Rearrangements in Neutron Shell Closures of Very Neutron-Rich Nuclei

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The study of the properties of extremely neutron- or proton-rich nuclei of light elements is a very important topic in the modern nuclear physics. The research in this field has revealed a halo and skin structure and other unique features that could result in the modification of magic numbers in very neutron-rich nuclei. A breaking of magicity has already been observed at the N=20 shell closure where an "island of inversion" in shell ordering has been shown to exist. Though some theoretical calculations predict the existence of new magic number N=16 [1], until recently no experimental evidence about magic numbers, substituting N=20, was available. Recently, we have presented a review [2] of experimental results obtained at GANIL suggesting the appearance of new magic number, N=16, in this region. Our finding was based on the following experiments.

An experiment on the LISE3 spectrometer, where we used the fragmentation of the neutron-rich projectile ^{36}S to produce and study very neutron-rich nuclei in vicinity of doubly magic ^{28}O [3]. No events were observed corresponding to oxygen isotopes ^{25,26,27,28}O and also to ^{24,25}N. It should be noted that the instability of ^{25,26,27,28}O and ^{24,25}N was also confirmed by Sakurai et al. [4] where, however, a new isotope, ^{31}F, was observed for the first time. Thus the heaviest experimentaly found isotopes of C, N and O have the same neutron number, N=16, while the heaviest isotope of fluorine was found to be ^{31}F with N=22.

The question of particle stability is directly related to the masses and nuclear binding energies, which are very sensitive to the existence of shells and may provide clear signature of shell closures. Therefore, an experiment on the mass measurement using a direct time of flight technique [5] was undertaken in order to investigate the N=20 and 28 shell closures for nuclei from Ne to Ar and thus to shed some light on the behaviour of magic numbers far from stability.

The nuclei of interest were produced by the fragmentation of a 60 AMeV ^{48}Ca beam on a Ta target. The separation energies of two last neutrons S_{2n} derived from the measured masses were plotted versus neutron number. The Ca, K and Ar isotopes show a behaviour typical of the filling of shells, with the two shell closures at N_{sh}=20 and 28 being evidenced by the corresponding sharp decrease of the S_{2n} at these points, and a slowly decreasing S_{2n} after the "flattening" point N_f=(N_{sh}+2) as the filling of the next shell starts to influence S_{2n}. The "flattening" point of the slope at N_f=22, corresponding to the existence of the shell N_{sh}=20, is clearly visible for Si-Ca region, while going to lower Z into the Al-Na region this point seems to move towards to lower N till it stabilizes at N_f=18 (new shell N_{sh}=16) for F and Ne.

Thus the behaviour of the "flattening" points in the S_{2n} values gives a very clear evidence for the existence of the new shell closure N=16 for Z=9 and 10 appearing between $2s_{1/2}$ and $1d_{3/2}$ orbitals. This fact strongly supported by the instability of C, N and O isotopes with N > 16, found in refs. [3,4], confirms the magic character of N=16 for the region 6$\leq$ Z $\leq$10, while the shell closure at N=20 tends to disappear for 6$\leq$ Z $\leq$13. This is in a good agreement with recently published work of Ozawa et al. [6] where the similar information on the magicity of N=16 was obtained from S_{1n} values and σ_I.

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