Chapter 1

FUNDAMENTALS OF CHEMISTRY

Time Allocation

Teaching periods	= 12
Assessment period	= 3
Weightage	= 12

Major concepts

1.1 Historical background of chemistry
1.2 Branches of chemistry
1.3 Basic definitions
1.4 Chemical species
1.5 Chemical equation and balancing chemical equations
1.6 Mole and Avogadro's number
1.7 Chemical Calculations

STUDENTS LEARNING OUT COMES (SLO'S)

Students will be able to:

- Know the historical background of chemistry.
- Explain the contribution of Muslim scientists in the development of chemistry.
- Define chemistry and its importance in daily life.
- Identify and explain different branches of chemistry with the help of examples.
- Differentiate between main branches of chemistry.
- Distinguish between matter and a substance.
- Define ions, molecular ions, formula units and free radicals.
- Define atomic number, atomic mass and atomic mass unit.
- Differentiate among element, compound and mixture.
- Define relative atomic mass based on C-12.
- Differentiate empirical and molecular formula.
- Distinguish between atoms and ions.
- Differentiate between molecule and molecular ions.
- Distinguish between ions and free radicals.
- Classify the chemical species from the given examples.
- Relate gram atomic mass, gram molecular mass, and gram formula mass to mole.
- Describe that how Avogadro's number is related to mole of any substance.
- Identify the chemical equation in terms of moles.
- Calculation with balance equation using mole representative particles masses.
- Distinguish the terms gram atomic mass, gram molecular mass and gram formula mass
- Change atomic mass, molecular mass and formula into gram mass, gram molecular mass and gram formula mass.

INTRODUCTION

As we Know that word science comes from latin word "Scientia" which means knowledge, This knowledge is based on hypothesis observation and experiments of universal science. In this universal sciences chemistry purely deals with the matter which have mass and occupy space. Even from the table salt we use in cooking to electro chemical interaction of our human brain show the differences of substance because of the composition, structure, properties and interaction of matter.

The matter is undergoing changes continuously in nature as rusting of iron, evaporation of spirit and burning of coal are examples of reaction in which new substance are formed and energy is absorbed or released. All of these things are different due to the presence of different substances. Which are different by means of composition, properties, interaction , structure of matter.

The chemists use chemistry to explain occurrence and description of things. They investigate material, their interactions and propose theories to illuminate our understanding from a particle to galaxies.

1.1 HISTORICAL BACKGROUND OF CHEMISTRY:

Table 1.1 Time Chronology of Chemistry

Period /Timeline	Name of Scientists	Contribution/invention	Origin of scientist
384 - 322 B.C	Aristotle	Proposed idea of a substance as a combination of *matter* and *form*. Described theory of the Four Elements, i.e. fire, water, earth, air	Greek
347 - 428 B.C	Plato	Proposed term 'elements' as composition of organic and inorganic bodies with particular shape.	Greek
357 - 460 B.C	Democritus	Proposed the idea of atom, an indivisible particle of matter.	Greek
721 - 803 A.D	Jabir Ibne-Hayan	Invented experimental methods of nitric acid, hydrochloric acid and white lead. Extraction of metals from their ores and dyeing clothes.	Muslim

862-930 A.D	Al-Razi	Prepared ethyl alcohol by fermentation process.	Muslim
973-1048 A.D	Al-Beruni	Determined densities of different substances.	Muslim
980-1037 A.D	Ibne –Sina	Contributed in medicines, philosophy and astronomy.	Muslim
1627-1691 A.D	Robert Boyle	Put forward idea of chemistry as systematic investigation of nature. Discovered the gaseous law.	English
1728-1799 A.D	J. Black	Discovered carbon dioxide	Scottish
1733-1804 A.D	J.Priesly	Discovered oxygen,sulphur dioxide and hydrogen chloride.	English
1742-1786 A.D	Scheele	Discovered chlorine	German
1731-1810 A.D	Cavendish	Discovered hydrogen	British
1743-1794 A.D	Lavoisier	Discovered that oxygen is one fifth of air	French
1766-1844 A.D	John Dalton	Proposed atomic theory of matter	English
1778-1850 A.D	Gay-Lussac	Discovered that water is composed of two parts hydrogen and one part oxygen by volume. Discovered several chemical and physical properties of air and other gases,	French
1776-1856 A.D	Avogadro	Proposed Avogadro's lawthat equal volumes of gases under constant temperature and pressure contain equal number of molecules.	Italian

1746-1823 A.D	Jacques Charles	Described the gaseous law.	French
1741-1820 A.D	Petit	Determined the classical expression for the molar specific [heat capacity] of certain chemical elements.	French
1779-1848 A.D	J.J.Berzellius	Introduced symbols, formula and chemical equation to make study more systematic	Swedish
1824-1907 A.D	Mendeleve	Discovered periodic arrangement of elements.	Russian
1859-1927 A.D	Arrhenius	Proposed acid base theoryand ions dissociation.	Swedish
1791-1867 A.D	M.Faraday	Contributed to the study of electromagnetism and electrochemistry.	British
1856-1940 A.D	J.J.Thomson	Discovered the electron by experiments.	British
1885-1962 A.D	Neil Bohr	Proposed a theory for the hydrogen atom based on quantum theory	British
1871-1937 A.D	Rutherford	Postulated the nuclear structure of the atom. Discovered alpha and beta rays, and proposed the laws of radioactive decay.	Scottish
1887 - 1961 A.D	Schrodinger	Proposed Quantum mechanical model of atom	Australian

1892 - 1987 A.D	De Broglie	Proposed hypothesis about wave particle duality nature of electron.	French
1894 - 1974 A.D	Stendra Nath Bose	Proposed fourth state of matter	Indian
1879 - 1955 A.D	Elbert Eienstein	Proposed fourth state of matter	German
1961 - Alive	Eric Cornell	Synthesized the first Bose Einstein Condensate.	American
1951 - Alive	Carl weiman	Produced first bose Einstein Condensate	American

1.1.1 Definition of Chemistry:

Chemistry is the branch of science which deals with the properties, composition and structure of matter. Chemistry also deals with the changes involved in the matter .

1.1.2 Importance of Chemistry in daily life

Our planet earth has only life in the all planet of universe, due to existence of water (H_2O). The water is basic need of human, animals and plants. The chemical reactions take place in human, animals and plants. Disorder in these reactions may cause different diseases. Which may be over come with the help of chemistry.
The role of chemistry in daily life is unavoidable fact.

