Electrons as essential constituents of all atoms. The discharge tube experiments showed that the electrons constituting the cathode rays are the same irrespective of

(*i*) the nature of the material of the cathode and

(*ii*) the gas used in the discharge tube.

All these electrons possess the same mass and the same charge and therefore, they have the same charge/mass (e/m) ratio. This means that the cathode rays do not consist of charged gaseous atoms, otherwise, e/m would have been different for different gases used. Thus, the rays are made up of fundamental common particles known as electrons.

Moreover, the electrons emitted from various sources and by various methods are found to have the same mass and the same charge. Thus, it may be concluded the ***electrons are universal constituents of all matters.***

Discovery of Proton: Study of Anode Rays

The presence of negatively charged electrons in an atom suggests that there must be some positively charged particles because the atom on the whole is electrically neutral. In 1836, E. Goldstein discovered that in addition to cathode rays, a new kind of rays are also found streaming behind the cathode in discharge tube experiments (Fig. 8). These rays travelled in opposite direction to the cathode rays.

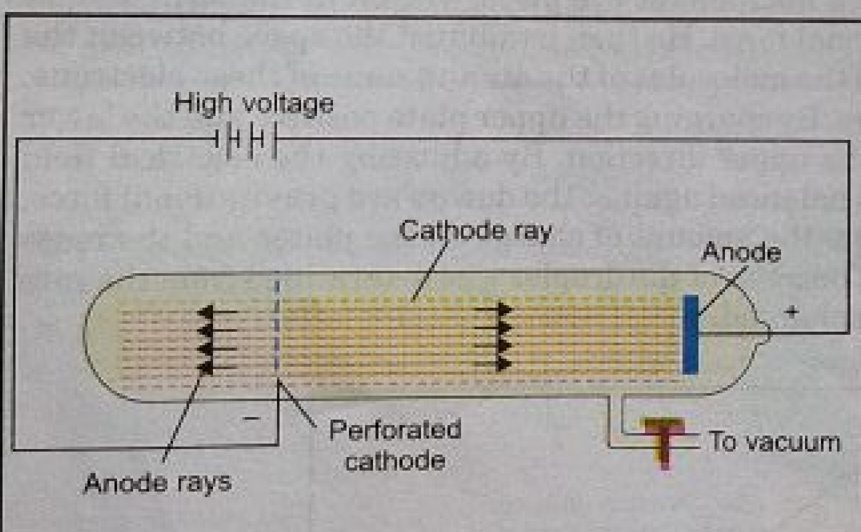

Fig. 8 Generation of anode rays (protons).

These rays are also deflected by the magnetic and electric fields like cathode rays. But the deflection of anode rays is in the opposite direction to that of cathode rays. For example, these rays were attracted towards the negative plate in the electric field as shown in Fig. 8. This means that these rays consist of positively charged particles and were also named **positive rays** or **canal rays** or **anode rays.**

Characteristics of Anode Rays

Some of the characteristics of anode rays are :

1. The anode rays travel in straight lines and cast shadow of the object placed in their path.

2. The anode rays are deflected by the magnetic and electric fields like cathode rays. But the deflection of anode rays is in the opposite direction to that of the cathode rays. For example, these rays are attracted towards the negative plate in the electric field (Fig. 9). This means that these rays consist of positively charged particles.

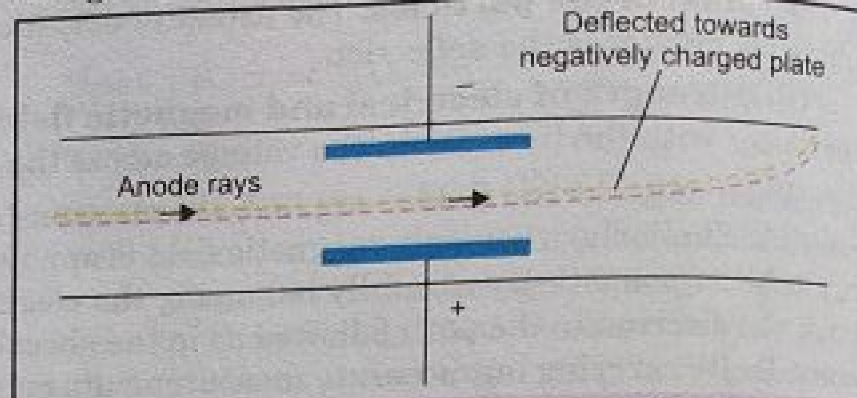

Fig. 9. Deflection of anode rays in an electric field.

