Single-particle states in *fp*-shell nuclei through the ^{50}Ca$(d,p)^{51}$Ca transfer reaction

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Neutron-rich calcium isotopes with a neutron number near $N = 34$ are key to investigating the evolution of the *fp*-shell single-particle orbitals. Beyond the $N = 28$ shell gap in ^{48}Ca, new magic numbers at $N = 32$ and 34 have been identified through spectroscopic studies of low-lying states and precise mass measurements. Recently, the occupation of the $1f_{7/2}$ and $2p_{3/2}$ neutron orbitals at $N = 32$ was probed using a one-neutron knockout reaction from ^{52}Ca.[1)] However, the experimental confirmation of the valence single-particle $2p_{1/2}$ and $1f_{5/2}$ orbitals, which define the shell gaps at $N = 32$ and 34, remains pending.

One-neutron transfer reactions are a powerful tool for investigating low-spin single-particle orbitals in the valence space. The reaction cross-section provides information on spectroscopic factors, whereas the angular distribution of reaction products reveals the angular momentum transfer. Thus, the vacancy and occupation of single-particle states can be probed.

In May 2024, the second part of the SHARAQ12 experiment[2)] was performed at RIKEN to study the single-particle structure of ^{51}Ca. A secondary ^{50}Ca beam was produced by fragmenting a primary ^{70}Zn beam at an energy of 345 MeV/nucleon. The beam was selected by the BigRIPS separator and its energy was decreased to an average energy of 16 MeV/nucleon in the optimized energy degrading optics (OEDO) beamline.[3)] After particle identification and selection, the beam impinged on a 644-μg/cm^2-thick CD_2 target and induced (d,p) one-neutron transfer reactions. Recoiling protons were detected with the TINA detector array at laboratory backward angles ($\theta_{\rm lab} = 95-165°$). The TINA detector array includes a box of 300-μm-thick double-sided silicon strip detectors and a ring of single-sided 300-μm-thick silicon strip detectors covering most backward angles. The excitation energy of states populated in ^{51}Ca is obtained from the four-momenta of the recoiling protons and the incident momentum vector of the projectile. Ejectiles were measured by the SHARAQ QQD spectrometer behind the target. Particle identification facilitated by the measured time-of-flight and positions at the S1 focal plane of SHARAQ, is shown in Fig. 1. This enables a clean selection of the (d,p) reaction channel. The analysis of excitation energy spectra and differential cross sections is currently in progress.

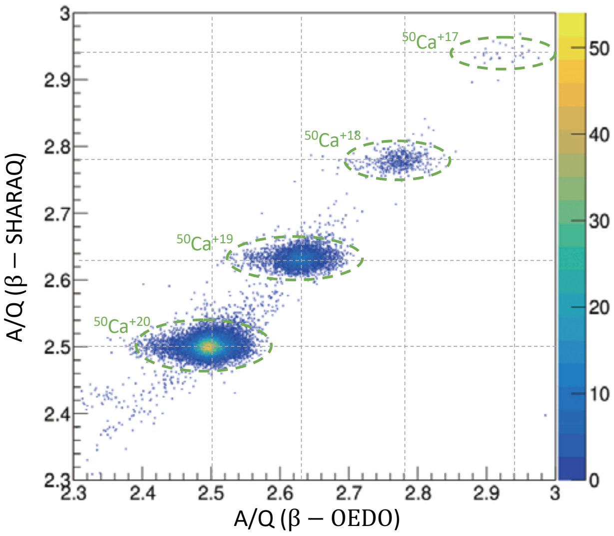

Fig. 1. SHARAQ spectrometer A/Q identification plot obtained from the time-of-flight in SHARAQ (β-SHARAQ) and the one extrapolated from before the target in the OEDO beam line (β-OEDO) after gating on incoming ^{50}Ca in the BigRIPS separator.

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References
1) M. Enciu *et al.*, Phys. Rev. Lett. **129**, 262501 (2022).
2) C. Ferrera *et al.*, RIKEN Accel. Prog. Rep. **56**, 8 (2023).
3) S. Michimasa *et al.*, Prog. Theor. Exp. Phys. **2019**, 043D01 (2019).

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