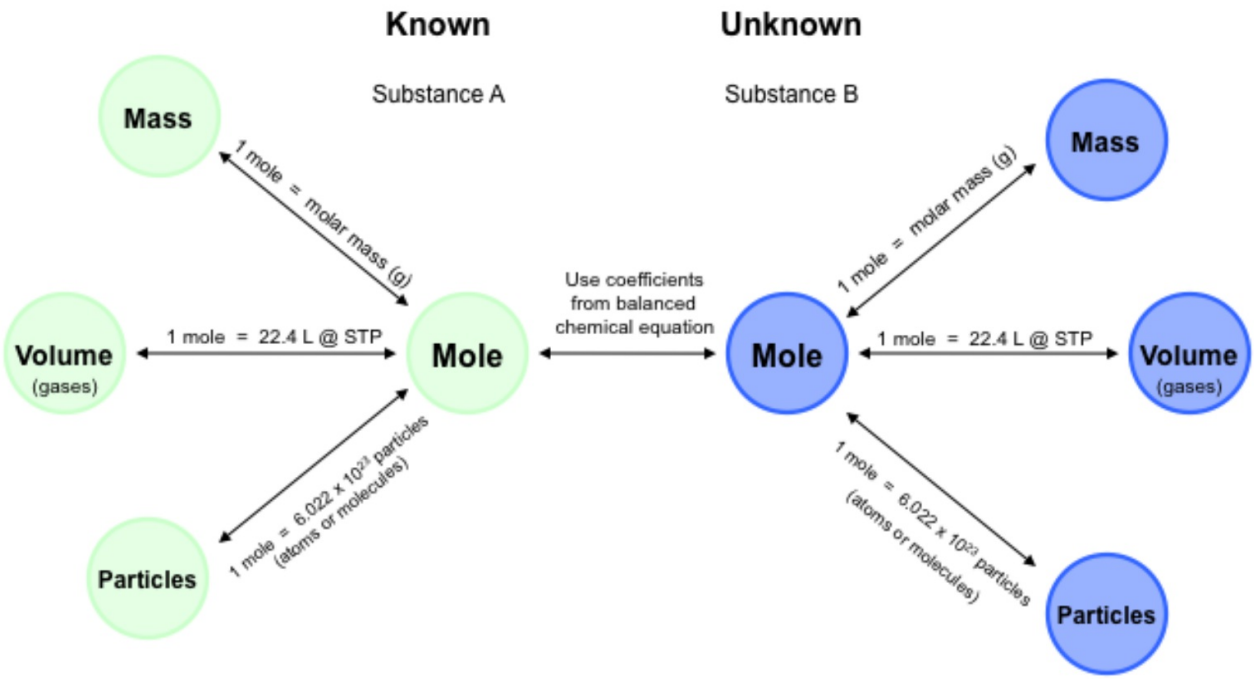


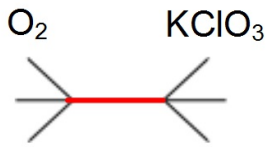
Stoichiometry Island Diagram

Stoichiometry Problems

How many moles of $KClO_3$ must decompose in order to produce 9 moles of oxygen gas?

$$2KClO_3 \rightarrow 2KCl + 3O_2$$

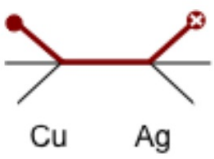
? mol 9 mol



How many grams of silver will be formed from 12.0 g copper?

$$Cu + 2\,AgNO_3 \rightarrow 2\,Ag + Cu(NO_3)_2$$

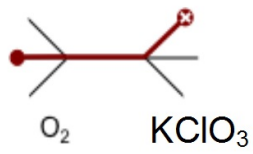
12.0 g ? g



How many grams of $KClO_3$ are required to produce 9.00 L of O_2 at STP?

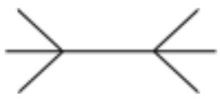
$$2KClO_3 \rightarrow 2KCl + 3O_2$$

? g 9.00 L



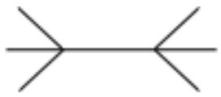
___ Cu + ___ $AgNO_3$ --> ___ Ag + ___ $Cu(NO_3)_2$

If you have 300g of $AgNO_3$, how many grams of copper nitrate would be produced?



___ TiO_2 + ___ Cl_2 + ___ C --> ___ CO_2 + ___ CO + ___$TiCl_4$

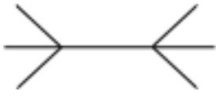
If you have 115 grams of titanium oxide, how many particles of titanium chloride would be produced?



Answer:

$2\ TiO_2 + 4\ Cl_2 + 3\ C \rightarrow 1\ CO_2 + 2\ CO + 2\ TiCl_4$

If you have 4.55 mols of carbon, how many mols of chlorine gas will be needed?



Answer:

$2\ TiO_2 + 4\ Cl_2 + 3\ C \rightarrow 1\ CO_2 + 2\ CO + 2\ TiCl_4$

If you have 4.55 mols of carbon, how many grams of titanium oxide will you need?

Answer:

Iron (III) combines with oxygen gas to form iron (III) oxide.

If you have 223g of Fe, how many grams of iron(III) oxide would be produced?

If you have 179 L of oxygen gas, how many grams of iron(III) oxide would be produced?

If you needed to produce 500 L of chlorine gas, how many grams of sodium chloride must be used in this single replacement reaction and what other halogen must be used?

The combustion of 2.5 kg of octane (C_8H_{18}) results in how many liters of carbon dioxide and water?

3 helpful reminders for the island diagram

1. Get everything to the mol to convert. Use coeffecient from the balanced chemical equation to find ratio between reactants and/or products. This is the only time the mol does not have to be 1.

