Stoichiometry

Composition Stoichiometry - deals with mass relationships of elements in compounds

* Reaction Stoichiometry - deals with the mass relationships between reactants and products in a chemical reaction

Reaction Stoichiometry Problems

- In these problems you will have a *given* and you will be asked to find the *unknown*

- The given and unknown could be both reactants, both products, or one of each

Problem Type 1 - Given and Unknown are amounts in moles

amount of given in mol → amount of unknown in mol

Problem Type 2 - Given an is amount in moles and unknown is a mass that is expressed in grams

amount of given in mol → amount of unknown in mol → mass of unknown in grams

Problem Type 3 - Given is a mass in grams and unknown is an amount in moles

amount of given in grams → amount of given in moles → amount of unknown in moles

Problem Type 4 - Given is mass in grams and unknown is amount in grams

amount of given in grams → amount of given in mol → amount of unknown in mol → amount of unknown in grams

mass - mass

Mole Ratio

- when solving any stoichiometry you will need to use a mole ratio

- A mole ratio is a conversion factor that relates the amounts in moles of any two substances involved in a chemical reaction

- This information is obtained from the balanced chemical equation

Ex.

$$2\ Al_2O_3 \longrightarrow 4\ Al + 3\ O_2$$

- The coefficients tell the amounts of moles of reactants and products

$$\frac{2\ mol\ Al_2O_3}{4\ mol\ Al} \quad or \quad \frac{4\ mol\ Al}{2\ mol\ Al_2O_3}$$

$$\frac{2\ mol\ Al_2O_3}{3\ mol\ O_2} \quad or \quad \frac{3\ mol\ O_2}{2\ mol\ Al_2O_3}$$

$$\frac{4\ mol\ Al}{3\ mol\ O_2} \quad or \quad \frac{3\ mol\ O_2}{4\ mol\ Al}$$

How many moles of Al can be produced from 13 moles of Al_2O_3

$2\ Al_2O_3 \longrightarrow 4Al + 3O_2$

$$13\ mol\ Al_2O_3 \times \frac{4\ mol\ Al}{2\ mol\ Al_2O_3} = 26\ mol\ Al$$

Molar Mass

- A conversion factor that relates the mass of a substance to the amount in moles of that substance

Al_2O_3 → 101.96 g/mol

O_2 → 32.00 g/mol

Al → 26.98 g/mol

Periodic Table

Find the number of grams of aluminum equivalent to 26.0 mol of aluminum

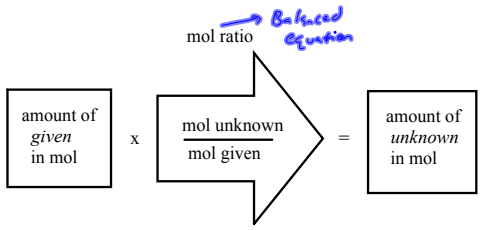
$$26.0\ mol\ Al \times \frac{26.98\ g\ Al}{1\ mol\ Al} = 701\ g\ Al$$

Solving any Stoichiometry Problem Must Begin with a BALANCED CHEMICAL EQUATION

Problem Type 1 - Conversions of quantities in moles

- the amount of given is in moles and you are asked to find the amount of unknown in moles

- requires only one conversion factor (mol ratio)



Ex.

In the spacecraft, CO_2 exhaled by astronauts can be removed by its reaction with LiOH, according to the following equation.

$$1\ CO_2 + 2\ LiOH \longrightarrow Li_2CO_3 + H_2O$$

How many moles of lithium hydroxide are required to react with 20 mol of CO_2.

$$20\ mol\ CO_2 \left| \frac{2\ mol\ LiOH}{1\ mol\ CO_2} \right. = 40\ mol\ LiOH$$

How many moles of NH_3 are produced when 6 mol of hydrogen gas react with nitrogen gas?

