CHAPTER 3

PARTICULATE NATURE OF MATTER

The concept or idea that matter is made of particles is referred to as the particulate nature of matter. We have seen that matter is made up of particles from the diagrammatic representation of the three states of matter. The fact that particles of matter are in constant motion can be seen from the fact that when a reagent bottle containing ammonia is opened in the chemistry laboratory, the odour will be perceived by somebody standing outside the laboratory after some seconds. Again if hydrogen sulphide gas is generated inside a chemistry laboratory, the odour of the gas can easily be perceived at different distances within the environment, or when a gas cylinder is opened in the laboratory without lighting the bunsen burner, the odour of the gas can also be perceived by people at different distances within the environment. If matter were not made of particles that were in constant motion, the odour of the gas will not be perceived at different distances from the source. Scientists discovered that matter is made up of particles which can be atoms, molecules or ions.

3.1 Atom:

An atom is the smallest particle of an element, which can take part in a chemical reaction. If a piece of solid element like copper or zinc is ground into very tiny pieces, the smallest part of it which can take part in a chemical reaction is called an atom.

3.2 Molecule:

A molecule of a compound or element is the smallest particle of a compound or element which is capable of independent existence. A molecule may be composed of atoms of the same element or atoms of different elements. For example, a nitrogen molecule (N_2) contains two atoms of nitrogen, an oxygen molecule (O_2) contains two atoms of oxygen but a molecule of water (H_2O) contains two atoms of hydrogen and one atom of oxygen.

3.3 Ion:

An ion is an electrically charged atom or group of atoms. It is formed as a result of the loss or gain of electrons. The electrons lost or gained are equal to the valence of the ions. There are two types of ions. These are:

i Positively charged ion or

cation ii Negatively charged ion or

anion.

A cation is formed when an atom or group loses electrons. For example

K **-** **e^-** $\longrightarrow$ **K^+**

Potassium 1 electron potassium ion

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

Sodium 1 electron sodium ion

Mg **-** **$2e^-$** $\longrightarrow$ **Mg^{2+}**

Magnesium 2 electrons magnesium ion

Cations include ammonium ion (NH^{4+}), hydrogen ion (H^+) and metallic ions.

An anion is formed when an atom or group gains electrons. For example;

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

Chlorine atom 1 electron Chloride ion

S + **$2e^-$** $\longrightarrow$ **S^{2-}**

Sulphur atom 1 electrons sulphide ion

O + **$2e^-$** $\longrightarrow$ **O^{2-}**

Oxygen atoms 2 electrons oxide ion

Anions include hydroxide ion and acid radicals. Examples of acid radical are:

SO_4^{2-} = Tetraoxosulphate (vi) ion

NO_3^- = Trioxonitrate (v) ion

3.4 Neutral Atom:

A neutral atom is an element in which the number of protons in the nucleus is equal to the number of electrons surrounding the nucleus. If an atom gains or loses an electron or electrons, it becomes an ion. So an ion may be defined again as an atom, which has lost or gained an electron or electrons. The loss or gain of electron can be caused by the chemical environment of the atom eg in electrolysis or by the absorption of energy eg the excited state of an atom results in the formation of negatively charged ion but the loss of electron results in the formation of positively charged ion as shown below.

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

Cl^- **Na** **-** **e^-** $\longrightarrow$

Na^+

In any electrically neutral substance the number of positive charge on the cation must be equal to the number of negative charge on the anion. For example, in (K^+Cl^-) the number of charge on the potassium ion is 1 and that on the chloride ion is 1, as a result, potassium chloride (KCl) is electrically neutral.

3.5 Atomicity:

Atomicity of an element is the number of atoms in one molecule of the element.

Elements whose molecule contains one atom is said to be mono-atomic e.g copper (Cu), sodium (Na).

Element whose molecule contains two atoms are said to be diatomic e.g O_2. Element whose molecule contains three atoms are tri-atomic eg O_3. Element whose molecule contains four atoms are said to be tetra-atomic while a molecule containing more than four atoms is said to be polyatomic eg S_8.

