UNIT 2

STRUCTURE OF ATOM

The existence of atoms has been proposed since the times of early Indian and Greek philosophers around 400 B.C. An Indian philosopher Maharishi Kanad postulated that if we go on dividing matter (*padarth*), we shall ultimately get smallest particle beyond which further division will not be possible. He named these particles as **parmanu.** Around the same era, ancient Greek philosophers Democritus and Leucippus suggested that if we go on dividing matter, a stage will come when particles obtained cannot be divided further. Democritus called these particles as atoms. The word 'atom' has been derived from the Greek word '**a-tomio**' meaning **uncutable** or **non-divisible**. However, all these ideas were based on philosophical considerations and not much experimental work to validate these ideas could be done till the 18th century.

The first definite theory about the structure of matter was put forward by John Dalton, a British school teacher in 1808. His theory called **Dalton's atomic theory** regarded atom as the ultimate particle of matter. According to his theory, all matter are composed of extremely small particles called **atoms.** The atoms were regarded to be structureless, hard spherical particles. The Dalton's atomic theory remained undisputed upto the end of 19th century. However, the discoveries towards the end of 19th and early 20th centuries showed that atom has a complex structure and is not indivisible. These studies further revealed that atom consists of still smaller particles such as ***electron, proton*** and ***neutron,*** into which it may be divided. These particles are regarded as **fundamental particles** because these are the main constituents of all atoms.

IN THIS UNIT..........

SUBATOMIC PARTICLES

The Dalton's atomic theory was able to successfully explain the laws of chemical combinations. However, many experimental observations made by scientists towards the end of nineteenth and beginning of twentieth century showed that atoms have an internal structure consisting of subatomic particles. Many different kinds of subatomic particles were discovered in the twentieth century. Let us briefly review historical development for the discovery of these fundamental particles.

Discovery of Electron

The electrical nature of matter has been known from ancient times. For example, it was known that glass or ebonite rod when rubbed with silk or fur generate electricity. In 1830, Michael Faraday gave the first important clue about the electrical nature of matter. He observed that when electricity is passed through a solution of an electrolyte, chemical reactions occurred at the electrodes, which resulted in the liberation and deposition of matter at the electrodes. This phenomenon is called **electrolysis.** He formulated certain laws known as **Faraday's laws of electrolysis**, which you will study in Class XII.

The importance of Faraday's laws lies in the fact that Faraday suggested the relationship between electricity and matter for the first time. Later on, in 1874, Stoney pointed out that like matter, electricity is composed of small discrete units of electricity. He proposed the name ***electron*** for these discrete units of electricity. However, the discovery of electron came as a result of experiments on conduction of electricity through gases as described below.

Studies of Cathode Rays : Discharge tube experiments

The electron was discovered by J.J. Thomson at the end of 19th century during the studies of the passage of electricity through gases at extremely low pressures. These experiments were known as ***discharge tube experiments***. Under ordinary conditions, gases are poor conductors of electricity. However, when a high voltage is applied to them at very low pressures, the gases become conductors and electricity begins to flow in the form of rays. These rays are called **cathode rays.** The existence of these rays was shown by scientists like Plucker, Crookes, etc., but the main credit goes to J.J. Thomson. He studied the properties of cathode rays in detail which led to the discovery of an electron.

The experiment in its simplest form consists of a cylindrical hard glass tube (about 50 cm long) closed at both ends [Fig.1]. It is known as **discharge tube** or **Crookes tube.** It is fitted with two metallic electrodes. The tube is connected to a side tube, through which it can be evacuated to any desired pressure with the help of a vacuum pump. The discharge tube is filled with the gas under study and the two electrodes are connected to a source of high voltage. During these experiments, the following observations are made :

(*i*) When the discharge tube contains any gas at normal pressure, nothing is observed even by applying high voltage (5,000 –10,000 V) between the electrodes. The gas remains non-conducting.

(*ii*) The pressure of the gas inside the tube is decreased by pumping out the gas with the help of a vacuum pump. When the pressure of the gas is decreased to about 10^{-2} atm (about 1 mm to 10 mm of Hg), the gas becomes conducting and light is emitted by the residual gas in the tube. The colour of the light depends upon the nature of the gas taken.

