Chapter 4 : Chemical Bonding ; Chemical Reaction
Lesson 12 : Reaction Stoichiometry, Limiting Reactants and Percent Yield

* Introduction :

- Stoichiometry is the calculation of the relative quantities of the reactants and products in a chemical reaction.

- Balanced equations

The coefficients in a balanced chemical equation show the relative amounts (in moles) of reactants and products.

e.g.

$$2\ C_8H_{18(l)} + 25\ O_{2(g)} \longrightarrow 16\ CO_{2(g)} + 18\ H_2O_{(g)}$$

2 mol 25 mol 16 mol 18 mol

Thus;

Balanced equations outline how reactants combine to form products.

i.e. 2 mol C_8H_{18} react with 25 mol O_2 (2 : 25)
also, 2 mol C_8H_{18} give 16 mol CO_2 (2 : 16)
2 mol C_8H_{18} give 18 mol H_2O (2 : 18)

} Stoichiometric Ratio

Q. Suppose that we burn 22 mol C_8H_{18}, Calculate the formed amount of CO_2 ?

From the equation: $2\ C_8H_{18} \longrightarrow 16\ CO_2$

2 mol — 16 mol
22 mol — ?

$$\text{moles } (CO_2) = \frac{22 \times 16}{2} = 176 \text{ mol } CO_2$$

Q. Calculate the mass of CO_2 produced if 114.22 g of C_8H_{18} was burnt? (Given that: Molar mass C_8H_{18} = 114.22 g/mol) & Molar mass CO_2 = 44 g/mol

From the equation:

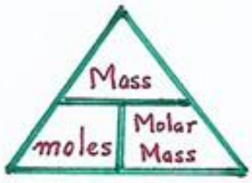
$$2\,C_8H_{18} \longrightarrow 16\,CO_2$$
$$2\text{ mol} \qquad\qquad 16\text{ mol}$$

So, Firsty Convert mass 114.22 g of C_8H_{18} to moles:

$$\text{moles }(C_8H_{18}) = \frac{\text{Mass}}{\text{Molar Mass}} = \frac{114.22}{114.22} = 1\text{ mol}$$

So;

$$2\,C_8H_{18} \longrightarrow 16\,CO_2$$
$$2\text{ mol} \qquad\qquad 16\text{ mol}$$
$$1\text{ mol} \qquad\qquad ?$$



$$\therefore \text{ moles }(CO_2) = \frac{1 \times 16}{2} = 8\text{ mol}$$

Now;

Convert moles of CO_2 to the required mass:

$$\text{Mass }(CO_2) = 8 \times 44 = 352\text{ g}$$

N.B. If you asked about the no. of CO_2 molecules produced use Avogadro's number (6.022×10^{23} molecules/mol).

$$\therefore \text{ Molecules of } CO_2 = \text{moles} \times \text{Avogadro's No.}$$
$$= 8 \times 6.022 \times 10^{23} = 4.82 \times 10^{24}\text{ molecules.}$$

Q. In the following photosynthesis process; how many grams of glucose ($C_6H_{12}O_6$) could be synthesized from 37.8 g CO_2 ?

Eqvation: $6\,CO_2 + 6\,H_2O \longrightarrow C_6H_{12}O_6 + 6\,O_2$ Molor mass ($C_6H_{12}O_6$) = 180.2

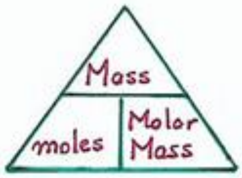
A. " " (CO_2) = 44

From the equation: $6\,CO_2 \longrightarrow C_6H_{12}O_6$

6 mol 1 mol

But we have the mass of CO_2 (37.8 g), so you have to convert it to moles:

$$\text{moles } (CO_2) = \frac{\text{Mass}}{\text{Molor Mass}} = \frac{37.8}{44} = 0.859 \text{ moles}$$



Thus;

from the stoichiometric ratio:

$6\,CO_2 \longrightarrow C_6H_{12}O_6$

6 mol 1 mol

0.859 mol ?

$$\therefore \text{moles}_{C_6H_{12}O_6} = \frac{0.859}{6} = 0.143 \text{ moles}$$

but the question asks about the mass of glucose.

