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The α- and β-Decay of ^{187}Pb

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Sources of ^{187}Pb were produced by the ^{142}Nd(^{48}Ti, $3n$)^{187}Pb reaction followed by on-line mass separation of the products. Measurements of γ-γ and α-γ coincidences and half-lives were performed. Two α-emitting states in ^{187}Pb were found with half-lives of 15.2 ± 0.3 s and 18.3 ± 0.3 s, respectively. The α-γ coincidences yielded excitation energy and possible spin values for a few levels in ^{183}Hg. Gamma-transitions in ^{187}Tl were identified and a level scheme for ^{187}Tl is proposed on the basis of the coincidence relationships and the level systematics of the heavier odd-thallium isotopes.

1. Introduction

Although much interest has been devoted to the neutron-deficient nuclides in the lead region, little information about the decay of ^{187}Pb is available in the literature. The first observation of this nuclide was made by Gauvin et al. [1], who assigned to ^{187}Pb an α-line of 6.08 MeV energy and a half-life of 17.5 s. The activity was observed during a study of ^{155}Gd + ^{40}Ar reactions using the helium-jet technique. The existence and assignment of the α-line was later confirmed by the same group by means of the reactions ^{180}W + ^{16}O [2] and ^{150}Sm + ^{40}Ca [3]. In the latter experiment an additional α-line of 6.19 MeV energy was also observed and assigned to the ^{187}Pb decay.

Recently we reported [4] the first results of a systematic study of neutron-deficient nuclides in the $Z = 82$ region using the mass separator on-line to the heavy-ion accelerator UNILAC at GSI. In these studies four α-lines with energies of 6,005, 6,090, 6,207, and 6,258 keV, all decaying with a half-life of about 17 s, were observed in the spectrum recorded with the mass-separated $A = 187$ activity, and assigned to the decay of ^{187}Pb. The Orsay group did not observe [1-3] the 6,005 keV α-line, which is comparable to the 6,207 keV line in intensity, because it is close in energy to the α-line from ^{188}Pb ($E_\alpha = 5{,}990$ keV), which is produced with a higher yield than that of ^{187}Pb. Therefore, the line from ^{188}Pb masks the 6,005 keV line if no mass separation is performed before the recording of α-particle spectra. Our later, more detailed studies have revealed that the 6,258 keV line does not represent a separate α-transition but occurs because of summing of 6,207 keV α-particles and coincident conversion electrons (see Sect. 3.2).

The observation of several α-lines with nearly the same half-life [4] suggests that several excited states in the strongly deformed [5] ^{183}Hg daughter nucleus are populated in this decay. We have, therefore, supplemented the initial studies with measurements of α-γ coincidences.

Earlier investigations of the γ-transitions following the β^+/EC-decay of ^{189}Pb were undertaken [6] to shed light onto the coupling of various states of the ^{188}Hg core and single-particle proton states in

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^{189}Tl. Although the ^{186}Hg nucleus is not explored to the same degree as ^{188}Hg, we thought it worthwhile to try to obtain analogous information about the levels of ^{187}Tl, the β-decay daughter of ^{187}Pb. For this purpose γ-X-coincidence, γ-γ-coincidence and γ-multispectrum measurements were also performed on the ^{187}Pb decay.
In the following we present the results of the α-γ- as well as the γ-γ-coincidence measurements, and discuss the deduced structure in the daughter nuclides ^{183}Hg and ^{187}Tl.

2. Experimental Techniques

The ^{187}Pb activity was obtained as one of the products from fusion-evaporation reactions induced by bombarding a 2.7 mg/cm^2 thick target of ^{142}Nd with 235 MeV ^{48}Ti ions from the UNILAC. The beam intensity, which was about 30 particle-nA, was monitored every 60 s by a Faraday cup inserted just in front of the target. The ^{142}Nd target (93.4% enriched) was mounted in a water-cooled cylindrical holder. Recoiling atoms from the target were stopped in a 0.1 mm thick graphite catcher in the FEBIAD ion source (type D of [7], which contains a detailed description of the ion source) of the on-line mass separator. The catcher was heated by electron bombardment to a temperature of ~2,200°C. Following reionization, the products were extracted, accelerated by 50 kV and separated in the GSI mass separator [8].
The $A=187$ mass-separated activity was implanted into an aluminized mylar tape of a tape transport system, which at 31.9 s intervals brought the collected sources in 280 ms to the counting position 30 cm away. Here, three detectors were placed in a collinear arrangement. Gamma and X-rays were detected by a Ge(Li) detector with 23% standard efficiency and an intrinsic germanium detector of 25 mm diam. × 10 mm depth. α-particles were recorded with a 450 mm^2 area × 100 µm thick silicon surface-barrier (SB) detector positioned between the tape and the Ge(Li) detector (see Fig. 6), so that it subtended a solid angle of 32% of 4π sr at the source position.
The energy and efficiency calibration of the germanium detectors was performed with standard γ-ray sources, and the resolutions were determined to be 3.0 keV FWHM at 1.33 MeV and 1.0 keV FWHM at 122 keV for both detectors.
In a supplementary experiment, the activity was collected in a 12 µg/cm^2 carbon foil placed at a distance of 16 mm from a 100 mm^2 × 100 µm SB detector. The energy calibration of each SB detector was performed with a standard source containing ^{239}Pu, ^{241}Am and ^{244}Cm. The energies and relative intensities of the ^{187}Pb α-lines were determined with the small detector because its energy resolution of 20 keV FWHM was almost two times better than that achieved for the large detector in close geometry during the 10-h measurement, and because of less summing (see Sect. 3.2) in the small detector.
During each counting period of the coincidence experiment, singles spectra from the germanium detectors were accumulated in a multispectrum mode, with 7 subgroups of 4.5 s duration each. A total of 1,175 cycles were completed. All events in the SB detector were stored in list mode format (i.e. event-by-event) on magnetic tape, using a PDP11/45 computer. For each event, the pulse height was recorded together with the real time (from a scaler driven at 100 kHz) and the time elapsed since the last transport of the tape system. List mode events from the germanium detectors were gated by fast α-γ or γ-γ time signals, so that both α-γ and γ-γ coincidence data were also recorded event-by-event.