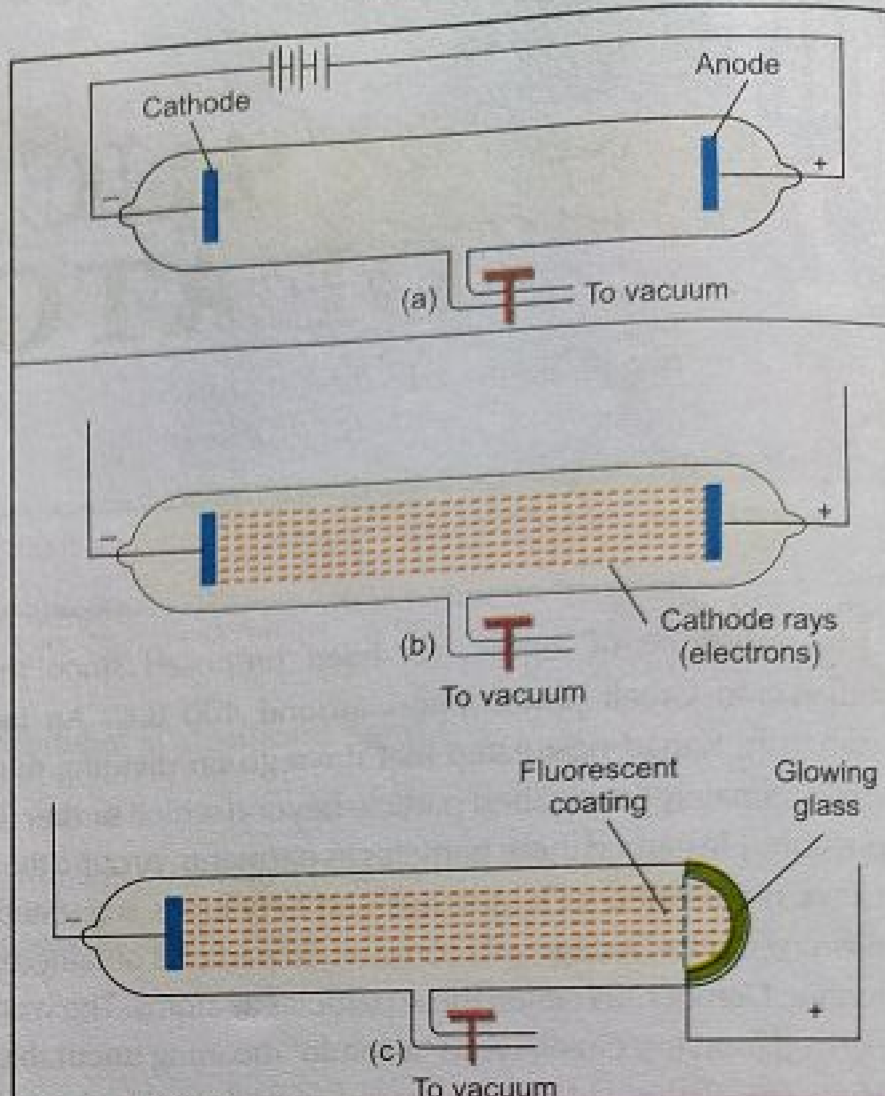

Fig. 1. Discharge tube experiments (*a*) Discharge tube containing a gas. (b) Emission of light (dotted portion in the figure) when the pressure of the gas is reduced to 10^{-2} atm. (c) Glowing of the glass at the anode end when the pressure is reduced to 10^{-4} atm.

(*iii*) When the pressure of the gas in the discharge tube is further reduced, the glow becomes weak. At about 10^{-4} atm pressure (about 0.01 mm of Hg), the glow between the electrodes disappears but the gas continues to conduct electricity. Moreover, if a perforated anode is used, a faint greenish glow is observed on the glass wall behind the anode.

It was discovered that the glowing of the tube is due to the bombardment of the glass by certain rays emitted from the cathode. These rays moved from the cathode towards the anode in the form of streaks of light. The flow of current from cathode to anode was further checked by making a hole in anode and coating the tube behind anode with fluorescent material zinc sulphide. When these rays after passing through anode strike the zinc sulphide coating, a bright spot on the coating is developed (same thing happens in a television set). These rays were named **cathode rays** because they originate from the cathode.

