LEVEL AND ISOMER SYSTEMATICS IN EVEN Sn ISOTOPES

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(Received 10 April 1968)

Levels of even Sn isotopes ($A=108$-118) have been studied in Cd(α,xn) reactions. Nanosecond time analysis of γ rays has revealed the systematic presence of isomers.

A method of systematically studying the existence of isomeric states with nanosecond lifetimes populated in (α,xn) reactions has been discussed earlier.[1] We have used this method to study isomeric states in even Sn isotopes from $A=108$ to 118. The present study has revealed the existence of new isomers in $A=112$ to 118 in addition to the known negative-parity (5^- and 7^-) isomers in ^{116}Sn, ^{118}Sn, and ^{120}Sn.[2-5] The energies of these new levels appear to vary systematically with A. Theoretical considerations suggest that new isomers from $A=114$ to 118 may arise from the $(h_{11/2})^2$ neutron configuration.

In our experiments metallic targets of separated cadmium isotopes were bombarded with α particles from the Berkeley 88-in. cyclotron. The beam energy was varied from 28 to 50 MeV to control the yield of the ($\alpha,2n$), ($\alpha,3n$), and ($\alpha,4n$) reaction products. Gamma rays from the targets were observed with Ge(Li) detectors of different active volumes and the time distributions of the gamma rays were measured by the method described in Ref. 1. The spectra were initially surveyed either with 2048 channels for energy analysis and two time channels (prompt and ~50-nsec delayed) or with 1024 channels for energy analysis and four time channels (prompt 25-, 50-, and 75-nsec delayed). These experiments provided immediate evidence of the existence of isomers and a rough estimate of transition lifetimes. A typical spectrum observed in the ^{110}Cd+28-MeV α reaction is shown in Fig. 1. This was taken with a 7-cm^2 (surface area)×1-cm (thickness) Ge(Li) detector.

Accurate estimates of half-lives were obtained by recording spectra with 256 channels for energy analysis and 16 channels for time analysis. The lower limit of observable half-lives in these runs was about 4 nsec. (In the survey runs, the lower limit was about 7 nsec.) The time spacing of the cyclotron beam bunches placed an upper limit of about 300 nsec for accurate lifetime measurements. Longer-lived isomers were easily identified but their half-lives could not be determined with accuracy. The half-lives of isomers in ^{112}Sn to ^{118}Sn were measured with this technique. Typical time distributions for gamma rays from the reaction ^{110}Cd($\alpha,2n$)^{112}Sn are shown in Fig. 2. The transitions shown all have a half-life of 14 nsec and are presumably fed by the same isomeric decay.

The results of the present measurements are summarized in Fig. 3. This figure includes level assignments derived from previous studies.[6] The isomeric states implied from our results are shown by heavy lines. Their positions rely upon expected systematic trends in the level schemes and additional experiments are required

