ATOMS AND MOLECULES

Concepts Covered

- Atoms, Molecule
- Laws of chemical combination
- Molecular and Atomic mass, Gram Molecular Mass (GMM), Gram Atomic Mass (GAM)
- Mole Concept

Introduction

The structure of matter has been a subject of speculation from very early times. According to Greek philosopher Democritus, if we go on dividing matter into smaller parts, a stage would be reached when particles obtained cannot be divided further. He called these particles 'atoms' meaning indivisible.

Conclusion:
All matter is made up of small particles called atoms. Different kinds of atoms and molecules have different properties due to which different kinds of matter also show different properties.

Laws of Chemical Combination

By studying the result of quantitative measurement of many reactions it was observed that whenever substances react, they follow certain laws. These laws are called the law of chemical combination.

(a) Law of conservation of mass.
(b) Law of constant proportions.
(c) Law of multiple proportions.

(a) Law of conservation of mass:

This law was given by the French chemist **A. Lavoisier in** 1774. This law states that in every chemical reaction, the total mass before and after the reaction remains constant.

That is, **"Mass can neither be created nor destroyed in a chemical reaction"**. Lavoisier showed that when mercuric oxide was heated, it produced free mercury and oxygen. The sum of masses of mercury and oxygen was found to be equal to the mass of mercuric oxide.

Mercuric oxide	→	Mercury	+	Oxygen
100g		92.6g		7.4g

Check Your Concept - 1

(i) In a reaction $5.3\ g$ of sodium carbonate reacted with $6\ g$ of ethanoic acid. The products were $2.2\ g$ of carbon dioxide. $0.9\ g$ water and $8.2\ g$ of sodium ethanoate. Show that these observations are in agreement with the law of conservation of mass.
Sodium carbonate + Ethanoic acid → Sodium ethanoate + Carbon dioxide + Water.

(ii) Which postulate of Dalton's atomic theory is the result of the law of conservation of mass?

(b) Law of constant proportions / Law of definite proportions:

This law was given by the French chemists **A. Lavoisier and Joseph Proust**. This law deals with the composition of chemical compounds.

This law is: **A pure chemical compound always contains the same elements combined together in the same proportion by mass.**

For Example:
Pure water obtained from different sources such as a **river, well,** etc. always contains hydrogen and oxygen combined together in the ratio of **1:8** by mass.

Similarly, carbon dioxide can be obtained by different methods such as burning carbon, by heating limestone. It shows that samples of carbon dioxide obtained from different sources contain carbon and oxygen in the ratio of **3:8** by mass. Thus, in water or CO_2 this proportion of hydrogen and oxygen or carbon and oxygen always remains constant.

Example:

Question: **Hydrogen and oxygen combine in the ratio of 1:8 by mass to form water. What weight of oxygen gas would be required to completely react with 3g of hydrogen gas?**

Answer: The ratio in which hydrogen and oxygen combine =1:8
1g of hydrogen combined with oxygen = 8g
$\therefore$ 3g of hydrogen will combine with oxygen =$8 \times 3 = 24$g.

(c) Law of multiple proportions:

It was given by Dalton in 1808. According to this law, when one element combines with the other elements to form two or more different compounds, the mass of one element, which combines with a constant mass of the other, bears a simple ratio to one another.

Example: Carbon and oxygen when combined, can form two oxides that are CO (carbon monoxide), and CO_2 (carbon dioxide). In CO, 12g of carbon combines with 16g of oxygen. In CO_2, 12g of carbon combines with 32g of oxygen. Thus, we can see the mass of oxygen which combine with a constant mass of carbon (12g) bear a simple ratio of 16:32 or 1:2.

Dalton's Atomic Theory

On the basis of the laws of chemical combination, John Dalton proposed atomic theory in 1808.

The main postulates of Dalton's atomic theory are:

1. All matter is made up of very tiny particles called Atoms.
2. Atoms are indivisible particles, which cannot be created or destroyed in a chemical reaction.
3. Atoms of a given element are identical in mass size and chemical properties.
4. Atoms of different elements have different mass sizes and chemical properties.
5. Atoms combine in the ratio of small whole numbers to form compounds.
6. The relative number and kinds of atoms are constant in a given compound.
7. Atoms of the same element can combine in more than one ratio to form more than one compound. For example, hydrogen and oxygen combine to give water and hydrogen peroxide. In water (H_2O), two atoms of hydrogen combine with one atom of oxygen while in hydrogen peroxide (H_2O_2), two atoms of hydrogen combine with two atoms of oxygen.

