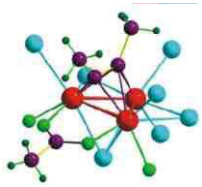


Chapter - 3

Atoms And Molecules

CONCEPT MAPPING

Law of Chemical Combination

Law of conservation of mass
- Mass can neither be created nor be destroyed
- eg. $C+O_2 \rightarrow CO_2$
  $12gm + 32gm \rightarrow 44gm$

Law of constant proportion
- Compound consists of the elements combined together in the same ratio
- $H_2O = 2 : 16$
  $1 : 8$

Dalton's Atomic Theory

(Atom) are :
- tiny particle
- indivisible
  (Can neither be created nor destroyed)
- Identical mass and chemical Properties
  (Same element)
- Different mass and chemical properties
  (diff. elements)
- Combine in the same ratio

Atom
- Smallest particle of an element
- Each atom shows all the properties of element

Molecule
- Smallest particle of elements or compounds
- Properties of the substances are the properties of molecules

Atomic mass
- mass of an atom
- equals to $\frac{1}{12}$ of mass C-12 atom

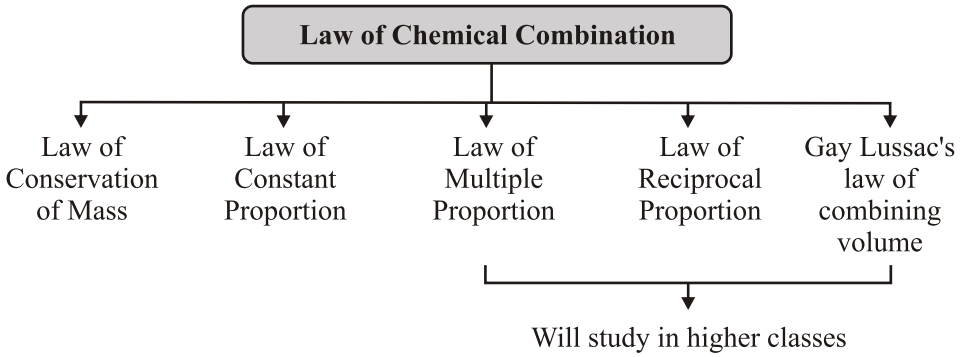
Existence of Atom
- Reactive
- Free
- Combine to form

Ions
- Monoatomic
- Polyatomic

- Types of molecule → Homoatomic, Heteroatomic
- Molecular mass → Sum of masses of all atoms
- Formula unit mass → Sum of atomic mass of ions and atoms
- Atomicity → no. of atoms present in one molecule

Laws of Chemical Combination :

The chemical reaction between two or more substances giving rise to products is governed by certain laws. These laws are called Laws of Chemical Combination'.



Law of Conservation of Mass

According to this law, "Mass can neither be created nor destroyed."

In a chemical reaction, this law can be understood in the following way:

" During a chemical reaction total mass of reactants will be equal to total mass of products."

For example, $A + B \rightarrow AB$

Reactant Product

Then, $m_A + m_B = m_{AB}$

where, m_A = Mass of A

m_B = Mass of B

m_{AB} = Mass of AB

$2H_2$ (g)	+	O_2 (g)	→	$2H_2O$ (l)
2 x 2 = 4 gm		2 x 16 = 32 gm		2 x (2 + 16) = 36 gm

Example : In a reaction 5.3 gm of sodium carbonate reacted with 6 gm of ethanoic acid. The products were 2.2 gm of CO_2, 0.9 gm of H_2O and 8.2 gm of sodium ethanoate. Show that these observation are all in agreement with law of conservation of mass.

