CHAPTER-3

ATOMIC STRUCTURE

You will learn in this chapter about:

- Dalton's atomic theory.
- Modern atomic theory.
- Fundamental particles of atoms.
- Discovery of Cathode particles i.e electrons.
- Discovery of Proton.
- Discovery of Neutron.
- Radioactivity.
- Rutherford's Atomic Model.
- Bohr's atomic Model.
- Atomic Number and Mass Number.
- Isotopes.
- Electronic Configuration based on Bohr's Model.
- Electronic Configuration.

3.1 INTRODUCTION

In the fifth century (B.C.) the Greek Philosopher Democritus expressed the belief that all matter consists of very small indivisible particles, which he named **ATOMOS** (Greek =Atomos = not cutable = indivisible) nowadays called atoms.

3.1.1 Daltons Atomic Theory:

In (1808) John Dalton, an English school teacher and Chemist suggested the fundamental ideas of atomic theory, which explains the chemical nature of matter and the existence of atoms. It is known as Dalton's atomic theory. The important postulates are as following:

1. All elements are made up of small indivisible, indestructible particles called atoms.
2. All atoms of a given element, are identical in all respects, having same size, mass and chemical properties. But the atoms of one element differ from the atoms of other element.
3. Compounds are formed when atoms of more than one element combine in a simple whole number ratio.
4. A chemical reaction is a rearrangement of atoms, but atoms themselves are not changed, this means that atoms are neither created nor destroyed in chemical reactions.

3.1.2 Modern Atomic Theory:

Daltons atomic theory assumed that atoms of elements are indivisible and that no particles smaller than atoms existed. But as the time passed new experimental facts led to the modification and extension of Dalton's atomic theory. Atom is a complex organisation, composed of even smaller particles called sub-atomic particles (fundamental particles). These are electrons, protons and neutrons. Dalton's view that all atoms of an element have the same mass is modified in the light of discovery of isotopes. Even then, we can say that the Dalton's atomic theory was largely successful in explaining the laws of chemical combinations.

3.1.3 Fundamental Particles of an Atom:

The atom was generally identified as the *smallest particle* of an element, consisting of sub atomic particles, the electrons, protons and neutrons. The first hint about the sub-atomic particles, came with the discovery of electron by M. Faraday (1832), William Crooks (1879) and J.J. Thomson (1897). Later, the second sub-atomic particle, the proton was identified and isolated by Goldstein, German scientist (1886) and Ernest Rutherford (1919). Finally an English scientist James Chadwick revealed the third particle the neutron in 1932. The structure of atom as we know it today, is because of these findings.

3.2. DISCOVERY OF ELECTRONS

The fundamental particle carrying a negative charge was discovered in 1897, by the British physicist J.J. Thomson. The apparatus used for this type of experiment is called the discharge tube (Neon sign and T.V. tube are examples of discharge tube) which consists of a glass tube, fitted with two metal electrodes connected to a high voltage source and a vaccum pump.

