Identification and decay of the 0.48 ms $13/2^+$ isomer in ^{181}Hg

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A new isomer with a half-life of 0.48(2) ms was identified in the nuclide ^{181}Hg, which was produced in the complete fusion reaction $^{40}\mathrm{Ca} + {}^{144}\mathrm{Sm} \rightarrow {}^{184}\mathrm{Pb}^*$ at the velocity filter SHIP (GSI, Darmstadt). The isomeric state was tentatively assigned a spin-parity of $13/2^+$. We propose that this isomer de-excites by a yet unobserved low-energy, strongly converted γ-ray transition, followed by a newly identified cascade composed of a 90.3 keV $M1$ and a 71.4 keV $E2$ γ-ray transition.

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I. INTRODUCTION

Recently we reported the identification of the new isotope ^{179}Pb [1] and detailed spectroscopic studies of ^{181}Pb [2] and ^{179,181}Tl [1,3]. These nuclides were produced in different evaporation channels of the complete fusion reaction $^{40}\mathrm{Ca} + {}^{144}\mathrm{Sm} \rightarrow {}^{184}\mathrm{Pb}^*$. The present work is a sequel to those studies and presents the identification in the same experiment of the $13/2^+$ isomer in the nuclide ^{181}Hg. The ground state of ^{181}Hg was found in an optical pumping experiment to have a prolate deformation and a spin and parity $I^\pi = 1/2^{(-)}$ [4,5]. This state is presumably based on the $1/2^-[521]$ Nilsson orbital from the neutron $p_{3/2}$ subshell [6]. A rotational band built on top of the ground state was identified in two prompt in-beam studies [7] by using relatively modest γ-ray arrays. Furthermore, a few "floating" rotational bands with unknown absolute excitation energies have also been observed in this nucleus (see Fig. 2 of Ref. [7]). They were proposed to be based on the low-lying prolate-deformed $5/2^-[512]$ orbital from the $h_{9/2}$ subshell and the $7/2^+[633]$ level from the $i_{13/2}$ subshell. A strongly fed, weakly oblate $13/2^+$ level based on the $i_{13/2}$ orbital was also proposed in Ref. [7] as a possible isomeric state, but no half-life or de-excitation path has been measured for it until now. However, it should be emphasized that some of the assignments in Ref. [7] are tentative and must be considered with caution.

In addition, two low-lying excited states at 64 and 269 keV with an assumed spin-parity assignment of $3/2^-$ were identified in ^{181}Hg via the α decay of ^{185}Pb [8]. Interestingly, neither these two states nor the prompt 205 and 269 keV $M1$ decays from the 269 keV excited state seen in Ref. [8] were observed in the in-beam study of Ref. [7]; see section 4.2.4 of Ref. [8] for a detailed discussion.

The method used in the present study allows searches to be performed for isomeric states with half-lives from ~0.1 ms up to a few milliseconds, which de-excite mainly via γ transitions. The method is described in detail in our study of ^{181}Tl [3]; therefore, only a short description of the most relevant features is given here.

II. EXPERIMENTAL METHOD AND RESULTS

The nuclide ^{181}Hg was produced in the reaction $^{40}\mathrm{Ca} + {}^{144}\mathrm{Sm} \rightarrow {}^{184}\mathrm{Pb}^* \rightarrow {}^{181}\mathrm{Hg} + 2pn$. The typical intensity of the ^{40}Ca beam, provided by the Universal Linear Accelerator (UNILAC) of GSI, was ~400 pnA. Eight ^{144}Sm targets, each of 96.4% isotopic enrichment and 350 μg/cm^2 thickness, were mounted on a wheel rotating synchronously with the UNILAC macropulsing. The targets were produced by evaporating the $^{144}\mathrm{SmF_3}$ material onto a carbon backing of 40 μg/cm^2 thickness and covered with a 10 μg/cm^2 carbon layer. Data were taken at several beam energies in the range 177–229 MeV in the middle of the target to allow for excitation function measurements.

