Basic Concepts of Chemistry

Molecular Formula: A Brief Overview

Just like each atom has a unique symbol, each compound has a unique molecular formula.

The molecular formula of a compound provides information about the names and numbers of atoms of the different elements present in a molecule of that compound.

Molecular formula is a **chemical formula** that indicates the kinds of atoms and the numbers of each kind of atom in a molecule of a compound.

Examples

- The molecular formula of glucose is $C_6H_{12}O_6$. One molecule of glucose contains 6 atoms of carbon, 12 atoms of hydrogen and 6 atoms of oxygen.
- The molecular formula of water is H_2O. One molecule of water contains 2 atoms of hydrogen and 1 atom of oxygen.

Salient features of chemical formula:

- Compounds are formed when two or more elements combine chemically. Hence, compounds can also be represented using symbols.
- The notation used for representing any compound is called chemical formula of that compound.
- Each compound has a unique chemical formula.
- The chemical formula of any compound tells us about : The different elements which combine to form the compound and the number of atoms of each element present in a molecule of the compound
- For example, H_2O is the chemical formula of water. This denotes that there are two atoms of hydrogen and one atom of oxygen present in one molecule of water.

Chemical Formulae

Let us understand the information derived from chemical formulae by taking the example of carbon dioxide. The chemical formula of carbon dioxide is CO_2. Using this formula, we can derive the following information about carbon dioxide.

- Two elements are present in carbon dioxide: carbon(C) and oxygen (O).
- CO_2 represents one molecule of carbon dioxide.
- Since one atom of carbon combines with two atoms of oxygen, the **valency** of carbon is twice that of oxygen.
- CO_2 is a neutral molecule. It has no charge.
- The relative atomic masses of carbon and oxygen are 12 u and 16 u respectively. So, the ratio by mass between carbon and oxygen is 12 : 32, i.e., 3 : 8.

Writing Chemical Formulae

To write the chemical formula of a compound, one should have prior knowledge of two things.

- **The symbols of the constituent elements.**
- **The combining capacity of the atom of each element constituting the compound.**

The number of atoms of other elements with which one atom of an element combines is decided by the valency of that element.

For example, both hydrogen (H) and chlorine (Cl) have a valency of 1. Therefore, one atom of hydrogen reacts with one atom of chlorine to form one molecule of hydrogen chloride (HCl).

The valency of an ion is equal to the charge on it.

Chemical Formulae

The valencies of some common ions are given in the following table.

Names of ions	Symbols	Valencies	Names of ions	Symbols	Valencies
Aluminium	Al^{3+}	3	Sulphite	SO_3^{2-}	2
Ammonium	NH_4^+	1	Bromide	Br^-	1
Calcium	Ca^{2+}	2	Carbonate	CO_3^{2-}	2
Copper(II)	Cu^{2+}	2	Chloride	Cl^-	1
Hydrogen	H^+	1	Hydride	H^-	1

Chemical Formulae

The valencies of some common ions are given in the following table.

Names of ions	Symbols	Valencies	Names of ions	Symbols	Valencies
Iron(II)	Fe^{2+}	2	Hydrogen carbonate	HCO_3^-	1
Iron(III)	Fe^{3+}	3	Hydroxide	OH−	1
Magnesium	Mg^{2+}	2	Nitrate	NO_3^-	1
Nickel	Ni^{2+}	2	Nitrite	NO_2^-	1
Potassium	K^+	1	Oxide	O2−	2
Silver	Ag^+	1	Phosphate	PO_4^{3-}	3
Sodium	Na^+	1	Sulphate	SO_4^{2-}	2
Zinc	Zn^{2+}	2	Sulphide	S2−	2

Chemical Formulae

The following rules need to be kept in mind while writing the chemical formulae of compounds.

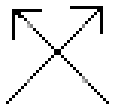
•The valencies or charges on the ions must be balanced. The charge on a cation must be equal in magnitude to the charge on an anion so that the opposite charges cancel each other out and the net charge of the molecule becomes zero.

Examples

- In case of CaO, the valency of Ca is +2 and that of O is −2. These are then crossed over and the compound formed is CaO.

Formula of calcium oxide

Symbols Ca O



Charges 2+ 2−

- The charge on Mg^{2+} is +2 and that on Cl^- is −1. Thus, one Mg^{2+} ion combines with two Cl^- ions to form a molecule with the formula $MgCl_2$.

- In case of a compound consisting of a metal and a non-metal, the symbol of the metal is written first.