3. Results and Discussion

3.1. The β^+-Decay of ^{187}Pb

The sum of the seven subgroups in the multispectrum analysis recorded by the intrinsic germanium detector is shown in Fig. 1. Gamma-lines were assigned to transitions in ^{187}Tl, ^{187}Hg and ^{187}Au by means of coincidences with X-rays. All the lines attributed to ^{187}Hg and ^{187}Au transitions have previously been observed in separate studies of ^{187}Tl and ^{187}Hg decay [9, 10]. The γ-lines observed to be in coincidence with thallium X-rays are listed in Table 1 together with their relative intensities and coincidence relationships. Half-lives are also given for the few lines which appear strongly in the multispectrum and which we have concluded are single lines without any contribution from transitions in nuclei other than ^{187}Tl.
The partial level scheme which we propose for ^{187}Tl on the basis of the γ-γ coincidence data is shown in Fig. 2. The existence of the 9/2$^-$ isomer in ^{187}Tl was established by Schmidt et al. [11], who observed conversion electrons of about 30 keV energy in coincidence with the 300 keV transition to the ground state. The line at 300 keV is by far the most intense of the lines assigned to ^{187}Tl in our spectrum, and its main source is direct production of the isomer. Fitting the decay of this line to a single exponential, we find the corresponding half-life to be 15.60 $\pm$0.12 s. This result is in good agreement with the value of 16$\pm$1 given by Schmidt et al. [11], who

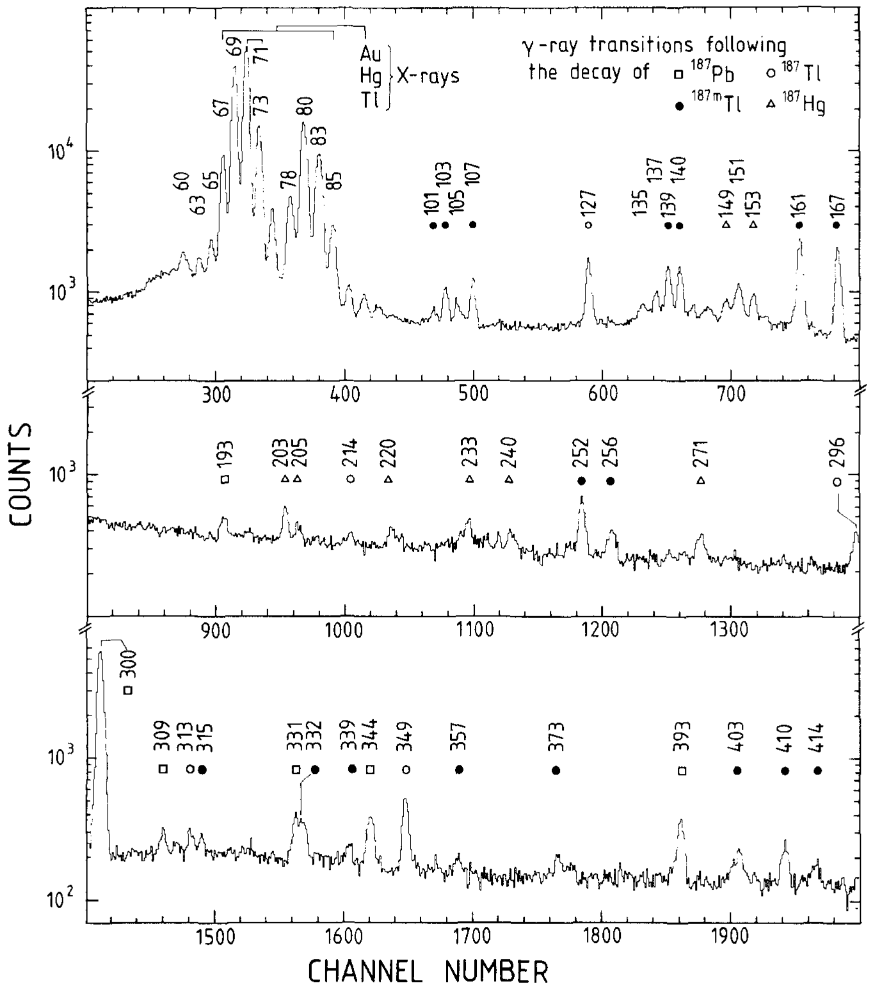

Fig. 1. Singles γ-ray spectrum recorded from mass-separated $A = 187$ sources. The spectrum was measured with the intrinsic germanium detector and represents the sum of the seven subgroups of the multispectrum analysis. The total measuring time was 10.3 h

Table 1. Energies, relative intensities and half-lives of the observed γ-lines, assigned as transitions in ^{187}Tl, together with the observed coincidences

