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*Short note*

# Neutron single-particle energies in the $^{132}$Sn region

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**Abstract.** Excited levels in $^{133}$Sn and $^{134}$Sb, populated in spontaneous fission of $^{248}$Cm, were studied by means of prompt-$\gamma$ spectroscopy, using the EUROGAM 2 multidetector array. The neutron $i_{13/2}$ single-particle energy has been determined for the first time in the $^{132}$Sn region. The energy of the $h_{9/2}$ neutron level, proposed previously, has been confirmed.

**PACS.** 21.60.Cs Shell model – 23.20.Lv Gamma transitions and level energies – 25.85.Ca Spontaneous fission – 27.60.+j $90 \leq A \leq 149$

Single-particle energies are a fundamental input to accurate calculations in nuclear physics. Despite of this, the excitation energy of the crucial $i_{13/2}$ neutron level in the $^{132}$Sn region is still unknown. In the $^{133}$Sn nucleus the neutron separation energy, $S_n$, is merely 2.45 MeV, which makes difficult studies of neutron levels through $\gamma$-ray measurements. In a recent work [1], the delayed-neutron $\beta$-decay of $^{134}$In was employed to populate excited states in $^{133}$Sn. Three excited states proposed at 854 keV, 1561 keV and 2005 keV were interpreted as the $p_{3/2}$, $h_{9/2}$ and $f_{5/2}$ neutron levels, respectively. The interpretation was based on indirect arguments derived from systematics and calculations. An independent, experimental confirmation of these results is therefore essential.

In this work we present new experimental data concerning neutron single-particle energies in the $^{132}$Sn region. For the first time, the experimentally-derived position of the $\nu i_{13/2}$ level is reported. Further experimental evidence confirming the $h_{9/2}$ neutron level proposed in [1] is also provided.

The data reported below results from the measurement of high-fold coincidences of prompt $\gamma$-rays following spontaneous fission of $^{248}$Cm, performed with the EUROGAM 2 array (see [2] for more experimental details). The $^{132}$Sn region has been already studied using this data [3]. The new results reported below were obtained due to new analysis techniques, which have significantly improved the peak to background ratio in the gamma spectra and made possible the analysis of $\gamma$-ray yields as small as $10^{-8}$ of the total intensity ($2{\times}10^{10}$ $\gamma\gamma\gamma$ coincidences).

The 1561 keV $\gamma$ decay of the $h_{9/2}$ neutron level, reported in [1], is now also seen in prompt $\gamma$ radiation following fission of $^{248}$Cm. The strongest fission partner to $^{133}$Sn is the $^{112}$Pd nucleus, with the $2^+\!\rightarrow\!0^+$ transition at 349 keV. The upper panel of Fig. 1 shows a spectrum double gated on the 1561 keV and 349 keV lines, where the 534 keV, $4^+\!\rightarrow\!2^+$ and and the 668 keV, $6^+\!\rightarrow\!4^+$ transitions in $^{112}$Pd are present. The observed lines are due to prompt coincidences between $\gamma$-rays from the $^{133}$Sn and $^{112}$Pd nuclei. In the lower panel of Fig. 1 a fragment of a spectrum, double gated on the 534 keV and 349 keV transitions in $^{112}$Pd, is shown. The 1561 keV line is clearly observed, with 430(80) coincidence events in the peak.

The observation of the 1561 keV transition in prompt-$\gamma$ spectra strongly supports the interpretation of the 1561 keV level in $^{133}$Sn as the $h_{9/2}$ neutron level [1], if one remembers that the fission process populates preferably the yrast excitations.

The neutron separation energy in $^{134}$Sb, $S_n$=3.12 MeV, is higher than the predicted [1] excitation energy of

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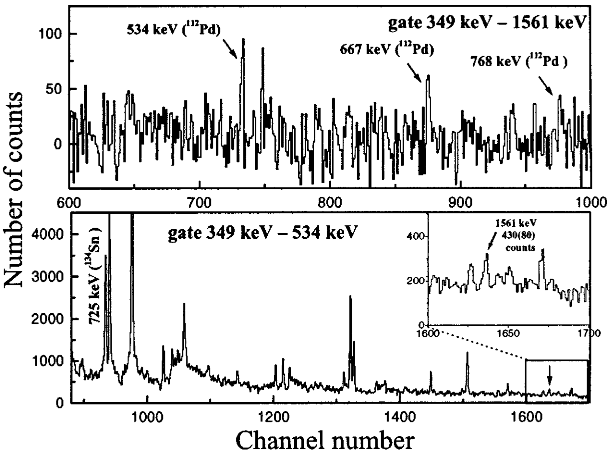