After separation by the velocity filter SHIP [9], the evaporation residues (ERs) were implanted into a 300-μm thick, 35×80 mm^2 16-strip position-sensitive silicon strip detector (PSSD), where their subsequent particle decays were measured by using standard implantation techniques [10]. A large-volume fourfold segmented clover germanium detector was installed behind the PSSD to measure the energies of γ rays and x rays. The search for γ-γ coincidences could be performed within a time interval of up to 5 μs, as defined by the electronics hardware settings. The energy threshold for γ-ray detection was ~15 keV; therefore, it was not possible to observe Hg L x rays ($E_\gamma \sim$ 9–12 keV) in this experiment.

All spectra shown in this work were collected at a beam energy of 192(1) MeV in the middle of the target, which corresponds to the measured maximum of the excitation function for ^{181}Hg. In total, $3.7(7) \times 10^6$ ^{181}Hg ERs were implanted into the PSSD at this beam energy. This number

was estimated based on the strongest 6005(4) keV, $I_{\alpha,\mathrm{rel}} = 87(15)\%$ [6] α decay of ^{181}Hg, taking into account the PSSD efficiency and the α-decay branching ratio of 27(2)% [11].

To search for isomers in ^{181}Hg, we used the fact that the UNILAC delivers a pulsed beam with a repetition rate of 50 Hz and a duty cycle of 25%. Thus, each 20-ms UNILAC "macropulse" in our experiment consisted of a pulse of 5 ms duration ("beam on" period) followed by a "beam off" period of 15 ms. The implantation of ERs into the PSSD occurs exclusively during "beam on" periods. Therefore, if a relatively short-lived isomer of $T_{1/2} \sim$ ms exists in ^{181}Hg, the corresponding internal γ transitions will occur mostly during the "beam on" periods and to some degree within a limited time interval of a few milliseconds after the end of the "beam on" interval.

Figure 1(a) shows low-energy parts of γ-ray spectra registered within the "beam on" interval of 5 ms and the "beam off" interval of 10–20 ms. Note that the same spectra for the broader energy interval up to 650 keV were shown in Ref. [3]. These spectra are dominated by the $K_{\alpha,\beta}$ x rays of long-lived Os-Tl isotopes, both produced directly in the reaction and also as the decay products of the implanted nuclei. Both spectra were normalized to the intensity of the 511 keV peak, which originates from longer-lived activities. Thus, the 511 keV decays are distributed homogeneously over the "beam on" and "beam off" periods. Already this plot demonstrates an excess of γ rays at some energies [e.g., at 90.3(3) keV] during the "beam on" time interval. To highlight this fact, Fig. 1(b) shows the difference between the two spectra in Fig. 1(a). In Fig. 1(b), the Hg K_α x rays (at 68.9 and 70.8 keV), Hg K_β x rays (at 79.8, 80.3, and 82.5 keV), and a γ-ray peak at 90.3 keV (with $\sim 2 \times 10^4$ counts) can clearly be seen.

A weak artificial oscillating structure at 60–66 keV in Fig. 1(b) is caused by the subtraction procedure and results from the intensity difference of the γ-ray spectra and background during the "beam on" and "beam off" time intervals. It is known that the γ-ray background in the experiments at SHIP is higher during the "beam on" interval, which results in a slight increase in deadtime for the germanium clover detector during the "beam on" period. Finally, the low-energy Compton scattering events from the 90.3 and 71.4 keV γ rays de-exciting the new 0.48 ms isomer found in our work occurs predominantly during the "beam on" time interval. However, none of these effects influence the conclusions of the present work and therefore they are not considered in more detail here.