- Cooking, eating and digestion of food are purely chamical processes.
- Construction, cleaning and washing of our homes are dependable on chemistry.
- The production of fertilizers, glass, plastic synthetic fiber, polymer, ceramics, petroleum products, soaps, and detergents are based on chemistry.
- The diseases transmitted through impure drinking water as cholera, typhoid, dysentery, skin and eye infections can be controlled with the help of chlorine treatment to kill the pathogenic organism to obtain pure water.
- The chlorine is most important chemical which is used commercially to produce more than one thousand compounds which are used in chemical industry as bleaching agent, disinfectants, solvents, pesticides, refrigerates, PVC and drugs all are miracles of chemistry.

Test Yourself

- Identify and list down the chemistry related products in your home?
- How you can relate living things with chemistry?

Do You Know?

1.2 BRANCHES OF CHEMISTRY

As we know that chemistry is serving humanity everywhere in our environment. Due to its wide scope Chemistry is divided into following main branches:

1.2.1 Physical Chemistry

Physical chemistry is the branch of chemistry which deals with relationship between composition and physical properties of matter with the changes in them. It also deals with the laws and principles governing the combination of atoms and molecules in chemical reactions.

1.2.2 Organic Chemistry

Organic chemistry is the branch of chemistry which deals with hydrocarbons and their derivatives. Organic chemistry is the study of structure, properties, composition, reactions, and preparation of carbon-containing compounds, which include hydrocarbons except oxides, carbonates, bicarbonates and cynites. The gasoline, plastics, detergents, dyes, food additives, natural gas, and medicines are studied in the organic chemistry.

1.2.3 Inorganic Chemistry

Inorganic chemistry is the branch of Chemistry which deals with the study of all elements and their compounds except hydrocarbons. These compounds are generally obtained from nonliving things. It is applicable in all areas of chemical industry. Such as glass, cement, ceramics and metallurgy.

1.2.4 Biochemistry

Biochemistry is the branch of Chemistry which deals with the compounds of living organisms (plants and animals) their metabolism and synthesis in the living body such as carbohydrates, proteins and fats. Biochemistry helps us to understand how living things obtain energy from food. It tells that how disorder or deficiency of these biomolecules causes diseases. This branch is useful in medicine, agriculture and food science.

1.2.5 Industrial Chemistry

The branch of Chemistry which deals with the study of chemical processes involved in the chemical industries for the manufacture of synthetic products like fertilizers, glass, cement and medicines is called as industrial chemistry.

1.2.6 Nuclear Chemistry

Nuclear chemistry is the branch of Chemistry which deals with the radioactivity, nuclear processes and properties of radioactive substances. Radioactive elements are widely used in medicine as diagnostic tools and as a means of treatment, especially for cancer, preservation of food and generation of electric power through nuclear power reactors.

1.2.7 Environmental Chemistry

It is the branch of Chemistry which deals with the study of the interaction of chemical materials and their effect on the environment of animals and plants. Personal hygiene, pollution, health hazards are the important areas of environmental chemistry.

1.2.8 Analytical Chemistry

Analytical chemistry is the branch of chemistry which deals with separation and analysis of kind, quality and quantity of various components in given substance. It used in chromatography, electrophoresis and spectroscopy.

1.2.9 Medicinal Chemistry

The branch of Chemistry which deals with synthetic organic chemistry, pharmacology and various biological specialties. The medicinal chemistry is used in synthesis of chemicals, bioactive molecules (Drugs) and pharmaceutical agents.

1.2.10 Quantum Chemistry

The branch of Chemistry which deals with application, mechanics and experiments of physical models in chemical system. It is also called molecular quantum mechanics.

1.2.11 Green Chemistry

The branch of chemistry which deals with study of processes and designing products, which are composed of less hazardous substances. It is also known as sustainable chemistry.

Safer chemical (polyphenylsulfon), less hazardous chemical (poly carbons) and safer solvents are examples of green chemistry. The main purpose of this branch is to use waste material efficiently and improvement of energy efficiency in chemical industry.

Test Yourself

- In which branch of chemistry analysis of quality and quantity of compounds studied?
- What happens due to deficiency of biomolecules?
- Identify and list down examples of green chemistry in our environment?
- Differentiate among Medicinal chemistry and Biochemistry?

1.3 BASIC DEFINITIONS

1.3.1 Matter

Matter is all around us i.e. The air we are breathing, book we are reading and the stuff we touch and see. Matter is simply defined as anything that has mass and occupies space. It is found in three common states solid, liquid and gas. The plasma is also considered as fourth state of matter. The different states of matter are due to difference of energy in increasing order.

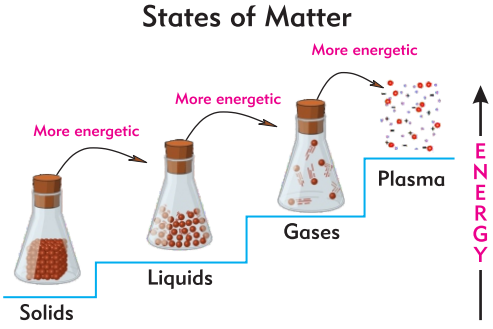
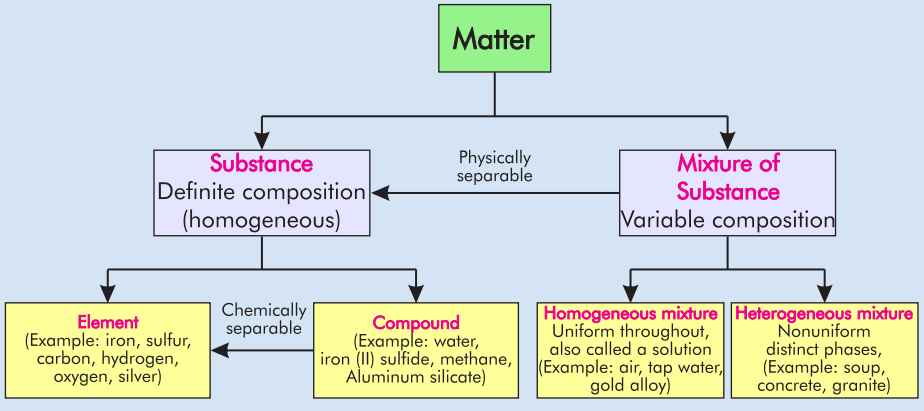


Fig 1.1 States of matter from solid to liquid, liquid to gases and gases to plasma due to increase in energy levels of the particles.

Do You Know?



