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# BEHAVIOR OF INTRUDER BASED STATES IN LIGHT Bi AND Tl ISOTOPES: THE STUDY OF $^{187}\text{Bi}$ $\alpha$ DECAY

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Intruder state excitation energies in odd-mass nuclei just outside a closed proton shell plotted versus neutron number generally exhibit parabola-shaped curves with minima near neutron mid-shells. The Bi isotopes, however, do not seem to follow this trend. Recent experiments performed at Argonne National Laboratory have identified the previously unobserved  $^{187}\text{Bi}$  ground state ( $h_{9/2}$ ) to  $^{183}\text{Tl}$  ground state  $s_{1/2}$   $\alpha$  transition. Its energy when combined with those of two earlier known transitions, namely  $^{187}\text{Bi}$  ( $h_{9/2}$ )  $\rightarrow$   $^{183m}\text{Tl}$  ( $h_{9/2}$ ) and  $^{187m}\text{Bi}$  ( $s_{1/2}$ )  $\rightarrow$   $^{183}\text{Tl}(s_{1/2})$ , establishes the excitation energies of the  $^{183m}\text{Tl}$  and  $^{187m}\text{Bi}$  to be 620(20) keV and 110(20) keV, respectively. This value for  $^{187m}\text{Bi}$  is 80 keV lower than the excitation energy of the same intruder level in  $^{189}\text{Bi}$ . Implications of this result with respect to intruder-state systematics are discussed.

## INTRODUCTION

In the spherical shell model, the proton  $1h_{9/2}$  orbital lies above the  $Z = 82$  closed shell while the proton  $3s_{1/2}$  lies below. Any  $1h_{9/2}$  configurations in  $Z < 82$  nuclei and  $3s_{1/2}$  configurations in  $Z > 82$  nuclei are referred to as proton "intruder" states. There has been much

experimental evidence to show that the excitation of these intruder states exhibit a parabolic dependence of its excitation energy with a minimum when the neutron number is midway between the major neutron shell closures. This behavior has been observed in both the  $Z = 50$  and  $Z = 82$  region (1,2). This is the result of the strongly attractive proton-neutron force between the

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"intruder" protons and the available valence neutrons. Hence, the maximum binding energy is obtained at the mid-point of the neutron shell (3).

While the picture presented above for the  $1h_{9/2}$  intruder in  $Z < 82$  nuclei is quite convincing, it was actually the odd mass Bi isotopes that provided the first evidence for intruder states in the  $Z = 82$  region (4). However, recent results indicate that, unlike the  $Tl\ 9/2^-$  intruder state (which reaches a minimum at  $N = 108$ ), the excitation energy of the  $1/2^+$  intruder state of Bi continues to drop as one proceeds from  $N = 108$  [ $^{191}Bi$ ; 242 keV] (5) to  $N = 106$  [ $^{189}Bi$ ; 190(40) keV] (6). Indeed this trend seemed to continue in  $^{187}Bi$  as reported in Ref (7), although this was based on data with very poor statistics (8). With this in mind, we reinvestigated the  $\alpha$  decay of  $^{187}Bi$ .

### EXPERIMENTAL

Bismuth-187 was produced via the  $^{97}Mo(^{92}Mo, pn)$  reaction. A  $1\text{-mg/cm}^2$  thick target of  $^{97}Mo$  (93% enrichment) was bombarded with 420-MeV  $^{92}Mo$  ions accelerated at the Argonne National Laboratory ATLAS facility. The average beam current on target was  $\sim 2$  pA. Following production, recoils of interest were passed through a fragment mass analyzer (FMA) (9) and a gas-filled parallel grid avalanche counter (PGAC) (for mass/charge identification), and then implanted into a 60- $\mu\text{m}$  thick double-sided silicon strip detector (DSSD) with 40 horizontal and 40 vertical strips. This strip arrangement results in a total of 1600 pixels. For each event in the DSSD, the time, energy, and event type (recoil or decay, depending on whether it is in coincidence with the PGAC or not) were recorded. Subsequent decays in a pixel can then be correlated with the parent allowing for nuclidic identification. This technique is known as parent-daughter correlations. Additional technical details have recently appeared in a paper (10) dealing with the proton decay of  $^{185m}Bi$ .

