Chapter 4: Structure Of The Atom

Charged Particles In Matter

Charged particles are particles that have an electric charge. In general, when two objects are rubbed together, they become electrically charged. This indicates that the atom contains some charged particles or that the atom is composed of some charged particles. Electrons and protons are two such particles.

Discovery Of Electrons

By 1900, it was established that the atom was not a simple, indivisible particle but comprised at least one subatomic particle—the electron, which was discovered by 1.1. Thomson while conducting cathode ray experiments with a discharge tube.

In the experiment, a low-pressure gas was collected in a glass discharge tube. Two electrodes (metal plates) were attached to the discharge tube's ends and connected to a battery for high voltage supply.

The electrode attached to the negative end was referred to as the cathode, while the electrode connected to the positive end was referred to as the anode.

He discovered a stream of negatively charged particles, named cathode rays since they emerged from the cathode, during this experiment. Electrons were the name given to these negatively charged particles.

Electrons are charged negatively and are indicated by the symbol ' e^{-}. **An electron has a charge of −1.6 x 10^{-19} Coulomb. Due to the fact that this charge is believed to be the smallest, the charge on e^{-} is assumed to be −1. An electron has a mass of 9.1 x 10^{-3} kg.**

Discovery Of Protons

1. Although an atom is electrically neutral, the creation of cathode rays shows that all atoms include negatively charged electrons. As a result, atoms must also include some positively charged particles to balance the electrons' negative charge. This was the reason for discovering protons.
2. E. Goldstein identified the existence of new radiations known as canal rays or anode rays in 1886, before the electron's discovery. When a high voltage is put between the electrodes, these rays are visible moving from the anode to the cathode in a specially built discharge tube (with a porous cathode).
3. The porous cathode is applied to generate a route for the anode rays to travel through. It was this finding that resulted in the discovery of another subatomic particle, the proton.
4. Protons are positively charged subatomic particles represented by the symbol 'p +'. The charge on a proton is similar to $+\ 1.6 \times\ 10^{-19}$Coulomb and is thus considered to be positive. A proton has a mass of $1.6\ \times 10^{-27}$ kg. Protons have a mass roughly 2000 times that of electrons.

The Structure Of An Atom

The atom, according to Dalton's atomic theory, was indivisible and unbreakable. Now that two basic particles (electrons and protons) have been discovered within the atom, this feature of Dalton's theory has been disproved.
Numerous scientists proposed numerous atomic models in order to determine the arrangement of electrons and protons inside an atom.

Thomson's Model Of An Atom

J.J. Thomson was the first scientist to suggest an atomic model. Thomson's atomic model is like Christmas pudding. The electrons in a positively charged sphere were analogous to the currants (dried fruits) in a spherical Christmas pudding.
Additionally, it may be likened to a watermelon, in which the positive charge in an atom is distributed evenly through, similar to the red edible part, while the electrons are contained in the positively charged sphere, similar to the seeds in a watermelon.

- Electrons are encased in a positively charged sphere.
- The magnitudes of the negative and positive charges are equal. As a result, the atom is electrically neutral.
- It is thought that an atom's mass is equally distributed across the atom.

Limitations Of Thomson's Model Of An Atom

1. Thomson's model could not account for the experimental findings of other scientists, such as Rutherford, since Thomson's atomic model lacked a nucleus.
2. It cannot explain an atom's stability, i.e. how positive and negative charges may exist so close together.

Rutherford's Model Of An Atom

Ernest Rutherford conducted an experiment to determine the arrangement of electrons inside an atom. He blasted a thin sheet of gold foil with rapidly moving a-particles (these are doubly charged helium ions with a mass of (4 u).
He chose gold foil because he desired a covering that was as thin as possible. The thickness of this gold foil was around 1000 atoms.

Rutherford made the following observations:

1. The majority of the high-speed a-particles passed directly through the gold foil.
2. The foil deflected a few of the a-particles at tiny angles.
3. A very small number of a-particles (one in 12000) seemed to rebound.

Rutherford determined the following based on his experiment:

1. The majority of space within the atom is unfilled since the majority of a-particles went through the gold foil undeflected.
2. Only a few particles were diverted off their course, showing that the atom's positive charge occupies a little space.
3. An extremely tiny percentage of a-particles deflected 180° (i.e. rebounded), showing that the atom's entire positive charge and mass were concentrated in a very small volume.

Rutherford created the nuclear model of an atom based on his experiment, which has the following characteristics:

1. In an atom, there is a positively charged, very dense centre called the nucleus. The nucleus contains almost all of the atom's mass.
2. The electrons follow a circular route around the nucleus.
3. The nucleus is very tiny (10^{-15} m) in comparison to the atom ($10^{-1°}$ m).

Limitations Of Rutherford's Model Of An Atom

Rutherford's model of an atom has the following limitations:

1. When accelerated, every charged particle is predicted to radiate energy. The electron would have to accelerate in order to maintain a circular orbit.

As a result, it would radiate.Thus, the spinning electron would lose energy and finally fall into the nucleus. If this is the case, then the atom should be very unstable.
As a result, matter would not exist, yet we know it does. This indicates that atoms are very stable. Thus, it cannot account for an atom's stability when charged electrons are travelling in the direction of the positively charged nucleus.

2. Rutherford's model could not account for the distribution of electrons in the atom's extranuclear region.

Bohr's Model Of An Atom

To address the criticisms levelled against Rutherford's atomic model, Neils Bohr advanced the following postulates concerning the atomic model:

1. The atom is made up of a positively charged nucleus around which electrons orbit in defined orbits, that is, electrons orbit in particular allowable orbits and not in any orbit.
2. Each of these orbits is connected with a certain energy value. As a result, these orbits are referred to as energy shells or levels of energy. Because an orbit's energy is constant (stationary), it is sometimes referred to as a stationary state.
3. The lowest energy electrons are found in the first energy level (E_1). Energy levels grow as they approach the outer energy levels.
4. Beginning with the nucleus, energy levels (orbits) are represented numerically (1, 2, 3, 4, etc.) or alphabetically (K, L, M, N etc.).
5. An electron's energy stays constant as long as it remains in a defined orbit and does not radiate energy while rotating.
6. When an electron receives energy, it may go to higher energy levels. While an electron descends When it radiates energy, it has a lower energy level.

Neutrons (N)

J. Chadwick discovered the neutron, another subatomic particle, in 1932. It is denoted by n. Neutrons are electrically neutral particles that weigh the same as protons (1.67493 x 10^{-27} kg), the same as a proton.
All atoms except hydrogen have neutrons in their nucleus. The mass of an atom is calculated by adding the masses of the protons and neutrons contained inside the nucleus.

Distribution Of Electrons In Different Orbits (Shells)

Bohr and Bury proposed that electrons are distributed across the many orbits of an atom. Certain principles are followed when expressing the amount of electrons in various energy levels or shells.

These include the following:

1. The maximum number of electrons in a shell is determined by the formula $2n^2$, where n denotes the orbit number or energy level, which may be 1, 2, 3, or 4.

As a result, the maximum number of electrons allowed in each shell is as follows:

First orbit or K-shell = $2X(1)^2 = 2$

Second orbit or L-shell = $2x(2)^2 = 8$

Third orbit or M-shell = $2x(3)^3 = 18$

Fourth orbit or N-shell = $2x(4)^4 = 32$ *and so on.*

2. The outermost orbit may hold a maximum of eight electrons.
3. Electrons cannot be contained inside a shell until the inner shells are completely filled (i.e. the shells are filled in a stepwise manner).

Valency

The electrons in an atom's outermost shell are referred to as valence electrons. They are in charge of atoms' chemical characteristics. Atoms of elements with a totally filled outermost shell have little chemical activity, i.e. they are very stable. These are referred to as inert elements.
This indicates that their valency is zero. Helium has two electrons in its outermost shell, whereas the other inert elements have atoms with eight electrons in their outermost shell.
The ability of atoms of the same or different elements to react and form molecules is an effort to fill the outermost shell completely. This implies that atoms react with one another in order to form a completely filled outermost shell. An octet is a phrase that refers to the outermost shell that contains eight electrons.
Thus, atoms would react to form an octet in the outermost shell.This was achieved by the sharing, gaining, or loss of electrons. The amount of electrons lost or gained or shared by an atom in order to attain stability or an octet in the outermost shell is referred to as the element's valency.
In other words, it is the ability of an element's atom to combine with the atom(s) of another element(s) to complete its octet.

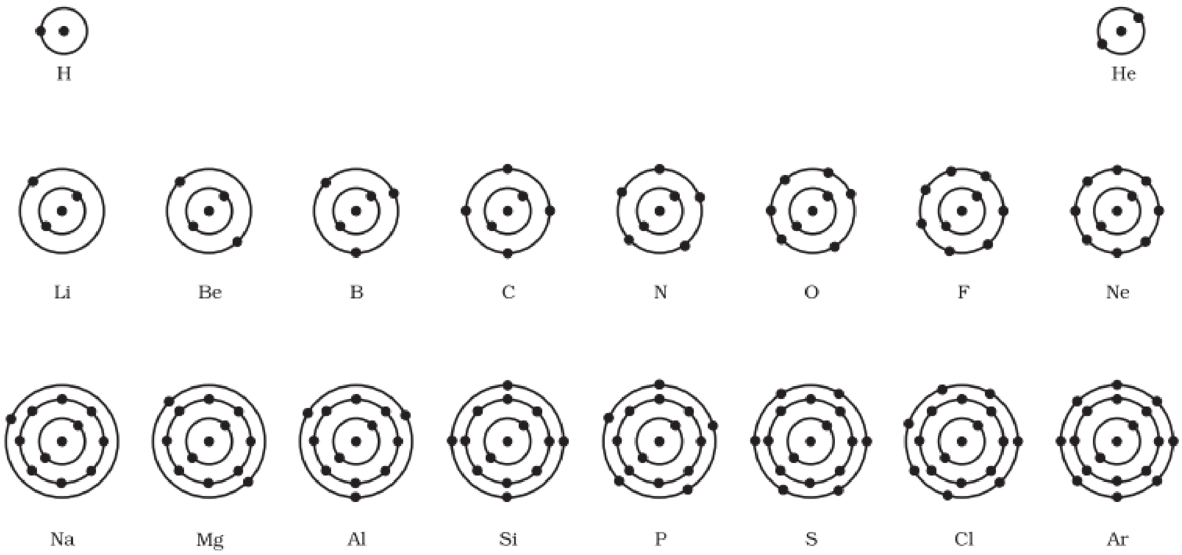

***Fig.4.4:** Schematic atomic structure of the first eighteen elements*

The following table describes the valencies of certain groups' elements:

- One electron is included in the hydrogen (H), lithium (Li), sodium (Na), and potassium (K) atoms.
- Each of them is in their outermost shell, and so each of them may lose one electron in order to become stable. As a result, their valency is 1.
- Mg, Ca, and Be all have two valence electrons and may lose these two electrons to form an octet of electrons in the outermost shell or to become stable.
- Boron and aluminium both have a valency of three due to their three valence electrons.
- Carbon and silicon both have a valency of four due to their four valence electrons.
- Nitrogen and phosphorus both have five valence electrons and hence have a valency of three since they may acquire three electrons (rather than losing five electrons) to become stable. As a result, their valency is calculated by deducting five electrons from the octet, i.e. $8 - 5 = 3$. However, P may also share five electrons, giving it a valency of five in addition to three.
- Each of oxygen and sulphur has six valence electrons; hence, their valency is two, since they may either gain or share two electrons to complete their octet.
- Similarly, fluorine and chlorine each have seven valence electrons; their valency is one due to their ability to obtain or share one electron to complete their octet.
- All inert elements, such as He, Ne, and Ar, have entirely occupied their outermost shells. As a result, their valency is equal to zero.

Atomic Number And Mass Number

Atomic Number : It is defined as the number of protons in an atom's nucleus. Each atom of the same element has the same number of protons in its nucleus, giving it the same atomic number. Z and is signified by a subscript to the left of the symbol. Examples, ${}^{4}_{2}He$, ${}^{7}_{3}Li$, where Z equals 2 and 3 for He and Li, respectively.

Mass Number : It is defined as the sum of the protons and neutrons in an atom's nucleus. Nucleons are made up of protons and neutrons. A is used to signify the mass number. The mass number (A) is equal to the sum of the protons and neutrons. For example, ${}^{4}_{2}He$, ${}^{7}_{3}Li$ where A equals 4 and 7 for He and Li, respectively.

Number of neutrons = Mass number – atomic number

(Atomic number = Number of protons)

To the left of the symbol, the mass number is represented as a superscript.

Different Atomic Species

Isotopes

1. These are classified as identical atoms of the same element with different mass numbers. For instance, there are three isotopes of the hydrogen atom: protium (${}^{1}_{1}H$), deuterium (${}^{2}_{1}H$), and tritium (${}^{3}_{1}H$).
2. In other words, isotopes have the same amount of protons but the change in their neutron count. Each element's isotope is a pure substance.
3. Due to the fact that the chemical characteristics of elements are highly dependent on their electronic configuration, or outermost electrons, and since isotopes of an element have similar electron configurations, isotopes of an element have comparable chemical properties.

4. We are aware that the masses of isotopes of elements vary. Because physical characteristics like density, light scattering, and so on are mass-dependent, they differ across isotopes of an element.

Average Atomic Mass

1. If an element has no isotopes, the mass of an atom is equal to the sum of the masses of its protons and neutrons.
2. However, if an element exists in isotopic forms, the average mass is determined as follows:

Average atomic mass of an element [(Atomic mass of isotope I x percentage of isotope I) + (Atomic mass of isotope II x percentage of isotope II)+...]

The two isotopic forms of chlorine atom with masses 35u and 37u occur in the ratio of 3 : 1.

Applications Of Isotopes

1. A chemical element of uranium (U-235) is used as a fuel in nuclear reactors to generate energy.
2. U-238 is used to calculate the age of rock formations and even the world.
3. A cobalt isotope (Co-60) is used to treat cancer.
4. Carbon isotopes (C-14) are used to assess the age of old wood specimens and fossilised bones of living animals.
5. Iodine isotope (I-131) is used to treat goitre.

Isobars

Isobars are atoms of various elements with various atomic numbers but the same mass number. In other words, isobars are atoms of different elements that share the same amount of nucleons (protons + neutrons) but vary in their proton count. ${}^{40}_{18}Ar$ and ${}^{40}_{20}\mathrm{ca}$, for example, are isobars.

Due to the fact that isobars have a different atomic number and electrical structure. As a result, their chemical nature is also different.