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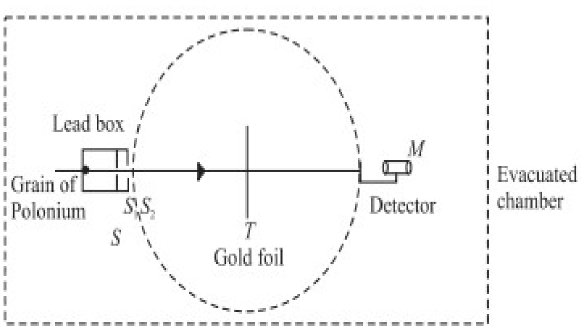
# STRUCTURE OF ATOM

## Rutherford’s Experiment on Scattering of α-Particles

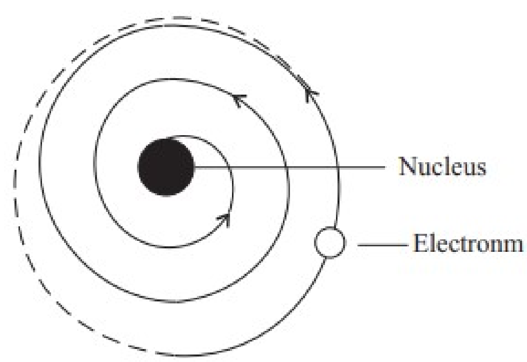
- Rutherford’s scattering experiment indicated the presence of small central region inside the atom where all the positive charge and most of the mass of the atom is concentrated.
- The region was named as the nucleus. Electrons revolve around the nucleus and total negative charge is equal to the total positive charge of the nucleus.
- Rutherford’s model of atom could not explain satisfactorily the observed stability of the atom and the electromagnetic radiation emitted by the atoms.




- Geiger and Marsden performed an experiment in which a beam of α-particles was bombarded on a thin gold foil

## Nuclear Model of Atom

- The entire charge and most of the mass of the atom is confined in a very small (~$10^{-15}$ m) central region, called the nucleus.
- The negatively charged electrons revolve at a distance around it such that the atom as a whole is electrically neutral and stable.




## Stability of the atom

- Electrons are negatively charged.
- These are attracted by the nucleus and get accelerated.
- An accelerated charged particle, according to classical wave theory, emits

electromagnetic radiations. Hence, the revolving electrons should lose energy eventually and spiral into the nucleus

**Frequency of electromagnetic radiation**

The electron spiralling towards the nucleus will emit electromagnetic radiations of all frequencies giving rise to a continuous spectrum. But experiments show that atoms emit radiations of certain well defined frequencies only.

**Bohr's Model of Hydrogen Atom**

- Electrons in an atom move in circular orbits around the nucleus with the centripetal force supplied by the Coulomb force of attraction between the electron and the nucleus. Mathematically,
$$\frac{mv^2}{r} = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r}$$
where Z denotes the number of positive charges in the nucleus.
- If the infinite number of possible circular orbits, only those orbits are allowed for which the value of orbital angular momentum of the electron is an integral multiple of h/2π :
$|L| = \text{mvr} = \frac{nh}{2\pi}$
where L is the orbital angular momentum, equal to mvr for a circular orbit. Here h is Planck's constant and n is an integer.
- An electron moving in an allowed orbit does not radiate any energy. In these allowed orbits, the energy of the electron is constant. These orbits are called stationary states. Note that an electron can move in a stationary state but its energy is constant.
- Energy is emitted by an atom only when its electron "falls" from an allowed higher energy level $E_f$ to another allowed lower level $E_i$ . The change in energy is the energy of the emitted photon.
- An electron only absorbs radiation when it "jumps" to a higher energy level from a lower energy level. The change in energy of an electron can be related to the frequency or wavelength of the emitted or absorbed photon:

## Energy Levels

$$r_n = 4\pi\varepsilon_o \frac{n^2h^2}{4\pi^2 mZe^2}$$

$$= \frac{n^2h^2\varepsilon_0}{Ze^2 m\pi} \qquad n = 1, 2, 3, ...$$

the radius of its inner most orbit is called Bohr radius. It is denoted by a0 and its magnitude is 5.3 × 10– 11m.

