

9th – Atoms & Molecules I

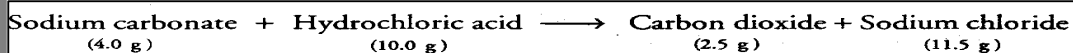


Ancient Indian and Greek philosophers believed that the wide variety of objects around us are made up of combinations of five basic elements: earth, fire, water, air and sky. In the present chapter, we shall discuss about the various laws (which explains how atoms combine to form molecule), symbols and formulae of atoms and molecules and various ways of expressing their masses.

Laws of chemical combination: Whenever reactants react together to form the products or the elements combine together to form a compound. This experimental work by Lavoisier, John Dalton and other scientists led to the formulation of certain laws. These laws are called laws of chemical combination.

1. **Law of Conservation of Mass:** It states, “mass can neither be created nor be destroyed during a chemical reaction.” This means that in any chemical reaction, the total mass of the reactants is equal to the total mass of the products and there is no change in mass during the chemical reaction. It is also known as law of indestructibility of matter.

Example 1: If 4.0 g of sodium carbonate reacts with 10 g of hydrochloric acid, it results in the formation of 2.5 g of carbon dioxide and 11.5 g of sodium chloride solution. Show that these results are in accordance with the law of conservation of mass.



Here, total mass of reactants = 4.0 + 10 = 14 g

Total mass of products = 2.5 + 11.5 = 14 g

Since, the reactants and products have the same mass, this means that there was no loss or gain of mass after the reaction. Hence, the data is in agreement with the law of conservation of mass.

2. **Law of Constant Proportions OR Law of Definite Proportions:** French chemist, Joseph Proust analysed the chemical composition (types and percentage of elements present) of a large number of compounds and came to the conclusion that the proportion of each element in a compound is constant (or fixed), irrespective of where the compound came from or who prepared it. On this basis he proposed the law of constant proportions, according to which “In a chemical substance (or compound), the elements are always present in definite proportions (or ratios) by mass.” Example: 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 9 g of water is decomposed, 1 g of hydrogen and 8 g of oxygen are always obtained. Similarly, carbon dioxide (CO₂) always contains carbon and oxygen in the ratio of 3 : 8. If a sample of CO₂ contains 36 g of carbon then it is compulsory that the sample has 96 g Oxygen.

Example 2: Copper oxide was prepared by two different methods. In one case, 1.75 g of the metal gave 2.19 g of oxide. In the second case, 1.14 g of the metal gave 1.43 g of the oxide. Show that the given data illustrate the law of constant proportions.

Case 1: Mass of copper = 1.75 g And mass of copper oxide = 2.19 g. So, mass of oxygen = Mass of copper oxide — Mass of copper = 2.19 — 1.75 = 0.44g

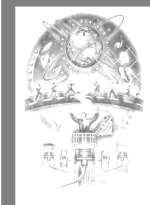
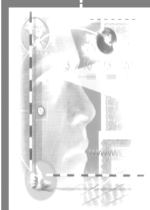
Now, in first sample of copper oxide compound. Mass of copper : Mass of oxygen = 1.75 : 0.44 = 3.98 : 1 = 4 : 1

Case 2: Mass of copper = 1.14g And mass of copper oxide = 1.43 g. So, mass of oxygen = Mass of copper oxide — Mass of copper = 1.43 — 1.14 = 0.29g

Now, in second sample of copper oxide compound. Mass of copper : Mass of oxygen = 1.14 : 0.29 = 3.93 : 1 = 4 : 1

From the above calculations we can see that the ratio (or proportion) of copper and oxygen elements in the two samples of copper oxide compound is the same, i.e. 4 : 1. So, the given data verify the law of constant proportions.

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Explanation of Laws of Chemical Combination: Dalton's Atomic Theory

Dalton's atomic theory provided an explanation for the law of conservation of mass and the law of definite proportions. According to Dalton's atomic theory, all matter (whether an element, a compound a mixture), is composed of small particles, called atoms.