For Examples:

- The postulates of Dalton's atomic theory that "Atoms can neither be created nor destroyed", was the result of the law of conservation of mass.
- The postulates of Dalton's atomic theory that "The element consists of an atom having fixed mass and that the number and kind of atom in a given compound are fixed", came from the law of constant proportions.

Check Your Concept - 2

(i) Which postulate of Dalton's atomic theory can explain the law of definite proportions?

(ii) When 3.0 g of carbon is burnt in 8.00 g oxygen, 11.00 g of carbon dioxide is produced? What mass of carbon dioxide will be formed when 3.00 g of carbon is burnt in 50.00 g of oxygen? Which law of chemical combination will govern your answer?

Drawbacks of Dalton's Atomic Theory

Some of the drawbacks of Dalton's atomic theory of matter are given below:

- According to Dalton's atomic theory, atoms were thought to be indivisible. But it is now known that atoms can be further divided into still smaller particles called electrons, protons, and neutrons.

- Dalton's atomic theory said that all the atoms of an element have exactly the same mass. But it is now known that atoms of the same element can have slightly different masses, as in the case of isotopes.
- Dalton's atomic theory said that atoms of different elements have different masses. But it is now known that even atoms of different elements can have the same mass as in the case of isobars.

Atoms:

All matter is made up of atoms. An atom is the smallest particle of an element that can take part in a chemical reaction. Atoms of most of the elements are very reactive and do not exist in the free state (as a single atom). They exist in combination with the atoms of the same element or another element. Atoms are very small in size.

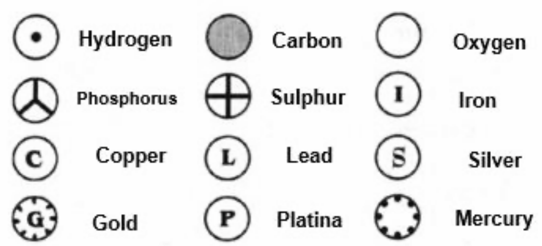
The size of an atom is indicated by its radius which is called atomic radius (radius of an atom). Atomic radius is measured in nanometre (nm) (1 meter = 10^{-9} nanometres or 1nm = 10^{-9}m). Hydrogen atoms are the smallest atom of all, having an atomic radius of 0.037 nm. Atoms are so small that we cannot see them under the most powerful optical microscope.

DID you KNOW

A Transmission Electron Microscope (TEM) is used to see an atom.

Symbol of Elements:

The symbol may be defined as the abbreviation used for the name of an element. The symbol of an element is generally either the first letter or the first two letters or the first and the third letters of the name of the element. For example, the symbol of the following elements is the first letter of the name of that element.



Symbols for some elements as proposed by Dalton

DID you KNOW

Mercury was named after a planet but derives its symbol Hg from the Latin word 'Hydragyrum' meaning liquid silver.

S.No	Element	Symbol
1	Hydrogen	H
2	Carbon	C
3	Nitrogen	N
4	Oxygen	O
5	Fluorine	F

Certain symbols seem to have no relationship to their names. The symbol of these elements is derived from their Latin names.

Element	Latin Name	Symbol
Iron	Ferrum	Fe
Gold	Aurum	Au
Copper	Cuprum	Cu
Potassium	Kalium	K
Sodium	Natrium	Na
Silver	Argentum	Ag
Mercury	Hydrargyrum	Hg
Lead	Plumbum	Pb

Atomic Mass: Atomic mass of an element may be defined as the average relative mass of an atom of the element as compared with the mass of an atom of carbon (C-12 isotope) taken as 12 amu.

$$\text{Atomic mass} : \frac{\text{Mass of 1 atom of the element}}{\frac{1}{12}\text{ of the mass of an atom of } C-12}$$

How do Atoms occur?

The atoms of only a few elements called noble gases (such as helium, neon, argon and krypton, etc.) which are chemically unreactive and exist in the free state (as a single atom). Atoms of the elements are chemically very reactive and do not exist in the free state (as a single atom).

Check Your Concept - 3

(i) Define the atomic mass unit.

(ii) Why is it not possible to see an atom with naked eyes?

DID YOU KNOW

One-gram atomic mass of any element contains the same number of atom of that element as there are carbon atoms in exactly 12 g of carbon- 12. This number is Avogadro's number 6.022 $\times$ 10^{23} atoms/g.

Molecules

A molecule is the smallest particle of a compound that has independent existence. A molecule contains one or more than one atom.

The molecules of elements contain atoms of only one kind.

The number of atoms in a molecule of an element is known as the atomicity of the element.

