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Chapter 3 Atoms And Molecules

Laws of Chemical Combination.

The following two laws of chemical combination

1. **Law of Conservation of Mass:**
It states that mass can neither be created nor destroyed in a chemical reaction

2. **Law of Constant Proportions:**
In a chemical substance the elements are always present in definite proportions by mass.

eg. In a compound such as water, the ratio of the mass of hydrogen to the mass of oxygen is always 1:8, whatever the source of water. Thus, if 9g of water is decomposed, 1g of hydrogen and 8g of oxygen are always obtained.

According to John Dalton's atomic theory, all matters, whether an element, a compound or a mixture is composed of small particles called atoms.

The postulates of this theory may be stated as follows:

(i) All matters is made of very tiny particles called atoms, which participate in chemical reactions.

(ii) Atoms are indivisible particles, which cannot be created or destroyed in a chemical reaction.

(iii) Atoms of a given element are identical in mass and chemical reaction.

(iv) Atoms of different elements have different masses and chemical properties.

(v) Atoms combine in the ratio of small whole numbers to form compounds

(vi) The relative number and kinds of atoms are constant in a given compound

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Questions

1. In a reaction, 5.3g of sodium carbonate reacted with 6g of acetic acid. The products were 2.2g of carbon dioxide, 0.9g water and 8.2g of sodium acetate. Show that these observations are in agreement with the law of conservation of mass

Sodium carbonate + acetic acid
⟶ Sodium acetate + Carbon dioxide + water.

Ans: Law of conservation of mass states that mass before reaction is equal to mass after reaction

Mass before reaction
= 5.3g + 6g
= 11.3g — (1)

Mass after reaction
= (2.2 + 0.9 + 8.2)g
= 11.3g — (2)

∴ (1) = (2)

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What is an Atom?

The building blocks of all matter are atoms.

All matter is made up of very tiny particles called atoms, which participate in chemical reactions.

Size of an Atom.

Atomic radius is measured in nanometres

$$\frac{1}{10^9}\ m = 1\ nm$$

$$1\ m = 10^9\ nm$$

Relative Sizes

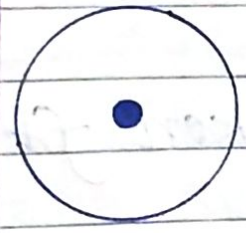
Radii (in m)		Example
10^{-10}	⟶	Atom of hydrogen
10^{-9}	⟶	Molecule of water
10^{-8}	⟶	Molecule of haemoglobin
10^{-4}	⟶	Grain of sand
10^{-3}	⟶	Ant
10^{-1}	⟶	Apple.

Modern Day Symbols of Atoms of Different Elements.

Dalton's was the first scientist to use the symbols for elements in a very specific sense.

Berzilius suggested that the symbols of elements be made from one or two letters of the name of the elements.

Symbols proposed by Dalton

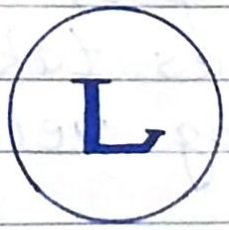

Hydrogen

Carbon

Phosphorus

Sulphur

Copper



Lead

Gold

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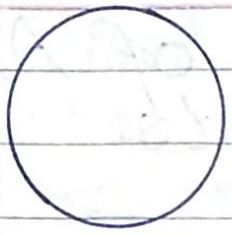
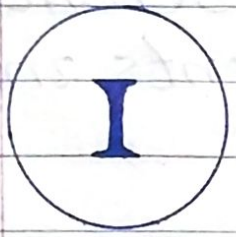
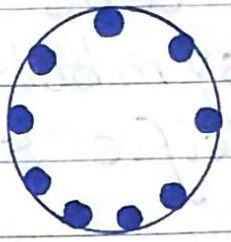

Oxygen

Silver



Iron


Mercury

In the beginning, the names of elements were derived from the name of the place where they were found for the first time.
For example,
the name copper was taken from Cyprus

Some names were taken from specific colours.
For example,
gold was taken from the English word meaning yellow.

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Now-a-days, IUPAC (International Union of Pure and Applied Chemistry) is an international scientific organisation which approves names of elements, symbols, and units.

- Many of the symbols are the first one or two letters of the element's name in English.
- The first letter of a symbol is always written as a capital letter (uppercase) and the second letter as a small letter (lowercase)

For example

(i) hydrogen, H
(ii) aluminium, Al
(iii) cobalt, Co.

