Spectroscopy of ^{52}K†

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The exploration of nuclear structure in regions far from stability has unveiled intriguing phenomena, including the evolution of shell structure and the emergence of new magic numbers. Notably, calcium isotopes develop new shell closures at $N = 32$ and $N = 34$ (see[1,2] and references therein), whereas potassium isotopes exhibit the inversion of the $\pi s_{1/2}$ and $\pi d_{3/2}$ orbitals, with a restoration of the conventional ordering observed in ^{51}K and heavier isotopes.[3] This study focuses on the spectroscopy of ^{52}K, an odd-odd nucleus surrounded by doubly magic and semi-doubly magic neighbors. While the energy levels of these neighboring nuclei display a single-particle character,[4,5] its argon neighbour, ^{51}Ar, exhibits a mix of collective and single-particle states.[6] We present the first spectroscopy of ^{52}K, populated through quasi-free (p, pn) and $(p, 2p)$ reactions.

The experiment was conducted at the RIKEN Radioactive Isotope Beam Factory using a ^{70}Zn primary beam fragmented on a Be target. The resulting cocktail beam was separated using the BigRIPS spectrometer, while the ^{52}K fragments were identified in the SAMURAI spectrometer. The MINOS TPC and liquid hydrogen target were employed for proton-induced knockout reactions. The final state of the ^{52}K fragments were tagged via γ-ray spectroscopy using the DALI2+ scintillator array. The gamma-ray spectra for both ^{53}Ca$(p, 2p)$ and ^{53}K(p, pn) reactions were analyzed, and three transitions with energies of 243(5) keV, 293(3) keV, and 540(13) keV were identified. Gamma-gamma coincidence analysis revealed that these transitions form a cascade, leading to the construction of the ^{52}K level scheme with excited states at 293(3), 536(6), and 1076(14) keV, shown in Fig. 1.

The momentum distributions of the ^{52}K fragments after the $(p, 2p)$ reaction were analyzed and interpreted within the distorted-wave impulse approximation (DWIA)[7] framework to determine the spin-parity assignments of the observed states. The ground state and the 293-keV state were found to be populated via $0d_{3/2}$ proton knockout, whereas the 1076-keV state was populated by $1s_{1/2}$ proton knockout. Additionally, the experimental level scheme was compared with theoretical calculations using the shell model with the SDPF-Umod interaction and the ab initio VS-IMSRG(2) with the 1.8/2.0 (EM) interaction, as in Fig. 1.

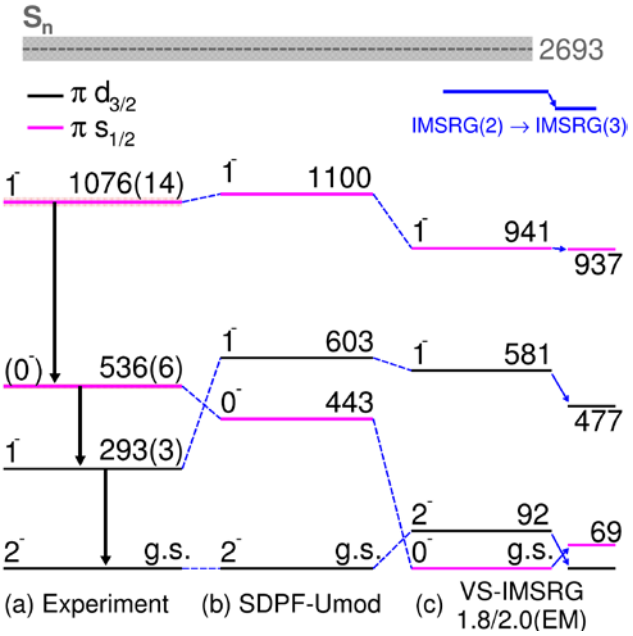

Fig. 1. Experimental (a) and calculated level scheme of ^{52}K with (b) SDPF-Umod interaction and (c) based on VS-IMSRG with 1.8/2.0 (EM) interaction.

The experimental inclusive and exclusive cross sections for both $(p, 2p)$ and (p, pn) reactions were also determined and compared with theoretical calculations using DWIA single-particle cross sections and shell-model spectroscopic factors, further confirming the single-particle nature of the observed states in ^{52}K.

This study provides the first spectroscopy of ^{52}K. The results show that the low-lying states in ^{52}K exhibit a single-particle nature, dominated primarily by proton excitations. The findings are consistent with the normal ordering of proton orbitals in ^{52}K, similar to those of its neighboring isotopes ^{51}K and ^{53}K.[3]

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