E2 TRANSITION PROBABILITIES FOR DECAYS OF ISOMERS OBSERVED IN NEUTRON-RICH ODD Sn ISOTOPES*

Ł.W. Iskra[a], R. Broda[a], R.V.F. Janssens[b], J. Wrzesiński[a]
C.J. Chiara[b,c], M.P. Carpenter[b], B. Fornal[a], N. Hoteling[b,c]
F.G. Kondev[d], W. Królas[a], T. Lauritsen[b], T. Pawłat[a]
D. Seweryniak[b], I. Stefanescu[b,c], W.B. Walters[c], S. Zhu[b]

[a]The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences
Radzikowskiego 152, 31-342 Kraków, Poland
[b]Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA
[c]Department of Chemistry and Biochemistry, University of Maryland
College Park, Maryland 20742, USA
[d]Nuclear Engineering Division, Argonne National Laboratory
Argonne, Illinois 60439, USA

(Received January 21, 2015)

High-spin states were investigated with gamma coincidence techniques in neutron-rich Sn isotopes produced in fission processes following ^{48}Ca + ^{208}Pb, ^{48}Ca + ^{238}U, and ^{64}Ni + ^{238}U reactions. By exploiting delayed- and cross-coincidence techniques, level schemes have been delineated in odd $^{119-125}$Sn isotopes. Particular attention was paid to the occurrence of $19/2^+$ and $23/2^+$ isomeric states for which the available information has now been significantly extended. Reduced transition probabilities, B(E2), extracted from the measured half-lives and the established details of the isomeric decays exhibit a striking regularity. This behavior was compared with the previously observed regularity of the B(E2) amplitudes for the seniority $\nu = 2$ and 3, 10^+ and $27/2^-$ isomers in even- and odd-Sn isotopes, respectively.

DOI:10.5506/APhysPolB.46.651
PACS numbers: 23.20.Lv, 21.60.Cs, 27.60.+j, 25.70.Jj

In neutron-rich Sn isotopes, neutrons from the $h_{11/2}$ orbital are primarily responsible for the formation of isomeric states. The most striking are isomers of seniority $\nu = 2(10^+)$ or $\nu = 3(27/2^-)(h_{11/2})^n$ in even and odd

* Presented at the Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", Zakopane, Poland, August 31–September 7, 2014.

isotopes, respectively, which have been identified in a series of experiments using deep-inelastic collisions [1–3] and fusion-evaporation reactions [4] covering the $^{116-128}$Sn isotopes. Reduced transition probabilities, B(E2), displayed a striking regularity over the entire range of isotopes. This finding reflects the gradual filling of the neutron $h_{11/2}$ orbital with increasing mass. The minimum of the B(E2) values observed for the ^{123}Sn isotope indicated that the $h_{11/2}$ orbital is half-filled at the $N = 73$ neutron number. The investigation of levels located above these known 10^+ and $27/2^-$ isomeric states became recently the subject of independent studies by several groups. Recently published papers [5, 6] presenting the identification of high-spin state structures in neutron-rich Sn isotopes were soon followed by a more detailed study of even-Sn isotopes [7] which not only confirmed most of the findings, but also significantly expanded the experimental information and often made it more accurate. In particular, the regular appearance of 15^- isomeric states was confirmed, in several instances their decays were clarified and half-life values corrected. In addition, the previously unobserved 13^- isomeric states were identified in the ^{120,122,124,126}Sn isotopes and their half-lives were determined. Also, many new levels with seniority $\nu = 6$ were identified. Spin-parity assignments to the majority of the observed levels were supported by theoretical calculations based on the shell model which also reproduced reasonably well the observed level schemes up to highest excitation energies. The results obtained for the even-Sn isotopes enabled the investigation of the behavior of the reduced transition probabilities for the 13^- and 15^- E2 isomeric decays along the isotopic chain. In both cases, a striking regularity of the B(E2) amplitudes was observed resembling that established earlier for the seniority 2 and 3 isomers.