Sodium carbonate + Ethanoic acid → Sodium ethanoate + CO_2 + H_2O

Solution :

$$\underbrace{\text{Sodium carbonate} + \text{Ethanoic acid}}_{\text{Reactants}} \rightarrow \underbrace{\text{Sodium ethanoate} + CO_2 + H_2O}_{\text{Products}}$$

Now, according to the law of conservation of mass :

Mass of sodium carbonate + Mass of ethanoic acid = Mass of sodium ethanoate + Mass of CO_2 + Mass of H_2O

Putting values of masses from the equation :

$$5.3 \text{ gm} + 6.0 \text{ gm} = 8.2 \text{ gm} + 2.2 \text{ gm} + 0.9 \text{ gm}$$

Or $$11.3 \text{ gm} = 11.3 \text{ gm}$$

Since, LHS = RHS

.: Law of conservation of mass is in agreement with the given values in equation.

Law of Constant Proportion

According to this law, "A pure chemical compound always contain the same elements combined together in the same proportion by mass irrespective of the fact from where the sample has been taken or from which procedure has it been produced."

For example :

18 gm of $H_2O \Rightarrow$ 16 gm of oxygen + 2 gm of hydrogen,

i.e., $m_H/m_O = 2/16 = 1/8$

36 gm of $H_2O \Rightarrow$ 32 gm of oxygen + 4 gm of hydrogen,

i.e., $m_H/m_O = 4/32 = 1/8$

09 gm pf $H_2O \Rightarrow$ 08 gm of oxygen + 1 gm of hydrogen,

i.e., $m_H/m_O = 1/8$

From the above three cases, differently weighing H, O samples were taken but the ratio of masses of 'H' to mass of 'O' comes out to be '1/8' is same, proving law of constant proportion.

Likewise, if a sample of 'H, O' was taken from anywhere *i.e.,* from well, pond, lake or anywhere the ratio of masses of 'H' to 'O' will come out to be same as '1/8'.

Example : Hydrogen and oxygen combine in the ratio 1 : 8 by mass to form water. What mass of oxygen gas would be required to react completely with 3.0 gm of hydrogen gas ?

Solution : $\frac{m_H}{m_O} = \frac{1}{8}$ Given in equation (For H_2O)

But, $m_H = 3.0$ gm (given)

Or $\frac{3}{m_O} = \frac{1}{8}$

Or $m_O = 24$ gm

.: Mass of oxygen will be 24 gm.

Or it will be a sample of 27 gm of H_2O where 3 gm of hydrogen is present with 24 gm of oxygen.

Dalton's Atomic Theory

Based upon laws of chemical combination, Dalton's Atomic Theory provided an explanation for the Law of Conservation of Mass and Law of Constant Composition.

Postulates of Dalton's atomic theory are as follows :

- All matter is made up of very tiny particles called 'Atoms' .
- Atom are indivisible particles, which can't be created or destroyed in a chemical reaction. (Proves 'Law of Conservation of Mass')
- Atoms of an element have identical mass and chemical properties.
- Atoms of different elements have different mass and chemical properties.
- Atom combine in the ratio of small whole numbers to form compounds. (proves 'Law of Constant Proportion')
- The relative number and kinds of atoms are constant in a given compound.

Atom

- According to modern atomic theory, an atom is the smallest particle of an element which takes part in chemical reaction such that during the chemical reaction, the atom maintain its identity, throughout the chemical or physical change.
- Atoms are very small and hence can't be seen even through very powerful microscope.
- Atomic radius of smallest atom in hydrogen is 0.37×10^{-10} m or 0.037 nm.

  Such that, $1 \text{ nm} = 10^{-9}$ m

IUPAC (International Union of Pure & Applied Chemistry) Symbols of Atoms of Different Elements

Element	Symbol	Element	Symbol
Aluminium	Al	Iodine	I
Argon	Ar	Iron	Fe
Barium	Ba	Lead	Pb
Calcium	Ca	Nitrogen	N
Carbon	C	Oxygen	O
Chlorine	Cl	Potassium	K
Cobalt	Co	Silicon	Si
Copper	Cu	Silver	Ag
Fluorine	F	Sulphur	S
Gold	Au	Zinc	Zn
Hydrogen	H		