1.3.2 Atom

Matter is made up of smallest particles which are known as atom. Atoms are the basic units of matter and define structure of elements. Now it is discovered that atoms are made up of three particles: protons, neutrons and electrons. Atoms are composed of even smaller particle as shown in figure 1.2. Where neutron and proton are situated in nucleus and electrons are revolving around the nucleus

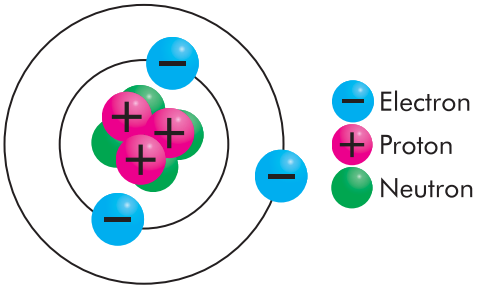


Fig 1.2 Particles of atom

1.3.3 Molecules

A molecule is the smallest particle in a chemical element or Compound that has the chemical properties of that element or Compound. Molecules are made up of atoms that are held together by chemical bonds. These bonds form as a result of the Sharing or exchange of electrons among atoms. Molecules are Mono, di and poly atomic molecules. Examples of mono,di and Poly atomic molecules are as follows.

Table 1.2 Examples of mono, di and poly atomic molecules

Monatomic elements					
					
Name	helium	argon	krypton	xenon	radon
Symbol	He	Ar	Kr	Xe	Rn
Diatomic molecules					
					
Name	nitrogen	oxygen	chlorine	bromine	iodine
Molecular formula	N_2	O_2	Cl_2	Br_2	I_2
Polyatomic molecules					
					
Name	ozone	phosphorus	sulphur		
Molecular formula	O_3	P_4	S_8		

1.3.4 Substance

A piece of matter in pure form is termed as a substance. Every substance has a fixed composition and specific properties. Every substance has physical and chemical properties. Examples of pure substances include tin, sulfur, diamond, water, pure sugar (sucrose), table salt (sodium chloride) and baking soda (sodium bicarbonate). Substances are elements and compounds.


Salt


Diamond


Sulphur

Fig 1.3 Examples of pure substance

1.3.5 Element

An Element is a substance made up of same type of atoms, Having same atomic number and cannot be decomposed into Simple substances by ordinary chemical reaction. Elements occur in nature in free or combined form in solid, Liquid and gaseous states. Till now 118 elements have been discovered. Majority of elements are solids as copper, gold, zinc etc. Very few elements are liquid as mercury and bromine. Few elements are gases as hydrogen, oxygen nitrogen etc. Elements are divided in to metals, nonmetals and metalloids on the basis of their properties.

Do you know?

Metal: solid material which is typically hard, shiny, malleable, fusible, and ductile, with good electrical and thermal conductivity (e.g. iron, gold, silver, aluminium, and alloys such as steel).

Nonmetal: is an element that doesn't have the characteristics of metal including: ability to conduct heat or electricity, luster, or flexibility. An example of a nonmetal element is carbon.

Metalloid: an element (e.g. arsenic, antimony, or tin) whose properties are intermediate between those of metals and non-metals i.e. semi conductor.

1.3.6 How to write Symbol?

Symbol is an abbreviation to represent the name of elements. A symbol is taken from the name of elements from English , Latin, Greek and German languages.

- Symbols are usually one or two letter long.
- Every symbol starts with capital letter as carbon with C or sulphur as S.
- If symbol is two letter then start with capital and second will be in small letter as He for helium, Cr for chromium.

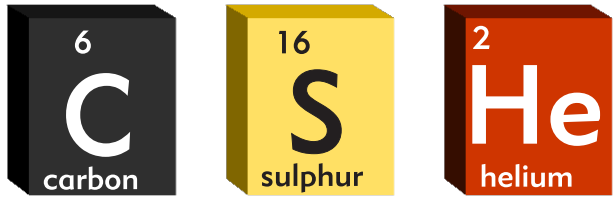


Fig 1.4 Symbols of elements

The symbols of 30 elements in English derived from Latin, Greek and German are given in table 1.3

Table 1.3 Symbols of first 30 Elements

S. No	Names of Elements in English	Derived from Latin and Greek	Symbol
01	Hydrogen	Greek (root genes)	H
02	Hellim	Greek (Helios)	He
03	Lithium	Greek (lithos)	Li
04	Beryllium	Greek (beryllos)	Be
05	Boron	Latin (Busaq)	B
06	Carbon	Latin (Carbone)	C
07	Nitrogen	Greek (nitrumgenes)	N
08	Oxygen	Greek (oxygeinomes)	O
09	Flourine	Latin (fluor)	F
10	Neon	Greek (neos)	Ne
11	Sodium	Latin (Natrium)	Na
12	Magnesium	Greek (magnesium)	Mg
13	Aluminium	Latin (alumen)	Al
14	Silicon	Latin (silen)	Si
15	Phosphorous	Greek (Phoros)	P
16	Sulphur	Latin (sulohur)	S
17	Chlorine	Greek (Chloros)	Cl
18	Argon	Greek (argon)	Ar
19	Potassium	Latin (Kalium)	K
20	Calcium	Greek (Claix)	Ca
21	Scandium	Latin (scandia)	Sc
22	Titanium	Greek (titan)	Ti
23	Vanidium	Greek (vanadis)	V
24	Chromium	Greek (Chroma)	Cr
25	Mangnese	Greek (Magnesia)	Mn
26	Iron	Latin (Ferrum)	Fe
27	Cobalt	German (Kobold)	Co
28	Nichel	German (kupanickel)	Ni
29	Copper	Latin (Cuprum)	Cu
30	Zinc	German (zink)	Zn

1.3.7 What is valency?

The Combining power of an element with other element is called valency. The valency depends upon the number of electrons in the outermost shell. Valency is the number of electrons of an atom of an element can gain, lose or share. Some elements with their symbol and common valencies are given below in table 1.4

S. No	Elements	Symbol	Atomic Number	Valency
1	Hydrogen	H	1	1
2	Helium	He	2	0
3	Lithium	Li	3	1
4	Beryllium	Be	4	2
5	Boron	B	5	3
6	Carbon	C	6	4 2
7	Nitrogen	N	7	3
8	Oxygen	O	8	2
9	Flourine	F	9	1
10	Neon	Ne	10	0
11	Sodium	Na	11	1
12	Magnesium	Mg	12	2
13	Aluminium	Al	13	3
14	Silicon	Si	14	4
15	Phosphorus	P	15	3
16	Sulphur	S	16	2
17	Chlorine	Cl	17	1
18	Argon	Ar	18	0
19	Potassium	K	19	1
20	Calcium	Ca	20	2
21	Scanidium	Sc	21	3
22	Titanium	Ti	22	2 3
23	Vanidium	V	23	5, 4
24	Chromium	Cr	24	3
25	Manganese	Mn	25	2, 4, 7

26	Iron	Fe	26	2 3
27	Cobalt	Co	27	2 , 3
28	Nickle	Ni	28	1 2
29	Copper	Cu	29	1 , 2
30	Zinc	Zn	30	2

1.3.8 What is Chemical formula?

The chemical formula represents the symbol of elements and ratios of elements to one another in a compound.

