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Chapter 1 - Chemical Reactions and Equations

Chemical change: - is a change in which one or more new substances are formed.
In a chemical change—

- New substances are formed.
- Energy changes are involved.
- There is a change in mass during the reaction.
- Permanent change takes place.

Examples –

- Cooking of food
- Rusting of iron
- Heating of Lead nitrate
- Souring of milk
- Ripening of fruit.

Rusting of iron is a chemical change because

- A new substance iron oxide is formed.
- The change is permanent; the article has got a rust layer (which may only peal off).
- There is an increase in mass when rust forms.
- An energy change has taken place (which may not be visible).

Chemical changes are also known as chemical reactions.

Exothermic Reaction - A chemical reaction which is accompanied by evolution of heat energy is known as exothermic reaction.
Examples:

$$C_{(s)} + O_{2\ (g)} \rightarrow CO_{2(g)} + 393.5kJ$$

$$N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)} + 92.3kJ$$

The amount of heat (energy) produced is written along with the products. This indicates that heat is given out.

Endothermic Reactions - A chemical reaction which is accompanied by absorption of heat energy is known as exothermic reaction.
Examples:

$$N_{2(g)} + O_{2(g)} + 180.5kJ \rightarrow 2NO_{(g)}$$

$$2HgO_{(g)} + 180kJ \rightarrow 2Hg_{(l)} + O_{2(g)}$$

The amount of heat (energy) produced is written along with the reactants. This indicates that heat is absorbed.

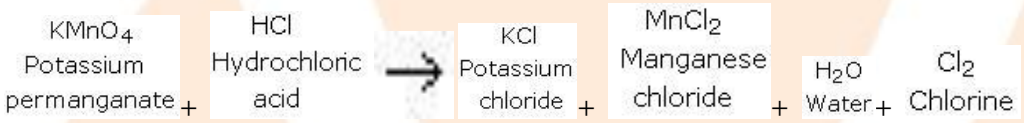
Chemical Formulae - The chemical formula of a substance is the symbolic representation of the actual number of atoms present in one molecule of that substance.

(a) Formula of one molecule of water is H_2O. It shows that one molecule of water is made up of 2 atoms of hydrogen and one atom of oxygen.

(b) Formula of one molecule of sulphuric acid is H_2SO_4. It shows that one molecule of sulphuric acid is made up of 2 atoms of hydrogen, 1 atom of Sulphur and 4 atoms of oxygen.

Chemical Equations - Representation of a chemical change in terms of symbols and formulae of the reactants and products is known as chemical equation of the reaction.

Example



Steps for writing Chemical Equation

Step I: Writing skeletal Equation

A word-equation shows change of reactants to products through an arrow placed between them ($\rightarrow$). The arrow may be read as "to yield" or "to form" or "to give" and shows the direction of the reaction.

The reactants are placed on the left hand side (LHS) of the arrow and the products on the right hand side (RHS). The different reactants as well as products are connected by a plus sign (+).

A complete chemical equation represents the reactants, products and their physical states symbolically and is a balanced account of a chemical transaction.

Step II: Balancing of Chemical Equation

An equation in which number of atoms of each element is equal on both the sides of the equation is known as balanced chemical equation.

A chemical equation is balanced so that the numbers of atoms of each type involved in a chemical reaction are the same on the reactant and product sides of the equation.

Equations must always be balanced.

Whenever H_2O is present on any side, the number of hydrogen on both the sides should be an even number (2 atoms of hydrogen in water). If there are $4H_2O$, then $4 \times 2 = 8$ hydrogen atoms. If there are $7H_2O$, then $7 \times 2 = 14$ hydrogen atoms i.e., all are even numbers.

∴ On the reactant side, there must be an even number in front of HCl. (What that number is, we will find out later). As a result, the number of chlorine atoms will also be even. But on the product side, the number of chlorine atoms is odd (i.e., KCl = 1, $MnCl_2$= 2, Cl_2 = 2. i.e., 1 + 2 + 2 = 5). The only odd number of chlorine atoms is in KCl. Let us change it into the simplest even number possible i.e., 2.

$\therefore \quad KMnO_4 + HCl \rightarrow 2\,KCl + MnCl_2 + H_2O + Cl_2$

Since number of K atoms in 2 KCl = 2, place 2 in front of $KMnO_4$ to balance K atom.

$2KMnO_4 + HCl \rightarrow 2\,KCl + MnCl_2 + H_2O + Cl_2$

In 2 $KMnO_4$, there are 2 K, 2 Mn, and 8 O. So add these numbers in front of K, Mn and O, (K is already done).