### RESULTS AND DISCUSSION

Figure 1(a) shows the total decay spectrum accumulated over a period of  $\sim 3$  days with an average beam intensity of 2 pA. One observes the well known Hg and Pb  $\alpha$ -peaks arising from the larger reaction channels. In addition, there are events  $\geq 7$  MeV that we assign to  $^{186}Bi$  (11) 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 recoil implantation of  $\leq 250$  ms. There are six peaks evident in this spectrum that we assign to the  $\alpha$ -decay of  $^{187}Bi$ . A further constraint on the time between implantation and decay of  $\leq 1.0$  ms results in Fig 1(c). This figure clearly demonstrates that peaks 5 and 6 have much shorter half-lives than peaks 1-4 so that

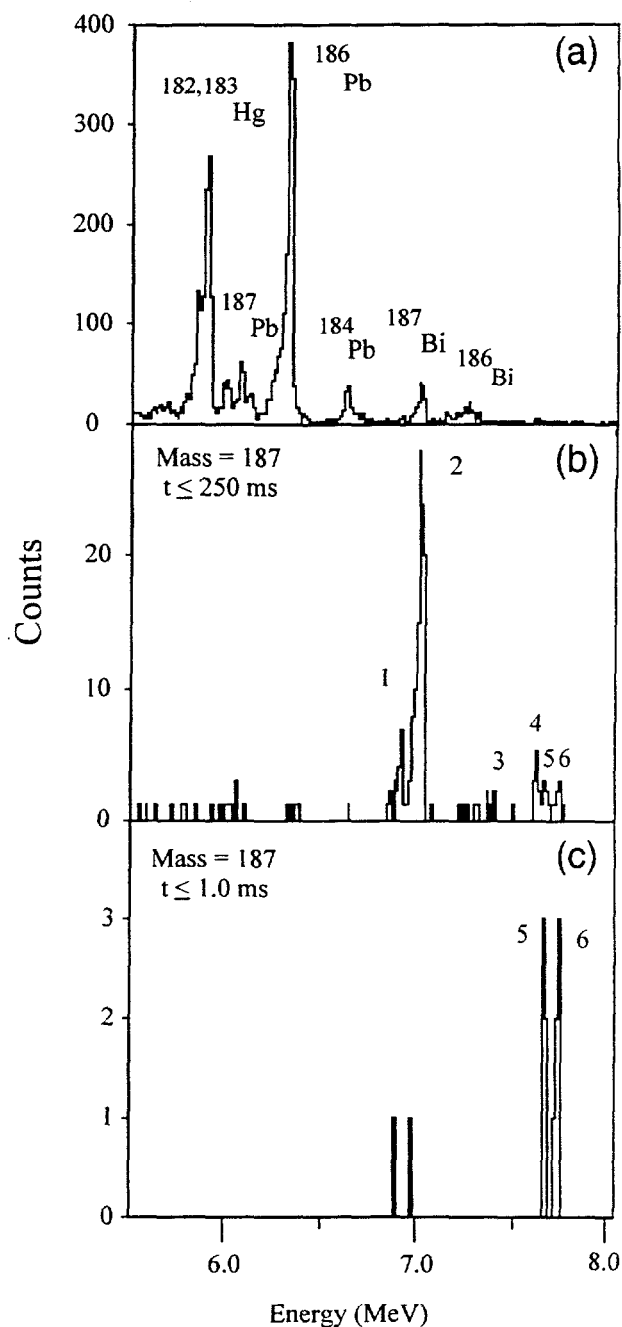


FIGURE 1. Alpha particle spectrum recorded in the DSSD during  $^{92}Mo$  bombardments on  $^{97}Mo$ . Part (a) shows the total decay spectrum accumulated. Part (b) is the spectrum obtained by gating on the recoils of mass = 187, and with a time between decay and recoil implantation of  $\leq 250$  ms. In part (c) there is a further constraint on the time to  $\leq 1.0$  ms. Numbered peaks are discussed in the text.

Table 1. Alpha-decay energies, half-lives, relative intensities and reduced widths in the decay of  $^{187}\text{Bi}$ .

#	$E_\alpha$ (keV)	$t_{1/2}$ (ms)	$I_\alpha$ (%)	$I_i \longrightarrow I_f$	$\delta^2_{\ell=0}$ (keV)	HF
1	6905(15)	$36^{+10}_{-6}$	13.7	$9/2^- \longrightarrow (11/2^+)$	29(4)	2.5
2	7006(10)	32(3)	74.6	$9/2^- \longrightarrow 9/2^-$	70(9)	1
3	7379(25)	$21^{+29}_{-8}$	3.7	$9/2^- \longrightarrow (3/2^+)$	0.2(7)	175
4	7624(20)	$25^{+9}_{-5}$	8.0	$9/2^- \longrightarrow 1/2^+$	0.08(2)	875
5	7670(25)	$0.27^{+0.16}_{-0.07}$	37	$1/2^+ \longrightarrow (3/2^+, 1/2^+)$	27(10)	2.6
6	7734(20)	$0.30^{+0.12}_{-0.06}$	63	$1/2^+ \longrightarrow 1/2^+$	30(10)	2.3

as in the case of heavier odd-A Bi isotopes, there are two isomers in  $^{187}\text{Bi}$ . Following the systematics of the heavier odd-mass Bi isotopes, we assign spins of  $9/2^-$  for the ground state, and  $1/2^+$  for the short-lived isomer. The relevant information on each of these six transitions is summarized in Table 1. These values compare with data from a previous report (8) of 6986(10) keV; 35(4) ms for the ground state decay, and 7583(10) keV; 0.8(6) ms.

