STOICHIOMETRY

Measurements in Chemical Reactions

STOICHIOMETRY

- The analysis of the quantities of substances in a chemical reaction.
- Stoichiometric calculations depend on the MOLE-MOLE relationships of substances.
- Therefore, a BALANCED chemical equation is required.

Mass-Mass Problem

- We can convert from the mass of a reactant or product to the mass of any other reactant or product.
- However, to do this, we must always convert from one substance to the other ***through moles***.
- ***EXAMPLE:*** Consider the combustion of 8.96 g hexane:

$$2\ C_6H_{14(l)} + 19\ O_{2(g)} \rightarrow 12\ CO_{2(g)} + 14\ H_2O_{(g)}$$

- *What mass of oxygen will be required for the complete combustion of the hexane?*
- *What masses of carbon dioxide & water will be formed by this reaction?*

Mole-Mole Relationships

- *Consider the acid-base neutralization:*

$$H_2SO_{4(aq)} + 2\ NaOH_{(aq)} \rightarrow 2\ H_2O_{(l)} + Na_2SO_{4(s)}$$

Number of moles BEFORE Reaction	**5**	? =	**0**	**0**
Number of moles AFTER Reaction	? =	? =	? =	? =

- How many moles of sodium hydroxide would be needed to completely react with 5 moles of sulfuric acid?
- How many moles of water and sodium sulfate would be formed?

Mole-Mole Relationships

- *Consider the acid-base neutralization:*

$$3\ Mg(OH)_{2(aq)} + 2\ H_3PO_{4(aq)} \rightarrow 6\ H_2O_{(l)} + Mg_3(PO_4)_{2(s)}$$

Number of moles BEFORE Reaction	? =	**6**	**0**	**0**
Number of moles AFTER Reaction	? =	? =	? =	? =

- How many moles of magnesium hydroxide would be needed to completely react with 6 moles of phosphoric acid?
- How many moles of water and magnesium phosphate would be formed.

Mass – Mass Problem (Continued)

- It is often helpful to set up a table to organize information that is needed.

$$\mathbf{2\ C_6H_{14} + 19\ O_2 \rightarrow 12\ CO_2 + 14\ H_2O}$$

molar mass (g/mol)	**86.18**	**32.00**	**44.01**	**18.02**
mass (g)	**8.96**			
Mole				

General Stoichiometry Steps:

1. Convert quantity of given substance to moles.
2. Convert moles of *given* substance to moles of the *unknown* substance.
3. Convert moles of the unknown substance to the desired units.

Stoichiometry Example

- In the reaction below, what mass of lead (II) chloride can be produced from the reaction of 75.0 g of aluminum chloride with excess lead (II) nitrate?

$2\ AlCl_3 + 3\ Pb(NO_3)_2 \rightarrow 2\ Al(NO_3)_3 + 3\ PbCl_{2(s)}$

molar mass	133.33 $^g/_{mol}$			278.11 $^g/_{mol}$
mass	75.0 g	***Excess*** *(more than needed)*		
mole				

Stoichiometry Example

What mass of chlorine gas is required to fully react with excess aluminum powder to produce 2.50 kg aluminum chloride?

$$2\ Al_{(s)} + 3\ Cl_{2(g)} \rightarrow 2\ AlCl_{3(s)}$$

Yield: quantity of product(s).

- **Theoretical Yield:** the calculated amount of product that can be formed in a chemical reaction if ALL of the reactants fully react. (Usually expressed in grams.)
- **Actual Yield:** the amount of product actually produced in a laboratory experiment.
- **Percent Yield** = $\frac{\text{Actual}}{\text{Theoretical}}$ x 100%

Theoretical Yield

- An excess of elemental iodine is reacted with 1.20 g of $NaBH_4$ to obtain 0.295 g of B_2H_6. What is the percent yield of B_2H_6?

$2\ NaBH_4 + I_2 \rightarrow B_2H_6 + 2\ NaI + H_2$

- 0.295 g B_2H_6 is the ACTUAL yield. It is NOT part of the stoichiometry problem
- Hint: Find the theoretical yield first.

Limiting Reagents & Oreo Cookies

2 cookies + 1 crèmes → 1 OREO

Oreo Cookies

How many OREOS can we make if we have 10 cookies and 5 crèmes?

2 cookies + 1 crèmes → 1 OREO

Initial	10	5	0
Change	- 10	- 5	+ 5
Final	0	0	5

We make 5 OREO's with nothing left over.

Oreo Cookies

How many OREOS can we make if we have 20 cookies and 15 crèmes?

2 cookies + 1 crèmes → 1 OREO

Initial	20	15	0
Change			
Final			

In this case, the cookies are the *limiting reagent*, and the crèmes are *in excess*.

Oreo Cookies

How many OREOS can we make if we have 14 cookies and 6 crèmes?

2 cookies + 1 crèmes → 1 OREO

Initial	14	6	0
Change			
Final			

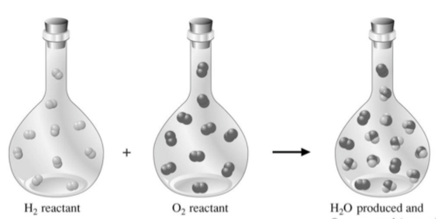
What is the limiting ingredient?
What will be left over?