so, we have to convert moles to mass using Molar mass:

$$\text{Mass } (C_6H_{12}O_6) = 0.143 \times 180.2 = 25.8 \text{ g}$$

Q. Estimate the amount of CO_2 (g) produced in 2007 by the combustion of 3.5×10^{15} g of gasoline?

A. Ratio: 2mol C_8H_{18} : 16 mol CO_2

1mol C_8H_{18} = 114.22 g

1 mol CO_2 = 44 g

Step 1: Convert 3.5×10^{15} g to moles of gasoline

$$\text{moles (gasoline)} = \frac{3.5 \times 10^{15}}{114.22} = 3.06 \times 10^{13} \text{ mol}$$

Step 2 :

From stoichiometric ratio: $2 \text{ mol } C_8H_{18} : 16 \text{ mol } CO_2$

$3.06 \times 10^{13} \text{ mol} \qquad ? \text{ mol}$

$$\therefore \text{moles } (CO_2) = \frac{(3.06 \times 10^{13}) \times 16}{2} = 2.45 \times 10^{14} \text{ mol}$$

Step 3: Convert moles of (CO_2) to mass :

$$\text{Mass } (CO_2) = \text{moles} \times \text{Molar mass}$$

$$= (2.45 \times 10^{14})(44 \text{ g/mol}) = 1.08 \times 10^{16} \text{ g}$$

$$\simeq 1.1 \times 10^{16} \text{ g } CO_2$$

* Limiting Reactant :

the limiting reactant determines the amount of product that will be produced in a reaction.

Example;

$$3\,Ca + 2\,P \longrightarrow Ca_3P_2$$

Stoichiometric ratio 3 : 2

If we start with 2 moles Ca and 2 moles of P ;

So, the amount of Ca isn't enough to react with the 2 moles of P.

Thus; Ca controls the production of Ca_3P_2 (will completely used up).

So, Ca is the limiting reactant (P is excess reactant).

* Excess Reactant :

This is any reactant that occurs in a larger quantity than is required for the reaction to take place.

* Theoretical Yield :

This is the amount of product that can be produced in a chemical reaction, based on the amount of limiting reactant.

* Actual Yield :

This is the amount of product actually produced in a reaction (usually < theoretical yield).

* Percentage Yield :

$$\%\,Yield = \frac{Actual\ Yield}{Theoretical\ Yield} \times 100$$

Q. If we have 5 molecules of CH_4 and 8 molecules of O_2; Which is the limiting reactant in the following reaction:

$$CH_{4(g)} + 2\,O_{2(g)} \longrightarrow CO_{2(g)} + 2\,H_2O$$

A.

To decide which one (CH_4 or O_2) is the limiting reactant Compare the amount of product that produced from each.

" Product amount "

Depending on CH_4 amount			Depending on O_2 amount		
Eq.	CH_4 →	CO_2	Eq.	$2\,O_2$ →	CO_2
Ratio	1	1	Ratio	2	1
Given	5	?	Given	8	?
Expected amount (CO_2) = 5 molecules			Expected amount (CO_2) = 4 molecules		

Thus; O_2 amount is enough only to produce 4 molecules of CO_2 (less amount); so, O_2 is the limiting reactant. #

Q. Ammonia, NH_3, was synthesized according to the following reaction using 86.3 g NO and 25.6 g H_2:

$$2\,NO_{(g)} + 5\,H_{2(g)} \longrightarrow 2\,NH_{3(g)} + 2\,H_2O_{(g)}$$

What is the theoretical yield of NH_3 in grams?