E_γ (keV)[a]	$I_{\gamma,\mathrm{rel}}$[b]	$T_{1/2}$ (s)	Coincident γ-lines[c]
193.0	15	-	343.5
299.5[d]	1,500	15.6±0.12	448.7, 511
309.4[e]	20	-	-
331.4	60	-	393.4
343.5	75	16.8±1.9	193.0, (393.4)
393.4	100	19.7±1.6	331.4
448.7	20	-	299.5
493.6[e]	40	-	-
617.2[e]	40	-	-
645.4[e]	15	-	-
747.7	15	-	-
865.8[e]	<10	-	-

[a] The accuracy of the energies, taking statistical errors and calibration uncertainties into account, is about ±0.3 keV

[b] The overall accuracy of the relative intensities is about ±5%

[c] In addition to the γ-lines given in this column all the γ-lines in the table were observed in coincidence with thallium K_{α_1} and K_{β_2} X-rays

[d] The major part of the intensity of this line is caused by the direct production of the $9/2^-$ isomer in ^{187}Tl (see text)

[e] Not placed in the level scheme of Fig. 2

used a reaction leading to a thallium compound nucleus. The α-decay studies yielded evidence (see Sect. 3.2) for two α-emitting states in ^{187}Pb with half-lives of 15.2 s and 18.3 s, respectively. The observation of a small number of coincidences between the 300 keV γ-line and annihilation radiation ($N_{300-511} = 20 \pm 9$) is evidence that the $3/2^+$ state is also fed directly or through a cascade by the β-decay of one or both states of ^{187}Pb. Compared to the population of this $3/2^+$ state via the direct production of the ^{187m}Tl isomer the feeding via the ^{187}Pb β-decay is relatively weak. This holds for both the feeding via a direct cascade as can be seen from the weak coincidence mentioned above and via the ^{187m}Tl isomer, as can be inferred from the relative intensities of the 300 keV γ-line and γ-rays following the ^{187}Pb β-decay. However, the feeding does affect the decay curve of the 300 keV γ-line. After including the effects of feeding with an unknown intensity (since we do not know the β branching-ratio of the ^{187m}Tl isomer), statistically acceptable fits to the decay curve are found with isomer half-lives between 14.5 s and 15.7 s.

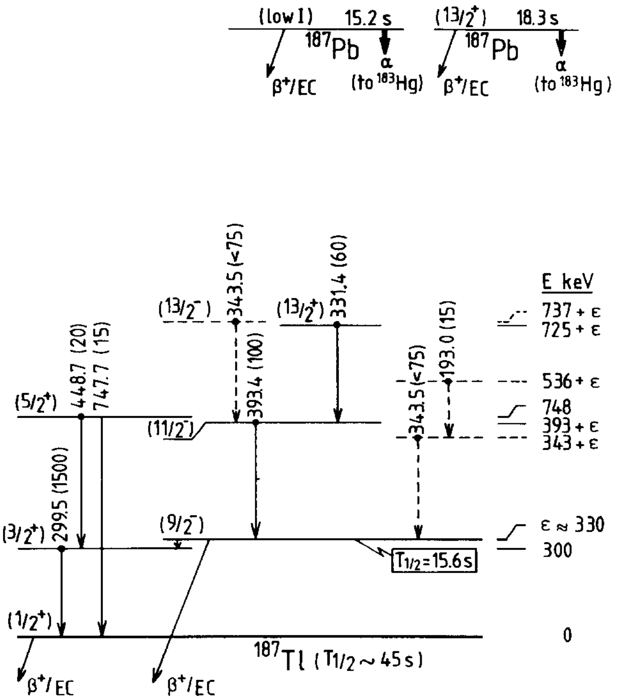

Fig. 2. Partial level scheme for ^{187}Tl proposed on the basis of data obtained in this work. The numbers in parentheses indicate relative γ-ray intensities

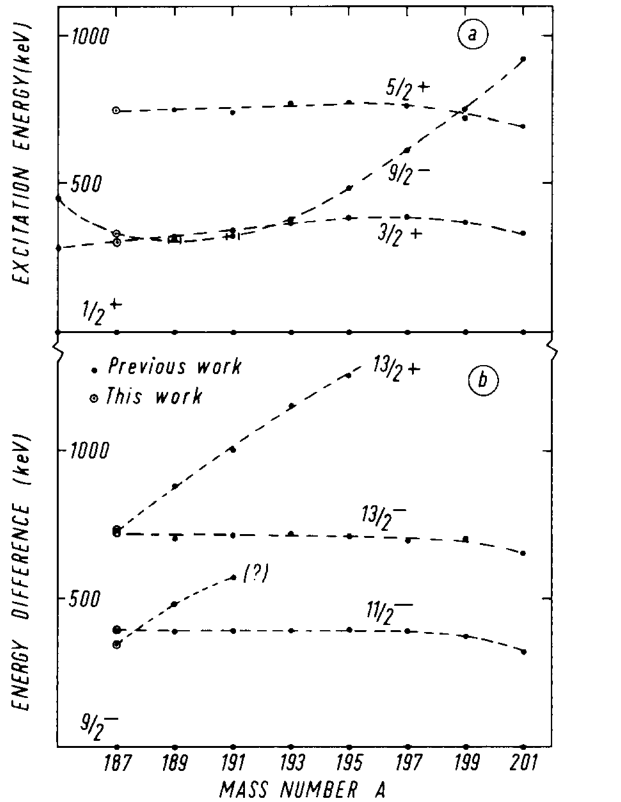

Fig. 3. Level systematics of the neutron-deficient odd mass Tl isotopes. Part (**a**) gives the excitation energy of the $3/2^+$, $5/2^+$ and $9/2^-$ states directly. The energy of the $9/2^-$ state in ^{189,191}Tl is not known; the points shown for these masses result from fitting a smooth curve through the known points at other masses. In part (**b**) the energies of the $11/2^-$, $13/2^-$ and $13/2^+$ states are given relative to the $9/2^-$ intruder state. The levels marked with "(?)" are not understood

The only γ-lines which are sufficiently intense to yield a half-life value for ^{187}Pb are at 344 keV and 393 keV. Since these two lines are at least partly coincident (see below), we have taken the average half-life of 18.4 ± 1.2 s to be representative for ^{187}Pb. This value agrees well with the longer half-life observed for the α-decay. Based on the position of the two γ-lines in the decay scheme, we assign a high spin value to the state in ^{187}Pb showing this half-life. From the systematics of the heavier isotopes, it is probable that $I^\pi = 13/2^+$.