- Symbols of some elements are formed from the first letter of the name and a letter, appearing later in the name.

For example.

(i) Chlorine, Cl.
(ii) Zinc, Zn

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- Other symbols have been taken from the names of elements in Latin, German or Greek.

For example,

(i) iron is Fe from ferrum
(ii) Sodium is Na from natrium
(iii) potassium is K from kalium.

Symbols for some elements

Element	Symbol	Element	Symbol
Aluminium	Al	Copper	Cu
Argon	Ar	Fluorine	F
Barium	Ba	Gold	Au
Boron	B	Hydrogen	H
Bromine	Br	Iodine	I
Calcium	Ca	Iron	Fe
Carbon	C	Lead	Pb
Chlorine	Cl	Magnesium	Mg
Cobalt	Co	Neon	Ne

Atomic Mass

Let us take the example of a compound, carbon monooxide (CO) formed by carbon and oxygen. It was observed experimentally that 3g of Carbon combine with 4g of oxygen to form CO. In other words, carbon combines with 4/3 times its mass of oxygen.

One atomic mass (1u) unit is a mass unit equal to exactly one-twelfth ($1/12^{th}$) the mass of one atom of carbon-12.

The relative atomic mass of the atom of an element is defined as the average mass of the atom, as compared to $1/12^{th}$ the mass of one atom of carbon-12.

Atomic masses of a few elements

Element	Atomic Mass (u)
Hydrogen	1
Carbon	12
Nitrogen	14
Oxygen	16
Sulphur	32
Chlorine	35.5

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Molecule

Atoms of the same element or of differents can join together to form molecules.

Molecules of Elements

The molecules of an element are constituted by the same type of atom.
eg. argon (Ar), Helium (He)

The molecules of more than one atoms
eg. O_2, O_3.

Atomicity: The number of atoms constituting a molecule is known as its atomicity.

Atomicity of some elements

Types of Element	Name	Atomicity
Non-metal	Argon	Monoatomic
	Helium	〃
	Oxygen	Diatomic
	Hydrogen	〃
	Nitrogen	〃
	Chlorine	〃
	Phosphorus	Tetra-atomic
	Sulphur	Poly-atomic

Molecules of Compounds

Atoms of different elements join together in definite proportions to form molecules of compounds.

Molecules of some compounds

Compound	Combining Elements	Ratio by Mass
Water (H_2O)	Hydrogen, Oxygen	1:8
Ammonia (NH_3)	Nitrogen, Hydrogen	14:3
Carbon dioxide (CO_2)	Carbon, Oxygen	3:8

Ion

Compounds composed of metals and non-metals contain charged species.
The charged species are known as ions

Anion: A negatively charged ion is called an anion.

Cation: A positively charged ion is called a cation.

NaCl → Na^+ (cation)
NaCl → Cl^- (anion)

Some ionic compounds

Ionic Compound	Constituting Elements	Ratio by Mass
Calcium oxide →	Calcium & Oxygen →	5 : 2
Magnesium Sulphide →	Magnesium and sulphur →	3 : 4
Sodium Chloride →	Sodium and Chloride →	23 : 35.5

Chemical Formulae

The chemical formula of a compound is a symbolic representation of its composition.

Valency : The combining power (or capacity) of an element is known as its valency

- Valency can be used to find out how the atoms of an element will combine with the atoms of another element to form a chemical compound

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Names and symbols of some ions

Valency	Name of ion	Symbol
1	Sodium	Na^+
	Potassium	K^+
	Silver	Ag^+
	Copper (I)	Cu^+
2	Magnesium	Mg^{2+}
	Calcium	Ca^{2+}
	Zinc	Zn^{2+}
	Iron (II)	Fe^{2+}
	Copper (II)	Cu^{2+}
3	Aluminium	Al^{3+}
	Iron (III)	Fe^{3+}

Valency	Non-metallic element	Symbol
1	Hydrogen	H^+
	Hydride	H^-
	Chloride	Cl^-
	Bromide	Br^-
	Iodide	I^-
2	Oxide	O^{2-}
	Sulphide	S^{2-}
3	Nitride	N^{3-}

Valency	Polyatomic ions	Symbol
1	Ammonium	NH_4^+
	Hydroxide	OH^-
	Nitrate	NO_3^-
	Hydrogen carbonate	HCO_3^-
2.	Sulphite	SO_3^{2-}
	Sulphate	SO_4^{2-}
3.	Phosphate	PO_4^{3-}

The rules to follow while writing a chemical formula are as follows:

- the valencies or charges on the ion must balance.
- when a compound consists of a metal and non-metal, the name or symbol of the metal written first.
  For example,
  calcium oxide (CaO), copper oxide (CuO)
  non-metals are written on the right and metals on the left.
- in compounds formed with polyatomic ions, the number of ions present in the compound is indicated by enclosing the formula of ion in a bracket and writing the number of ions outside the bracket. For example, $Mg(OH)_2$. In case the number of polyatomic ion is one, the bracket is not required. For example, NaOH.