Given that: molar mass NO = 30.01 g/mol
" " H_2 = 2.02 g/mol
" " NH_3 = 17.03 g/mol

A. $2\,NO_{(g)} + 5\,H_{2(g)} \longrightarrow 2\,NH_{3(g)} + 2\,H_2O_{(g)}$

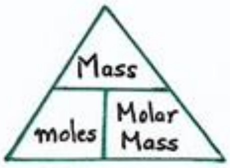
* Step 1:

Hint:

For NO : g NO $\xrightarrow{(\div 30.01)}$ mol NO $\xrightarrow[2:2\ (\times 2/2)]{\text{From Eq.}}$ mol NH_3

For H_2 : g H_2 $\xrightarrow{(\div 2.02)}$ mol H_2 $\xrightarrow[5:2\ (\times 2/5)]{\text{From Eq.}}$ mol NH_3

Smallest mol NH_3 $\xrightarrow{(\times 17.03)}$ g NH_3



« Which is the limiting reactant ? »

For NO:

	$2NO$	$\longrightarrow$	$2NH_3$
Ratio:	2 moles		2 moles
Given	$\frac{86.3}{30.01}$ moles		?

moles (NH_3) = 2.8757 mol

less product is produced from the limiting reactant NO

For H_2 :

	$5H_2$	$\longrightarrow$	$2NH_3$
Ratio:	5 moles		2 moles
Given	$\frac{25.6}{2.02}$ moles		?

moles (H_2) = 5.0693 mol

* Step 2:

To Calculate theoritical yield (mass of product); Convert the produced moles of product (2.8757 mol) to mass :

Theoretical yield (NH_3) = 2.8757 X Molar mass

= 2.8757 X 17.03 = 49.0 g

Q. 53.2 g Na and 65.8 g Cl_2 react according to the equation:

$$2\,Na_{(s)} + Cl_{2\,(g)} \longrightarrow 2\,NaCl_{(s)}$$

- Which is the limiting reactant ?
- The actual yield was 86.4 g of NaCl. What is the theoretical yield and percentage yield ?

Atomic Mass Na = 23
Molar mass Cl_2 = 70.9

A.

Which is the Limiting reactant

For Na :

Eq.	2Na	→	2 NaCl
Ratio	2 mol		2 mol
Given	$\frac{53.2}{23}$		?

∴ moles (NaCl) = 2.31

For Cl_2 :

Eq.	Cl_2	→	2 NaCl
Ratio	1 mol		2 mol
Given	$\frac{65.8}{70.9}$		?

∴ moles (NaCl) = 1.85 Small.

∴ Cl_2 is the limiting reactant.

Thus;

Theoretical yield (NaCl) = moles X Molar mass = 1.85 X 58.5 = 108 g

From the given actual yield (NaCl) = 86.04 g

$$\therefore \ \%\ \text{yield} = \frac{\text{Actual yield}}{\text{Theoretical Yield}} \times 100$$

$$= \frac{86.4}{108} \times 100 = 80.0\ \%$$

Ch. 4: Chemical bonding & Chemical Reaction

Lesson 13: Solution Concentration & Types of aqueous solutions

* Solution Concentration & Solution stoichiometry

Solution is a homogenous mixture of two or more substances.

Solution = Solvent + Solute(s)
(largest amount) (small amounts)

e.g.

- Sugar solution : water is solvent & sugar is solute.
- Air : N_2 gas is Solvent & other gases (O_2, CO_2, H_2O ...) are solutes.

* Solution Concentration:

Solute to solution relationship.

« Molarity »

It is the number of moles of solute per liter of solution.

$$M = \frac{\text{No. of moles of Solute}}{\text{Volume of solution (L)}}$$

Unit: mol/L

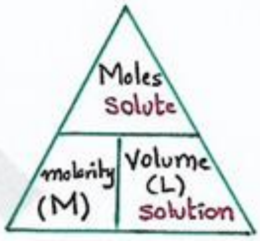
* Prepare 1 L of a 1.00 M NaCl solution:

* Weigh out and 1.00 mol of NaCl (58.44 g) in graduated flask then add water to dissolve the salt, then add to the mark 1 L.

Q. Find the molarity (M) of a solution that has 25.5 g KBr dissolved in 1.75 L solution? Given: molar mass (KBr) (1 mol KBr = 119.00 g)

A.

$$\because M = \frac{\text{moles of solute (KBr)}}{\text{Volume of Solution (L)}} = \frac{n_{solute}}{V_{Soln.(L)}}$$



$$\because n_{solute} = \frac{\text{Mass}}{\text{Molar Mass}} = \frac{25.5}{119.00} = 0.214 \text{ mol}$$

$$\therefore M = \frac{0.214}{1.75} = 0.122 \text{ M}$$ (Unit: mol/L or M)

N.B. Most solutions are between 0 and 18 M, so the answer makes sense.