The 300 keV line was observed to be in coincidence with the 449 keV line, which is thus interpreted as a $5/2^+ \rightarrow 3/2^+$ transition in the ground-state band of ^{187}Tl. This assignment is supported by the existence of the 748 keV cross-over transition and by the energy systematics of the low-lying levels of the neutron-deficient odd-mass thallium isotopes shown in Fig. 3 [12]. The upper part (a) of this figure shows the ground-state band and the $9/2^-$-state. The parentheses around the $9/2^-$ states in ^{189}Tl and ^{191}Tl indicate that these states are known as β-decaying isomers, but that their excitation energy is not known; from the non-observation of $E3$ transitions to the $3/2^+$ states it can be inferred, however, that they lie below the $3/2^+$ states.

The spin of the $9/2^-$-isomer in ^{191}Tl has been directly measured in an atomic-beam magnetic resonance experiment [13] at ISOLDE. The energies of the levels in the ground-state band vary only slowly with neutron number, and as expected, the 748 keV level in ^{187}Tl fits on the smooth curve extrapolated from the energies of $5/2^+$ states in the heavier isotopes.

The strongest γ-line associated with the ^{187}Pb decay is the one at 393 keV. This line is also the strongest γ-transition observed by Riedinger et al. [14] who studied ^{187}Tl by means of in-beam γ-spectroscopy. This suggests that the 393 keV line is the last transition in the cascade feeding the $9/2^-$ isomeric state from high-spin states at higher energy (see Fig. 2). Again the assignment is supported by energy systematics. The lower part (b) of Fig. 3 shows the energies, relative to the $9/2^-$ isomer, of states in the odd-mass thallium isotopes which are not members of the ground-state band. The constancy of the energy separations of the $9/2^-$, $11/2^-$ and $13/2^-$ states reflects the unchanging even-A mercury cores, and the position of the 393 keV transition on the diagram can be taken as a confirmation of its assignment as $11/2^- \rightarrow 9/2^-$.

The only line which shows strong coincidence with the 393 keV line is at 331 keV. This line was also observed by Riedinger [14]. It is evident from the coincidence relationships and the energy systematics of Fig. 3b that this line could represent either the $13/2^- \rightarrow 11/2^-$ or the $13/2^+ \rightarrow 11/2^-$ transition. We prefer the $13/2^+ \rightarrow 11/2^-$ assignment on the grounds that in the β-decay of the $13/2^+$ isomer in the heavier odd-mass lead isotopes the subsequent $13/2^+ \rightarrow 11/2^-$ transitions in the thallium daughter nuclides were found to be more intense than the $13/2^- \rightarrow 11/2^-$ transitions, e.g. $I_\gamma(13/2^+ \rightarrow 11/2^-)$: $I_\gamma(13/2^- \rightarrow 11/2^-) = 3:1$ in the ^{189}Pb decay [6]. Even though the 344 keV line is stronger than the 331 keV line, we do not assign it to the $13/2^+ \rightarrow 11/2^-$ transition, as only a small part of it is coincident with the 393 keV line (see below).

The second strongest line after the 393 keV line, which is assigned to the ^{187}Pb decay, is the one at 344 keV. It is in strong coincidence with a 193 keV line, and very weakly in coincidence with the 393 keV line. However, the 193 keV line shows no coincidences with the 393 keV line, and since the 393 keV line is much stronger than the 344 keV line, it can be concluded that the 193 keV and 393 keV lines are not coincident. This suggests that the 344 keV line has two components, one of which is a transition to the $11/2^-$ state. We have tentatively assigned it to the $13/2^- \rightarrow 11/2^-$ transition, since the transition energy is in accordance with the systematics of Fig. 3b. The other component, which is in coincidence with the 193 keV line, we have tentatively assigned as a transition to the $9/2^-$ state. Transitions, apparently analogous to this component of the 344 keV line, have been found in ^{189}Tl and ^{191}Tl at 464 keV and 561 keV, respectively [6]; the corresponding levels are shown in the lower part of Fig. 3. At present these levels are not understood. For the γ-lines at 309, 494, 617, 645 and 866 keV no strong coincidences were observed, nor do their energies match any energy difference of the levels deduced above. We have therefore not been able to place these transitions in the level scheme.