The excitation function for the 90.3 keV γ ray matches well, both in shape and position on the beam energy axis, to the excitation functions for the three nucleon evaporation channels, including that for the 6005 keV α decay of the isotope ^{181}Hg, produced in the $2pn$ evaporation channel. This unambiguously establishes the source of the 90.3 γ line as one of the mass $A = 181$ isotopes of Pb, Tl, or Hg. However, due to its considerably lower production [2], ^{181}Pb must be ruled out from consideration. Furthermore, in our recent dedicated study of the $9/2^-$ isomer in ^{181}Tl [3], performed in the same experiment, no other isomeric states were found in this nucleus. Therefore, ^{181}Hg is the most probable candidate

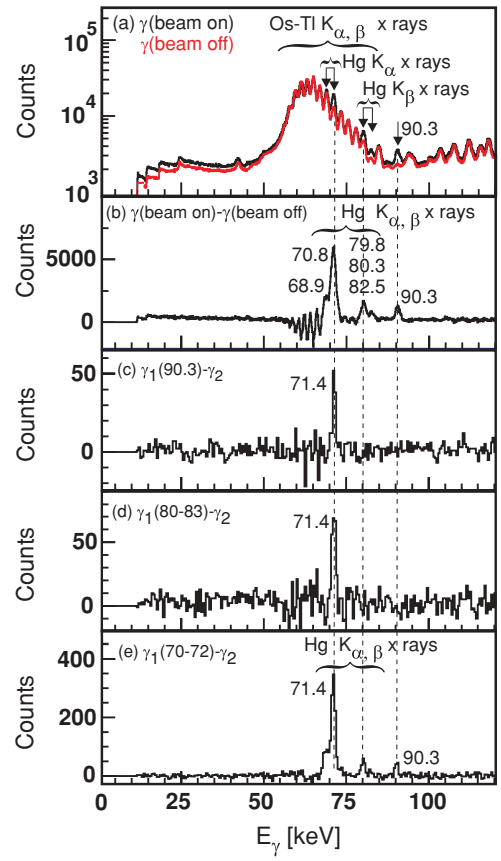

FIG. 1. (Color online) (a) γ-ray spectra collected within the "beam on" interval of 5 ms (in black) and within the "beam off" interval of 10–20 ms (red) of the UNILAC macropulse. The spectra are normalized to the intensity of the 511 keV γ line. Some γ lines are marked by their energies in keV. (b) Difference of the two spectra in (a). (c) Background-subtracted γ_1-γ_2 coincidence spectrum with a gate on the 90.3 keV γ ray within the time interval of $\Delta T(\gamma_1\text{-}\gamma_2) \leqslant 5$ μs. (d) The same as (c), but with a gate on the Hg K_β x rays at 80–83 keV. (e) The same as (c), but with a gate on the 70–72 keV γ-ray energy interval.

source of the 90.3 keV decay, which is confirmed by the following discussion.

The time distribution of the 90.3 keV γ ray from Fig. 1(b) within the 20 ms macropulse of UNILAC is shown in Fig. 2(a). A half-life value of 0.46(3) ms was determined for this activity by fitting the "beam off" part of the spectrum in Fig. 2(a) with an exponential function and a constant background. Similar half-life values were deduced for the Hg $K_{\alpha,\beta}$ x rays from Fig. 1(b). As one example, Fig. 2(b) shows the time distribution for the strongest peak at 70–72 keV from Fig. 1(b), which comprises the Hg $K_{\alpha 1}$ x rays (and a new γ ray at 71.4 keV, see below). This proves the presence of a ms isomeric state in the isotope ^{181}Hg, which is actually the first isomeric state with a measured half-life identified in this isotope. Due to a larger number of observed events, a more precise half-life of 0.48(2) ms was deduced from these latter data and has been adopted as the half-life of the new isomeric state in ^{181}Hg. It is worth mentioning that this half-life rules out both $E4$ and $M4$ multipolarities for any γ-ray transition with an energy of