For example: The atomicity of the noble gases is 1, that of hydrogen, nitrogen, oxygen, etc. is 2 each, and of ozone is 3. Thus, noble gases, hydrogen, and ozone are respectively monoatomic, diatomic, and triatomic molecules.

Molecules of elements:

The molecules of an element contain two similar atoms chemically bonded together. For example, ozone gas has 3 oxygen atoms combined together, so ozone exists in the form of O_3. A recently discovered form of carbon called **Buckminsterfullerene** has the molecular formula C_{60}.

Molecules of compounds:

The molecules of a compound contain two or more different types of atoms chemically bonded together. For example, the molecule sulphur dioxide (SO_2) contains one atom of sulphur chemically bonded with two atoms of oxygen.

Molecular mass and formula mass:

The molecular mass of a substance (an element or a compound) may be defined as the average relative mass of a molecule of the substance as compared with the mass of an atom of carbon (C-12 isotope) taken as 12amu.

The molecular mass of a compound can be obtained by adding atomic masses of all the atoms present in the molecule of the compound. For example, molecular mass of CO_2 is $\rightarrow 12 \times 1 + 16 \times 2 = 44$ u

$$\textbf{Molecular} : \frac{\text{Mass of 1 Molecule of the substance}}{\frac{1}{12}\text{ of the mass of an atom of C}-12}$$

Gram Molecular Mass:

Gram molecular mass of a substance is defined as that quantity of the substance whose mass expressed in grams is numerically equal to its molecular mass.

For Example:

The molecular mass of CO_2 is 44 u, its gram molecular mass is 44g. The gram molecule mass of a substance is also known as the gram-molecular mass of the substance.

Formula Mass:

The formula mass of an ionic compound is obtained by adding atomic masses of all the atoms in a formula unit of the compound.

For Example:

Formula mass of potassium chloride (KCl) = Atomic mass of potassium + atomic mass of chlorine $\Rightarrow$ 39 + 35.5 = 74.5

Check Your Concept - 4

(i) Calculate the molecular masses of $\mathbf{H_2, O_2, Cl_2, CO_2, CH_4, C_2H_6, C_2H_4, NH_3, CH_3OH}$.

(ii) Calculate the formula unit masses of $\mathbf{ZnO, Na_2O, K_2CO_3}$, given atomic masses ($\mathbf{Zn = 65u, Na = 23u}$, $\mathbf{K = 39u, C = 12u}$ and $\mathbf{O = 16u}$)

(iii) Calculate the molar mass of the following substances.
(a) Ethyne, $\mathbf{C_2H_2}$
(b) Sulphur molecule, $\mathbf{S_8}$
(c) Phosphorous molecule, $\mathbf{P_4}$ (Atomic mass of phosphorus $= \mathbf{31}$)
(d) Hydrochloric acid, $\mathbf{HCl}$
(e) Nitric acid, $\mathbf{HNO_3}$

Chemical Formula:

The chemical formula of a compound describes the composition of a molecule of the compound in terms of the symbols of elements and the number of atoms of each element present in one molecule of the compound.

In the chemical formula of a compound, the elements present are denoted by their symbols and the number of atoms of each element is denoted by writing their number as subscripts to the symbols of the respective element.

Example: Water is a compound whose one molecule is made up of two atoms of hydrogen and one atom of oxygen hence, its chemical formula is H_2O.

- While writing the formula of an ionic compound the metal is written on the left-hand side while the non-metal is written on the right-hand side. The name of the metal remains as such but that of the non-metal is changed to have the suffix 'ide'.
  Example: MgO is named magnesium oxide, KCl has named potassium chloride, etc.
- Molecular compounds, formed by the combination of two different non-metals, are written in such a way that the less electronegative element is written on the left-hand side while the more electronegative element is written on the right-hand side. In naming molecular compounds, the name of the less negative non-metal is written as such, but the name of the more electronegative element is changed to have the suffix 'ide'.
  Example: H_2S is named hydrogen sulphide.
- When there is more than one atom of an element present in the formula of the compound, then the number of atoms is indicated by the use of appropriate prefixes (Mono for 1, di for 2, tri for 3. tetra for 4 atoms, etc.) in the name of the compound.
  Example: CO_2 is named carbon dioxide, and CCl_4 is named carbon tetra chloride.
- The prefixes are needed in naming those binary compounds in which the two non-metals form more than one compound (by having different numbers of atoms).
  Example: Two non-metals, nitrogen, and oxygen combine to form different compounds like nitrogen monoxide (NO), nitrogen dioxide (NO_2), Nitrogen trioxide (N_2O_3), etc.
- But, if two non-metals form only one compound, then prefixes are not used in naming such compounds.
  Example: Hydrogen and sulphur combine to form only one compound H_2S. So H_2S is named hydrogen sulphide and not hydrogen monosulphide.

