In-beam γ-ray spectroscopy of ^{32}Mg

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The disappearance of the canonical magic numbers, e.g., 8, 20, 28, has been observed in unstable nuclei [1]. This can be understood as a consequence of evolving shell structure moving away from stability [2]. In the "island of inversion" in the nuclear chart [3], ground states of neutron-rich sd-shell nuclei are dominated by intruder configurations involving fp orbitals across the $N = 20$ major shell gap, and the breakdown of the neutron magic number $N = 20$ is firmly established. This realm continues to serve as an excellent testing ground for the understanding of the nuclear interactions and correlations that drive the dramatic changes in the shell structure.

The nucleus ^{32}Mg lies at the heart of the island of inversion and is one of the most important isotopes in this region. While the ground state of ^{32}Mg is strongly deformed, the remnants of the $N = 20$ shell closure are proposed to manifest themselves in excited 0^+ states, which are associated with a spherical shape [4, 5]. The competition of these distinct shapes, and thus the emergence of the island of inversion, is considered to strongly depend on the delicate balance between the 2p2h intruder and 0p0h normal configurations. However, recent theoretical studies suggest that the inclusion of stronger mixing, particularly 4p4h configurations, may be essential in describing the $N = 20$ island of inversion [6, 7].

To discriminate between different nuclear models, confrontation with high-quality experimental data is required. To achieve this objective, detailed in-beam γ-ray spectroscopy of ^{32}Mg was performed. Two different reaction probes, the one-neutron (two-proton) knockout reactions on ^{33}Mg (^{34}Si), respectively sensitive to intruder and normal configurations, were used to populate states in ^{32}Mg. The first results were reported in Reference [8]. The subsequent publication, Reference [9], provides more comprehensive information about this study.

The experiment was performed at the National Superconducting Cyclotron Laboratory at Michigan State University. Secondary beams of ^{33}Mg and ^{34}Si were produced by fragmenting a ^{48}Ca beam at 140 MeV/nucleon on a ^{9}Be primary target. The beams of ^{33}Mg and ^{34}Si were then directed onto a ^{9}Be secondary target with a thickness of 375 mg/cm^2, to induce nucleon knockout reactions. The outgoing particles of ^{32}Mg were identified and their momenta were reconstructed by the S800 spectrograph. The secondary reaction target was surrounded by an array of γ-ray detectors, Gamma-Ray Energy Tracking In-beam Nuclear Array, GRETINA [10]. By utilizing its γ-ray interaction position sensitivity, the Doppler correction of γ rays emitted from the fast outgoing nucleus was performed on an event-by-event basis. We note that the experimental setup is identical to a previous study described in Reference [11], but with different rigidity settings of the beamline and spectrograph.

The strong selectivity of the one-neutron and two-proton knockout reactions, as well as the high statistics collected in the present measurement, allowed a significantly updated level scheme to be made (see Figure 1). Parallel momentum distributions for each state were extracted from the experimental data, and through comparisons with eikonal-based reaction model calculations, spins and parities were assigned to each level.

The utilization of one-neutron knockout has provided evidence supporting a $3/2^-$ spin-parity assignment for the ground state of ^{33}Mg, which points to its 3p2h nature. One-neutron knockout is expected to preferentially populate 3p3h

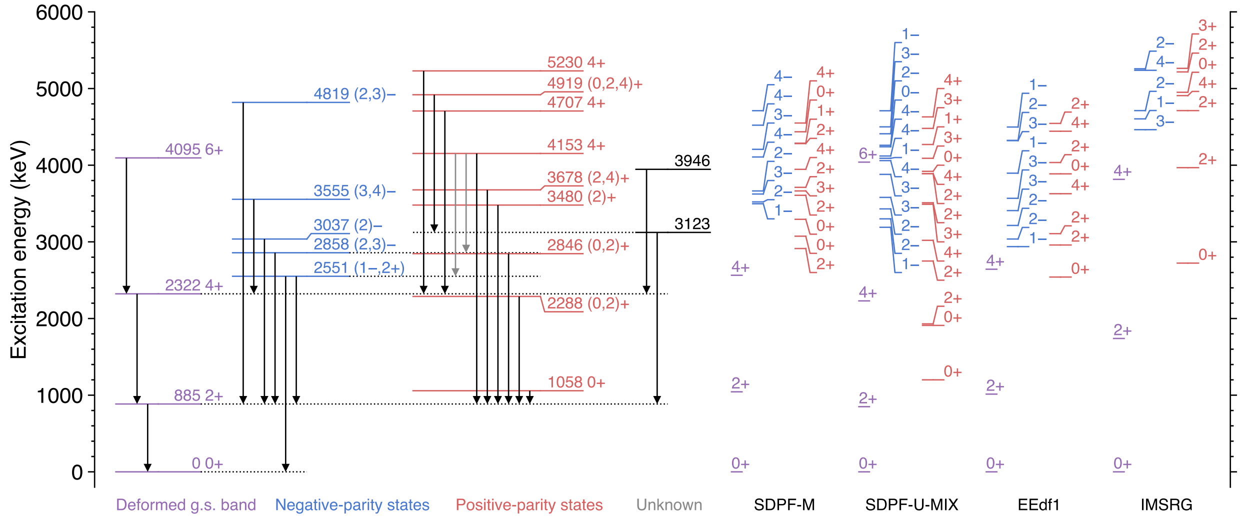

Figure 1. Level scheme of ^{32}Mg constructed in the present measurement. States are sorted into three categories, (i) deformed ground-state band, (ii) negative- and (iii) positive-parity states. The experimental levels were then compared with predictions given by four different models.

negative-parity states in ^{32}Mg. Such states were experimentally identified, with the lowest-energy negative-parity state established at 2858 keV. This highlights the evolving shell structure as we approach the island of inversion.

New positive-parity states, presumably described by normal 0p0h configurations, were found in the two-proton knockout reaction. Notably, candidates for the 0_3^+ state (see Reference [7]) that has been awaiting discovery, were identified at excitation energies of 2288 and 2846 keV. This finding expands our understanding of this key nucleus. To summarize, the present work unraveled yet another type of structures coexisting in ^{32}Mg: (i) the known ground-state rotational band, (ii) 3p3h intruder negative-parity levels, and (iii) 0p0h normal positive-parity states, revising the picture of shape coexisting in this nucleus.

The experimental level energies and exclusive cross sections for each state were confronted with theoretical calculations that combine the well-established, eikonal-based reaction model and the state-of-the-art structural models: SDPF-M [12], SDPF-U-MIX [6], EEdf1 [13], and IMSRG [14]. While different aspects of the structure of ^{32}Mg are captured in some of these models, a consistent description of this nucleus is not yet obtained. For instance, the experimental level energies are very well reproduced by the SDPF-U-MIX calculations (see Figure 1), whereas discrepancies remain in the two-proton knockout cross sections. For the full details, the reader is referred to the most recent publication of Reference [9].

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