STRUCTURE OF ATOMS

CONTENTS

➢ Introduction

Atoms are made up of three subatomic particles electrons, Protons and neutrons. Electron has negative charge, proton has positive charge, whereas neutron has no charge, it is neutral. Protons and neutrons are present in a small nucleus at the centre of the atom. Electrons are outside the nucleus. The atoms of different elements differ in the number of electrons, protons and neutrons.

➢ Cathode rays

A discharge tube is long glass tube. This tube is fitted with metal electrodes on either end across which high voltage can be applied. The electrode which is connected to the negative terminal of the power source is called cathode while the electrode which is connected to the positive terminal is called anode. The tube is also connected to a vacuum pump for controlling the pressure of gas inside the discharge tube. The gas pressure is reduced to about 10^{-2} atmospheres and a potential difference of about 10000 volts is applied to the electrodes, an electric current flows and at the same time light is emitted by the gas. The fluorescence was caused due to the bombardment of the walls of the tube by rays emanating from cathode. These rays were called cathode rays.

◈ Properties of cathode rays

- Cathode rays always travel in straight line.
- Cathode rays consist of material particles and possess energy, hence they can produce mechanical effects.
- Cathode rays consist of negatively charged particles.
- Cathode rays can penetrate through thin metalic sheets.
- Cathode rays ionize the gas through which they travel.
- Cathode rays heat up the object on which they fall. When they strike an object, a part of the kinetic energy is transferred to the object resulting in a rise in temperature.
- Cathode rays produce a green fluorescence on glass surface.

- When cathode rays fall on certain metals like copper, X-rays are produced. X-rays are not deflected by any electrical or magnetic fields but they pass through the opaque material and are only stopped by solid objects like bones.
- The mass of electrons is very small compared to the mass of an atom. The same type of negatively charged particles are formed even if different gases are taken in the discharge tube or different metals are used as cathode.

Anode rays

The pressure in the tube is decreased, it was observed that in addition to cathode rays, a new kind of rays are also found which came through the perforations (holes) of the cathode. These rays travelled in opposite direction of the cathode rays and passed through the holes of the cathode and struck the other end of the discharge tube. When these radiations struck the end of the tube P, the fluorescent radiations were also produced. These rays were called canal rays because they are passed through the holes or canals in the cathode. These were also called anode rays because they move from the anode. It was found that the anode rays consist of positively charged particles. Therefore, these rays were also called positive rays.

Properties of Anode Rays

- Anode rays travel in straight lines.
- Anode rays consist of material particles.
- Anode rays are deflected by electric field towards negatively charged plate. This indicates that they are positively charged.
- Anode rays are deflected by magnetic field. The direction of deflection indicates that they are positively charged.
- The charge to mass ratio of the particles in the anode rays was determined by W. Wien by using Thomson's technique. Charge to mass ratio of the particles in the anode rays depends upon nature of the gas taken in the discharged tube.
- The nature of anode rays depend on the nature of the gas taken in discharge tube.

Electron

Electron was discovered by J.J. Thomson. Cathode rays consist of small, negatively charged particles called electrons. The electron is a negatively charged particle found in the atoms of all the elements. The electrons are located outside the nucleus in an atom. An electron is usually represented by the symbol e^-

Characteristics of an electron

- **Mass of an electron :**

The mass of an electron is about of the mass of hydrogen atom. Since the mass of a hydrogen atom is 1 u. The absolute mass of an electron is, however, 9×10^{-28} gram.

- **Charge of an electron :**

The absolute charge on an electron is 1.6×10^{-19} coulomb of negative charge. The relative charge of an electron is, – 1

Proton

Proton was discovered by Goldstein. The proton is a positively charged particle found in the atoms of all the elements. The protons are located in the nucleus of an atom. Only hydrogen atom contains one proton in its nucleus, atoms of all other elements contain more than one proton. A proton is usually represented by the symbol P^+

Characteristics of a proton

- **Mass of proton :** The mass of proton has been found to be equal to 1.67×10^{-27} kg. This is almost equal to that of an atom of hydrogen. Since the mass of a hydrogen atom is 1 a.m.u., therefore, the relative mass of a proton is also 1 a.m.u.
- **Charge of proton :** The charge of proton is equal and opposite to the charge of an electron. The value of charge on proton is 1.602×10^{-19} coulomb of positive charge.

