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Short note

Three-valence-particle fission product $^{135}_{51}\mathrm{Sb}_{84}$

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Abstract. By analysis of fission product γ-ray data measured at Eurogam II using a ^{248}Cm source, yrast levels up to about 2 MeV in the N=84 three-particle nucleus ^{135}Sb have been identified. These levels are interpreted as $\pi g_{7/2}\nu f_{7/2}^2$ and $\pi g_{7/2}\nu f_{7/2}h_{9/2}$ states with the help of shell model calculations using empirical nucleon-nucleon interactions.

PACS. 21.60.Cs Shell model – 23.20.Lv Gamma transitions and level energies – 27.60.+j $90 \leq A \leq 149$

Excitations of few-valence-particle nuclei near doubly-magic ^{132}Sn are worth studying, since they can yield information about nucleon-nucleon interactions and effective charges in an important neutron-rich section of the nuclidic chart. A recent investigation using a large γ-ray detector array to study fission fragments from ^{248}Cm has identified prompt and delayed γ-ray cascades from individual product nuclei around ^{132}Sn, and has opened prospects for broad exploration of the yrast spectroscopy of the region. Main results for the two- and three-proton N=82 nuclei ^{134}Te and ^{135}I [1], for the two-neutron nucleus ^{134}Sn [2], and for N=83 isotones, including the proton-neutron nucleus ^{134}Sb [3], have already been published. In this note we report first findings for the little studied N=84 nucleus ^{135}Sb, which has one proton and two neutrons outside the ^{132}Sn core.

In the γ-ray measurements, the Eurogam II array, consisting of 124 Ge detector elements and four LEPS spectrometers, recorded more than 2 x 10^9 three-fold or higher-fold γ-ray coincidence events from a ^{248}Cm source delivering ~6 x 10^4 fissions/sec. Additional experimental details have been given in our earlier publications [1–3].

Systematic analyses of the $\gamma\gamma$ cross-coincidence intensity patterns observed between complementary Sb and Rh fission products first led to the identification of low-lying γ-ray cascades in A=109-113 Rh isotopes; it helped considerably that $(9/2^+)\rightarrow(7/2^+)$ ground state transitions in ^{109}Rh, ^{111}Rh and ^{113}Rh were already known from β-decay [4]. When gates were set on ^{111}Rh transitions, known γ-rays of ^{133}Sb and ^{134}Sb, the 4n and 3n fission partners, appeared in coincidence, as well as new 224.9, 410.9 and 706.5 keV γ-rays (in order of increasing intensity), which we here assign to the 2n partner ^{135}Sb. These new γ-rays showed coincidences with ^{111}Rh, ^{110}Rh and ^{109}Rh transitions, the γ-rays of the 2n fission partner ^{111}Rh being by far the strongest; this result is similar to the cross-coincidence findings in the case of ^{134}Sn [2]. Double gating on the 411 and 707 keV γ-rays gave the spectrum displayed in Fig. 1(a), in which the 225 keV γ-ray and $^{109-111}$Rh γ-rays are clearly seen, as well as a 629.1 keV transition that is also assigned to ^{135}Sb. (Coincidences involving a known 410.5 keV γ-ray in the ^{111}Rh level scheme account in part for the enhanced ^{111}Rh γ-ray intensities in Fig. 1(a)). The clean spectrum obtained by gating on the 707 and 629 keV transitions (Fig. 1(b)) confirms the 225 and 411 keV γ-rays in coincidence and establishes the four transition cascade illustrated in Fig. 2. Although the available $t_{\gamma\gamma}$ time distribution data were not of top quality, they did indicate clearly that the 225, 411, and 707 keV γ-ray cascade de-excites an isomeric state with $t_{1/2}$ ~20 ns at 1343 keV in ^{135}Sb, while the 629 keV transition feeds the isomer (Fig. 2).

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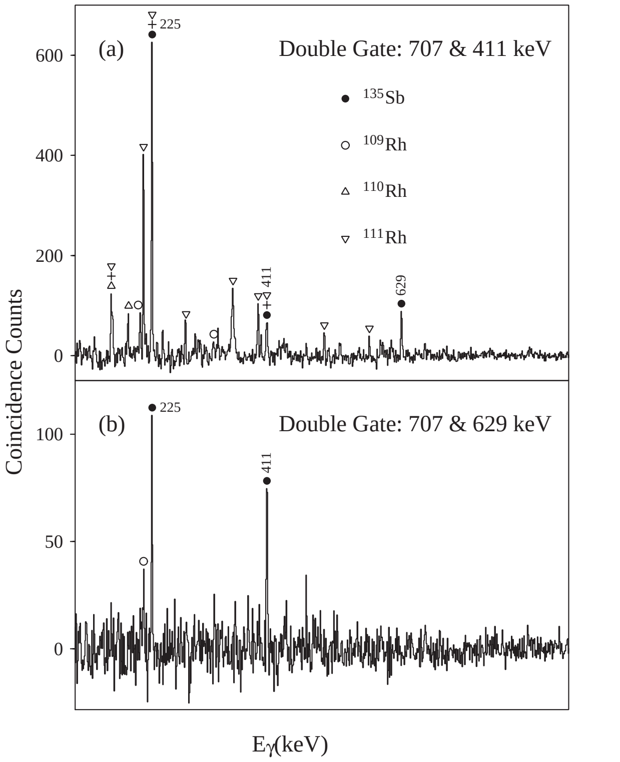

