BRUSH UP YOUR CONCEPTS

Class XI

This specially designed column will help you to brush up your concepts by practicing questions. You can mail us your queries and doubts related to this topic at editor@mtg.in. The queries will be entertained by the author.*

STRUCTURE OF ATOM

After the study of subatomic particles, the structure of atom developed to explain the stability, difference of properties of different elements, formation of compounds and origin of electromagnetic radiation and related effects.

Electrons were discovered in the form of particles of cathode rays whose properties do not change by changing the material of glass tube, gas taken in discharge tube and material of electrodes.

In 1897, J.J. Thomson determined the ratio of charge and mass (specific charge) of electron to be -1.75882×10^{11} C kg^{-1} while the charge was determined by Millikan as -1.6022×10^{-19} C. These gave the mass equal to 9.1094×10^{-31} kg.

This mass of electron is called stationary mass. The mass of electron moving with velocity 'v' m s^{-1} is $\dfrac{m_{rest}}{\sqrt{1-\left(\dfrac{v}{c}\right)^2}}$.

Here, c is velocity of light in m s^{-1}.

When H_2 gas was filled in discharge tube, anode rays were found to be composed of protons with same charge as that of electron but positive in nature to explain the neutrality of atom. Mass of proton was determined to be 1.67262×10^{-27} kg.

Neutron was discovered by Chadwick in 1932.

$$^{9}_{4}\text{Be} + {}^{4}_{2}\text{He} \rightarrow {}^{12}_{6}\text{C} + {}^{1}_{0}n$$

The idea of nucleus present at the centre of atom and having total protons in it, was given by Rutherford using α-rays scattering experiment which was actually expansion of Lenard's (Denmark) experiment on Al.

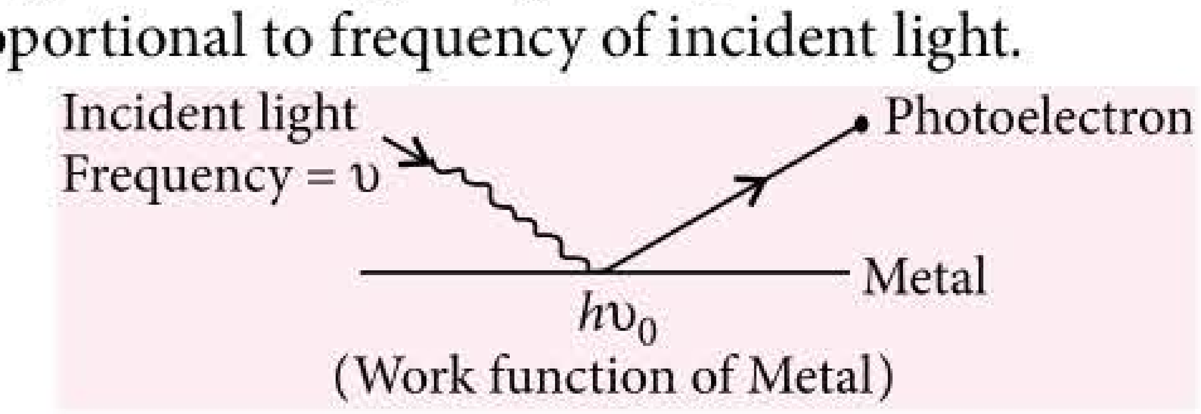
The number of α-particles deflected at angle θ in Rutherford's experiment $\propto \dfrac{Z^2}{\left(\sin\dfrac{\theta}{2}\right)^4}$.

Electrons were supposed to revolve around nucleus in some circular paths which was against the electromagnetic theory of Maxwell which says that when charged particle is accelerated it should emit radiations and as per calculations electron should fall into nucleus in less than 10^{-8} seconds.

Density of nucleus is fixed 1.685×10^{14} g cm^{-3}. Radius of nucleus is $1.33 \times 10^{-13} \times$ (mass number)$^{1/3}$ cm.

In 1900, Max Planck gave the name quantum to the smallest quantity (packet) of energy that can be absorbed or emitted in the form of electromagnetic radiation. This energy E is product of frequency of radiation and Planck's constant h (6.626×10^{-34} J s or 3.99×10^{-10} J s mol^{-1}), *i.e.*, $E = h\nu$. This explains that frequency of emitted radiation, from the black body, goes from a lower frequency to higher by increase in temperature.

In 1887, Hertz performed experiment in which electrons were ejected from certain metals like K, Cs, etc. when they were exposed to light of certain minimum frequency. The phenomenon is called photoelectric effect. The number of electrons ejected is directly proportional to intensity of light and energy of ejected photoelectron is directly proportional to frequency of incident light.