3. Like cathode rays, these rays also rotate the wheel placed in their path and also have heating effect.

4. The charge to mass ratio (e/m) for these rays is considerably smaller than electrons.

5. Unlike cathode rays, the e/m ratio of positive rays depends upon the nature of the gas taken in the tube.

The Charge and Mass of Particles Constituting Anode Rays

By means of deflections in electric and magnetic field, charge to mass ratio (e/m) of the particles constituting anode rays was determined for different gases (in the same manner as described for cathode rays). It was found that the value of e/m for these rays is not constant and is considerably smaller than that for electrons. Unlike cathode rays, the charge to mass (e/m) ratio of anode rays was found to depend upon the nature of the gas taken in the discharge tube. This is obvious because positively charged particles are produced by the loss of one or more electrons from the neutral atoms of the gas contained in the discharge tube. Therefore, the mass of the positively charged particles will depend upon the nature of the gas. **In case of hydrogen, the charge to mass (*e/m*) ratio was maximum.** The value was found to be **9.58×10^7 coulombs per kg.** Its charge has been found to be **1.6022×10^{-19} coulombs** which is equal in magnitude but opposite in sign to that of an electron *i.e.*, it has one unit of positive charge.

Since e/m is maximum for hydrogen, the mass (m) of the positive particle obtained from hydrogen is the smallest. Its mass can be calculated from the value of e and e/m as :

$$m = \frac{e}{e/m} = \frac{1.6022 \times 10^{-19}\ \text{C}}{9.58 \times 10^{7}\ \text{C kg}^{-1}} = \mathbf{1.67 \times 10^{-27}\ kg}$$

This mass is about 1837 times the mass of an electron. This mass is practically equal to that of hydrogen atom and is regarded as **one unit mass.** This lightest positively charged particle was named proton and is also regarded as a fundamental particle. Thus, a **proton** is

> ***a sub-atomic particle which carries one unit positive charge (1.6022×10^{-19} coulombs) and has mass (1.67×10^{-27} kg) equal to that of an atom of hydrogen.***

It has been observed that the mass of positively charged particles was one unit mass or 1.67×10^{-27} kg only when hydrogen gas was used. For other gases, it was found to be whole number multiple of this value i.e., mass of the proton. This means that the atoms of other gases consist of two or more protons, i.e. multiples of proton.

Origin of Positive Rays

We have studied that in discharge tube, cathode rays are emitted from the cathode. These rays consist of stream of electrons which move towards anode with very high speeds. When these fast-moving electrons strike the atoms or molecules of the gas contained in the discharge tube, they knock off one or more electrons. The removal of electrons from neutral atoms or molecules of gas results in the formation of positively charged ions. These positively charged ions move towards perforated cathode and constitute the beam of **positive rays** or **anode rays** coming through the holes of the cathode. These charged ions carry various amounts of positive charge depending upon the number of electrons lost by the corresponding atoms or molecules.

R.U. Curious...

❑ **What is the basic principle of television picture tube or fluorescent light tubes ?**

➢ Television picture tube is basically a cathode ray tube in which a picture on the screen is produced due to fluorescence phenomenon on the television screen coated with a suitable material.

Fluorescent light tubes are also cathode ray tubes coated inside with a suitable material which produce visible light on being hit with cathode rays.

DISCOVERY OF RADIOACTIVITY

The discovery of cathode rays and anode rays showed that atoms are divisible into subatomic particles. This was further supported by the discovery of radioactivity by a French scientist Henri Becquerel in 1896. He was studying the properties of uranium salts. One day, Becquerel placed a uranium salt (potassium uranium sulphate) wrapped in a black paper and a photographic plate together in a drawer.

