New proton and neutron magic numbers in neutron rich nuclei

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Abstract

It is now known that in neutron rich nuclei, old magic numbers disappear and new ones appear. Single nucleon and double nucleon separation energies are plotted here in all possible manner. Using this data it is shown here for the first time that nuclei with pair of proton number $Z$ and neutron number $N (Z,N) : (6,12), (8,16), (10,20), (11,22) \text{ and } (12,24)$ exhibit exceptional stability or magicity. As such these magic numbers appear in pairs. This correlation is shown here to be indicative of predominance of tritons in the ground state of these neutron rich nuclei. Thus $^{30}\text{Ne}$ has the structure of $^{10}_{1}H_{2}$ in the ground state. This confirms the prediction of the author that triton clustering in neutron rich nuclei as a new phenomenon.
The study of neutron rich nuclei with the help of RI beams has been proving to be full of surprises. First the halo structure cropped up and now the realization that in the neutron rich nuclei the standard magic numbers may disappear and new ones may arise in an unanticipated manner [1,2,3,4]. In this letter the focus is the study of these new magicities in neutron rich nuclei. Single nucleon and double nucleon separation energies are analyzed in the standard manner and also in a slightly different manner as discussed below. Evidence for new magic numbers will be discussed. Interestingly proton and neutron numbers are found to be uniquely and consistently correlated in these new magicities. It shall be pointed out that the only possible way to understand this correlation is through the effect of triton clustering in neutron rich nuclei. It will be emphasized that triton clustering - a new effect predicted by the author [5], is for real.

To discuss magicity one normally plots separation energies \( S_{1n} \) and \( S_{2n} \) as a function of neutron number \( N \) for a particular proton number \( Z \) or plot \( S_{1p} \) and \( S_{2p} \) as a function of \( Z \) for a particular \( N \). It is very common to plot \( S_{2n} \) and look for kinks as evidence for magicity [3,4]. In addition to plotting the separation energies in the above standard manner, we plot the separation energies a little differently. We plot \( S_{1n} \) and \( S_{2n} \) as a function of \( Z \) for a particular \( N \). The same with \( S_{1p} \) and \( S_{2p} \) as a function of \( N \) for a particular \( Z \). We shall find here that these new plots give useful and distinguishable information regarding stability and magicity in these light nuclei.

We plot separation energies for neutron number \( N \) and for proton number \( Z \) fixed separately at 4, 6, 8, 10, 11, 12, 16, 20, 22 and 24. For example Fig 1 and Fig 2 are respectively plots of \( S_{1n} \) and \( S_{2n} \) for fixed \( N= 4, 6, 8, 10, 11, 12, 16, 20, 22 \) and 24 plotted as a function of \( Z \). Figs 3 and 4 are respectively plots of \( S_{1n} \) and \( S_{2n} \) for fixed \( Z= 4, 6, 8, 10, 11, 12, 16, 20, 22 \) and 24 as a function of \( N \). Figs 5 and 6 plot \( S_{1p} \) and \( S_{2p} \) respectively for \( N \) fixed at the above set as a function of \( Z \) and Figs. 7 and 8 are \( S_{1p} \) and \( S_{2p} \) plotted respectively for \( Z \) fixed at the above set for different \( N \). So what we have plotted are \( N \) fixed ( isotones ) for \( S_{1n}, S_{2n}, S_{1p} \) and \( S_{2p} \) all as functions of \( Z \) and also for \( Z \) fixed ( isotopes ) \( S_{1n}, S_{2n}, S_{1p} \) and \( S_{2p} \) all as functions of \( Z \).

In every case we notice the extra stability for all the cases wherein \( N=Z \). This extra stability for even-even \( N=Z \) nuclei is attributed to the significance of \( \alpha \) clusters. So for \( ^{20}_{10} Ne^{10} \) ground state it is the 5-\( \alpha \) configuration which is believed to be important and thereby providing extra stability.

The reader’s attention is drawn to the extra-ordinary stability manifested
by the plotted data for the proton and neutron pairs (Z,N): (6,12), (8,16), (10,20), (11,22) and (12,24). The stability at these pair of numbers is sometimes as prominent as that at the N=Z pair. In fact the Z,N pair (10,20) stands out as the best example of this. Hence it is clear that the separation energy data very clearly shows that there are new magicities present in the neutron rich sector for the pair (Z,N) where N=2Z.