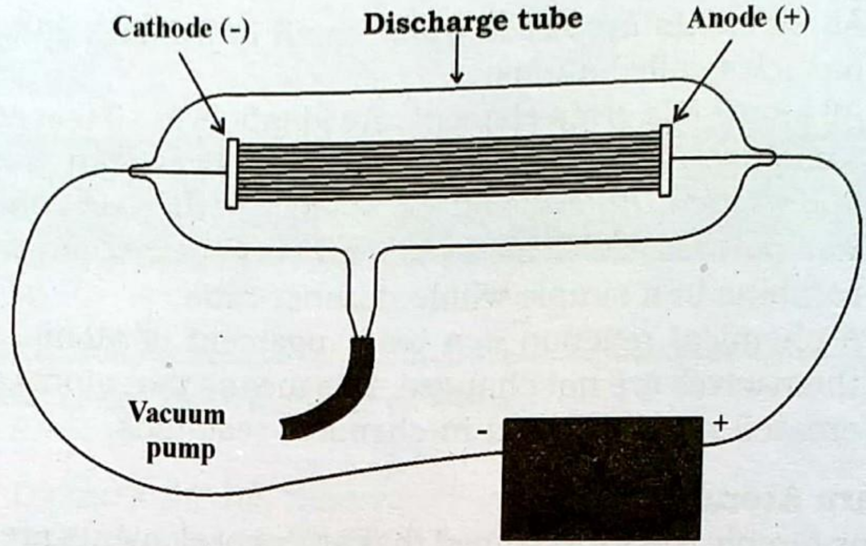

Fig: 3.1 A simple gas discharge tube

When the tube is evacuated and a current of high potential is passed between the electrodes, streaks of bluish light extending from negative electrode (cathode) towards positive electrode (anode). The rays appear to travel in straight lines, from the cathode to anode, cause the wall at the opposite end of the tube glow where they strike. These rays were called cathode rays. Thomson showed that these rays were deflected towards the positive plate in electric and magnetic field. This shows that these rays consisted of negatively charged particles. The name electron was given to these units of negative charges. Electrons were obtained irrespective of the nature of cathode or the gas in the discharge tube. This proves that electrons are constituents of all matter.

Properties of Cathode Rays:

1. They cast shadows of objects placed in their path towards the anode, proving that they travel in straight lines.
2. They *cause a light paddle* wheel to rotate (revolve). Showing that they are material particles.
3. These rays although invisible cause some material to glow or produce fluorescence.
4. They are deflected towards the positive plate in an electric field, showing that they are negatively charged particles.
5. The $\left(\frac{\text{charge}}{\text{mass}}\right)$ e/m ratio of cathode particles is 1.7588×10^8 c/g (coulomb per gram), i.e same for all electrons, regardless of any gas in the tube.

6. They can produce mechanical pressure indicating they possess kinetic energy (K.E.).

3.2.1. Discovery of Protons:

Since atoms are electrically neutral and electrons carry negative charge, it follows that for each electron, there must be one equivalent positive charge to neutrilize that electron. This particle is called a proton. It is one of the fundamental units of structure of all atoms. The simplest atom of hydrogen (H) is therefore made up of one electron and one proton.

e. g $H \longrightarrow H^{+} + e^{-}$
(Proton) (Electron)

Protons were first observed in apparatus similar to cathode rays tube, with a perforated cathode by German Physicist Goldstein in 1886,their existence was verified and their properties were investigated in 1897 by J.J. Thomson.

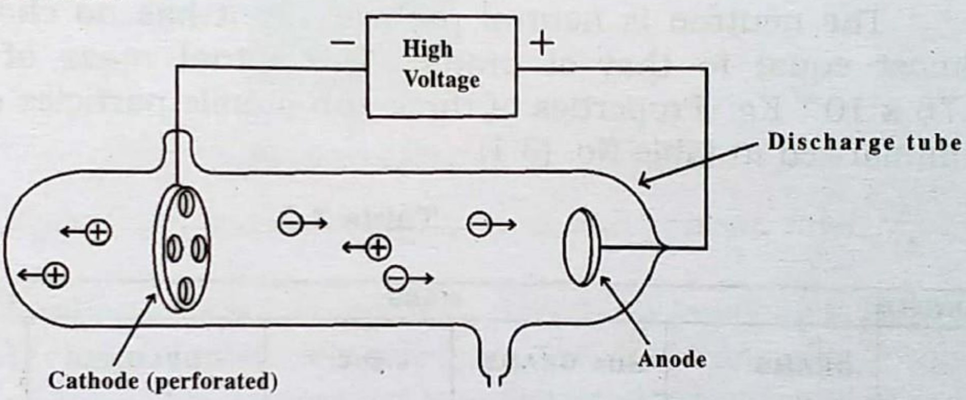

Fig: 3.2 Goldstein's apparatus for studying positive particles

Properties of positive rays :

1. These rays also travel in straight line from anode to cathode.
2. These are deflected towards the negative plate when passed through an electric field, showing that these carry a positive charge.
3. The $\frac{\text{charge}}{\text{mass}}$ i.e., e/m ratio of positive particle is much smaller than that for electron and it varies with the nature of gas in the tube.

