## Chapter 3 Vocabulary:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>average atomic mass</td>
<td>the weighted average mass of the atoms in a naturally occurring element</td>
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<tr>
<td>Avogadro's Number</td>
<td>the number of atoms in exactly 12 grams of pure $^{12}\text{C}$, equal to 6.022 x $10^{23}$</td>
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<tr>
<td>chemical equation</td>
<td>a representation of a chemical reaction showing the relative numbers of reactant and product molecules.</td>
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<tr>
<td>empirical formula</td>
<td>the simplest whole number ratio of atoms in a compound.</td>
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<tr>
<td>Haber process</td>
<td>the manufacture of ammonia from nitrogen and hydrogen, carried out at high pressure and high temperature with the aid of a catalyst.</td>
</tr>
<tr>
<td>limiting reactant (reagent)</td>
<td>the reactant that is completely consumed when a reaction is run to completion</td>
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<tr>
<td>mass spectrometer</td>
<td>an instrument used to determine the relative masses of atoms by the deflection of their ions on a magnetic field.</td>
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<tr>
<td>molar mass</td>
<td>the mass in grams of one mole of molecules or formula units of a substance</td>
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<tr>
<td>mass percent</td>
<td>the percent by mass of a given element in a compound.</td>
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<tr>
<td>mole</td>
<td>the number equal to the number of carbon atoms in exactly 12 grams of pure $^{12}\text{C}$: Avogadro's number. One more represents $6.022 \times 10^{23}$ units.</td>
</tr>
<tr>
<td>molecular formula</td>
<td>the exact formula of a molecule, giving the types of atoms and the number of each type.</td>
</tr>
<tr>
<td>mole ratio</td>
<td>the ratio of moles of one substance to moles of another substance in a balanced chemical equation.</td>
</tr>
<tr>
<td>percent yield</td>
<td>the actual yield of a product as a percentage of the theoretical yield.</td>
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</table>
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**products** - a substance resulting from a chemical reaction. It is shown to the right of the arrow in a chemical equation.

**reactants** - a starting substance in a chemical reaction. It appears to the left of the arrow in a chemical equation.

**stoichiometry** - the calculation of the quantities of material consumed and produced in chemical reactions.

**stoichiometric quantities** - quantities of reactants mixed in exactly the correct amounts so that all are used up at the same time.

**theoretical yield** - the maximum amount of a given product that can be formed when the limiting reactant is completely consumed.

**CONVERSIONS**

“Conversions” are what you need to do to “convert” one unit to another unit. The conversion is accomplished by multiplying the given unit by a conversion factor, which yields the wanted unit after the math is done. The conversion factor is a ratio that relates the given and wanted unit. (see eq 1)

\[
\text{given \ unit} \times \frac{\text{wanted \ unit}}{\text{given \ unit}} = \text{wanted \ unit} \quad \text{eq 1}
\]

Conversion equations are not sentences! They are never written left to right. First write the given number (#.#) and the given unit on the left, followed by an empty set of (--)’s with the fraction bar in it, then write the wanted unit on the right. Finally, fill in the ( )’s with the units: given unit on the bottom so it cancels, wanted unit on the top so you have an equality. NO numbers are in the ( )’s at this time!

The ratio of units tells you what numbers to write in the ( )’s. For mole conversions there are really only three potential ratios of units that you will have.

1. \((\frac{g}{mol})\) or \((\frac{mol}{g})\)

   g : mol ratios are the units of molar mass. It does not matter which unit is on the top or bottom the ratio is still molar mass. You calculate molar mass from the periodic table, by summing the atomic masses of all the atoms in the molecule. Molar mass is defined as the number of grams that are in one mole of a substance, so the numerical answer that you calculate always goes with the grams and a 1 always goes with the moles.

   For instance: molar mass of H\(_2\)O = 18.02. In a conversion factor this is written: \((\frac{18.02 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}})\) or \((\frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}})\)

   Note that the ratio is still the same ratio whether it is written as g/mol or mol/g, still 18.02 g of water in 1 mol of
water. Remember that the given and wanted units dictate which unit is on top or bottom in the conversion factor.

2. \((\frac{\text{mol} A}{\text{mol} B})\) or \((\frac{\text{mol} B}{\text{mol} A})\)

mol : mol ratios relate the number of a molecule in a chemical reaction to the number of another molecule in a chemical reaction. The values that are plugged into the conversion factor are the coefficient for each molecule, which are found in the balanced chemical equation.