What is the significance of this extraordinary stability or magicity for the nuclei $\frac{3Z}{Z}A_{2Z}$? We already know that for the even-even Z=N cases it is the significance of $\alpha$ clustering for the ground state of these nuclei which explains this extra stability. Quite clearly the only way we can explain the extra magicity for these N=2Z nuclei is by invoking the significance of triton clustering in the ground state of these neutron rich nuclei. Thus $^{30}_{10}Ne_{20}$ has significant mixture of the configuration $10^3H_2$ in the ground state. It is these tritonic clusters which give the extra stability to these nuclei thereby provoking us with these unique new sets of magic numbers.

This tendency of triton clustering in neutron rich nuclei was already predicted by the author a few years ago [5]. The present paper shows that there is indeed strong empirical evidence in support of the author’s prediction [5]. If fact this may be treated as ”smoking gun” kind of evidence in support of significance of triton clusters in the ground state of $\frac{3Z}{Z}A_{2Z}$ nuclei.

One may ask to why the stability for a particular set is not manifesting itself in all the plots. One reason is that due to the limitation of the span of individual isotones and individual isotopes over the corresponding (Z,N) sets may not be rich enough. So it seems that neither the very low mass nor the high mass nuclei would provide discriminatory evidence in this regard. Intermediate mass nuclei like $^{30}_{10}Ne_{20}$ tend to show up this effect most prominently for the isotonic data. However there may be other pairs like (4,8) where though somewhat weaker there does appear to be manifestation of possible magic pairs. In this regard significance of the presence of different clusters like $\alpha$ and/or tritons for the ground state of a particular nucleus and also whether it is proton/protons or neutron/neutrons being pulled out will manifest itself in the structure of the data. This point is at present under investigation by the author.

Once the triton clustering aspect of nucleus $\frac{3Z}{Z}A_{2Z}$ is understood then extra stabilities in the intermediate cases like N=20 stability in $S_{2n}$ data for Z=16 can be understood as tendency of triton clustering to bring it about. One should be able to understand theses extra stabilities as mixing in the
shell model configuration of $\alpha$ - clustering and t-clustering configurations. Similarly the helion ("h") $^{3}He$ configuration may manifest itself especially in odd-odd N=Z nuclei. One already knows that h-t configuration mixes considerably with $\alpha$-n-p configuration to give a good understanding of the ground state of $^{\frac{6}{3}}Li_3$. Similar must be the case for the Z=12 stability of N=22 case of $S_{22}$ where all - $\alpha$-, t- and h- clustering may all be playing a role. Such cases have to be sorted and worked out in the future. Also there would be other explicit manifestations of triton clustering in data and which should be looked for. Here the purpose has been to bring out a few clear cut cases of the same so that there can be no doubt as to the correctness of the idea [5].

In short, here the aim is to understand as to which new magic numbers are arising in the neutron rich nuclei. With this aim single nucleon and double nucleon separation energies are plotted here in all possible manner. It is shown here that nuclei with pair of proton number Z and neutron number N (Z,N) : (6,12), (8,16), (10,20), (11,22) and (12,24) ( and possibly (4,8)) exhibit exceptional stability or magicity. This correlation is shown to prove the significance of tritons in the ground state of these neutron rich nuclei. Thus $^{30}_{10}Ne_{20}$ has the structure of $^{10}_{1}H_{2}$ in the ground state. This confirms the prediction of the author on the tendency of triton clustering in neutron rich nuclei [5]. Whole new questions shall arise from this new empirical fact.

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References

Figure 1: Single neutron separation energy as a function of Z for fixed N
Figure 2: Double neutron separation energy as a function of Z for fixed N
Figure 3: Single neutron separation energy as a function of N for fixed Z
Figure 4: Double neutron separation energy as a function of N for fixed Z
Figure 5: Single proton separation energy as a function of $Z$ for fixed $N$
Figure 6: Double proton separation energy as a function of Z for fixed N
Figure 7: Single proton separation energy as a function of N for fixed Z
Figure 8: Double proton separation energy as a function of $N$ for fixed $Z$.