**Fig. 1.** Fragments of double gated spectra illustrating the presence of the 1561 keV transition in $^{133}$Sn

3 MeV for the $i_{13/2}$ neutron level. In [3] two excited states were reported at 1073 keV and 2127 keV above the $7^-$, $(\pi g_{7/2}\nu f_{7/2})$ isomeric level and were interpreted in terms of the $(\pi g_{7/2}\nu h_{9/2})_{8^-}$ and $(\pi h_{11/2}\nu f_{7/2})_{9^+}$ configurations, respectively. The present analysis revealed higher lying excited states in $^{134}$Sb. A full decription of these results will be given elsewhere [4]. In the present work we report on the identification of an excited state in $^{134}$Sb with a configuration, which includes a neutron in the $i_{13/2}$ orbital. In Fig. 2 spectra double-gated on lines corresponding to the known [3] 1072.5 keV and 2126.5 keV transitions in $^{134}$Sb are shown. The new 307.5 keV and 1361.5 keV lines seen in the spectra define a new level at 2434.0 keV above the $(7^-)$ isomer.

A partial level scheme of $^{134}$Sb, as observed in the present work, is shown in Fig. 3.

Angular correlations of the 1072.5 keV - 1053.2 keV and 2126.5 keV - 307.5 keV cascades in $^{134}$Sb are shown in Fig. 4 together with the expected correlations for various transition multipolarities. The dipole character of both transitions in the 1072.5 keV - 1053.2 keV cascade confirms the I=9 spin assignment for the 2126.5 keV level. The other angular correlation is consistent with a mixed M2/E3 character for the 2126.5 keV transition and a $\Delta$I=1 character for the 307.5 keV transition, indicating spin I=10 for the 2434.0 keV level.

A $10^+$ state with a dominant $(\pi g_{7/2}\nu i_{13/2})_{10^+}$ configuration is expected close to an excitation energy of 2.5 MeV. Taking the appropriate proton-neutron interactions from the $^{210}$Bi nucleus [5,6] with the $A^{-1/3}$ scaling and experimental single-particle energies from the $^{132}$Sn region region, the $i_{13/2}$ neutron excitation energy can be estimated from the position of the 2434 keV level, assuming its $(\pi g_{7/2}\nu i_{13/2})_{10^+}$ character. The relevant input data and results are shown in Table 1.

In view of the very good agreement between the calculated and measured excitation energies for the $8^-$ and $9^+$ levels, we calculated the $\nu i_{13/2}$ excitation energy in $^{133}$Sn (denoted by Y in Table 1) from the relation Y - 260 = 2434 (see Table 1.). The $\nu i_{13/2}$ excitation energy obtained