ELEMENT	MOLECULAR FORMULA	ATOMICITY
Carbon	C	1
Copper	Cu	1
Sodium	Na	1
Hydrogen	H_2	2
Oxygen	O_2	2
Nitrogen	N_2	2
Ozone	O_3	3
Phosphorus	P_4	4
Sulphur	S_8	8

3.6 Dalton's Atomic Theory:

Dalton's atomic theory is the idea put forward to explain atom. It was first postulated in the year 1808 by a scientist called John Dalton.

Dalton's atomic theory states that:

1. Matter is made up of small indivisible particles called atoms.

2. Atoms of a given element are all exactly alike.

3. Atoms cannot be created or destroyed.

4. Atoms combine in small whole numbers.

3.7 Recent Modification of Dalton‟s Atomic Theory:

1. Number one postulate is no longer acceptable because radioactive elements are dividing spontaneously. The atomic nucleus is giving out particles and so producing two less complex atoms, eg radium disintegrates to produce two noble gases, helium and randon.

$$^{226}_{88}Ra \longrightarrow ^{4}_{2}He + ^{222}_{86}Rn$$

1. Number two postulate is no longer acceptable because of isotopy. Isotopy is a phenomenon that occurs when an element can exist in two or more forms having similar chemical properties but different atomic masses. Thus chlorine has isotope $^{35}_{17}Cl$ and $^{37}_{17}Cl$. Both have the same number of electrons in their outermost shells. So they have the same atomic number and exhibit the same chemical properties, but the 37-isotope has two extra neutron in the nucleus and so is the higher atom. Potassium also have isotope $^{39}_{19}K$ and $^{41}_{19}K$.

2. Number three postulate is only acceptable and applicable to chemical reactions, in which atoms react as whole units. The changes that occurs as a result of atomic fission, destroy atoms of the element involved. The nuclei are broken into smaller units forming simpler atoms (atoms are created). The nucleus of the uranium isotope U=235, can absorb a neutron and break up into two unequal atoms with mass numbers of 95 and 140.

3. Number four theory is still acceptable for most elements in inorganic chemistry. In organic chemistry, the statement is no longer acceptable because carbon can form very complex organic compounds that do not react in small whole numbers. Examples of complex organic compounds are:

Name	**Molecular Formula**
Heptane	C_7H_{16}
Octane	C_8H_{18}
Nonane	C_9H_{20}
Decane	$C_{10}H_{22}$

3.8 Atomic Structure:

An atom is made up of three fundamental particles. These are electron, proton and neutron. An electron is negatively charged. It has a mass of 1/1840 Unit. It is found in the shell or orbit. A proton is positively charged. It has a mass of 1 unit. It is found in the nucleus. A neutron has no charge. It has a mass of 1 unit. It is found in the nucleus.

Characteristics of the fundamental particles of an atom.

Name of Particle	**Charge**	**Mass based on carbon-12 Isotope**	**Location in the atom**
Electron	-1 (negative)	1/1840	In the shell or orbit
Proton	+1 (positive)	1	Inside the nucleus
Neutron	0 (neutral)	1	Inside the nucleus

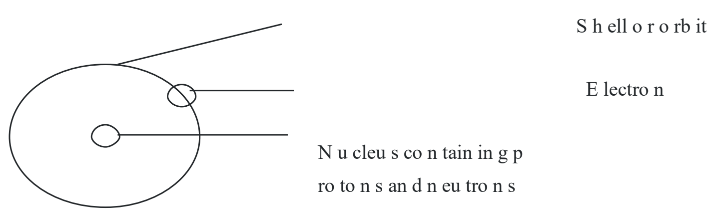

Fig. 3.1 structure of an atom.

3.9 Atomic Number:

Atomic number is the number of proton in the nucleus of an atom. For instance, if an atom has 11 protons, the atomic number is 11. In an atom, the number of proton is equal to the number of electron. An atom is therefore said to be electrically neutral because of the equality of electrons and protons.

3.10 Mass Number:

Mass number is the number of protons and neutrons in the nucleus of an atom.