3.2.2 Discovery of Neutrons:

In 1932 the English Physicist James Chadwick discovered a third type of fundamental particle of atomic structure through artificial radioactivity, further it will be discussed in the definition of artificial radioactivity.

Properties of Electrons Protons and Neutrons:

Electron :

Electron is negatively charged particle. The charge measured in coulombs. The electric charge is equal to 1.602×10^{-19} coulombs. The electron carries a negligible mass. Its mass is $\frac{1}{1836}$ part of that of proton. The actual mass of an electron is 9.109×10^{-31} Kg.

Proton:

Proton is positively charged particle. The actual charge on a proton is 1.602×10^{-19} coulombs. A proton is 1836 times heavier than electron. The actual mass of a proton is 1.672×10^{-27} Kg.

Neutron:

The neutron is neutral particle, i.e. it has no charge. Its mass is almost equal to that of proton. The actual mass of a neutron is 1.76×10^{-27} Kg. Properties of three sub-atomic particles of the atoms are summarized in table No. (3.1)

Table 3.1

PARTICLE	MASS			CHARGE		
	GRAMS	Kilo GRAMS	a.m.u.	COULOMBS	e.s.u.	CHARGE UNIT
Electron	9.109390×10^{-28}	9.109390×10^{-31}	0.0005485	$-1.602177 \times 10^{-19}$	-4.8×10^{-10}	– 1
Proton	1.672623×10^{-24}	1.672623×10^{-27}	1.007276	1.602177×10^{-19}	4.8×10^{-10}	+ 1
Neutron	1.764929×10^{-24}	1.764929×10^{-27}	1.008664	NONE (0)	NONE (0)	NONE(0)

3.2.3 Radioactivity:

The first conclusive evidence that atoms are complex rather than **indivisible** as stated in the atomic theory, came with the discovery of radioactivity by Henry Becquerel, a French Physicist in 1896.

Definition of Radioactivity:

Radioactivity is the spontaneous disintegration of nucleus of an atom, in which invisible radiations are emitted from the nucleus of atoms. The substances which emit such kind of radiations are known as radio-active elements and the phenomenon is termed as Radioactivity.

Nature of Radioactivity: (Types of rays)

The British physicist Ernest Rutherford in 1902 determined the nature of Radioactive rays by the following experiment and showed that, it is composed of three types of rays.

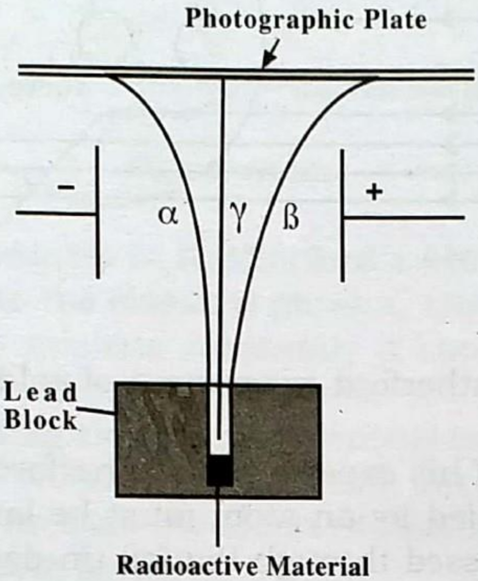

Fig.3.3 Shows separation of alpha, beta and gamma rays.

A sample of radioactive substance was placed in a lead block, between the two oppositely charged plates (electric field). The radiaitons were resolved into three components. One component was deflected towards the negative plate, proving that it carried a positive charge. These were named α-rays. The second component deflected towards the positive plate, showing that it carried a negative charge. These were named β-rays. The third type carried no charge no mass and were not deflected in the electric field. These were, named γ-rays.

