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Behavior of Intruder Based States in Light Bi and Tl Isotopes: The Study of ^{187}Bi α Decay

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The excitation energies of the single-particle normal and intruder levels in both ^{183}Tl and ^{187}Bi were measured for the first time via the α decay of ^{187}Bi produced in the ^{97}Mo(^{92}Mo,pn)^{187}Bi reaction. The previously unobserved ^{187}Bi ground state ($h_{9/2}$) to ^{183}Tl ground state ($s_{1/2}$) α transition was identified, establishing the ^{187}Bi intruder state excitation energy to be 112(21) keV, 70 keV less than that of the same level in ^{189}Bi.

INTRODUCTION

For neutron deficient spherical nuclei near Z = 82, with filled $h_{11/2}$, $d_{3/2}$, and $s_{1/2}$ orbitals and unfilled $h_{9/2}$, $i_{13/2}$ orbitals one observes [1] in odd-Z, even-N isotopes low-lying $9/2^-$ and $1/2^+$ states for Z < 82 and Z > 82 respectively. These states are called "proton intruder" excitations. In this paper, we are reporting new data for the α decay of ^{187}Bi to levels in ^{183}Tl that reveal new features of the structure of particle-hole intruder states in this mass region. Our data clearly

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DISCLAIMER

Experimental Results

Figure 1(a) shows the total decay spectrum accumulated over a period of ~ 3 days with an average beam intensity of 2 pnA. One observes the well-known Hg and Pb α peaks arising from the larger reaction channels. In addition, there are events above 7 MeV that we assign to ^{186}Bi [10] and ^{187}Bi. Figure 1(b) shows the same decay spectrum correlated with a previous recoil of mass 187, and a time between decay and implantation of ≤ 250 ms. Four peaks (labeled 1-4) in this spectrum are assigned to ^{187}Bi decay. A further constraint on the time between implantation and decay of ≤ 1 ms results in Fig. 1(c). A comparison of Figs. 1(b) and 1(c) clearly demonstrates that peak 4 has a much shorter half-life than peaks 1-3 so that, as in the case of heavier odd-A Bi isotopes, there are two α-emitting states in ^{187}Bi. Following the systematics of the heavier odd-mass Bi isotopes, we assign the longer-lived species to the ^{187}Bi $9/2^-$ ground state, and the shorter-lived radioactivity to the $1/2^+$ isomer. The relevant information on ^{187}Bi α decay is summarized in Table I, while Fig. 2 shows our proposed scheme for the α decay of ^{187}Bi. These assignments are bolstered by the fact that of the two states, the longer-lived level had a far greater yield (~7/1) as would be expected when high- and low-spin radioactivities are produced in heavy-ion reactions.

The individual half-lives for peaks 1-3 are consistent with each other and lead to our adopted value of 32(3) ms for the $9/2^-$ ground state. This compares with the 35(4) ms half-life reported by Schneider [8] who observed only one transition, 6986(10) keV, which presumably corresponds to our 7000(8)-keV transition. The previous study also reported only one transition from the $s_{1/2}$ isomer with an energy of 7583(10) keV and a half-life of 0.8(6) ms. This half-life agrees only marginally with the $\left(0.29^{+0.09}_{-0.05}\right)$-ms value that we adopt for the $s_{1/2}$ isomer, while the decay energy is not in agreement with the value of 7721(15) keV that we measured for the transition assigned to the $s_{1/2}$ isomer. Our data therefore cast doubt on the original identification of the ^{187}Bi $s_{1/2}$ state claimed in Ref. [8]. Further evidence that the 32-ms activity represents ^{187}Bi α decay was established by observing that peaks 1 and 3 are correlated with ^{183}Hg 5.91-MeV α particles which originate from the sequence: $^{187}Bi \xrightarrow{\alpha} {}^{183}Tl \xrightarrow{\beta+/EC} {}^{183}Hg \xrightarrow{\alpha} {}^{179}Pt$. The second step is not detected in our experiment since the thin DSSD is not sensitive to either positron or electron-capture decays. Peak 1 is also correlated with one 6.38-MeV α particle which we assign to the a decay of the known [4] $9/2^-$ isomer in ^{183}Tl. These correlations allow for the first experimental determination of the $^{183}Tl^m$ α-branching ratio, namely a value of ~1.5%. However, due to the low statistics (i.e. one correlated event), this is not conclusive. Peak 2 is not correlated

Table I. Alpha-decay energies, half-lives, relative intensities, and reduced widths in the decay of ^{187}Bi. All energies are expressd in keV.