Nature of Cathode Rays

The following experiments help in understanding the nature of cathode rays :

1. *The cathode rays travel in straight lines.* These rays start from cathode and move towards anode. Whenever an object is placed inside the tube, it casts a shadow on the wall opposite to the cathode (Fig. 2) During this experiment, the gas fluoresces only in regions outside the shadow. This experiment showed that the *cathode rays travel in straight lines.* Further, since the shadow falls on the wall opposite to the cathode, it shows that *the rays travel from cathode towards the anode.*

Fig. 2. Cathode rays cast shadow of the object placed in the path.

2. *These rays themselves are not visible* but their behaviour can be observed with the help of certain kinds of materials (fluorescent or phosphorescent) which glow when hit by them. It may be remembered that television tubes are also cathode tubes and television pictures result due to fluorescence on the television screen coated with certain fluorescent or phosphorescent materials.

3. *Cathode rays produce* ***mechanical effects***. For example, when a small paddle wheel is placed between the electrodes, it starts rotating. [Fig. 3]. This indicates that the *cathode rays consist of material particles* and produce mechanical effects.

Fig. 3. Cathode rays rotate the light paddle wheel.

4. In the absence of electrical or magnetic fields, these rays travel in straight lines. *When electric and magnetic fields are applied to the cathode rays in the discharge tube, the rays are deflected, thus establishing that they consist of charged particles.* The direction of the deflection shows that the charge was negative as shown below :

(*i*) **Effect of electric field.** The effect of electric field on the cathode rays was studied by J. J. Thomson in 1897. When the beam of cathode rays is allowed to pass between electrically charged plates (Fig. 4), these are deflected towards the positively charged plate. This shows that the particles in the cathode rays carry negative charge.

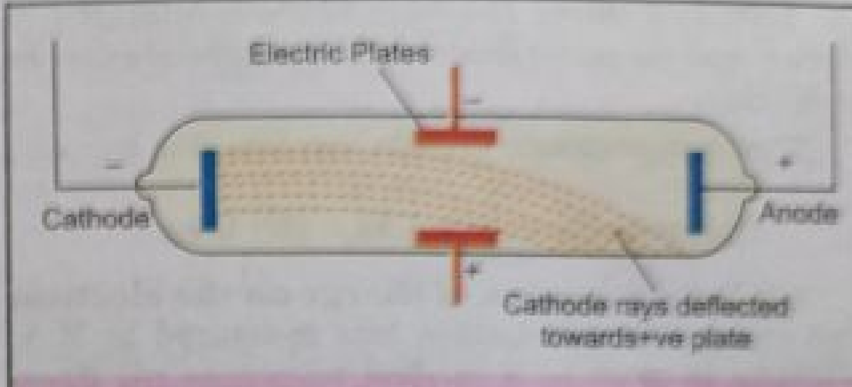

Fig. 4. Deflection of cathode rays in an electric field indicating negative charge on its particles.

(*ii*) **Effect of magnetic field.** When the cathode rays are made to pass through a magnetic field, these are deflected in the direction corresponding to the presence of the negative charge on the particles. This is shown in Fig. 5

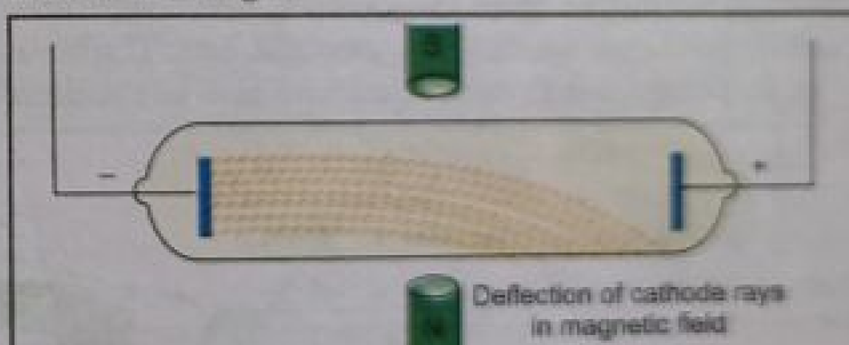

Fig. 5 Deflection of cathode rays in a magnetic field

5. When the cathode rays are allowed to strike a thin metal foil, it gets heated up. Thus, the *cathode rays possess heating effect.*