Mass no. = no. of protons + no. of neutrons

Mass number is also called an atomic mass. An atom with 10 protons and 12 neutrons has an atomic mass or mass number of 22.

An element X with mass number 14 and the atomic number of 7 has the symbol $^{14}_{7}X$

Thus an element $^{14}_{7}X$ has mass number of 14 and atomic number of 7.

Particles: Size, Mass and Quantity Size of a molecule

Scientists can prove that molecules exist. Yet they have not been able to see them even with an electron microscope which magnifies an object up to about 200000 times its normal size. How small, then, is a molecule? Is there a way by which we can measure it?

When a drop of oil is placed on a water surface, it will spread out into a very thin film or layer about one molecule thick. Using this fact, we can find the size of a molecule which is usually about n × 10-7 cm. where 0 < n < 10.

Relative atomic mass

Early scientists expressed the mass of atoms as a ratio by comparing the mass of one atom of any element with the mass of the hydrogen atom, the lightest known atom. The mass of an atom or the relative atomic mass carries no units; it is only a ratio.

The relative atomic mass of oxygen was found to be 16 times that of hydrogen, while that of sodium was 23 times that of hydrogen. The hydrogen atom was then assigned a basic mass value of 1. When using the hydrogen atom as the standard, the relative atomic mass of oxygen was 16 while that of sodium was 23.

Today, the mass of atoms can be measured very accurately with the mass spectrometer. The mass of the hydrogen atom is 1.67 x 10-24 g, while that of the oxygen atom is 2.66 × 10-23 g. These mass values are too small to be of practical use. So the masses of atoms of elements are still expressed as relative atomic masses.

Mass spectrometric studies show that the atoms of most elements exist in more than one form known as isotopes. For instance, chlorine exists as two isotopes: one isotope. 3'Cl, has a relative atomic mass of 35 and the other,

"Cl, a relative atomic mass of 37.

3.11 Isotopy:

Isotopy is the occurrence of atoms of the same element having the same atomic number but different mass number. These atoms of the same element having the same atomic number but different mass number are called isotopes. The difference in the mass number of these isotopes are due to difference in the number of neutron in their nuclei.

Isotopes of a given element exist in a constant ratio in nature.

Each isotope of an element has its own mass, known as the isotopic mass. The atomic mass of an element that exhibits isotopy is actually the weighted average isotopic mass of the isotopes of the element.

This also applies to the relative atomic mass of an element. The standard used for comparing relative atomic masses also had to be defined correctly in view of the presence of isotopes.

Carbon has two stable isotopes, "C and "C, which are present in nature in relative quantities of 98.9% and 1.1% respectively. The atom of carbon-12 has now been adopted by modern chemists as the standard for defining the relative atomic mass of the other elements and has been given a basic mass value of 12 units. The earlier relative atomic masses of elements were readjusted. Now the relative atomic mass of hydrogen is 1.008, oxygen, 15.999, and sodium, 22.989.

The relative atomic mass, A of an element is the number of times the average mass of one atom of that element is heavier than one-welfth the mass of one atom of carbon-12.

The relative atomic mass of each element has bee verified accurately with the aid of the mass spectrometer

Mass spectrometer

This measures the masses of isotopes, molecule and compounds. It is the most accurate instrument for getting the mass of compounds and can also differentiate between isotopes of the same element.

A pure substance will, therefore, give one value for the molar mass of the substance.

The term atomic mass unit (amu) is sometimes used, where l amu is an amount of matter that has a mass one-twelfth that of carbon-/2. From this definition, one carbon atom has a mass of 12 amu, one oxygen atom, a mass of 16 amu and one hydrogen atom, a mass of 1 amu.

Examples of elements and their isotopes:

Hydrogen: It has three isotopes

i. Protium

$^{1}_{1}H$ ii.

Deuterium $^{2}_{1}$

H iii. Tritium

$^{3}_{1}H$

Chlorine: It has two isotopes; chlorine 35 and chlorine 37. They are represented as follows:

$^{35}_{17}Cl$ and $^{37}_{17}Cl$.