Peak #	E_α	$t_{1/2}$ (ms)†	E_α	$t_{1/2}$ (ms)	I_α	$I_i \rightarrow I_f$	δ^2 *	HF
	this work		Ref. [6]				this work	
1	7000(8)	32(3)	6986(10)	35(4)	88.3	$9/2^- \rightarrow 9/2^-$	82(10)	1
2	7367(30)	21^{+29}_{-8}			3.7	$9/2^- \rightarrow 3/2^+$	0.2(1)	410
3	7612(15)	25^{+9}_{-5}			8.0	$9/2^- \rightarrow 1/2^+$	0.08(1)	1025
4	7721(15)	$0.29^{+0.09}_{-0.05}$	7583(10)	0.8(6)	100	$1/2^+ \rightarrow 1/2^+$	31(10)	2.6

† The maximum likelihood method was used in this work to determine the experimental half-lives.

* Reduced widths were determined assuming $\Delta l = 0$ transitions.

with any α particles from ^{183}Hg; however, this can easily be explained due to the low statistics.

Discussion

On the basis of the decay data in Table I and using the formalism developed by Rasmussen [11] α reduced widths (δ^2) were calculated for the four ^{187}Bi transitions, assuming that they all involve $\Delta l = 0$ transfers. These widths (included in Table I) are to be compared with δ^2 values for ground-state-to-ground-state (s-wave) transitions for neighboring even-even α emitters which range from about 40 to 90 keV for Po and Pb nuclei [7]. Hindrance factors (HF) are defined as the ratio of s-wave δ^2 values to those of transitions under consideration. On that basis the 7000-keV transition (peak 1) is clearly unhindered reinforcing the statement given above that it connects the $h_{9/2}$ states in ^{187}Bi and ^{183}Tl. For further discussion we have assigned a HF of 1 to the 7000-keV peak and with that normalization have deduced HF for the remaining four transitions. Peaks 2 and 3 have HF of 410 and 1025, respectively. They are similar in value to HF observed (see the discussion in Ref. [7]) in heavier Bi isotopes for transitions originating from the $h_{9/2}$ ground state and proceeding to $d_{3/2}$ excited and $s_{1/2}$ ground states in the Tl daughters. Thus, our data provide evidence that the new 250(34)-keV level, established by the 7367- and 7000-keV transitions, represents the previously unobserved $d_{3/2}$ state in ^{183}Tl. Its 250-keV excitation is consistent with the energy systematics for the $d_{3/2}$ level, which from ^{185}Tl to ^{201}Tl, is located between 285 and 385 keV [12]. However, it does not agree with the 387(22)-keV value listed in

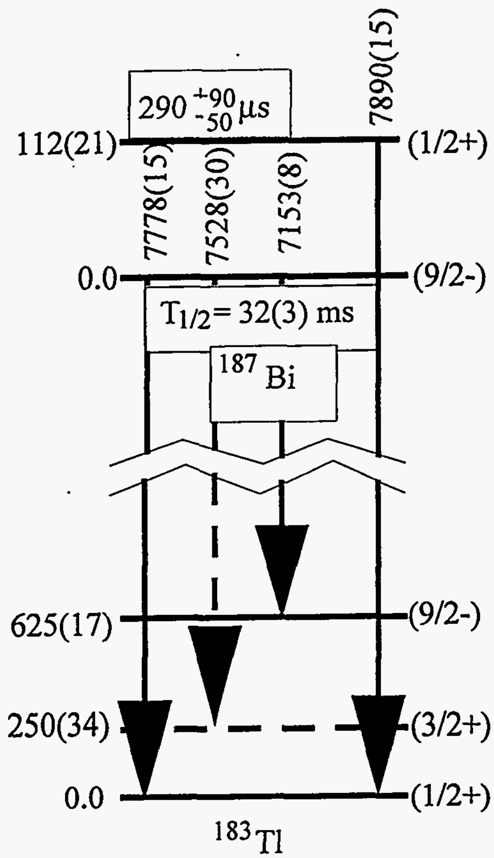

FIGURE 2. Alpha-decay scheme for ^{187}Bi. Note that energies shown for the α transitions are Q_α values.

Nuclear Data Sheets for A = 183 [3]. The 7612- and 7000-keV transitions determine the excitation energy of the $h_{9/2}$ intruder state in ^{183}Tl to be 625(17) keV. As in the case of the $d_{3/2}$ level, this energy is substantially different from the adopted [3] value of ~550 keV which was deduced by Schrewe *et al* [4] based primarily on the 60-ms half-life that they measured for $^{183}Tl^m$. Our measured value emphasizes the parabolic behavior of the Tl $\pi h_{9/2}$ intruder states (see Fig. 3).

According to the rules for level assignments adopted by Nuclear Data Sheets, α decays with HF less than four are considered to be unhindered. On this basis, the transition assigned to the ^{187}Bi $s_{1/2}$ isomer is unhindered. We propose that the 7721-keV *transition* (peak 4) proceeds to the ^{183}Tl $s_{1/2}$ ground state. The difference between the energies of peaks 3 and 4 establish for the first time the excitation energy of the $1/2^+$ ^{187}Bi isomer as 112(21) keV. Thus the downward trend of the $s1/2$ intruder observed for ^{189}Bi continues to ^{187}Bi.

