High-Spin States of the Neutron-Rich Nucleus ^{125}Sb *

LIU Zhong[1] ZHANG Yu-Hu[1] MA Ying-Jun[2] Y. Sasaki[2] K. Yamada[2] H. Oshima[2] S. Yokose[2] M. Ishizuka[2] T. Komatsubara[2] K. Furuno[2]

1 (Institute of Modern Physics, The Chinese Academy of Sciences, Lanzhou 730000, China)

2 (Institute of Physics and Tandem Accelerator Center, University of Tsukuba, Ibaraki 305-0006, Japan)

Abstract High spin states of ^{125}Sb have been investigated for the first time by means of in-beam γ-ray spectroscopy techniques via the ^{124}Sn(^{7}Li, α2n) reaction at 32 MeV beam energy. Based on the measurements of γ-γ coincidence and γ-ray anisotropies, a level scheme including 21 new γ-transitions and 14 new excited levels was established up to 23/2$^+$. Three isomers at 1970, 2110 and 2471 keV levels have been identified and proposed as three-quasiparticle $\pi g_{7/2}\nu(h_{11/2}s_{1/2})$, $\pi g_{7/2}\nu(h_{11/2}d_{3/2})$ and $\pi g_{7/2}\nu(h_{11/2}^2)$ configurations, respectively. The level structure of ^{125}Sb is discussed in terms of particle-core coupling.

Key words in-beam γ-ray spectroscopy, isomer, particle-core coupling

Spectroscopic studies of the high-spin states in odd-A Sb isotopes have revealed completely different excitation modes. In the heavier Sb isotopes with $A \geqslant 127$, single particle excitations manifest, and isomers originated from coupling the odd proton and two-quasineutron 5$^-$, 7$^-$, 10$^+$ isomeric states of the even Sn cores were identified[1—3]. While in the lighter isotopes with $A \leqslant 121$, $\Delta I = 1$ collective rotational bands built on $g_{9/2}$ proton-hole intruder states have been systematically observed[4—6]. The nucleus ^{125}Sb is located in between, it is of interest to investigate the property of its high-spin structure. So far, available information concerning its structure comes only from β decay and light-ion (p, d, t, ^{3}He) induced reactions[7]. In this letter we present the first identification of high spin states in this neutron-rich nucleus by means of in-beam γ-ray spectroscopy techniques.

The experiment was performed with ^{7}Li beam bombarding an enriched self-supporting 4 mg/cm^2 thick ^{124}Sn metallic foil at the tandem accelerator laboratory in the University of Tsukuba, Japan. A γ-ray detector array consisting of 9 BGO-Compton-suppressed Ge detectors was used for γ-ray detection. Five Ge detectors were placed at 37° and the others near 90° with respect to the beam direction so that the ADO ratios (Angular Distributions of γ-rays de-exciting the Oriented states) could be deduced from the coincidence data. All the detectors were calibrated with standard ^{152}Eu and ^{133}Ba sources. Typical energy resolution was 2.0—2.5 keV for the 1332 keV line from ^{60}Co source. The γ-γ coincidence measurements were performed at a beam energy of 32 MeV. A total of 40 million γ-γ-t coincidence events were accumulated; t is the time interval between two coincident γ-rays. During the measurement, the coincidence time window was set to be 100 ns. These data were sorted

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into one symmetric and two non-symmetric ADO matrices for off-line analysis. In order to investigate the presence of isomers, a delayed coincidence matrix was also created with a timing condition of 40 ns < t < 100 ns.

Based on detailed analysis of γ-γ coincidence relationships, γ-ray relative intensities and anisotropies, a high-spin level scheme has been established for ^{125}Sb as shown in Fig.1. Low-spin excited states of ^{125}Sb were already studied via β decay and light-ion induced reactions[7]. The previously known low-lying 1089, 1067, 332, 1088, 823, 916, 270, 800, 893, 1420 and 470 keV transitions are observed in the present work and their coincidence relationships as shown in the left part of Fig.1 are confirmed. Multipolarities have been measured for most of these known transitions. Our data based on their angular anisotropies are found in agreement with the previous assignments. In addition, 21 new γ transitions are observed in coincidence with the strongest 1089 and 1067 keV transitions. They form the new level structures as shown in the middle and right part of the Fig.1. The spectra gated on the 1089 and 146 keV transitions are presented in Fig.2 to show the quality of the data. The 141, 246, 105, 108 and 255 keV peaks are very weak in the spectrum gated on the 1089 keV transition due to the presence of isomeric states at 1970 and 2110 keV as will be described later.

