ATOMIC STRUCTURE

Fundamental Particles:

Main Fundamental Particle :

(a) Electron: It is a fundamental particle of an atom which carries a unit negative charge. It was discovered by J.J. Thomson (1897) from the studies carried out on cathode rays in the discharge tube. When a high voltage current (10, 000 volts) is passed between two electrodes in a discharge tube containing a gas (which is a poor conductor of electricity) at a very low pressure (0.01 mm Hg), a stream of negatively charged particles flow from cathode (metal rod) to anode. These rays were called cathode rays & consisted of stream of negatively charged particles called electrons.

Properties :

- It is the lightest particle also known as β - particles
- It carries 1.6×10^{-19} coulombs or 4.8×10^{-10} esu charge.
- It's mass is about 1/1837 times the mass of hydrogen atom. Thus mass of electron is 9.1×10^{-28} gm or 9.1×10^{-31} kg or 0.0005486 amu.
- The e/m ratio of electron is constant irrespective of the nature of the gas & the metal, used in discharge tube experiment.
- Ratio of e/m, as estimated by Thomson is 1.76×10^{8} coulombs / gm
- It is represented by $_{-1}e^{0}$.
- Radius of electron is 2.8×10^{-13} cm .

(b) Proton: An atom is electrically neutral and electron contain negative charge, it follows that an equal magnitude of positive electricity must also be present in an atom. Goldstein (1886), when used perforated cathode in discharge tube experiment found that in addition to cathode rays, there are positive rays, called canal rays; moving in the opposite direction. By studying the behaviours of these rays in electron & magnetic field, these rays were found to consist of heavy positively charged particles, called protons.

Properties:

- It contain $+1.6\times10^{-19}$ coulombs or $+4.8\times10^{-10}$ esu charge.
- The mass of proton is nearly equal to that of the hydrogen. It is 1.672×10^{-27} kg or 1.672×10^{-24} gm or 1.00782 amu
- e/m ratio for proton depends on the gas taken in the discharge tube experiment. e/m of proton is 9.58×10^{-38} coulomb/gm
- Volume of proton is 1.5×10^{-38} cm^3 or nuclear density is of the order of 10^{14} gm/cm^3.

(c) Neutron: Chadwick (1932) discovered that when Beryllium was bombarded by α – particle , a subatomic particle of mass slightly greater than proton & neutral in origin obtained. It is called neutron. It is not deflected by electric and magnetic field.

Properties:

- It has mass 1.675×10^{-24} gm or 1.675×10^{-27} kg or 1.00866 amu
- It is heaviest particle of an atom.
- Neutron and proton resides at the centre of atom called nucleus.
- Neutron and proton together called as nucleons.
- Neutron can disintegrate into proton and neutron.

Some Uncommon Fundamental particles:

(i) Positron : $\left({}_{+1}e^{0}\right)$ - It is the positive counterpart of electron, discovered by Anderson (1932). It is very unstable and combines with electron producing γ – rays

(ii) Neutrino: These are discovered by Paulling (1934) & have small ($\simeq 0$) mass and zero charge.

(iii) Antineutrino: These were discovered by Fermi (1934) & is identical to neutrino but having opposite spin.

(iv) Mesons: These were discovered by Yukawa (1935). They may be positively, negatively or neutral. Their mass is intermediate between that of an electron and a proton.

Mesons	Charge	Mass
μ	$+/-$	$286\ m_e$
π	$+/-/0$	$270\ m_e$
k	$+/-/0$	$970\ m_e$

(v) Antiproton: It mass is equal to a proton and charge is equal to an electron.

(vi) Antneutron: It's mass is equal to a neutron and charge is equal to zero. It is identical to neutron but opposite spin.

Some Important Definitions:

(i) Isotopes: The atoms of an element which have the same atomic numbers but different atomic mass. They have same chemical properties but different physical properties. Isotopes have different number of neutrons.

e.g. (i) ${}^{16}_{8}O, {}^{17}_{8}O, {}^{18}_{8}O$ (ii) ${}^{1}_{1}H, {}^{2}_{1}H, {}^{3}_{1}H$ (iii) ${}^{14}_{7}N, {}^{15}_{7}N$

(ii) Isobars: Different atoms which same atomic masses but different atomic numbers.

e.g. ${}^{40}_{18}Ar, {}^{40}_{19}K, {}^{40}_{20}Ca$

(iii) Isotones: Those which contain same number of neutron.

e.g. ${}^{30}_{14}Si, {}^{31}_{15}P, {}^{32}_{16}S$

(iv) Isoelectronic: Those atoms or ion which have same no. of electrons are known as isoelectronic.

e.g. ${}_{17}Cl^{-}, {}_{18}Ar^{-}, {}_{19}K^{+}, {}_{20}Ca^{++}$

(vi) Isodiaphers: The element which have the same value of (N – P) is called isodiapheres.

e.g. ${}^{7}_{3}Li, {}^{9}_{4}Be, {}^{11}_{5}B, {}^{13}_{6}C$

Bohr's theory of hydrogen atom

It depends upon Max Planck's Quantum theory.