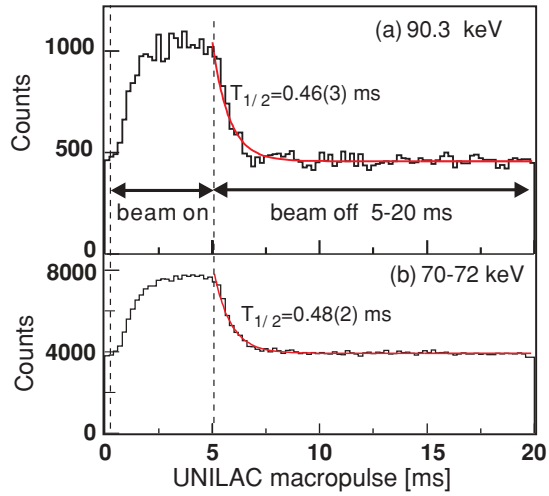

FIG. 2. (Color online) (a) The time distribution of the 90.3 keV γ ray of ^{181}Hg, shown by a histogram, within the 20 ms macropulse of UNILAC. The time intervals used as "beam on" and "beam off" are shown by arrows. The fit performed by an exponent with a constant background is shown by the continues (red) line. (b) The same for the γ rays in the 70–72 keV energy.

$E_\gamma \leqslant 2$ MeV, because such transitions are expected to have much longer half-lives [6].

Based on the intensity balance between the number of 90.3 keV γ decays in Fig. 1(b) and the total number of implanted ^{181}Hg nuclei, an upper limit for the total conversion coefficient of $\alpha_{\rm tot} < 20$ was deduced for the 90.3 keV transition. This limits its possible multipolarity to $E1$, $M1$, or $E2$, because all other multipolarities have much higher total conversion coefficients (e.g., $\alpha_{\rm tot}(M2) = 98.7$ [12]). This also proves that the 90.3 keV decay cannot be responsible for the observed isomer, because the corresponding Weisskopf single-particle half-life estimates are in the range of $\sim 10^{-12}$–10^{-11} s for the $E1$ and $M1$ multipolarities, or $\sim 10^{-7}$ s for the $E2$ multipolarity [6].

Figure 1(c) shows the spectrum of γ rays in coincidence with the 90.3 keV transition within the time interval of $\Delta T(\gamma\text{-}\gamma) \leqslant 5$ μs. The sole peak in this spectrum is at 71.4(3) keV ($\sim$100 counts) with no coincident γ rays seen in the higher-energy part of the spectrum (not shown). This energy is different from the Hg $K_{\alpha 1}$ x-ray energy of 70.8 keV. Moreover, there is no evidence in Fig. 1(c) for the Hg $K_{\alpha 2}$ x rays at 68.9 keV or for the Hg K_β x rays at 80–83 keV. The absence of observed Hg K x rays in coincidence with the 90.3 keV transition additionally proves that no strongly K-converted γ-ray transition exists with an energy above the K-electron binding energy in Hg [$B_e(K) = 83.1$ keV] in coincidence with the 90.3 keV decay (and, thus, coincident with the 90.3–71.4 keV cascade). We stress, however, that the preceding discussion does not exclude the presence of a lower-energy, strongly L/M-converted γ decay coincident with the 90.3 keV γ ray, since this could not have been observed. These inferences are very important because they put strong constraints on the possible de-excitation path of the new isomer.

A similar γ-γ coincidence analysis was performed with a gate either on the Hg $K_{\alpha 2}$ x rays at 68.9 keV or on the Hg K_β x rays at 80–83 keV. In both cases only the 71.4 keV peak was present in the coincidence spectrum; see Fig. 1(d) for the latter case. The preceding arguments confirm that the 71.4 keV line represents a γ ray occurring in ^{181}Hg, which is in coincidence with both the 90.3 keV γ decay and with the Hg $K_{\alpha,\beta}$ x rays.

Figure 1(e) shows the γ_1-γ_2 coincidence spectrum within the γ_1-energy interval of 70–72 keV, which necessarily includes both the 71.4 keV transition discussed above and the Hg $K_{\alpha 1}$ x rays at 70.8 keV. Because of this, in Fig. 1(e) we indeed see both the 90.3 keV decay and the Hg $K_{\alpha,\beta}$ x rays. It is important that the ratio of the γ intensities in the range of the Hg K_α and K_β x rays in this spectrum is 6.8(4), which is nearly twice as large as both the tabulated intensity ratio of 3.6 [6] and the same ratio of intensities in Fig. 1(b).