Q. How many liters of 0.125 M NaOH contain 0.255 mol NaOH?

A.

0.125 M NaOH means that: 0.125 mol NaOH ⟶ 1 L solution

0.255 mol NaOH ⟶ ?

$$V_{Solution} = \frac{0.255 \times 1}{0.125} = 2.04 \text{ L solution (Acceptable)}$$

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* Solution Dilution:

Often, solutions are stored as concentrated stock solutions.

To make solutions of lower concentrations, only more solvent is added.

Thus; the amount of solute doesn't charge, Just the volume of Solution

Moles of solute before dilution = Moles of solute After dilution

$$M_1 \cdot V_1 = M_2 \cdot V_2$$

Q. Prepare 3.00L solution of a 0.500 M $CaCl_2$ from 10.0 M stock solution ?

A.

diluted Solution (1)	stock solution (2)
V = 3 L ; M = 0.5	V = ? ; M = 10.0

$\because M_1 \cdot V_1 = M_2 \cdot V_2$

$(0.5 \times 3) = (10.0 \times V_2) \Rightarrow V_2 = \frac{0.5 \times 3}{10} = 0.150 \text{ L}$

Thus;

we take 0.150L from the stock solution and add water to reach volume of 3.00 L.

Q. How would you prepare 200 mL of 0.25 M NaCl solution from a 2.0 M solution ?

A.

Diluted solution	stock solution
V_1 = 200 ml ; M_1 = 0.25 M	V_2 = ? ; M_2 = 2 M

$\because M_1 \cdot V_1 = M_2 \cdot V_2$

$(200 \times 0.25) = (2 \times V_2) \Rightarrow V_2 = \frac{200 \times 0.25}{2} = 25 \text{ mL}.$

Thus;

take 25 ml of 2.0M solution, and add water up to 200 mL.

* Types of aqueous solutions and solubility :

Case A : Dissolve NaCl salt in water ⟶ Homogeneous solution .

Case B : 〃 Sugar $C_{12}H_{22}O_{11}$ in water ⟶ 〃 〃 .

Now;

How do solids such as salt and sugar dissolve in water ?

OR :

What happens when a solute dissolves ?

A.

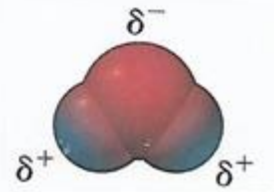
In general, dissolution of solute in solvent depends on :

A) Attractive forces between solute molecules.

B) 〃 〃 〃 Solvent 〃 .

C) 〃 〃 〃 solute and solvent molecules.

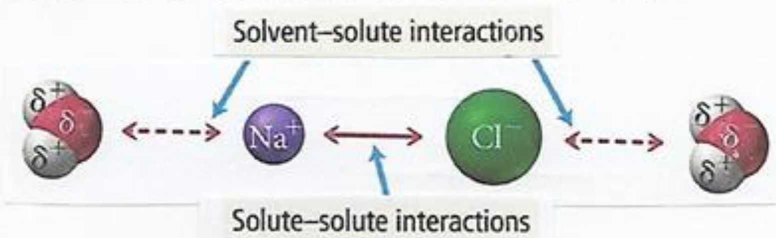
If the attraction forces between solute and solvent are strong enough, the solute will dissolve.



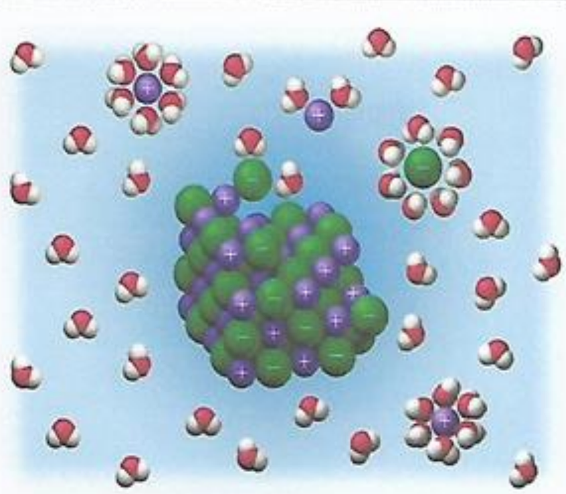
* Charge distribution in water molecule :

In water molecule; there is an uneven distribution of electrons in such way that oxygen has partial −ve charge and hydrogen has partial +ve charge , Thus water is a polar molecule.