Fig. 1. Key γ-ray coincidence spectra double gated on ^{135}Sb γ-rays

The 1.7 s ($7/2^+$) ground state of ^{135}Sb is known from β-decay studies [4], but no excited states have been located previously. Excited levels in the two valence neutron nucleus ^{134}Sn have been interpreted [2] as I^π = 2^+, 4^+, and 6^+ states of mainly $\nu f^2_{7/2}$ character. One may expect low-lying $\pi g_{7/2}\nu f^2_{7/2}$ states in ^{135}Sb, and the 707, 1118 and 1343 keV levels located here are assigned as I^π = $11/2^+$, $15/2^+$, and $19/2^+$ members of this multiplet. The 1972 keV level is probably the $(\pi g_{7/2}\nu f_{7/2}h_{9/2})23/2^+$ excitation, with one neutron promoted from $\nu f_{7/2}$ to $\nu h_{9/2}$. The interpretation relies heavily on results of shell model calculations performed using the OXBASH code [5]. These calculations included the $\pi g_{7/2}$, $\nu f_{7/2}$ and $\nu h_{9/2}$ orbitals, and adopted the $\nu f_{7/2} - \nu h_{9/2}$ single particle energy spacing of 1561 keV from ^{133}Sn [6]. The required $\pi\nu$ interaction matrix elements were estimated from known ^{210}Bi interactions [7] with slight modifications to achieve agreement with the ^{134}Sb data, as described in detail in ref. [3]. The $\nu f_{7/2} - \nu f_{7/2}$ interactions were taken from the ^{134}Sn spectrum, and $\nu f_{7/2} - \nu h_{9/2}$ interactions were estimated, with appropriate $A^{-1/3}$ scaling, from the counterpart $\nu g_{9/2} - \nu i_{11/2}$ multiplet known in ^{210}Pb [7]. The calculated level energies displayed in Fig. 2 are in generally good agreement with experiment, and provide firm support for the proposed assignments. The approximate half-life determined for the 1343 keV isomer is also consistent with these assignments, but more accurate lifetime measurements for both ^{134}Sn and ^{135}Sb will allow a more useful comparison of B(E2) values for the $\nu f^2_{7/2}$ $6^+ \rightarrow 4^+$ in ^{134}Sn and the related $19/2^+ \rightarrow 15/2^+$ transition in ^{135}Sb.

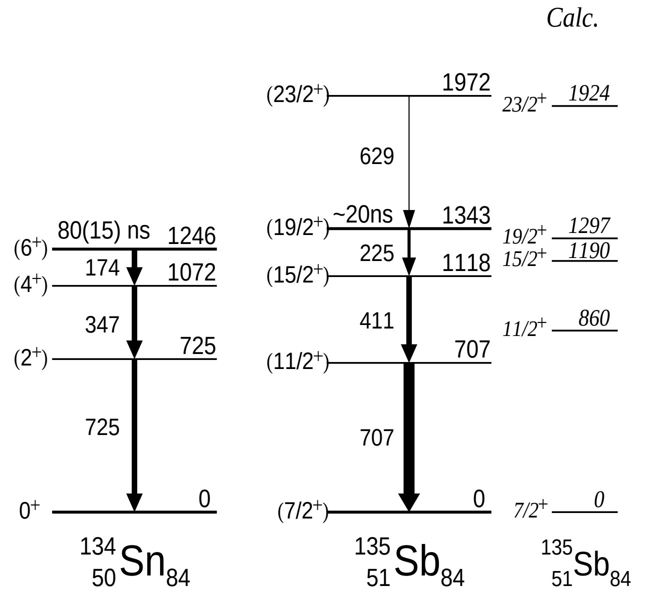

Fig. 2. The proposed ^{135}Sb level scheme. The scheme for the N=84 isotone ^{134}Sn as well as the calculated level spectrum of ^{135}Sb are also shown

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