Based on the intensity balance between the 90.3 keV decay from Fig. 1(b) and the 90.3–71.4 keV γ-γ cascade from Fig. 1(c), a total conversion coefficient of $\alpha_{\rm tot} = 19(4)$ was determined for the 71.4 keV decay. This establishes an $E2$ multipolarity for the 71.4 keV transition, because the theoretical total conversion coefficients are $\alpha_{\rm tot}(M1) = 3.8$, $\alpha_{\rm tot}(E2) = 24.3$, and $\alpha_{\rm tot}(M2) = 98.7$ [12]. We emphasize here that the preceding derivation relies on the experimental fact that we did not observe any γ decays that are coincident with the 90.3 keV transition and that proceed "parallel" to the 71.4 keV decay. The Weisskopf single-particle half-life estimate for this 71.4 keV decay is $\sim 10^{-7}$ s [6], which suggests that, similar to the 90.3 keV decay, this transition cannot be responsible for the observed isomer.

On these grounds, we conclude that another, long-lived and highly converted, γ transition must be present to explain the 0.48 ms isomer in ^{181}Hg. This transition must be followed by the 90.3–71.4 keV cascade. Based solely on the available data, we cannot determine the order of the 90.3 and 71.4 keV transitions within the cascade. However, in the Discussion section of this paper a tentative scenario is presented, which proposes that the 90.3 keV transition is the first in this cascade.

Let us now discuss the origin of the strong Hg $K_{\alpha,\beta}$ x rays seen in Fig. 1(b). Since the energy of 71.4 keV decay is below the K-electron binding energy in Hg, no K conversion is possible for this γ transition. Therefore, the Hg $K_{\alpha,\beta}$ x rays in Fig. 1(b) can only originate from the internal conversion of the 90.3 keV decay and/or, possibly, from other highly K-converted (thus yet unobserved) γ-ray transitions, being in coincidence with the 71.4 keV decay but not in coincidence with the 90.3 keV decay.

Let us first consider the latter scenario, which necessarily requires that such a K-converted decay must proceed parallel to the 90.3 keV decay. In this case, we first must estimate a possible contribution of the K conversion of the 90.3 keV decay to the observed Hg K x rays in Fig. 1(b). As mentioned earlier, the possible multipolarity of the 90.3 γ ray is limited to $E1$ ($\alpha_K = 0.43$ [12]), $M1$ ($\alpha_K = 8.63$), or $E2$ ($\alpha_K = 0.61$).

If one assumes an $M1$ multipolarity for the 90.3 keV decay, *all* Hg K x rays in Fig. 1(b) can be well accounted for as being due to the K conversion of this decay (after subtraction of a small contribution of the 71.4 keV transition to this region of γ-ray energies). Indeed, by comparing the number of 90.3 keV γ rays and of Hg K x rays in Fig. 1(b), a K-conversion coefficient of $\alpha_K(90.3\ {\rm keV}) = 7.3(4)$ can be

deduced, which compares quite well with the theoretical value of $\alpha_K(\text{calc.})(M1) = 8.6$ [12]. In other words, if the 90.3 keV decay is of an $M1$ multipolarity, then the aforementioned scenario with another γ decay proceeding in parallel with the 90.3 keV transition can be safely ruled out.

In contrast, if an $E1$ or $E2$ multipolarity is assigned to the 90.3 keV decay, the corresponding K conversion contributes relatively weakly (e.g., at most ~10% for $E2$) to the observed yield of the Hg K x rays in Fig. 1(b). Therefore, the bulk of observed Hg K x rays must be attributed to the additional decay proceeding in parallel with the 90.3 keV decay. However, this scenario must also be ruled out based on the following arguments. In this case, to account for the observed yield of the Hg K x rays in Fig. 1(b) and simultaneously not to be seen in Fig. 1(b), such γ decay must have a K-conversion coefficient of at least $\alpha_K = 100$. According to Ref. [12], for Hg isotopes, this could only be possible for the $M3$ decays with an energy of ~100 keV. However, according to the Weisskopf estimate [6], such a decay would have a half-life of the order of ~1 s, which is much longer than the half-life of the new isomer.