$\therefore \quad 2KMnO_4 + HCl \rightarrow 2\,KCl + 2MnCl_2 + 8H_2O + Cl_2$

If there are 8 H_2O on the product side, there should be 16 H (8 x 2) on the reactants side as well.

$\therefore \quad 2KMnO_4 + 16HCl \rightarrow 2\,KCl + 2\,MnCl_2 + 8H_2O + Cl_2$

Now the only unbalanced one is → Chlorine. On the left hand side, there are 16 Cl. On the right hand side, firstly, there are 2 Cl in 2 KCl + 4 Cl in 2 $MnCl_2$, making total of 6(2 + 4). Subsequently 10 more Cl atoms are to be accounted for. So place 5 in front of Cl_2 to make it 10 (5 x 2).

$\therefore \quad 2KMnO_4 + 16HCl \rightarrow 2\,KCl + 2MnCl_2 + 8\,H_2O + 5Cl_2$

This type of balancing the chemical equations is known as the Hit and trial method.

Information conveyed by a chemical equation

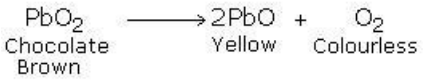
1. Names of various reactants and products
2. Formulae of reactants and products
3. Relative number of moles of the reactants and products
4. Relative masses of reactants and products
5. Relative volumes of gaseous reactants and products

Limitation of a Chemical Equation

- It does not mention the state of the substances. Accordingly, the following symbols should be added to make it informative: (s) for solid, (l) for liquid, (aq) if the reactant or product is present as a solution in water, (g) for gas and (vap) for vapour.
  Example: $CaCO_3$ (s)+ HCl (aq) → $CaCl_2$ (s) + H_2O (l) + CO_2(g)
- The reaction may or may not be complete. An equation does not reveal this.
- It does not give any information regarding the speed of the reaction.
- It does not give the concentration of the substances. In some cases, terms like diluted (dil) and concentrated (conc) may be added.
- It does not give the conditions of temperature, pressure, catalyst, etc. This is overcome by mentioning these above or below the arrow. e.g.

$$2SO_2 + O_2 \xrightarrow[450-500°C]{\text{Pt catalyst}} 2SO_3$$

- It does not give any idea about color changes, which has to be mentioned separately.

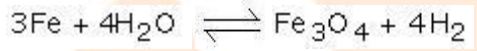


- It does not give any indication regarding the production or absorption of heat. This is mentioned separately.

  $C + O_2 \rightarrow CO_2 + Heat$

  $2C + O_2 \rightarrow 2CO + Heat$

- Some reactions are reversible. They are represented by $\rightleftharpoons$ or $\longleftrightarrow$



- Chemical reactions that proceed with evolution of heat energy, that is, in which heat is given out along with the product, are called exothermic reactions.
- Chemical reactions that proceed with the absorption of heat energy are called endothermic reactions.

Balancing of simple Chemical Equations - The number of atoms of each element should remain same before and after the reaction.
Balancing: To make the number of atoms of all the elements equal on both the sides in a skeletal equation. A simple equation is balanced by **Hit and trial** method.

Steps involved in balancing a Chemical Equation:

Step 1: Write the correct skeleton equation.
Step 2: Start with the compound that has the maximum atoms or maximum kinds of atoms and the atoms present in it are balanced first.
Step 3: Balance elements that appear only once on each side of the arrow first. Then balance elements that appear more than once on a side.
Step 4: Elementary substances are balanced last of all.
Step 5: If required the whole equation is multiplied by some suitable number in order to make all the coefficients whole numbers.

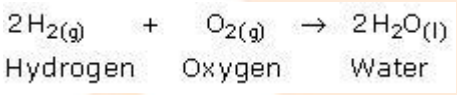
Balancing of Ionic Equations:
A balanced ionic equation must satisfy mass as well as charge balance.

Calculations based on Chemical Equations:
We can get a lot of quantitative information from a chemical reaction. Number of moles of reactants and products can be calculated from a chemical reaction.

Types of Reactions

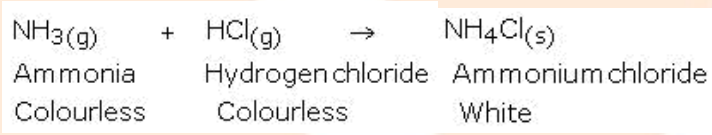
Combination or Synthesis Reactions:
The reactions in which two or more substances combine to form a single new substance.

Types of Combination reactions:
1. Combination of two elements to form a compound
   - Burning of hydrogen in air or oxygen to produce water.