6. The cathode rays produce X-rays when they strike against hard metals like tungsten, copper, etc.

7. The cathode rays upon striking glass or certain other materials cause them to glow (produce fluorescence).

8. The cathode rays penetrate through thin sheets of aluminium and other metals.

9. The cathode rays affect the photographic plates.

10. The characteristics of cathode rays do not depend upon the nature of electrodes and the nature of gas present in the cathode rays. ***The ratio of charge to mass i.e., charge /mass is same for all the cathode rays irrespective of the gas used in the tube.***

All these observations led to the conclusion that cathode rays consist of negatively charged particles. These charged particles constituting the cathode rays were named **electrons**.

Charge and Mass of Electron

(*i*) Determination of charge to mass ratio (*e*/*m*) of electrons

In 1897, J.J. Thomson determined the ratio of the charge (e) of the electron to its mass (m) by measuring the deflection under the simultaneous influence of electric and magnetic fields, applied perpendicular to each other.

The charge/mass ratio, e/m was found to be:

$$\text{Charge/mass} = \frac{e}{m} = 1.76 \times 10^{11}\ \text{C/kg}$$

(*ii*) Determination of charge on the electron
The charge on the electron was measured by R.A. Millikan in 1909 by a method known as **oil drop method.** The charge on the electron was found to be

$$\text{Charge} = \text{E} = 1.60 \times 10^{-19}\ \text{C (Coulomb)}$$

Calculation of the mass of the electron. From the values of e/m and e, the mass (m) of the electron was determined by dividing e by e/m. Thus,

$$\text{Charge/mass } (e/m) = 1.76 \times 10^{11}\ \text{C kg}^{-1}$$

$$\text{Charge } (e) = 1.60 \times 10^{-19}\ \text{C}$$

$$\text{Mass of electron } (m) = \frac{e}{e/m} = \frac{1.60 \times 10^{-19}\text{C}}{1.76 \times 10^{11}\text{C kg}^{-1}}$$

$$= 9.10 \times 10^{-31}\text{kg}$$

The mass of the electron is much smaller than the mass of an atom of hydrogen. It has been found that the mass of an electron is approximately 1/1837th* (or 5.45×10^{-4} times) the mass of an atom of hydrogen. However, *this mass is very small and for all practical purposes, it may be taken as negligible.* The charge of the electron is the smallest known electrical charge and is usually referred to as *unit negative charge.*

Thus, an **electron** may be defined as

a sub-atomic particle which carries one unit negative charge (1.6022×10^{-19} C) and has a mass (9.10×10^{-31} kg) equal to 1/1837th of that of hydrogen atom.

LEARNING PLUS

❑ Thomson's Experiment for Determination of Charge/Mass (e/m) of the electron

The apparatus is shown in Fig. 6. A high potential is maintained between the cathode and the anode. Electrons emitted from the cathode are accelerated by the high voltage. The circular disc after the anode selects the beam moving in a straight line. The beam then passes through electric and magnetic fields which are perpendicular to each other and also to the direction of the motion. Thomson suggested that the amount

