Notes: Balancing Chemical Equations

Effects of chemical reactions:

- Chemical reactions rearrange atoms in the reactants to form new products.
- The identities and properties of the products are completely different from that of the reactants.
- Production of gases and color changes are signs of chemical reactions.

Energy and Reactions

Energy must be ADDED to BREAK bonds.

Energy is RELEASED when bonds are FORMED.

Chemical energy is CONSERVED in chemical reactions.

EXOTHERMIC REACTIONS: release energy (More energy is released as the products form bonds than is absorbed to break the bonds in the reactants.)

ENDOTHERMIC REACTIONS: absorb energy

Chemical equations are used to represent or describe chemical reactions. An equation shows:

- formulas of reactants
- formula of products
- Molar ratios of all compounds in the reaction

- The "+" means "reacts with"
- The "→" means "yields" or "reacts to produce"

To show physical states of each substance:

(s) or ↓ - solid
(l) - liquid
(g) or ↑ - gas
(aq) - aqueous

* aqueous means dissolved in water

- Consider the reaction of iron with oxygen to form iron (III) oxide, or rust.

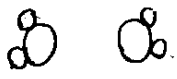
$Fe(s) + O_2(g) \longrightarrow Fe_2O_3(s)$ (unbalanced)

COEFFICIENTS: numbers in front of compound that represents the number of molecules of that compound

SUBSCRIPTS: small numbers that help define the compound.

Ex: Coefficient → $2H_2SO_4$ ← Subscript

H_2O: 

$2H_2O$: 

H_2O_2: 

- During a chem. rxn.: atoms are rearranged (NOT created or destroyed!)
- Chemical equations must be balanced to show the relative amounts of all substances.
- Balanced means: each side of the equations has the same # of atoms of each element.

$CH_4 + O_2 \rightarrow H_2O + CO_2$

$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$

RULES to follow in balancing:

1. Correct formulas for all reactants & products.
2. Reactants → Products
3. Count the # of atoms of each element in reactants & products.
4. Balance one at a time using coefficients.
5. Check for balance.
6. Are the coefficients in the lowest possible ratio?

$\underline{4}\,Fe + \underline{3}\,O_2 \rightarrow \underline{2}\,Fe_2O_3$

Examples:

$3\,CuCl_{2(aq)} + 2\,Al_{(s)} \rightarrow 3\,Cu_{(s)} + 2\,AlCl_{3(aq)}$

(3:2:3:2)

Propane, C_3H_8, burns in oxygen, O_2, to form carbon dioxide and water.

$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$ (unbalanced)

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ (balanced) 1:5:3:4

Pentane, C_5H_{12}, burns in oxygen, O_2, to form carbon dioxide and water.

$C_5H_{12} + O_2 \rightarrow CO_2 + H_2O$ (unbalanced)

$C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$ (balanced) 1:8:5:6

Silver nitrate reacts with copper to produce silver and copper nitrate.

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

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

Phosphorus reacts with oxygen, O_2, to produce disphosphorus pentoxide.

$P + O_2 \rightarrow P_2O_5$

$4P + 5O_2 \rightarrow 2P_2O_5$

$2\,C_7H_{14} + 21\,O_2 \rightarrow 14\,CO_2 + 14\,H_2O$

Types of Chemical Reactions

In chemistry, there are 5 general types of reactions:

1) Synthesis or Combination: 2 or more reactants combine to form 1 product.

$A + B \rightarrow AB$

Examples:

$2K(s) + Cl_2(g) \rightarrow 2KCl(s)$

$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$

2) Decomposition: 1 reactant decomposes to form 2 or more products.

$AB \rightarrow A + B$

Examples:

$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$

$CaCO_3 \rightarrow CaO + CO_2$

Activity Series

Increasing Activity ↑

Li
K
Ca
Na
Mg
Al
Zn
Fe
Pb
(H)*
Cu
Hg
Ag

Any element will replace any element below it

3) Single Replacement: One metal replaces another metal in an ionic compound, producing a new ionic compound and a metal.

$XA + B \rightarrow BA + X$

Examples:

$2AgNO_3 + Mg \rightarrow Mg(NO_3)_2 + 2Ag$

$Mg + LiNO_3 \rightarrow$ No reaction

Ag always has a charge of +1

4) Double Replacement: Two positive ions "switch places" forming 2 new ionic compounds:

$XA + BY \rightarrow BA + XY$

Examples:

$2NaCN(aq) + H_2SO_4(aq) \rightarrow 2HCN(g) + Na_2SO_4(aq)$

$Na_2S(aq) + Cd(NO_3)_2(aq) \rightarrow CdS(s) + 2NaNO_3(aq)$

5) Combustion: a hydrocarbon (containing C and H) or other substance burns in the presence of oxygen gas (O_2) to produce CO_2 and H_2O.

Examples:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + heat + light$

$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

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Calculations Based on Balanced Chemical Equations

Iron (III) oxide reacts with carbon monoxide to form iron and carbon dioxide.