To his great surprise, he noticed that the photographic plate below the crystals was darkened. There was no sunlight coming in the drawer and, therefore, he had no rasons to believe that the plate would be exposed to light. When he developed the plate, he observed that it had clear image of the salt. This led him to interpret that the uranium salt emitted *certain high energy invisible radiations* capable of penetrating the black paper and therefore, affected the photographic plate. Later on, it was observed that these rays can ionise air, penetrate solid matter and produce luminosity in substances such as ZnS.

> ***The phenomenon of spontaneous emission of active radiations by certain elements*** is called ***radioactivity.***

The substances which emit such radiations are called **radioactive substances.** The common radioactive substances are uranium, radium, polonium, thorium, etc.

The effect of magnetic and electric fields on these radiations was studied by placing a small sample of radioactive substance, uranium, in a cavity of a block of lead. The radioactive radiations coming out from a narrow slit were allowed to pass through a strong electric or magnetic field. The deflections of these rays were recorded on a photographic plate as shown in Fig. 10. The radiations were found to split into three types of rays. These were :

(*i*) **Alpha (α) rays.** *The rays which are deflected towards the negative electrode are called* **alpha (α) rays.** *These rays were found to consist of positively charged He^{2+} particles.* Each particle has a mass of 4 a.m.u. ($m = 6.6 \times 10^{-24}$g) and carries two units of positive charge, +2 ($e = 3.20 \times 10^{-19}$ Coulomb).

(*ii*) **Beta (β) rays.** *The rays which are deflected towards the positive electrode are called* **beta (β) rays.** These are negatively charged particles which have the same e/m value as the cathode rays. Therefore, *β-rays were considered to be the streams of electrons.*

(*iii*) **Gamma (γ) rays.** *The rays which are not deflected at all and are therefore, neutral are called* **gamma (γ) rays.** These rays were regarded as high

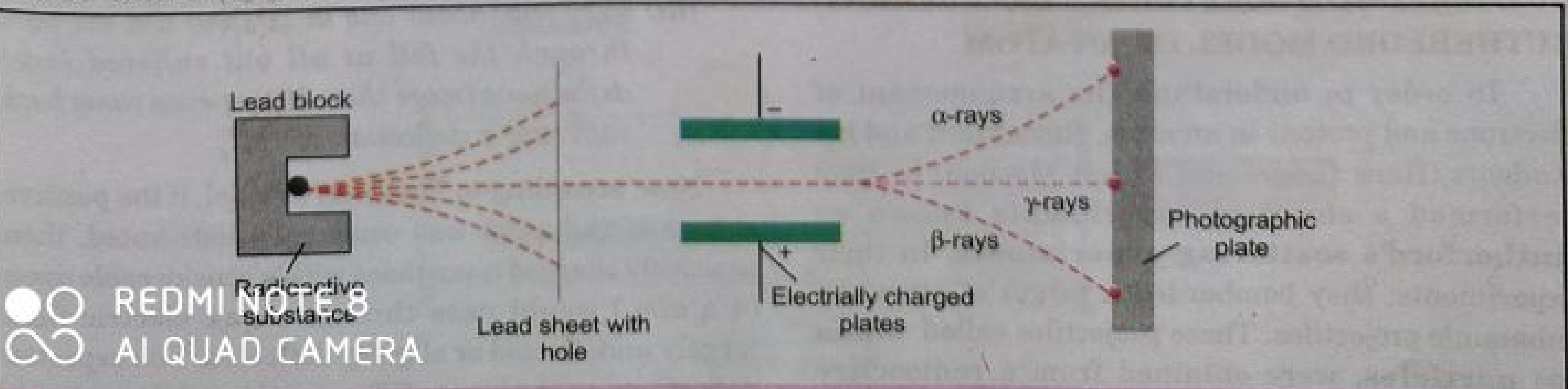

Fig. 10. The effect of the electric field on the radiations from a radioactive substance.

energy electromagnetic radiations having no charge and negligible mass.