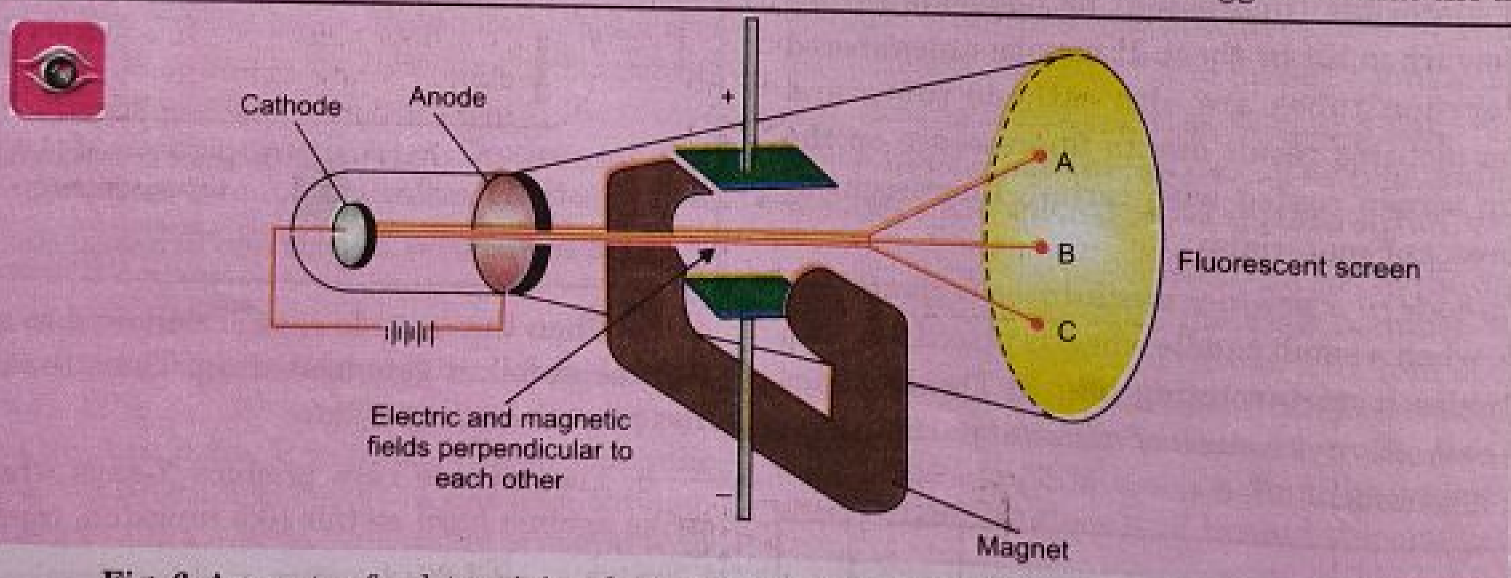

Fig. 6. Apparatus for determining the ratio of electric charge (e) to mass (m) of electrons.

* Mass of an electron relative to that of hydrogen atom can be easily calculated from the fact that the number of atoms in one gram atom of any element is 6.022×10^{23} (Avogadro number). Therefore,

$$\text{1 Gram atom of hydrogen} = 1.008\ \text{g}$$

$$6.022 \times 10^{23}\ \text{atoms of hydrogen weigh} = 1.008\ \text{g}$$

$$\text{One atom of hydrogen weighs} = \frac{1.008}{6.022 \times 10^{23}} = 1.674 \times 10^{-24}\ \text{g or } = 1.674 \times 10^{-27}\ \text{kg}$$

$$\text{Now, mass of electron} = 9.1094 \times 10^{-31}\ \text{kg (exact value)}$$

$$\therefore \frac{\text{Mass of one atom of hydrogen}}{\text{Mass of electron}} = \frac{1.674 \times 10^{-27}\text{kg}}{9.1094 \times 10^{-31}\text{kg}} = 1837$$

Thus, an atom of hydrogen is 1837 times heavier than an electron or an electron has a mass which is about 1/1837[th] (or 5.45×10^{-4} times) the mass of an atom of hydrogen.

deviation of the particles from their path in the presence of electrical and magnetic fields depends upon the following :

(i) **Magnitude of the negative charge on the particles**. Greater the magnitude of the charge on the particles, greater is the interaction with the electric or magnetic field and therefore, greater is the deflection.

(ii) **Mass of the particles.** The extent of deviation depends upon the mass of the particles. Lighter the particles greater is the deflection.

(iii) **Strength of electrical and magnetic field**. The deflection of the particles from their original path increases with the increase in the voltage across the electrodes or strength of the magnetic field.

When only electric field is applied, the electrons deviate from their path and hit the cathode ray tube at point A. Similarly, when only magnetic field is applied, electrons deviate from their path and hit the cathode ray tube at point C. By carefully balancing the electrical and magnetic field strength, it is possible to bring back the electron to the path followed as in the absence of electric or magnetic field and they hit the screen at point B. By carrying out accurate measurements on the deflections observed by electron on the electric field strength or magnetic field strength, Thomson was able to calculate the value of charge / mass ratio *i.e,* e/m. The value of e/m was found to be

$$e/m = 1.758820 \times 10^{11}\ \text{C kg}^{-1}$$

or

$$= 1.76 \times 10^{11}\ \text{C kg}^{-1}$$

where m is the mass of electron in kg and e is the magnitude of the charge on the electron in Coulombs (C). Since electrons are negatively charged, the charge on electron is negative, $-e$.