$h\upsilon_0$ is the work function of metal, *i.e.*, the minimum energy required to eject electron.

In 1905, A. Einstein calculated the kinetic energy of photoelectron as $\dfrac{1}{2}mv^2 = h\upsilon - h\upsilon_0$

If λ and λ_0 are wavelengths of incident light and wavelength that corresponding to υ_0,

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velocity of ejected electron is

$$v = \left[\frac{2hc}{m}\left(\frac{\lambda_0 - \lambda}{\lambda_0\lambda}\right)\right]^{1/2}$$

In 1885, Balmer observed the emission in visible spectrum of hydrogen under excited state. Balmer's formula for this emission was ($\bar{\upsilon}$, wave number $= \frac{1}{\lambda}$, the number of waves in unit length).

Wave number, $\bar{\upsilon} = \left(\frac{1}{2^2} - \frac{1}{n^2}\right) R\ \text{cm}^{-1}$.

Here R, has value 109677 cm^{-1} and $n > 2$

Later, in 1890, Rydberg generalised the equation as $\bar{\upsilon} = \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) R Z^2\ \text{cm}^{-1}$, to explain other emissions in one electron species having atomic number Z, like Li^{2+}, He^+, etc.

$n_1 = 1$, Lyman series – UV region

$n_1 = 2$, Balmer series – Visible region, H_α – red line, H_β – green line, H_γ – blue line and H_δ – violet line

$n_1 = 3$, Paschen series – IR region

$n_1 = 4$, Brackett series – IR region

$n_1 = 5$, Pfund series – Far IR region

$n_1 = 6$, Humphrey series – Far IR region

When $n_2 = \infty$, the spectral line is called limiting line.

In 1913, using Planck's theory of quantisation of energy and quantisation of angular momentum of motion of electron, Bohr gave following postulates and calculations (formulae) related to energy, angular momentum, velocity, etc., related to electron in H atom and species having one electron only.

(a) Electrons move around the nucleus in some definite circular paths or shells or orbits or stationary states numbered as 1, 2, 3, ... n (Principal quantum number) or denoted as K, L, M, ... etc. n^{th} shells has n complete electronic waves.

Higher the shell number, higher is the energy $E_1 < E_2 <$ .... but $(E_2 - E_1) > (E_3 - E_2) >$ ....

$$\text{Energy } E_n = -\frac{2\pi^2 me^4 Z^2 k^2}{n^2 h^2}\ [k = 9 \times 10^9\ \text{N m}^2\ \text{C}^{-2}]$$

$$= -2.18 \times 10^{-18}\frac{Z^2}{n^2}\ \text{J atom}^{-1} \text{ or } -13.6\frac{Z^2}{n^2}\ \text{eV atom}^{-1}$$

$$\text{or } 1.312 \times 10^6 \frac{Z^2}{n^2}\ \text{J mol}^{-1}$$

$$[1\ \text{eV} = 1.6 \times 10^{-19}\ \text{J} = 96.48\ \text{kJ mol}^{-1} = 23.06\ \text{kcal mol}^{-1}]$$

–ve sign of energy shell indicates the release of energy of electron as it enters the vicinity of nucleus from infinity where its energy *w.r.t.* force of nucleus is considered zero.

Radius of n^{th} shell,

$$r_n = \frac{n^2h^2}{4\pi^2\ me^2 Zk} = 0.529\frac{n^2}{Z}\ \text{Å} = r_0\frac{n^2}{Z}\ \text{Å}$$

Total energy of an electron = *K.E.* + *P.E.*

$$= \frac{kZe^2}{2r} - \frac{kZe^2}{r} = -\frac{kZe^2}{2r}$$

Velocity of electron in n^{th} shell,

$$V_n = 2.18 \times 10^8\ Z/n\ \text{cm s}^{-1}$$

Number of revolutions (orbit frequency) per second

$$= 6.66 \times 10^{15}\ Z^2 / n^3$$

Time period, time for one revolution

$$= 1.5 \times 10^{-16}\frac{n^3}{Z^2}\ \text{second}$$

(b) Only those shells are possible for which the angular momentum mvr is integral multiple of $\frac{h}{2\pi}$, *i.e.*, $mvr = \frac{nh}{2\pi}$.

(c) So long as an electron is in its normal or ground state, it does not lose energy and the energy of electron is equal to that of the orbit. Jump of electron from higher (excited state) to lower orbit releases the difference of energy between the two orbits as photons and reverse results in absorption of photon.

$$\Delta E = E_{\text{final}} - E_{\text{initial}}$$

$$= -2.18 \times 10^{-18}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) Z^2\ \text{J atom}^{-1}$$

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