Nuclear Models

(Paper CC -V, M.Sc. Sem II)

History of Nuclear Models

- The discovery of neutron by Chadwick in 1932 and the recognition of the fact that nuclei of all atoms consists of neutrons and protons progressed the knowledge of atomic nuclei.
- Between, 1932-1936, it was believed that certain number of nucleons of one kind, proton or neutrons formed closed shells and they don’t interact with one another as similar to the electrons in different orbitals in outer sphere of atoms.
- 1936-1948, Neil Bohr and Frenkel independently suggested the opposite of above mentioned fact that nucleons interact strongly irrespective of their charge. According to them, the nucleus is a homogenous entity with strong interaction amongst all the neighbors.

- This model envisages the nucleus as homogenous entity with interaction among the neighbours as molecules of ***liquid drop.*** The behaviour is explained on the basis of statistics and not on the individual characteristics.
- In 1948, Maria Geoppart-Mayer and Jensen highlighted many discontinuities in the nuclear properties experimentally. These were stability, abundance, binding energy, neutron absorption and cross section recurring every time the number of protons or neutrons reached 2, 8, 20, 50, 82 and 126 and they termed it as ***Magic Numbers.***
- Geoppart-Mayer, Jensen, Haxel and Suess also contributed to the development of independent particle or ***Shell Model*** that envisages spin-orbit coupling of nucleons in the same shell.

SHELL MODEL

- The shell model assumes that the nucleons are distributed in a series of discreet energy levels satisfying certain quantum mechanical conditions, not unlike the electrons in outer-sphere.
- A close shell is formed as the capacity of the level is reached and the protons and neutrons are in different shells.
- Since, the motion of individual particle is taken into consideration here, this model is also known as single particle model applicable mostly to the nucleons in the ground state.
- The model is consistent with observed periodicity in the nuclear properties.

Periodicity in Nuclear Properties: The Magic Numbers

- Similar to the periodic variations in the properties of elements with the number of electrons in the atoms, as 2, 10, 18, 36,54 and 86 for the classification of elements, there is analogy in the nuclear properties that vary periodically.
- The period comes to an end when the number of protons or neutrons in nucleus is equal to 2, 8, 20, 50, 82 or 126 referred as Magic numbers.
- The variations in properties can be discussed as further.

1. Tendency of Pairing

- Nucleons form pair up to form a stable bonds similar to that of electrons (neutrons form pair with neutrons and protons form pair with the protons).
- Even-Z, even-N nuclides are the most abundant amongst stable nuclides in nature:165 out of 274.
- The (n+n); (p+p); (n+p) rule for the formation of stable nuclides from ^{16}O to ^{35}Cl is another evidence for this. According to this rule all odd-Z elements have only one while even-Z elements have three stable isotopes over this region.
- The heaviest stable nuclide in nature is ^{209}Bi with 126 neutrons.
- The stable end product of naturally occurring radioactive series of elements is Pb with 82 protons, while for man made is ^{209}Bi with 126 neutrons.

2. High Mean Binding Energy

- The maxima occur in a plot of mean Binding energy as a function of A, at the magic numbers of Z or N.
- The Z and N are magic numbers and in $^{4}He,\ ^{40}Ca,\ ^{208}Pb,\ ^{16}O,$ the binding energy per nucleon is very high.

3. Abundance in Nature

- The abundantly occurring nuclide are those with magic numbers of protons or neutrons or both. Oxygen (n+p=16) is one such examples.
- The large fluctuations up-to ^{19}F are attributed to the preferential use up in the subsequent thermonuclear reactions.

4. Number of Stable isotopes and Isotones

- The number of isotopes of a given element (Z constant) which are stable is a reflection of the relative stability of that element. If this number is plotted as a function of Z, distinct peak occurs at Z=20 (Ca), 50 (Sn) and 82 (Pb) compared with their immediate neighbours of Z value ± 1 of the above values, similarly for the isotones where the number of neutrons are constant.