The alpha peaks labeled 1-4 are assigned to the decay of the  $9/2^-$  ground state of  $^{187}\text{Bi}$ . All four have individual half-lives which are consistent with each other and lead to our adopted value of 32(3) ms for the  $9/2^-$  ground state. In addition, peaks 1, 2 and 4 are correlated not only with  $A = 187$  implants, but have parent-daughter correlations with  $^{183}\text{Hg}$  5.89-MeV  $\alpha$  particles. These  $^{183}\text{Hg}$  alpha decays originate from the decay sequence  $^{187}\text{Bi} \xrightarrow{\alpha} ^{183}\text{Tl} \xrightarrow{\beta+/\text{EC}} ^{183}\text{Hg} \xrightarrow{\alpha} ^{179}\text{Pt}$ . The second step is not observed in our spectra since the thin (60 $\mu\text{m}$ ) DSSD is not sensitive to  $\beta^+$  particles, i.e., they do not leave enough energy in the detector to rise above the noise threshold. Peak #2 also has a parent-daughter correlation with the known alpha transition arising from the  $9/2^-$  isomer of  $^{183}\text{Tl}$  (12). This corresponds to an alpha branching ratio of  $\sim 1.5\%$ . A previous estimate based on systematics was 3% (11).

A calculation of the alpha reduced width (13) with  $\ell = 0$  reveals that peaks # 1 and 2 are essentially unhindered. On the basis of systematics of the heavier odd-mass Bi isotopes, peak # 2 is clearly the  $9/2^- \longrightarrow 9/2^-$  transition. Peak #1 is a transition to a state which lies 103 keV above the  $9/2^-$  isomer level. From the reduced width we can conclude that this state is probably  $9/2^-$  or  $11/2^+$ . Peaks 3 and 4 have hindrance factors of 175 and 875 respectively. These are consistent with transitions from the  $9/2^-$  ground state to a 250(25) keV  $3/2^+$  state and the  $1/2^+$  ground state respectively. Peaks # 5 and 6 are both unhindered alpha transitions from the short-lived  $1/2^+$  isomer of  $^{187}\text{Bi}$ . These are interpreted as transitions to the ground state and

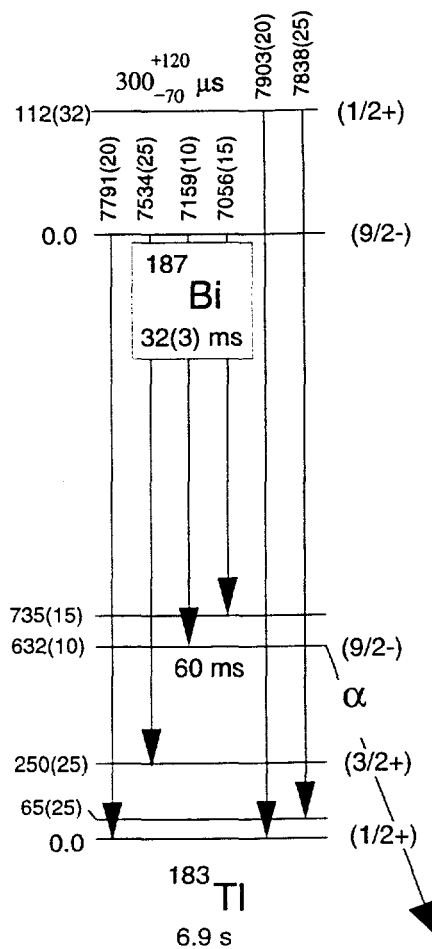


FIGURE 2. Partial  $\alpha$  decay scheme of  $^{187}\text{Bi}$ . All Energies shown are in keV. Note that for the  $^{187}\text{Bi}$   $\alpha$  transitions, energies shown are  $Q_\alpha$  values.