Chemical Formulae

Example

- In calcium chloride ($CaCl_2$) and zinc sulphide (ZnS), calcium and zinc are metals, so they are written first; chlorine and sulphur are non-metals, so they are written after the metals.

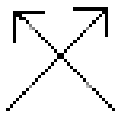
- In case of compounds consisting of polyatomic ions, the polyatomic ions are enclosed in brackets before writing the number to indicate the ratio.

Example

- In case of aluminium sulphate, to balance the charges, two SO_4^{2-} ions combine with one Al^{3+} ion. Thus the formula for aluminium sulphate is $Al_2(SO_4)_3$. Here, the brackets with the subscript 3 indicate that three sulphate ions are joined to two aluminium ions.

Formula of aluminium sulphate

Symbols Al SO_4



Charges 3+ 2−

Chemical Formulae

Naming Certain Compounds

Compound	Rule	Example
A metal and a non-metal	Metal is written first Non-metal is written last with suffix −ide	Calcium nitride (Ca_3N_2)

Two non-metals	Less electronegative non-metal is written first In case, more than one atom of a non-metal is present then prefix like −di, −tri, −tetra etc. is added	Phosphorous pentachloride (PCl_5)
Two elements and oxygen	Oxygen is placed at end of the formula Following prefixes or suffixes are used depending on the number of oxygen atoms present: Less than two oxygen atom: hypo (prefix) Two oxygen atoms: −ite (suffix) Three oxygen atoms: −ate (suffix) More than three oxygen atoms: −per (prefix)	Sodium hypochlorite (NaClO) Sodium chlorite ($NaClO_2$) Sodium chlorate ($NaClO_3$) Sodium perchlorate ($NaClO_4$)
Acids	Binary acids Prefix: hydro Suffix: −ic with the name of second element Polyatomic radicals Suffix: −ic on the basis of second element Prefix not used	Hydrochloric acid (HCl) Sulphuric acid (H_2SO_4)
Trivial names	Used for specific compounds No systemic rule followed	Ammonia (NH_3) Water (H_2O)

Solved Examples

Easy

Example 1:

Give two examples each of molecules having one atom, two atoms and three atoms.

Solution:

Molecules having one atom (/monatomic molecules): Argon (Ar) and Neon (Ne)

Molecules having two atoms (/diatomic molecules): Nitrogen (N_2) and Oxygen (O_2)

Molecules having three atoms (/triatomic molecules): Nitrogen dioxide (NO_2) and carbon dioxide (CO_2)

Medium

Example 2:

The valencies of a few ions are provided below.

H^+ = 1, SO_4^{2-} = 2, Br^- = 1, Mg^{2+} = 2 and K^+ = 1

Write the formulae for magnesium bromide, magnesium sulphate, hydrogen bromide and potassium sulphate.

Solution:

•Magnesium bromide: $MgBr_2$

•Magnesium sulphate: $MgSO_4$

•Hydrogen bromide: HBr

•Potassium sulphate: K_2SO_4

Hard

Example 3:

Write the names of the following compounds.

i)H_2CO_3

ii)KNO_3

iii)$(NH_4)_3PO_4$

iv)Na_2CO_3

v)$Al(NO_3)_3$

vi)$NaHCO_3$

Solution:

