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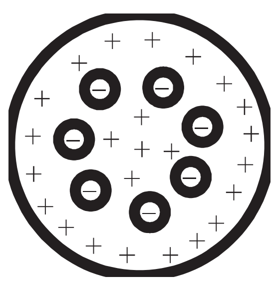
Atomic Physics

Dalton's Atomic Theory

All elements are consists of very small invisible particles, called atoms. Atoms of same elements are exactly same and atoms of different elements are different.

Thomson's Atomic Model

Every atom is uniformly positive charged sphere of radius of the order of 10^{-10} m, in which entire mass is uniformly distributed and negative charged electrons are embedded randomly. The atom as a whole is neutral.



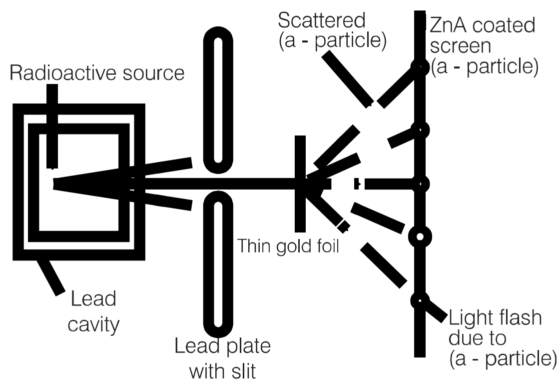
Limitations of Thomson's Atomic Model

(i) It could not explain the origin of spectral series of hydrogen and other atoms.

(ii) It could not explain large angle scattering of α-particle.

Rutherford's Atomic Model

The setup of Rutherford's α-particle scattering experiment is shown in the figure given below



On the basis of this experiment, Rutherford made following observations.

(i) The entire positive charge and almost entire mass of the atom is concentrated at its centre in a very tiny region of the order of 10^{-15} m, called nucleus.

(ii) The negatively charged electrons revolve around the nucleus in different orbits.

(iii) The total positive charge on nucleus is equal to the total negative charge on electron. Therefore, atom is overall neutral.

(iv) The centripetal force required by electron for revolution is provided by the electrostatic force of attraction between the electrons and the nucleus.

Distance of Closest Approach

$$r_0 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2Ze^2}{E_K}$$

where, E_K = kinetic energy of the α-particle.

Impact Parameter

The perpendicular distance of the velocity vector of α-particle from the central line of the nucleus, when the particle is far away from the nucleus is called impact parameter.

$$\text{Impact parameter, } b = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Ze^2 \cot\left(\frac{\theta}{2}\right)}{E_K}$$

where, Z = atomic number of the nucleus,
E_K = kinetic energy of the α-particle and
θ = angle of scattering.

Rutherford's Scattering Formula

$$N(\theta) = \frac{N_i nt Z^2 e^4}{(8\pi\varepsilon_0)^2 r^2 E^2 \sin^4\left(\frac{\theta}{2}\right)}$$

where, $N(\theta)$ = number of α-particles, N_i = total number of α-particles reaching the screen, n = number of atoms per unit volume in the foil, Z = atomic number, E = kinetic energy of the α-particle and t = foil thickness.

$$\therefore \qquad N \propto \frac{1}{\sin^4\left(\frac{\theta}{2}\right)}$$

Limitations of Rutherford 's Atomic Model

(i) **About the Stability of Atom** According to Maxwell's electromagnetic wave theory, electron should emit energy in the form of electromagnetic wave during, its orbital motion. Therefore, radius of orbit of electron will decrease gradually and ultimately it will fall in the nucleus.

(ii) **About the Line Spectrum** Rutherford atomic model cannot explain atomic line spectrum.

Bohr's Atomic Model

Electron can revolve in certain non-radiating orbits called **stationary orbits** for which the angular momentum of electron is an integer multiple of $\left(\frac{h}{2\pi}\right)$.

$$mvr = \frac{nh}{2\pi}$$

where, $n = 1, 2, 3, \ldots$ called principal quantum number.

The radiation of energy occurs only, when any electron jumps from one permitted orbit to another permitted orbit.

Energy of emitted photon, $h\nu = E_2 - E_1$

where, E_1 and E_2 are energies of electron in orbits.

Radius of orbit of electron is given by

$$r = \frac{n^2h^2}{4\pi^2\, mK\; Ze^2}$$

$$\Rightarrow \qquad r \propto \frac{n^2}{Z}$$

where, n = principal quantum number, h = Planck's constant, m = mass of an electron, $K = \frac{1}{4\pi\,\varepsilon_0}$, Z = atomic number and e = electronic charge.

The radius of the first orbit ($n = 1$) of H-atom is given as

$$r_1 = \frac{h^2\varepsilon_0}{\pi me^2} = 0.53\ \text{Å}$$

This is called Bohr's radius.

Velocity of electron in any orbit is given by

$$v = \frac{2\pi KZe^2}{nh}$$

$$\Rightarrow \qquad v \propto \frac{Z}{n}$$

Frequency of electron in any orbit is given by

$$\nu = \frac{KZe^2}{nhr} = \frac{4\pi^2Z^2e^4mK^2}{n^3h^3}$$

$$\Rightarrow \qquad \nu \propto \frac{Z^2}{n^3}$$

Kinetic energy of electron in any orbit is given by

$$E_K = \frac{2\pi^2me^4Z^2K^2}{n^2h^2} = \frac{13.6\,Z^2}{n^2}\ \text{eV}$$

Potential energy of electron in any orbit is given by

$$E_P = \frac{-4\pi^2me^4Z^2K^2}{n^2h^2} = -\frac{27.2\,Z^2}{n^2}\ \text{eV}$$

Total energy of electron in any orbit is given by

$$E = \frac{-2\pi^2 me^4 Z^2 k^2}{n^2 h^2} = -\frac{13.6\, Z^2}{n^2}\ \text{eV}$$

$$\Rightarrow \qquad E \propto \frac{Z^2}{n^2}$$

Wavelength of radiation emitted in the radiation from orbit n_2 to n_1 is given by

$$\frac{1}{\lambda} = \frac{2\pi^2 mK^2 e^4 Z^2}{ch^3}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

where,

$$R = \frac{2\pi^2 mK^2 e^4 Z^2}{ch^3}$$

$$= 1.097 \times 10^7\ \text{m}^{-1}$$

Excitation Energy and Potential

The energy required to take an atom from its lower state to higher state is called excitation energy.