The Main Postulates of Dalton's Atomic Theory

1. Every matter is made up of very small particles, called the atoms.
2. Atoms are indivisible particles which can neither be created nor be destroyed in a chemical reaction.
3. Atoms of a given element are identical in mass as well as in chemical properties.
4. Atoms of different elements have different masses and chemical properties.
5. Atoms combine in the ratio of small whole numbers to form compounds
6. The relative numbers and kinds of atoms are constant in a given compound

Merits of Dalton's Atomic Theory

1. This theory explains the laws of chemical combination.
2. Dalton was the first to recognise a workable distinction between the ultimate particle of an element (atom) and that of a compound (molecule).

Demerits of Dalton's Atomic Theory

1. Atom is no longer considered as the smallest indivisible particle. It has been established that it is made up of electrons, protons and neutrons.
2. Atoms of the same element may have slightly different masses (Isotopes).
3. Atoms of different elements may have the same masses (Isobars).
4. Substance made up of the same kind of atoms may have different properties.
5. The ratio in which the different atoms combine to compound may be fixed and integral but may not be simple.

Q1: 20 g silver nitrate solution is added to 20 g of sodium chloride solution. What change in mass do you expect after the reaction and why?

Q2: If 100 g of calcium carbonate on heating produces 44 g of carbon dioxide, how much quicklime will be formed? Which law is followed for solving this problem?

Q3: In a given sample of ammonia, 9g hydrogen and 42g nitrogen are present. In another sample, 5 g hydrogen is present along with nitrogen. Calculate amount of nitrogen in the second sample.

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ATOMS: Atoms are the smallest particles of an element which may have or may not have independent existence but take part in a chemical reaction. These are the building blocks of all matter. E.g. atoms of hydrogen, oxygen, nitrogen etc., are not capable of independent existence whereas atoms of helium, neon etc., are capable of existing independently.

Size of Atoms: Atoms are very small and their radius is measured in nanometres. $1\text{m}=10^9\text{nm}$

Hydrogen atom is the smallest atom and its radius is 0.1 nm.

Modern Day Symbols of Atoms of Different Elements: In chemistry, symbols are the representation of an element. It is simple to use the symbol of an element rather writing a whole word of an element. Therefore, symbols are used to represent an element.

Dalton was the scientist who introduced symbols for representing elements for the first time. As Dalton's symbol for elements were difficult to draw and inconvenient to use, modern symbols for the elements were introduced by JJ Berzilius. These are defined as "a short hand representation of the name of an element". In the beginning, the names of elements were

Element	Dalton's symbol	Element	Dalton's symbol
Hydrogen		Iron	
Carbon		Copper	
Oxygen		Silver	
Phosphorus		Gold	
Sulphur		Lead	
Platina		Mercury	

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derived from the name of the place where they were found for the first time. Nowadays, it is the IUPAC (International Union of Pure and Applied Chemistry) who approves the names and symbols of the elements. 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 in capital letter and the second letter as a small letter. E.g. chlorine (Cl), zinc (Zn) and aluminium (Al). Symbols of some elements have been taken from their names in different languages such as Latin, German, Greek etc. E.g. Iron — Fe from Ferrum (Latin name) and Gold – Au from Aurum (Latin name).

Atomic Mass: According to Dalton's, each element has a characteristic atomic mass. But determining the mass of an individual atom was a relatively difficult task due to its very small size. Hence, their relative atomic masses were determined using the laws of chemical combinations and the compounds formed. For this purpose, initially 1/16 of the mass of an atom of naturally occurring oxygen was taken as standard unit because of the following two reasons:

1. Oxygen reacted with a large number of elements and formed compounds.
2. This unit gave masses of most of the elements as whole numbers.

However in 1961, carbon (C- 12 isotope) was chosen as standard reference for measuring atomic masses universally because C-12 isotope of Carbon is the most abundant.