Atomic Mass

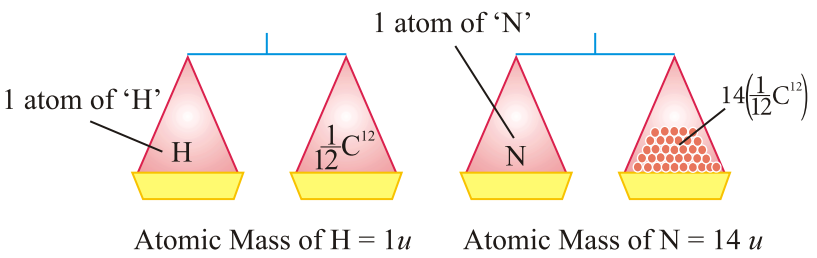
- The mass of an atom of an element is called its atomic mass.
- In 1961, IUPAC have accepted 'atomic mass unit' (u) to express atomic and molecular mass of elements and compounds.

Atomic Mass Unit

The atomic mass unit is defined as the quantity of mass equal to 1/12 of mass of an atom of carbon-12.

$$1 \text{ amu or } u = \frac{1}{12} \text{x Mass of an atom of C}$$

$$1\ u = 1.66 \times 10^{-27} \text{ kg}$$



Atomic Mass of H = 1u Atomic Mass of N = 14 u

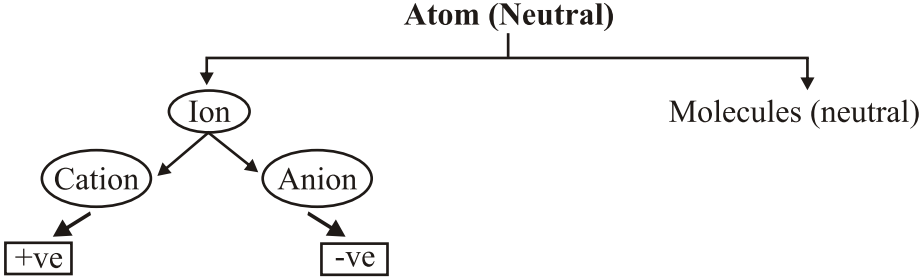
Likewise,

This means atomic mass unit $\frac{1}{12}$th of Carbon – 12

Atomic Mass of some elements					
Element	**Symbol**	**Atomic Mass**	**Element**	**Symbol**	**Atomic Mass**
Hydrogen	H	1u	Sodium	Na	23u
Helium	He	4u	Magnesium	Mg	24u
Lithium	Li	7u	Aluminium	Al	27u
Beryllium	Be	9u	Silicon	Si	28u
Boron	B	11u	Phosphorous	P	31u
Carbon	C	12u	Sulphur	S	32u
Nitrogen	N	14u	Chlorine	Cl	35u
Oxygen	O	16u	Potassium	K	39u
Fluorine	F	19u	Calcium	Ca	40u
Neon	Ne	20u	Iron	Fe	56

How do atoms exist ?

- Atoms of most of the elements are very reactive and does not exist in free state.
- Only the atoms of noble gases (such as He, Ne, Ar, Kr, Xe and Rn) are chemically unreactive and can exist in the free state as single atom.
- Atoms of all other elements combine together to form molecules or ions.



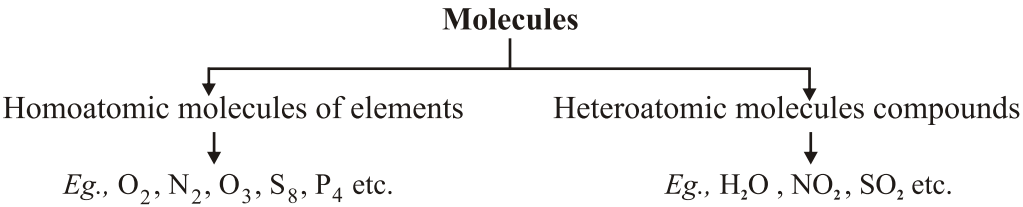
Molecule

- A molecule is a group of two or more atoms which are chemically bonded with each other.
- A molecule is the smallest particle of matter (except element) which is capable of an independent existence and show all properties of that substance.