For instance, consider \(2\text{NaN}_3 \rightarrow 2\text{Na} + 3\text{N}_2\). The mole ratio between \(\text{NaN}_3\) and \(\text{N}_2\) would be written as follows:

\[
\frac{2\text{ mol} \text{NaN}_3}{3\text{ mol} \text{N}_2} \quad \text{or} \quad \frac{3\text{ mol} \text{N}_2}{2\text{ mol} \text{NaN}_3}
\]

Note that the ratio is the same ratio whether it is written; \(\text{mol} \text{NaN}_3/\text{mol} \text{N}_2\) or \(\text{mol} \text{N}_2/\text{mol} \text{NaN}_3\), still 2 mol \(\text{NaN}_3\) to 3 mol \(\text{N}_2\). Remember that the given and wanted units dictate which unit is on top or bottom in the conversion factor.

3. \((\frac{\text{molecules}}{\text{mol}})\) or \((\frac{\text{mol}}{\text{molecules}})\)

The ratio of molecules to moles is by definition \(6.022 \times 10^{23}\) molecules in 1 mole. This ratio is written

\[
\left(\frac{\text{6.022} \times 10^{23} \text{ molecules}}{1 \text{ mol}}\right) \quad \text{or} \quad \left(\frac{1 \text{ mol}}{\text{6.022} \times 10^{23} \text{ molecules}}\right)
\]

Note that the ratio is the same ratio whether it is written; \(\text{molecules/mol}\) or \(\text{mol}/\text{molecule}\): \(6.022 \times 10^{23}\) molecules in 1 mol. Remember that the given and wanted units dictate which unit is on top or bottom in the conversion factor.

**STOICHIOMETRY**

Conversions become more difficult when no relationship between the given and wanted units exists in nature. This is mainly found in **STOICHIOMETRY** when you convert grams of one substance to grams of another substance. There is no ratio to express this! Molecules react by count (MOLES) not by mass! Therefore the following sequence must be done to convert grams of one substance to grams of another substance.

**example**

How many grams of \(\text{C}\) are produced from a given number of grams of compound \(\text{A}\), \# g \(\text{A}\), in the equation \(\text{aA} + \text{bB} \rightarrow \text{cC} + \text{dD}\)?

This must be calculated using the following series of conversions,

\[\# \text{ g A} \rightarrow \text{mol A} \rightarrow \text{mol C} \rightarrow \text{g C}\]

This is a sequence of three conversions. The first and third are \(\text{g/mol}\) conversions of type 1 above and the second is a \(\text{mol/mol}\) conversion of type 2 above. All three may be written as follows:

\[
given \# \text{ g A} \left(\frac{1 \text{ mol A}}{\# \text{ g A}}\right) \left(\frac{\# \text{ mol B}}{\# \text{ mol A}}\right) \left(\frac{\# \# \text{ g B}}{1 \text{ mol B}}\right) = wanted \text{ g B}
\]
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One thing to notice in stoichiometry is that the units all cancel on the diagonal. So, a quick way to check your work is to see if all the units are the same diagonally. If they are not, then one of your conversion factors is probably upside-down.

A second thing to notice is that whenever you need to relate an amount of one substance in a chemical equation with an amount of another substance in that equation; you are really doing a mole-to-mole conversion. You just have to do an extra step at the beginning to get to moles and then an extra step at the end to get away from the moles.

Overall, the three ( )’s problem outlined above works anytime that you have a stoichiometry problem that converts grams A → grams C. You can use this scheme to convert grams → grams of any 2 substances in a balanced chemical equation. (not just grams of a reactant to grams of a product).

What about grams A → mol C conversions? And what about mol A→ grams C conversions? These problems are really short stoichiometry problems. Check out the series that was listed above:

\[ g \text{ A} \rightarrow \text{mol A} \rightarrow \text{mol C} \rightarrow \text{g C} \]

Generally speaking identify where you are in the series (the given unit) and identify where you are to end in the series (the wanted unit), and do those conversions.

For example,

**grams A → mol C**

\[ \text{scheme} \quad g \text{ A} \rightarrow \text{mol A} \rightarrow \text{mol C} \rightarrow \text{g C} \]

\[ \text{given} \quad g \text{ A} \quad \text{wanted} \quad \text{mol C} \]

Overall 2 conversions (2 →'s): g A → mol A → mol C

So, do the first TWO ( )'s of stoichiometry.