3.3 RUTHERFORD ATOMIC MODEL

Lord Rutherford in 1911, carried out series of experiments. He passed a beam of α-particles through a very thin gold metal foil. He found that most of the α-particles passed through it without any deflection. However some of them deflected at large angles and very few of them bounced back.

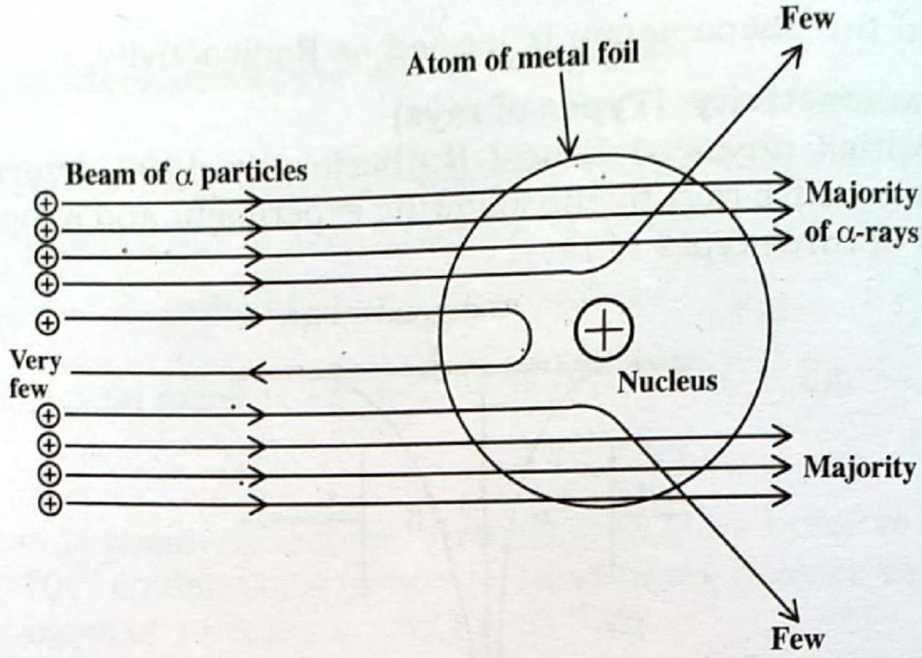

Fig: 3.4 Rutherford experiment of gold metal foil.

From the result of his experiment, Rutherford concluded that:

(1) The volume occupied by an atom must be largely empty as most of the ∝-particles passed through the foil un-deflected.

(2) The positive charge, in the atom is concentrated in extremely dense region which he called the nucleus. This was from the fact that ∝-particles after collision with a heavy positively charged nucleus had bounced back.

From the above observations, Rutherford proposed that the atom consists of very small, positively charged nucleus in which the most of the mass of the atom is concentrated. The rest of the volume is empty space, However this space is not completely empty and that in it electrons revolve around the nucleus.

According to the Rutherford model, an atom consisted of two parts.

1. Nucleus.
2. Extra nuclear part.

The proton and neutron reside in the nucleus. Since the protons are positive charged particles, therefore, the nucleus has positive charge. Further since the weight of the atom due to presence of protons and neutrons, as these particles are residing in the nucleus, the weight of the atom is concentrated in the nucleus.

The electrons are revolving around the nucleus in the extra nuclear part in various orbits, which are also called as shells, or energy levels.

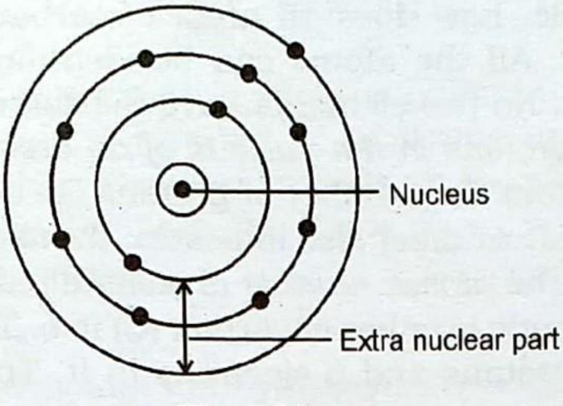

Fig: of Atom.