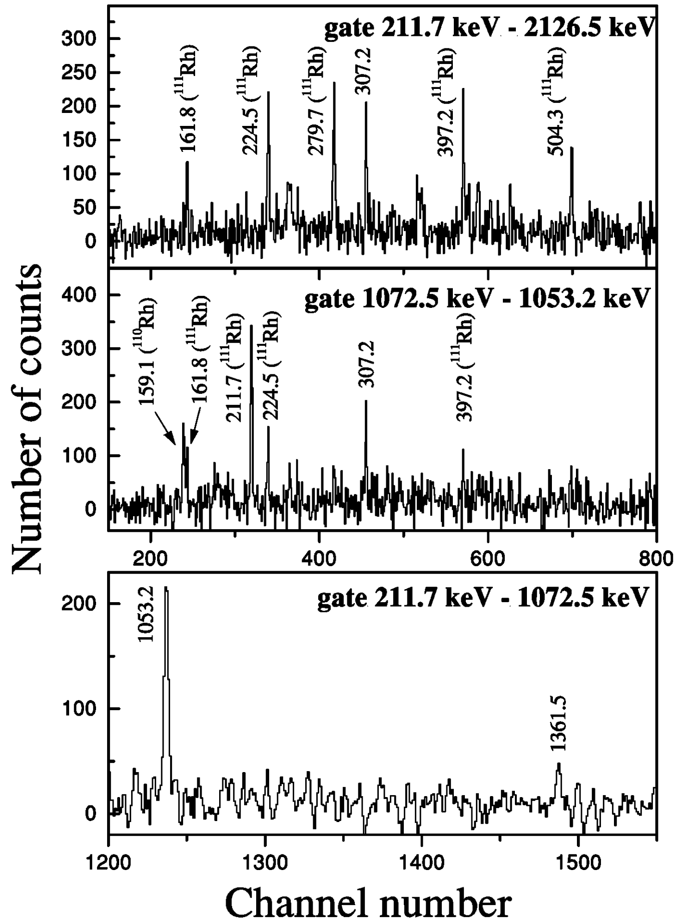


**Fig. 2.** Fragments of double gated spectra indicating the existence of the 2434.0 keV level in $^{134}$Sb

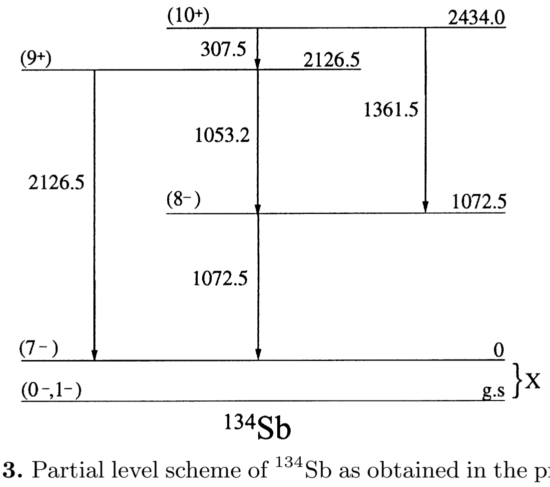


**Fig. 3.** Partial level scheme of $^{134}$Sb as obtained in the present work. X is the unknown excitation energy of the $7^-$ level

in this way is $E_{s.p.}(1i_{13/2})$ = 2694 keV. The $E_{s.p.}(1i_{13/2})$ value, higher than the neutron separation energy in $^{133}$Sn explains the non-observation of this level in $^{133}$Sn, in [1] and in the present work. An estimated error $\Delta E_{s.p.}(1i_{13/2})$ of about 200 keV accounts for the uncertainities connected

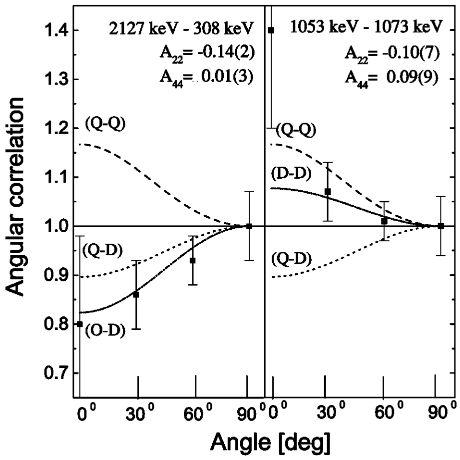


**Fig. 4.** Angular correlations in $^{134}$Sb vs. expected quadrupole-quadrupole (Q-Q), dipole-dipole (D-D), quadrupole-dipole (Q-D) and octupole-dipole (O-D) correlations

with the scaling of the residual interaction from the $^{208}$Pb region and with the adjustment to other levels in $^{134}$Sb.

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**Table 1.** Calculations of excitation energies in the $^{134}$Sb

| | | | |
|---|---|---|---|
| Empirical single-particle energies (keV): | | | |
| protons ($^{133}$Sb) | | neutrons ($^{133}$Sn) | |
| $g_{7/2}$ | 0 | $f_{7/2}$ | 0 |
| $d_{5/2}$ | 962 | $h_{9/2}$ | 1561 |
| $h_{11/2}$ | 2792 | $i_{13/2}$ | Y |
| Proton-neutron residual interactions (keV): | | | |
| $^{210}$Bi([6]) | | $^{134}$Sb (A$^{-1/3}$ scaled) | |
| $(\pi h_{9/2}\nu g_{7/2})_{9^-}$ | -398 | $(\pi g_{7/2}\nu f_{7/2})_{7^-}$ | -462 |
| $(\pi h_{9/2}\nu i_{11/2})_{10^-}$ | -778 | $(\pi g_{7/2}\nu h_{9/2})_{8^-}$ | -903 |
| $(\pi i_{13/2}\nu g_{9/2})_{11^+}$ | -961 | $(\pi h_{11/2}\nu f_{7/2})_{9^+}$ | -1116 |
| $(\pi h_{9/2}\nu j_{15/2})_{12^+}$ | -622 | $(\pi g_{7/2}\nu i_{13/2})_{10^+}$ | -722 |

Excitation energies in $^{134}$Sb (in keV, relative to $7^-$):

| configuration | E$^{exc}$(calc.) | E$^{exc}$(exp.) |
|---|---|---|
| $\pi g_{7/2}\nu f_{7/2})_{7^-}$ | 0 | 0 |
| $\pi g_{7/2}\nu h_{9/2})_{8^-}$ | 1120 | 1073 |
| $\pi h_{11/2}\nu f_{7/2})_{9^+}$ | 2138 | 2127 |
| $\pi g_{7/2}\nu i_{13/2})_{10^+}$ | Y-260 | 2434 |

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