$A = 3$ Clustering in Nuclei

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Nuclear physics is studied within the framework of various models. The Independent Particle Shell Model and the Liquid Drop Model form the backbone of current nuclear physics. However due to strong evidences of the presence of α-cluster, (as per current understanding) there has been a growing acceptance of the so called α-cluster model.

Here we point out that the equally prominent and equally significant is the role of $A = 3$ clusters in nuclei and highlight several experiments which provide equally strong evidences as that of α, of the presence of triton and helion in nuclei. Some of the empirical informations, we feel, are very compelling and should not be ignored. This point of view is however in conflict with the prevailing view that due to the requirement of Pauli Exclusion principle primarily, this just can not be. We examine these arguments in depth and point out as to how to get around this conundrum - that is how to reconcile the compelling evidences of the presence of helion(h)- and triton(t)- clusters in nuclei versus the theoretical models which do not really allow them (h- and t-) as pre-existing entities inside nuclei. These arguments will be shown here to lead us to a model which should allow us to attain a better, improved and more internally consistent understanding of the nucleus.

Though the concept of alpha cluster studies have been a dominating factor in experimental studies of nuclei, very significant and in some situations, quite prominent, have been experimental studies proving the clear and unambiguous existence of ^{3}He and ^{3}H clusters in nuclei. In fact, these empirical evidences of $A = 3$ clustering in nuclei are as strong as that of $A = 4$ clustering (e.g. [1] for small samples) and also that $A = 4$ has itself a substructure of $A = 3$ [2].

As to why h-, t-, and α- form sub clusters inside nucleus? It is very often stated that formation of α-clusters inside nuclei is due to the fact that α- has such large binding energy of 28 MeV. But then t- and h- have much smaller binding energy $\sim$8 MeV. Therefore if this was the only requirement for the creation of cluster inside nucleus, then h- and t- clusters should not exist inside nuclei. But as we have seen there have been several experiments which have clearly indicated presence of t- clusters and h- clusters in nuclei. If the reason for cluster formation inside nuclei is not only due to their binding energies then why do these cluster at all exist inside nuclei?

For this let us point out the t- and h- nuclei are pretty much compact and have unique density distributions too. When one looks at the density distribution of all nuclei $A = 2$ to large, one is struck by the remarkable fact that the 'average' central density of α- and ^{3}He is about twice as large as the density of all the nuclei. Note that the density of t- is also like that of ^{3}He nucleus. Here the densities of α-, h-, t- are completely different from those of other nuclei. This difference clearly indicates the fact that these h, t, and α should be treated differently from other nuclei. In addition ^{3}He, ^{3}H, and ^{4}He have a hole at the center which again mark them off as quite different from all other nuclei. We suggest here that the primary reason for the formations of clusters of $A = 3$ and $A = 4$ nuclei is due to their unique and identical density distributions. It also shows why no other nucleus may form good cluster substructures in nuclei. None have such high and hole-like density profiles.

In our model the fundamental building blocks are (n, p) as basis for $SU(2)_T$ isospin

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symmetry and (h, t) as basis for a new $SU(2)_{\mathcal{A}}$ nusospin symmetry. The motivation and experimental justifications are discussed elsewhere [3]. Here we point to a further support for $SU(2)_{\mathcal{A}}$ nusospin symmetry. Nagatani et al. [4] have demonstrated high selectivity in reactions involving transfer of three nucleons which is just as good as was the case for α- particle transfer and also transfers to mirror final states yield essentially identical spectra. Very significant is the fact that essentially identical spectra was found in all the helion transfer studies by different groups they concluded that these reactions represents a powerful reaction-mechanism-independent method of finding corresponding analogue states in the residual nuclei.

This significance of analog states for mirror nuclei is due to isospin symmetry $SU(2)_T$ of (n, p) fundamental representation. Isospin invariance means that the wave function of a given isospin T are unchanged if we replace some of the neutrons by protons or vice versa. This transformation takes us from one member of isobar to another. The wave function of these two isolated analogue states are related to each other through isospin raising and lowering operator. Hence the two states must have essentially the same properties except that some of the neutrons are replaced by corresponding protons. A special case is that of mirror nuclei which have the same number of nucleons except the mirror change of number of protons and neutrons. Thus isospin requires that in these mirror nuclei, the energy level spectra and the properties of various states should be similar (ignoring coulomb interaction) to each other. But is this what they [3] are getting [3].

Suppose we were not aware of isospin symmetry $SU(2)_T$ between n and p states and we did same experiments of a single nucleon transfer only and found spectra independent of whether it was n or p which was transfered. So for example for ^{15}O and ^{15}N we may have the structure

$$^{15}_{8}\mathrm{O}_7 \sim {}^{14}_{7}\mathrm{N}_7 + p; \quad {}^{15}_{7}\mathrm{N}_8 \sim {}^{14}_{7}\mathrm{N}_7 + n$$

and support that in these residual nuclei in one nucleon transfer we found similar spectra, then we would conclude that there is a "new symmetry" indicating invariance under the change $n \leftrightarrow p$. And that this would be $SU(2)_T$ the isospin symmetry for (n, p) representation.

But here in the experiments under discussion it is **one shot transfer** of h- and t- as a single entity. The residual nuclei which show identity of spectra have actually a structure

$$^{15}_{8}\mathrm{O}_7 \sim {}^{16}_{6}\mathrm{C}_6 + {}^{3}_{2}\mathrm{He}_1; \quad {}^{15}_{7}\mathrm{N}_8 \sim {}^{12}_{6}\mathrm{C}_6 + {}^{3}_{1}\mathrm{H}_2$$

hence the identity of spectra here should be indicature of a new symmetry where the spectra does not distinguish between the exchange of ${}^{3}_{2}\mathrm{He}_1 \leftrightarrow {}^{3}_{1}\mathrm{H}_2$. this means that there should exist a 'new' $SU(2)$ symmetry with (h, t) forming the fundamental representation. And indeed this is exactly the $SU(2)_{\mathcal{A}}$ nusospin symmetry already discussed. Hence, in contrast to what they claimed [3], these experiments are demonstrating invariance under the new nusospin symmetry $SU(2)_{\mathcal{A}}$ and not under the $SU(2)_T$ isospin symmetry. This clearly shows that the (h, t) as leading to a new $SU(2)_{\mathcal{A}}$ nusospin symmetry be taken as fundamental, actually fundamental as $SU(2)_T$ (n, p) isospin symmetry.

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