Ions

An ion is a positively or negatively charged atom (or group of atoms).
These are two types of ions: -e⁻
(1) Cations
(2) Anions

Cations	Anions
A positively charged ion is known as a cation. For example: Sodium ion (Na^+), Magnesium ion ($\mathbf{Mg^{2+}}$), A cation is formed by the loss of one or more electrons by an atom. For example, a sodium atom loses one electron to form a sodium ion $\mathbf{Na^+}$. $\underset{\text{(Sodium atom)}}{Na} \xrightarrow{-e^-} \underset{\text{Sodium ion (A cation)}}{(-e^-) \rightarrow \mathbf{Na^+}}$	A negatively charged ion is known as an anion. $\mathbf{Cl^-}$(Chloride ion), $\mathbf{O^{2-}}$ (oxide ion) etc. An anion is formed by the gain of one or more electrons by an atom. For example, a chlorine atom gains one electron to form a chloride ion $\mathbf{Cl^-}$. $\underset{\text{Chlorine atom}}{Cl} \xrightarrow{+e^-} \underset{\text{Chloride ion (An anion)}}{\mathbf{Cl^-}}$

Valency of ions:

The valency of an ion is the same as the charge present on the ion.
Monovalent cation (Valency of cation +1)

Example: Sodium ion ($\mathbf{Na^+}$), Potassium ion ($\mathbf{K^+}$), Hydrogen ion ($\mathbf{H^+}$).
Divalent cations (valency of cations 2^+)

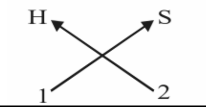
Example: Magnesium ion ($\mathbf{Mg^{2+}}$) Ferrous ion ($\mathbf{Fe^{2+}}$)
Trivalent cations (valency of cations + 3)

Steps for writing formula of a Molecular Compound

The steps to be followed for writing the formula of a molecular compound are-

- First, write the symbols of the elements contributing to the compound.
- Then, below each symbol, write its corresponding valency.
- Finally, we exchange the valencies of the combining atoms i.e with the first atom, we write the valency of the second atom and with the second atom, we write the valency of the first atom, the valencies to be written as subscripts to the symbols.
- If the valencies have any common factor, then the formula is divided by the common factor. This gives the required formula of the compound.
  Example: To work out the formula of hydrogen sulphide

(1) Hydrogen sulphide compound is made up of hydrogen and sulphur elements. So first we write down the symbol of hydrogen and sulphur.
(2) The valency of hydrogen is 1 and the valency of sulphur is 2. So below the symbol H, we write 1 and below the symbol S we write 2.

Criss – Cross Method		
Symbol	H	S
Valencies	1	2
		
	Cross-Over Valencies	

- We now cross over the valencies of H and S atoms. With the H atom, we write the valency of S (which is 2) so that it becomes H_2 with the S atom we write the valency of H (which is 1) so that it becomes S1. Now, joining together H_2 and S_1 the formula of hydrogen sulphide becomes H_2S_1 or H_2S, (This is because we don't write the subscript 1 with an atom in a formula).

Check Your Concept - 5

(i) What is meant by the term chemical formula?

(ii) How many atoms are present in a
(i) H_2S molecule and (ii) $\mathbf{PO_4^{3-}}$ ion?

(iii) What are polyatomic ions? Give examples.

(iv) Give the names of the elements present in the following compounds
(a) Quick lime (b) Hydrogen bromide
(c) Baking powder (d) Potassium sulphate

DID you KNOW

The gain or loss of electrons by an atom to form negative or positive ions has an enormous impact on the chemical and physical properties of the atom. Sodium metal, which consists of neutral sodium atoms, bursts into flame when it comes in contact with water. But positively charged Na^+ ions are so unreactive with water they are essentially inert. Neutral chlorine atoms instantly combine to form Cl_2 molecules, which are so reactive that entire communities are evacuated when trains carrying chlorine gas derail. However, chloride ions do not react with one another.

Writing the Formula of Ionic compounds:

Steps:

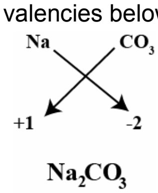
- First, write the symbols of the ions from which the ionic compound is made. A cation is written on the left side while the anion is written on the right side.
- Then, the valencies of the respective cation and anion are written below their symbols.
- The valencies of the cation and anion are exchanged. The number of cation and anions in the formula of the compound is adjusted in such a way that the total positive charge of cation becomes equal to the total negative charge of the anions making the ionic compound electrically neutral.
- The final formula of the ionic compound is then written but the charges present on the cation and the anion are not shown.