Chemical formula tells us number of atoms of each element in a compound with symbols.

For Example: Chemical formula of water is H_2O which indicates that 2 atoms of hydrogen combines with 1 atom of oxygen, or Chemical formula of ammonia NH_3 shows that one nitrogen atom combines with 3 atoms of hydrogen.

1.3.9 Compounds:

The Compound is a substance formed when two or more elements are chemically bonded together in a fixed ratio by mass, As a result a new entirely different properties possessing substance is formed.

The type of bonds holding elements may be ionic bond or covalent bond.

For Example: NaCl, $CuSO_4$, KBr are ionic compounds and H_2O, CH_4, H_2SO_4 are covalent compounds.

Table 1.5 Some Common Compounds with their Formula

Compounds	Chemical Formula
Water	H_2O
Silicon dioxide(sand)	SiO_2
Sodium hydroxide (caustic soda)	NaOH
Sodium chloride(common salt)	NaCl
Sodium carbonate(washing soda)	$Na_2CO_3.10H_2O$
Calcium carbonate(lime stone)	$CaCO_3$
Sugar	$C_{12}H_{22}O_{11}$
Ammonia	NH_3
Sulphuric acid	H_2SO_4
Calcium oxide	CaO

1.3.10 Mixture

When two or more than two elements or compounds physically combined without any fixed ratio is known as Mixture. The component substances retain their chemical properties. Mixtures can be separated again by physical methods, as Filtration, Evaporation, Distillation and Crystallization. There are two main types of mixtures, which are shown in figure 1.5, Homogeneous mixture and Heterogeneous mixture. In a homogenous mixture all the substances are evenly distributed throughout the mixture (Salt water, air, blood). In a heterogeneous mixture the substances are not evenly distributed (chocolate chip cookies, pizza, rocks)

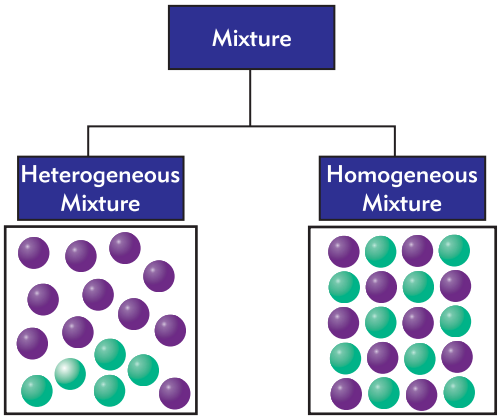


Fig 1.5 Types of Mixture

Table 1.6 Difference between Element, Compound, Mixture

Element	Compound	Mixture
Element is a substance made up of same atoms, and discovered naturally.	Compound is formed by a chemical combination of atoms of the elements.	Mixture formed by the simple mixing of the substances.
Element shows unique properties due to similarity of atoms. Atoms of elements have same atomic number.	Constituent of compound lose their identity and form a new substance with new properties.	Constituents of mixture retain their properties in mixture.
	Compounds have fixed composition by mass.	Mixtures have no fixed composition by mass.
Element cannot be decomposed in to simple substances by ordinary means.	Components cannot be separated by physical means.	The components can be separated by physical means.

Element represented by symbols, which are abbreviations for the names of elements.	Every compound represented by chemical formula.	It consists of two or more components and does not show any chemical formula.
Elements are homogenous	Compounds have homogenous composition.	Mixtures have homogenous as well as heterogeneous composition.
As the atomic number increases in elements melting points increases.	Compounds have sharp and fixed melting points	Mixtures do not have sharp and fixed melting points.

Test Yourself

- How you can differentiate between matter and substance?
- Which elements do the following compounds contains?
  Washing soda, sugar, sand, caustic soda
- Identify mixture, element or compound from the following?
  Table salt, ice cream, blood, silicon, coca cola, tin, zinc, water, sulphur

1.3.11 Relative Atomic Mass and Atomic Mass Unit

Relative Atomic mass:

The Relative atomic mass of an atom is the average mass of naturally occurring isotopes, compared with $^{1}/_{12^{th}}$ mass of one atom of carbon (C-12)

$$A_r = \frac{\text{Average mass of one atom of the element}}{\frac{1}{12} \times \text{the mass of one atom of carbon} - 12}$$

The unit of relative atomic mass is atomic mass unit, with symbol a.m.u .

$$1\text{a.m.u} = 1.66 \times 10^{-24}\ \text{gram}$$

1.3.12 Empirical Formula and Molecular Formula

The compounds are represented by Chemical Formula as elements are represented by symbols. Chemical formula are of two types Empirical Formula and Molecular Formula.

Empirical Formula

The formula showing minimum relative numbers of each type of atoms in a molecule is called Empirical Formula.

- Empirical Formula shows simplest ratio of each atoms present in a molecule.
- Empirical Formula does not show the actual number of atoms in the molecule.
- Empirical Formula tells us the type of element present in it.

For Example:

(1) Benzene has molecular formula C_6H_6. The simplest ratio of hydrogen and carbon is 1:1, so the empirical formula becomes CH.

(2) Glucose has molecular formula $C_6H_{12}O_6$. It shows the ratio as follows

$C_6H_{12}O_6$

6:12:6

1: 2: 1

C: H_2: O

So the empirical formula of glucose is CH_2O and has simple ratio 1:2:1 of atoms in molecule of glucose.

Molecular Formula

The Molecular formula is the formula which shows actual number of atoms of each element present in a molecule.

- Molecular formula is derived from empirical formula.
- Molecular formula Mass calculated by adding atomic masses of its atoms.
- Molecular formula of a compound may be same or multiple of empirical formula.

For Example: Molecular Formula of benzene is C_6H_6, which have six carbon and six Hydrogen, molecular formula is an integral multiple (1,2,3 etc.) of the empirical Formula.