E.g., 'H, O' is the smallest particle of water which shows all the properties of water.

- A molecule may have atom of same or different elements, depending upon this, molecule can be categorized into two categories :

Homoatomic molecules (containing atom of same element) and **Heteroatomic molecules** or **compounds** (containing atoms of different elements)



Molecules of some compounds	
Compound	**Combining Elements**
Water (H_2O)	Hydrogen, Oxygen
Ammonia (NH_3)	Nitrogen, Hydrogen
Carbon Dioxide (CO_2)	Carbon, Oxygen
Hydrogen Chloride (HCl)	Hydrogen, Chlorine
Methane (CH_4)	Carbon, Hydrogen
Ehtane (C_2H_6)	Carbon, Hydrogen
Sodium Chloride (NaCl)	Sodium, Chlorine
Copper Oxide (CuO)	Copper and Oxygen

Atomicity

The number of atoms present in one molecule of an element is called its atomicity.

	Name	Formula	Atomicity	
1.	Argon	Ar	Monoatomic (1)	Noble gasses constitute monoatomic molecules
2.	Helium	He	Monoatomic (1)	
3.	Oxygen	O_2	Diatomic (2)	
4.	Hydrogen	H_2	Diatomic (2)	
5.	Phosphorus	P_4	Tetratomic (4)	
6.	Sulphur	S_8	Polyatomic (8)	
7.	Ozone	O_3	Triatomic (3)	

Chemical formulae

It is the symbolic representation of the composition of a compound.

Characteristics of chemical formulae

- The valencies or charges on ion must balance.
- When a compound is formed of metal and non-metal, symbol of metal comes first. *E.g.*, CaO, NaCl, CuO.
- When polyatomic ions are used, the ions are enclosed in brackets before writing the number to show the ratio. E.g., $Ca(OH)_2$, $(NH_4)_2 SO_4$

Molecular Mass

It is the sum of atomic masses of all the atoms in a molecule of that substance.
e.g., Molecular mass of H_2O = 2 x Atomic mass of Hydrogen + 1 x Atomic mass of Oxygen

So, Molecular mass of H_2O = 2 x 1 + 1 x 16 = 18 *u*

Formula Unit Mass

It is the sum of atomic mass of ions and atoms present in formula for a compound.

e.g., In NaCl, Na = 23 a.m.u. , C1 = 35.5 a.m.u.
So, Formula unit mass = 1 x 23 + 1 x 35.5 = 58.5 *u*

Examples:

(i) Symbol : H S
Valencies : 1 2 H_2S_1 or H_2S (Hydrogensulphide)

(ii) Symbol : C O eg.$(NH_4)_2SO_4$,$Al_2(SO_4)_3$
Valencies : 4 2 C_2O_4 or CO_2 (Carbon dioxide)

[Take 2 common and dividethe formula by2]

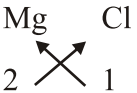
(iii)For Hydrochloric acid (Hydrogen chloride)

H Cl
1 1 H_1Cl or HCl

(iv)For Carbon tetrachloride

C Cl
4 1 C_1Cl_4 or CCl_4

(v) For Magnesium chloride

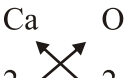


$MgCl_2$

(vi) For aluminium oxide

Al_2O_3

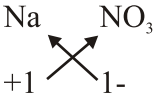
(vii) For Calcium oxide



Ca_2O_2 or CaO

[Take 2 common and divide the formula by 2]

(viii) For Sodium nitrate (For ions)



