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New level information on Z = 51 isotopes, $^{111}Sb_{60}$ and $^{134,135}Sb_{83,84}$

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Abstract. New data for low-spin low-energy levels in ^{111,134,135}Sb are presented. The observed structures are compared to shell-model calculations. The monopole shifts for the $d_{5/2}$ and $g_{7/2}$ single-proton levels and the spin-orbit splitting for the $d_{5/2}$ and $d_{3/2}$ orbitals as N/Z moves from ∼1 up to 1.6 are discussed.

PACS. 23.40.-s β decay; double β decay; electron and muon capture – 21.10.-k Properties of nuclei; nuclear energy levels – 21.60.-n Nuclear structure models and methods

1 Introduction

The systematic changes in structures of the low-spin states below 2.0 MeV of odd-A Sb nuclides from ^{101}Sb to ^{135}Sb provide important information regarding the monopole shift of the $g_{7/2}$ single-proton state between the $N = 50$ and $N = 82$ closed neutron shells and beyond. Levels below 2.0 MeV arise from coupling the 2^+ phonon of the Sn core to single-particle $g_{7/2}$ and $d_{5/2}$ states, and the presence or absence of degeneracy with the position of the 2^+ core level is one indication of the extent of configuration mixing.

For odd-A Sb nuclei with $115 \leq A \leq 133$, the structures of states below 2.0 MeV have been established by a number of different experiments. Whereas, only a recent study of the structure of ^{109}Sb by Ressler *et al.* [1], has provided new data for low-spin levels below ^{113}Sb. In this paper new data for levels in ^{111}Sb populated in the decay of ^{111}Te are presented.

Above the $N = 82$ shell closure, single-particle states have been identified in ^{133}Sb [2], and the $d_{5/2}$ single-particle state has been identified in ^{135}Sb [3]. The positions of these single-particle levels are important for understanding the evolution of nuclear structure as N/Z exceeds 1.5 and the neutron dripline is approached. Also presented in this paper are new data for the low-spin states of both ^{134}Sb and ^{135}Sb.

2 Experimental

Low-spin states in ^{111,113,115}Sb were populated via β^+/EC decay of ^{111,113,115}Te nuclei that were produced at Argonne National Laboratory using the ^{58}Ni(^{56}Fe,2pn)^{111}Te, ^{60}Ni(^{56}Fe,2pn)^{113}Te, and ^{62}Ni(^{56}Fe,2pn)^{115}Te fusion-evaporation reactions. Reaction products were separated in the Fragment Mass Analyzer on the basis of their mass to charge (A/Q) ratio, and following mass separation, the recoils were implanted in the tape of a moving tape collector (MTC). As the half-life of ^{111}Te ($T_{1/2} = 26.2(6)$ s) is shorter than nuclei produced from other reaction channels, the tape was moved periodically to a Pb-shielded counting station to maximize coincidence events; and to reduce contribution to the γ spectra from both the decays of daughter and granddaughter nuclides, and the decays of nuclides that are collected on the tape owing to similar A/Q values.

Levels in ^{134,135}Sb were populated by βdn and β^- decay of ^{135}Sn, respectively. Neutron-rich Sn nuclei were produced at ISOLDE, CERN by using a 1.4 GeV proton beam pulse to induce fission of a UC_2 target. Sn isotopes were then selectively ionized using the Resonance Ionization Laser Ion Source which consists of three copper vapor

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pumped dye lasers tuned to two resonant atomic excitations and a third to an energy which allowed for ioniztion of the electron into the continuum. Following mass separation, ^{135}Sn was implanted into the tape of a moving tape collector, data were collected, and the tape was moved to remove daughter, granddaughter, and isobaric nuclides prior to the next proton pulse. Data were collected with the "laser-on" and with the "laser-off" to distinguish which peaks in the γ spectra could be assigned to the decay of Sn, and which were a result of the decay of surface ionized ^{135}Cs. In both experiments, γ singles, γ-time, and γ-γ coincidences were collected.