Molecular Formula = (Empirical Formula)n where n=1,2,3,etc

Table 1.7 Some Compounds with their Empirical and Molecular Formula

Compound	Empirical Formula	Molecular Formula
Carbon dioxide	CO_2	CO_2
Glucose	CH_2O	$C_6H_{12}O_6$
Hydrogen peroxide	HO	H_2O_2
Benzene	CH	C_6H_6
Acetic Acid	CH_2O	CH_3COOH

1.3.13 Atomic Number and Atomic Mass

The Atomic Number is number of protons present in the nucleus of atom of any Element. It is represented by symbol Z. All atoms of an element have same atomic number due to the presence of same number of protons. For example all oxygen (O_8) atoms have 8 number of protons due to this atomic number is 8 (Z=8).

The Atomic Mass is sum of number of protons and neutrons present in the nucleus of atom of any element. It is represented by symbol A and calculated by A=Z+n where n is number of neutrons. For example nitrogen atom have 7 number of protons and 7 number of electrons then Atomic mass of nitrogen is 14 (A=7+7=14).

Example 1.1: If any element have number of protons 11 and number of neutrons 12, find out its atomic number and atomic mass?

Data:

Number of protons = 11

Number of neutrons = 12

Z =?

A =?

As we know atomic number Z is number of protons due to this

Atomic number Z = 11

Atomic mass is A = Z+n

A = 11+12

A =23

Example 1.2: How many number of protons and neutrons are there in an atom having A= 40 and Z= 20?

Data:

A = 40

Z = 20

Number of protons?

Number of neutrons?

As Number of protons is Z = 20

Number of neutrons = A - Z

= 40 - 20

= 20

1.3.14 Molecular Mass and Formula Mass

Molecular Mass:

The Molecular Mass is the sum of atomic masses of all the atoms present in one molecule of a substance. For example molecular mass of CO_2 is 44 a.m.u and H_2O is 18 a.m.u .

Example 1.3: Calculate the molecular mass of HNO_3

Solution

Atomic mass of H = 1 a.m.u

Atomic mass of N = 14 a.m.u

Atomic mass of O = 16 a.m.u

Molecular mass = 1(At. Mass of H) +1(At. Mass of N) +3(At. Mass of O)

= 1 + 14 +3(16)

= 1 + 14 + 48

= 63 a.m.u

Formula Mass:

The ionic compounds which form three dimensional solid crystals are represented by their formula units. In such cases formula mass calculated by sum of atomic masses of all atoms in formula unit is called Formula Mass of that substance. For example formula mass of sodium chloride is 58.5 a.m.u

Example 1.4: Calculate the Formula mass of $Al_2(SO_4)_3$

Solution

Atomic mass of Al = 26.98 a.m.u

Atomic mass of S = 32 a.m.u

Atomic mass of O = 16 a.m.u

Formula unit = $Al_2(SO_4)_3$

Formula mass of $Al_2(SO_4)_3$ = 2(26.98) + 3(32) +12(16)

= 53.96 + 96 + 192

= 341.96 a.m.u

Test Yourself

- How you can differentiate empirical formula and molecular formula?
- Why formula mass and molecular mass calculated separately while process of calculation is same?

1.4 CHEMICAL SPECIES:

If one molecule is identical to another we can say they are the same chemical species. Chemical species is a chemical entity, such as particular atom, ion or molecule.

1.4.1 Ions (anions, cations), Molecular ions and Free Radicals

Ions (anions, cations): ion is an atom or group of atoms having a charge on it. The charge may be positive or negative. There are two types of ions, cations and anions. The cations are formed when an atom loses electrons form its outer most shells.

For example: Na^+, K^+ are cations. The following equation shows formation of cations.

$$Na \longrightarrow Na^+ + 1e^-$$

An atom or group of atom that has a negative charge on it is called anion. Anion is formed by the gain or addition of electrons to an atom. For example: Cl^- and O^{2-}, following examples shows formation of an anion by addition of electrons to an atom.

$$Cl + 1e^- \longrightarrow Cl^-$$

Molecular ions: when a molecule loses or gains electrons the species formed called molecular ions. Molecular ions also possess positive or negative charge like any ion. If it has negative charge known as anionic molecular ion, if they have positive charge known as cationic molecular ions. For example CH_4^+, So_4^{2-} etc.

Free Radicals: Free radicals are atoms and group of atoms having number of unpaired electrons. It is represented by putting a dot over the symbol of an element.

For example: H°, Cl°, H_3C°

Free radicals are formed when homolytic breakage of bond between two atoms takes place by the absorption of heat or light energy. Free radical is very reactive chemical species.

With the above mentioned definitions of ions, molecular ions and free Radicals. Question arises that what is difference between Atom and Ions, Molecule and Molecular ion. Even what is difference between ion and free Radical? Let's discuss it one by one.

Table 1.8 Difference between Atom and Ions

Atom	Ion
Atom is the smallest particle of an element.	Ion is the smallest unit of ionic compound
Atom can or can not exist independently and take part in chemical reaction.	Ion can not exist independently and surrounded by oppositely charged ions.
Atom is electrically neutral.	Ion has negative or positive charge.

Table 1.9 Difference between Molecule and Molecular ion

Molecule	Molecular Ion
Molecule is the smallest particle in a chemical element or compound that has chemical properties of that element or compound.	Molecular ion formed by gain and lose of electrons by a molecule.
Molecule is always neutral.	Molecular ion have positive or negative charge.
Molecule is stable unit.	Molecular ion is reactive species.
Molecule is formed by the combination of atoms.	Molecular ion formed by the ionization of a molecule.

Table 1.10 Difference between ion and Free Radicals

Ion	Free Radicals
Ions are atoms which have positive or negative charge.	Free Radicals are atoms with odd number of unpaired electrons.
Ions exist in crystals and solutions.	Free Radicals exist in air and solutions.
Ion are not affected by the presence of light.	Free Radicals are affected by the presence of light.

1.4.2 Molecule and Types of Molecules:

Molecule:
Molecule is chemical combination of atoms
Molecule is smallest unit of a substance.
Molecule shows properties of substance.
Molecule can exist independently.

(1) Mono atomic Molecule	(2) Di atomic Molecule	(3) Tri atomic Molecule	(4) Poly atomic Molecule	(5) Homo atomic Molecule	(6) Hetero Molecule
Molecule consists of one atom.e.g. helium (He), neon(Ne), argon(Ar)	Molecule consists of two atoms. e.g Hydrogen (H_2) Oxygen (O_2), Chlorine (Cl_2)	Molecule consists of three atoms.e.g. H_2O, CO_2	Molecule consists of many atoms.e.g. CH_4,H_2SO_4 ,$C_6H_{12}O_6$	Molecule consists of same type of atoms.e.g H_2,O_3,P_4,S_8	Molecule consists of different type of atoms.e.g CO_2, H_2O, NH_3

Test Yourself

- Identify the cations, anions, free Radical, molecular ion, molecule from the following.