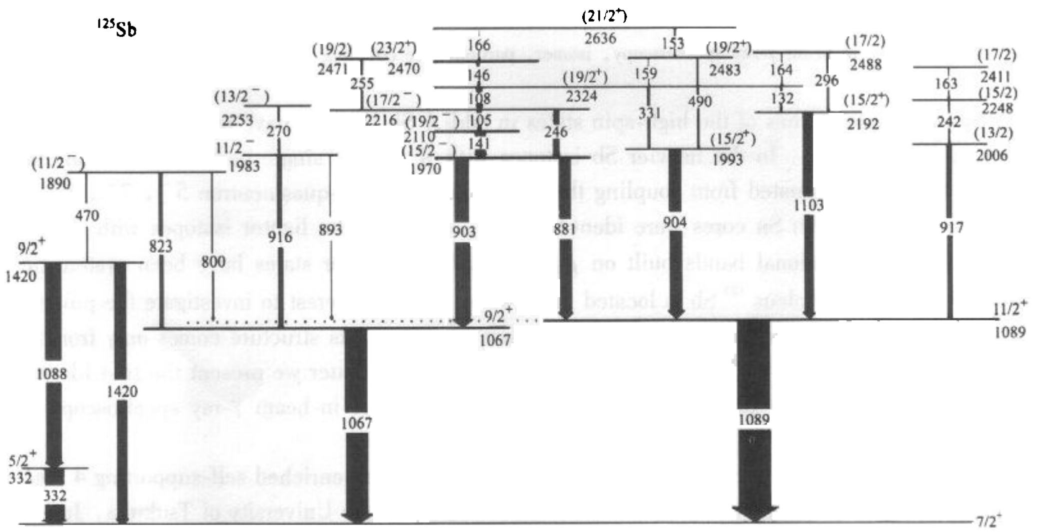

Fig.1. Level scheme of ^{125}Sb proposed by the present work.

The ADO (40°/90°) ratios of the 904, 1103, 132, 332, 146 and 490 keV γ-rays are large than unity, suggesting that they are stretched quadrupole ($\Delta I = 2$) transitions. They are in prompt coincidence with the 1089 keV transition, so they are assigned as E2 transitions (since prompt M2 transitions are very rare). Positive-parity are thus tentatively assigned for the 1993, 2193, 2325, 2471 and 2484 keV levels. For the 132 keV transition, by gating on higher lying transitions and considering the intensity balance, its internal conversion coefficient was extracted to be around 0.7, supporting the above E2 assignment. According to the spin assignments for the 2325 and 2484 keV levels, the 159 keV transition should be a $\Delta I = 0$ transition, in agreement with its large ADO ratios of about 1.36. The ADO ratios of the 296, 153, 917, 242 and 163 keV γ-rays are less than unity, implying that they are typical stretched dipole ($\Delta I = 1$) transitions.

The anisotropies of the 881 and 903 keV transitions are very close to unity, implying that they

