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Lifetime measurements in ^{131}Sb at LOHENGRIN

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Abstract. The neutron-rich ^{131}Sb nucleus was studied at Institut Laue-Langevin, with the LOHENGRIN spectrometer, via neutron-induced fission of ^{235}U and lifetime measurements using LaBr$_3$(Ce) detectors. The lifetimes of the $11/2^+_1$ and $19/2^+_1$ states were measured with the generalized centroid difference and the decay slope methods, yielding $T_{1/2}$=3(2) ps and $T_{1/2}$=1347(171) ps, respectively. The measured value for the $11/2^+_1$ is at the limit of the fast-timing technique. The level scheme of ^{131}Sb and the decay properties of the $11/2^+_1$ state were described by realistic shell-model calculations, which reproduce well both the experimental spin and energy sequences of ^{131}Sb and the measured B(E2;$11/2^+_1 \rightarrow 7/2^+_1$) value, pointing to an almost pure $2^+(^{130}\text{Sn}) \otimes \pi g_{7/2}$, core-proton coupled configuration for the $11/2^+_1$ state.

1. Introduction

Particle(hole) core couplings can be investigated around shell closures by adding or removing particles (holes) on both proton and neutron sides. This was recently studied around ^{40}Ca and ^{48}Ca [1], ^{132}Sn [2, 3], and ^{208}Pb [4]. In Sb nuclei (Z=51), the energies of the $11/2^+_1$ states are similar to those of the 2^+ states in the underlying Sn nuclei [5], pointing to a possible core-proton coupling scheme. However, recent results for ^{129}Sb [3] have shown that the proton-neutron interference enhances the low-lying quadrupole strength compared to the one of the core. In this work, the structure of the $11/2^+_1$ and $19/2^+$ states in ^{131}Sb, closer to ^{132}Sn, were studied by lifetime measurements using γ-ray spectroscopy techniques and results are compared with realistic shell-model calculations. The $2^+(^{130}\text{Sn}) \otimes \pi g_{7/2}$ proton-core coupled nature of the $11/2^+_1$ state is discussed.

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2. The experiment

The experiment was carried out at Insititut Laue-Langevin (ILL) using thermal neutron-induced fission of ^{235}U. Antimony-131 nuclei were selected with the LOHENGRIN spectrometer [6] and their γ decay from isomeric states was measured at the focal plane with two HPGe clover detectors and four LaBr$_3$(Ce) scintillators. The latter were used to obtain lifetimes with fast-timing techniques.

The lifetime of the $11/2^+_1$ in state in ^{131}Sb was measured by using the *generalized centroid difference* (GCD) method [7], applied to the 450-1226-keV, feeding-decaying transitions. Possible sources of background were taken into account by using the method introduced in Ref. [8]. Three different pairs of background regions were identified, namely the p|b, peak-background, b|p, background-peak, and b|b, background-background regions, shown in the left panel of Fig. 1 with green, purple and gold bars, respectively, for the delayed time distribution displayed in red. The height of the bars is proportional to the number of counts in each time distribution. The lifetime of the $11/2^+_1$ state was obtained by $2\tau = \Delta$C-PRD, where ΔC is the centroid difference between the delayed and antidelayed time distributions and the PRD correction is the so-called *prompt response difference* [7]. The results is τ=5(3) ps, which corresponds to $T_{1/2}$=3(2) ps, at the edge of the sensitivity of the fast-timing method.

On the other hand, the lifetime of the $19/2^+_1$ state ^{131}Sb turned out to be much longer and was measured with the *decay slope method*, by fitting the delayed and antidelayed time distributions using a Gaussian distribution covoluted with an exponential function. Statistics was enhanced by applying gates on both the $19/2^+ \rightarrow 17/2^-$ and $19/2^+ \rightarrow 19/2^-$ decaying transitions, the time difference of which was considered with respect to the 97-keV $23/2^+ \rightarrow 19/2^+$ feeding transition. The results are shown in the right panel of Fig. 1 in pink and blue for the delayed and antidelayed time distributions, respectively. The weighted average lifetime obtained from their separate analysis is τ = 1944(246) ps, corresponding to $T_{1/2}$=1347(171) ps.