Expression for the speed of the electron in the nth orbit

$$\upsilon_n = \frac{nh}{2\pi m r_n} = \frac{nh}{2\pi m}.\frac{Ze^2 m\pi}{n^2h^2\varepsilon_0}$$

$$= \frac{1}{2}\frac{Ze^2}{\varepsilon_0 nh}$$

Potential energy

$$U = -\frac{1}{4\pi\varepsilon_0}\int_{r_n}^{\infty}\frac{Ze^2}{r^2}dr$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}\Big]_{r_n}^{\infty}$$

$$= -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r_n}$$

Total energy

$$E = -\frac{m}{2}\left(\frac{2\pi Ze^2}{4\pi\varepsilon_0 nh}\right)^2$$

$$= -\frac{m}{8\varepsilon_0^2}\frac{Z^2e^4}{n^2h^2}$$

$$= \frac{RZ^2}{n^2}\text{ ; } n = 1, 2, 3...$$

$$R = \frac{me^4}{8\varepsilon_0^2h^2}$$

R is Rydberg constant

- Energy of an electron in various allowed orbits is inversely proportional to the square of the number of orbit; and
- The energy in an orbit is negative, which implies that the electron is bound to the nucleus.

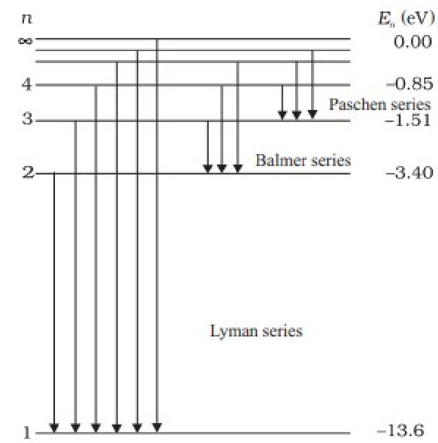
**HYDROGEN SPECTRUM**

**Lyman series**

It was discovered by Lymen in 1906. According to Bohr, this series arises

- When an electron jumps to the first orbit (m = 1) from an higher orbit (n = 2, 3, 4...). The frequencies of various spectral lines of this series are given by

$$v_{1n} = \frac{R}{h}\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$$




**Balmer series**

It was discovered in 1885 in the visible region. According to Bohr, this series arises,

- When electron jumps to the second orbit (m = 2) from higher orbits (n = 3, 4, 5...). The frequencies of various spectral lines of the series are given by

$$v_{2n} = \frac{R}{h}\left(\frac{1}{2^2} - \frac{1}{n^2}\right); n > 2$$

**Paschen series**

It was discovered in 1908 in the near infra-red region.

- The existence of this series can be explained by assuming that electrons jump to third orbit (m = 3) from higher orbits (n = 4, 5, 6...). The frequencies of various spectral lines in the region are given by

$$\nu_{3n} = \frac{R}{h}\left(\frac{1}{3^2}-\frac{1}{n^2}\right); n_2 > 3$$

**Brackett series**

It was discovered in mid infra-red region. In this series,

- Electrons jump to fourth orbit (n = 4) from higher orbits (n = 5, 6...). Therefore, the frequencies of various spectral lines in the region are given by

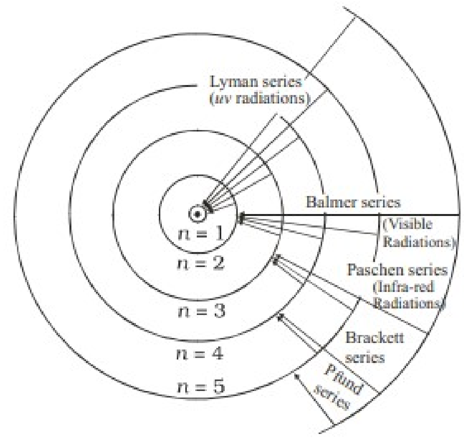
$$\nu_{4n} = \frac{R}{h}\left(\frac{1}{4^2}-\frac{1}{n^2}\right); n > 4$$