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Formulae of Simple Compounds

The simplest compounds, which are made up of two different elements are called binary compounds.

While writing the chemical formulae for compounds, we write the constituent elements and their valencies as shown below.

Then we must crossover the valencies of the combining atoms.

Examples

1. Formula of hydrogen chloride

Symbol H Cl

Valency 1 1

Formula would be HCl

2. Formula of carbon tetrachloride

Symbol C Cl

Valency 4 1

Formula would be CCl_4

For magnesium chloride, we write the symbol of cation (Mg^{2+}) first followed by the symbol of anion (Cl^-). Then their charges are criss-crossed to get the formula.

Formula of magnesium chloride

Symbol Mg Cl

Charge 2+ 1−

Formula : $MgCl_2$

Some more examples

(a) Formula for aluminium oxide :

Symbol Al O

Charge 3+ 2−

Formula : Al_2O_3

(b) Formula for calcium oxide :

Symbol Ca O

Charge 2+ 2−

Formula : CaO

(c) Formula of Sodium nitrate

Symbol Na NO_3

Charge 1+ 1-

Formula : $NaNO_3$

(d) Formula of calcium hydroxide

Symbol Ca OH

Charge 2+ 1-

Formula: $Ca(OH)_2$

(e) Formula of sodium carbonate

Symbol Na CO_3

Charge 1+ 2-

Formula : Na_2CO_3

(f) Formula of ammonium sulphate

Symbol NH_4 SO_4

Charge 1+ 2-

Formula: $(NH_4)_2SO_4$

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Questions:

1. Write down the formulae of
(i) Sodium oxide
(ii) aluminium chloride
(iii) sodium sulphide.
(iv) magnesium hydroxide.

2. Write down the names of compounds represented by the following formulae
(i) $Al_2(SO_4)_3$
(ii) $CaCl_2$
(iii) K_2SO_4
(iv) KNO_3
(v) $CaCO_3$

3. What is meant by the term chemical formula.

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

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Molecular Mass and Mole Concept

Molecular Mass:

The molecular mass of a substance is the sum of the atomic masses of all atoms in a molecule of the substance.

the relative mass of a molecule expressed in atomic mass units (u)

Example: (a) Calculate the relative molecular mass of water (H_2O).
(b) Calculate the molecular mass of HNO_3

Solution:

(a) Atomic mass of hydrogen = 1 u
" " " oxygen = 16 u

So the molecular mass of water, which contains two atoms of hydrogen and one atom of hydrogen is

$= 2 \times 1 + 1 \times 16$
$= 18$ u

(b) The molecular mass of ~~water~~ HNO_3 = atomic mass of H + atomic mass of N + 3 x atomic mass of O

$= 1 + 14 + 48 = 63$ u.

Formula Unit Mass.

The formula unit mass of a substance is a sum of the atomic masses of all atoms in a formula unit of a compound.

- Formula unit mass is calculated in the same manner as we calculate the molecular mass. The only difference is that we use the word formula unit for those substance whose constituent particles are ions.

Example: Calculate the formula unit mass of $CaCl_2$

Solution: Atomic mass of Ca + (2× atomic mass of Cl)

$= 40 + 2 \times 35.5 = 40 + 71 = 111\ u$

Questions.

1. Calculate the formula unit masses of ~~atomic~~ ZnO, Na_2O, K_2CO_3, given atomic masses of Zn = 65 u, Na = 23, K = 39 u, C = 12 u and O = 16 u
2. Calculate the molecular masses of H_2, Cl_2, O_2, CO_2, CH_4, C_2H_6, C_2H_4, NH_3, CH_3OH.

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Mole Concept

One mole of any species (atoms, molecules, ions or particles) is that quantity in number having a mass equal to its atomic or molecular mass in grams.