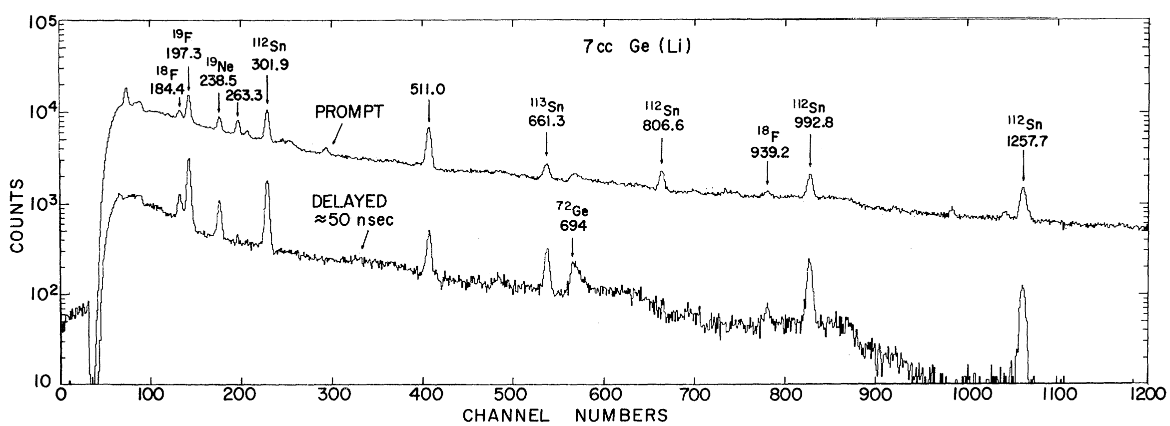

FIG. 1. Prompt and delayed energy spectra of γ rays emitted in ^{110}Cd+28-MeV α reaction. Most γ rays are due to the reaction ^{110}Cd($\alpha,2n$)^{112}Sn. Delayed γ rays in ^{18}F, ^{19}F, and ^{19}Ne from the backing and impurity are also identified.

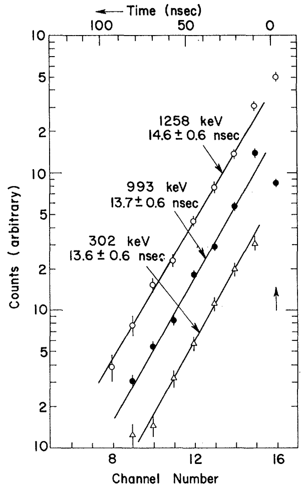

FIG. 2. Time distribution curves for three prominent delayed γ rays of ^{112}Sn.

to establish with certainty the energies and spin assignments of these levels. The detailed analysis of the experimental data will be described elsewhere.[7]

There have been several theoretical calculations of the level structure of tin isotopes.[8-11] Kisslinger and Sorenson[8] used a pairing plus quadrupole-quadrupole interaction. More recently Arvieu and co-workers[9] have made extensive calculations using the pairing scheme and a Gaussian type of residual interaction and later a surface delta interaction.[10] The experimental data shown in Fig. 3 allow us to make the following qualitative comparisons with the theoretical predictions. For reference we show the quasiparticle energies for the $(h_{11/2})^2$, $(d_{5/2})^2$, and $(g_{7/2})^2$ configurations used by Arvieu.[11]

(1) The energy of the first 2^+ level increases with N from $N=58$ to $N=64$, where it reaches a maximum, and then starts to decrease. This is the result of a slight shell effect at $N=64$.

(2) The energy of the 4^+ level shows a dependence on N similar to that of the 2^+ level energy, except at $N=64$ where there is an appreciable depression. This is not reproduced in Arvieu's earlier calculations but is in qualitative agreement with later calculations for $N \geqslant 64$ by Plastino, Arvieu, and Moszkowski[10] in which a surface delta interaction was used. A qualitative understanding of the dip in energy may also be obtained by considering the structure of the 4^+ state. Below $N=64$ its structure is dominated by the $(d_{5/2})^2$, $(g_{7/2})^2$, and $d_{5/2}g_{7/2}$ components. Above $N=64$ the structure is dominated by the $(h_{11/2})^2$ component. At $N=64$ all components contribute

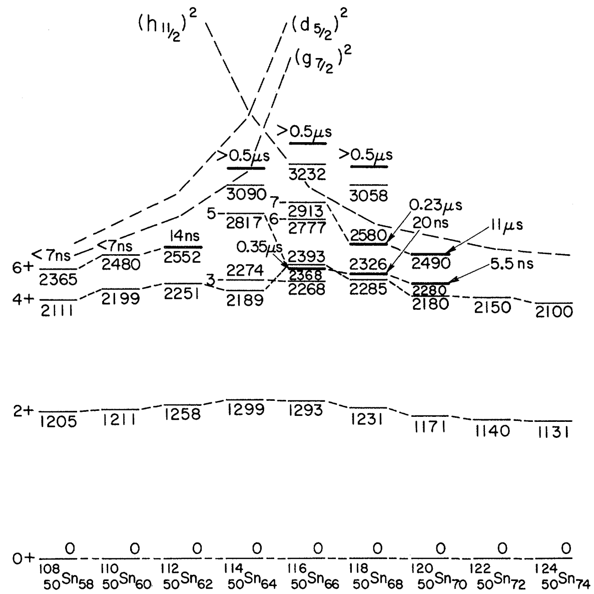

FIG. 3. The level and isomer systematics revealed in the present study. Levels of the same spin and parity are connected by broken lines. Previously known levels are ^{112}Sn (2^+), ^{114}Sn $(2^+$ and $3^+)$, ^{116}Sn $(2^+, 3^+, 5^-, 4^+, 6^-,$ and $7^-)$, ^{118}Sn $(2^+, 4^+, 5^+,$ and $7^-)$, ^{120}Sn $(2^+, 4^+, 5^-,$ and $7^-)$, ^{122}Sn $(2^+$ and $4^+)$, and ^{124}Sn $(2^+$ and $4^+)$. References are given in the recent compilation of Lederer, Hollander, and Perlman (Ref. 6).