3.3.1 Weaknesses or Defects in Rutherford's Atomic Model:

1. According to the classical physics, since electron is revolving around the nucleus constantly it should lose energy and it ultimately falls into the nucleus.
2. If the revolving electron emits energy continuously, then there would be a continuous spectrum, but in contrast to it, we get line spectrum from the atoms of element.

3.3.2 Neil Bohr's Atomic Model:

After Planks and Einstein's disçoveries, Niel Bohr, a Danish Physicist in 1913 offered a theoretical explanation of line spectra. The important assumptions for the atomic structure are given below:

1. Neil Bohr adopted Planks idea, that energies are quantized. He proposed that the electrons in atoms move only in certain allowed energy levels (energy states), so an electron in an allowed energy state will not radiate energy continuously and therefore will not fall in the nucleus.
2. That the atom radiates energy as a light only when the electron jumps from higher energy level (E_2) to lower energy level (E_1). The quantity of energy radiated is in discrete quantity, called quanta. A quantum of energy is directly proportional to the frequency of the radiation.

i.e. $\Delta E = E_2 - E_1 = h\nu$

Where h = Planks constant

ν = is the frequency of the radiation.

3.4 ATOMIC NUMBER (Z) AND MASS NUMBER (A)

Why the atoms of one element differ from the atoms of another element? For example, how does an atom of carbon (C) differs from an atom of nitrogen (N). All the atoms can be identified by the number of protons they contain. No two elements have the same number of protons. *Thus the number of protons in the nucleus of an atom is called the atomic number.* In neutral atom the number of protons is equal to the number of electrons, so the atomic number also indicates, the *total number of electrons outside the nucleus. The atomic number is generally denoted by (Z).*

For example, atomic number of carbon (C) is 6. This means that each carbon atom has 6 protons and 6 electrons in it. The atomic number of nitrogen (N) is 7, it means that nitrogen atom has 7 protons and 7 electrons in it.

Atomic number = Z = number of protons in the nucleus or total number of electrons around the nucleus.

Atomic number (Z)is written as subscript on the left hand side of the chemical symbol e.g ${}_{6}C$ and ${}_{7}N$

3.4.1 Mass Number (A):

The nuclei of atoms contain both protons and neutrons, except the ordinary hydrogen atom, which consists of a single proton. The total sum of the protons and neutrons in the nucleus of an atom is called the mass number and is denoted by A. For example, the sodium (Na) atom has atomic number 11 and the mass number 23. It indicates that sodium atom has 11 protons and 12 neutrons. The mass number "A" is written as superscript on the left hand side of the chemical symbol.

e.g $\,^{23}_{11}Na$

Mass number (A) = Number of Protons (Z)+ Number of neutrons (N).

or mass no. $A = (Z+N)$

and number of neutrons $= (A-Z)$

3.4.2 Isotopes:

Atoms of the same element having the same atomic number but different atomic masses are called isotopes.

For example, chlorine element is composed of two kinds of chlorine atoms. These have masses 35 and 37. Both type of chlorine (Cl) atoms have atomic number 17 which means that each chlorine atom has 17 protons in the nucleus. The difference is only in the number of neutrons. Thus Cl-35 has 18 neutrons and Cl-37 has 20 neutrons. They are denoted by writing the atomic number as a sub-script and mass number as a superscript on the left hand side of chemical symbol.

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

It is important to remember that the different isotopes of the same element differ only in the number of neutrons in the nucleus. Since chemical properties of an element depends on the electrons in the shells, the isotopes of an element have the same chemical properties but they differ in physical properties.

Isotopes of Hydrogen:

There are three isotopes of hydrogen. These are known as protium, deuterium and tritium. Protium has one proton and no neutron in the nucleus. Deuterium has one proton and one neutron in the nucleus. Tritium has one proton and two neutrons in the nucleus.