3.2. *The α-Decay of ^{187}Pb*

The α-particle spectra recorded at mass 187 with the two SB detectors mentioned earlier are shown in Fig. 4a and 4c, respectively. Figure 4b shows, for comparison, an α-spectrum measured at the same mass setting of the separator, but with the activity being produced through the ^{107}Ag(^{84}Kr, $p3n$)^{187}Pb

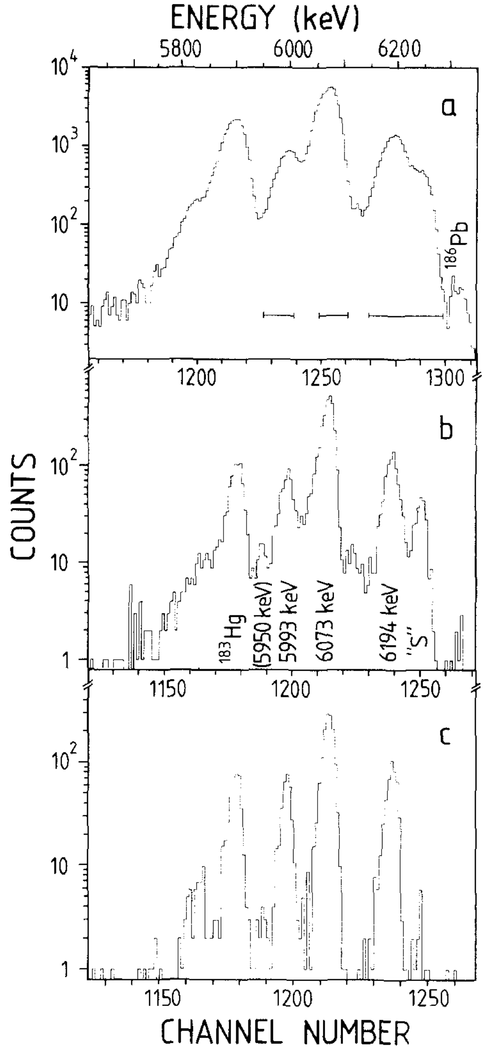

Fig. 4. Singles α-particle spectra obtained from mass separated $A = 187$ sources using three different detector set-ups (see text). The energies of the lines representing α-decay of ^{187}Pb are given in part (**b**) together with lines belonging to the α-decay daughter ^{183}Hg, while the line arising from contamination of ^{186}Pb is indicated in part (**a**). The line marked with "*S*" results from the coincident detection of a 6,194 keV α-particle and a conversion electron of about 50 keV and is therefore hardly seen in spectrum (**c**), which was recorded with a SB detector subtending a substantially smaller solid angle. The energy windows applied for the half-life analyses are indicated by the horizontal bars in part (**a**)

reaction. This spectrum was recorded using a 450 mm^2, 100 μm thick SB detector situated behind an 8 μg/cm^2 thick carbon foil in which the activity was collected. This detector covered a solid angle of 27% of 4π sr.

In the report [4] on our initial α-spectroscopic investigations in this mass region, an α-line of 6,258 keV was assigned to ^{187}Pb. From the more detailed studies including the α-γ coincidence measurements treated below, it emerged, however,

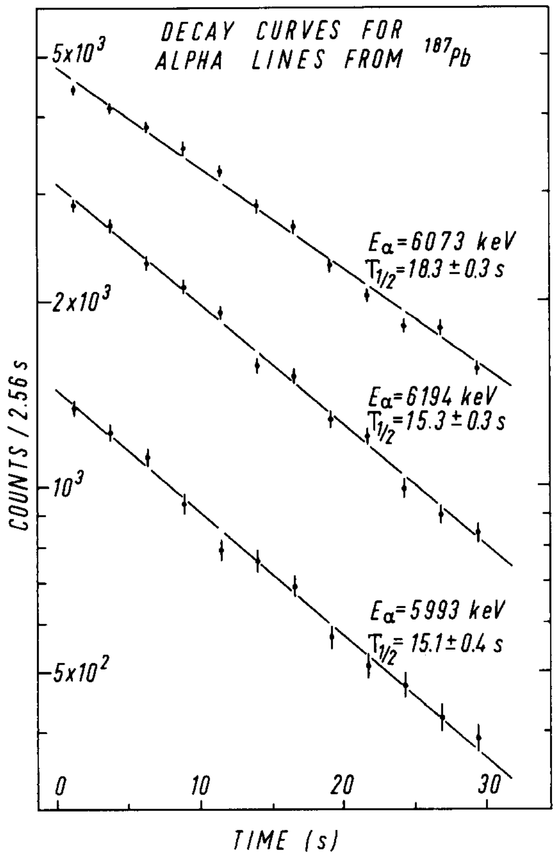

Fig. 5. Decay curves for the three strong α-lines assigned to ^{187}Pb, obtained by application of the energy windows given in Fig. 4a

that the energy of this line did not match with any sum of energies of coincident α-particles (corrected for nuclear recoil) and γ-rays. We have, therefore, tested an interpretation of the high energy line as being caused by summing of α-particles with coincident conversion electrons from the transition deexciting the level fed by the α-transition. This was done by comparing the intensities of the α-lines recorded in the geometries with large (Fig. 4b) and small (Fig. 4c) solid angles, respectively, and the near absence of the 6,258 keV line in Fig. 4c was taken to be a confirmation of this interpretation. Hence, three intense α-lines remain assigned to the decay of ^{187}Pb. In addition, Fig. 4b contains weak lines at 5.95 MeV and 6.13 MeV. The latter may also arise from summing, a hypothesis which is supported by the absence of this line in Fig. 4c, while the first one is also present here. However, we cannot make any assignment of this line from the present data.