Example: To write the formula for sodium carbonate.

(1) First, write the symbol of sodium ion and carbonate ion and write their valencies below their symbols are shown.

Symbols	**Na**	**CO_3**
Valencies (or charges)	**+1**	**–2**

(2) Now, we exchange the valencies of sodium ion and carbonate ion,



(3) So, -2 gets associated with Na and +1 gets associated with CO_3 in this way, we get Na_2 and CO_3 and the final formula of sodium carbonate is Na_2CO_3.

Name of the compound	Positive ion (cation)			Negative ion (anion)			Chemical Formula
	Name	Formula	Valency number	Name	Formula	Valency number	
Hydrogen chloride	Hydrogen	H	1	Chloride	Cl	1	HCl
Hydrogen sulphide	Hydrogen	H	1	Sulphide	S	2	H_2S
Sulphuric acid (hydrogen sulphate)	Hydrogen	H	1	Sulphate	SO_4	2	$H_2(SO_4)_1$, $H_2(SO_4)$
Sodium nitrate	Sodium	Na	1	Nitrate	NO_3	1	$Na_1(NO_3)_1$, $NaNO_3$
Aluminium Phosphate	Aluminium	Al	3	Phosphate	PO_4	3	$Al_3(PO_4)_3$, $AlPO_4$
Aluminium sulphate	Aluminium	Al	3	Sulphate	SO_4	2	$Al_2(SO_4)_3$
Ferrous sulphate	Ferrous	Fe	2	Sulphate	SO_4	2	$Fe_2(SO_4)_2$, $FeSO_4$
Ferric sulphate	Ferric	Fe	3	Sulphate	SO_4	2	$Fe_2(SO_4)_3$
Potassium dichromate	Potassium	K	1	Dichromate	Cr_2O_7	2	$K_2(Cr_2O_7)_1$, $K_2Cr_2O_7$
Magnesium nitrate	Magnesium	Mg	2	Nitrate	NO_3	1	$Mg(NO_3)_2$
Silver chromate	Silver	Ag	1	Chromate	Cr_2O_4	2	Ag_2CrO_4
Barium carbonate	Barium	Ba	2	Carbonate	CO_3	2	$Ba_2(CO_3)_2$, $BaCO_3$
Potassium permanganate	Potassium	K	1	Permanganate	MnO_4	1	$KMnO_4$
Calcium hydroxide	Calcium	Ca	2	Hydroxide	OH	1	$Ca(OH)_2$
Aluminium oxide	Aluminium	Al	3	Oxide	O	2	Al_2O_3
Magnesium phosphate	Megnesium	Mg	2	Phosphate	PO_4	3	$Mg_3(PO_4)_2$
Ammonium sulphate	Ammonium	NH_4	1	Sulphite	SO_3	2	$(NH_4)_2SO_3$
Zinc phosphate	Zinc	Zn	2	Phosphate	PO_4	3	$Zn_3(PO_4)_2$

Check Your Concept - 6

(i) Write down the formulae of.
(a) Sodium oxide (b) Aluminium chloride
(c) Sodium sulphide (d) Magnesium hydroxide

(ii) Write down the names of compounds represented by the following formulae:
(a) $Al_2\,(SO_4)_3$ (b) $CaCl_2$ (c) K_2SO_4
(d) KNO_3 (e) $CaCO_3$

Mole Concept:

Mole: Mole is a link between the mass of atoms (or molecules) and the number of atoms (or molecules). A group of $\mathbf{6.022} \times \mathbf{10^{23}}$ particles (atoms, molecules, or ions) of a substance is called a mole of that substance.
Thus, 1 mole of atoms $= \mathbf{6.022} \times \mathbf{10^{23}}$ atoms.
1 mole of molecules $= \mathbf{6.022} \times \mathbf{10^{23}}$ molecules.

For Example, the oxygen atom in $\mathbf{O}$ and the oxygen molecule is $\mathbf{O_2}$.
1 mole of oxygen atoms $(\mathbf{O}) = \mathbf{6.022} \times \mathbf{10^{23}}$ oxygen atom.
1 mole of oxygen molecules $= \mathbf{6.022} \times \mathbf{10^{23}}$ oxygen molecules.
Number of $\mathbf{6.022} \times \mathbf{10^{23}}$, which represents a mole is known as the **Avogadro number**.