ARRANGING ELECTRONS AND PROTONS IN AN ATOM

THOMSON'S MODEL OF ATOM

After the discovery of electron and proton, the scientists started thinking of arranging these particles in an atom. Different models were proposed to explain the distribution of subatomic particles in an atom. The first simple model was proposed by J.J. Thomson known as **Thomson's atomic model.**

J.J. Thomson proposed that an atom consists of a uniform sphere in which positive charge is uniformly distributed. The electrons are embeded into it in such a way as to give the most stable electrostatic arrangement (Fig. 11) The radius of the sphere is of the order of 10^{-10} m, which is equal to the size of the atom. This model was much like pudding or cake (of positive charge) with raisins (electrons) embedded into it. Therefore, this model is also known as **raisin pudding model.** This model was also compared with *water melon model* of positive charge in which seeds (electrons) are embedded. Therefore, this model is

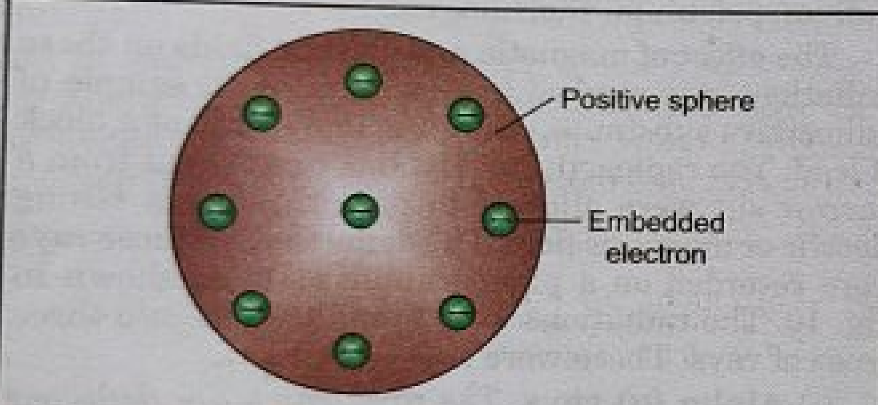

Fig. 11. Thomson's model of an atom.

given different names such as *raisin pudding*, plum *pudding* or *watermelon model*. An important feature of this model is that the mass of the atom is considered to be evenly spread over the atom.

This model explains some of the known properties and electrical neutrality of atom. However, it was soon discarded, when Rutherford and his co-workers observed unusual scattering of α-particles by the thin metal foils. Since this model could not explain the experimental results, it was therefore, rejected.

RUTHERFORD'S SCATTERING EXPERIMENT: RUTHERFORD MODEL OF AN ATOM

In order to understand the arrangement of electrons and protons in an atom, Rutherford and his students (Hans Geiger and Ernest Masden) in 1909 performed a series of experiments known as **Rutherford's scattering experiments.** In their experiments, they bombarded a target of atoms by subatomic projectiles. These projectiles called **alpha (α) particles,** were obtained from a radioactive substance. Alpha particles are high energy positively charged helium ions having charge +2 and mass 4 u. They bombarded alpha (α) particles emitted from a radioactive substance on a piece of thin foil of gold or some other heavy metals.

In this experiment, a piece of radioactive substance (radium) is placed in a lead block (Fig. 12). The block is constructed in such a way with slits that only a narrow beam of α-particles could escape. The beam of high energy α-particles was directed at a thin gold foil (thickness about 100 nm). In order to detect the α-particles after scattering, a movable circular screen coated with zinc sulphide is placed around the gold foil.

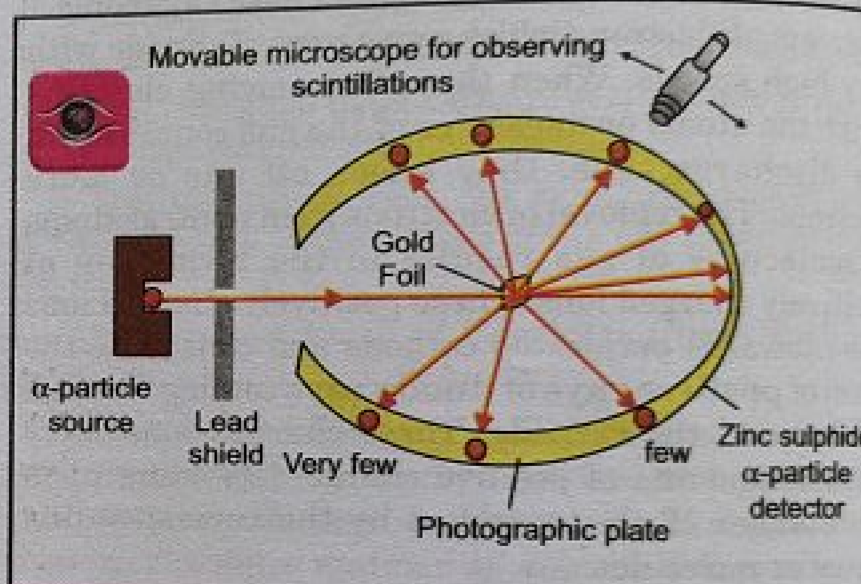

Fig. 12. Rutherford's α-particle scattering experiments.