The number of particles (atoms, molecules or ions) present in 1 mole of any substance is fixed, with a value of 6.022×10^{23}.

Avagadro Constant or Avagadro Number (N_0) = 6.022×10^{23}.

1 mole (of anything) = 6.022×10^{23} in number.

Molar mass of atoms is also known as gram atomic mass.

For example,

atomic mass of hydrogen = 1 u. So, gram atomic mass of hydrogen = 1 g.

1 u hydrogen has only 1 atom of hydrogen,
1 g hydrogen has 1 mole atoms, that is, 6.022×10^{23} atoms of hydrogen

Similarly,
16 u oxygen has only 1 atom of oxygen
16 g oxygen has 1 mole atoms, that is, 6.022×10^{23} atoms of oxygen.

To find the gram molecular mass or molar mass of a molecule, we keep the numerical value the same as the molecular mass, but simply change units from u to g.
For example, molecular mass of water (H_2O) is 18 u.
18 u water has only 1 molecule of water,
18 g water has 1 mole molecule of water, that is, 6.022×10^{23} molecules of water.

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Relationship between mole, Avagadro number & mass.

1 mole of carbon atoms

- 6.022×10^{23} atoms of C
- 12 g of carbon atoms

1 mole of hydrogen atoms

- 6.022×10^{23} atoms of H
- 1 g of H atoms

1 mole of any particle (atoms, molecules, ions)

- 6.022×10^{23} number of that particles
- Relative mass of those particles in grams

1 mole of molecules

- 6.022×10^{23} numbers of molecules
- Molecular mass in grams

Example:

1. Calculate the number of moles for the followings:

(i) 52g of He

(ii) 12.044×10^{23} number of He atoms.

Solution:

No. of moles $= n$

Given mass $= m$

Molar mass $= M$

Given number of particles $= N$

Avagadro number of particles $= N_0$

(i) Atomic mass of He $= 4u$

Molar mass of He $= 4g$

$$\text{Number of moles} = \frac{\text{given mass}}{\text{molar mass}}$$

$$n = \frac{m}{M} = \frac{52}{4} = 13$$

(ii) 1 mole $= 6.022 \times 10^{23}$

$$\text{Number of moles} = \frac{\text{given no. of particles}}{\text{Avagadro No.}}$$

$$n = \frac{N}{N_0} = \frac{12.044 \times 10^{23}}{6.022 \times 10^{23}} = 2$$

Example:

Calculate the mass of the following:

(i) 0.5 mole of N_2 gas

(ii) 0.5 mole of N atoms

(iii) 3.011×10^{23} number of N atoms

(iv) 6.022×10^{23} number of N_2 atoms

Solution.

(i) No. of moles $= \frac{\text{given mass}}{\text{Molar mass}}$.

$$n = \frac{m}{M}$$

$$m = n \times M = 0.5 \times 28 = 14\ g$$

(ii) $$m = n \times M = 0.5 \times 14 = 7\ g$$

(iii) $$n = \frac{N}{N_0} = \frac{3.011 \times 10^{23}}{6.022 \times 10^{23}} = 0.5$$

$$m = n \times M = 0.5 \times 14 = 7\ g$$

(iv) $$n = \frac{N}{N_0} = \frac{6.022 \times 10^{23}}{6.022 \times 10^{23}} = 1$$

$$m = n \times M = 1 \times 28 = 28\ g.$$

Example: Calculate the number of particles in each of the following:

(i) 46 g of Na atoms

(ii) 8 g of O_2 molecules

(iii) 0.1 mole of carbon atoms

Solution:

(i) The number of atoms

$$= \frac{\text{given mass}}{\text{molar mass}} \times \text{Avagadro number}$$

$$N = \frac{m}{M} \times N_0$$

$$= \frac{46}{23} \times 6.022 \times 10^{23}$$

$$N = 12.044 \times 10^{23}$$

(ii) $$N = \frac{m}{M} \times N_0$$

$$N = \frac{8}{32} \times 6.022 \times 10^{23}$$

$$N = 1.51 \times 10^{23}$$

(iii) $$N = n \times N_0$$

$$= 0.1 \times 6.022 \times 10^{23}$$

$$= 6.022 \times 10^{22}$$

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Questions

1. If one mole of carbon atoms weight 12 grams, what is the mass (in gram) of 1 atom of carbon?

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

Note:

Do all the questions from chapter 3. page no. - 43 & 44.

~ The End ~