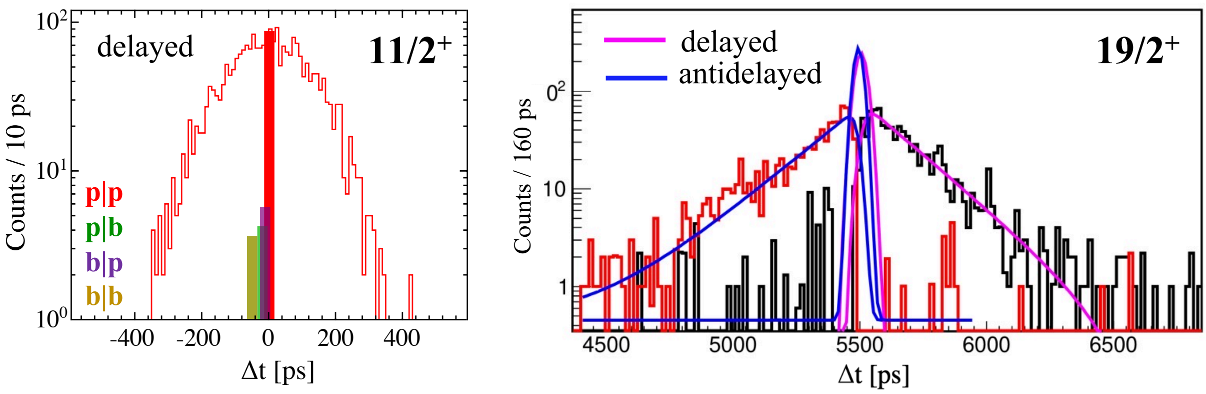

Figure 1. (Left) Delayed time distributions for the 450-1226-keV cascade involving the $11/2^+_1$ state. Vertical bars show the centroid positions of the p|p (red), p|b (green), b|p (purple), and b|b (gold) components, with their height being proportional to the number of counts in each time distribution (see text for details). (Right) Delayed (pink) and antidelayed (blue) time distribution for the sum of the 97-343-keV and 97-382-keV cascades involving the $19/2^+_1$ state.

3. Discussion

The measured lifetime of the $11/2^+$ state in ^{131}Sb can be translated into electric-quadrupole reduced transition probability to the ground state for the 1226-keV transition, yielding B(E2;$11/2^+_1 \rightarrow 7/2^+_1$)=$1.4^{+1.4}_{-0.6}$ W.u. This suggests that the extra proton does not perturb the

Sn core, being B(E2;$2^+_1 \rightarrow 0^+_1$)=1.18(26) W.u the reduced transition probability of the ^{130}Sn nucleus [9]. Realistic shell-model calculations were performed with the KSHELL code [10], using an inert ^{100}Sn core and a valence space composed by the $0g_{7/2}$, $1d_{5/2}$, $1d_{3/2}$, $2s_{1/2}$ and $0h_{11/2}$ orbitals for both protons and neutrons. The two-body effective interaction was obtained with many-body perturbation theory from the CD-Bonn nucleon-nucleon potential [11], renormalized by way of the $V_{\mathrm{low-k}}$ approach [12] with the addition of the Coulomb potential. The $\hat{Q}$ - box folded-diagram approach [13] including one and two-body diagrams up to the third order was also used. Effective charges are chosen to be $e_p = 1.7e$ and $e_n = 0.67e$, to reproduce the experimental B(E2; $2^+_1 \rightarrow 0^+_1$) = 31.5(1.0) and 1.18(26) W.u. of ^{134}Te and ^{130}Sn, respectively. The experimental level scheme of ^{131}Sb, as measured in this work, is presented in Fig. 2 (left) along with the results of shell-model calculations (right). We note that the level scheme is well reproduced and the calculated B(E2;$11/2^+_1 \rightarrow 7/2^+_1$)=1.6 W.u is in good agreement with the measured value. This, together with the computed wave-function which is dominated by the $2^+(^{130}\mathrm{Sn}) \otimes \pi g_{7/2}$ configuration (88%) indicates that the $11/2^+_1$ state is well described in terms of proton-core coupling. This result can be compared with the B(E2;$11/2^+_1 \rightarrow 7/2^+_1$) value measured in the neighbouring ^{129}Sb nucleus [3], which already exceeds the B(E2;$2^+_1 \rightarrow 0^+_1$) of the ^{128}Sn core (7.5(5) W.u. and 4.2(3) W.u [14], respectively). The same shell-model calculations suggests that this is due to a constructive proton-neutron interference, which is less pronounced in the case of ^{131}Sb, the latter having only two neutron holes with respect to the doubly-magic ^{132}Sn nucleus.