As a continuation of the study presented in Ref. [7], a similar effort was undertaken to investigate the neutron-rich odd-Sn isotopes. This involved the detailed delineation of states populated in the decay of the known $27/2^-$ isomeric states in the odd ^{119,121,123,125}Sn isotopes as well as the identification of new levels located above these isomers which correspond to seniority $\nu = 5$ excitations. While the established level schemes, half-life determinations for the isomeric states and comparisons with theoretical calculations will be described in detail in Ref. [8], here considerations will be restricted to the presentation of new values of the reduced transition probabilities obtained for the decays of the reinvestigated $19/2^+$ and $23/2^+$ isomers.

The data used in the present analysis were collected during three experiments carried out at Argonne National Laboratory using the Argonne Tandem Linear Accelerator System (ATLAS). All of the investigated isotopes were produced in fusion-fission reactions with 6.9 MeV/A ^{48}Ca beams on ^{208}Pb and ^{238}U targets and in fission of a ^{238}U target induced by 6.7 MeV/A ^{64}Ni beams. Level schemes up to excitation energies in excess of 8 MeV have been established based on multi-fold γ-ray coincidence relationships measured with the Gammasphere array. The beams were pulsed with a 412 ns repetition rate to provide a clean separation between prompt and delayed transitions. The detailed description of the experiments can be found in Refs. [7, 9].

Using the delayed coincidence technique described in Ref. [10], the decays of the $27/2^-$ isomers were reinvestigated over the entire range of neutron-rich odd-Sn isotopes. In each instance, the isomeric E2 decay feeds the $23/2^-$ state, with subsequent deexcitation via a cascade down to the ground state and via a competing E1 branch feeding the $23/2^+$ isomeric state. In the ^{119}Sn isotope, the $23/2^+$ isomer has been identified for the first time, while in ^{121}Sn the half-life of the previously postulated $23/2^+$ isomer has been experimentally determined. These $23/2^+$ levels deexcite to the long-lived $19/2^+$ isomer via E2 transitions, which, in turn, decay by two or three parallel transitions with M2, E2, or E3 multipolarity. While these $19/2^+$ decays have been identified by Mayer *et al.* [3] in the ^{119,121,123}Sn isotopes, the transition intensities necessary to extract the reduced transition probabilities were determined for the first time in the present work. In Fig. 1, the amplitudes of the respective B(E2) values extracted in the present analysis are displayed. In the lower part of the figure, a set of B(E2) amplitudes established earlier for the seniority $\nu = 2$ and 3 isomers in the full range of $^{116-130}$Sn isotopes is given for comparison. Here, a geometrical factor of 0.514 [4] was used to renormalize the amplitudes of the $27/2^- \rightarrow 23/2^-$ transitions in the odd-Sn isotopes to be compared with the corresponding $10^+ \rightarrow 8^+$ values in the even ones. The amplitudes of the B(E2) reduced transition probabilities displayed at the top of Fig. 1 correspond to the E2 decays of the $23/2^+$ and $19/2^+$ isomers which were determined in the present work. For completeness, the B(E2) values determined earlier for the same isomers in ^{125,127,129}Sn isotopes [11] and in the ^{117}Sn [12] are also included in the figure. It should be noted that, in the ^{119,121}Sn isotopes, the decay of the $19/2^+$ isomer via the E2 transition was not observed. Most likely, the very low intensity of the expected transitions was below the detection limit of the measurements. The most important observation in Fig. 1 is that, for the $23/2^+$ and $19/2^+$ isomers, the B(E2) transition amplitudes display a behavior very similar to that exhibited by E2 decays of the seniority $\nu = 2, 3$ states. Moreover, apart from the similarity of the regular decline of the B(E2) amplitudes with increasing mass number, the B(E2) values are also similar to those displayed in the lower part of the figure and this observation is valid without multiplication by the geometric factor of 0.514 characteristic of the seniority $\nu = 3$ states. This suggests that in the isomeric E2 decays from the $23/2^+$ and $19/2^+$ states, the seniority $\nu = 2$ excitations of $h_{11/2}$ neutrons play a dominant role. Indeed, theoretical calculations carried