Neutron

In 1932, Chadwick discovered the fundamental particle neutron. The neutron is a neutral particle found in the nucleus of an atom. The subatomic particle not present in a hydrogen atom is neutron. A hydrogen atom contains only one proton and one electron. A neutron is represented by the symbol n.

Characteristics of a Neutron

- **Mass of a neutron :** The mass of neutron is equal to the mass of a proton. The relative mass of a neutron is 1 u. The absolute mass of a neutron is 1.6×10^{-27} kg.

- **Charge of an neutron :** Neutron has no charge. It is electrically neutral.

Comparision between Proton, Neutron and Electron:

	Electron	Proton	Neutron
(i) Symbol	e/e^-	p/p^+	n
(ii) Nature	Negatively charge	Positively charge	Neutral
(iii) Relative	1/1840 of a H atom	equal to H atom	equal to H atom
(iv) Actual mass	9.1×10^{-28} g	1.67×10^{-24} g	1.67×10^{-24} g
(v) Charge	(– 1)	(+ 1)	No charge
	(1.602×10^{-19} C)	(1.602×10^{-19} C)	

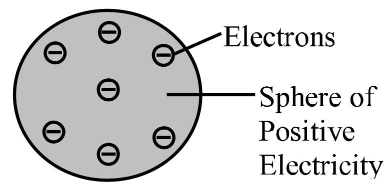
Structure of atom

After the discovery of electron and proton, the scientists started thinking of arranging these particles in an atom. J.J. Thomson was the first scientist to propose a model for the structure of atom. Mainly there are three model preposed.

(A) Thomson's model of an atom
(B) Rutherford model of an atom
(C) Bohr's model of an atom

(A) Thomson's model of an atom

Thomson was the first to propose a detailed model of the atom. He proposed that an atom consists of a uniform sphere of positive electricity in which the electrons are distributed more or less uniformly. The negative and the positive charge are equal in magnitude. Thus, the atom as a whole is electrically neutral. This model of atom is known as the "**Plum pudding model**".



(B) Rutherford model of an atom

Rutherford and his co-workers made a fundamental contribution in understanding the structure of the atom and establishing the presence of a small nucleus in the atom. They performed a number of experiments known as scattering experiments. They took very thin sheets of gold foil (only 4×10^{-5} cm thick) and bombarded it with a stream of alpha (α) particles. The alpha particles are positively charged helium ions (He^{2+}) which carry two units of positive charge and mass four times that of an atom of hydrogen (i.e., mass of helium ions = 4 a.m.u.). These are emitted from radioactive elements such as radium.

Following important observations :

- Most of the fast moving α-particles passed straight through the gold foil without any deflection from their original path.

- Some of the α-particles were deflected from their path through small angles.

- Very few (about 1 in 12,000) did not pass through the foil at all but suffered large deflections (more than 90º) or even came back in the direction from which they came.

The main conclusions of Rutherford's experiment :

- Most of the space inside the atom is empty. Therefore, most of the α-particles went through the gold foil without deflecting from their path.

- There is a positive tiny part in the atom in its centre, which deflects or repels the α-particles. This must be containing the whole mass of the atom. Moreover, this mass must be occupying a very small space within the atom because only a few α-particles suffered large deflections. This positively charged heavy mass in the centre of the atom is called nucleus. The α-particle get deflected from their normal path when they came close to nucleus due to force of repulsion (similar charges).

- The deflections of the α-particles to large angles indicate that the α-particles has direct collision with the positively charged nucleus.

  It was observed that the volume of the nucleus is very small as compared to the total volume of the atom. The radius of the atom is of the order of 10^{-10} m, while the radius of the nucleus has been estimated to be of the order of 10^{-15} m. This means that the size of the nucleus is extermely small i.e., about 10^5 times less than the size of the atom.