Definitions

- The ***LIMITING REAGENT*** (or limiting reactant) is the reactant that runs out first in a chemical reaction.
- The ***EXCESS REAGENT*** is the reactant present in a quantity greater than needed to fully react with the L.R.

$2 H_2 + O_2 \rightarrow 2 H_2O$

- When 10 moles of hydrogen is mixed with 10 moles of oxygen and allowed to react, 10 moles of water is produced, with 5 moles oxygen left over.



Limiting Reagent Example

- If 5 mol of nitrogen gas and 12 mol of hydrogen gas are mixed and allowed to react to form ammonia,
  - What is the limiting reagent?
  - How many moles of NH_3 can be formed?
  - How many moles of the excess reagent will be left over?

$N_{2(g)} + 3 H_{2(g)} \rightarrow 2 NH_{3(g)}$

Initial			
Change			
Final			

Example – Limiting Reagents

Nitrogen gas can be reacted with sodium metal at high pressure to make sodium azide. What is the limiting reagent if 5.50 g of sodium is mixed with 8.00 g of nitrogen?

$$2\ Na_{(s)} + 3\ N_{2(g)} \rightarrow 2\ NaN_{3(s)}$$

Example – Limiting Reagents

Consider the reaction of 5.00 g of elemental sulfur, S_8, with 5.00 g of chlorine gas, Cl_2, to form $SCl_{3(l)}$.

$$S_{8(s)} + 12\ Cl_{2(g)} \rightarrow 8\ SCl_{3(g)}$$

A) What is the Limiting Reagent?

B) What is the theoretical yield (in g) of sulfur trichloride?

C) What mass of the excess reagent will remain?

A) What is the Limiting Reagent?

- We must compare moles to moles, taking into account the STOICHIOMETRY (mole ratios) of the reaction.
- One method to determine which reactant will provide fewer moles of the desired product.
- The one that could produces less product is the LIMITING REAGENT.

B) What mass of sulfur trichloride will be produced?

- Use the number of moles of the product that the limiting reagent will produce to determine the mass of product that is expected.
- The *limiting reagent* **always** determines what the *theoretical yield* of the products will be.

C) What mass of the excess reagent will remain?

Determine how much of the excess reagent is required to *react with* the given quantity of the limiting reagent.

Mass remaining =

Initial mass – Mass reacted

Stoichiometry Example

Consider the preparation of titanium metal:

$$TiCl_4 + 2\ Mg \rightarrow Ti + 2\ MgCl_2$$

If 2.55 kg of titanium (IV) chloride is reacted with 1.00 kg of magnesium metal,

A. What is the limiting reagent?
B. What is the theoretical yield of titanium?
C. What mass of excess reagent remains?

Other routes to the MOLE (starting from volumes)

- **Density ($^g/_{cm^3}$)** – allows you to convert the volume of a solid or a pure liquid (not a solution) to grams, which may then easily be converted to moles using molar mass.
- **Molar Gas Density** (**22.4 $^L/_{mol}$**) – One mole of any IDEAL gas will occupy 22.4 L at 1.00 atm pressure and 0°C (also known as STP conditions – standard temperature and pressure.) This conversion factor can be used to convert volume of a gas to moles.
- **Concentration in Molarity ($^{mol}/_L$)** – Molar concentrations can be used to convert directly from the volume of a solution (easy to measure in the lab) to moles of the solute.

Stoichiometry Example

Consider the reaction: $2\ K_{(s)} + I_{2(s)} \rightarrow 2\ KI_{(s)}$

A chemistry lab student began with 125.0 g of potassium and 40.5 cm^3 of iodine. When the product was obtained and massed, the student found that 244.2 g of KI had actually been produced. What is the percent yield of the reaction?

Stoichiometry Example

What volume of H_2 gas (at STP) could be produced by the reaction of 1.00 kg of methane gas with excess water?

$$CH_4 + H_2O \rightarrow CO + 3\ H_2$$

Solution Stoichiometry

- Stoichiometry problems that involve solutions are just like other stoichiometry problems. **Molarity** serves as the *conversion factor* to get to and from moles.
- ***Example:***
  What volume of a 0.250 *M* $AgNO_3$ solution is required to produce 5.00 g of AgCl when mixed with excess $MgCl_2$ solution?

_ $AgNO_{3(aq)}$ + _ $MgCl_{2(aq)}$ → _ $Mg(NO_3)_{2(aq)}$ + _$AgCl_{(s)}$

Solution Stoichiometry (cont.)

- If the problem asks for molarity, you will need to know both the moles of solute and the volume of solution.
- ***Example:*** What is the molarity of an $AlCl_3$ solution if 100.0 mL of the solution completely reacts with 75.0 mL of a 0.110 *M* $Pb(NO_3)_2$ solution?

$2\ AlCl_{3(aq)} + 3\ Pb(NO_3)_{2(aq)} \rightarrow 2\ Al(NO_3)_{3(aq)} + 3\ PbCl_{2(s)}$

Stoichiometry Example

Consider the reaction of 7.31 x 10^{24} atoms of magnesium with 865 mL of 4.00 ***M*** hydrochloric acid (HCl). What is the theoretical yield (in grams) of H_2 gas?

$$Mg_{(s)} + 2\ HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$$