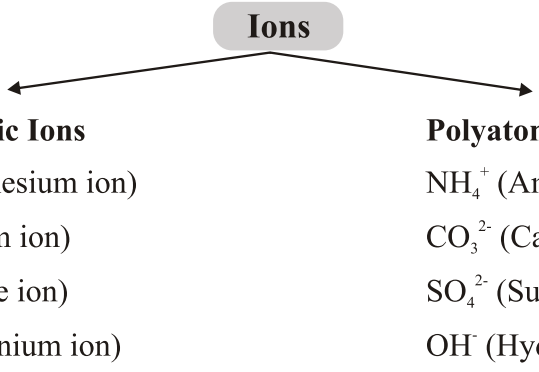
$NaNO_3$

Ions

An ion may be defined as an atom or group of atoms having positive or negative charge.

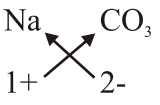
Some positively charged ions : Na^+, K^+, Ca^{2+}, Al^{3+}

Some negatively charged ions : Cl- (chloride ion), S^{2-} (sulphide ion), OH^- (hydroxide ion), SO_4^{2-} (sulphate ion)



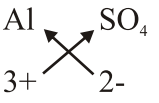
Chemical Formulae of Ionic Compounds (Polyatomic)

(i) Sodium carbonate



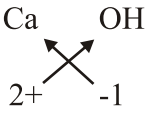
Na_2CO_3

(ii) Aluminium sulphate



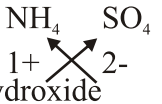
$Al_2 (SO_4)_3$

(iii) Calcium hydroxide



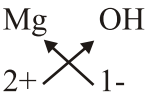
$Ca(OH)_2$

(iv) Ammonium sulphate



$(NH_4)_2SO_4$

(v) Magnesium hydroxide



$Mg(OH)_2$

Molar Mass

The molar mass of a substance is the mass of 1 mole of that substance.

It is equal to the 6.022×10^{23} atoms of that element/substance.

Example :

(a) Atomic mass of hydrogen (H) is 1 *u.* Its molar mass is 1 g/mol.

(b) Atomic mass of nitrogen is 14 *u.* So, molar mass of nitrogen (N) is 14 g/mol.

(c) Molar mass of S_8 = Mass of S x 8 = 32 x 8 = 256 g/mol

(d) Molar mass of HCl = Mass of H + Mass of Cl

= 1 = 35.5 = 36.5 g/mol

Mole concept

A group of 6.022×10^{23} Particles (atoms, molecules or ions) of a substance is called a mole of that substance.

1 mole of atoms $= 6.022 \times 10^{23}$ atoms

1 mole of molecules $= 6.022 \times 10^{23}$ molecules

Example, 1 mole of oxygen $= 6.022 \times 10^{23}$ oxygen atoms

6.022×10^{23} is Avogadro Number

- 1 mole of atoms of an element has a mass equal to gram atomic mass of the element.

Improtant Formulae

(i) Number of moles $(n) = \boxed{\dfrac{\text{Given mass}}{\text{Molar mass}} = \dfrac{m}{M}}$

(ii) Number of moles $(n) = \boxed{\dfrac{\text{Given number of particles}}{\text{Avogadro's number}}}$

$$\boxed{n = \frac{N}{N_0}}$$

$$\boxed{\text{(iii)}\ \frac{m}{M} = \frac{N}{N_0}} \qquad m = \frac{MxN}{N_0}$$

(iv) Percentage of any atom in given compound $= \dfrac{\text{Mass of element x100}}{\text{Mass of compound}}$

Example. *Calculate no. of iron atoms in a piece of iron weighing 2.8 gm (Atomic mass = 54 u).*

Solution : 1 mole of iron = 56 gm (Gram atomic mass of iron)

1 mole of iron element contains 6.022×10^{23} atoms of iron.