When α-particles strike the zinc sulphide screen, these produce flashes of light or scintillations which can be detected. By examining different portions of the screen, it was possible to determine the proportions of the α-particles which got deflected through various angles. The following **observations** were made from these experiments :

(i) *Most of the α-particles (nearly 99%) passed through the gold foil undeflected.*

(ii) *A small fraction of α - particles got deflected through small angles.*

(iii) *Very few (about one in 20,000) did not pass through the foil at all but suffered large deflections (more than 90°) or even came back suffering a deflection of 180°.*

Now, according to Thomson's model, if the positive charge of the atom was uniformly distributed, then positively charged α-particles with a considerable mass (4 a.m.u.) would pass through weak electric field largely undeflected or slightly deflected. The expected deflections on the basis of Thomson's model are shown in Fig. 13. However, he noticed that some of the α-particles experienced strong deflections. Even some particles returned back from the foil. *Thus, Thomson's model could not provide answers for these observations and therefore, was discarded.*

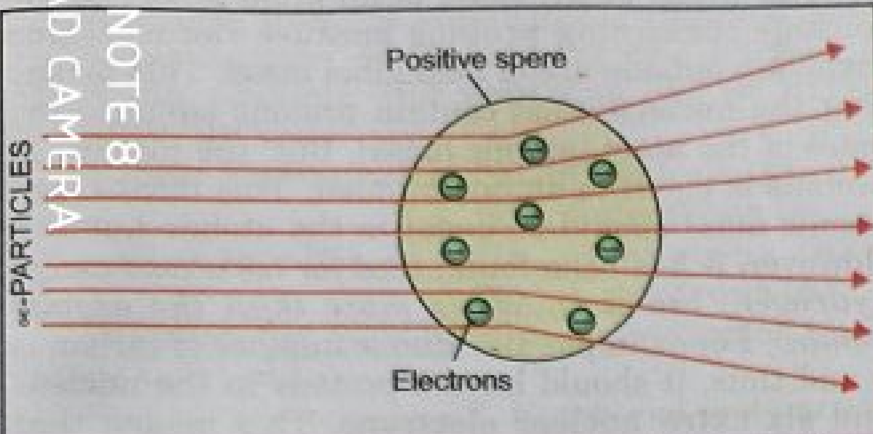

Fig. 13. The expected deflections of α-particles on the basis of Thomson's model.

Rutherford explained these observations as follows :

(*i*) Since most of the α-particles passed through the gold foil undeflected, *it means that there must be very large empty space within the atom.*

(*ii*) Alpha particles are positively charged and have considerable mass. They can be deflected only if they come close to some heavy positively charged mass due to enormous force of repulsion. Since some of the α-particles are deflected to certain angles, *it means that there is a heavy positively charged mass present in the atom. Moreover, this mass must be occupying a very small space within the atom because only a few α-particles suffered large deflections.*

(*iii*) The strong deflections or even bouncing back of α-particles from the foil, were explained to be *the direct collision with the heavy positively charged mass.*

The positively charged heavy mass which occupies only a small volume in an atom is called **nucleus.** It is supposed to be present in the centre of the atom.

All these types of deflections of α-particles from atoms are shown in Fig. 14. It is clear from the figure that the α-particles which pass at large distances from the nucleus do not suffer any deflections (marked *a*), those which pass close to the nucleus suffer small deflections (marked *b*), while very few which hit the nucleus are either deflected to large angles or they retraced their paths (marked *c*).