$$3\ H_2 + N_2 \longrightarrow 2\ NH_3$$

$$6\ mol\ H_2 \left| \frac{2\ mol\ NH_3}{3\ mol\ H_2} \right. = 4\ mol\ NH_3$$

The decomposition of potassium chlorate is used to produce oxygen. How many moles of potassium chlorate ($KClO_3$) are required to produce 15 mol of Oxygen

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

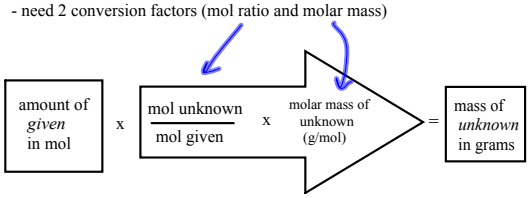
? mol

$$15\ mol\ O_2 \left| \frac{2\ mol\ KClO_3}{3\ mol\ O_2} \right. = 10.\ mol\ KClO_3$$

Problem Type 2 - Conversion of amounts in moles to mass

- the amount of given is in moles and you are asked to find the mass of unknown in grams

- need 2 conversion factors (mol ratio and molar mass)



Ex.

In photosynthesis, plants use energy from the sun to produce glucose, $C_6H_{12}O_6$, and oxygen from the reaction of carbon dioxide and water. What is the mass in grams of glucose that is produced when 3.00 mol of water react with carbon dioxide

$$6\ CO_2 + 6\ H_2O \longrightarrow C_6H_{12}O_6 + 6\ O_2$$

g?

$$3.00\ mol\ H_2O \left| \frac{1\ mol\ C_6H_{12}O_6}{6\ mol\ H_2O} \right| \frac{180.12\ g\ C_6H_{12}O_6}{1\ mol\ C_6H_{12}O_6}$$

$$90.06\ g\ C_6H_{12}O_6$$

$$90.1\ g\ C_6H_{12}O_6$$

What mass of carbon dioxide, in grams, is needed to react with 3.00 mol of water in the photosynthetic reaction described in the previous problem?

$$6\ CO_2 + 6\ H_2O \longrightarrow C_6H_{12}O_6 + 6\ O_2$$

g?

$$3.00\ mol\ H_2O \left| \frac{6\ mol\ CO_2}{6\ mol\ H_2O} \right| \frac{43.99\ g\ CO_2}{1\ mol\ CO_2}$$

$$132\ g\ CO_2$$

$$2\ Mg + O_2 \longrightarrow 2\ MgO$$

What mass, in grams, of oxygen combines with 2.00 mol of magnesium in the above reaction?

$$2.00\ mol\ Mg \left| \frac{1\ mol\ O_2}{2\ mol\ Mg} \right| \frac{31.98\ g\ O_2}{1\ mol\ O_2}$$

3. s.f.

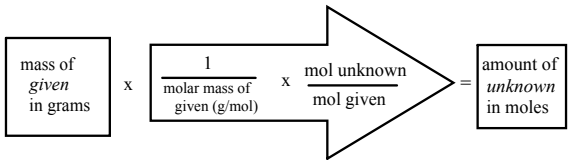
$$31.98\ g\ O_2 \longrightarrow 32.0\ g\ O_2$$

$$32.0\ g\ O_2 \longrightarrow 32.0\ g\ O_2$$

Problem Type 3 - Conversion of mass to amounts in moles

- the mass of given is in grams and you are asked to find the amount of unknown in moles

- need 2 conversion factors (molar mass and mol ratio)



Ex.

The first step of industrial manufacture of nitric acid is the catalytic oxidation of ammonia.