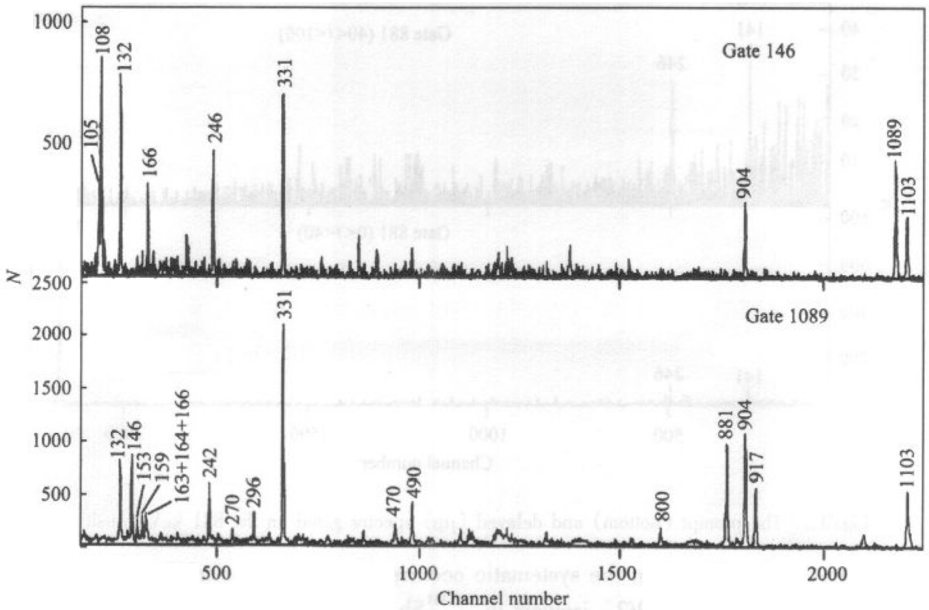

Fig.2. Coincidence spectra gated on the 1089 and 146 keV transitions.

are de-excition of one excited state with half-life long enough. Indeed, as shown in Fig.3, low peaks at 141 and 246 keV appear in both the prompt and delayed spectra gated on the 881 keV transition, verifying the existence of a long-lived isomer at 1970 keV. Similarly, the 166 keV line also show a considerable delayed components in the spectra gated on the transitions below the 2471 keV level, indicating the presence of an isomer at 2471 keV. Because the statistics of the delayed 141, 245 and 166 keV γ-rays are very low, the half-lives of the 1970 and 2471 keV levels are estimated only from the ratios between the counts of the delayed components and the total counts of these γ-rays in coincidence spectra. The half-life is extracted to be in the range of 40—200 ns and an average value of 85 ns is obtained for the 2471 keV $23/2^+$ level. For the 1970 keV level, its half-life is in the range of 70—600 ns, averaged to be 300 ns. In this experiment the 10^+ isomer in ^{128}Te was also populated and an average half-life of 350 ns is obtained using this method, while its half-life was measured to be 370 ns in a pulsed-beam experiment[8], giving confidence to our results. In addition, the 105 keV γ-line is not observed in the spectra gated on the transitions below the 2110 keV level, either does the 141 keV peak appear in the spectra gated on the transitions above the 2110 keV level, implying that the 2110 level is an isomer with much longer half-life. A lower limit of 2 μs is obtained from the experimental sensitivity and the coincidence time window.

We have proposed spin and parity of $15/2^-$ for the 1970 keV level since the partial half-lives of the 903 and 881 keV transitions are most compatible with E3 or M2 multipolarities. In addition, the anisotropies of the 246 and 108 keV transitions manifest stretched dipole character, also supporting the spin assignment (15/2) for the 1970 keV level made above. In fact $15/2^-$ isomers have been systematically observed in $^{131,129,127}Sb$ at 1677, 1861 and 1920 keV, respectively. We can see that the 1970 keV isomer in ^{125}Sb follows closely the energy systematics of $15/2^-$ isomeric states in neutron-rich $^{125-131}Sb$ isotopes.

The 105 keV line is also measured to be a dipole transition. Spin of 15/2 or 19/2 could be assigned for the 2110 keV isomer. The long half-life of this level excludes M1 or E1 multipolarity for