  O_2 , H^-, N_2 , Cl_2 ,CO_3^{2-}, H_2O , Br^- , H_2 , H_3C° Na^+
- Justify the classification of molecules?

1.5 CHEMICAL EQUATION AND BALANCING CHEMICAL EQUATION

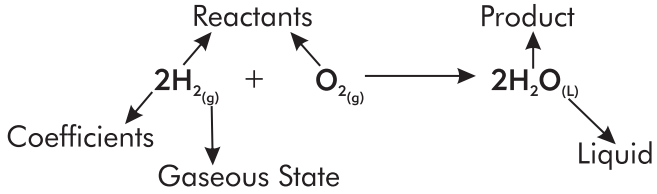
1.5.1 Chemical Equation:

Chemical equation is short hand method of describing the chemical reaction in terms of symbols and formulae of substances.

- The starting substances are known as reactants and always written on the left hand side of arrow,
- The substances which are formed due to reactions of reactants are known as products and written on the right side of arrow.
- The reactants and products are separated from one another by using (→) single arrow or (⇌) double arrow depending on type of reaction.
- The number written in front of formula is called coefficient which shows number of molecules of that reactant or product.
- The expression (s),(g) and(l) shows the state i.e. solid ,gaseous and liquid of reactants and products.
- The expression (aq) expresses that substance is in the form of solution.

  Similarly if a catalyst is used then this catalyst is shown over the arrow.

For example : when two molecules of hydrogen and one molecule of oxygen react then two molecules of water are formed instead of writing the full names of reactants and products, chemists show this reaction as follows in form of equation.



1.5.2 Balancing of Chemical equation

The chemical equation must be balanced in order to fulfill Law of conservation of mass. Mostly chemical equations can be balanced by inspection method (trial and error method). We can balance the equation by following steps.

1.Write the correct formula of all reactants on the left side and products on the Right side of an arrow.

2.Balance the number of atoms on each side.

3.If the number of atoms may appears more or less than other side, balance the equation by inspection method. Multiply the coefficient with formula to make the number of atoms same on the both (reactants and products) sides of equation.

4. The covalent molecules of hyderogen, nitrogen and chlorine exist as diatomic molecules. e.g H_2, O_2, N_2 and Cl_2. We must write them as diatomic molecule rather than isolated atoms in chemical equation.

5. Finally check the equation to be sure that number and kind of atom are same on the reactant and product side. If yes now equation is balanced.

For Example: Let us consider, in laboratory oxygen (O_2) gas is prepared by heating potassium chlorate ($KClO_3$). The products are potassium chloride (KCl) and oxygen (O_2) gas.

Now balance the equation step wise.

Step no1: Write correct formula of all reactants on left side and product on right side of an equation.

$KClO_{3\,(s)} \longrightarrow KCl_{(s)} + O_{2\,(g)}$

Step no2: Balance the number of atoms on each side.

Reactants		Products
K (1)	⟶	K (1)
Cl (1)	⟶	Cl (1)
O (3)	⟶	O (2)

We see that K and Cl elements have same number of atoms on both sides of equation but O is not balance because three atoms on reactant side and two atoms on product side.

Step no3: Now multiply the formula ($KClO_3$) with co efficient 2 on reactant side and 3 in front of oxygen on product side to balance the oxygen atoms.

$2KClO_{3\,(s)} \qquad KCl_{(s)} + 3O_{2\,(g)}$

Reactants		Products
K (2)	⟶	K (1)
Cl (2)	⟶	Cl (1)
O (6)	⟶	O (6)

Step no4: Now again check and balance the equation by placing 2 in front of KCl on product side.

$2KClO_{3\,(s)} \longrightarrow 2KCl_{(s)} + 3O_{2\,(g)}$

Reactants		Products
K (2)	⟶	K (2)
Cl (2)	⟶	Cl (2)
O (6)	⟶	O (6)

Now this chemical equation is balanced.

Test Yourself

- Balance the following equation with coefficient 4 in front of $KClO_3$ on reactant side and 4 in front of KCl on product side.

  $KClO_{3\,(S)} \longrightarrow KCl_{(S)} + O_{2(g)}$

- Balance the following equation.

  $CaCO_3 + HCl \longrightarrow CaCl_2 + H_2O + CO_2$

1.6 MOLE AND AVOGADRO'S NUMBER

1.6.1 Gram Atomic Mass, Gram Molecular Mass, Gram Formula Mass

As we have discussed before that all substances are made up of atoms, molecules or formula units.

The mass of atom is atomic mass, mass of molecule is molecular mass and mass of formula unit is formula mass. All of these masses are expressed in a.m.u. When these masses are expressed in Gram they are termed as Gram atomic mass, Gram molecular mass and Gram formula mass.

Gram Atomic Mass: The atomic mass of an element expressed in gram is called gram atomic mass. It is also called 1 mole.

1 gram atomic mass of oxygen = 16.00g = 1 mole of oxygen atom
1 gram atomic mass of carbon = 12.00g = 1 mole of carbon atom
1 gram atomic mass of nitrogen = 14.00g = 1 mole of nitrogen atom

Its means 1 gram atomic mass of different elements has different masses.

Gram Molecular Mass: The molecular mass of an element or a compound expressed in gram is called gram molecular mass. It is also called 1 mole.

1 gram molecular mass of oxygen (O_2) = 32.00g = 1 mole of oxygen molecule
1 gram molecular mass of water (H_20) = 18.00g = 1 mole of water
1 gram molecular mass of ethanol C_2H_5OH = 46.00g = 1 mole of ethanol

Gram Formula Mass: The formula mass of an ionic compound expressed in grams is called gram formula mass. It is also called 1 mole.

1 gram formula of NaCl = 58.5g = 1 mole of sodium chloride

1gram formula mass of $CaCO_3$ = 100g = 1 mole of calcium carbonate

1.6.2 Mole:

The atomic mass, molecular mass and formula mass of a substance expressed in grams is known as mole. A mole is defined as "amount of substance containing particles equal to the avogadro's number 6.02×10^{23} .