$4\ NH_3 + 5\ O_2 \longrightarrow 4\ NO + 6\ H_2O$ (unbalanced)

The reaction is run using 824 g of NH_3 and excess oxygen

a) How many moles of NO are formed

$$824\ g\ NH_3 \left| \frac{1\ mol\ NH_3}{17.04\ g\ NH_3} \right| \frac{4\ mol\ NO}{4\ mol\ NH_3}$$

48.356

48.4 mol NO

$4\ NH_3 + 5\ O_2 \longrightarrow 4\ NO + 6\ H_2O$ (unbalanced)

The reaction is run using 824 g of NH_3 and excess oxygen

b) How many moles of H_2O are formed

$$824\ g\ NH_3 \left| \frac{1\ mol\ NH_3}{17.04\ g\ NH_3} \right| \frac{6\ mol\ H_2O}{4\ mol\ NH_3}$$

72.5 mol H_2O

$2\ NaCl + 2\ H_2O \longrightarrow 2\ NaOH + Cl_2 + H_2$ ✓

If you have 250 g of NaCl how many moles of Cl_2 gas can be produced?

$$250\ g\ NaCl \left| \frac{1\ mol\ NaCl}{58.44\ g\ NaCl} \right| \frac{1\ mol\ Cl_2}{2\ mol\ NaCl}$$

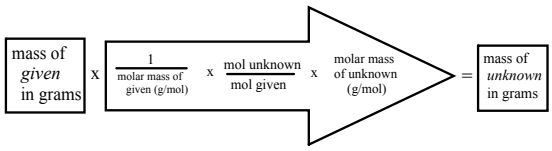
2.1389 mol Cl_2

2.1 mol Cl_2

Problem Type 4 - Mass-Mass calculations

- the mass of given is in grams and you are asked to find the mass of unknown in grams

- need 3 conversion factors (molar mass of given, mol ratio, molar mass of unknown)



Ex.

Tin (II) fluoride, SnF_2, is used in some toothpastes. It is made by the reaction of tin with hydrogen fluoride according to the following equation

$Sn + 2\ HF \longrightarrow SnF_2 + H_2$ ✓

How many grams of SnF_2 are produced from the reaction of 30.00 g of HF with Sn

$$30.00\ g\ HF \left| \frac{1\ mol\ HF}{20.01\ g\ HF} \right| \frac{1\ mol\ SnF_2}{2\ mol\ HF} \left| \frac{156.17\ g\ SnF_2}{1\ mol\ SnF_2} \right.$$

117.1 g SnF_2

$NH_4NO_3 \longrightarrow N_2O + 2\ H_2O$

How many grams of NH_4NO_3 are required to produce 33.0 g N_2O?

$$33.0\ g\ N_2O \left| \frac{1\ mol\ N_2O}{44.01\ g\ N_2O} \right| \frac{1\ mol\ NH_4NO_3}{1\ mol\ N_2O} \left| \frac{80.06\ g\ NH_4NO_3}{1\ mol\ NH_4NO_3} \right.$$

60.0 g NH_4NO_3

How many grams of water are produced in this reaction?

When copper is added to silver (I) nitrate, silver metal and copper (II) nitrate are formed. What mass of silver is produced from 100. g of Cu?

$2\ AgNO_3 + 1\ Cu \longrightarrow 2\ Ag + Cu(NO_3)_2$

$$100.\ g\ Cu \left| \frac{1\ mol\ Cu}{63.55\ g\ Cu} \right| \frac{2\ mol\ Ag}{1\ mol\ Cu} \left| \frac{107.87\ g\ Ag}{1\ mol\ Ag} \right.$$

340. g Ag

Limiting Reactants

- Very few reactions are carried out in ideal conditions (all reactants are converted to product). Often one reactant is present in excess. Once one of the reactants is used up, no more product can be made.

- The substance that is used up first is called the limiting reactant

↳ All used up

the reactant that limits the amounts of the other reactants that can combine and the amount of product that can form in a chemical reaction

- the substance that is not used up completely in a reaction is called the excess reactant

↳ left over

Solving limiting reactant problems

If amounts of two reactants are given, you are dealing with a limiting reactant problem

Steps to solving these problems

1. Write a balanced chemical equation
2. Convert all known information to moles (if it is already in moles move to step 3)
3. Pick one of the reactants and use a mole ratio to calculate how many moles of the other substance is needed to fully react with the chosen reactant
4. Compare the moles needed (# 3) with the moles available (#2)

If moles needed > moles available, the reactant being looked at is the limiting reactant

If moles needed < moles available, the reactant being looked at is NOT the limiting reactant and the other reactant is limiting

Ex.