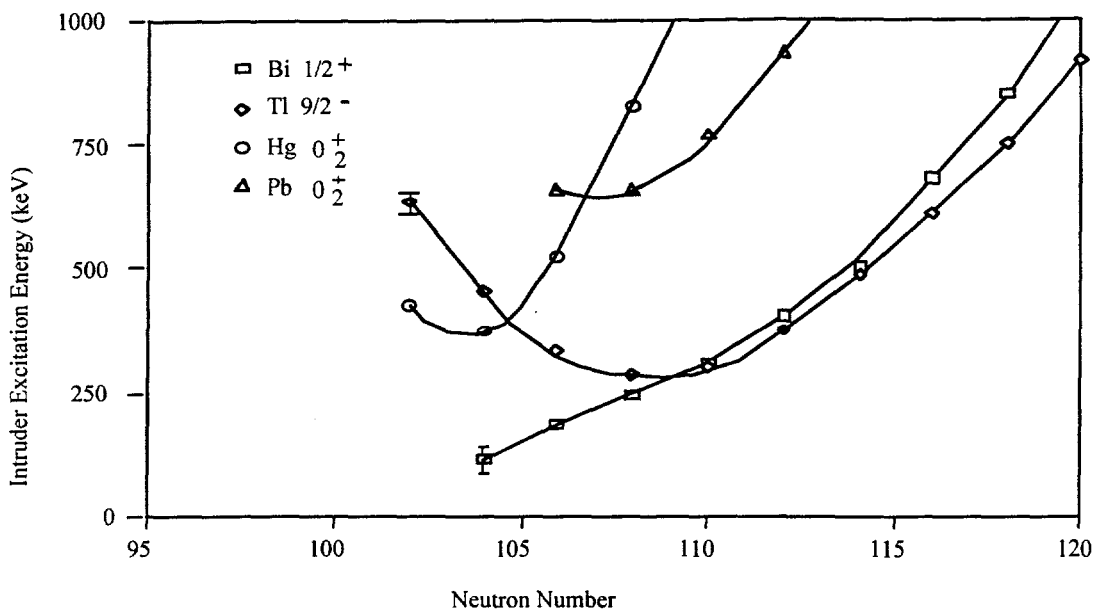


Figure 3. Plot of the intruder state excitation energies versus  $N$  for odd-mass Tl ( $\pi h_{9/2}$ ), Bi ( $\pi s_{1/2}$ ) and even-mass Pb and Hg isotopes.

a low-lying  $1/2+$  or  $3/2+$  state at 65(25) keV, respectively. A partial  $\alpha$  decay scheme for  $^{187}\text{Bi}$  is shown in figure 2. It should be noted that the alpha energies of peaks # 2, 4 and 6 establish the excitation energies of both the  $^{183}\text{Tl}$  and  $^{187}\text{Bi}$  isomers.

Figure 3 shows a plot of level energies of the intruder states in odd-A Tl and Bi nuclei and even-mass Pb and Hg nuclei versus neutron number, including the new values of 112 (28) keV for the  $\pi s_{1/2}$  state of  $^{187}\text{Bi}$  and 632(22) keV for the  $\pi h_{9/2}$  state of  $^{183}\text{Tl}$ . The Tl  $\pi h_{9/2}$  levels fall on a parabola-shaped curve with a broad minimum at  $N \approx 108$ . The light Bi isotopes, however continue to drop further down in both energy and neutron number.

The  $\pi s_{1/2}$  intruder state in the Bi isotopes is believed to be due to transferring a proton from the  $s_{1/2}$  shell to the  $h_{9/2}$  shell, resulting in a two-particle one hole state ( $2p-1h$ ). The further dropping of the excitation energy of this state may indicate that it is a more strongly deformed prolate structure than the corresponding Pb intruder state configuration. This could result in a high degree of mixing, where a hole mixes with the  $4p-3h$  state similar to the  $4p-2h$  deformed structure in the Po nuclei.

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### References

1. Heyde, K., *et al.*, *Phys. Rep.* **102**, 291-393 (1983).
2. Wood, J. L., *et al.*, *Phys. Rep.* **215**, 101-201 (1992).
3. Heyde, K., *et al.*, *Nuc. Phys. A* **484**, 275-294 (1988).
4. Alpsten, M. and Astven, G., *Nucl. Phys. A* **134**, 407-418 (1969).
5. Leino, M. E., *et al.*, *Phys. Rev. C* **24**, 2370 (1981).
6. Batchelder, J. C., *et al.*, *Phys. Rev. C* **52**, 1807-1809 (1995).
7. Coenen, E., *et al.*, *Phys. Rev. Lett.* **54**, 1783-1786 (1985).
8. J. Schneider, Gesellschaft für Schwerionenforschung, Darmstadt, Thesis Report No. GSI-84-3, 1984 (unpublished).
9. Davids, C.N., *et al.*, *Nucl. Instr. Meth.* **B70**, 358-361 (1992).
10. Davids, C.N., *et al.*, *Phys. Rev. Lett.* **76**, 592-595 (1996).
11. Batchelder, J. C., *et al.*, submitted to *Z. Phys. A*.
12. Schrewe, U. J., *et al.*, *Phys. Lett.* **91B**, 46-48 (1980).
13. Rasmussen, J. O., *Phys. Rev.* **113**, 1953-1598 (1959).