Triton clustering in neutron-rich nuclei

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In 1965, The phenomenological Elementary Particle Model (EPM) was first introduced by Kim and Primakoff [1], in which, trinucleon systems, $(^3\mathrm{He},^3\mathrm{H}) \simeq (\mathrm{h},\mathrm{t})$ are treated as elementary. In analogy with the corresponding nucleon weak currents, EPM parametrizes the nuclear charge-changing currents in terms of the trinucleon form factors. Amazingly this is found to give as good a result as those obtained with more complicated composite structures for the ground state in nuclear microscopic models.The point is that in EPM there is surprising elementarity being associated with the nuclear pair (h,t).

Within the sphere of low energy nuclear structure studies a new group $\mathrm{SU}_{\mathcal{A}}(2)$ called nusospin has been proposed [2]. Just as one takes the pair (p,n) as forming the fundamental representation of the nuclear SU(2) isospin group, in the same manner one hypothesises that the pair (h,t) forms the fundamental representation of the new nusopin $\mathrm{SU}_{\mathcal{A}}(2)$ group. In support of the nusopin group we find strong empirical evidence favouring A=3 clustering in nuclei [3]. We carry this concept forward by studying the role of the elemental nature of (h,t) in neutron rich nuclei to find new magicities and new properties supported by experimental and theoretical evidences which may demand new shell structure. We, therefore investigate the N=2Z neutron rich nuclei assuming that triton is their elementary constituent.

First of all, we look for the available experimental binding energies for such nuclei and extract one- and two-triton separation energies, which may respectively be obtained as,

$$\mathrm{s}_{1\mathrm{t}} = \mathrm{B}(^{\mathrm{A}}_{\mathrm{Z}}\mathrm{X}_{\mathrm{N}}) - \mathrm{B}(^{\mathrm{A}-3}_{\mathrm{Z}-1}\mathrm{Y}_{\mathrm{N}-2}) - \mathrm{B}(^{3}_{1}\mathrm{H}_2), \text{ and}$$

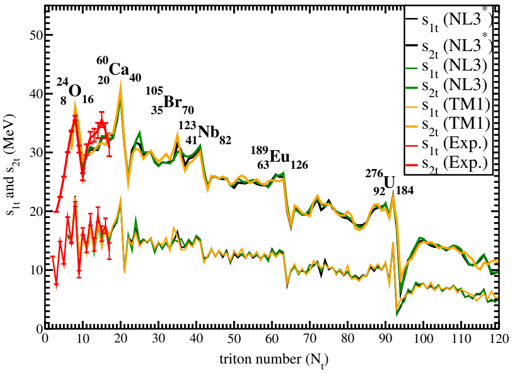

FIG. 1: One- and two-triton separation energies.

$$\mathrm{s}_{2\mathrm{t}} = \mathrm{B}(^{\mathrm{A}}_{\mathrm{Z}}\mathrm{X}_{\mathrm{N}}) - \mathrm{B}(^{\mathrm{A}-6}_{\mathrm{Z}-2}\mathrm{Y}_{\mathrm{N}-4}) - 2\mathrm{B}(^{3}_{1}\mathrm{H}_2)$$

The experimental binding energies are not available beyond $\mathrm{N}_t = 17$ bound systems. We, therefore, resort to relativistic mean field (RMF) theory to extend our calculation for a wide spectrum of N=2Z nuclei, $5 \leq \mathrm{N}_t \leq 120$.

The RMF theory has been successful in reproducing the experimental observations throughout the periodic table near as well as far from the stability line [4, 5]. It has also been persued to examine cluster structures inside the nuclei [6]. The relativistic Lagrangian for a many-body system contains all the information of nucleon-nucleon interaction via exchanges of $\sigma-$, $\omega-$ and $\rho-$ mesons. The possible interactions like TM1, NL3 and NL3* are used to solve the field equations.