* Solute and Solvent interactions : NaCl in water



Dissolution of an Ionic Compound



* Dissolving NaCl in water:

When NaCl is added to water:

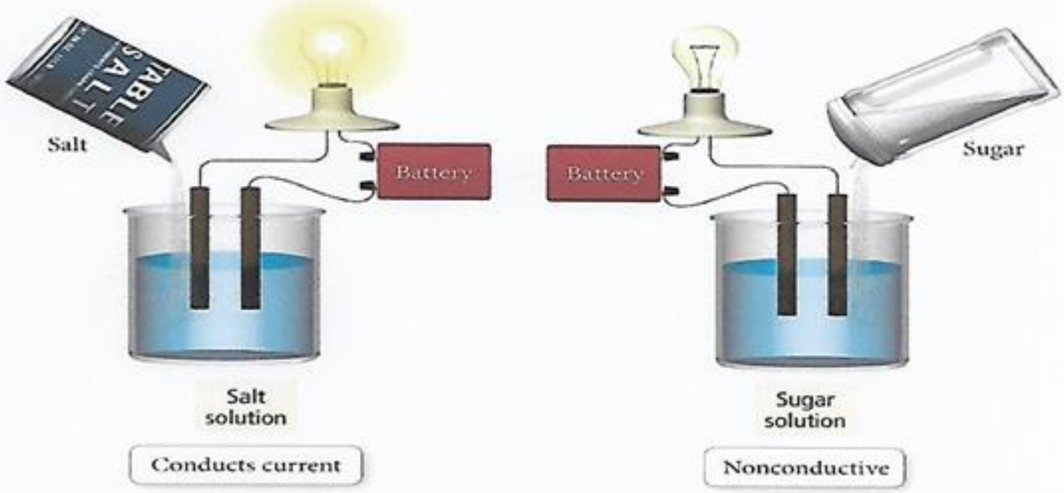
1. Each ion (Na^+ or Cl^-) is attracted toward H_2O molecules and away from the solid Crystal.
2. When the ion enters the solution, it is surrounded by water molecules Through the opposite charged pole.
3. As result, solution with free moving ions is formed and can conduct the electricity.

* Compare electrolyte and nonelectrolyte solutions?

	Stronge electrolytes	Weak electrolytes	Nonelectrolytes
Ionization	ionize Completely	ionize partially	don't ionize at all
Examples	Soluble salts and Strong acids or bases $CuCl_2 \rightarrow Cu^{2+} + 2Cl^-$	weak acids or bases $CH_3COOH \rightleftharpoons CH_3COO^- + H^+$	polar substances like sugar and alcohol $C_6H_{12}O_{6(s)} \rightarrow C_6H_{12}O_{6(aq.)}$
Electrical Conductivity	good Conductors for electricity	weak Conductors	don't Conduct electricity