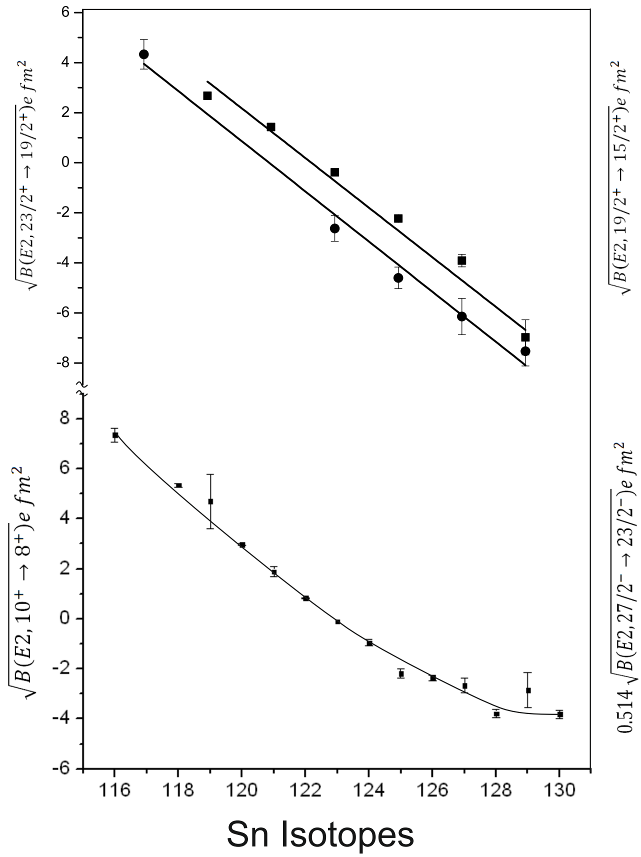

Fig. 1. Transition amplitudes for E2 isomeric decays observed in the neutron-rich Sn isotopes. In the bottom part of the figure, the mass dependence of E2 amplitudes established in the decay of the 10^+ and $27/2^-$ isomers is displayed. The E2 amplitudes extracted for the $23/2^+$ (squares) and $19/2^+$ (circles) states are shown at the top. See the text for details.

out according to the procedure described in Ref. [7] confirm this property: the $23/2^+$ states have a pure $\nu(h_{11/2})^2d_{3/2}$ configuration, while the corresponding $19/2^+$ wave functions involve the $\nu(h_{11/2})^2d_{3/2}$ and $\nu(h_{11/2})^2s_{1/2}$ configurations where the $s_{1/2}$ and $d_{3/2}$ neutrons act only as spectators and cannot contribute to the E2 transition strength. The results reported here will be more broadly discussed in Ref. [8].

This work was supported by the Polish National Science Center, Projects No. UMO-2012/07/N/ST2/02861, the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357 (ANL) and Grant No. DE-FG02-94ER40834 (UM), as well as by the Marian Smoluchowski Kraków Research Consortium Matter-Energy-Future as a Leading National Center (KNOW).

REFERENCES

[1] S. Lunardi *et al.*, *Z. Phys.* **A328**, 487 (1987).
[2] R. Broda *et al.*, *Phys. Rev. Lett.* **68**, 1671 (1992).
[3] R.H. Mayer *et al.*, *Phys. Lett.* **B336**, 308 (1994).
[4] C.T. Zhang *et al.*, *Phys. Rev.* **C62**, 057305 (2000).
[5] N. Fotiades *et al.*, *Phys. Rev.* **C84**, 054310 (2011).
[6] A. Astier *et al.*, *Phys. Rev.* **C85**, 054316 (2012).
[7] Ł.W. Iskra *et al.*, *Phys. Rev.* **C89**, 044324 (2014).
[8] Ł.W. Iskra *et al.*, unpublished.
[9] R. Broda *et al.*, *Phys. Rev.* **C86**, 064312 (2012).
[10] Ł.W. Iskra *et al.*, *Acta Phys. Pol. B* **44**, 395 (2013).
[11] R.L. Lozeva *et al.*, *Phys. Rev.* **C77**, 064313 (2008).
[12] O. Hashimoto *et al.*, *Nucl. Phys.* **A318**, 145 (1979).