Postulates: Neils Bohr (1913)

(i) The electrons travel in orbits that have discrete quantized speeds & therefore, quantized energies. That is, not every orbit is possible but only certain specific ones, at certain specific distances from nucleus.

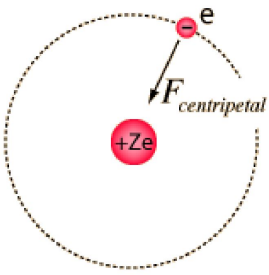
(ii) The electrons do not continuously lose energy as they travel. They can only gain & loose energy by jumping from one allowed orbit to another.

(iii) When an electron makes a jump from one orbit to another, the energy difference is carried away (or supplied) by a single quantum of light (called a photon) which has an energy equal to the energy difference between two orbit.

(iv) The frequency of the emitted photon is one over the classical orbit period, corresponding to the classical emission frequency.

(v) Electron can move only in those orbit in which their angular momentum is an integral multiple of $h/2\pi$.

$$\text{i.e. } mvr = \frac{nh}{2\pi}$$



Newton's Second Law

$$= \frac{mv^2}{r} = \frac{Ze^2}{4\pi\varepsilon_0 r^2} \text{ so } T = \frac{mv^2}{2} = \frac{Ze^2}{8\pi\varepsilon_0 r}$$

Kinetic Energy T

Potential Energy

$$U = \frac{-Ze^2}{4\pi\varepsilon_0 r}$$

Total Energy

$$T + U = \frac{-Ze^2}{8\pi\varepsilon_0 r}$$

The orbit energy is negative because this is a bound state.

This is the energy of a single electron in orbit around a bare nucleus.

Thus angular momentum is quantized.

Application of Bohr's theory:

1. Radius of nth orbit: For H and H like atoms $\left(Li^{+}, Be^{++}\right)$

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

where h = Planck's constant, m = mass of electron, e = charge on electron
Z = atomic number, n = orbit number

On putting value of known constant.

$$\boxed{r_n = 0.529 \times \frac{n^2}{z} \text{Å}}$$

2. Velocity of an electron in n^{th} shell:

$$v_n = \frac{2\pi Ze^2}{nh}; \quad \boxed{v_n = 2.188 \times 10^8 \times \frac{Z}{n} \text{cm/sec}}$$

3. Energy of electron in n^{th} orbit:

$$\boxed{E_n = -\frac{2\pi^2 m\, e^4\, Z^2}{n^2h^2}}$$

$$\text{Total energy} = \frac{\text{Potential energy}}{2} = -\text{kinetic energy}$$

(i) $\text{Total energy} = -13.6 \times \frac{Z^2}{n^2}\ \text{eV/atom} = -1312 \times \frac{Z^2}{n^2}\ \text{kJ/mole} = -2.18 \times 10^{-19} \times \frac{Z^2}{n^2}\ \text{J/atom}$

Ionisation Energy: During ionisation an electron moves from lowest energy state to infinity, where there is no force of attraction and thus $E_\infty = 0$

$$\therefore \quad \Delta E = E_\infty - E_1 = 0 - \left(-13.6\,\frac{Z^2}{n^2}\right)\text{eV/atom}\,; \quad \boxed{\Delta E = 13.6\,\frac{Z^2}{n^2}\ \text{eV/atom}}$$

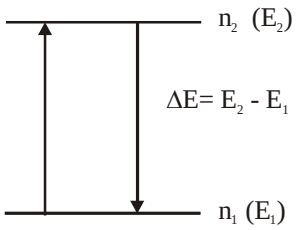
Electromagnetic Radiations: The radiations which do not deviate from electric and magnetic field, and travel in vacuum with speed of light.

e.g.: Radio waves, microwaves, X-rays, γ – rays , I.R. UV, visible and Cosmic rays.

Emission Spectrum of hydrogen: During the display of emission spectrum, material is radiated with heat or electricity, this causes excitation of electron by absorption of energy. On relaxation this absorbed energy is lost as light radiation and gives emission spectrum. In emission spectrum of hydrogen atom, there are six types of emission lines. It can be explained by taking a sample of hydrogen which contain millions of hydrogen atom. Thus different atoms absorb different amount of energy and then relaxes upto different level. Thus gives various spectral line.

