# Identification of $^{180}$Tl $\alpha$ decay

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With the use of a fragment mass analyzer, the $\alpha$ decay of $^{180}$Tl was identified in $^{92}$Mo bombardments of $^{90}$Zr. At least three $\alpha$ transitions were observed but on the basis of the data obtained it was not possible to conclude if they originate from one or more levels in $^{180}$Tl. In the same irradiations a new $\alpha$ group was also identified in $^{179}$Tl$^{m}$ decay. Based on energy and half-life systematics, it appears that $^{179}$Tl$^{m}$, in contrast to the isomers in heavier odd-$A$ Tl nuclei, is not the $h_{9/2}$ intruder level but rather the $h_{11/2}$ proton state.
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The only data available on the decay properties of $^{180}$Tl were reported by Lazarev *et al.* [1] in 1987. They observed a 0.7-s delayed-fission activity which they proposed followed the electron capture (EC) and $\beta^{+}$ decay of $^{180}$Tl. Their assignment was based on measured half-lives and production yields determined with fission-track detectors in a series of irradiations at different bombarding energies which utilized various target-beam combinations. To obtain more information on the decay properties of $^{180}$Tl, we mounted a search for its $\alpha$ decay by irradiating $^{90}$Zr with $^{92}$Mo ions.

A 1.05-mg/cm$^2$-thick target of $^{90}$Zr was bombarded with 420-MeV $^{92}$Mo ions (404 MeV at the target midpoint) extracted from the Argonne National Laboratory tandem linac accelerator system, with an average beam current on target of $\sim$2 particle nA during a period of 72 h. Recoil nuclei of interest were passed through a fragment mass analyzer [2] and a gas-filled parallel grid avalanche counter (PGAC) for mass and charge identification, and then implanted into a 65-$\mu$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, each acting as an individual detector. For each event in the DSSD, the time (from a continuously running clock), 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 were then correlated with the parent allowing for nuclidic identification.

Figure 1(a) shows the spectrum of $\alpha$ particles recorded in the DSSD within 4 s of recoil implantation. The most intense peak in Fig. 1(a) is that of the $(2p)$ product $^{180}$Hg; other $\alpha$ emitters present in the spectrum are $^{177}$Hg, $^{178}$Hg, $^{179}$Hg, $^{179}$Au, and $^{176}$Pt, the $\alpha$-decay daughter of $^{180}$Hg. Figure 1(b) shows the same data gated by the restriction that the decay events must be correlated with $A=180$ recoils. Here, in addition to $^{180}$Hg and $^{176}$Pt, one observes the recently identified [3] 7.23-MeV $^{180}$Pb as well as three peaks between 6.2 and 6.5 MeV which decayed with half-lives of about 1.5 s. While the 6281-keV group could be that of $^{179}$Hg ($t_{1/2}=1.1$ s), the 6362- and 6560-keV peaks, because of their half-lives, could not be assigned to known $\alpha$ emitters in the $A=180$ mass region. The second or daughter spectrum correlated with $A=180$ parents revealed the presence of $^{176}$Au $\alpha$ particles [4,5] demonstrating that $^{180}$Tl had been produced in our experiment. By setting a correlation with $\alpha$ particles that preceded $^{176}$Au $\alpha$ decays we obtained the parent ($^{180}$Tl) spectrum shown in Fig. 1(c). One sees that the $^{180}$Tl spectrum is indeed complex and that in addition to the three transitions (6281, 6362, and 6560 keV) observed in Fig. 1(b) there are peaks at 6208 and 6470 keV.