2. Combination Reactions involving an Element and a Compound
   - Burning of carbon monoxide in oxygen to form carbon dioxide.
     $2CO\ (g) + O_2(g) \rightarrow 2CO_2\ (g)$

3. Combination Reactions involving Two Compounds
   - Combination of ammonia and hydrogen chloride to produce ammonium chloride.

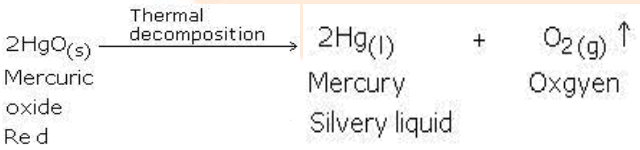


Decomposition reactions: are opposite to combination reactions. In a decomposition reaction a compound breaks down into two or more simple substances by the application of heat or electricity.
When a substance decomposes due to heat it is called **thermal decomposition,** while decomposition due to electricity, is called **electrolytic decomposition.**

Electrolysis: The decomposition of a substance by passing electric current through it is called electrolysis.

Photolysis: The decomposition of a compound with light is called photolysis.

1. Mercuric oxide, when heated, undergoes thermal decomposition, to give mercury and oxygen.



2. Similarly, if blue crystals of copper nitrate are heated, they undergo thermal decomposition to give black colored copper oxide, reddish brown fumes of nitrogen dioxide, and a colorless gas of oxygen.

$$2Cu(NO_3)_2(s) \xrightarrow{\text{Thermal Decomposition}} 2CuO(s) + 4NO_2(g) + O_2(g)$$

Copper nitrate (Blue) → Copper oxide (Black) + Nitrogen dioxide (Reddishbrown) + Oxygen

3. When water taken in an electrolytic cell, is acidified with a small quantity of sulphuric acid and a direct current passed through it undergoes electrolytic decomposition to yield hydrogen and oxygen.

$$2H_2O_{(l)} \xrightarrow{Electrolytic\ Decomposition} 2H_{2(g)} + O_{2(g)}$$

Water → Hydrogen + Oxygen

4. If an electric current is passed through molten lead bromide, it decomposes to give lead and bromine.

$$PbBr_2 \xrightarrow{\text{Electrolytic decomposition}} Pb_{(s)} + Br_{2(l)}$$

Lead bromide (molten) → Lead + Bromine

Activity Series: The activity series of metals is a list of metals in the order of their decreasing chemical activity.

A substitution or displacement reaction is a chemical change in which atoms of one element replace the atoms of another element from the molecules of a compound. Elements which are higher in the Activity Series displace those elements which are placed below them. More electro positive elements displace lesser electropositive elements. Conversely, higher electro negative elements will displace lesser electro negative elements. For e.g.,

$$Fe_{(s)} + CuSO_4(aq) \rightarrow FeSO_4(aq) + Cu(s)\downarrow$$

Iron + Copper Sulphate (Blue) → Iron(II) Sulphate (Green) + Copper (Reddish Brown)

$$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2O(g)$$

Magnesium + Sulphuric acid → Magnesium sulphate + Water

$$2KI(aq) + Cl_2(g) \rightarrow 2KCl(aq) + I_2(s)$$

Potassium iodide + Chlorine → Potassium chloride + Iodine

The iodine so liberated, dissolves in the chloroform, giving it a purple color.

Double Displacement Reactions / Metathesis reactions: The reactions in which two compounds react to form two different compounds by mutual exchange of ions.

$A^+B^- + C^+D^- \rightarrow A^+D^- + C^+B^-$

$Na^+Cl^-(aq) + Ag^+NO_3^-(aq) \rightarrow Na^+NO_3^-(aq) + Ag^+Cl^-(s)\downarrow$

Sodium chloride Silver nitrate Sodium nitrate Silver chloride White

$2H^+Cl^-(aq) + Pb^{2+}(NO_3)_2^-(aq) \rightarrow 2H^+NO_3^-(aq) + Pb^{2+}Cl_2^-(s)\downarrow$

Hydrochloric acid Lead nitrate Nitric acid Lead chloride White

$Zn^{2+}SO_4^{2-}(aq) + Ba^{2+}Cl_2^-(aq) \rightarrow Zn^{2+}Cl_2^-(aq) + Ba^{2+}SO_4^{2-}(s)\downarrow$

Zinc sulphate Barium chloride Zinc chloride Barium Sulphate White

Types of Double displacement reactions:

1. Precipitation Reaction
2. Neutralization Reactions

1. Precipitation

In all the above reactions a white substance, which is insoluble in water, is formed. This insoluble substance formed is known as a precipitate. A reaction that produces a precipitate is called a precipitation reaction.