- **Rutherford's Atomic model :** The main features of Rutherford's model of an atom are :

- The atom consists of a positively charged centre called the nucleus.

- Most of the mass of the atom is concentrated in the nucleus.

- The volume of the nucleus is very small as compared to the total volume of the atom.

- The nucleus is surrounded by the negatively charged electrons. the electrons balance the positive charge of the nucleus. Therefore, the number of electrons in an atom is equal to the number of protons in it.

- The magnitude of the positive charge on the nucleus is different for different atoms.

- The electrons are not stationary but they are revolving around the nucleus at very high speeds like planets revolving around the sun. As a result, the electrons are also known as planetary electrons.

- **Drawbacks of Rutherford's model :**

  Rutherford model failed in view of electromagnetic theory given by Maxwell. According to this theory a charged particle when accelerated emits energy in the form of electromagnetic radiation. According to Rutherford's model, electrons are revolving around the nucleus. This means, electrons would be in a state of acceleration all the time. Since electrons are charged particles, therefore, electron revolving in an orbit should continuously emit radiations. As a result of this, it would slow down and would no longer be able to withstand the attractive force of the nucleus. Hence, it would move closer and closer to the nucleus and would finally fall in the nucleus by following a spiral path. This means atom would collapse. But actually we know atom is stable. Thus, Rutherford's model failed to explain stability of atoms.

(C) Bohr's model of an atom

In 1912, Niels Bohr put forward a model to explain the structure of an atom. The main postulates of the model are**:**

- An atom is made up of three particles **:** electons, protons and neutrons. Electrons have negative charge, protons have positive charge whereas neutrons have no charge, they are neutral. Due to the presence of equal number negative electrons and positive protons, the atom on the whole is electrically neutral.

- The protons and neutrons are located in a small nucleus at the centre of the atom. Due to the presence of protons, nucleus is positively charged.

- The electrons revolve rapidly around the nucleus in fixed circular paths called energy levels or shells. The energy levels or shells are represented in two ways: either by the numbers 1, 2, 3, 4, 5 and 6 or by the letters K, L, M, N, O and P. The energy levels are counted from the centre outwards.

- There is a limit to the number of electrons which each energy level can hold. For example, the first energy level (or K shell) can hold a maximum of 2 electrons; second energy level (or L shell) can hold a maximum of 8 electrons; third energy level (or M shell) can hold a maximum of 18 electrons and fourth energy level (or N shell) can hold a maximum of 32 electrons.

- Each energy level (or shell) is associated with a fixed amount of energy, the shell nearest to the nucleus having minimum energy and the shell farthest from the nucleus having the maximum energy.

- There is no change in the energy of electrons as long as they keep revolving in the same energy level, and the atom remains stable. The change in the energy of an electron takes place only when it jumps from a lower energy level to a higher energy level or when it comes down from a higher energy level to a lower energy level. When an electron gains energy, it jumps from a lower energy level to a higher energy level, and when an electron comes down from a higher energy level to a lower energy level, it loses energy.

➢ Atomic number

The number of protons present in the nucleus of an atom of an element is known as its atomic number.

Ex. An atom of carbon has 6 protons so, the atomic number of carbon is 6. The atomic number is denoted by Z. Now positive charge on the nucleus is due to the presence of protons in it and each proton carries one unit of positive charge. Therefore, the atomic number of an element is equal to number of positive charges carried by the nucleus of an atom of the element.

Atomic number of an element (Z)

= Number of protons (p)

= Number of positive charges carried by the nucleus of the atom

or = Number of electrons (e)

➢ Mass number

The sum of the number of protons and neutrons in an atom of the element.

Mass number (A)

= No. of protons (p) + No. of neutrons (n)

Ex. Helium atom has 2 protons, 2 neutrons and 2 electron. Its mass number is equal to $2 + 2 = 4$.

Ex. Oxygen has 8 protons, 8 neutrons and 8 electrons. its mass number is 16.

In some cases, particularly heavier elements, the number of neutrons is more than the number of protons.

Ex. Mercury has atomic number equal to 80. So, it has 80 protons and 80 electrons. But the mass number of mercury is 200. Therefore, the number of neutrons in mercury is $200 – 80 = 120$.