Moles of Atoms:

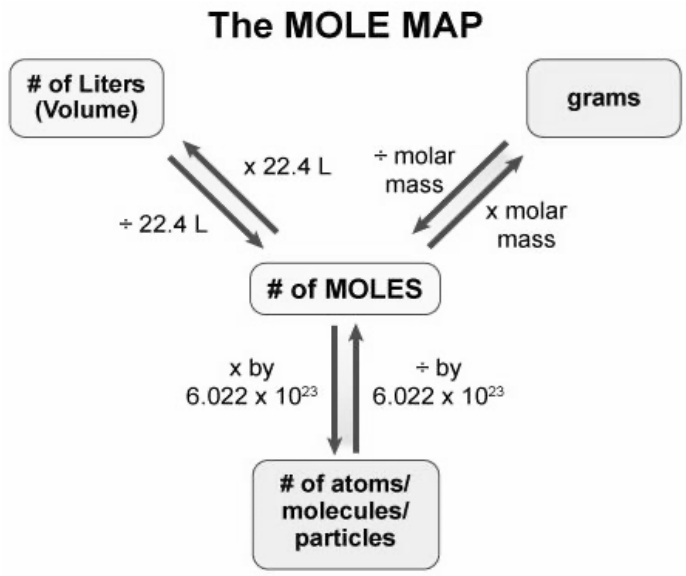
One mole of atoms of an element has a mass equal to the gram atomic mass of the element.
1 mole of atoms of an element = Gram atomic mass of the element.

For Example, the atomic mass of oxygen (O_2) is $\mathbf{16u}$, so gram atomic mass of oxygen will be 16 grams.
1 mole of oxygen atoms = Gram atomic mass of oxygen = $\mathbf{16}$ gram.

Mole of Molecules:

1 mole of molecules of a substance has a mass equal to the gram molecular mass of the substance.
1 mole of molecules of a substance = Gram molecular mass of the substance.

For example, the molecular mass of oxygen (O_2) is 32u. So, the gram molecular mass of oxygen molecule is 32 grams.
1 mole of oxygen molecules = Gram molecular mass of oxygen = 32 gram



Check Your Concept - 7

(i) If one mole of carbon atoms weighs 12 grams, what is the mass (in grams) of 1 atom of carbon?

(ii) Which has more number of atoms, 100 grams of sodium or 100 grams of iron?
(Given, atomic mass of Na = 23u, Fe = 56u)

(iii) A 0.24 g sample of compound of oxygen and boron was found by analysis to contain 0.096 g of boron and 0.144 g of oxygen. Calculate the percentage composition of the compound by weight.

(iv) When 3.0 g of carbon is burnt in 8.00 g oxygen, 11.00 g of carbon dioxide is produced. What mass of carbon dioxide will be formed when 3.0 g of carbon is burnt in 50.00 g of oxygen? Which law of chemical combination will govern your answer?

(v) What is the mass of –
(a) 1 mole of nitrogen atoms?
(b) 4 moles of aluminium atoms (Atomic mass of aluminium = 27)?
(c) 10 moles of sodium sulphite (Na_2SO_3)?

(vi) Convert into mole.
(a) 12 g of oxygen gas (b) 20 g of water (c) 22 g of carbon dioxide

Mass percentage of an element from the molecular formula

The molecular formula of a compound may be defined as the formula which specifies the number of atoms of various elements in the molecule of the compound.

For Example, the molecular formula of glucose is $C_6H_{12}O_6$. This shows that a molecule of glucose contains six atoms of carbon, twelve atoms of hydrogen, and six atoms of oxygen. With the help of the molecular formula of a compound, we can calculate its percentage composition by mass. First, we calculate the molecular mass of the compound.

From this, we can find out the mass of one mole of the compound, which is equal to its gram molecular mass. Then we calculate the mass of each element in one mole of the compound. The mass percentage of each element is then calculated by the following formula:

$$\text{Mass percentage of element} = \frac{\text{Mass of element in 1 mole of the compound}}{\text{Molar mass of the compound}} \times 100$$

Determination of Molecular formula

To find out the molecular formula of a compound, first we need to determine its empirical formula from the percentage composition. The empirical formula of a compound may be defined as the formula which gives the simplest whole number ratio of atoms of the various elements present in the molecule of the compound.