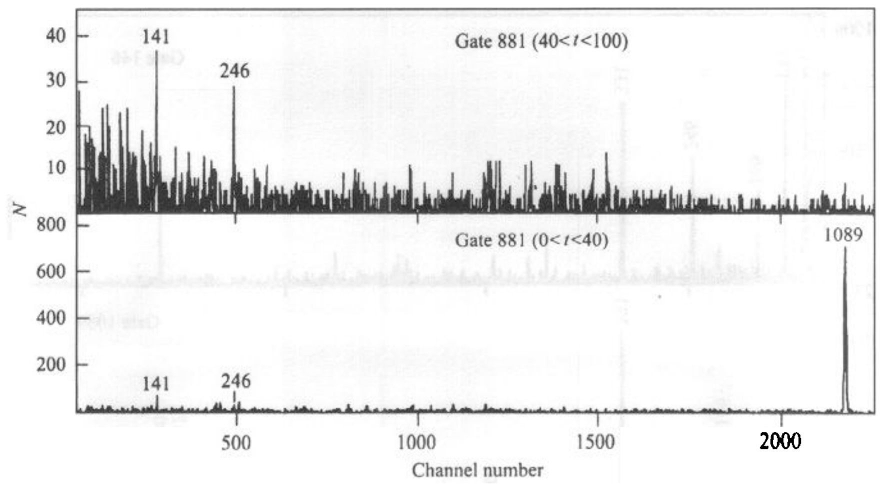

Fig.3. The prompt (bottom) and delayed (μp) spectra gated on the 881 keV transition.

the 141 keV transition. Based on the systematic occurrence of microsecond 7^- isomers in the even Sn isotopes and observation of $19/2^-$ isomers in ^{129,131}Sb, we have assigned spin and parity of 19/2 to the 2110 keV isomer.

The dipole 917—242—163 keV cascade was assigned to ^{125}Sb based on their coincidence relationships with the 1089 keV transition. According to the CASACADE calculations, in the present reaction the residues produced with observable cross-sections are $^{126-128}$I, $^{126-128}$Te, and ^{124,125}Sb. Among these nuclei, only ^{125}Sb has an yrast transition with energy in the range of 1087—1091 keV, so the assignment of these transitions to other nuclei could be excluded. Parities can not be determined for this level sequence.

Now we give some discussions on the configurations of the observed levels. It is already known from one-nucleon transfer reactions that in ^{125}Sb the ground state, 332 and 1890 keV levels are originated from the $g_{7/2}$, $d_{5/2}$ and $h_{11/2}$ proton orbitals above the $Z = 50$ shell closure, respectively[7]. Other excited states could be formed by coupling the odd proton and the core excitations of ^{124}Sn. The 1067, 1089 keV levels are the $9/2^+$ and $11/2^+$ members of the $\pi g_{7/2} \otimes 2^+$ multiplet, respectively, formed by coupling one-phonon 2^+ state of ^{124}Sn with $g_{7/2}$ proton, while the 1420 keV level is formed by coupling with the $d_{5/2}$ proton state. The 270 keV transition feeding only the 1983 keV 11/2 level is a stretched dipole, so the 2253 keV level is tentatively assigned as 13/2. These two levels decay to the $\pi g_{7/2} \otimes 2^+$ multiplet, implying that they have considerable $g_{7/2}$ single particle component. They most probably originate from coupling of the $g_{7/2}$ proton and the octupole excitations of the core. Such negative-parity states were predicted to lie between 2.0 and 2.5 MeV by theoretical calculations[9], in agreement with the present experimental observation.

The excitation energies of the two $15/2^+$ levels (1993 and 2193 keV) in ^{125}Sb are close to those of the two 4^+ levels in ^{124}Sn. They are very likely formed by coupling the $g_{7/2}$ proton with these two 4^+ core states.