Relative Atomic Mass: It is defined as the number of times a given atom is heavier than 1/12th of mass of 1 atom of carbon-12 (C-12) or it is the average mass of the atom as compared to 1/12th the mass of one carbon-12 atom.

Atomic Mass Unit: It is defined as the mass unit equal to exactly 1/12th of the mass of one atom of C- 12 isotope. Earlier, it was abbreviated as amu but according to latest recommendations of IUPAC, it is now written as 'u'— unified mass.

Note Atoms of most of the elements are not able to exist independently. Atoms form molecules and ions. These molecules or ions aggregate in large numbers to form the matter that we can see, feel or touch.

Molecules: The smallest particle of an element or compound which is capable of independent existence and shows all the properties of that substance is called a molecule. In general, molecule is a group of two or more atoms that are chemically bonded together. Atoms of the same element or of different elements can join together to form molecules.

Molecules can be divided into two categories:

1. **Molecules of Elements:** The molecules of an element contain same type of atoms. Molecules of many elements are made up of one atom of that element. E.g. noble gases like argon (Ar), helium (He) etc. The molecules of most of the non-metals are made up of more than one atom. E.g. a molecule of oxygen (O₂) consists of two atoms of oxygen and is known as diatomic molecule, Ozone (O₃) consists of three atoms of oxygen.

Atomicity: It is defined as the number of atoms present in a molecule. On the basis of atomicity, molecules can be classified as:

- Monoatomic molecules: They consist of only one atom. E.g. He, Ne Ar, Xe, Fe, Al etc.
- Diatomic molecules: They consist of two atoms. E.g. H₂, O₂, N₂,
- Triatomic molecules: They consist of three atoms. E.g. O₃ CO₂, NO₂ etc.
- Tetraatomic molecules: They consist of four atoms. E.g. P₄, H₂O₂ etc.
- Polyatomic molecules: They consist of more than four atoms. E.g. CH₄(pentaatomic), S₈ (octaatomic) etc.

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2. Molecules of Compounds: Atoms of different elements join together in definite proportions to form molecules of compounds. E.g. H₂O molecule is made up of hydrogen and oxygen elements in the ratio of 1:8 by mass.

Prediction of Number of Atoms from Mass Ratio: In order to predict the number of atoms from mass ratio, divide the given mass of each element by the atomic mass of the element and calculate the simplest ratio between the obtained moles.

For example: we know that mass ratio of nitrogen and hydrogen in ammonia molecule is 14: 3. From the table given: In ammonia molecule, one N and three H-atoms are present hence, the formula of ammonia is NH₃.

Q: What is the difference between 2Cl and Cl₂? Which one of these two forms exists in nature?

Also give the atomic mass of this element.

Q: An oxide of nitrogen is found to contain nitrogen and oxygen combined together in the ratio of 7:16 by mass. Derive the formula

IONS: Then atoms, groups of atoms or molecules lose or gain electron(s) they become charged. These charged species are known as ions. Atoms in solution generally exist in the form ions. These can be negatively or positively charged, thus can be categorised into two groups.

Cations: The positively charged ions are known as cations. E.g. Na⁺, K⁺, Ca⁺², Al⁺³ etc. These are formed when elements uses electrons. Usually, metals form cations.

Anions: The negatively charged ions are known as anions. E.g. Cl⁻, Br⁻, O²⁻, N³⁻ etc. These are formed when elements gain electrons. Usually, non-metals form anions.

Polyatomic Ion: A group of atoms carrying charge a single entity is known as a polyatomic ion. It carries a fixed charge. E.g. NO₃⁻ (nitrate ion), CO₃²⁻ (carbonate ion) and SO₄²⁻ (sulphate ion) etc.

