Shell evolution beyond $Z = 28$ and $N = 50$: spectroscopy of $^{81-84}$Zn[†]

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The Shell Evolution and Search for Two-plus states At the RIBF (SEASTAR) experimental campaigns were conducted at the Radioactive Isotope Beam Factory (RIBF). For the experiments a ^{238}U primary beam was accelerated to 345 MeV/nucleon and subsequently impinged onto a 3 mm thick ^{9}Be production target at the entrance of the BigRIPS separator. Secondary fission beams of interest were then selected within BigRIPS using the $B\rho$-ΔE-$B\rho$ technique. The results presented here on neutron-rich Zn isotopes were obtained from settings centered on ^{79}Cu and ^{85}Ga in the first (2014) and second (2015) SEASTAR campaigns, respectively.

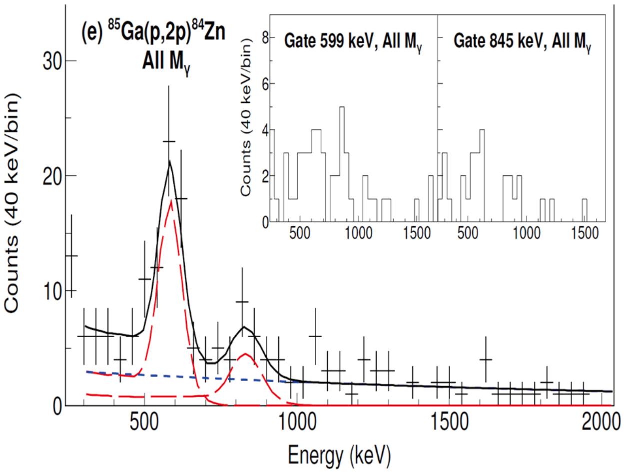

Fig. 1. Doppler corrected γ-ray spectrum of ^{84}Zn.

The incoming ions were impinged on the liquid H_2 target of the MINOS device, while the resulting γ rays were detected with the DALI2 high-efficiency NaI(Tl) array. Low-lying excited states in the neutron-rich $^{81-84}$Zn isotopes have been investigated. The 4_1^+ state in ^{82}Zn and the 2_1^+ and 4_1^+ states in ^{84}Zn (see Fig. 1) were observed for the first time. In addition, γ-ray transition were identified in odd-mass ^{81,83}Zn. The main experimental conclusion of the work is that the magicity is confined to neutron number $N = 50$ only, as indicated by the increased $R_{4/2} = E(4^+)/E(2^+)$ ratios in ^{82,84}Zn when compared to than in the neutron-magic ^{80}Zn nucleus.

A magic or semi-magic core can be distorted as valence nucleons are added to a closed shell. The samarium isotopes present a typical case. Shape evolution proceeds from a seniority level pattern in $N = 82$ semi-magic ^{144}Sm, to a vibrational pattern at $N = 86$ in ^{148}Sm, and finally a rotational one at $N = 92$ in ^{154}Sm. At $N = 84$ ^{146}Sm provides the transition between the seniority and vibrational schemes. In the case of Zn isotopes, with only two protons outside the $Z = 28$ shell, the situation is rather different. As deduced from the present experiment for the first time, the proton-neutron correlations are strong enough for a rapid change from the semi-magic structure at $N = 50$ to a collective structure at $N = 52$. This is partly due to the weak $Z = 28$ sub-magic structure, which is a consequence of the repulsive nature of the tensor force between the proton $f_{7/2}$ and the fully occupied neutron $g_{9/2}$ orbits.

The experimental results were compared to three state-of-the- art shell-model calculations (see Fig. 2), considering different model spaces. They all correctly predict that the ^{82,84}Zn isotopes exhibit collective-like character. The good agreement between experiment and theory suggests that breaking the ^{78}Ni core provides a significant contribution to low-lying states beyond $Z = 28$ and $N = 50$.

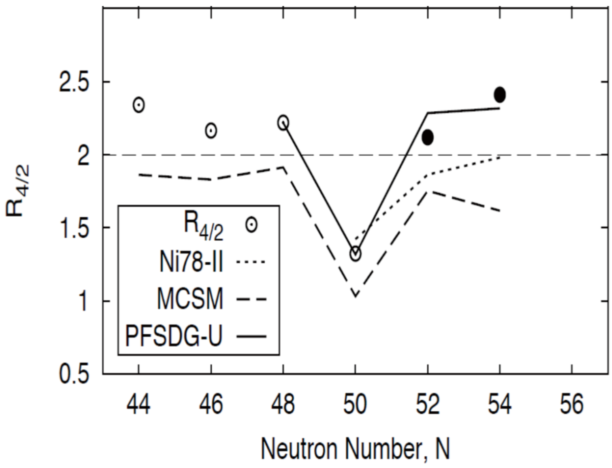

Fig. 2. Systematics of $R_{4/2} = E(4^+)/E(2^+)$ for Zn isotopes. The filled symbols are from this work. The results of the Ni78-II,[1)] A3DA-m,[2)] and PFSDG-U[3)] shell-model calculations are also indicated. The line at $R_{4/2} = 2$ indicates the vibrational limit.

References
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