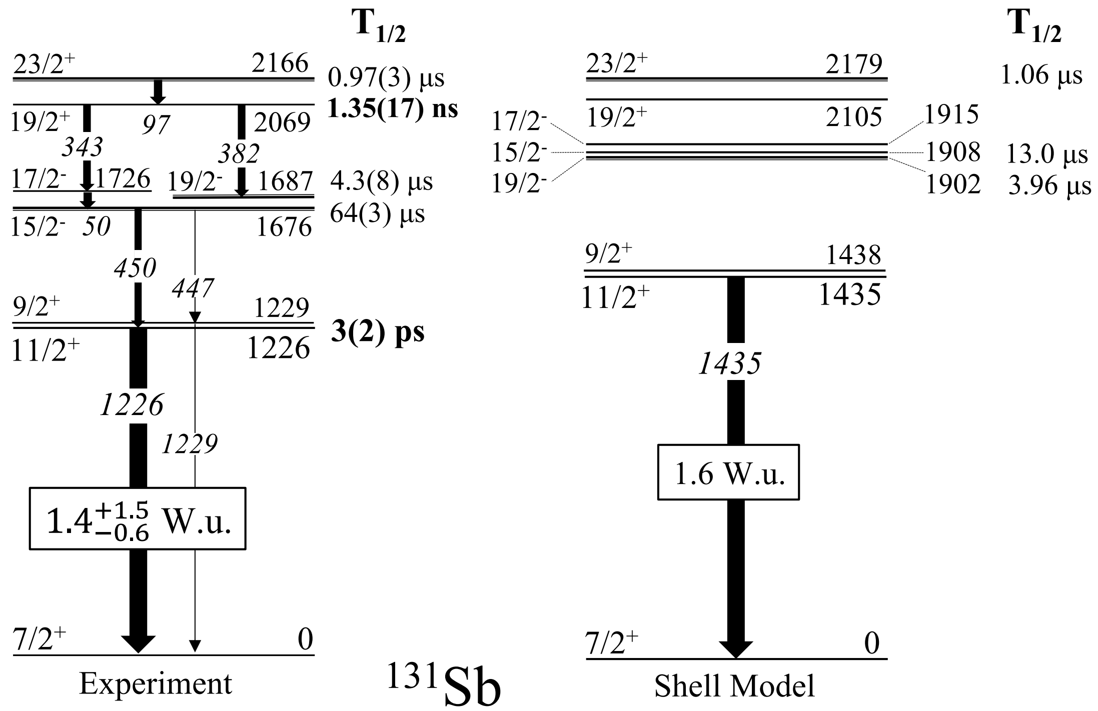

Figure 2. (Left) Experimental level and decay scheme of ^{131}Sb observed in the present experiment. Half lives measured in this work are highlighted in bold. The obtained B(E2;$11/2^+_1 \rightarrow 7/2^+_1$) value is also reported. (Right) Realistic shell-model calculations for the level scheme and the B(E2;$11/2^+_1 \rightarrow 7/2^+_1$) value (see text for details).

4. Conclusions

In conclusion, the lifetimes of the $11/2^+$ and $19/2^+$ states in ^{131}Sb were measured at the LOHENGRIN spectrometer of Insititut Laue-Langevin, using neutron-induced fission of ^{235}U and the fast timing technique with $LaBr_3$(Ce) detectors. Half-lives of 3(2) ps, at the edge of the experimental method, and 1347(171) ps were measured, respectively. A B(E2;$11/2^+_1 \rightarrow 7/2^+_1$)=$1.4^{+1.4}_{-0.6}$ W.u was obtained for the stretched E2 decay of the $11/2^+_1$ state, which is well reproduced by realistic shell model calculations indicating an almost pure $2^+(^{130}\mathrm{Sn}) \otimes \pi g_{7/2}$ core-proton coupled structure for this state.

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