Ionic compounds are formed by cations and anions, e.g. sodium chloride or common salt (NaCl) consists of a positively charged sodium ion (Na cation) and negatively charged chloride ion (Cl anion). The compound which consists of ions as its constituent particles is known as **ionic compound**. It contains ionic bonds. Calcium oxide or quicklime (CaO) consist of calcium cation (Ca²⁺) and oxide anion (O²⁻).

Molecular compounds are those compounds in which the atoms of the elements share electrons via **covalent bonds**. Thus, in these compounds, covalent bonds are present. E.g. methane (CH₄), water (H₂O) etc.

Valency: The combining power (or capacity) of an element is called its valency. Valency can be used to find out how the atoms of an element will combine with the atom(s) of another element to form a chemical compound. The valency of an ion is equal to the charge on the ion.

Molecules of Some Compounds		
Compound	Combining Elements	Ratio by Mass
Water (H ₂ O)	Hydrogen and oxygen	1 : 8
Carbon dioxide (CO ₂)	Carbon and oxygen	3 : 8
Hydrogen sulphide (H ₂ S)	Hydrogen and sulphur	1 : 16
Ammonia (NH ₃)	Nitrogen and hydrogen	14 : 3
Sulphuric acid (H ₂ SO ₄)	Hydrogen, sulphur and oxygen	1 : 16 : 32
Glucose (C ₆ H ₁₂ O ₆)	Carbon, hydrogen and oxygen	6 : 1 : 8
Baking powder (NaHCO ₃)	Sodium, hydrogen, carbon and oxygen	23 : 1 : 12 : 48
Common salt (NaCl)	Sodium, chlorine	23 : 35.5

Element	Mass Ratio (x)	Atomic Mass (y)	Mole Ratio (x/y)	Simplest Ratio
N	14	14	$\frac{14}{14} = 1$	1
H	3	1	$\frac{3}{1} = 3$	3



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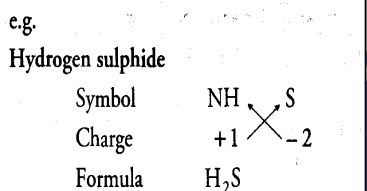
Writing chemical formulae: The shortest way to represent a compound with the help of symbols and valency of elements is known as chemical formula. Chemical formula of a compound shows its constituent elements and the number of atoms of each combining element. In ionic compounds, the charge on each ion is used to determine the chemical formula of a compound. There are some rules for writing the chemical formula:

1. The valencies or charges on the ion must be balanced.
2. When a compound consists of a metal and a non-metal, the symbol of the metal is written first and on the left whereas of non-metal on its right. E.g. calcium oxide (CaO), sodium chloride (NaCl), iron sulphide (FeS), copper oxide (CuO) etc., where oxygen, chlorine, sulphur are non-metals and are written on the right, whereas calcium, sodium, iron and copper are metals and are written on left.
3. When compound is formed with polyatomic ions, the ion is enclosed in a bracket before writing the number to indicate the ratio. e.g. Ca(OH)₂.

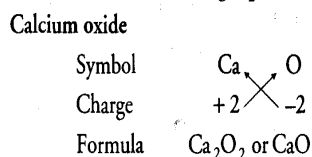
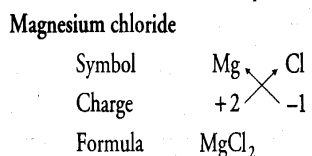
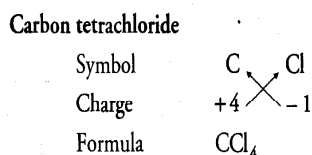
In case if the number of polyatomic ion is one, the bracket is not required. e.g. NaOH.

Formulae of Simple Compounds: To write the chemical formula for simple compounds:

1. Write the symbols of constituent elements and their valencies as shown below.
2. Write the symbol of cation first followed by the symbol of anion.
3. Then criss-cross their charges or valencies to get the formula.
4. The positive and negative charges must balance each other and the overall structure must be neutral.



Note When the subscript is number 1, subscript is not written.



