Shell evolution beyond \( Z = 28 \) and \( N = 50 \): spectroscopy of \(^{81-84}\text{Zn}\)\(^{\dagger}\)

C. M. Shand,\(^{\ast 1}\) Zs. Podolyák,\(^{\ast 1}\) M. Górska,\(^{\ast 2}\) P. Doornenbal,\(^{\ast 3}\) A. Obertelli,\(^{\ast 3,4}\) F. Nowacki,\(^{\ast 5}\) T. Otsuka,\(^{\ast 6}\) K. Sieja,\(^{\ast 5}\) J. A. Tostevin,\(^{\ast 1}\) and Y. Tsunoda\(^{\ast 6}\) for the SEASTAR collaboration

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 \(^{238}\text{U}\) primary beam was accelerated to 345 MeV/nucleon and subsequently impinged onto a 3 mm thick \(^{9}\text{Be}\) production target at the entrance of the BigRIPS separator. Secondary fission beams of interest were then selected within BigRIPS using the \( B\rho-\Delta E-B\rho \) technique. The results presented here on neutron-rich \( \text{Zn} \) isotopes were obtained from settings centered on \(^{79}\text{Cu}\) and \(^{85}\text{Ga}\) in the first (2014) and second (2015) SEASTAR campaigns, respectively.

The incoming ions were impinged on the liquid \( \text{H}_2 \) target of the MINOS device, while the resulting \( \gamma \) rays were detected with the DALI2 high-efficiency NaI(Tl) array. Low-lying excited states in the neutron-rich \(^{81-84}\text{Zn}\) isotopes have been investigated. The \( 4^{+}_{1} \) state in \(^{82}\text{Zn}\) and the \( 2^{+}_{1} \) and \( 4^{+}_{1} \) states in \(^{84}\text{Zn}\) (see Fig. 1) were observed for the first time. In addition, \( \gamma \)-ray transition were identified in odd-mass \(^{81,83}\text{Zn}\). 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 \(^{82,84}\text{Zn}\) when compared to than in the neutron-magic \(^{80}\text{Zn}\) 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 \(^{144}\text{Sm}\), to a vibrational pattern at \( N = 86 \) in \(^{146}\text{Sm}\), and finally a rotational one at \( N = 92 \) in \(^{154}\text{Sm}\). At \( N = 84 \) \(^{146}\text{Sm}\) provides the transition between the seniority and vibrational schemes. In the case of \( \text{Zn} \) 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 \(^{82,84}\text{Zn}\) isotopes exhibit collective-like character. The good agreement between experiment and theory suggests that breaking the \(^{78}\text{Ni}\) core provides a significant contribution to low-lying states beyond \( Z = 28 \) and \( N = 50 \).

Fig. 1. Doppler corrected \( \gamma \)-ray spectrum of \(^{84}\text{Zn}\).

Fig. 2. Systematics of \( R_{4/2} = E(4^{+})/E(2^{+}) \) for \( \text{Zn} \) 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