The $\alpha$-decay properties of $^{180}$Tl are summarized in Table I. Within error limits the individual half-lives of the three transitions seen in Fig. 1(b) are the same. If one assumes that they all originate from the same level then the combined decay data yield a $^{180}$Tl half-life of 1.5(2) s. We cannot, however, exclude the existence of more than one low-lying state in $^{180}$Tl as is the case for heavier odd-odd Tl nuclei where there are $7^{+}$ and $2^{-}$ isomers with similar half-lives. In particular, three $\alpha$ transitions have been observed [6,7] emitted by $^{184}$Tl. They decay with a 10(2)-s half-life which, within error limits, is the same as the 10(1)-s value reported [8] for the isotope's (EC+$\beta^{+}$) decay. This branch populates both high- and low-spin levels in $^{184}$Hg indicating the presence of two low-lying $[(7^{+}),(2^{-})]$ states in $^{184}$Tl whose half-lives are similar. If there is more than one 1.5-s level in $^{180}$Tl, then the intensities listed in Table I for the five transitions assigned to $^{180}$Tl decay have folded in the relative production of the different isomers. Note that all three $^{180}$Tl half-lives listed in Table I are longer than the $(0.7^{+0.12}_{-0.09})$-s value published in Ref. [1], perhaps indicating that the $\beta$-delayed fission activity may not be associated with the $\alpha$-emitting level(s).

Figure 2(a) shows the $A=179$ recoil-gated spectrum of $\alpha$ particles where the time constraint between implants and decays is 2 s. At the higher-energy portion of Fig. 2(a) one sees the 6569- and 7213-keV $\alpha$ transitions previously ascribed [9,10] to $^{179}$Tl and $^{179}$Tl$^{m}$, respectively. In addition, we observed a peak at 7096 keV whose half-life of 1.6(8) ms is close to the 1.8(4)-ms value we measure for the 7213-keV transition. This new transition can be seen in Fig. 2(b) where the $A=179$ data now have a constraint of 50 ms between implantation and decay. The parent $\alpha$ particles correlated with the 6435-keV $^{175}$Au transition [4,9,10] are displayed in Fig. 2(c) and one sees that $^{175}$Au $\alpha$ decay is preceded by all three $^{179}$Tl $\alpha$ transitions. We suggest that the 7096- and 7213-keV transitions proceed from the same $^{179}$Tl level and that the lower-energy decay feeds a $^{175}$Au state $\sim 120$ keV above the one fed by the 7213-keV decay. Note also that unless the $^{175}$Au $\alpha$ peak is an unresolved doublet, the 6569- and 7213-keV transitions either feed the same $^{175}$Au level or else two states connected by prompt $\gamma$-ray deexcitation. Information from the present work and previous studies concerning the $\alpha$-decay properties of $^{179}$Tl is summarized in Table I.

In an earlier paper [11] wherein we reported on the $\alpha$ decay of $^{181}$Pb, the assignment [12] of a 6180-keV $\alpha$ transition to $^{181}$Tl decay was also confirmed. We were, however, unable to see a 6566-keV $\alpha$ peak assigned to a 2.7-ms isomeric level in $^{181}$Tl by Schneider [5]. During our present experiment, in an accompanying set of irradiations of a 0.51-mg/cm$^2$-thick target of $^{92}$Zr with 420-MeV $^{92}$Mo, we accumulated data with improved statistics on $^{181}$Tl decay. This time, we did observe a 6578-keV peak correlated with $^{177}$Au $\alpha$ decay. However, its half-life was measured to be 1.4(5) ms rather than the 2.7(10)-ms value reported in Ref. [5]. Our $^{181}$Tl data are summarized and compared with earlier results in Table I.

In odd-$A$ Tl nuclei the ground states and the shorter-lived isomers have been taken to be the $s_{1/2}$ and $h_{9/2}$ (intruder) proton levels, respectively. Excitation energies of these $h_{9/2}$ intruders follow a parabolic dependence on neutron number with a minimum located midway between $N=126$ and $N=82$ (see, e.g., Ref. [13]). With the exception of $^{189}$Tl and $^{191}$Tl the $h_{9/2}$ levels lie above the $d_{3/2}$ proton states whose excitation energies remain fairly constant between 250 and 350 keV. Schmidt *et al.* [13] measured the intruder $h_{9/2}$ energy to be 330 and 453 keV in $^{187}$Tl and $^{185}$Tl, respectively,

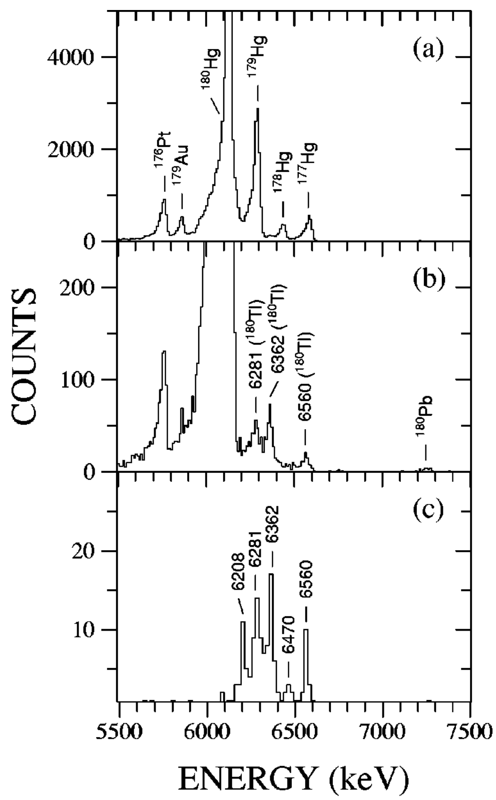


FIG. 1. Data obtained in $^{92}$Mo bombardments of $^{90}$Zr. Part (a) shows $\alpha$ particles recorded in the DSSD within 4 s of recoil implantation. Part (b) has an additional restriction set on the data in part (a), namely, the $\alpha$ decays are correlated with $A=180$ implants. Part (c) is the parent spectrum correlated with $^{176}$Au $\alpha$ decays seen in the second or daughter spectrum.

TABLE I. Summary of results from the present work compared with literature values where available.

| | $E_\alpha$ (keV) | | $T_{1/2}$ (ms) | | $I_\alpha$ (relative) | |
|---|---|---|---|---|---|---|
| Isotope | This work | Previous | This work | Previous | This work | Previous |
| $^{181}$Tl | 6186(10) | 6180 [12] | 3200(300) | 3400(600) [12] | 100 | 100 [12] |
| $^{181}$Tl$^{m}$ | 6578(10) | 6566(20) [5] | 1.4(5) | 2.7(10) [5] | 100 | 100 [5] |
| $^{180}$Tl | 6208(10) | | | | 18(5)[a] | |
| | 6281(10) | | 1600(400) | | 30(6)[a] | |
| | 6362(10) | | 1500(300) | | 30(6)[a] | |
| | 6470(20) | | | | 7(3)[a] | |
| | 6560(10) | | 1400(300) | | 15(3)[a] | |
| $^{179}$Tl | 6569(10) | 6568(18) [9] | 230(40) | 430(350) [9] | 100 | 100 [9] |
| | | 6560(20) [10] | | $160^{+90}_{-40}$ [10] | | 100 [10] |
| $^{179}$Tl$^{m}$ | 7213(10) | 7201(20) [9] | 1.8(4) | $0.7^{+0.6}_{-0.4}$ [9] | 80(20) | 100 [9] |
| | | 7200(10) [10] | | 1.4(5) [10] | | 100 [10] |
| | 7096(10) | | 1.6(8) | | 20(9) | |

[a]Intensities deduced from the parent spectrum [Fig. 1(c)] correlated with $^{176}$Au $\alpha$ decay.