We have performed half-life analyses on the α-lines by determination of the time distributions with respect to the tape transport. The decay curves resulting for the three intense α-lines by selecting events within the energy windows given in Fig. 4a, are dis-

Table 2. Energies, relative intensities and half-lives of ^{187}Pb α-lines together with the coincident γ-lines

E_α (keV)	$I_{\alpha,\mathrm{rel}}$ (%)	$T_{1/2}$ (s)	Energies of strongly coincident γ-lines (keV)[a]
5,993 ± 10	14.5 ± 1.0	15.1 ± 0.4	67.4, 208.0, 275.5[b]
6,073 ± 10	64.0 ± 2.5	18.3 ± 0.3	none
6,194 ± 10	21.5 ± 1.5	15.3 ± 0.3	67.4

[a] The uncertainty of the gamma energies is about 0.3 keV
[b] The 5,993 keV α-line is also strongly coincident with mercury *K* X-rays

played in Fig. 5. The extracted half-lives are given in Table 2 together with the energies and relative intensities, which were determined from the spectrum in Fig. 4c, since it was considered to be essentially free of summing effects. The energies differ slightly from the values quoted in our previous report [4], where the energy calibration was based on α-lines recorded in parallel with the lines from the lead activity. In the present work only the standard-source α-lines were applied for calibration. In addition, Table 2 also gives the γ-lines observed in strong coincidence with the α-transitions (see below). The half-life of the 6,073 keV line is significantly different from that of the 5,993 keV and 6,194 keV lines, indicating the existence of two α-emitting states in ^{187}Pb with half-lives of 18.3 ± 0.3 s and 15.2 ± 0.3 s respectively. The longer lifetime is consistent with the lifetime of a high spin state, probably $13/2^+$, found in the β-decay of ^{187}Pb (see Sect. 3.1). We therefore assume that there is a $13/2^+$ state in ^{187}Pb which has intense α- and β-decay branches. The reason for selecting only events belonging to the high-energy part of the 6,073 keV line (see Fig. 4a) for the determination of the corresponding half-life is the presence, particularly in the lower part of this line, of events representing coincident detection of a 5,993 keV α-particle and a conversion electron. In fact, an analysis using only the lower part of the line results in a half-life more than one second shorter than the one obtained for the upper part.

The low-energy part of the coincident γ-spectra measured with the intrinsic germanium detector and obtained by setting gates on the 5,993 keV and 6,194 keV lines, respectively, are shown in Fig. 6. Gamma-ray spectra measured with both germanium detectors in coincidence with the 5,993 keV α-line are displayed in Fig. 7. From the spectra in these two figures it appears that the 5,993 keV line is in strong coincidence with mercury *K* X-rays, which confirms the assignment to ^{187}Pb, and with γ-lines of 67, 208 and 275 keV, whereas the 6,194 keV α-line

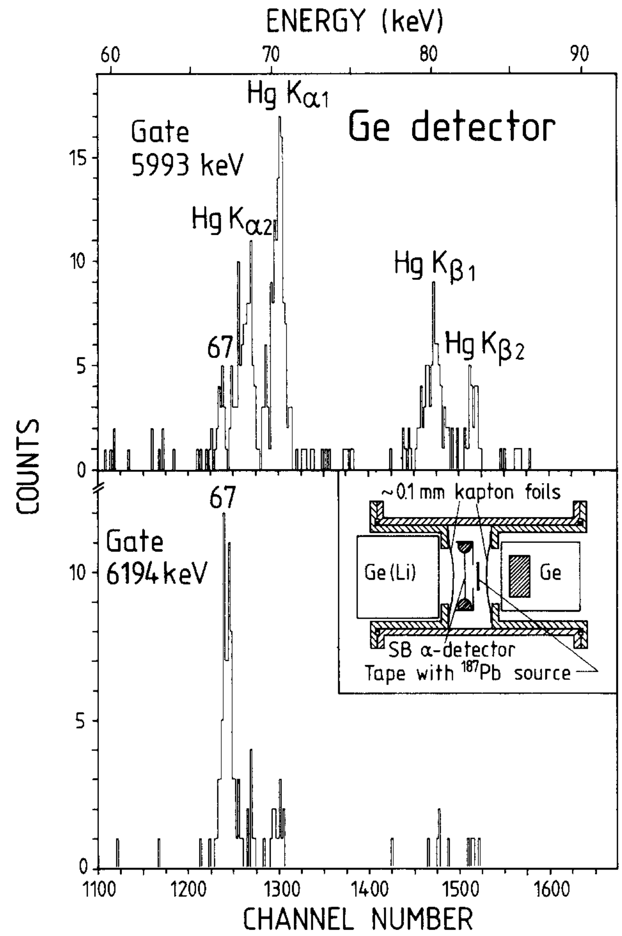

Fig. 6. Low-energy region ($E_\gamma \lesssim 90$ keV) of the γ-spectra recorded with the intrinsic germanium detector in coincidence with the 5,993 keV (upper part) and 6,194 keV (lower part) α-lines. The inset shows a sketch of the experimental set-up for coincidence measurements

is observed to be only in coincidence with the 67 keV γ-ray. The 67 keV γ-transition cannot lead to coincidences between the 6,194 keV α-line and mercury K X-rays because its energy is less than the binding energy of the K electrons in mercury. The binding energy of L electrons is about 14 keV, leaving an energy of about 53 keV for conversion electrons, thus accounting for the sum peak in the upper spectra of Fig. 4. The weak appearance of mercury K X-rays in the γ-spectrum gated with the 6,194 keV α-line may be caused by summing of conversion electrons from the 275 keV transition and 5,993 keV α-particles.

No γ-rays were observed to be in coincidence with the 6,073 keV α-line. Since this α-transition is believed to originate from the $13/2^+$ state in ^{187}Pb, it is not very probable that it leads to the $1/2^-$ ground state of ^{183}Hg. It is more likely that it represents a favoured transition to a $13/2^+$ level in ^{183}Hg, which then has a lifetime which is appreciably longer than the coincidence time of 8 μs applied in our studies.

