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On the structure of the anomalously low-lying 5/2$^+$ state of ^{135}Sb

A. Korgul[1,a], H. Mach[2], B.A. Brown[3], A. Covello[4], A. Gargano[4], B. Fogelberg[2], R. Schuber[2,5], W. Kurcewicz[1], E. Werner-Malento[1], R. Orlandi[6,7], and M. Sawicka[1]

[1] Institute of Experimental Physics, Warsaw University, Warsaw, Poland
[2] Department of Radiation Sciences, Uppsala University, Uppsala, Sweden
[3] Department of Physics and Astronomy and NSCL, Michigan State University, East Lansing, MI, USA
[4] Dipartimento di Scienze Fisiche, Università di Napoli Federico II and Istituto Nazionale di Fisica Nucleare, Napoli, Italy
[5] Department of Physics, University of Konstanz, Konstanz, Germany
[6] Institut Lave-Langevin, Grenoble, France
[7] Schulster Laboratory, University of Manchester, Manchester, UK

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Abstract. Recently the first-excited state in ^{135}Sb has been observed at the excitation energy of only 282 keV and, due to its properties, interpreted as representing mainly a configuration of a $d_{5/2}$ proton coupled to the ^{134}Sn core. It was suggested that its low-excitation is due to a relative shift of the proton $d_{5/2}$ and $g_{7/2}$ orbits due to the neutron excess. With the aim to provide more spectroscopic information on this anomalously low-lying $5/2^+$ state, we have measured its lifetime by the Advanced Time-Delayed $\beta\gamma\gamma(t)$ method at the OSIRIS fission product mass separator at Studsvik. The preliminarily measured half-life, $T_{1/2} = 6.0(7)$ ns, yields an exceptionally low $B(M1; 5/2^+_1 \rightarrow 7/2^+_1)$ value of $\leq 2.9 \times 10^{-4} \mu_N^2$. The result is discussed in the framework of shell model calculations.

PACS. 21.10.-k Properties of nuclei; nuclear energy levels – 21.10.Tg Lifetimes – 23.40.-s β decay; double β decay; electron and muon capture

Theoretical studies predict that very neutron-rich medium-heavy nuclei are governed by a shell structure that differs from that established along the line of stability [1]. Although the "neutron skin effects" are expected to occur at a very high neutron excess, thus closer to the neutron drip line, yet some limited effects related to specific orbits, could perhaps be observed much earlier. This study is focused on ^{135}Sb as new experimental results on this nucleus have been puzzling. Recently, its first-excited state was identified at the OSIRIS facility to lie at only 282 keV [2]. A subsequent study at ISOLDE concluded [3] that the energy of this state seems anomalous —likely due to a high neutron excess that decreases the relative separation energy between the $d_{5/2}$ and $g_{7/2}$ orbitals. This idea can be examined via combined experimental and theoretical studies.

A strong β-feeding to the 282 keV state in ^{135}Sb [3] from the ground state of ^{135}Sn points towards a strong $d_{5/2}$ single-particle component in this state. The $M1$ transition is forbidden between the $d_{5/2}$ and $g_{7/2}$ single-particle states and $E2$ collectivity is small in these nuclei. Consequently, one would expect for the 282 keV transition in ^{135}Sb a very slow $B(M1)$ rate if there is shift of the orbits, and a faster one if the lowering of the state is due to collective effects. Thus, a new insight can be provided by the $B(M1)$ rate for the 282 keV γ-ray.

The measurement has been performed at the OSIRIS fission-product mass separator at Studsvik, operated by the Uppsala University. The levels in ^{135}Sb were populated in the β decay of ^{135}Sn produced in the thermal neutron induced fission of ^{235}U.

The mass-separated beam of $A = 135$ isobars was implanted into an aluminized mylar tape at the experimental station, where two Ge detectors and fast timing β and BaF$_2$ γ detectors were positioned in a close geometry (for more details on the $\beta\gamma\gamma(t)$ method see [4]). A partial level scheme of ^{135}Sb is presented in fig. 1. By selecting in the Ge spectrum the 732 and 923 keV γ-rays feeding the 282 keV state from above [2] and in the coincident BaF$_2$ spectrum the very strong and clean 282 keV peak (fig. 2) one obtains the time-delayed $\beta\gamma(t)$ spectrum due to the lifetime of the 282 keV state in ^{135}Sb (fig. 3). The feeding γ transitions do not carry any time-delayed components, which could affect fitting of the slope (they are semi-prompt with $T_{1/2} \leq 0.3$ ns).

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[a] Conference presenter; e-mail: `korgul@fuw.edu.pl`

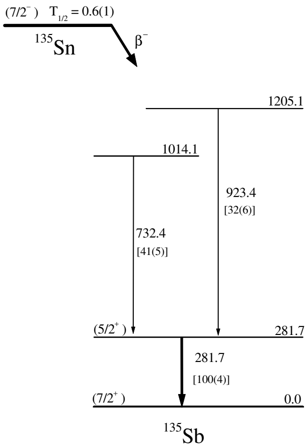

Fig. 1. Partial level scheme of ^{135}Sb [2].

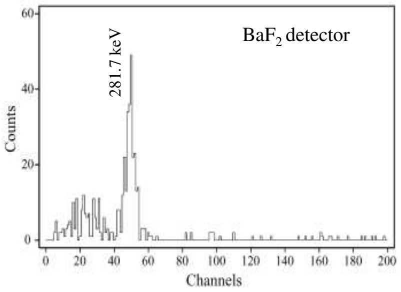

Fig. 2. The BaF$_2$ spectrum measured in coincidences with the 732 and 923 keV transitions observed in the Ge detectors.