$^{1}_{1}H$ Protium $^{2}_{1}H$ $(^{2}_{1}D)$ Deuterium $^{3}_{1}H$ $(^{3}_{1}T)$ Tritium

Isotopes of Oxygen:

Oxygen atom has also three isotopes having mass number 16, 17, and 18. It shows that these atoms contain 8,9 and 10 neutrons respectively. Thus there are three isotopes of oxygen, i.e.

$^{16}_{8}O$ $^{17}_{8}O$ $^{18}_{8}O$

Isotopes of Uranium: (U)

There are three common isotopes of uranium with mass numbers 234, 235 and 236, respectively.

$^{234}_{92}U$ $^{235}_{92}U$ $^{236}_{92}U$

Some of the isotopes of C:

Symbol	No. of protons	No. of electrons	No. of neutrons
$^{12}_{6}C$	6	6	6
$^{13}_{6}C$	6	6	7
$^{14}_{6}C$	6	6	8

3.4.3 Applications of Isotopes:

Isotopes are used as tracers in physical, chemical and biological researches as well as in the treatments and dignoses of disease like cancer. Since radio isotopes are easily detected, it is relatively easy to trace their movements, even through it is a complicated system.

3.5. ELECTRONIC CONFIGURATION BASED ON BOHR'S MODEL

When atoms react, it is actually the electrons that interact. For this reason, the arrangement of electrons is responsible for the structure of atom. The arrangement of electrons refers not only to the number of electrons that an atom possesses, but also their distribution around the nucleus.

According to Bohr's theory, the electron move in a specific circular orbits around the nucleus, much like the earth moves around the sun. These orbits are called energy levels or shells and are designated as K, L, M, N, O, P orbits and represented by 1, 2, 3, 4, 5, 6, starting from one nearest to the nucleus.

Therefore, K shell is the first shell, L shell is second shell, M shell is the third shell, and so on. The maximum number of electrons in the given shell is governed by the formula $2n^2$, where n is the number of orbits (shell or energy level). Thus first orbit can have a maximum of two electrons (n=1). The second orbit can have a maximum of eight electrons (n=2) and the third orbit can have a maximum of eighteen electrons (n=3) and so on.

The arrangement of electron in the first twenty elements in the periodic table is as under :

Table 3.3 Shows the Arrangement of Electrons in the First 20 Elements.

Elements	Atomic Numbers	Electrons in the Shells			
		K or 1st	L or 2nd	M or 3rd	N or 4th
H	1	1	–	–	–
He	2	2			
Li	3	2	1	–	–
Be	4	2	2		
B	5	2	3	–	–
C	6	2	4	–	–
N	7	2	5	–	–
O	8	2	6	–	–
F	9	2	7	–	–
Ne	10	2	8	–	–

Na	11	2	8	1	–
Mg	12	2	8	2	–
Al	13	2	8	3	–
Si	14	2	8	4	–
P	15	2	8	5	–
S	16	2	8	6	–
Cl	17	2	8	7	–
Ar	18	2	8	8	–
K	19	2	8	8	1
Ca	20	2	8	8	2

Summary

1. Dalton in 1808 published his work under the name Dalton's Atomic Theory.
2. The fundamental particles in an atom are electrons, protons and neutrons. Electrons are negatively charged particles, protons are positively charged particles and neutrons are neutral particles.
3. Protons and neutrons are found in the nucleus of an atom. Electrons move around the nucleus in regions called shells or energy levels.
4. The atomic number of an element is the number of protons in the nucleus of an atom, it determines the identity of an element.
5. The mass number is the sum of the number of protons and the number of neutrons in the nucleus.
6. Isotopes are atoms of same element that have the same atomic number (number of protons) but different number of neutrons.
7. Substances which give off invisible rays that affect photographic plates in the same way as light does, are called radio-active substances and the phenomenon is termed as Radio-activity. The radiation from Radioactive substances are of three types (a) Alpha particles or helium nuclei (b) Beta particles or electrons and (c) gamma rays or high energy x-rays.
8. According to Rutherford atomic model, an atom consists of small, dense, and positively charged centre, called nucleus, which is surrounded by electrons at relatively greater distance from it.