The relative strengths of electric and magnetic fields and the ratio e/m control the deflections. Hence, by measuring the deflection and the field strength, e/m can be calculated.

❑ Determination of charge on the electron.

The charge on the electron was measured by R.A. Millikan in 1909 by a method known as **oil drop method.** The apparatus used is shown in Fig 7. Small drops of oil in the form of mist are formed by a sprayer and these are allowed to fall in between two metal plates, which could be electrically charged. A single drop between the plates is observed by means of a telescope equipped with a micrometer eye piece. The oil in the form of mist drop falls through the air under the influence of gravitational force. He then irradiated the space between the plates with X-rays. These knocked electrons out of some of the molecules of the air and some of these electrons, were caught by oil droplets which acquired electrical charge. By charging the upper plate positive and the lower plate negative, the oil drop experiences electric field in the upper direction. By adjusting the electrical field strength, the upward electrical field on the oil droplet was balanced against the downward gravitational force. Under these conditions, the drop remains stationary. From the amount of charge on the plates and the mass of the droplet, the charge on the droplet was determined. The mass of the droplet was determined from the rate of fall of droplet through the air when the plates were uncharged.

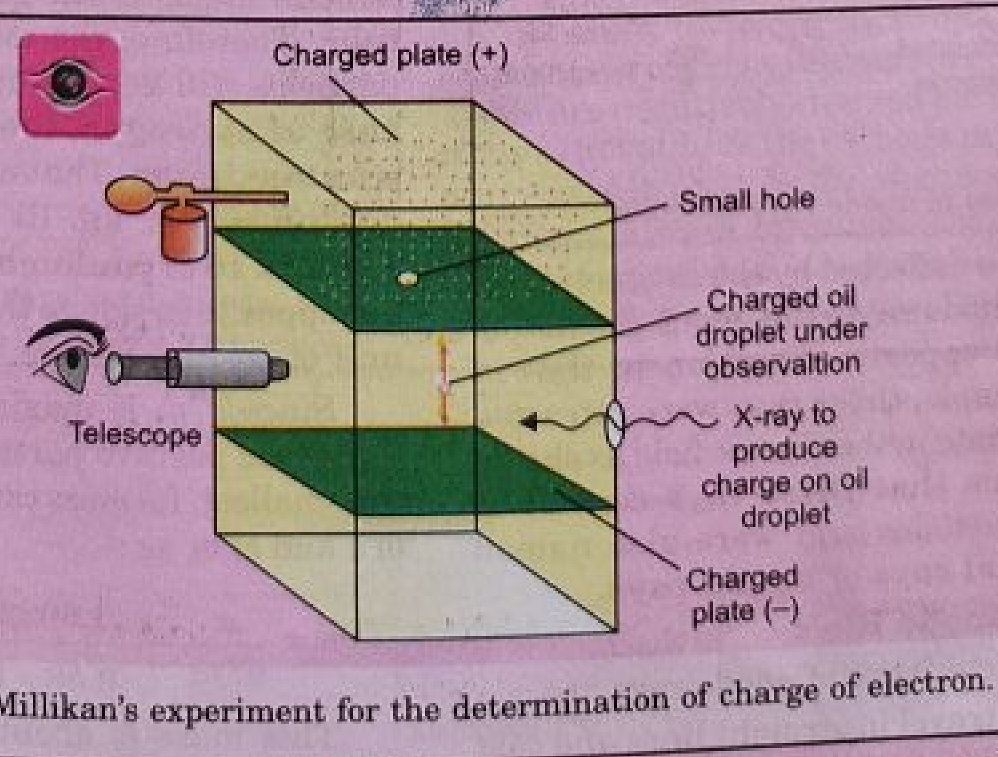

Fig. 7. Millikan's experiment for the determination of charge of electron.

From his experiments, Millikan found the charge of the electron to be 1.6022×10^{-19} coulombs.