$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

1 : 3 : 2 : 3

- How many CO molecules are required to react with 25 particles of Fe_2O_3?

$$\frac{25 \text{ form units } Fe_2O_3}{1} \cdot \frac{3 \text{ molecules CO}}{1 \text{ form unit } Fe_2O_3} = 75 \text{ CO molecules}$$

- How many iron atoms can be produced by the reaction of 2.5×10^5 particles of Fe_2O_3 with excess CO?

$$\frac{2.5 \times 10^5 \text{ form units } Fe_2O_3}{1} \times \frac{2 \text{ atoms Fe}}{1 \text{ form unit } Fe_2O_3} = 5.0 \times 10^5 \text{ atoms Fe}$$

***Formulas can also represent MOLES of substances involved in chem. rxns.**

***Equations define reaction ratios, i.e. the mole ratios of reactants and products.**

- What mass of CO is required to react with 146 grams of iron (III) oxide?

$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

146g ?(g)

$$146 \text{ g } Fe_2O_3 \times \frac{1 \text{ mol } Fe_2O_3}{159.6 \text{ g } Fe_2O_3} \times \frac{3 \text{ mol CO}}{1 \text{ mol } Fe_2O_3} \times \frac{28 \text{ g CO}}{1 \text{ mol CO}} = 76.8 \text{ g CO}$$

- What mass of iron (III) oxide is required to produce 8.65 g of carbon dioxide?

$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

?g 8.65g

$$8.65 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44 \text{ g } CO_2} \times \frac{1 \text{ mol } Fe_2O_3}{3 \text{ mol } CO_2} \times \frac{159.6 \text{ g } Fe_2O_3}{1 \text{ mol } Fe_2O_3} =$$

$10.5 \text{ g } Fe_2O_3$

Limiting Reactants (Reagents)

Calculations need to be based on the limiting reactant, or the reactant that is present in lesser amount.

Example: Suppose a box contains 87 bolts, 110 washers, and 99 nails. How many sets consisting of one bolt, two washers and one nail, can you construct from the contents of the box?

55 sets; washers limit the amount

Example: What is the maximum mass of sulfur dioxide that can be produced by the reaction of 95.6 g carbon disulfide with 100. g oxygen?

$$\underset{95.6}{CS_2} + \underset{100.g}{3O_2} \rightarrow CO_2 + \underset{?g}{2SO_2}$$

$$95.6\,g\,CS_2 \times \frac{1\,mol\,CS_2}{76.2\,g\,CS_2} \times \frac{2\,mol\,SO_2}{1\,mol\,CS_2} \times \frac{64.1\,g\,SO_2}{1\,mol\,SO_2} = 161\,g\,SO_2$$

$$100.g\,O_2 \times \frac{1\,mol\,O_2}{32.0\,g\,O_2} \times \frac{2\,mol\,SO_2}{3\,mol\,O_2} \times \frac{64.1\,g\,SO_2}{1\,mol\,SO_2} = \boxed{134\,g\,SO_2}$$

O_2 limits the amount of SO_2 that can be produced. CS_2 is in excess.

Example: What mass of CO_2 could be formed by the reaction of 8.0 g CH_4 with 48 g O_2?

$$\underset{8.0g}{CH_4} + \underset{48g}{2O_2} \rightarrow \underset{?g}{CO_2} + 2H_2O$$

$$8.0g\,CH_4 \times \frac{1\,mol\,CH_4}{16.05\,g\,CH_4} \times \frac{1\,mol\,CO_2}{1\,mol\,CH_4} \times \frac{44.0\,g\,CO_2}{1\,mol\,CO_2} = \boxed{22\,g\,CO_2}$$

$$48.g\,O_2 \times \frac{1\,mol\,O_2}{32.g\,O_2} \times \frac{1\,mol\,CO_2}{2\,mol\,O_2} \times \frac{44.0\,g\,CO_2}{1\,mol\,CO_2} = 33\,g\,CO_2$$

CH_4 limits the amount of CO_2 that can be produced. O_2 is in excess

Percent Yield

Many chem. rxns do not go to completion (reactants are not completely converted to products)

Percent yield indicates how much of a desired product is obtained.

Percent yield may be represented as:

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

So far the masses we have calculated from chemical equations were based on the assumption that each reaction occurred 100%.

- The theoretical yield is the yield calculated assuming 100% reaction and isolation of 100% of the desired product.

- The **actual yield** is the yield actually obtained form a particular "run" of a rxn.

Example: A 10.0 g sample of ethanol, C_2H_5OH, was boiled with excess acetic acid, CH_3COOH, to produce 14.8 g of ethyl acetate, $CH_3COOC_2H_5$. What percent yield of ethyl acetate is this?

$$CH_3COOH + \underset{10.0g}{C_2H_5OH} \rightarrow CH_3COOC_2H_5 + H_2O$$

$$10.0\text{g } C_2H_5OH \times \frac{1\text{mol } C_2H_5OH}{46.08\text{g } C_2H_5OH} \times \frac{1\text{mol } CH_3COOC_2H_5}{1\text{mol } C_2H_5OH} \times \frac{88.12\text{g } CH_3COOC_2H_5}{1\text{ mol } CH_3COOC_2H_5} = 19.1\text{ g } CH_3COOC$$

$$\frac{14.8\text{ g}}{19.1\text{ g}} \times 100 = 77\%$$