Evidence for a new nuclear 'magic number' in ^{54}Ca[†]

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Over recent years, the evolution of nuclear shell structure in exotic, neutron-rich nuclei has attracted much attention on both the experimental and theoretical fronts. In the neutron-rich fp shell, the onset of the $N = 32$ subshell closure is well established from the structural characteristics of ^{52}Ca[1,2], ^{54}Ti[3,4] and ^{56}Cr[5,6]. This subshell gap is reproduced successfully by numerous theoretical predictions. In the framework of tensor-force-driven shell evolution[7], the onset of the $N = 32$ subshell closure results as a direct consequence of a sizable $\nu p_{3/2}$–$\nu p_{1/2}$ gap, which presents itself as the $\nu f_{5/2}$ orbital shifts up in energy owing to a weakening of the attractive $\pi f_{7/2}$–$\nu f_{5/2}$ interaction as protons are removed from the $\pi f_{7/2}$ orbital. Another important manifestation of some theories is the prediction of a large subshell gap at $N = 34$, which develops if the $\nu f_{5/2}$ orbital lies sufficiently high in energy above the $\nu p_{1/2}$ orbital. It has already been shown that no significant $N = 34$ subshell gap exists in ^{56}Ti[4,8] or ^{58}Cr[6,9] and, therefore, the size of the energy gap in ^{54}Ca is an important structural characteristic that requires experimental input. Moreover, the single-particle states of ^{53}Ca should also reflect the nature of the $N = 34$ subshell closure in isotopes far from stability.

The structures of ^{54}Ca and ^{53}Ca were investigated using in-beam γ-ray spectroscopy at the RIBF to address this issue. A primary beam of $^{70}Zn^{30+}$ ions at 345 MeV/u was used to create a radioactive beam containing ^{55}Sc and ^{56}Ti, which was focused on a 10-mm-thick Be reaction target located inside the DALI2 γ-ray detector array at F8. Reaction products were identified with the ZeroDegree spectrometer (see Fig. 1).

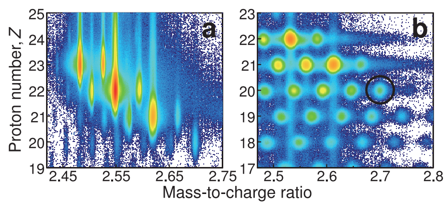

Fig. 1. (colour) Particle identification plots measured by (a) the BigRIPS separator and (b) the ZeroDegree spectrometer. The black circle indicates ^{54}Ca events.

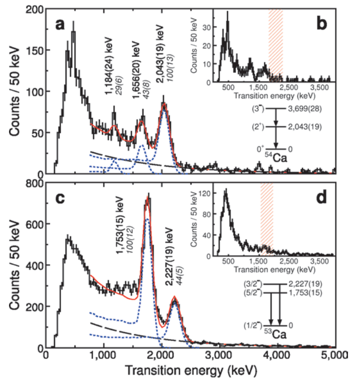

Fig. 2. (colour) Doppler-corrected γ-ray energy spectra for (a) ^{54}Ca and (c) ^{53}Ca. Insets (b) and (d) indicate γ rays in coincidence with the 2043- and 1753-keV lines.

The energy spectra for ^{54}Ca and ^{53}Ca deduced in the present work are presented in Fig. 2. The most intense peak in the ^{54}Ca spectrum, the line at 2043(19) keV, is assigned as the $2^+_1 \rightarrow 0^+$ ground-state transition. Several other weaker lines are also reported. The relatively high energy of the 2^+_1 state reflects the doubly magic nature of ^{54}Ca and provides direct experimental evidence for the onset of a sizable subshell closure in $N = 34$ isotones far from stability. Shell-model calculations adopting a modified GXPF1B Hamiltonian indicate that the strength of the $N = 34$ subshell gap in ^{54}Ca (the $\nu p_{1/2}$–$\nu f_{5/2}$ SPO energy gap) is in fact comparable to the $N = 32$ subshell gap in ^{52}Ca (the $\nu p_{3/2}$–$\nu p_{1/2}$ SPO energy gap) (see original Letter for details). In the ^{53}Ca spectrum, the 1753(15)-keV transition is reported for the first time, while the line at 2227(19) keV is consistent in energy with a transition previously measured in a decay study[10].

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