i)H_2CO_3: Hydrogen carbonate

ii)KNO_3: Potassium nitrate

iii)$(NH_4)_3PO_4$: Ammonium phosphate

iv)Na_2CO_3: Sodium carbonate

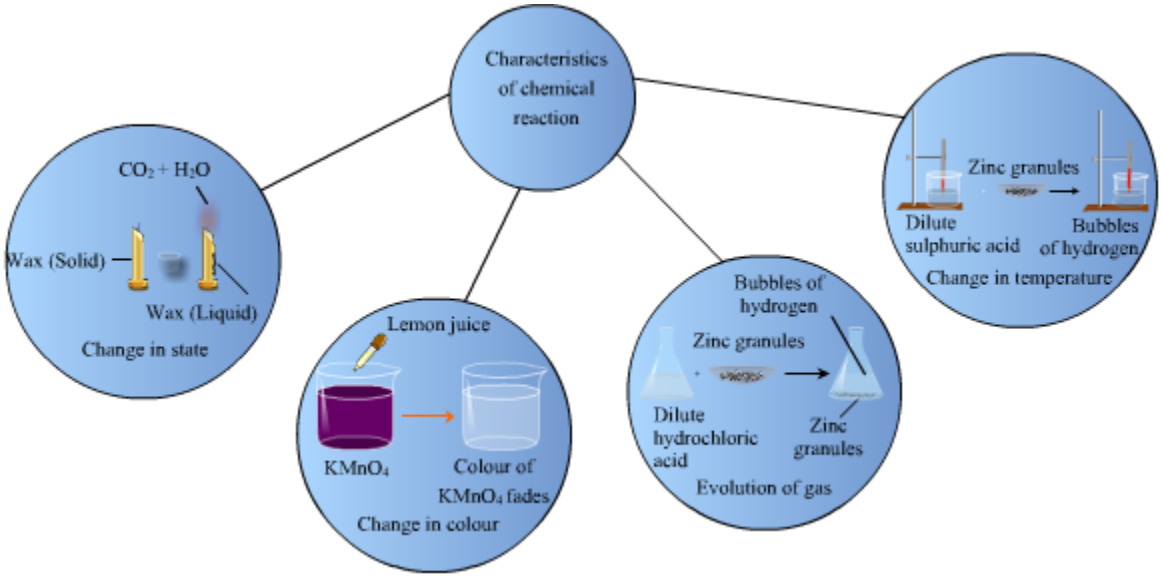
v)$Al(NO_3)_3$: Aluminium nitrate

vi)$NaHCO_3$: Sodium hydrogen carbonate

Chemical Changes and Their Representation in the Form of Chemical Equations

A chemical change can be confirmed by any or all of the following observations-

- change in state
- change in colour
- change in temperature
- evolution of gas
- formation of a precipitate



A chemical change is always accompanied by a chemical reaction. **Reaction** is the term used for depicting a change or transformation in which a substance decomposes, combines with other substances, or interchanges constituents with other substances. Let us see how we can represent a chemical change using a reaction.

Thus, a chemical equation is an easier and more concise method for representing a chemical reaction. It involves writing symbols and formulae (instead of words) for all substances involved in the reaction.

A chemical equation also indicates the number of atoms of each element involved in a reaction. In which reactants are given on left-hand side of a reaction and products are given on right-hand side.

Reactants: The substance which takes part in a chemical reaction.
Products: The new substances produced as a result of chemical reaction.

Try to represent the statements given below as chemical equations.

(a) Potassium metal reacts with water to give potassium hydroxide and hydrogen gas.

(b) Hydrogen gas combines with nitrogen to form ammonia.

Symbols of elements:

Potassium = K

Hydrogen =H

Nitrogen = N

Questions asked in previous years' board examinations

Ques.
Write any two observations in an activity which may suggest that a chemical reaction has taken place. Give an example in support of your answer.

(**2 marks)**

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Sol: A chemical change can be confirmed by any of the following observations:

Change in temperature
Evolution of gas

For example: Calcium oxide reacts vigorously with water to produce calcium hydroxide. During this process, a large amount of heat is also evolved, which increases the temperature of the system. This confirms that a chemical reaction has taken place.

$$\underset{\text{Calcium oxide}}{CaO(s)} + \underset{\text{Water}}{H_2O(l)} \rightarrow \underset{\text{Calcium hydroxide}}{Ca(OH)_2(aq)}$$

Also, when calcium carbonate is heated, it decomposes to form calcium oxide and carbon dioxide.

$$\underset{\text{Calcium carbonate}}{CaCO_3(s)} \xrightarrow{\Delta} \underset{\text{Calcium oxide}}{CaO(s)} + \underset{\text{Carbon dioxide}}{CO_2(g)}$$

In this reaction, calcium carbonate breaks down to form calcium oxide and carbon dioxide. Here, evolution of the gas (carbon dioxide) confirms that a chemical reaction has taken place.

Balanced Chemical Equations

To describe a chemical reaction more concisely, equations of the reactions are written.

Chemical equation

A chemical equation is a concise form which uses symbols and formulae of the chemical compounds or elements involved in the reaction. It also indicates the number of atoms of each element involved in a reaction.

In a chemical reaction, the total mass of the reactants should be equal to the total mass of the products. This means that the total number of atoms of each element should be equal on both sides of a chemical equation. Such an equation is called a **balanced chemical equation**, and the method by which it is obtained is called the balancing of chemical equations.