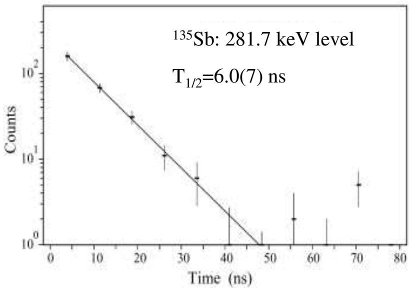

Fig. 3. The time-delayed $\beta\gamma(t)$ spectrum due to the 282 keV level in ^{135}Sb; see text for discussion.

The (preliminary) half-life of the level is measured as $T_{1/2} = 6.0(7)$ ns. Since the $M1/E2$ mixing ratio for the transition is not known, we deduce the upper limits for the $B(M1)$ and $B(E2)$ rates, assuming either a 100% pure $M1$ or 100% pure $E2$ transition, respectively.

Table 1. Comparison of the experimental $B(M1)$ values and shell model predictions of by Brown (B) and Covello and Gargano (CG).

$B(M1)^{\rm exp}$ (μ_N^2)	$B(M1)^{\rm B}_{\rm free}$ (μ_N^2)	$B(M1)^{\rm B}_{\rm eff}$ (μ_N^2)	$B(M1)^{\rm CG}$ (μ_N^2)
$< 0.29 \cdot 10^{-3}$	$4.8 \cdot 10^{-3}$	$2.2 \cdot 10^{-3}$	$44 \cdot 10^{-3}$

We have performed shell model calculations in order to understand the low excitation energy of the $5/2^+$ state and its very low $B(M1)$ value. Table 1 presents a comparison of the experimental $B(M1)$ values to the shell model predictions by Covello and Gargano (CG) and Brown (B). The calculations by Covello and Gargano use two-body effective interactions derived from CD-Bonn nucleon-nucleon potential with standard parameters for ^{132}Sn region (not adjusted for ^{135}Sb) and single-particle energies taken from the experimental spectrum od ^{133}Sb and ^{133}Sn. Transitions rates were calculated using the free g-factors and $e_p(\text{eff}) = 1.55$, $e_n(\text{eff}) = 0.7$. The calculations predict a fast $B(M1)$ for the 282 keV transition. Morevover, a relatively pure $7/2^+$ ground state is predicted as predominantly representing $g_{7/2}$ proton coupled to the ^{134}Sn core with 78% $\pi g_{7/2}(\nu f_{7/2})^2$, while the $5/2^+$ state calculated at 560 keV, has significant admixtures with the leading terms of 44% $\pi d_{5/2}(\nu f_{7/2})^2 + 27\%\ \pi g_{7/2}(\nu f_{7/2})^2$. (Lowering the separation energy between the proton $d_{5/2}$ and $g_{7/2}$ states by 400 keV would indeed decrease the excitation energy of the 5/2 state to the experimental value of 282 keV, and would also lower the $B(M1)$ rate by about a factor of 5, bringing it thus somewhat closer to the experimental limit. In addition, the composition of the state would become more pure: 65% $\pi d_{5/2}(\nu f_{7/2})^2 + 6\%\ \pi g_{7/2}(\nu f_{7/2})^2$.)

The calculation performed by Brown makes use of the wave functions obtained in ref. [3]. These were calculated with the CD-Bonn G-matrix evaluated in an oscillator potential with a renormalization based on the $\hat{Q}$-box method that includes nonfolded diagrams to third order and folded diagrams to infinite order. The single-particle energies are taken from the experimental level scheme of ^{133}Sb and ^{133}Sn, except for the proton $d_{5/2}$ energy, which is shifted down by 300 keV [3]. As discussed in [3] part of this shift may be attributed to the difference between the G-matrix monopole interactions for the $g_{7/2}$-$d_{5/2}$ splitting and that obtained in a Hartree-Fock (finite-well) potential. With free-nucleon g-factor $B(M1) = (0.172 - 0.102)^2 = 4.8 \cdot 10^{-3}\ \mu_N^2$; the terms inside the brackets are from the orbital and spin contributions, respectively. With the effective $M1$ operator, one obtains $B(M1) = (0.160 - 0.045 - 0.163)^2 = 2.2 \cdot 10^{-3}\ \mu_N^2$, where the terms inside the bracket are from effective orbital, spin and tensor operators, respectively.

The low excitation energy of the $5/2^+$ state in ^{135}Sb and an exceptionally low $B(M1; 5/2_1^+ \to 7/2_1^+)$ value of $\leq 2.9 \cdot 10^{-4}\ \mu_N^2$ tend to support the concept of a diffused core. However, caution must be taken in the comparison to the theory since due to a delicate balance between terms of the $M1$ operator of opposite signs, a better determination of these terms in this region is required before more firm conclusions can be drawn. Our effort is now focused on the lifetime and angular correlation measurements in ^{135}Te, ^{135}I and ^{137}I.

References

1. K. Amos *et al.*, Phys. Rev. C **70**, 024607 (2004).
2. A. Korgul *et al.*, Phys. Rev. C **64**, 021302(R) (2001).
3. J. Shergur *et al.*, Phys. Rev. C **65**, 034313 (2002).
4. H. Mach *et al.*, Nucl. Phys. A **523**, 197 (1991) and references therein.