On the basis of the above experiments and observations, Rutherford proposed a model for the structure of the atom called *Rutherford's nuclear model of atom.*

Rutherford's Nuclear Model of Atom

The main features of this model are :

(*i*) In an atom, the entire mass and the positive charge is concentrated in a very small region at the centre known as **nucleus.** It was observed that the volume occupied by the nucleus is negligibly small as compared to the total volume of the atom.

From X-rays experiments, it has been found that the radius of the nucleus is of the order of 10^{-15} m whereas, the radius of the atom is of the order of 10^{-10} m (or 1Å). Thus,

$$\frac{\text{Size of the nucleus}}{\text{Size of the atom}} = \frac{10^{-15}\text{ m}}{10^{-10}\text{ m}} = 10^{-5} \text{ i.e. } \frac{1}{100,000}$$

This means that the size of the nucleus is extremely small (only about 1/100,000) as compared to the size of the atom. In terms of volume,

$$\frac{\text{Volume of the nucleus}}{\text{Volume of the atom}} = \frac{\left(10^{-15}\right)^3 \text{m}^3}{\left(10^{-10}\right)^3 \text{m}^3} = 10^{-15}$$

Thus, nucleus is too small in comparison to the atom. This difference can be easily visualised by realising that if a cricket ball represents a nucleus then radius of the atom would be about 5 km.

(*ii*) The positive charge of the nucleus is due to protons. The magnitude of the positive charge on the nucleus (number of protons) is different for different atoms.

(*iii*) The mass of the nucleus is due to protons and some other neutral particles each having mass nearly equal to the mass of the proton. This neutral particle

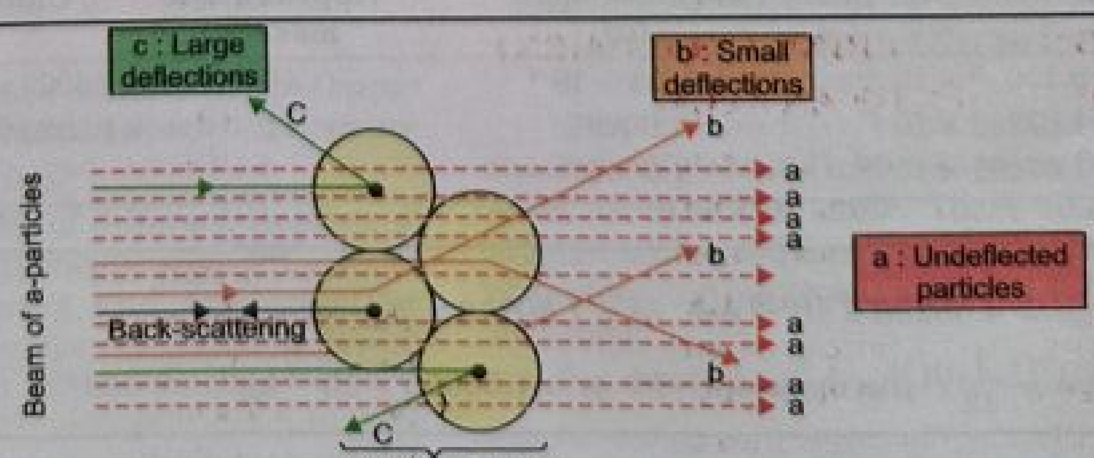

Fig. 14. Rutherford's model for deflections of α-particles.

was discovered later on by Chadwick in 1932. It was called **neutron.**

> Protons and neutrons present in the nucleus are collectively called **nucleons.**

(iv) The nucleus is surrounded by negatively charged electrons which balance the positive charge on the nucleus. Thus, the atom is electrically neutral.

(v) The electrons are not stationary but are revolving around the nucleus at very high speeds like planets revolving around the sun. As a result, the electrons are also called *planetary electrons.**

Thus, the Rutherford's model of atom resembles the solar system in which the nucleus plays the role of the sun and revolving electrons play the role of planets.

(vi) The electrons and the nucleus are held together by electrostatic forces of attraction.

(vii) Most of the space in an atom between the nucleus and the revolving electrons is empty.

CONCEPT OF ATOMIC NUMBER, MASS NUMBER AND DISCOVERY OF NEUTRON

In 1913, Moseley determined the magnitude of the positive charge on the nucleus of an atom by studying