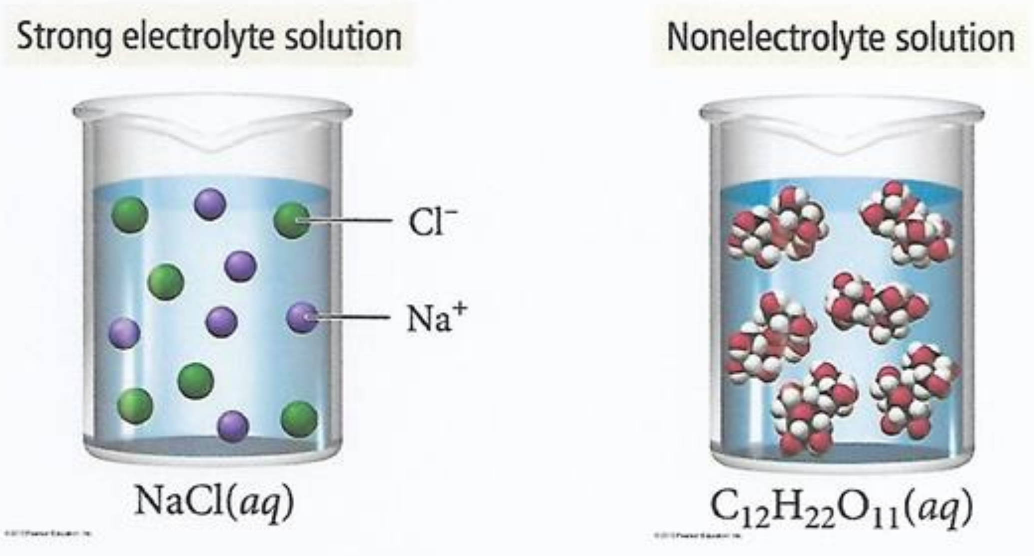
Electrolytes and Nonelectrolytes

Electrolyte and Nonelectrolyte Solutions



- **A solution of salt (an electrolyte) conducts electrical current**
- **A solution of sugar (a nonelectrolyte) does not.**

Salt (Ionic compound) vs. Sugar Dissolved in Water



Salts (ionic compound) ionize when

Molecular compounds do not

Ch. 4: Chemical Bonding & Chemical Reaction

Lesson 14: Acid-Base Reactions & Redox Reactions

* Acid-Base Reactions:

They are very common in chemistry.

e.g. HCl "hydrochloric acids" exists in stomach and helps in food digestion. When it is leaked into the esophagus, it causes the "heartburn". So, Antacids are used to neutralize the stomach acid by Acid-Base chemical reaction.

« Arrhenius definitions for acid and base:

Acid: A substance that produces H^+ ions in aqueous solution.

Base: A substance that produces OH^- ions in aqueous solution.

Examples;

$HCl_{(aq.)} \longrightarrow H^+_{(aq.)} + Cl^-_{(aq.)}$; $NaOH_{(aq.)} \longrightarrow Na^+_{(aq.)} + OH^-_{(aq.)}$

Acid ; Base

⇨ $HA \longrightarrow H^+ + A^-$; $BOH \longrightarrow B^+ + OH^-$

HA: Acid formula; H^+: proton; BOH: Base formula; OH^-: hydroxide ion

Acid-Base "Neutralization" Reaction:

General equation: Acid + Base ⟶ Salt + water

e.g. $HCl_{(aq.)} + NaOH_{(aq.)} \longrightarrow NaCl_{(aq.)} + H_2O$

Net ionic equation: $H^+_{(aq.)} + OH^-_{(aq.)} \longrightarrow H_2O_{(L)}$

N.B.

* Protons released by acids associate with water (H_2O) in solution to form Hydronium ions " H_3O^+ "

$$\text{Acid} \longrightarrow \underset{\text{proton / water}}{H^+ + H_2O} \longrightarrow \underset{\text{hydronium ion}}{H_3O^+_{(aq.)}}$$

So,

$$HCl_{(aq.)} + H_2O_{(l)} \longrightarrow H_3O^+_{(aq.)} + Cl^-_{(aq.)}$$

* Hydroxide ions released by bases in water

$$\text{Base} \longrightarrow \underset{\text{hydroxide / water}}{{}^-OH + H_2O} \longrightarrow OH^-_{(aq.)}$$

But !!

Ammonia does not contain hydroxyl group (OH) but produces hydroxide ions (OH^-) in water, thus it is a base.

$$\underset{\text{Ammonia}}{NH_3} + H_2O \longrightarrow NH_4^+{}_{(aq.)} + {}^-OH_{(aq.)}$$

* Polyprotic acids :

Some acids contain more than ionizable proton

e.g. Sulfuric acid (H_2SO_4) is diprotic acid

- $H_2SO_{4\,(aq.)} \longrightarrow H^+_{(aq.)} + HSO^-_{4\,(aq.)}$ (1st step is strong)
- $HSO^-_{4\,(aq.)} \rightleftharpoons H^+_{(aq.)} + SO^{--}_{4\,(aq.)}$ (2nd step is weak)

Similarly; Bases can release more than one ^-OH per mole.
e.g.

$$Sr(OH)_{2(aq.)} \longrightarrow Sr^{2+}_{(aq.)} + 2\,OH^-_{(aq.)}$$

Q. How to write the acid - Base equations?

A.