$SiO_2 + 4HF \longrightarrow SiF_4 + 2H_2O$

Have Have

If 2.0 mol of HF are exposed to 4.5 mol SiO_2, which is the limiting reactant

$4.5 \text{ mol } SiO_2 \left| \frac{4 \text{ mol HF}}{1 \text{ mol } SiO_2} \right. = 18 \text{ mol HF needed}$

HF is limiting

$2.0 \text{ mol HF} \left| \frac{1 \text{ mol } SiO_2}{4 \text{ mol HF}} \right. = 0.50 \text{ mol } SiO_2 \text{ needed}$

SiO_2 is excess

HF is limiting

$3Fe + 4H_2O \longrightarrow Fe_3O_4 + 4H_2$

When 36.0 g of H_2O is mixed with 167 g of Fe, what is the limiting reactant

theoretical

mass of H_2?

$36.0 \text{ g } H_2O \left| \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \right. = 2.00 \text{ mol } H_2O$ - HAVE -

$167 \text{ g Fe} \left| \frac{1 \text{ mol Fe}}{55.85 \text{ g Fe}} \right. = 3.00 \text{ mol Fe}$

$2.00 \text{ mol } H_2O \left| \frac{3 \text{ mol Fe}}{4 \text{ mol } H_2O} \right. = 1.50 \text{ mol Fe needed}$

Fe is excess

H_2O is limiting

$2.00 \text{ mol } H_2O \left| \frac{4 \text{ mol } H_2}{4 \text{ mol } H_2O} \right| \frac{2.02 \text{ g } H_2}{1 \text{ mol } H_2} = 4.04 \text{ g } H_2$

$8Zn + S_8 \longrightarrow 8ZnS$

Have Have

If 2.00 mol of Zn are heated with 1.00 mol of S_8 what is the limiting reactant?

$1.00 \text{ mol } S_8 \left| \frac{8 \text{ mol Zn}}{1 \text{ mol } S_8} \right. = 8.00 \text{ mol Zn needed}$

Zn is limiting

S_8 is excess

How many moles of excess reactant remain?

① what is excess → S_8

② How much do we have → 1.00 mol

③ " " " " need → $2.00 \text{ mol Zn} \left| \frac{1}{8} \right. = 0.250$

How many grams of product are formed?

$8Zn + S_8 \longrightarrow 8ZnS$ (2.00 mol Zn / 1.00 mol S_8)

$2.00 \text{ mol Zn} \left| \frac{8 \text{ mol ZnS}}{8 \text{ mol Zn}} \right| \frac{97.46 \text{ g ZnS}}{1 \text{ mol ZnS}}$

194.92 → 195 g ZnS

Theoretical Yield

The maximum amount of product that can be produced from a given amount of reactant

grams

- Solve for the limiting reactant and then do a mole-mass or a mass-mass calculation to get the theoretical yield.

① Limiting reactant + ② Stoichiometry

Ex.

$C_2H_6 + Cl_2 \longrightarrow C_2H_5Cl + HCl$

When 36.8 g of C_2H_6 reacts with excess Cl_2, find the theoretical yield of C_2H_5Cl that is produced

Always use the LIMITING as your GIVEN

Percent Yield

Actual yield - the measured amount of product obtained from a reaction
→ From the lab

- The percent yield is the ratio of actual yield to theoretical yield multiplied by 100

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

actual yield → you get in lab
theoretical yield → you should get
% yield → want to be 100%

Ex.

The actual yield of C_6H_5Cl is 38.8 g. What is the % yield of C_6H_5Cl?

Theoretical = 4.04 g H_2

LAB = 3.82 g H_2

$\frac{3.82\text{ g}}{4.04\text{ g}} \times 100$

94.6%