The total conversion coefficient α_{tot}^{67} for the 67 keV γ-line can be determined from the relation between the number N_α of 6,194 keV α-events in the singles spectrum and the number $N_{\alpha,67}$ in coincidence with the 67 keV γ-line:

$$N_{\alpha,67}(1+\alpha_{\text{tot}}^{67}) = N_\alpha \cdot \varepsilon_\gamma^{67} \tag{1}$$

where ε_γ^{67} is the absolute efficiency of the γ-detector at 67 keV. This expression leads to $\alpha_{\text{tot}}^{67} = 26 \pm 4$. The α-γ coincidence-time spectrum recorded for this sequence shows only a "prompt" peak (FWHM ≃ 16 ns), thus restricting the multipolarity of the 67 keV transition to $E1$, $E2$ or $M1$. Of these, only the $E2$ solution has a theoretical conversion coefficient ($\alpha_{E2}^{67} = 32$) [15] which agrees with the experimental value. For $M1$ transitions the theoretical conversion coefficient is $\alpha_{M1}^{67} = 4.7$; hence, the transition must be $E2$ with less than 36% admixture of $M1$. For reasons discussed later, the pure $E2$ solution is considered to be most probable.

The time spectrum of α-γ coincidences gated on the 5,993 keV α-line also shows only a prompt peak, thus excluding the possibility that either of the 208 keV and 275 keV transitions, which evidently are the strongest transitions deexciting the 275 keV level, has multipolarity greater than $E2$ or $M1$. Other γ-transitions may, however, contribute to the deexcitation of this level since the region between the Compton edge of the 275 keV transition and the 208 keV γ-line in Fig. 7 is not clean. As the structures at 187 keV and 195 keV show up in the coincidence spectra of both germanium detectors, it is assumed that they represent γ-lines and not scattered γ-rays. These two lines certainly do not arise from random coincidences, since only the 5,993 keV α-line, which is far from being the strongest line in the α-singles spectrum, appears in the spectra gated with these two γ-lines.

Even in the presence of the two γ-transitions, which may contribute to the population of the 67 keV level, it is possible to obtain limits for the total conversion coefficient $\alpha_{\text{tot}}^{208}$ for the 208 keV transition from the 208 − 67 keV cascade. The upper limit is derived under the assumption of no extra feeding of the 67 keV level, while the lower limit is derived assuming that there are 187 keV and 195 keV transitions of $M2$ multipolarity feeding the 67 keV level. The resulting values are $0.87 \leqq \alpha_{\text{tot}}^{208} \leqq 5.3$. When pure multipolarities are assumed, this allows for $M1$, $M2$ and $E3$ assignments, and since the two latter possibilities can be ruled out from the lifetime argument, we are led to the conclusion that the 208 keV transition most probably is of $M1$ multipolarity.

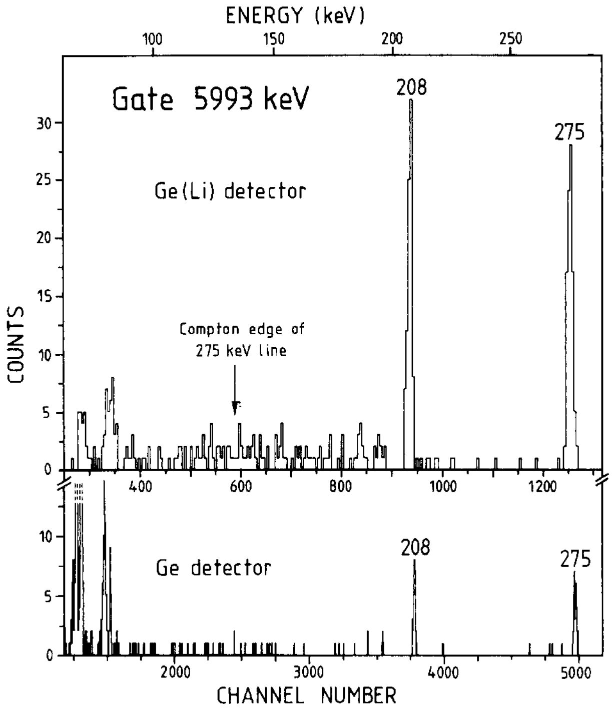

Fig. 7. Spectra recorded in coincidence with the 5,993 keV alpha-line. The upper spectrum was taken with the Ge(Li) detector, the lower one with the intrinsic Ge detector (the low-energy region is already shown in Fig. 6)

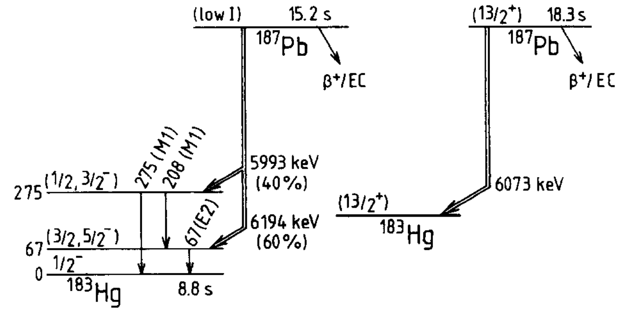

Fig. 8. Proposed α-decay scheme of ^{187}Pb. Estimated data are given within parentheses. The relative position of the two levels in ^{187}Pb is not known

Based on this assignment and still on the extreme assumption of $M2$ for the 187 keV and 195 keV transitions, there remain too many α(5,993 keV)-mercury K X-ray coincidences to be accounted for, to make an $E1$ or $E2$ assignment probable for the 275 keV transition, i.e. the most likely multipolarity is $M1$. Furthermore, an $E1$ assignment can be ruled out from parity arguments, if the 67 keV and 208 keV transitions are $E2$ and $M1$, respectively.