Another example of a balanced chemical equation is the reaction of limewater with carbon dioxide, that results in the formation of a precipitate of calcium carbonate and water is represented as:

$$\underset{\text{Calcium hydroxide}}{Ca(OH)_2(aq)} + \underset{\text{Carbon dioxide}}{CO_2(g)} \rightarrow \underset{\text{Calcium carbonate}}{CaCO_3(s)} + \underset{\text{Water}}{H_2O(l)}$$

In this reaction, calcium hydroxide is present in the form of a solution in water, carbon dioxide is present as a gas, calcium carbonate is produced as a precipitate i.e. in the solid state, and water is formed in the liquid state.

The energy changes involved in a reaction are denoted by writing the changes involved in the equation itself.

If energy is used in the reaction, then it will be written on the left-hand side. If it is released in the process, then it is written on the right-hand side.

For example, combustion of butane (or any other hydrocarbon i.e., the compounds made up of carbon and hydrocarbon) is accompanied by the evolution of heat and light energy along with the production of carbon dioxide and water. Therefore, the equation for the same will be written as:

$$2C_4H_{10} + 13O_2 \rightarrow 10H_2O + 8CO_2 + \text{Heat} + \text{Light}$$

The reaction conditions (such as temperature, pressure, catalyst etc.) for a reaction are indicated above or below the forward arrow in a reaction.

Below are some balanced chemical equations:

$$\underset{\text{Carbon monoxide}}{(1)\ CO_{(g)}} + \underset{\text{Hydrogen}}{2H_{2(g)}} \xrightarrow[ZnO+CrO_3]{300\ \text{atm},\ 300^\circ C} \underset{\text{Methyl alcohol}}{CH_3OH_{(aq)}}$$

$$\underset{\text{Potasium chlorate}}{(2)\ 2KClO_{3(s)}} \xrightarrow[MnO_2]{\Delta} \underset{\text{Potassium chloride}}{2KCl_{(s)}} + \underset{\text{Oxygen}}{3O_{2(g)}}$$

Chemical Reaction	Chemical Equation
One reactant or two or more products	$CaCO_3 \rightarrow CaO + CO_2$
Two reactants and one product	$N_2 + H_2 \rightarrow 2\ NH_3$
Two reactants and two products	$Na_2SO_4 + BaCl_2 \rightarrow BaSO_4 + 2\ NaCl$
Two reactants and three or more products	$Cu + 2\ H_2SO_4 \rightarrow CuSO_4 + 2H_2O + SO_2$

Write the balanced equations for the following chemical reactions.

1. Barium chloride + Sodium sulphate → Barium sulphate + Sodium chloride.

2. Sodium + Water → Sodium hydroxide + Hydrogen

Other questions asked in previous years' board examinations

Ques. On what basis is a chemical equation balanced?

(**1 mark)**

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Sol: Law of conservation of mass forms the basis of balancing chemical equations. In a balanced chemical equation, the number of atoms of each element is equal on both sides of the equation.

Ques. Balance the following chemical equation:

$Pb(NO_3)_2\,(s) \xrightarrow{\text{heat}} PbO\,(s) + NO_2\,(g) + O_2\,(g)$

(**1 mark)**

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Sol: The balanced chemical equation for the given reaction is:

$$2Pb(NO_3)_2(s) \xrightarrow{\text{Heat}} 2\,PbO(s) + 4NO_2(g) + O_2(g)$$

Information conveyed by balanced chemical equations

- Result of the chemical change
- Number of molecules of reactants being consumed and products being formed
- Chemical composition of reactants and product species

- Molecular mass of reactants and products
- Proves the law of conservation of mass

Limitation of a chemical equation
A chemical equation does not provide some other important chacteristics of a chemical reaction, such as:

- time needed to complete the reaction
- physical state of reactants and products
- concentration of each reactant and product
- rate of the reaction

Making a chemical reaction more informative

- Providing the information about catalyst used, temperature and pressure of the reaction above or below the arrow.

$$\mathrm{N_2\ (g)\ +\ H_2\ (g)\ \xrightarrow[450^{o}\ C,\ 200-900\ atm]{Fe\ +\ Mo}\ 2\ NH_3\ \ (g)}$$

- Stating whether heat is being evolved or absorbed in a chemical reaction
  $C(s) + O_2(g) \longrightarrow CO_2(g) + \text{Heat}$
- Mentioning the physical state of reactants and products.
  $C(s) + O_2\,(g) \longrightarrow CO_2\,(g)$
- Adding concentration of acids and bases
  $Mg\,(s) + H_2SO_4\,(aq) \longrightarrow MgSO_4\,(aq) + H_2\,(g)$