2. The middle conversion (ratio conversion) is the only one with the different substances in it.

3. Read the question. Give the answer it is asking for.

The Limiting Reactant

Let us consider putting together tricyles:

You Need: 3 wheels, 2 pedals, 1 seat, and 1 handlebar

If we were to write out a chemical equation for a tricyle:

___W + ___P + ___S + ___H --> W_3P_2SH

Now: Consider the following:

With:	...and...	...one can make...
50 pedals	excess of all other reactants	___W_3P_2SH
50 seats	excess of all other reactants	___W_3P_2SH
50 wheels	50 seats and excess of all other reactants	___W_3P_2SH

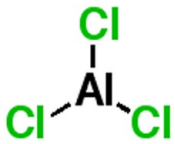
So, how does this apply to Chemistry? Consider the following example

Solid aluminum reacts with chlorine gas to yield aluminum chloride.

Write an equation.

If 125g Al reacts with excess chlorine, how many grams of aluminum chloride are made?

If 125g chlorine reacts with excess Al, how many grams of aluminum chloride are made?



If 125g of aluminum reacts with 125g of chlorine, how many grams of aluminum chloride are made?

Why???

<u>Limiting Reactant</u> (LR): the reactant that runs out first.
- the amount of product is based on the LR

Any reactant you don't run out of is an <u>excess reactant</u> (ER).

How do we find the limiting reactant?

For the generic reaction $R_a + R_B \rightarrow P_1$

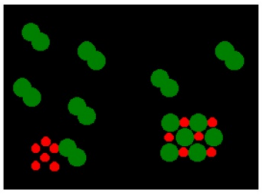
assume that the amount of R_a or R_b are given

Should you use R_a or R_b in your calculations?

1. Calculate the number of mols of R_a and R_b you have.

2. Divide by the respective coefficients in balanced chemical equation.

3. Reactant having the smaller result is the LR.



Examples:

Al / Cl_2 / $AlCl_3$ example:

125g of Al

125g of Cl_2

$2Al + 3Cl_2 \rightarrow 2AlCl_3$

$2Fe + 3Cl_2 \rightarrow 2FeCl_3$

You have 223g of Fe and 179L of Cl_2. Which is the limiting reactant?

How many grams iron(III) chloride is produced?

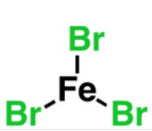
You have 13g of hydrogen gas and 80g of oxygen gas. Which reactant is the limiting reactant when these two gases combine to form water?

How much water is formed?

How much of each reactant is left over?

181g of iron (III) reacts with 96.5L of bromine gas to produce Iron(III) bromide. Which reactant is the limiting reagent and how much product is produced?

How many grams of each reactant are left over?



$FeBr_3$

Iron (III) bromide (ferric bromide) is a Lewis acid. It is useful for promoting the bromination of aromatic compounds, as well as in the Friedel-Crafts reaction.

Percent Yield

Let's consider the following reaction:

molten sodium reacts with solid aluminum oxide to produce molten aluminum and solid sodium oxide

Find mass of aluminum produced if you start with 575g of Na and 357g of aluminum oxide.

The amount of product is the theoretical yield.

- amount of product if reaction is perfect
- found by calculation

Now supposed that we perform this reaction in the lab and only got 172 grams of aluminum.

Why did this happen?

- couldn't collect all Al
- not all Na and Al_2O_3 reacted
- some reactant or product spilled and was lost

Percent Yield - percentage of product that was produced

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

% yield cannot be larger than 100%

Calculate the % yield of aluminum from example

$B_2H_6 + 3\ O_2 \rightarrow B_2O_3 + 3\ H_2O$

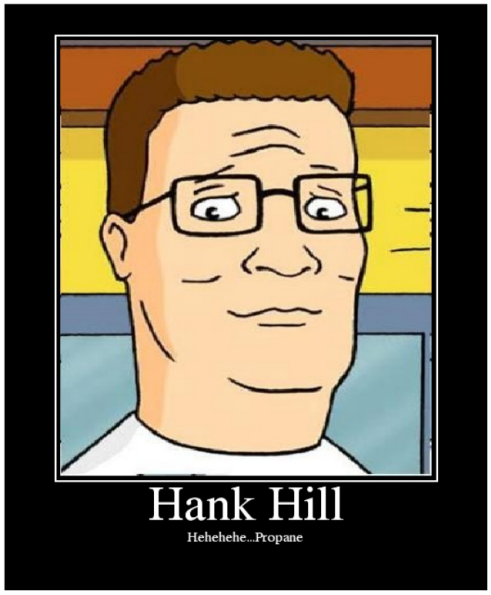
If you have 10g of B_2H_6 and 30g of oxygen, how many grams of B_2O_3 would be produced?

Boron Oxide Powder

If only 19.7g of B_2O_3 was produced, what was the percent yield?

200g of propane (C_3H_8) reacts with 200g of oxygen to produced carbon dioxide and water. How much water is produced?

If only 78g of water was produced, what is the % yield?



Example:

Automobile air bags inflate with nitrogen via the decomposition of sodium azide:

$2\ NaN_3 \rightarrow 3\ N_2 + 2\ Na$

At STP and a % yield of 85%, what mass of sodium azide is needed to yield 74 L nitrogen?

__ZnS + __O_2 --> __ZnO + __SO_2
100g 100g

How much ZnO is produced when the reaction only produces 81% of product?

Aluminum reacts with iron(III) oxide to produce 800g of Fe and aluminum oxide.

How much of each reactant must we use if this reaction only produces an 80% yield?