In the even-mass Sn isotopes, the two-quasineutron $\nu(h_{11/2}s_{1/2})5^-$, $\nu(h_{11/2}d_{3/2})$ 7 and $\nu(h^2_{11/2})$ 10^+ states are nanosecond, microsecond and microsecond isomers, respectively. The three-quasiparticle states formed by coupling the single proton with these 5^-, 7^-, 10^+ core states are also expected to be isomers. With the average half-life of the $15/2^-$ isomer, the reduced transition probability for the 903 keV transition is $B(E3) = 4.4$ W.u., very close to the $B(E3) = 1.5$ W.u. of the $\nu(h_{11/2}s_{1/2})5^- \to 2^+$ E3 decay in ^{124}Sn[10]. This suggests a $\pi g_{7/2} \otimes \nu(h_{11/2}s_{1/2})_{5^-}$ configuration for the 15/2 isomer. The reduced transition probability of the 141 keV transition is $B(E2) < 0.13$ W.u, implying that the main parts of the wavefunctions of the two isomers at 2110 and 1970 keV are different. For a similar E2 decay, i.e. $\nu(h_{11/2}d_{3/2})7^- \to \nu(h_{11/2}s_{1/2})5^-$ in ^{124}Sn, $B(E2) = 0.1$ W.u. was measured. So it is very reasonable to assign a $\pi g_{7/2} \otimes (\nu h_{11/2}d_{3/2})_7$ configuration for this $19/2^-$ isomer as in the heavier ^{129,131}Sb isotopes[1,2]. The 2471 keV $23/2^+$ isomer is expected to be a $\pi g_{7/2} \otimes \nu(h_{11/2}^2)_{10^+}$ three-quasiparticle state. For the 146 keV transition, the reduced transition probability corresponding to the average half-life is $B(E2) = 2.7$ W.u. This suggests that the 2471 and 2325 keV levels have a large E2 overlap between their wavefunctions. So the 2325 keV level should correspond to the $19/2^+$ member of the $\pi g_{7/2} \otimes \nu(h_{11/2}^2)_{10^+}$ multiplet.

It's interesting to point out that, in ^{125}Sb the $15/2^-$ and $19/2^-$ isomers are the $J_{max} - 1$ members of $\pi g_{7/2} \otimes 5^-$ and $\pi g_{7/2} \otimes 7^-$ states, respectively, while the $23/2^+$ isomer is the $J = J_{max} - 2$ member of the $\pi g_{7/2} \otimes 10^+$ multiplet. Similar level structures have been observed in $Z = 83$ odd-proton Bi isotopes with neutron number $N < 126$[11]. Empirical shell model calculations will be performed to understand this behavior in ^{125}Sb.

References

1 Genevey J, Pinston J A, Faust H et al. Eur. Phys. J., 2000, **A9**:181
2 Stone C A, Walters W B. Z Phys., 1987, **A328**:257
3 Apt K E, Walters W B. Phys. Rev., 1974, **C9**:310
4 Piel W F, Jr Chowdhury P et al. Phys. Rev., 1985, **C31**:456
5 Gaigalas A K, Shroy R E, Schatz G et al. Phys. Rev. Lett., 1975, **35**:555
6 Shroy R E, Gaigalas A K, Schatz G et al. Phys. Rev., 1979, **C19**:1324
7 Katakura J. Nuclear Data Sheets, 1999, **86**:955
8 ZHANG C T, Bhattacharyya P, Daly P et al. Nucl. Phys., 1998, **A628**:386
9 Vanden Berghe G, Hedye K. Nucl. Phys., 1971, **A163**:478
10 Fogelberg B, Carle P. Nucl. Phys., 1979, **A323**:205
11 Piel W F, Jr Chapuran T et al. Phys. Rev., 1985, **C31**:2087

丰中子核 ^{125}Sb 的高自旋态*

刘忠[1] 张玉虎[1] 马英君[2] Y.Sasaki[2] K.Yamada[2] H. Oshima[2] S. Yokose[2] M.Ishizuka[2] T.Komatsubara[2] K.Furuno[2]

1(中国科学院近代物理研究所 兰州 730000)

2(Institute of Physics and Tandem Accelerator Center, University of Tsukuba, Ibaraki 305 - 0006, Japan)

摘要 利用在束γ谱学方法,通过^{124}Sn(^{7}Li, α2n)反应首次研究了丰中子核^{125}Sb的高自旋态. 建立了自旋达23/2^{+}、激发能至2637keV的能级纲图,其中包括21条新γ跃迁和14个新能级. 在1970,2110和2471keV识别出了3个同质异能态,估计了它们的寿命范围,并建议分别具有$\pi g_{7/2}\nu(h_{11/2}s_{1/2})$, $\pi g_{7/2}\nu(h_{11/2}d_{3/2})$, $\pi g_{7/2}\nu(h^{2}_{11/2})$三准粒子组态. 根据价质子与^{124}Sn核芯激发态的耦合讨论了^{125}Sb的能级结构.

关键词 在束γ谱学 同质异能态 粒子-核芯激发态的耦合

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