Pairing forces govern population of doubly magic ^{54}Ca from direct reactions†

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In exotic nuclei, the proton-neutron attraction between orbits of the same angular momentum, but different intrinsic spin directions ($j_{>} = \ell + s$ and $j_{<} = \ell - s$) can affect the evolution of single-particle energies.[1)] Tensor-driven shell evolution is responsible for the emergence of two non-canonical nuclear magic numbers, $N = 34$ in ^{54}Ca[2)] and $N = 16$ in ^{24}O.[3)] In these nuclei a lack of $\pi 0f_{7/2}$ and $\pi 0d_{5/2}$ occupation, respectively, allows their neutron $j_{<}$ orbits to increase through the absence of the tensor attraction.

Single-proton knockouts from the valence orbital of ^{25}F (^{24}O plus one proton in $\pi 0d_{5/2}$) have shown a reduction of spectroscopic strength to the ground state compared to expectation.[4)] The explanation of this was due to the mixing of the neutron configurations resulting from the tensor attraction between the $\pi 0d_{5/2}$ and $\nu 0d_{3/2}$ orbitals. In ^{55}Sc (^{54}Ca plus one proton in $\pi 0f_{7/2}$), a similar erosion of the $N = 34$ shell gap is observed (*e.g.* Ref. 5)), therefore, a similar reduction of spectroscopic strength as in ^{25}F might be expected.

A primary beam of ^{70}Zn of intensity 240 particle nA was accelerated to 345 MeV/nucleon and underwent fragmentation on a 10-mm-thick ^{9}Be target. From the secondary beam, ^{55}Sc isotopes were selected and transported to the MINOS LH$_2$ target system where they underwent knockout reactions at ∼200 MeV/nucleon. Populated states of ^{54}Ca were measured through γ-ray detection with the DALI2$^+$ array, and invariant-mass spectroscopy through detection of residual nuclei and their emitted neutrons in the SAMURAI set-up. Parallel momentum distributions were measured to determine the ℓ-value of the knocked out proton.

Level energies were calculated from the nuclear shell model employing the GXPF1Br interaction.[2)] Theoretical cross sections to states were calculated from DWIA estimates multiplied by shell model spectroscopic factors, which quantify the overlap of the ^{55}Sc and ^{54}Ca wavefunctions. A comparison between the observed and predicted cross sections is shown in Fig. 1.

Despite the shell model calculations showing a significant amplitude of excited neutron configurations in the ground-state of ^{55}Sc, removing the $\pi 0f_{7/2}$ valence proton populated predominantly the ground-state of ^{54}Ca. This counter-intuitive result is attributed to the off-diagonal matrix elements of the pairing interaction leading to a dominance of the ground-state spectroscopic factor.[6)] Owing to the ubiquity of the pairing interaction, this argument should be generally applicable to direct knockout reactions from odd-even to even-even nuclei.

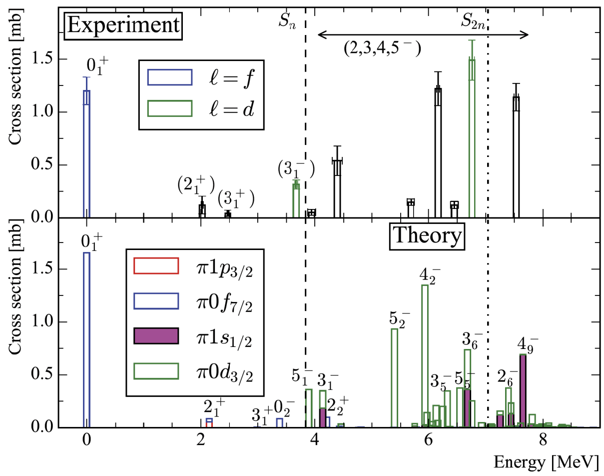

Fig. 1. (Top panel) Observed cross sections to states following the ^{55}Sc$(p, 2p)$ reaction. Above S_n the cross sections are shown at the energy centroids of fitted values and likely represent contributions from several states. States with conclusive ℓ-value assignments are colored accordingly, otherwise are black. (Bottom panel) Theoretical predictions of state energies and their population cross sections. Contributions to cross sections from proton removals from the different orbitals are indicated.

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