Therefore, we rule out the scenario with the existence of a parallel path to the 90.3 keV decay and we conclude that *all* Hg K x rays in Fig. 1(b) must originate from the K conversion of the 90.3 keV decay, which occurs in a cascade with the 71.4 keV decay. As mentioned earlier, the isomeric half-life must then be defined by a lower-energy [$E_\gamma \leqslant B_e(K) = 83.1$ keV] strongly L/M-converted (yet unobserved) decay, which is followed by the 90.3–71.4 keV cascade. This sequence is shown in the right-hand side of Fig. 3, where the first decay is denoted by the symbol Δ. The discussion section of this paper provides further arguments in support of this scheme.

A total of $1.9(3) \times 10^6$ of the 90.3 keV (thus, also 71.4 keV) decays occurred during our experiment, which was estimated based on the measured number of these decays in Fig. 1(b) after accounting for the registration efficiency of the germanium clover detector and the internal conversion of this decay. By comparing this number with the total number of implanted ^{181}Hg nuclei [$3.7(7) \times 10^6$; see Sec. II], we conclude that 51(9)% of the total de-excitation path of ^{181}Hg proceeds via the 0.48 ms isomer, decaying eventually via the 71.4–90.3 keV cascade.

III. DISCUSSION

Let us now compare the de-excitation intensity pattern of ^{181}Hg deduced in our study with the prompt de-excitation pattern of ^{181}Hg from Ref. [7]. To be consistent with Ref. [7], in Fig. 3 we schematically reproduce the low-energy part of the level diagram of ^{181}Hg from Ref. [7] that is relevant for our discussion (bands 1–5 in Fig. 3). A comment on the I^π assignments for bands 1–5 performed in Ref. [7] is in order here. According to Ref. [7], "the spin and parity assignments were based on the measured directional correlation information (DCO ratios) with further help from available systematics of heavier Hg isotopes." However, no specific information was provided [7] on each particular state and/or transition. Therefore, some of the spin and parity assignments, apart from the ground-state spin $I = 1/2^{(-)}$ [4,5], should be considered tentative, especially for low-intensity transitions.

Unfortunately, no absolute intensity values were given in Ref. [7], but it was mentioned that positive parity bands 4 and 5 had by far the highest intensity. Furthermore, the strongest 248.4 keV γ ray of very weakly populated band 2 had an intensity of only ~7% relative to the strongest γ ray in the level scheme (416.8 keV; see Fig. 3). Band 5 is apparently the most intense in the level scheme and feeds the presumed $13/2^+$ state at an excitation energy of $E^* = y$ keV, mostly via the 416.8 keV transition. Similarly, the $11/2^+$ state at $y + 75$ keV of band 4 should decay, at least partially, by a prompt (yet unobserved) 75 keV $M1$ decay to the $13/2^+$ state. The latter decay, shown by a dashed arrow, was not observed