**mol A → grams C**

\[ \text{scheme} \quad g \text{ A} \rightarrow \text{mol A} \rightarrow \text{mol C} \rightarrow \text{g C} \]

\[ \text{given} \quad \text{mol A} \quad \text{wanted} \quad \text{g C} \]

Overall 2 conversions (2 →'s): mol A → mol C → g C

So, do the last TWO ( )'s of stoichiometry.

**Review of Stoichiometry**

To convert grams of one molecule to grams of another molecule you use a series of multiplication known as Stoichiometry. You will be using a total of three parentheses to complete this process.

1. Place given information outside of the first set of parentheses. In the first parentheses will be the given molecules molar mass. This multiplication will allow you to cancel out the given grams and will be left with just moles

2. The next parentheses will contain the number of moles wanted over the number of moles from the given information. This will cancel out the given information completely leaving you with the moles of wanted value.
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3. In the final parentheses put the molar mass of the wanted molecule, grams over moles. This causes the two moles to cancel leaving you with the wanted amount of grams.

Mole Conversion-
There are three ratios to always remember. They are grams : moles; mole : mole; and molecules : moles. Always put the given information outside and the given unit on the bottom inside the parentheses. This will produce your answer.

EX:

How many grams of P is in 5.00 mol P₄O₆
\[
5.00 \text{ mol P}_4\text{O}_6 \left( \frac{4 \text{ mol P}}{1 \text{ mol P}_4\text{O}_6} \right) \left( \frac{30.87 \text{ g P}}{1 \text{ mol P}} \right) = 619 \text{ g P}
\]

How many molecules are in 1.00 g P₄O₆
\[
1.00 \text{ g P}_4\text{O}_6 \left( \frac{1 \text{ mol P}_4\text{O}_6}{219.8 \text{ g P}_4\text{O}_6} \right) \left( \frac{6.022 \times 10^{23} \text{ molecules}}{1 \text{ mol P}_4\text{O}_6} \right) = 2.74 \times 10^{21} \text{ molecules}
\]

Limiting Reactant-
The limiting reactant is the atom that runs out first, limiting the amount of products you can make. For example if you have four pieces of bread and six pieces of turkey. Each sandwich will have two pieces of bread and one piece of turkey. You will be able to make two sandwiches. The bread is the limiting reactant because it is consumed by the reaction first, making the turkey the item in excess by four slices.

EX: What is the limiting reactant if 2 grams of Ag reacts with 2 grams of S₈.

16Ag + S₈ \rightarrow 8Ag₂S

Ag: 2.00 g Ag \left( \frac{1 \text{ mol Ag}}{107.87 \text{ g Ag}} \right) \left( \frac{1}{16 \text{ mol Ag}} \right) = 0.00116

S₈: 2.00 g S₈ \left( \frac{1 \text{ mol S₈}}{25.56 \text{ g S₈}} \right) \left( \frac{1}{1 \text{ mol S₈}} \right) = 0.00780

Since, 0.00116 < 0.00780, Ag is the LR

To find the amount of excess reactant remaining, use a Stoichiometry problem, using the 2 grams of Ag as you’re given information.

\[
2.00 \text{ g Ag} \left( \frac{1 \text{ mol Ag}}{107.87 \text{ g Ag}} \right) \left( \frac{1 \text{ mol S₈}}{16 \text{ mol Ag}} \right) \left( \frac{25.56 \text{ g S₈}}{1 \text{ mol S₈}} \right) = 0.0297 \text{ g S₈}
\]

Empirical and Molecular Formula-
An empirical formula is the formula that is derived from the elemental analysis (percent composition) and uses whole numbered subscripts that give the simplest ratio of atoms in the molecule. An example would be H₂O for water or CH₂O for glucose.

A molecular formula uses whole number subscripts that give the actual number of each specific atom in the molecule. An example would be H₂O for water or C₆H₁₂O₆ for glucose. To
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find the molecular formula you have to multiply the subscripts of the empirical formula by a constant that is found from the ratio of the known molecular molar mass (given, known from experiments or calculated elsewhere) and the empirical molar mass.

EX:

Empirical Formula:
Adipic acid:
49.31 % C → 49.31g C
43.79 % O → 43.49g O
6.9 % H → 6.9g H
Molar mass: 146.1 g/mol

Molecular Formula:

Mass Percentage (percent composition)
The percent composition is the amount of mass one type of atom contributes to the molecule. It is calculated by multiplying the atomic mass of the atom in question by its subscript and then dividing by the molecular molar mass. For example if you wanted to know the percent by mass of carbon in C₈H₁₀N₄O₂ you would do the following.

EX: