Structure Of Atom

6.1 Discovery of Subatomic Particles

You have learnt about the development of models of the structure of the atom. You would recall that in 1803, Dalton proposed that atoms are the smallest indivisible particles of matter. However, this idea could not explain the results of several experiments. For example, it was observed that substances like glass or ebonite, when rubbed with silk or fur, acquire electric charge. This and many other experiments on electrical discharge through gases showed that atoms are not indivisible. They are made up of smaller particles called subatomic particles.

J. J. Thomson, in 1897, discovered the electron as a constituent of the atom and confirmed that the atom is not the smallest particle of matter. He proposed the so-called plum-pudding model of the atom, in which electrons are embedded in a sphere of positive charge. This model was later shown to be incorrect by Rutherford, as it could not explain the results of the gold foil experiment. Rutherford then proposed a model in which electrons revolve around a small, positively charged nucleus. However, this model could not explain the stability of the atom. Thereafter, another model was proposed by Niels Bohr.

Here, you will learn about the discovery of the subatomic particles—electron, proton, and neutron—which contribute to our understanding of atomic structure. Before discussing these exploration we must recall a basic principle: like charges repel each other, while unlike charges attract each other.

6.1.1 Discovery of Electron

In the late nineteenth century, many scientists, including Michael Faraday, William Crookes, and others, studied electrical discharge in partially evacuated tubes known as cathode ray discharge tubes. J.J Thomson carried out experiments by taking gases at low pressure in discharge tube which is a long glass tube in which two metal plates connected to oppositely charged poles of battery (Fig 1)

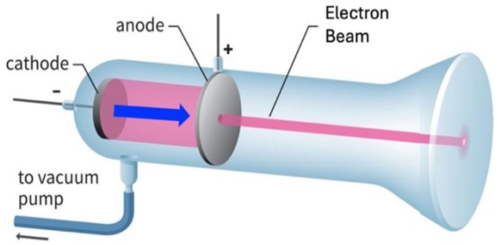

Fig. 6.1: A schematic representation of cathode ray tube showing the cathode rays going from the cathode to anode in a straight line

When a sufficiently high voltage is applied across the electrodes, rays are observed to travel from the negatively charged electrode (cathode) towards the positively charged electrode (anode). (Fig 2)

These are called cathode rays. The presence of these rays can be detected by allowing them to pass through a hole in the anode and strike at screen coated with a special material placed behind it. A bright spot is observed on the screen, indicating that the rays travel in straight lines.

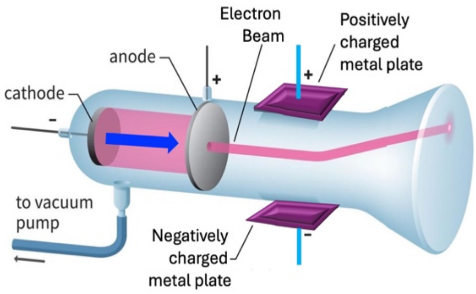

Fig.6.2: A schematic representation of the deflection of cathode rays to positive plate of the applied electric field.

Further to determine the nature of these rays, Thomson carried out experiments by applying electric and magnetic fields in the path of the rays. He observed that the rays were deflected towards the positively charged plate.

This showed that the particles in the rays carry negative charge on further experimentation. Thomson concluded that cathode rays consist of tiny negatively charged particles, later called electrons.

When these experiments were repeated using different gases (such as hydrogen, nitrogen, neon, etc.) and different electrode materials, it was found that the properties of cathode rays remained unchanged. This showed that electrons are present in all atoms.

The main characteristics of cathode rays are as follows:

- They originate from the cathode and move towards the anode.
- They are not visible themselves but produce bright spot when they strike certain materials.
- They travel in straight lines in the absence of external fields.
- They are deflected by electric and magnetic fields in such a way that indicates them to be negatively charged.
- Their properties do not depend on the nature of the gas or the electrode material.

Thus, electrons are a fundamental constituent of all atoms.

6.1.2 Discovery of Protons

After the discovery of the electron, it was realised that since electrons are negatively charged, atoms must also contain positive charge to maintain electrical neutrality.

Eugen Goldstein, in 1886, performed experiments using a discharge tube similar to that used for cathode rays, but with a cathode having holes in it (perforated cathode). When high voltage was applied, a faint glow was observed behind the cathode. The rays responsible for this glow passed through the holes (or canals) in the cathode and were therefore called canal rays.

Further studies showed that these rays were deflected towards the negatively charged plate in electric and magnetic fields, indicating that they consist of positively charged particles.

However, it is important to note that canal rays are not made up of a single type of particle. They consist of positively charged ions of the gas present in the tube. Therefore, their properties depend on the nature of the gas used.

When hydrogen gas was used in the discharge tube, the positively charged particles obtained were the lightest known and were identified as hydrogen ions (H^+). These particles were later recognised as protons. The proton was finally established as a fundamental particle by Rutherford in 1919.

The main characteristics of canal rays are:

- They are positively charged.
- Their behaviour in electric and magnetic fields is opposite to that of electrons.
- Their properties depend on the nature of the gas present.
- The lightest positive particle was obtained from hydrogen and is called the proton.

6.1.3 Discovery of Neutrons

Once electrons and protons were known, it appeared that the structure of the atom was understood. However, another problem arose when atomic masses were measured. The mass of atoms was found to be greater than the sum of the masses of their protons and electrons. For example, helium contains two protons, yet its mass is about four times that of hydrogen. This indicated the possibility of the presence of another particle contributing to the mass of the atom.

It was proposed that there must be a neutral particle present in the atom. This particle was discovered by James Chadwick in 1932. He bombarded a thin sheet of beryllium with alpha particles and observed the emission of powerful neutral radiation. This radiation consisted of particles having no charge and a mass nearly equal to that of the proton. These particles were called neutrons.

Neutrons are present in the nuclei of almost all atoms. The most common isotope of hydrogen that does not contain a neutron is protium ($_1H^1$) but its heavier isotopes Deuterium ($_1H^2$) and Tritium ($_1H^3$) contains neutrons.

Thus, the presence of neutrons explains the mass of atoms. For example, helium contains two protons and two neutrons, which accounts for its mass being approximately four times that of hydrogen.

Chadwick was awarded the Nobel Prize in Physics in 1935 for the discovery of the Subatomic particle neutron.

From these discoveries, it became clear that atoms are composed of three subatomic particles:

- Electrons (negative charge)
- Protons (positive charge)
- Neutrons (no charge)

These particles together determine the structure and properties of atoms.

Quick Check:

1. Why do cathode rays bend towards the positive plate?
2. What conclusion did Thomson draw from using different gases in discharge tubes?
3. Why are canal rays different from cathode rays in nature?
4. Why was the discovery of neutron necessary?
5. In a cathode ray experiment, it was observed that the rays bend towards a positively charged plate. What can we conclude about the nature of these rays?
6. In a discharge tube experiment, the gas is changed from hydrogen to neon, but the behaviour of cathode rays remains unchanged. What does this observation tell us about electrons?
7. If cathode rays were neutral instead of being negatively charged, how would their behaviour differ in an electric field?
8. In an experiment with canal rays, different gases are used and different masses of particles are observed. What conclusion can be drawn about the nature of canal rays?

9. Why did scientists feel the need to propose the existence of neutral particles even after discovering electrons and protons? Explain using the example of helium.
10. In Chadwick's experiment, the emitted particles were not deflected by electric or magnetic fields. What does this observation indicate about the nature of these particles?

6.2. Spectrum

When white light passes through a glass prism, what do we observe? We see a rainbow, that consists of a continuous spread of many colours from violet to red (VIBGYOR). Such a spread is called a **continuous spectrum** in which the colours are present without any gap.

Fig 6.3 Continuous Spectrum

Now, suppose we take a sodium vapour lamp, which you would have seen at street lights or in parks, and pass the 'yellow light' given out by it, through a prism. We find that we do not get all the colours but only a few bright coloured lines. Two of these are intense yellow lines. We may do a similar experiment with mercury vapour lamp and observe another set of distinct lines. Such a spectrum that contains distinct lines is called a **line spectrum**.

Fig 6.4 (a) Sodium vapour lamp

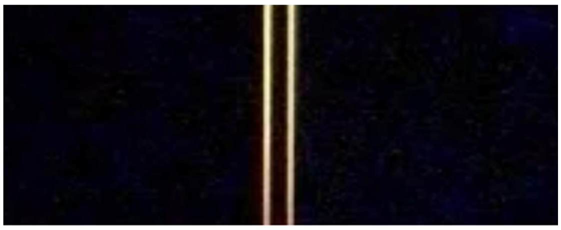

Fig 6.4 (b) Lines Spectrum of Sodium

Line spectrum means only specific radiation are emitted, not all. It is important to know that the line spectrum is characteristic of the element causing it. This fact is used to identify elements present in stars by studying their spectra. Even without going to the star, we can know what it is made of.

6.3 Line Spectrum of Hydrogen

Now, when the radiation from a discharge tube containing hydrogen gas in it is passed through a prism, it also gives line spectrum called **hydrogen atom spectrum**.

The Spectral lines for atomic hydrogen are:

Series	**n_i**	**n_f**
Lyman	1	2,3_ _ _ _ _
Balmer	2	3,4_ _ _ _ _
Paschen	3	4,5_ _ _ _ _
Brackett	4	5,6_ _ _ _ _
Pfund	5	6,7_ _ _ _ _

The energies of the distinct spectral lines observed in hydrogen atom spectrum could be expressed empirically in terms of mathematical expressions involving two sets of integers. This equation is known as Rydberg Equation.

$$\Delta E = R_E Z^2 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right),$$

$R_E = 109{,}677\ cm^{-1}$

Where, R_E is the Rydberg constant expressed in terms of energy and Z is the atomic number. These empirical formulas worked very well but could not be explained until Bohr's model came.

6.4 Limitation of Rutheford Model of Atom

- Rutherford could not explain stability as the electron continuously loses energy when it moves around the nucleus.
- As the electron in the atom is allowed to have continuous energies, therefore the emitted radiation is expected to give a continuous set of radiation. However, we observe a line spectrum. Therefore, we say that Rutherford's model fails to explain the existence of line spectrum of hydrogen.

6.5 Bohr's model

Neils Bohr, a student of Rutherford, in 1913 proposed his model for an atom. He combined Rutherford's nuclear model with the new quantum idea introduced by Max Planck. He made two revolutionary assumptions which are as below:

- Electrons can move only in certain allowed circular orbits without radiating energy. That is, they have a fixed energy as long as they are in a given orbit.
- The radiation is emitted or absorbed only when an electron jumps from one allowed orbit to another,

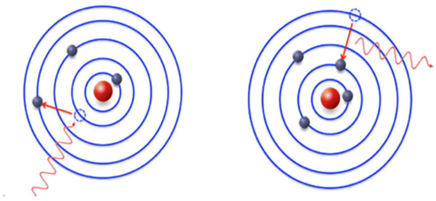

Fig 6.5:Energy change is electron jump

6.5.1 Achivement of Bohr Model

"When an electron jumps from an orbit of higher energy to that of a lower energy it releases energy in the form of radiation. The amount of energy released depends on the difference in the energies of the two levels. Since the orbits of only certain energies exist, only of fixed quantity energy differences are possible. Therefore, we get a line spectrum. Bohr's model could explain the observed line spectrum of hydrogen fairly well.

6.5.2 Limitations of Bohr's model

Bohr model was unable to explain:

- Finer details (that is closely spaced lines) of hydrogen atom spectrum observed by sophisticated spectroscopic techniques.
- The spectrum of atom other than hydrogen.
- The splitting of spectral lines in presence of magnetic field (Zeeman effect) or an electric field (Stark's effect).

6.6 Check Your Understanding

1. The hydrogen spectrum consists of only a few sharp spectral lines instead of a continuous spectrum. What information does it provide about the energy of electrons in an atom.
2. Explain why would Rutherford's model predict a continuous spectrum rather than a line spectrum.
3. A discharge tube filled with an unknown gas produces a line spectrum identical to hydrogen. What can you conclude about the gas? Give reason.
4. If electrons in an atom were allowed to have a continuous set of energy values, what kind of spectrum would you expect? Why is this not observed?
5. "Bohr's model solved all problems of atomic structure." Comment.
6. How does the concept of fixed energy levels explain the stability of atoms?

7. Why do different elements produce different line spectra? Give a conceptual explanation.
8. Explain why Bohr's model works well for hydrogen but not for multi-electron atoms.
9. State two limitations of Rutherford's model.
10. Rutherford's model explained the structure of the atom but failed to explain atomic stability and spectra. Discuss.
11. What was the main drawback of Rutherford's model regarding electron motion? What assumption was made by Bohr to overcome this problem.
12. How does Bohr's model explain line spectrum of hydrogen?
13. Outline the limitations of Bohr's model.
14. Define line spectrum and continuous spectrum with one example each.
15. Write two main postulates of Bohr's model.
16. What is meant by fine structure in hydrogen spectrum?
17. What is the significance of Rydberg equation?