Generally, an atom is represented by its symbol for the element. Atomic number is written on the lower side of the symbol and the mass number is written on the upper side.

$${}^{A}_{Z}X$$

A = Mass number

Z = Atomic number

X = Symbol of element

Ex. Indicates that lithium has atomic number equal to 3 and mass number equal to 7.

◈ **Relationship between mass number and atomic number :**

Mass number = No. of protons + No. of neutrons

Mass number = Atomic number + No. of neutrons

Ex. The atomic nucleus of an element has mass number 23 and number of neutrons 12. What is the atomic number of the element ?

Sol. We know that

Mass No. = No. of protons + No. of neutrons

23 = No. of protons + 12

∴ No. of protons = 23 – 12 = 11

Now, Atomic No. = No. of protons = 11.

Ex. Calculate the number of :

(i) electrons (ii) protons

(iii) neutrons and (iv) nucleons in

Sol. Mass No. = 39

Atomic No. = 19

(i) We know that

atomic No. = No. of protons= No. of electrons

No. of electrons = 19

(ii) No. of protons = 19

(iii) Mass No. = No. of neutrons + No. of electrons

No. of neutrons = mass number – No. of protons

= 39 – 19 = 20

(iv) Nucleons = No. of protons + No. of neutrons

= 19 + 20 = 39

➢ Electron Distribution

The distribution of electrons in different orbits or shells is governed by a scheme known as **Bohr bury scheme**.The arrangement of electrons in various energy levels of an atom is known as the electronic configuration of the atom. According to this scheme.

- The electrons are arranged around the nucleus in different energy levels or energy shells. The electrons first occupy the shell with the lowest energy i.e., closest to the nucleus.
- The first or the innermost energy shell (K or n = 1) can take only two electrons.
- The second shell (L or n = 2) can contain upto 8 electrons.
- From third shell (M or n = 3) onwards, the shells become bigger. The third shell can accommodate as many as 18 electrons. In general, the maximum number of electrons that can be present in any shell is $2n^2$ where n is the number of energy shell. Thus, the first orbit (n = 1, known as K shell) can contain

  $2 \times 1^2 = 2$ electrons, the second orbit (n = 2, known as L shell) can contain $2 \times 2^2 = 8$ electrons.

Maximum No. of electrons in different orbits

Orbit	Value of n	Maximum no. of electrons in the orbit
K	1	$2 \times 1^2 = 2$
L	2	$2 \times 2^2 = 8$
M	3	$2 \times 3^2 = 18$
N	4	$2 \times 4^2 = 32$

- The outermost shell of an atom cannot have more than 8 electrons and the shell next to the outermost shell cannot have more than 18 electrons.

(A) Valence shell

The outermost orbit of an atom is called its valence shell.

❖ Valence electrons

The electrons present in the outermost orbit are called valence electrons.

Ex. The electronic configuration of lithium is 2, 1 or it may be represented as :

K	L
2	1

the outermost orbit is L shell and the number of electrons in its valence shell is one. Only the valence electrons of an atom take part in chemical reactions because they have more energy than all the inner electrons of the atom.

(B) Valency :

Valency of an element is the combining capacity of the atoms of the element with atoms of the same or different elements.

❖ Types of valency

There are two types of valency : Electrovalency and covalency. If an element combines by the loss or gain of electrons to form electrovalent compounds (or ionic compounds), its valency is known as electrovalency, and if an element combines by the sharing of electrons to form covalent compounds (or molecular compounds), its valency is known as covalency.

- **Electrovalency :** In the formation of an electrovalent compound (or ionic compound), the number of electrons lost or gained by one atom of an element to achieve the nearest inert gas electron configuration is known as its electrovalency. The elements which lose electrons form positive ions, so they have positive electrovalency. So they have positive electrovalency. The elements which gain electrons form negative ions, so they have negative electrovalency.

- **Covalency :** In the formation of a covalent compound the number of electrons shared by one atom of an element to achieve the nearest inert gas electron configuration is known as its covalency. If an atom shares 1 electron, its covalency will be 1.