Example; Reaction of hydrogen iodide (HI) with barium hydroxide $Ba(OH)_2$

Step 1: Main unbalanced equation:

$$\underset{\text{(Acid)}}{HI_{(aq.)}} + \underset{\text{(Base)}}{Ba(OH)_{2(aq.)}} \longrightarrow \underset{\text{(Salt)}}{BaI_{2(aq.)}} + \underset{\text{(water)}}{H_2O_{(L)}}$$

Step 2: Balance the equation: "Molecular equation"

$$2HI_{(aq.)} + Ba(OH)_{2(aq.)} \longrightarrow BaI_{2(aq.)} + 2H_2O_{(L)}$$

Step 3: Net ionic equation (By removing spectator ions of salt)

$$H^+_{(aq.)} + OH^-_{(aq.)} \longrightarrow H_2O_{(L)}$$

Some common acids

Name of Acid	Formula
Hydrochloric acid	HCl
Hydrobromic acid	HBr
Hydroiodic acid	HI
Nitric acid	HNO_3
Sulfuric acid	H_2SO_4
Perchloric acid	$HClO_4$
Acetic acid	$HC_2H_3O_2$ (weak acid)

Some common bases

Name of Base	Formula
Sodium hydroxide	$NaOH$
Lithium hydroxide	$LiOH$
Potassium hydroxide	KOH
Calcium hydroxide	$Ca(OH)_2$
Barium hydroxide	$Ba(OH)_2$
Ammonia	NH_3 (weak base)

« Oxidation – Reduction Reactions » "Redox" Reactions

They are the reactions in which electron(s) are transferred from one reactant to the other.

examples; Rusting of iron & combustion of gasoline (octane).

where;

Oxidation: gain of oxygen or loss of hydrogen.

Reduction: gain of hydrogen or loss of oxygen.

$$Fe_{(s)} + 3\,O_{2\,(g)} \longrightarrow 2\,Fe_2O_3$$ Rusting of iron

gain of Oxygen "Oxidation"

* Redox Reactions without Oxygen:

During the formation of ionic compounds, metal loses electron(s) "Oxidation" and nonmetal gains the electron(s) "Reduction".

e.g. NaCl

(metal) $^{11}Na_{(s)}$ (2, 8, 1) + $^{17}Cl_{(g)}$ (2, 8, 7) (nonmetal)

↓ Redox

Na^+ (2,8) Cl^- (2,8,8)

↓

$NaCl_{(s)}$

Na (metal) loses electron "Oxidized" and Cl (nonmetal) gains this electron "reduced".

Equation: $$2\,Na_{(s)} + Cl_{2\,(g)} \longrightarrow 2\,NaCl_{(s)}$$

* Very Important Note :

* The element which is oxidized is Known as "Reducing agent or Reductant e.g. Na is oxidized but reduces Cl.
* The element which is reduced is Known as "Oxidizing agent or Oxidant e.g. Cl is reduced but oxidizes Na.

* Rules for Assigning Oxidation state :

It is very important to know the oxidation number (state) to identify the redox reactions that occur between nonmetals.

Rule (1) : Oxidation state of an atom and free element is Zero.

Rule (2) : Oxidation state of monoatomic ion is equal to its charge.

Rule (3) : Sum of oxidation states of all atoms in:

- Neutral molecule or formula unit is Zero.
- An ion is equal to its charge.

Rule (4) : For metals, oxidation number equals to the group number.

e.g. Group 1A have +1 oxidation state.

Group 2A have +2 oxidation state.