approximately equally and lead to a lowering in the energy of the state. The 2^+ state is less affected because more configurations are available.

(3) The 5^- state $(h_{11/2}, s_{1/2})$ or $(h_{11/2}, d_{3/2})$ is isomeric for $A=116$, 118, and 120, but not for $A=114$, where the energy difference between the 5^- and the 4^+ levels is too great for the $E1$ transition to have a lifetime measurable in our experiments. The 7^- state $(h_{11/2}, d_{3/2})$ is isomeric for $A=118$ and 120 due to the highly hindered $E2$ decay, but not for $A \leqslant 116$ as it feeds the 6^- state via a fast $M1$ transition. The 7^- level for $A=114$ could not be identified, presumably because it lay too high for observation. The systematics of these negative-parity states are consistent with the assumed behavior of the $h_{11/2}$ orbit.

(4) In addition to the negative-parity isomers, we observed at least one long-lived isomer (>100 nsec) for each isotope in the region $N \geqslant 64$. On the other hand, no such isomers were seen in the region $N<64$. The half-life of the isomer in ^{116}Sn has been determined by Chang, Hageman, and Yamazaki[12] to be 0.8 μsec. From the quasiparticle states available these long-lived isomers are tentatively assigned to the 10^+ state of the $(h_{11/2})^2$ configuration. For $N \geqslant 64$, the 8^+ and

10^+ states of the $(h_{11/2})^2$ configuration are expected to lie around 3 MeV and, as no other configuration contributes to these high-spin states, they should remain relatively unperturbed. The energy spacing between the 8^+ and 10^+ levels is estimated to be ~100 keV and the 10^+ state could be expected to have a half-life of ~1 μsec. In the region $N<64$, the $(h_{11/2})^2$ energy becomes so large that this configuration may no longer be the sole contributor to the lowest 8^+ and 10^+ states. Four-quasiparticle states and vibrational states may also contribute. This may explain why the long-lived isomer does not exist in this region.

(5) It is interesting that for $N<64$ the highly populated levels terminate at 6^+. This is consistent with the fact that no higher spin state is available at low energy with the $d_{5/2}$ and $g_{7/2}$ orbits. The half-life of the 6^+ state in ^{112}Sn was found to be 14 nsec, which is comparable with the Weisskopf estimate for an $E2$ transition. It is striking that no delayed state was observed for the lighter nuclei, although the level structure is unchanged. This implies that the $B(E2, 6^+ \rightarrow 4^+)$ value increases rapidly as N decreases. This is in disagreement with the pairing theory which predicts that the $B(E2, 6^+ \rightarrow 4^+)$ should decrease due to the $UU-VV$ factor. This will be discussed in detail in the forthcoming paper.[7]

In conclusion we emphasize the possible presence of $[(h_{11/2})^2]_{10^+} \rightarrow [(h_{11/2})^2]_{8^+}$ isomers in the region $N \geqslant 64$, which preserve pure quasiparticle states. In the region $N<64$, such an isomer is not observed and the ground band terminates at a spin of 6^+. The discontinuance of the ground-band structure at $N \leqslant 64$ is also seen in the $Z=52$ Te isotopes studied by Bergström et al.[13] These facts raise the question as to the real nature of the ground band of levels and the relation between the so-called vibrational sequence and the lowest seniority scheme. Further experiments are planned to elucidate these problems.

We are grateful to Dr. J. M. Hollander and Dr. B. G. Harvey for support and encouragement, to Professor Mottelson, Dr. T. Udagawa, and Dr. R. A. Broglia for stimulating discussions, and to Professor I. Perlman and J. O. Rasmussen for the hospitality of the Lawrence Radiation Laboratory.

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