Pfund series

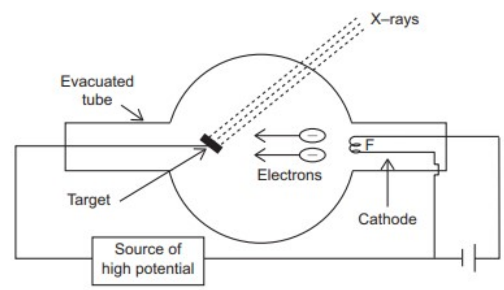
It was discovered in far infra-red region. According to Bohr, this series is obtained when

- Electron jumps to fifth orbit (n1 = 5) from any higher orbit (n = 6, 7,...). The frequencies of various spectral lines of the series are given by

$$\nu_{5n} = \frac{R}{h}\left(\frac{1}{5^2}-\frac{1}{n^2}\right); n > 5$$




## X–RAYS




X–rays are produced when fast moving electrons are suddenly stopped by a heavy metal in a glass tube having extremely low pressure.

The electrons emitted by the hot filament are focused on the target which is made up of metal of high melting point and high atomic number

Properties of X–rays

X–rays show the following properties:

(i) They affect the photographic plate
(ii) They cause fluorescence in certain chemical compounds.
(iii) They ionize the gases
(iv) They show no reflection in mirrors, no refraction in glass, no diffraction with the conventional gratings but

when refined techniques are used with atomic layers of crystals, they show all these familiar phenomena of light.

(v) They do not get deviated by electric or magnetic field.

**X– Rays Spectra:**

- The element whose X–ray spectra is studied is placed at the place of target of the X–rays tube.
- The X–ray wavelengths are determined by the Bragg’s spectrometer.
- The intensity of X–rays increases at all wavelengths as the voltage across the tube is increased.
- The shortest wavelength $\lambda_{min}$ emitted is sharply defined and it depends on the voltage applied.
- As the voltage is increased, the wavelength at which the maximum emission occurs shifts towards the shortest wavelength side
- Continuous X–rays are produced when the kinetic energy of the incident electrons is transformed into electromagnetic radiation upon collision with atoms. Before being stopped, electrons make several collisions and produce photons of all frequencies

**Mosley’s law**

Mosley investigated the characteristic X–rays of a large number of elements.

- some specific characteristic lines appeared in the spectra of all elements but at slightly differing wavelengths Each characteristic line obeyed a specific equation. For example, K2 lines obey the following relation

$$\bar{\nu} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right](Z-1)^2$$

**Check Yourself**

1. The size of the atom is approximately equal to
   - **A.** $10^{-4}$ cm to $10^{-8}$ m
   - **B.** $10^{-6}$ cm to $10^{-8}$ m
   - **C.** $10^{-8}$ cm to $10^{-10}$ m
   - **D.** $10^{-12}$ cm to $10^{-14}$ m
2. Rutherford in his experiment bombarded thin metallic foils by
   - A. Electron
   - B. α-Particles
   - C. proton
   - D. neutron
3. According to Bohr’s model of Hydrogen atom
   - A. The angular momentum of the electron is quantized
   - B. The angular velocity of the electron is quantized
   - C. The linear momentum of the electron is quantized
   - D. The linear velocity of the electron is quantized

4. The Lithium atom has 3 electron. The third electron will bein
   - A. L-shell
   - B. K -shell
   - C. M -shell
   - D. N –shell
5. A Hydrogen atom is in p-state.For this value of Jare
   - A. 5/2,3/2,1/2
   - B. 3/2,1/2
   - C. -1/2,+1/2,3/2
   - D. -1/3,-3/2

## Stretch Yourself

1. The Rydberg constant for hydrogen is 1096700 m–1. Calculate the short and long wavelength limits of Lyman series.
2. In Rutherford's α-particle scattering experiment, what observation led him to predict the existance of nucleus?
3. State the postulates of Bohr's model of atom.
4. The energy transition in H-atom occurs from n = 3 to n = 2 energy level. Given R = 1.097 × 107 m–1. (i) What is the wavelength of the emitted radiations? (ii) Will this radiation lie in the range of visible light? (iii) To which spectral series does this transition belong?
5. How are continuous x-rays produced? What is the condition for the production of photons of highest frequency?

## Hint to Check Yourself

**1C 2 B 3 A 4 A 5 B**