Names, Symbols and Valency of Some Ions

Valency	Ion of Metallic Element	Symbol	Ion of Non-Metallic Element	Symbol	Polyatomic Ions	Symbol
1	Sodium	Na ⁺	Hydrogen	H ⁺	Ammonium	NH ₄ ⁺
	Potassium	K ⁺	Hydride	H ⁻	Hydroxide	OH ⁻
	Silver	Ag ⁺	Chloride	Cl ⁻	Nitrate	NO ₃ ⁻
	Copper (I)*	Cu ⁺	Bromide	Br ⁻	Hydrogen carbonate (bicarbonate)	HCO ₃ ⁻
			Iodide	I ⁻		
2	Magnesium	Mg ²⁺	Oxide	O ²⁻	Carbonate	CO ₃ ²⁻
	Calcium	Ca ²⁺	Sulphide	S ²⁻	Sulphite	SO ₃ ²⁻
	Zinc	Zn ²⁺			Sulphate	SO ₄ ²⁻
	Iron (II)*	Fe ²⁺				
	Copper (II)*	Cu ²⁺				
3	Aluminium	Al ³⁺	Nitride	N ³⁻	Phosphate	PO ₄ ³⁻
	Iron (III)*	Fe ³⁺	Phosphide	P ³⁻		

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

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Q: Predict the total number of atoms in each case.

- (i) Calcium phosphate (ii) Hydrogen sulphide
(iii) Magnesium bromide (iv) Sodium oxide
(v) Aluminium hydroxide

Q: An element X forms $X_2(CO_3)_3$ type compound. What is the formula of its phosphate and chloride?

Q: Write the formula of the following compounds.

1. Magnesium sulphate
2. Sodium bromide
3. Calcium chloride
4. Potassium nitrate
5. Sodium phosphate

Molecular mass: The molecular mass of a substance is the sum of the atomic masses of all the atoms in a molecule of the substance. It is therefore, the relative mass of a molecule expressed in atomic mass units (u). E.g. the relative molecular mass of water (H_2O) is 18 u, which can be calculated as

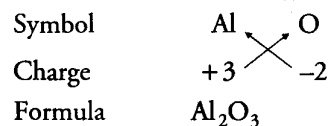
atomic mass of hydrogen = 1 u

atomic mass of oxygen = 16 u

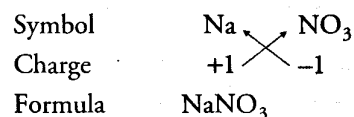
[O contains two hydrogen atoms and one oxygen atom. therefore, molecular mass of water is
 $= 2 \times 1 + 1 \times 16 = 18$ u

Note When the valency of both elements are numerically equal, the subscripts are not written.

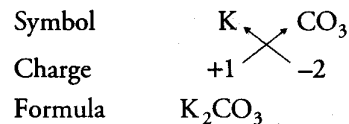
Aluminium oxide



Sodium nitrate

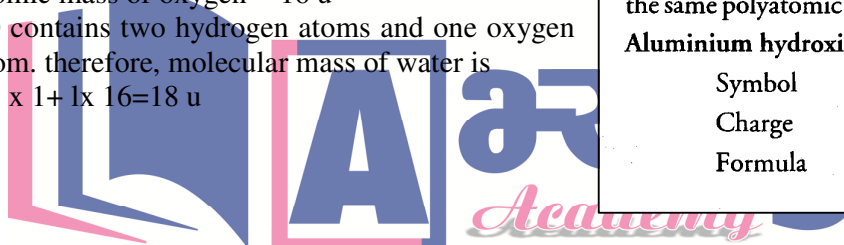
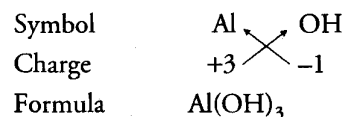


Potassium carbonate



We use brackets when we have two or more of the same polyatomic ions in the formulae. e.g.

Aluminium hydroxide



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