So, 56 gm of iron $= 6.022 \times 10^{23}$ atoms

2.8 gm of iron $= \dfrac{6.022 \times 10^{23}}{56} \times 2.8$

$= 3.011 \times 10^{22}$ atoms

Example. *Mass of one molecule of a substance is 5.32×10^{-23} g. What is its molecular mass ?*

Solution : Mass of 1 molecule of substance

$= 5.32 \times 10^{-23}$ g

Mass of 6.022×10^{23} molecules of substance

$= 5.32 \times 10^{-23} \times 6.022 \times 10^{23}$

$= 32g$

Example. *Calculate the mass of 0.5 mole of N_2 gas.*

Solution: 1 mole of N_2 = Gram molecular mass of N_2

Or 1 mole of N_2 = 28 gm

.: 0.5 mole of N_2 gas = 0.5×28

= 14 gm of N_2

Example. *Calculate the total number of O_2 molecules present in 8 gm of O_2*

Solution: Gram molecular mass of O_2

$= 6.022 \times 10^{23}$ O_2 molecules

Or 32 gm of O_2 $= 6.022 \times 10^{23}$ O_2 molecules

Or 8 gm of O_2 $= 6.022 \times 10^{23} \times 8/32$ O_2 molecules

$= 1.51 \times 10^{23}$ O_2 molecules

QUESTIONS

VERY SHORT ANSWER TYPE QUESTIONS

1. What do you understand by valence electrons.
2. Name the anion and cation that constitute the molecule of calcium oxide.
3. An element 'X' has atomic number 13. Write the formula of its oxide.
4. Write the names of elements present in common salt.
5. If 'K' and 'L' shells of an atom are completely filled with electrons then what will be the total number of elections in an atom.
6. Name two elements that exist as independent atoms.
7. How many atoms are there in 1g of hydrogen.
8. Identify poly atomic ion in $MgCO_3$.
9. State the law of definite proportion.

SHORT ANSWER TYPE QUESTIONS

1. Write the chemical formulae of-

(a) Calcium chloride
(b) Magnesium bicarbonate
(c) Aluminum sulphate
(d) Sodium carbonate
(e) Lead Nitrate
(f) Calcium Phosphate
(g) Iron (II) sulphide
(h) Mercury (I) chloride.

2. Write the molecular formulae of all the compounds that can be formed by the combination of following ions.

Cu^{2+}, Na^{+}, Fe^{3+}, Cl^{-}, SO_4^{2-}, PO_4^{3-}

3. Write the cations (Positively charged ions) and anions (negatively charged ions) **Present** (If any) in the following compounds.

(a) NaCl (c) NH_4NO_3

(b) H_2 (d) $Ca(HCO_3)_2$

4. Give the formulae of the compounds formed from the following sets of elements

(a) Calcium and fluorine (d) Sulphur and Oxygen

(b) Nitrogen and Hydrogen (e) Carbon and Oxygen

(c) Nitrogen and Oxygen (f) Carbon and Chlorine

5. Classify each of the following on the basis of their atomicity.

(a) F_2 (b) NO_2 (c) CH_4 (d) P_4 (e) H_2O_2

(f) P_4O_{10} (g) O_3 (h) HCl (i) He (j) Ag

6. Calculate the number of moles of magnesium present in a magnesium ribbon weighing 12 gm. Molar atomic mass of Magnesium is 24 gm/mol.

7. Write postulates of Daltion's atomic theory (atleast three).

8. What is the difference between the molecules of an element and the molecule of a compound? Give one example of each.

9. What is the difference between 2H and H_2? (atleast two differences)

10. (a) What would be gram atomic mass of 5 moles of chlorine?

(b) Calculate the gram atomic mass of one atom of oxygen.
(gm at. mass of oxygen = 16 gm.)

