Yrast structure of neutron-rich $^{51}$Ca


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Around doubly-magic $^{48}$Ca, the neutron $p_{3/2}$, $p_{1/2}$ and $f_{5/2}$ orbitals are significantly separated in energy. As evidenced in earlier studies, a $N=32$ subshell closure in neutron-rich nuclei occurs [1-3], reflecting the presence of an energy gap between the $\nu p_{3/2}$ orbital and the two other neutron states. This closure disappears when going towards the stability line due to the strong proton $\pi f_{7/2}$ - neutron $\nu f_{5/2}$ monopole interaction, primarily governed by the tensor force. Such interaction causes a decrease in energy of the $\nu f_{5/2}$ single-particle orbital with respect to the $\nu p_{3/2}$ and $\nu p_{1/2}$ levels as protons are added to the $\pi f_{7/2}$ shell [4,5]. It has been shown that the magnitude of this decrease is high enough to reduce a possible second gap, i.e., between the $\nu p_{1/2}$ and $\nu f_{5/2}$ states, in the Ti and Cr isotopes [6-8]. In Ca nuclei, however, the $\nu p_{3/2}$, $\nu p_{1/2}$ – $\nu f_{5/2}$ splitting may be sufficient to produce a subshell closure also at $N=34$, but this feature is difficult to detect, as the states involving the $\nu f_{5/2}$ orbital in such species like $^{51-54}$Ca are hard to reach.

We investigated the yrast structure of $^{51}$Ca by analyzing data from two complementary experiments. In the first measurement, $\gamma$-$\gamma$ coincidence events, from neutron-rich species produced in deep-inelastic collisions of a $^{48}$Ca beam on a thick $^{238}$U target, were collected with the Gammasphere array at the Argonne National Laboratory. The production rate of the $^{51}$Ca nucleus was, however, too low to locate unambiguously new $\gamma$ rays that weakly appeared in coincidence gates on the known (from the $^{51,52}$K $\beta$-decay studies [9]) groundstate transitions in $^{51}$Ca. In the second experiment the same system was investigated by employing the PRISMA spectrometer coupled with the CLARA $\gamma$-ray multi-detector array at the INFN, LNL Legnaro. A $\gamma$-ray spectrum from CLARA, gated on the $^{51}$Ca products, showed a series of lines clearly belonging to $^{51}$Ca. Out of those, three $\gamma$ rays were known from the $\beta$-decay study [9]. Subsequent analysis of $\gamma$ coincidence data taken with Gammasphere allowed us to establish coincidence relationships between the observed lines and to construct an extended level scheme for $^{51}$Ca. Of special interest is a state located at 4320 keV with a tentative spin-parity assignment of $9/2^-$ arising mostly from the $\nu p_{3/2}^2 f_{5/2}$ configuration, which involves an $f_{5/2}$ neutron. The energy of this state can be described quite well by shell-model calculations assuming a sizable energy gap between the $\nu p_{3/2}$ and $\nu f_{5/2}$ neutron orbitals at $Z=20$.

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