The behavior of the intruder states near Z = 82 (Tl, Pb and Bi) are presented in Fig. 3, where their excitation energies are plotted as a function of neutron number. As shown in the figure, the 1p-2h intruder states in Tl follow closely a parabolic shape but the curve for the 2p-1h (Bi) intruder states shows no sign of leveling off. The overall shape of the Bi curve seems to follow more closely that of the known Pb 2p-2h intruder states. This may well be due to mixing with an underlying Pb core *structure in the light Bi isotopes.*

We note the recent measurements [13] in which two 0^+ states have been established in ^{186}Pb, a weakly deformed oblate intruder configuration and a strongly deformed prolate intruder configurations. If a similar situation exists in the light Bi isotopes, we may be observing a crossing of two different $1/2^+$ states, the expected $1/2^+$ 2p-1h states at higher mass whose systematic behavior parallels that of the $9/2^-$ 1p-2h intruder in the Tl nuclides, and the prolate $1/2^+$ state that might be better viewed as a prolate Nilsson $1/2^+[660]$ *state. It* should be stressed however, that with the current data a firm conclusion cannot safely be reached.

In conclusion, we have investigated the α decay of ^{187}Bi to ^{183}Tl and have observed the previously unidentified ^{187}Bi ground state ($h_{9/2}$) to ^{183}Tl ground state ($s_{1/2}$) α transition, establishing the ^{187}Bi intruder state ($s_{1/2}$) excitation energy to be 112(21) keV. Previously its excitation had been estimated as low as 60 keV [2]. This work also establishes the excitation of the ($h_{9/2}$) state in ^{183}Tl to be 625(17) and provides evidence that the ($d_{3/2}$) state lies at 250(31) keV.

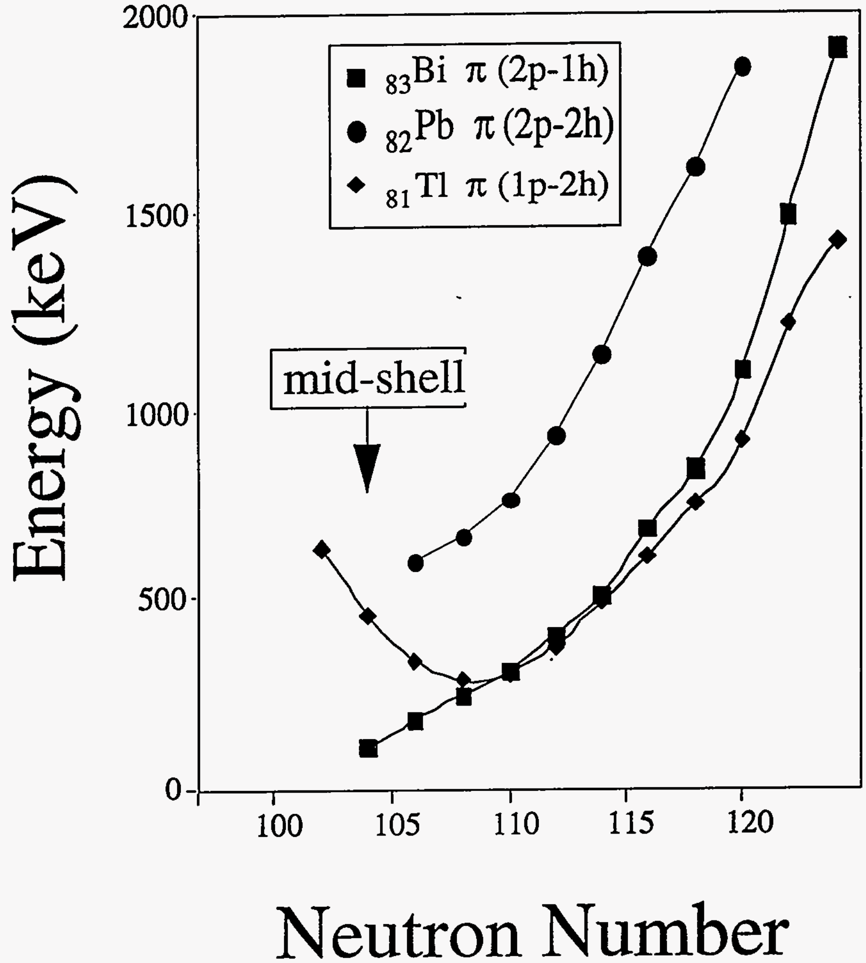

FIGURE 3. Plot of the intruder state excitation energies versus N for nuclei near the Z = 82 closed proton shells, containing the energies of odd-mass Tl π(1p-2h), Bi π(2p-1h), and even-mass Pb π(2p-2h) isotopes.

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