For Example, The empirical formula of the compound glucose ($C_6H_{12}O_6$) is CH_2O which shows that C, H, and O are present in the simplest ratio of $1:2:1$. The molecular formula is a whole number multiple of empirical formula thus,

Molecular formula $=$ Empirical formula $\times$ n
$n = \dfrac{\text{Molecular formula}}{\text{Empirical formula}}$ Where $n = 1,2,3 \ldots \ldots \ldots$
$n = \dfrac{\text{Molecular Mass}}{\text{Empirical formula mass}}$

Steps for writing an empirical formula:

The percentage of the element in the compound is determined by suitable methods and from the data collected, the empirical formula is determined by the following steps-

- Divide the percentage of each element by its atomic mass. This gives the relative number of moles of various elements present in the compound.
- Divide the quotients obtained in the above step by the smallest of them to get a simple ratio of moles of various elements.
- Multiply the figures, obtained by a suitable integer, if necessary, to obtain a whole number ratio. Finally, write down the symbols of the various elements side by side and put the above number as the subscripts in the lower right-hand corner of each symbol. This will represent the empirical formula of the compound.

Steps for writing the molecular formula:

- Calculate the empirical formula as described above.
- Find out the empirical formula mass by adding the atomic masses of all the atoms present in the empirical formula of the compound.
- Divide the molecular mass (determined experimentally by some suitable method) by the empirical formula mass and find out the value of "n".
- Multiply the empirical formula of the compound with n to find out the molecular formula of the compound.

Mole and Gram Atomic Mass: One mole of atoms $= 6.022 \times 10^{23}$ atoms $=$ Gram atomic mass of an element $=$ 1 gram atom of the element	**Mole and Gram Molecular Mass:** One mole of molecules$= 6.022 \times 10^{23}$ molecules $=$ Gram molecular mass $=$ 1 gram molecule of the compound
Mole in terms of volume: One mole of a gas $=$ 22.4 liters at STP	
Moles of a compound $= \dfrac{\text{Mass of the compound}}{\text{Molecular mass or GMW}}$	Moles of an element $= \dfrac{\text{Mass of the element}}{\textbf{Atomic mass or GAW}}$
Mass of one molecule $= \dfrac{\text{Molecular Mass or GAW}}{6.022\times10^{23}}$	Mass of one atom $= \dfrac{\textbf{Atomic Mass or GA}}{\mathbf{6.022\times10^{23}}}$
Number of atoms $=$ Moles $\times\ 6.022 \times 10^{23}$	Number of molecules $=$ Moles $\times\ \mathbf{6.022 \times 10^{23}}$

Solved Examples

(1) Give an example to show that the law of conservation of mass applies to physical changes also.

Answer: The Law of conservation of mass states that mass can neither be created nor destroyed in a chemical reaction. However, this law applies to physical changes also. For example, when the ice melts into water, the mass of ice equals the mass of water i.e., the mass is conserved. This verifies the law of conservation of mass.

(2) Which of the following symbols of elements are incorrect? Give their correct symbols.

(a) Cobalt CO **(b) Carbon c** **(c) Aluminium AL**
(d) Helium He **(e) Sodium So**

Answer: (a) Incorrect, the correct symbol of cobalt in Co.
(b) Incorrect, the correct symbol of carbon is C.
(c) Incorrect, the correct symbol of aluminium is Al.
(d) Correct (He)
(e) Incorrect, the correct symbol of sodium is Na.

(3) Which of the following are tri-atomic and tetra-atomic molecules?
$\mathbf{CH_3Cl, CaCl_2, NH_3, PCl_3, P_2O_5, H_2O, C_2H_5OH}$

Answer: (i) Tri-atomic molecules are $\mathbf{CaCl_2, H_2O}$.
(ii) Tetra-atomic molecules are $\mathbf{NH_3, PCl_3}$.

(4) Write the atomicity of the following molecules:
(i) Sulphur **(ii) Phosphorus**

Answer: (i) 8 (ii) 4

(5) What is an ion? Give one example.

Answer: The negatively and positively charged particles are called ions.
For example: $\mathbf{Cl^-, Br^-, SO_4^{2-}, PO_4^{3-}, H^+, Pb^+}$, etc.

(6) Give one word for the following:
(i) A group of atoms carrying a charge **(ii) Positively charged ion**

Answer: (i) Ion (ii) Cation

(7) The atomic number of three elements A, B, and C are 9, 10, and 13 respectively. Which of them will form a cation?

Answer: Electronic configuration of A: 2, 7
Electronic configuration of B: 2, 8
Electronic configuration of C: 2, 8, 3
'C' will form a cation because a cation is formed by the loss of one or more electrons by an atom.

(8) What is wrong with saying 'one mole of nitrogen'?