Gram atomic mass and a.m.u

- Gram atomic mass of carbon atom = 12g
- Atomic mass of one atom of C=12a.m.u

Thus

Gram Atomic mass of carbon is 12gram = 1 mole of carbon atom

Gram Molecular mass of H_2SO_4 is 98gram = 1mole of H_2SO_4

The relationship between mole and mass can be expressed as

$$\text{Number of moles} = \frac{\text{Given mass of a substance}}{\text{Molar mass of the substance}}$$

Or

$$\text{Mass of substance (gm)} = \text{Number of moles} \times \text{Molar mass}$$

Example 1.5: Calculate the number of moles in 40g of Na.

Solution

Given mass of Na =40g

Molecular mass of Na =23 a.m.u

Number of moles =?

$$\text{Number of moles} = \frac{\text{Given mass of a substance}}{\text{Molar mass of the substance}}$$

$$\text{Number of moles of Na} = \frac{40}{23} = 1.73 \text{ moles of Na}$$

Example 1.6: What is the mass of 4 moles of CO_2?

Solution

Number of moles of CO_2 = 4 moles

Formula mass of CO_2 = 44 a.m.u

mass of CO_2 = ?

Mass of CO_2 = number of moles of CO_2 × formula mass of CO_2

= 4 x 44 = 176 gm

1.6.3 Avogadro's Number

Avogadro an Italian scientist, calculated the number of atoms, molecules or ions present in one mole. The value is found to be 6.02×10^{23}. This value is represented by N_A and is called as Avogadro's number.

For example: 1 mole of O_2 molecule = 32 g

So 32gm of O_2 will contain 6.02×10^{23} molecules

Similarly 1 mole of NaCl = (23+35.5) = 58.5g of NaCl

$= 6.02 \times 10^{23} Na^{+} + 6.02 \times 10^{23} Cl^{-}$

Example 1.7: Calculate the number of atoms present in 9.2gm of Calcium (Ca).

Solution:

Atomic mass of Calcium (Ca) = 40

1g atomic weight of Calcium = 40gm

40g of Calcium contains $= 6.02 \times 10^{23}$ atoms of Calcium

By using the formula $$\text{Number of atoms} = \frac{N_A \times \text{Given Mass in g}}{\text{Atomic mass}}$$

$$\text{Number of atoms} = \frac{6.02 \times 10^{23} \times 9.2}{40}$$

$= 1.384 \times 10^{23}$ atoms of Ca

Example 1.8: Calculate the number of moles, number of molecules present in 8g of $C_6H_{12}O_6$?

Solution

Molecular weight of glucose ($C_6H_{12}O_6$) = (6x12) + (12x1) + (6x16) = 180

Given Mass of $C_6H_{12}O_6$ = 8gm

$$\text{Number of moles} = \frac{8}{180} = 0.04 \text{ mole}$$

$$\text{Number of molecules} = \text{Number of moles} \times N_A$$

$$= 0.04 \times 6.02 \times 10^{23}$$

$$= 0.240 \times 10^{23}$$

$$= 2.40 \times 10^{22} \text{ molecules of glucose}$$

Test Yourself

- Prove that Avogadro's number is related to mole of any substance.
- Calculate the number of moles in 30gm of H_3PO_4.

1.7 CHEMICAL CALCULATIONS

In all type of chemical calculations we calculate number of moles and number of particles of a substance. These calculations are based on mole. In the sequence of calculation first moles are calculated then number of particles.

1.7.1 Mole-Mass Calculation

In this calculation we calculate number of moles of a substance with the help of following equation.

$$\text{Number of Moles} = \frac{\text{Given mass of substance}}{\text{Molar mass of substance}}$$

We can calculate mass of a substance with the given moles of substance with following equation.

$$\text{Mass of substance} = \text{Number of moles} \times \text{Molar Mass}$$

Example 1.9: A coin of silver (Ag) having 8.5 gm weight. Calculate the number of moles of silver in coin?

Solution

The mass is converted to number of moles by the following equation:

$$\text{Number of Moles} = \frac{\text{Given mass of substance}}{\text{Molar mass of substance}}$$

$$= \frac{8.5}{107}$$

= 0.07 moles of silver in 8.5 gm silver coin

1.7.2 Mole-Particle Calculation

In this calculation we calculate number of moles of a substance in the given number of Particles (atom, molecules or formula unit).

$$\text{Number of Moles} = \frac{\text{Given number of particles}}{\text{Avogadro's number}} = \frac{\text{Given number of particles}}{6.02 \times 10^{23}}$$

We can calculate number of particles as

$$\text{Number of particles} = \text{Number of moles} \times 6.02 \times 10^{23}$$

Example 1.10: Calculate the number of moles and number of molecules present in 10gm of H_2SO_4?

Solution

The given mass of H_2SO_4 = 10gm

Molar mass of H_2SO_4 = 98.0gm

$$\text{Number of Moles of } H_2SO_4 = \frac{\text{Given mass of substance}}{\text{Molar mass of substance}} = \frac{10}{98} = 0.10 \text{ mole}$$

$$\text{Number Of molecules} = \text{Number of moles} \times \text{Avogadro's number}$$

$$= 0.10 \times 6.02 \times 10^{23}$$

$$= 0.602 \times 10^{23}$$

$$= 6.02 \times 10^{22} \text{ molecules of } H_2SO_4 \text{ in 10g.}$$

1.7.3 Mole Volume Calculation

The mole quantities of gases can be expressed in terms of volume, According to Avogadro, one gram mole of any gas at STP occupies volume of 22.4dm^3 (where standard temperature is $0^{\circ}C$ and standard pressures is 1 atm)

Example 1.11: How many liters of carbon dioxide would be produced if 0.450 mole of carbon monoxide reacts with excess oxygen at STP.

Solution:

The equation for the reaction is

$2CO(g) + O_2(g) \_\_\_\_\_ 2CO_2(g)$

$x_1 = 0.450$ moles $\qquad x_2$ liters = ?

2 moles of CO $\qquad$ 2 moles of Co_2

So,

Step 1 $\quad \frac{0.450}{2} = \frac{x_2}{2} \longrightarrow x_2 = \frac{0.450 \times 2}{2} = \frac{0.450}{\text{moles}}$

1 mole of gas at STP means 0°C temperature, 1 atm pressure and occupied volume $22.4dm^3$.

Step 2 $\quad$ Volume in litre/dm^3 = moles × $22.4dm^3$

= 0.45 × 22.4 = 10.08 litre of CO_2

So 10.08 liter of CO_2 would be produced when 0.450 mole of carbon monoxide reacts with excess oxygen at STP.