Figure 8 shows the α-decay scheme of ^{187}Pb based on the conclusions drawn above. No attempt has been made to place the 187 keV and 195 keV transitions in the scheme, since from our data it cannot be concluded whether they originate directly from the 275 keV state or that they are preceded by a low-energy γ-transition. The relative position of the two states in ^{187}Pb cannot be decided either, since no transition between them was observed and none of the decay curves contain significant growing-in components.

We have not been able to establish a time correlation between the ^{183}Hg α-line, which decays with a half-life of 8.8 s [16], and any of the parent ^{187}Pb lines. However, the state decaying with 8.8 s half-life is known to have $I=1/2$ [17], and is believed to be the $1/2^-$ [521] Nilsson state. Since it was shown in Sect. 3.1 that the ^{187}Pb state which decays by the 6,073 keV α-line and by intense β-decay is most probably a high-spin state we assume that the 5,993 keV and 6,194 keV lines are feeding low-spin states of ^{183}Hg, and that the state fed by the 67 keV γ-transition is in fact the $1/2^-$ state. From the multipolarities of the γ-transitions it follows then, that the 67 keV state may be $3/2^-$ or $5/2^-$, and the 275 keV state $1/2^-$ or $3/2^-$. The more likely sequence is $5/2^-$ for the 67 keV state, and $3/2^-$ for the 275 keV state, on the grounds that at such a low energy as 67 keV an $E2$ transition between states with $\Delta I \leqq 1$ would not be expected to compete favourably with $M1$ unless it were of a collective character connecting members of the same rotational band. The $E2$ transition is fast – the α-γ time spectrum shows that its lifetime can be no more than one Weisskopf unit – but it cannot be a member of a band built on the $1/2^-$ state because of the absence of an α-transition to the $1/2^-$ state.

The few counts in Fig. 4c above the 6,194 keV line correspond certainly within the statistical errors to the number of α-electron coincidences in the SB-detector calculated using the number of events in the 6,194 keV line. On the other hand, one can obtain an upper limit of 1.5×10^{-2} of all α-decays from the low-spin state for the intensity of a transition to the ground state of ^{183}Hg, by applying the extreme assumption that the 6.24 MeV events all represent such a transition.

4. Summary and Conclusions

We have been able to establish the energies of some of the low-lying levels in the ^{187}Tl and ^{183}Hg daughters following the β- and α-decay of ^{187}Pb. In the case of ^{187}Tl, comparison with neighbouring odd-mass thallium isotopes allowed some spins and parities to be assigned with considerable confidence. A few transitions could not be fitted into the level scheme because of the limited coincidence data. It should be realized though, that it is certainly possible to learn more about these transitions by a continuation of the present study, which was limited with respect to accelerator time. Furthermore, to allow for firm element assignments one of the γ-detectors was chosen to give good X-ray resolution, which corresponds on the other hand to low efficiency at high γ-energy. Although it will hardly be possible at present to arrive at decay schemes of the same detail as in nuclides near stability, there are already hints of new structures in the very neutron-deficient thallium nuclei, and it would be interesting to have more information available.

The excitation energy of the $9/2^-$ isomer, which is much lower than originally expected, has been discussed by Newton et al. [18, 19], who also observed rotational bands built on this state, which presumably is of prolate deformation, in the heavier odd thallium isotopes. Our results can be taken as a continuation of their observations, covering $^{191-199}$Tl, in so far as the constancy of the relative position of the $9/2^-$, $11/2^-$ and $13/2^-$ states was observed to persist at least until ^{187}Tl.

Fewer levels were probed in the ^{183}Hg daughter, the spectroscopic information deduced being somewhat tentative. However, the multipolarities deduced for the 67 keV, 208 keV and 275 keV transitions can be accommodated consistently in the decay scheme. The experimental data did not suffice to place the 187 keV and 195 keV transitions in the decay scheme. It is tempting, though, to speculate on the basis of an assignment of those transitions as connections from the 275 keV level to rotational states built on the $1/2^-$ state, which is known to be strongly deformed [5, 17].

If this is true, the 3/2 and 5/2 members of this band would have excitation energies of 80 keV and 88 keV, respectively, in strong resemblance to the neutron-deficient platinum isotopes [20].

No attempt was made to determine the lifetime nor the excitation energy of the level in ^{183}Hg fed by the 6,073 keV α-line. We found strong indication that this α-decay has its origin in a $13/2^+$ state in ^{187}Pb, and the presence of a 13/2 isomer in all odd-A mercury isotopes with $185 \leqq A \leqq 199$ [21] makes it probable that the final state in ^{183}Hg is the corresponding 13/2 [606] state, so that this α-line represents a favoured transition. The excitation energy of the 13/2 isomer in the heavier mercury isotopes is only known for $A \geqq 193$, but it would be interesting to determine, whether the constancy of the energy difference of the $3/2^-$ and the $13/2^+$ states in ^{193,195,197}Hg ($\sim$140 keV) is maintained down to ^{183}Hg. Furthermore, a determination of the relative position of the final states of the α-decays from the two states in ^{187}Pb would also imply that one could decide which of these states is the ground state.

It is interesting that no α-transitions leading to the $1/2^-$ state of ^{183}Hg were observed. For α-particles of the energy derived for such a transition, transmission coefficients only alter by a factor of two for angular momentum changes up to $\Delta l = 3$. The short lifetime of the 67 keV level indicates a low spin difference between this state and the ground state. Combining this with the strong hindrance of the α-decay to the ground state, we conclude that the states concerned, both in ^{187}Pb and ^{183}Hg have a rather pure single-particle character.

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