2. Neutralization

Neutralization is a type of double displacement reaction, in which, the reactants are a base and an acid, and the products are salt and water. The positive charge of the hydrogen ion of the acid, and the negative charge of hydroxyl ions or oxide ions of the base, lose their electrical charge, and become covalent molecule of water.

$Na^+OH^- + H^-Cl^- \rightarrow Na^+Cl^- + H_2O$

Base Acid Salt water

$Zn^{2+}O^{2-} + 2H^+NO_3^- \rightarrow Zn^{2+}(NO_3)_2^- + H_2O$

A neutralization reaction is basically a reaction between H^+ and OH^- ions i.e.,

$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

Oxidation - Reduction Reactions/Redox Reactions

Classical Concept of Oxidation and Reduction

"Oxidation is a reaction in which oxygen is added or hydrogen is removed from a substance."

Addition of Oxygen - Oxygen adds on to magnesium to become magnesium oxide.

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

Magenesium Oxygen Magnesium oxide

Removal of Hydrogen - Hydrogen is removed from hydro iodic acid to liberate free iodine.

$2HI(g) \rightarrow 2H_2(g) + I_2(g)$

Hydroiodic acid — Hydrogen — Iodine

"Reduction is a reaction in which oxygen is removed from a substance or hydrogen is added to a substance."

Removal of Oxygen - Oxygen is removed from copper oxide to form copper metal.

$CuO(s) + CO(g) \rightarrow Cu(s) + CO_2(g)$

Copper oxide (Black) — Carbon monoxide — Copper (Reddish Brown) — Carbon dioxide

Addition of Hydrogen - Hydrogen adds to chlorine to form hydrogen chloride gas.

$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

Hydrogen — Chlorine — Hydrogen chloride

Oxidation and reduction reactions may occur simultaneously, these reactions as "redox" reactions.

Example of Redox Reaction

$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$

Magnesium — sulphuric acid — Magesium Sulphate — Hydrogen

Example of Non-redox Reaction

$NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s)\downarrow + NaNO_3(aq)$

Sodium Chloride — Silver Nitrate — Silver Chloride — Sodium Nitrate

Redox reactions are the reactions in which oxidation and reduction takes place simultaneously.

Oxidizing and Reducing Agents

Oxidizing Agent: A substance that brings about oxidation.

Reducing Agents: A substance that brings about reduction.

Another definition of Oxidation and Reduction

Oxidation: The process of addition of electronegative element or radical or removal of electropositive element or radical.

Reduction: The process of addition of electropositive element or radical or removal of electronegative element or radical.

Electronic Concept of Oxidation and Reduction

Oxidation: The process in which there is loss of electrons.

Reduction: The process in which there is gain of electrons.

The Effects of Oxidation Reactions in Every Day Life

Corrosion

Many metals are chemically active elements and get easily affected by substances like moisture, air, acids, etc. One must have observed iron articles that are shiny when new, but get coated with a reddish brown powder when left for some time. This process is commonly known as rusting of iron. The problem with iron (as well as many other metals) is that oxidation takes place and the oxide formed does not firmly adhere to the surface of the metal causing it to flake off easily. This eventually causes structural weakness and disintegration of the metal.

Hence metal is attacked by substances around it, it is said to corrode and this process is called corrosion. Corrosion causes deterioration of essential properties in a material.

What happens to copper vessels or artifacts when exposed to air and water? They slowly get tarnished by acquiring a thin green oxide layer. Similarly, silver quickly acquires a thin black oxide coating in moist air. The heaviest metal lead also tarnishes in moist weather. The black coating on silver and the green coating on copper are examples of corrosion in which the oxides formed strongly bond to the surface of the metal, preventing the surface from further exposure to oxygen and consequently slowing down corrosion.

Rancidity

Have you ever tasted or smelt the fat/oil containing food materials left for a long time? This unpleasant change in the flavor and odour of a food is called rancidity. The most important cause of rancidity is the deterioration in fats and fatty foods because of oxidation process. When an oxygen atom replaces hydrogen atom in the fatty acid molecule it destabilizes the molecule. Factors which accelerate fat oxidation include, salt, light, water, bacteria, moulds trace metals (iron, zinc, etc.).

Usually substances which retard fat oxidation or rancidity are called antioxidants (such as BHT, BHA, vitamin E, and vitamin C, and spices such as sage and rosemary). These are added to foods containing fats and oil to prevent such spoiling. Keeping food in air tight containers or air tight wrapping also helps to slow down oxidation.

Some high fat foods such as potato chips are packaged in materials that protect them from light and oxygen and the containers are flooded with nitrogen to further exclude oxygen. At times, to avoid the presence of oxygen altogether, vacuum packaging is used in some processed foodstuff.