The $\mathrm{s}_{1\mathrm{t}}$ and $\mathrm{s}_{2\mathrm{t}}$ extracted from calculated binding energies, agree with experimental data to a great extent in their overlap region. We plot $\mathrm{s}_{1\mathrm{t}}$ and $\mathrm{s}_{2\mathrm{t}}$ as a function of triton numbers (N_t) in Fig. 1.These separation energies exhibit odd-even effect in triton numbers. Whenever triton number is even,the triton separation energy is significantly higher

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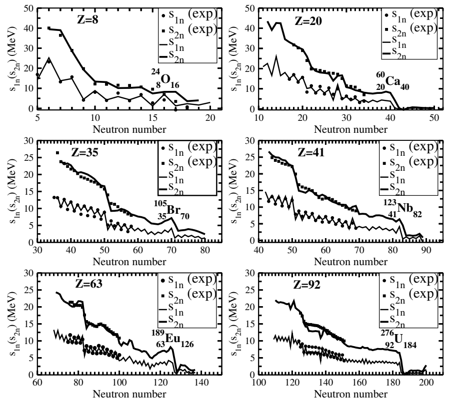

FIG. 2: One- and two-neutron separation energies (s_{1n} and s_{2n}, respectively) for the isotopes of the newly identified magic nuclei in Fig-1[taken from Ref. [7]].

than the adjoining odd triton numbers. This feature is similar to the odd-even effects seen in one neutron and one proton separation energies plotted with respect to the neutron and proton numbers, respectively. Two tritons in the same shell seem to be strongly paired, thereby leading to a stronger binding with respect to a single unpaired Titan. This appears like an identical particle t-t pairing in neutron rich nuclei. The odd-even effect of nucleons is found to be translated to effective tritons. The next most prominent feature in Fig. 1 is the first peak shown by data and RMF both e.g. for N_t=8 *i.e.* for $^{24}_{8}O_{16}$ and an equally sharp dip for N_t=9 i.e. for $^{27}_{9}F_{18}$. We know that such drops in one-neutron and one-proton separation energies when going from one Z/N number to the next one is a signal of magicity character of a particular Z/N number.Hence, N_t=8 is a magic number with respect to different bound states of tritons. Besides limited experimental data the vast RMF results clearly show N_t=8, 20, 35, 41, 63 and 92 as magic numbers, which correspond to N=16, 40, 70, 82, 126 and 184.

To know if these magic nuclei are effective manifestations of proton and neutron magic numbers or not, We investigate it in Fig. 2, wherein we plot one- and two-neutron separation energies (s_{1n} and s_{2n}) for the isotopes of these nuclei. This figure shows that for N=40, 70, 82, 126 and 184 there is a sharp fall indicating magicities at Z=N/2 i.e. triton numbers N_t=20, 35, 41, 63 and 92. A less significant fall is also seen for N=50 in the plots of Z=35 and Z=41 isotopes , which do not show up as magic numbers in the triton picture.

We further investigate the structural properties of these magic nuclei and calculate their quadrupole deformations. We observe smaller departure from sphericity for these newly identified magic nuclei compared to their nearby isotopes as given by deformation parameter (β_2) in Table 1.

TABLE I: β_2 for N=2Z and surrounding nuclei.

Nuclei	β_2	Nuclei	β_2	Nuclei	β_2
^{22}O	0.00580	^{58}Ca	0.0028	^{103}Br	0.04394
^{23}O	0.00505	^{59}Ca	0.00199	^{104}Br	0.07139
^{24}O	0.00468	^{60}Ca	0.0018	^{105}Br	0.01404
^{25}O	0.04971	^{61}Ca	0.00301	^{106}Br	0.03821
^{26}O	0.00553	^{62}Ca	0.00504	^{107}Br	0.03909
^{121}Nb	0.04916	^{187}Eu	0.06467	^{274}U	0.00007
^{122}Nb	0.00105	^{188}Eu	-0.00389	^{275}U	0.00387
^{123}Nb	0.01638	^{189}Eu	-0.00405	^{276}U	0.00005
^{124}Nb	0.04968	^{190}Eu	-0.00242	^{277}U	0.00020
^{125}Nb	0.04661	^{191}Eu	0.06915	^{278}U	0.00024

What seems to be happening in the neutron rich nuclei is that the degree of freedom changes from (p,n) of $SU_I(2)$ isospin structure to (h,t) $SU_{\mathcal{A}}(2)$ nusospin structure so much so that for $^{3Z}_{Z}X_{2Z}$ nuclei the predominant structure is that of Z-tritons [3]. With this hindsight now one look at Fig 1 and then the wisdom of the $SU_{\mathcal{A}}(2)$ nusospin model drawn upon us with the possibility of a new shell structure of tritons as proposed. The results discussed here are present in details in our recently published paper [7].

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