➢ Isotopes, Isobars & Isotones

(A) Isotopes

Isotopes are atoms of the same element which have the same atomic number but different mass numbers.

Ex. Hydrogen is the common example which has three isotopes. These have the same atomic number, one, but different mass numbers 1, 2, and 3. These three isotopes are commonly known as hydrogen or protium, deuterium (D) and tritium (T) respectively. Since atomic number is same for all the three, they all have one electron and therefore, one proton but different neutrons.

(1) Hydrogen At. No. = 1, Mass no. = 1

Electrons = 1, Protons = 1, Neutrons = 0

It is also represented as ${}^{1}_{1}H$

(ii) Deuterium At. No = 1, Mass no. = 2

Electron = 1, Protons = 1, Neutrons = 1

It is also represented as ${}^{2}_{1}H$ or D

(iii) Tritium At. No = 1, Mass no. = 3

Electron = 1, Protons = 1, Neutrons = 2

It is also represented as ${}^{3}_{1}H$ or T.

Isotopes of hydrogen

	Protium	**Deuterium**	**Tritium**
Atomic number, Z	1	1	1
Mass number, A	1	2	3
Number of protons	1	1	1
Number of electrons	1	1	1
Number of neutrons	0	1	2
Electronic configuration	K 1	K 1	K 1

◈ **Some important points regarding isotopes**

- Isotopes are atoms of same element having the same atomic number but different mass numbers.
- Isotopes have same number of protons and electrons but different neutrons.
- Isotopes have same electrical charge on their nuclei
- Since all the isotopes contain same number of electrons, they have same chemical properties.

There are two types of isotopes : Stable & unstable.

◈ **Radioactive isotopes :**

The isotopes which are unstable (due to the presence of extra neutrons in their nuclei) and emit various types of radiations, are called radioactive isotopes.

Ex. Some of the common radioactive isotopes are : Carbon-14, Arsenic-74, Sodium-24, Iodine-131, Cobalt-60 and Uranium-235.

◈ **Applications of Radioactive isotopes :**

Isotopes are used in alsmost all the fields such as medicines, agriculture, biology, chemistry, engineering and industry.

- Radioactive isotopes are used as a fuel in nuclear reactors of nuclear power plants for generating electricity.

Ex. Uranium-235 isotope is used as a fuel in the reactors of nuclear power plants for generating electricity.

- Radioactive isotopes are used as ‘tracers’ in medicine to detect the presence of tumors and blood clots, etc., in the human body.

Ex. Arsenic-74 tracer is used to detect the presence of tumors and sodium-24 tracer is used to detect the presence of blood clots.

- Radioactive isotopes are used to determine the activity of thyroid gland which helps in the treatment of diseases like goitre.

Ex. Iodine-131

- Radioactive isotopes are used in the treatment of cancer.

Ex. Cobalt-60 radioisotope is used to cure cancer.

- Radioactive isotopes are used in industry to detect the leakage in underground oil pipelines, gas pipelines and water pipes.

(B) Isobars

- Isobars are the atoms of different elements having same mass number but different atomic numbers.
- Since isobars have the same mass number, therefore sum of the protons and neutrons in the nucleus of each is the same. These atoms differ in their atomic number and therefore, they have different number of protons and also different number of neutrons. Due to different atomic numbers, the isobars will have different atomic structures and therefore, will differ in chemical properties.

Ex. Argon (atomic number 18) and calcium (atomic number 20) are isobars because they have same mass number 40.

Argon (${}^{20}_{18}Ar$)	Calcium (${}^{40}_{20}Ca$)
At. no. = 18,	At. no. = 20,
Mass no. = 40	Mass no. = 40
No. of electrons = 18	No. of electrons = 20
No. of protons = 18	No. of protons = 20
No. of neutrons = 22	No. of neutrons = 20

(C) Isotones

- The atoms having same number of Neutrons but diffrent mass number are called Isotones.
- The atoms have different number of protons of atomic number.
- The isotones belong to two of more different elements.
- "(A–Z) is same" "A & Z are different".

⇓	⇓	⇓
(A–Z) = 5 & 5	10	10