Nuclear forces

After the establishment of proton - neutron structure of the nucleus, a question came to the minds of scientists that what holds the nucleons inside the nucleus of very small size i.e 10^{-15} m. First of all, it was thought that the gravitational force (due to masses of protons) which is attractive in nature is greater than the Coulomb's repulsive force between the protons. But, calculations showed that Coulomb's repulsive force between two protons is 10^{36} times greater than the gravitational force between them. Then to account for the stability of a nucleus, a new force called nuclear force was postulated by a Japanese physicist Yukawa. This nuclear force was assumed to be strong attractive force and its magnitude is greater than the Coulomb's repulsive force. Yukawa predicted that the nuclear forces arise due to the exchange of particles known as π-mesons between the nucleons.

Since these forces are highly complex in nature and there is no simple way to demonstrate how the exchange of meson particles between nucleons lead to attractive forces, so the process can be understood with the help of the following simple analogy:

Imagine two interacting nucleons are two dogs and a meson particle as a piece of bone. Each of the two dogs tries to snatch the piece of bone from each other. The bone is rapidly exchanged between the two dogs as neither of them can part with it. Thus, the rapidly exchanging bone keeps the two dogs bound together. Similarly, the exchange of π-mesons keeps the two nucleons bound together in the nucleus.

So nuclear forces are the strong forces of attraction which hold together the nucleons (neutrons and protons) in the tiny nucleus of an atom, inspite of strong electrostatic forces of repulsion between protons.

These forces are very complex in nature. Some of the important characteristics of these forces are:

(i) Nuclear forces act between a pair of neutrons a pair of protons and also between a neutron, proton pair with the same strength. This shows that nuclear forces are independent of charge.

(ii) Nuclear forces are the strongest forces in nature. The magnitude of nuclear forces is 100 times that of electrostatic forces and 10^{38} times that of gravitational forces between nucleons. That is why, nucleons are held together in a nucleus in spite of electrostatic force of repulsion between protons.

(iii) The nuclear forces are very short range forces. They are operative upto distances of the order of a few fermi.

(iv) ⓐ Nuclear forces are negligible, when distance between nucleons is more than 10 fermi.

ⓑ When nucleons are brought closer, nuclear force of attraction develops which goes on increasing rapidly with decreasing distance.

ⓒ When distance between nucleons becomes less than 0.5 fermi; the nuclear forces become strongly repulsive.

(v) The nuclear forces show saturation properties i.e each nucleon interacts with its immediate neighbours only, rather than with all the other nucleons in the nucleus.

(vi) The nuclear forces are dependent on spin or angular momentum of nuclei.

(vii) Nuclear forces are non central forces. This shows that the distribution of nucleons in a nucleus is not spherically symmetric.

(viii) According to Yukawa, nuclear forces can be treated as exchange forces which result from the continual exchange of a particle called π-meson between a proton and a neutron.

In brief → Nuclear forces are the strongest attractive forces between nucleons - which are independent of charge, short range, non-central, non conservative forces not obeying inverse square law.