The potential through which an electron should be accelerated to gain higher state is called excitation potential.

Ionisation Energy and Potential

$$E_{\text{ionisation}} = E_\infty - E_n = \frac{13.6 Z^2}{n^2}\ \text{eV}$$

$$\text{Ionisation potential} = \frac{E_{\text{ionisation}}}{e} = \frac{13.6 Z^2}{n^2}\ \text{V}$$

de-Broglie's Explanations of Bohr's Second Postulate

According to de-Broglie, a stationary orbit is that which contains an integral number of de-Broglie waves associated with the revolving electrons. For electron revolving in nth orbit of radius r_n.

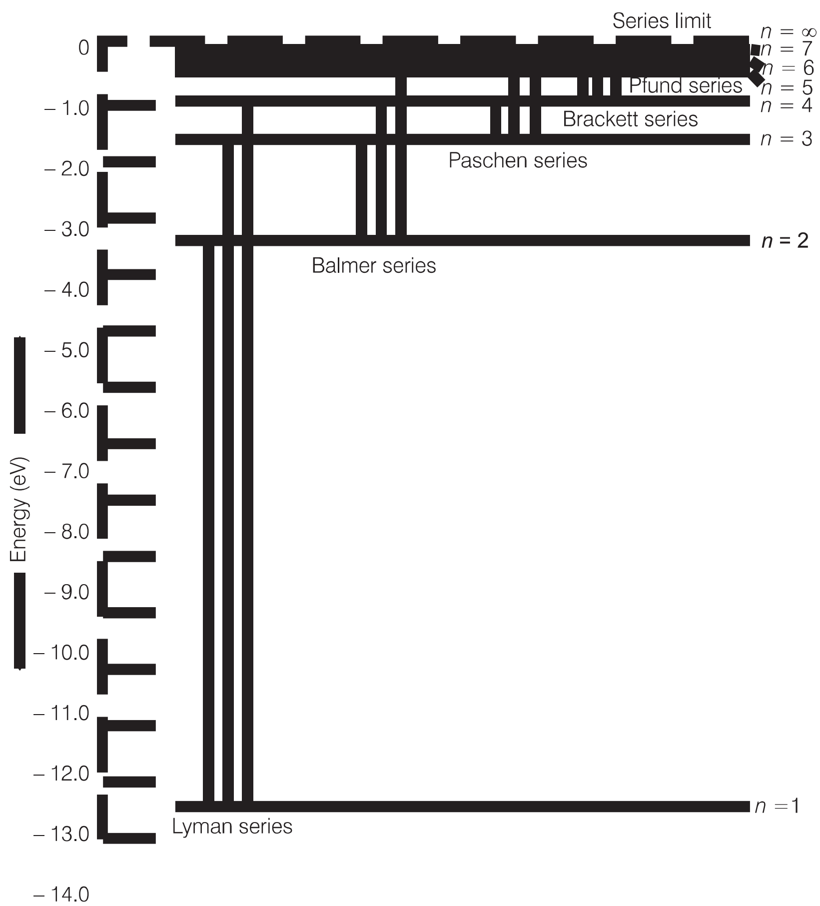
$$2\pi r_n = n\lambda = \frac{nh}{mv_n}$$

or

$$mv_n r_n = \frac{nh}{2\pi}$$

Hydrogen Spectrum Series

Each element emits a spectrum of radiation, which is characteristic of the element itself. The spectrum consists of a set of isolated parallel lines and is called the **line spectrum.**



Hydrogen spectrum contains five series.

(i) **Lyman Series** When electron jumps from $n = 2, 3, 4, \ldots$ orbit to $n = 1$ orbit, then a line of Lyman series is obtained.

This series lies in **ultra violet region**.

(ii) **Balmer Series** When electron jumps from $n = 3, 4, 5, \dots$ orbit to $n = 2$ orbit, then a line of Balmer series is obtained.

This series lies in **visible region.**

(iii) **Paschen Series** When electron jumps from $n = 4, 5, 6, \dots$ orbit to $n = 3$ orbit, then a line of Paschen series is obtained.

This series lies in **infrared region.**

(iv) **Brackett Series** When electron jumps from $n = 5, 6, 7, \dots$ orbit to $n = 4$ orbit, then a line of Brackett series is obtained.

This series lies in **infrared region**.

(v) **Pfund Series** When electron jumps from $n = 6, 7, 8, \dots$ orbit to $n = 5$ orbit, then a line of Pfund series is obtained.

This series lies in **infrared region.**

Wave Model

It is based on wave mechanics.

Quantum numbers are the numbers required to completely specify the state of the electrons.

In the presence of strong magnetic field, the four quantum numbers are

(i) Principal quantum number (n) can have value 1, 2, …∞.

(ii) Orbital angular momentum quantum number l can have value $0, 1, 2, \dots, (n-1)$.

(iii) Magnetic quantum number (m_e) which can have values $-l$ to l.

(iv) Magnetic spin angular momentum quantum number (m_s) which can have only two value $+\frac{1}{2}$.