LONG ANSWER TYPE QUESTIONS

1. Verify by calculating that 5 moles of CO_2 and 5 moles of H_2 do not have the same mass.
[Hint : molar mass of CO_2 = 44 g and molar mass of H_2O = 18 g]

2. If you take 5 moles of carbon atoms in a container and your friend take 5 moles of sodium atoms in another container of same weight.
   [Hint : molar mass of carbon = 12 gm. molar mass of sodium = 23 gm]
   (a) Whose container will be heavier?
   (b) Whose ontainer has more number of atoms?
3. Which has more number of atoms?
   100 gm of N_2 or 100 gm of Ammonia NH_3

$$\left[\text{Hint : No. of atoms} = \frac{\text{mass}}{\text{molar mass}} \text{X } 6.022 \text{ X } 10^{23}\right]$$

4. Hydrogen and oxygen combine in the ratio of 1:8 by mass to form water, What mass of oxygen gas would be required to react completely with 3 gm of Hydrogen gas?
5. (a) Which postulate of Dalton's atomic theory is the result of the law of conservation of mass?
   (b) Which postulate of Dalton's atomic theory can explain the law of constant proportion.?

Objective Type Questions

1. Which of the following statements is not true about an atom?
   a. Atoms are not able to exist independently
   b. Atoms are the basic units from which molecules and ions are formed
   c. Atoms are always neutral in nature
   d. Atoms aggregate in large numbers to form the matter that we can see, feel or touch
2. The chemical symbol for nitrogen gas is
   a, Ni
   b. N_2
   c. N^+
   d. N

3. The Chemical symbol for sodium is
    a. So
    b. Sd
    c. NA
    d. Na
4. Which of the following correctly represents 360 g of water?
    i. 2 moles of water.
    ii. 20 moles of water
    iii. 6.022 x 1023 molecules of water
    iv. 1.2044 x 1025 molecules of water
    a. i.
    b. i.and iv
    c. ii and iii
    d. ii and iv
5. Give the formulae of the formed from the following sets of elements
    a. Calcium and fluorine
    b. Hydrogen and sulphur
    c. Nitrogen and hydrogen
    d. Carbon and chlorine
    e. Sodium and oxygen
    f. Carbon and oxygen
6. Write the molecular formulae for the following compounds
    a. Copper (II) Bromide. .....
    b. Aluminium (III) nitrate. .....
    c. Calcium (II) phoshate .....
    d. Iron (III) sulphide .....
    e. Mercury (II) chloride .....
    f. Magnesium (II) chloride .....

7. An element 'X' form an oxide X_2O_3

   a. State the valency of X

   b. Write the formula for chloride of X.

8. Write the molecular formulae of the compounds that can be formed by the combination of following ions

   a. Cu^{2+} and Cl^- .....

   b. Na^+ and NO_3- .....

   c. Fe^{3+} and SO_4^{2-} .....

   d. Fe^{3+} and Cl^- .....

9. Classify each of the following on the basis of their atomicity.

Elements	Atomicity
F_2	
NO_3	
N_2O	
P_4	
H_2O_2	
He	
Ag	
CH_4	
P_4O_{10}	

10. Fill in the blanks

    a. In a chemical reaction, the sum of the masses of the reactants and product remains unchanged. This is called .....

    b. A group of atoms carrying a fixed charge on them is called .....

    c. The formula unit mass of $Ca_3(PO_4)_2$ is .....

    d. Formula of sodium carbonate is ..... and that of ammonium sulphate is .....

Assertion and reason type questions:-

Two statements are given one labelled assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below:

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true but R is not the correct explanation fo A.

(c) A is true but R is false.

(d) A is false but R is true.

1. Assertions (A) : Sulphates are poly atomic ions.

Reason (R) : The sulphate ion consists of one sulphur atom and four oxygen atom and corries an overall charge of 2-

Answer: (a) The Sulphate ion is SO_4^{2-}. The atoms of a poly atomic ion are tightely bonded together and so the entire ion behaves as a s unit.

2. Assertion (A) : Atomicity of oxygen is 2.

Reason (R) : 1 Mole of an element contain 6.023×10^{23} atom

Answer: (b) Number of atoms present in a molecule of a gaseous element is called atomicity e.g. O_2 has two atoms and hence, its atomicity is 2.