Summary

- Chemistry is the branch of science which deals with the properties, composition and Structure of matter. Chemistry also deals with the changes involved in the matter.
- Chemistry is everywhere in our environment and serving the humanity day and night. Due to its wide scope Chemistry is divided into physical chemistry, organic chemistry, inorganic chemistry, biochemistry, industrial chemistry, nuclear chemistry, environmental chemistry, analytical chemistry, medicinal chemistry, quantum chemistry, green chemistry.
- Matter is simply defined as anything that has mass and occupies Space.it is found in three common states solid, liquid and gas. The plasma is also considered as fourth state of matter. The different states of matter are due to difference of energy in increasing order.
- Matter is made up of smallest particles which are known as Atom. Atoms are the basic units of matter and define Structure of elements. Now it discovered that atoms are made up of three particles: protons, neutrons and electrons.
- A molecule is the smallest particle in a chemical element or Compound that has the chemical properties of that element or Compound. Molecules are made up of atoms that are held together by chemical bonds. These bonds form as a result of the Sharing or exchange of electrons among atoms. Molecules are Mono, di and poly atomic molecules.

- A piece of matter in pure form is termed as a substance. Every substance has a fixed composition and specific properties. Every substance has physical and chemical properties.
- An Element is a substance made up of same type of atoms having same atomic number and cannot be decomposed into Simple substances by ordinary chemical reaction.
- Elements occur in nature in free or combined form in solid, Liquid and gases states.

  Now 118 elements have been discovered.
- Symbol formula is an abbreviation to represent the name of element. A symbol is taken from the name of that element in English, Latin and Greek. If it is one letter, it will be capital as H for Hydrogen, C for carbon, S for Sulphur and N for Nitrogen etc. in case of two letters symbol, only first letter is capital as Na for sodium, Cr for Chromium, He for Helium and Zn for Zinc.
- When two or more than two elements or compounds physically combined without any fixed ratio is known as Mixture. The component substances retain their chemical properties. Mixtures can be separated again by physical methods, as Filtration, Evaporation, Distillation and crystallization.
- The Atomic Number is number of protons present in the nucleus of atom of any Element. It is represented by symbol Z. All atoms of an element have same atomic number due to the presence of same number of protons.
- The Atomic Mass is sum of number of protons and neutrons present in the nucleus of atom of any element.it represented by symbol A and calculated by $A=Z+n$ where n is number of neutrons.
- The atomic mass of an element expressed in gram is called gram atomic mass. It is also called 1 mole.
- The molecular mass of an element or a compound expressed in gram is called gram molecular mass. It is also called 1 mole.
- The formula mass of an ionic compound expressed in grams is called gram formula mass. It is also called 1 mole.
- The atomic mass, molecular mass and formula mass of a substance expressed in grams is known as mole.
- Avogadro an Italian scientist, calculated the number of atoms, molecules or ions present in one mole. The value is found to be 6.02×10^{23} . This value is represented by N_A and is called as Avogadro's number.

Exercise

SECTION- A: MULTIPLE CHOICE QUESTIONS

Tick Mark (✓) the correct answer

1. The branch of Chemistry which deals with hydrocarbons:

   (a) Industrial chemistry (b) Inorganic chemistry

   (c) Organic chemistry (d) Physical chemistry

2. The atomic mass of an element expressed in gram is:

   (a) Gram molecular mass (b) Gram atomic mass

   (c) Gram formula mass (d) Mole

3. Which of the following can be separated by physical means?

   (a) Mixture (b) Element

   (c) Compound (d) Substance

4 The molar mass of H_2SO_4 is:

   (a) 98 a.m.u (b) 9.8gm

   (c) 98gm (d) 9.8 a.m.u

5. The Molecule consist of two atoms is :

   (a) Monoatomic molecule (b) Polyatomic molecule

   (c) Hetero atomic molecule (d) Di atomic molecule

6. A formula that indicates actual number and type of atoms in a molecule is called:

   (a) Chemical formula (b) Empirical formula

   (c) Molecular formula (d) Formula mass

7. Ethyl alcohol was prepared by:

   (a) Ibne-Sina (b) Al-Razi

   (c) Al-Beruni (d) Jaber bin-Hayan

8. which of the following is a homo atomic molecule:

   (a) H_2 (b) NH_3

   (c) H_2O (d) CO_2

9. The Empirical formula of hydrogen peroxide (H_2O_2) is:

   (a) H_2O_2 (b) HO

   (c) OH_2 (d) O_2H_2

10. A piece of matter in pure form is termed as:

   (a) Redical (b) Mixture

   (c) Compound (d) substance

SECTION- B: SHORT QUESTIONS:

1. Differentiate between the physical and analytical chemistry?
2. Write down the classification of molecule?
3. Identify the differences among the following:
   (a) Atom and Ion
   (b) Molecule and Molecular ion
   (c) Compound and Mixture
4. Define the following terms:
   (a) Gram atomic mass
   (b) Gram molecular mass
   (c) Gram formula mass
5. Write down the empirical and molecular formula of the following?
   Sulphuric acid, Carbon dioxide, Glucose, Benzene
6. What is Free Radical?
7. Describe relationship between empirical and molecular formula? Explain with examples.
8. Explain why hydrogen and oxygen are considered as element whereas water is compound?

SECTION- C: DETAILED QUESTIONS:

1. What do you mean chemical species, explain ion, molecular ion and free radical?
2. Write down the applications of chemistry in daily life?
3. Explain in detail empirical and molecular formula?
4. Explain the steps for balancing the equation?
5. Name the branches of chemistry and discuss any five branches?

SECTION- D: Numerical

.(1) Balance the following equations by inspection method:

(a) $NH_3 + O_2 \longrightarrow NO + H_2O$

(b) $KNO_3 \longrightarrow KNO_2 + O_2$

(c) $Ca + H_2O \longrightarrow Ca(OH)_2 + H_2$

(d) $NaHCO_3 \longrightarrow Na_2CO_3 + H_2O + CO_2$

(e) $CO + O_2 \longrightarrow CO_2$

(2) Calculate the formula mass (a.m.u) of the following?

Al_2O_3 , $MgCl_2$, NaCl , KNO_3

(3) Calculate the molecular mass (a.m.u) of the following?

C_2H_5OH, H_2O, NH_3, CO_2

(4) How many moles are present in 40 gm of H_2SO_4?

(5) Calculate the number of moles and number of molecules present in the following?

(a) 16 g of H_2CO_3 (b) 20g of $C_6H_{12}O_6$