The wavelength or wavenumber of light can be obtained by energy difference between two levels.

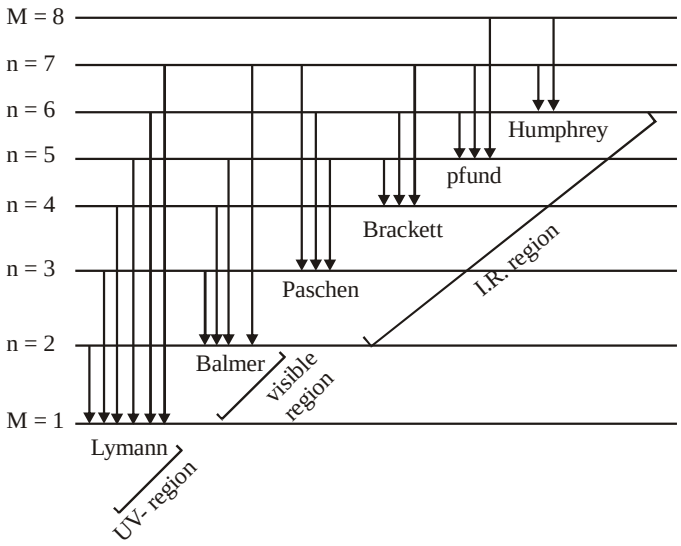
$$\Delta E = -\frac{2\pi^2 Z^2 e^4 m}{n_2^2 . h^2} - \left(-\frac{2\pi^2 Z^2 e^4 m}{n_1^2\, h^2}\right)$$



$$\frac{hc}{\lambda} = \frac{2\pi^2 me^4}{h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]Z^2\,; \quad \boxed{\bar{V} = R_H\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]Z^2}\ \text{cm}^{-1}$$

Where, $\bar{V} = \frac{1}{\lambda}$ = wavenumber; R_H = Rydberg constant (109677 cm^{-1})

$$\boxed{\bar{V} = 109677\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]Z^2}$$



(i) For Lymann series :

$$n_1 = 1,\ n_2 = 2,3,4,5.... \qquad \therefore \qquad \bar{V} = R_H\left[\frac{1}{1^2} - \frac{1}{n_2{}^2}\right]Z^2$$

(ii) For Balmer Series:

$$n_1 = 2;\ n_2 = 3,4,5,6.... \qquad \bar{V} = R_H\left[\frac{1}{2^2} - \frac{1}{n_2^2}\right]Z^2$$

(iii) For Paschen series:

$$n_1 = 3;\ n_2 = 4,5,6,7....; \qquad \bar{V} = R_H\left[\frac{1}{3^2} - \frac{1}{n_2^2}\right]Z^2$$

(iv) For Brackett series:

$$n_1 = 4;\ n_2 = 5,6,7,8.... \qquad \bar{V} = R_H\left[\frac{1}{4^2} - \frac{1}{n_2^2}\right]Z^2$$

(v) For pfund Series:

$$n_1 = 5;\ n_2 = 6,7,8,9; \qquad \bar{V} = R_H\left[\frac{1}{5^2} - \frac{1}{n_2^2}\right]Z^2$$

(vi) For Humphrey Series:

$$n_1 = 6;\ n_2 = 7,8,.... \qquad \bar{V} = R_H\left[\frac{1}{6^2} - \frac{1}{n_2^2}\right]Z^2$$

Note: If an electron from nth excited state comes to various energy states, the maximum spectral lines obtained will be $= \frac{n(n-1)}{2}$.

Limitations of Bohr's theory:

(i) It fails to explain spectra to atoms with more than one electron. It can only explain the spectra of hydrogen and single electron species like He^+, Li^{2+}, Be^{3+} etc.

(ii) It does not explain fine structure of spectral lines.

(iii) It does not explain Zeeman effect (Splitting up of spectra lines in presence of a magnetic field) & stark effect (splitting up of spectral lines in presence of an electric field)

(iv) Fails to recognise wave property of electron propode by de Broglie.

Wave - Particle Duality of Matter/de-broglie equation: "All the discrete particles of matter in motion (e.g. electron, proton, neutron, atoms and molecules) possess particle as well as wave characteristics, i.e. dual character is not only possessed by radiation but also by all the microscopic particles of matter."

It means that an electron or other microscopic particle is neither a particle nor a wave. It is an entity which is capable of developing one of these features depending upon the type of the interaction with external world.

de-broglie's equation:

From Planck' equation, $E = hv$, $\left(\because\ v = \frac{c}{\lambda}\right)$

$$E = \frac{hc}{\lambda} \qquad \text{... (1)}$$