Answer: The statement does not clarify whether we are talking about atoms or molecules of nitrogen. We should say 'one mole of nitrogen atoms' or 'one mole of nitrogen molecule'.

(9) A sample of ammonia weighs 3.00 g. What mass of sulphur trioxide contains the same number of molecules as are present in 3.00 g of ammonia?

Answer: Number of moles of ammonia in $\mathbf{3.00\ g} = \frac{\mathbf{3.00}}{\mathbf{17}}\ \mathbf{mol} = \mathbf{0.1764\ mol}$
Molecular mass of $\mathbf{SO_3} = \mathbf{1 \times 32u + 3 \times 16u = 80u}$
1 mole of $\mathbf{SO_3}$ weighs $\mathbf{80\ g}$
$\therefore$ $\mathbf{0.1764}$ moles weigh $= \mathbf{80 \times 0.1764\ g = 14.11\ g}$

(10) Carbon dioxide produced by the action of dilute hydrochloric acid on potassium hydrogen carbonate is moist whereas that produced by heating potassium hydrogen carbonate is dry. What would be the difference in the composition of carbon dioxide in the two cases? State the associated law.

Answer: The composition of CO_2 in both cases would be the same i.e., the carbon and oxygen will combine in the same ratio of 1:2.
The law associated is the law of constant proportion.

Exercise

OBJECTIVE TYPE QUESTIONS

(1) How many molecules are present in 9g of water -
(A) 3.01×10^{23} (B) 6.022×10^{23}
(C) 6.08×10^{23} (D) 3.82×10^{23}

(2) What is true about potassium chlorate -
(A) It gives oxygen gas on strong heating.
(B) Its molecular mass is 122.5kg/mol.
(C) 122.5g of it contain oxygen atoms three times the Avogadro number.
(D) Its molecular formula is $KClO_4$.

(3) Mass of one Avogadro's number of O atom is equal to -
(A) 16 amu (B) 16g
(C) 32g (D) 6kg

(4) Hydrogen reacts with oxygen to form water (H_2O). The ratio between masses of Hydrogen and Oxygen is -
(A) 1: 8 (B) 63.5: 8
(C) 2: 1 (D) 63.5: 16

(5) The correct formula for aluminium sulphate is
(A) $AlSO_4$ (B) Al_2SO_4
(C) $Al_3(SO_4)_2$ (D) $Al_2(SO_4)_3$

(6) $27 \mathrm{~g}$ of Al will react completely with how many grams of oxygen? **[IIT (1978)]**
(A) $8 \mathrm{~g}$ (B) $16 \mathrm{~g}$
(C) $32 \mathrm{~g}$ (D) $24 \mathrm{~g}$

(7) One mole of carbon atom weighs $12 \mathrm{~g}$, the number of atoms in it is equal to (Mass of carbon -12 is $19926 \cdot 10^{-23} \mathrm{~g}$) **[NEET (Oct.) 2020]**
(A) $1.2 \cdot 10^{23}$ (B) $6.022 \cdot 10^{22}$
(C) $12 \cdot 10^{22}$ (D) $6.022 \cdot 10^{23}$

(8) The volume occupied by one molecule of water (density $= 1 \mathrm{~g} \mathrm{~cm}^{-3}$) is **[CBSE AIPMT 2008]**
(A) $9.0 \cdot 10^{-23} \mathrm{~cm}^{3}$ (B) $6.023 \cdot 10^{-23} \mathrm{~cm}^{3}$
(C) $3.0 \cdot 10^{-23} \mathrm{~cm}^{3}$ (D) $5.5 \cdot 10^{-23} \mathrm{~cm}^{3}$

(9) The number of oxygen atoms in $\mathbf{4.4~g}$ of $\mathbf{CO_2}$ is **[CBSE AIPMT 1990]**
(A) $1.2 \cdot 10^{23}$ (B) $6 \cdot 10^{22}$
(C) $6 \cdot 10^{23}$ (D) $12 \cdot 10^{23}$

(10) The number of gram molecules of oxygen in $\mathbf{6.02 \cdot 10^{24} CO}$ molecules is **[CBSE AIPMT 1990]**
(A) $10 \mathrm{~g}$ molecules (B) $5 \mathrm{~g}$ molecules
(C) $1 \mathrm{~g}$ molecule (D) $\mathbf{0.5~g}$ molecule

Answer Key

OBJECTIVE TYPE QUESTIONS

(1)	(A)	**(6)**	(D)
(2)	(C)	**(7)**	(D)
(3)	(B)	**(8)**	(D)
(4)	(A)	**(9)**	(C)
(5)	(D)	**(10)**	(A)