3 Levels in proton-rich Sb nuclides

On the proton-rich side, eleven new states were identified in ^{111}Sb, including tentative assignments of the yrast $1/2^+$ and $3/2^+$ levels at 487 and 881 keV, respectively [4]. These data were combined with similar levels in ^{109}Sb [1] to improve the estimate for the positions of the $s_{1/2}$ and $d_{3/2}$ single-proton basis states in ^{101}Sb that underlie nuclear structure calculations in this mass region. With the position of the $d_{3/2}$ level at 2.9 MeV, the spin-orbit splitting in ^{101}Sb can be seen to be about twice the 1477 keV separation known for the $d_{5/2}$ to $d_{3/2}$ separation in ^{133}Sb, in agreement with the conjecture made by Schiffer *et al.* [5]. There are, of course, numerous other approaches to a full description of the spin-orbit splitting, however, we note that a further reduction of the $d_{5/2}$ to $d_{3/2}$ separation is found going from $^{133}Sb_{82}$ to $^{207}Tl_{126}$ where that separation is reduced to > 1332 keV [6]. We include the "greater than" symbol to recognize that, although the $3/2^+$ level at 351 keV has a large spectroscopic factor, the $5/2^+$ level at 1653 keV does not contain all of the $d_{5/2}$ strength. Hence, the centroid of the spin-orbit splitting is surely larger than 1332 keV, perhaps even approaching the 1477 keV splitting observed in ^{133}Sb.

4 Levels in neutron-rich Sb nuclides

On the neutron-rich side, new level structures have been identified in ^{135}Sb and ^{134}Sb where the levels were populated following direct β^- and β-delayed neutron decays of ^{135}Sn, respectively. The observed levels in ^{135}Sb below 1.0 MeV are shown in fig. 1, along with the results of a shell model calculation using the CD Bonn interaction, where the single-proton $d_{5/2}$ and $d_{3/2}$ levels have been lowered by 300 keV as described previously, thereby holding the spin-orbit splitting the same as for ^{133}Sb [3]. As can be seen, the positions for the calculated levels are in good agreement with the positions of the observed levels. The new levels populated in β-delayed neutron decay in odd-odd ^{134}Sb below 1.5 MeV are also shown in fig. 1, along with the levels calculated in an OXBASH calculation using the KH5082 interaction. Levels in ^{134}Sb at 13, 330, and 383 keV were previously reported by Korgul *et al.* [7]. Again, an excellent fit is found, in spite of the fact that the KH5082 interaction for this mass region has been imported from the ^{208}Pb region and scaled by $A^{-1/3}$.

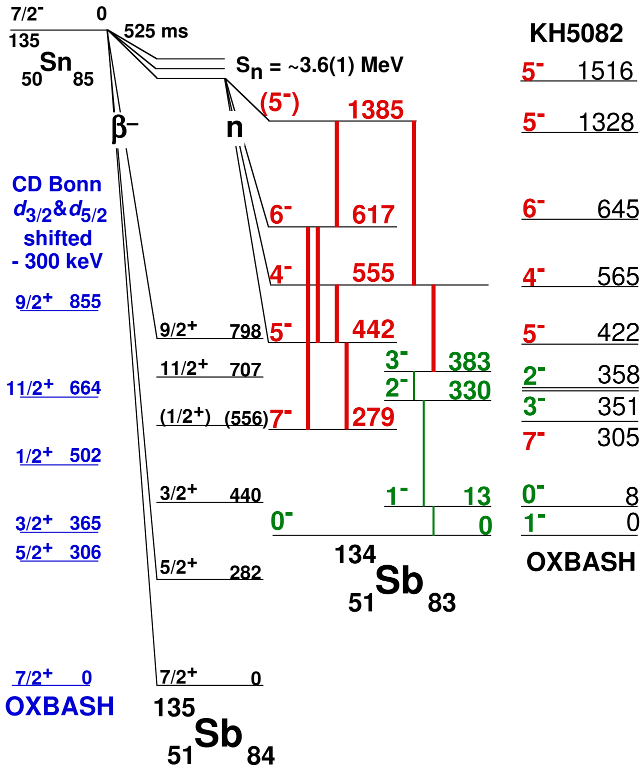

Fig. 1. The β^- and βdn decays of ^{135}Sn. The structures of ^{134}Sb and ^{135}Sb are compared with shell model calculations with the parameters described in the text.

5 Conclusions

These new data have provided improved values for the monopole shifts of single-proton states from $^{109}Sb_{58}$ through $^{135}Sb_{85}$. For both light and heavy Sb nuclides, shell model calculations provide a good description of the observed structures. It should be noted that other approaches to monopole shifts in neutron-rich nuclides have recently been published by both Otsuka *et al.* [8], and by Hamamoto [9].

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