Rule (5) : For nonmetals

Oxidation States of Nonmetals

Nonmetal	Oxidation State	Example
Fluorine	-1	MgF_2 -1 ox state
Hydrogen	+1	H_2O +1 ox state
Oxygen	-2	CO_2 -2 ox state
Group 7A	-1	CCl_4 -1 ox state
Group 6A	-2	H_2S -2 ox state
Group 5A	-3	NH_3 -3 ox state

- Sulfur as single ion has (−2) oxidation state but in polyatomic ion is different. e.g. H_2SO_4

→ H : is +1 (group 1A)
→ O : is −2 (group 6A)

Sum of Charges = Zero (Rule 3)

$2(+1) + 1(X) + 4(-2) = 0$

$\therefore X = +6 \qquad \therefore S = +6$

Q. Is the following reaction a redox reaction?

$$C + 2S \longrightarrow CS_2$$

A.

From the rules of oxidation states;

$$\underset{(0)}{C} + \underset{(0)}{2S} \longrightarrow C\,S_2 \quad (+4)\ (-2)$$

C: Oxidation (0 → +4); S: Reduction (0 → −2)

Where;

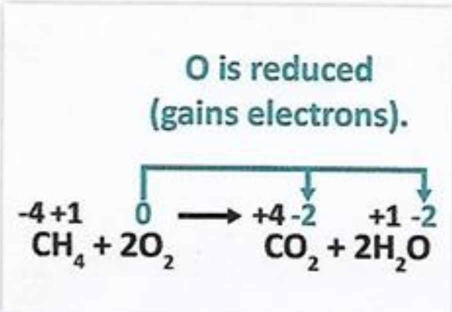
Oxidation : loss of electron(s) or increase in oxidation state. (C)

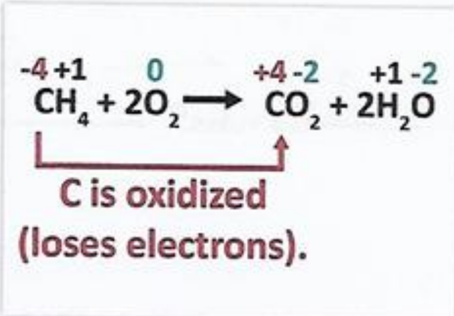
Reduction : gain of electron(s) or decrease in oxidation state. (S)

Q. Identify which element oxidized and that reduced in the following reaction?

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

A. From the rules of oxidation states;

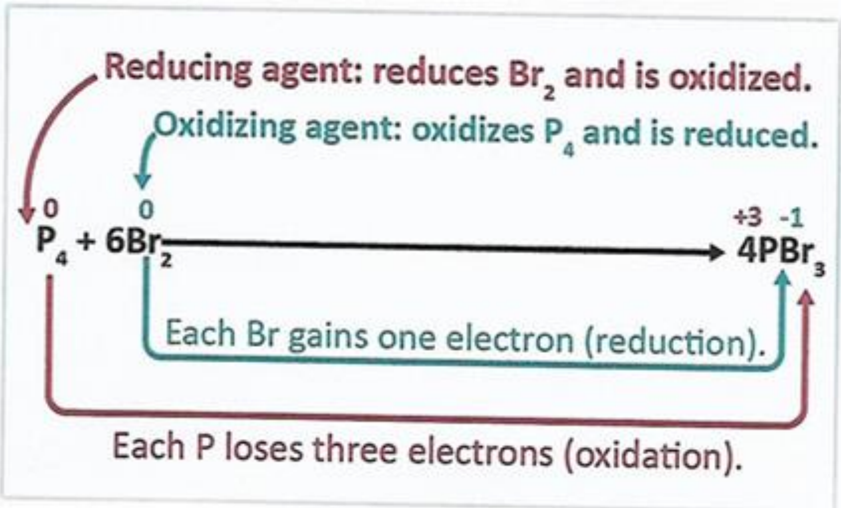




Q. In the following reaction, which substance is the oxidizing agent and which is the reducing agent?

$$P_4 + 6\,Br_2 \longrightarrow 4\,PBr_3$$

A.



Thus;

* The element which is <u>oxidized</u> ⇒ Reducing agent or Reductant.
* " " " " <u>reduced</u> ⇒ Oxidizing agent or Oxidant.

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