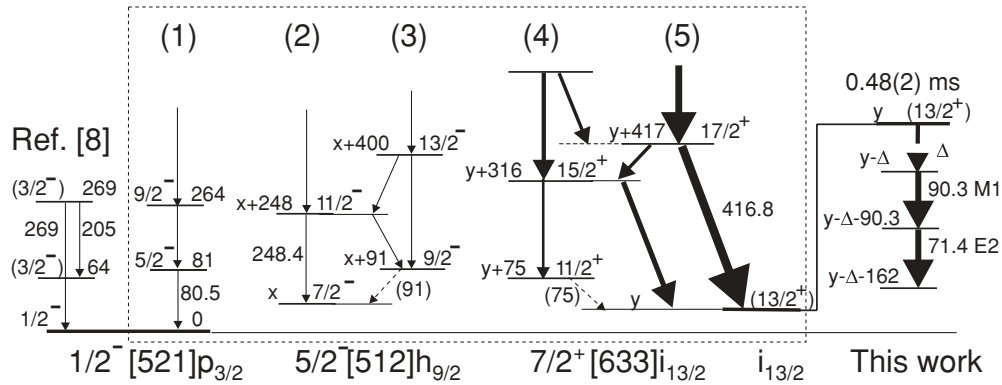

FIG. 3. Scheme of the low-lying states in ^{181}Hg up to the excitation energy of $E^* \sim 400$ keV. The higher-lying states of five rotational bands, denoted by (1)–(5) within the dashed rectangle, can be seen in Fig. 2 of Ref. [7]. The data on the left-hand side are from the α-decay study [8]. The data from the present study are shown on the right-hand side of the figure. The symbol Δ denotes the unknown energy of the (yet unobserved) low-energy, strongly converted γ decay proposed in our study to explain the 0.48 ms, presumably, $I^\pi = (13/2^+)$ isomeric state in ^{181}Hg. Note that this state has an unknown excitation energy denoted as "y" ($y = 162 + \Delta$ keV; see text) and is shown twice in the plot. The expected (yet unobserved) transitions are shown by dashed arrows and their energies are shown in parentheses. The tentative spin-parity assignments are shown in parentheses; see also a comment in the main text on the I^π assignments for bands (1)–(5).

in Ref. [7], most probably both due to its partial internal conversion, $\alpha_{\rm tot}(M1) = 3.3$ [12], and due to the competition with the expected prompt $E2$ decay to the yet unobserved $7/2^+$ band head of band 4. Based on these arguments and on the schematic intensity pattern shown in Fig. 2 of Ref. [7], we roughly estimated that ∼60% of the prompt de-excitation path of ^{181}Hg in study [7] proceeds via bands 4 and 5 to the presumed $13/2^+$ state at $E^* = y$ keV. As discussed in Ref. [7], the nonobservation of the prompt de-excitation γ rays from this state hints that it could be an isomeric state.

The close similarity of the de-excitation intensity patterns in our study and in Ref. [7] strongly suggests that the 0.48 ms isomer observed in our work must be associated with the same $13/2^+$ state at y keV, which is fed by the prompt bands 4 and 5 of Ref. [7]. This is why, for the sake of keeping the drawing of bands 1–5 as given in Fig. 2 of Ref. [7], we duplicate this 0.48 ms $13/2^+$ state on the right-hand side of Fig. 3 and keep its excitation energy denoted by y keV.

An important fact, crucial for the following discussion, is that, apart from bands 4 and 5, all other known states in ^{181}Hg have negative parity. Hence, we must assume the existence of another, *parity-changing* (yet unobserved) strongly converted γ decay which would proceed directly from the $13/2^+$ isomer to one of the lower-lying negative-parity states from bands 1–3. As explained in the previous section, the existence of such a decay is also required by the half-life considerations for the new isomer. Taken together, both arguments strongly support the proposed cascade of three γ rays of Δ–90.3–71.4 keV de-exciting the $13/2^+$ isomer (see Fig. 3). This would then establish the lower limit for the excitation energy of the $13/2^+$ isomeric state in ^{181}Hg as $y = E^*(13/2^+) = 162 + \Delta$ keV.

The Weisskopf half-life estimate suggests that the most probable multipolarity for the isomeric transition denoted by Δ should be $E3$. Indeed, the Weisskopf half-life value for an $E3$ γ transition in the range of $E_\gamma = 10$–80 keV is ∼10–80 ms [6]. By considering the upper recommended limit for the ratio $t_{1/2}$(W.u.)/$t_{1/2}$(exp) = 100 for the $E3$ decays [6], the expected half-life will be reduced up to a value of 0.1–0.8 ms, which is in good agreement with the measured half-life value. The total conversion coefficient for a 10–80 keV $E3$ decay is in the range 4.9×10^7–4.9×10^2, which would explain its non-observation in our experiment.