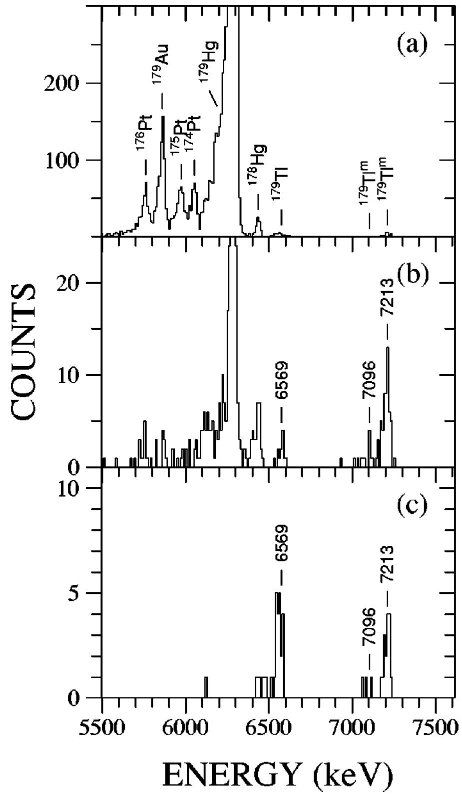


FIG. 2. Data obtained in $^{92}$Mo bombardments of $^{90}$Zr. Parts (a) and (b) show the $A=179$ gated spectrum for $\alpha$ particles recorded in the DSSD within 2 s and 50 ms of recoil implantation, respectively, and part (c) is the parent spectrum correlated with $^{175}$Au $\alpha$ decays seen in the second or daughter spectrum.

indicating that the level had begun its upward trend. Recently, a study [14] of $^{187}$Bi $\alpha$ decay to states in $^{183}$Tl has further confirmed the parabolic behavior by determining that the $h_{9/2}$ level is located at 632 keV; the $d_{3/2}$ state was found to lie at an energy of 250 keV.

Except for $^{189}$Tl and $^{191}$Tl the $h_{9/2}$ isomers decay primarily via $E3$ transitions to the $d_{3/2}$ levels which in turn deexcite by emitting $(M1+E2)$ $\gamma$ rays to the Tl ground states. Half-lives of these $E3$ transitions are strongly dependent on their energies. For example, on the proton-rich side of the parabola, $E3$ half-lives and energies are as follows: (1) $^{187}$Tl [13], 16 s and 30 keV, (2) $^{185}$Tl [13], 1.8 s and 169 keV, and (3) $^{183}$Tl [14], 60 ms and 382 keV. In Ref. [14] the $\alpha$-decay branch of the $^{183}$Tl $h_{9/2}$ intruder was determined for the first time to be $\sim 1.5\%$ showing that the state does indeed decay predominantly via $E3$ $\gamma$-ray emission as had been speculated earlier [7]. Extending the energy vs N parabola to $^{181}$Tl yields an $h_{9/2}$ excitation energy of $\sim 850$ keV and an $E3$ energy of $\sim 600$ keV if the $d_{3/2}$ level remains at 250 keV. On the basis of the Tl $E3$ systematics [13] the 600-keV energy leads to a half-life of $\sim 2$ ms, that is, close to the two $^{181}$Tl values listed in Table I. If one assumes instead that the isomer is a 100% $\alpha$ emitter with a 1.4-ms half-life, then its $\alpha$ reduced width [15] is calculated to be 14.5 MeV. This width is far greater than the values of 40 to 90 keV observed [16] for unhindered $\alpha$ decays in this mass region, indicating that $^{181}$Tl$^m$ has a small branching for $\alpha$-particle emission.

One expects the intruder state in $^{179}$Tl to be well above 1 MeV excitation which, based on arguments presented above, would yield an $E3$ half-life of $<100$ $\mu$s, which is shorter than the three $^{179}$Tl$^m$ values given in Table I. By using our half-life of 1.8 ms and assuming a 100% $\alpha$ branch, a reduced width of 55 keV is calculated. This value is in the unhindered range and suggests that the $^{179}$Tl isomer, in contrast to $^{181}$Tl$^m$, decays mostly by $\alpha$-particle rather than $\gamma$-ray emission. A possible explanation may be that, because of the progressive elevation of the intruder level with decreasing neutron number, the $h_{11/2}$ proton state in $^{179}$Tl is below the $h_{9/2}$ level and its $\alpha$ decay now competes successfully with a much slower $M4$ $\gamma$ ray.

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