9. Neil Bohr proposed a model of the atom in which the electrons in a hydrogen atom moves around the nucleus in fixed orbits. The line spectrum is only produced when an electron jumps from higher orbit to lower orbit.

10. An electronic configuration is a particular distribution of electrons among the different shells of an atom.

EXERCISE

1. Fill in the blanks :

(i) .... model, says that atom consists of small, dense, positively charged nucleus which is surrounded by electrons, revolving arround it.

(ii) Atomic number of sodium is...................

(iii) Number of proton + number of neutrons is the .... of an element.

(iv) .... are the atoms of the same elements, having same number of protons but different number of neutrons.

(v) The number of isotopes of hydrogen is.............

(vi) .... is the number of positive charges in the nucleus of an atom.

(vii) A-Z indicates the number of .... in the nucleus of an atom.

(viii) Z = number of protons in the nucleus of an atom = number of .... in a neutral atom.

2. Tick the correct answer :

(i) The nucleus of an atom consists of:
(a) Electrons and protons.
(b) Protons and neutrons.
(c) Electrons and neutrons.
(d) None of these.

(ii) Which particle is the lightest in the following :
(a) Electron.
(b) Proton.
(c) Neutron.
(d) α-particles.

(iii) Which particle is heavier than others.
(a) Electron.
(b) Proton.
(c) Neutron.
(d) α-particles.

(iv) The mass of electron is:

(a) $9.11x10^{-26}$g. (b) $9.11x10^{-27}$g.

(a) $9.11x10^{-28}$g. (d) $9.11x10^{-30}$g.

(v) The mass of proton is:

(a) $1.67x10^{-22}$g. (b) $1.67x10^{-23}$g.

(c) $1.67x10^{-24}$g. (d) $1.67x10^{-25}$g.

(vi) Charge on an electron is:

(a) $1.6x10^{-16}$C. (b) $1.602 x10^{-17}$C.

(c) $1.67x10^{-18}$C. (d) $1.602 x10^{-19}$C.

3. Write answer of the following questions:

(i) Outline the main points of Daltons atomic theory.

(ii) What evidence is there that electrons are negatively charged particles?

(iii) Discuss Rutherford's gold metal foil experiment? What did it tell about the structure of the atom.

(iv) Explain the main features of Bohr's theory.

(v) What are protons and how were these produced?

(vi) What are distinguishing characters of electrons, protons and neutrons?

(vii) Define the following terms.

(a) α-particles (b) β-particles (c) γ -rays.

(viii) What is the proof that all atoms contain electrons?

(ix) Describe the three types of rays emitted by radio-active substances.

(x) Why it is believed that the atom has mostly empty spaces.

(xi) Define the terms:-

(a) Atomic number (b) Mass number (c) Isotopes.

(xii) In what way do isotopes of a given element differ form each other?

(xiii) A given isotope of nitrogen (N) contains 7 electrons, 7 protons and 8 neutrons.

(a) What is its mass number?

(b) What is its atomic number?

(xiv) C-14 and N-14 both have same mass number yet they are different elements. Explain.

(xv) What are the names of three sub-atomic particles? What are their masses in atomic mass units (a.m.u) and what is the unit charge on each?

(xvi) Give the names and symbols for the following elements.

(a) An element with atomic No. 6.

(b) An element with 18 protons in the nucleus.

(c) An element with 17 electrons.

(xvii) How many electrons and protons are there in each atom of the following?

(a) Carbon (b) Aluminium (c) Argon

(d) Fluorine (e) Potassium (f) Sulphur

(xviii) How many protons, neutrons and electrons are present in the following atoms?

(a) ${}^{15}_{7}N$ (b) ${}^{60}_{27}Co$ (c) ${}^{131}_{53}I$ (d) ${}^{207}_{82}Pb$