Thus, in this scenario, the $13/2^+$ isomer at $y = E^*(13/2^+) = 162 + \Delta$ keV should decay by this low-energy Δ keV $E3$ decay to a lower-lying $7/2^-$ state at $x = y - \Delta = 162$ keV, which should subsequently decay by the 90.3($M1$)–71.4($E2$) keV γ cascade to the $1/2^-$ ground state. If this scenario is correct, then the position of the previously unobserved $5/2^-$ band head of the $5/2^-[512]$ band is also fixed at 71.4 keV above the $1/2^-$ ground state, whereas the lowest state denoted as $y - \Delta - 162$ keV in the right-hand part of Fig. 3 would actually become the $1/2^-$ ground state.

It is important to note that opposite ordering for the 71.4–90.3 keV cascade would require the presence of a $3/2^-$ state at 90.3 keV in ^{181}Hg, in addition to the $3/2^-$ states at 64 and 269 keV proposed in study [8]; see Fig. 3. However, in this scenario, the $3/2^-$ state should also have been populated by the α decay of the parent ^{185}Pb, which was not the case in study [8]. This argument strongly supports the ordering of the 90.3 and 71.4 keV decays, as shown in Fig. 3.

However, another scenario should also be mentioned in which the 90.3 keV $M1$ decay seen in our study could represent the (yet unobserved) decay between the presumed $9/2^-$ state at $x + 91$ keV (band 3) and the $7/2^-$ state at x keV (band 2) of the $5/2^-[512]$ configuration (see Fig. 3). In Ref. [7], the corresponding 91 keV γ ray was not observed both due to its relatively large total conversion coefficient of $\alpha_{\rm tot} = 10.6$ [12] and due to the low statistics for these weakly populated bands. However, this scenario would require that the spins of all states in bands 2 and 3 should be decreased by one unit in such a way that the band-head state of this configuration would become $5/2^-$ instead of $7/2^-$ as proposed by authors of Ref. [7]. In this case, if the $E3$ Δ keV γ ray represents the $13/2^+ \rightarrow 7/2^-$ decay, the 90.3 keV decay would become the $7/2^- \rightarrow 5/2^- M1$ decay, whereas the 71.4 keV transition would represent the $5/2^- \rightarrow 1/2^- E2$ decay to the $1/2^-$ ground state of ^{181}Hg, similar to the first scenario. A weakness of this scenario is that the expected $I^\pi = 5/2^-$ assignment for the lowest *observed* level of the $5/2^-[512]$ configuration was explicitly discussed but finally ruled out in favor of the $I^\pi = 7/2^-$ state in Ref. [7] based on systematics of the static moments of inertia for bands 1–5 of ^{181}Hg and for some neighboring nuclei.

IV. CONCLUSIONS

This study adds yet another intriguing result to a few previously known puzzles involving ^{181}Hg. With the inclusion of our data, excited states in ^{181}Hg have been studied via three complementary spectroscopic methods: prompt in-beam spectroscopy [7], the α decay of ^{185}Pb [8], and the isomer spectroscopy in this work. Interestingly, three nonoverlapping sets of γ-ray transitions have been observed in these studies (see Fig. 3), with none of the γ rays seen in one study being confirmed by either of the other two works.

In this respect, we believe that our data for the $13/2^+$ isomer provide a possible key to understanding the whole decay scheme of ^{181}Hg. This situation also asks for a new dedicated study of ^{181}Hg, by using modern multidetector Ge arrays. Such an experiment should employ both prompt and delayed in-beam γ-ray spectroscopy, possibly combined with the recoil decay tagging [13,14] and/or recoil isomer tagging techniques (see, e.g., [15,16] and references therein). Very important for such a study would be the possibility of measuring low-energy γ rays and Hg L x rays. Altogether, these data should shed extra light on the low-energy shape coexistence in this complex nucleus and should allow the relative positions of the multitude of coexisting prolate and oblate configurations to be established.

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