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Microsecond isomers in ^{187}Tl and ^{188}Pb

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Abstract. Lifetime measurements of states in nuclei with A=187 and 188 have been performed, using reactions between ^{155}Gd and ^{36}Ar and following the transport of evaporation residues to the focal plane of a gas-filled recoil separator. In a separate experiment using the ^{159}Tb(^{32}S,$4n$) reaction the γ-decay of isomeric levels in ^{187}Tl has been studied using delayed γ-γ coincidence measurements. From observation of their subsequent γ decay, the mean lifetimes were measured to be 1000 ± 55 ns and 1600 ± 100 ns. Although it was not possible to characterize the isomers completely, they are proposed as candidates for one-proton, two-neutron excitations. In the course of this study, the decay of an isomer in ^{188}Pb was also observed and its lifetime was measured as 1150 ± 30 ns, and limits of 20-600 ns were placed on the meanlife of an isomer conjectured in ^{187}Pb.

PACS. 21.10.Re Collective levels – 23.20.Lv Gamma transitions and level energies – 27.70.+q $150 \leq A \leq 189$

1 Introduction

The very neutron-deficient nuclei in the lead region provide the possibility of the co-existence of states arising from a variety of potential minima. Their decay schemes are marked by the presence of isomeric states which can result both from structural changes and also from the reduction of intra-multiplet transition rates as one moves to the middle of the $i_{13/2}$ neutron shell. However, such studies are complicated by the difficulty of producing neutron-deficient nuclei against strong competition from fission. This paper reports the results of a search for isomeric states prompted by the observation that the intensity of decays of yrast states in ^{187}Pb, above the long-lived $13/2^+$ isomer, was much weaker than would be expected from the production rate of ^{187}Pb indicated by the observed yield of α particles from its decay [1].

Initial measurements failed to identify directly any isomeric state in ^{187}Pb, but did detect isomers in ^{188}Pb and ^{187}Tl. The decay properties of isomers in ^{188}Pb have been the subject of a separate investigation published elsewhere [2]. The decay from isomers in ^{187}Tl were investigated in a further experiment, and these results are also reported in the present paper.

2 Experimental measurements

2.1 Recoil separator measurements

A self-supporting ^{155}Gd target was bombarded with a beam of 176 MeV ^{36}Ar ions from the $K = 130$ cyclotron at the Accelerator Laboratory of the University of Jyväskylä. The target was 0.8-mg/cm^2 thick and enriched to 92% in ^{155}Gd. Under these conditions, ^{187}Pb, ^{187}Tl and ^{188}Pb were produced with similar yields although it is likely that the yield of ^{188}Pb owed more to reactions with the residual amounts of heavier Gd isotopes in the target. The data for ^{188}Pb were supplemented by a short run, identical except for replacement of the "^{155}Gd" target with one enriched to 89% in ^{157}Gd, to give an enhanced yield of ^{188}Pb through the ^{157}Gd(^{36}Ar,$5n$) reaction.

Evaporation residues recoiling from the target were transported by the gas-filled, magnetic recoil separator RITU [3], set at 0° to the beam, to a silicon strip detector (SSD) at its focal plane. Gamma-radiation emitted by residues, after arriving at the focal plane, was detected in four germanium detectors (without Compton suppression) placed 4 cm from the silicon detector.

The SSD provided signals giving the energy, position and detection time of particles arriving at the focal plane.

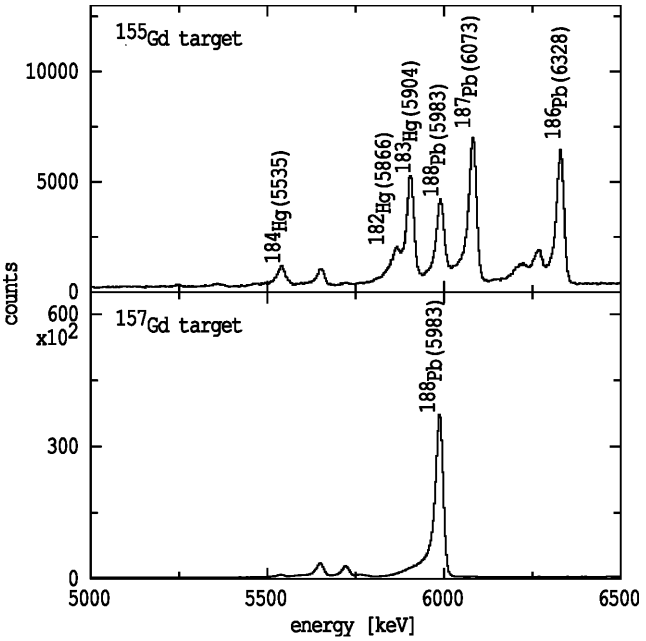

Fig. 1. Alpha spectra obtained in the SSD for the ^{36}Ar beam on Gd targets. Peaks are labeled by the α–particle energies

The time between arrival of an evaporation residue at the SSD and the detection of its subsequent γ-decay was measured with a time-to-amplitude converter (TAC) with a range of 50 μs. A second TAC, with a range of 4 μs, was used to measure γ-γ-time correlations gated by detection of recoils.

Figure 1 shows spectra of α-particles detected in the SSD of the recoil separator RITU during the runs with the two Gd targets. With the ^{155}Gd target (top panel), the largest peaks in the spectrum are identified with the α-decay branches from the ground states of ^{183}Hg, ^{186}Pb and ^{188}Pb and from the $13/2^{+}$ isomer in ^{187}Pb. The α-particle energies given in Fig. 1 are from the recommended values of Rytz [4] for ^{182}Hg, ^{183}Hg, ^{186}Pb and ^{188}Pb, from [5] for ^{184}Hg and from [6] for ^{187}Pb. Some of the smaller peaks could not, on the basis of energies and relative intensities, be assigned unambiguously to a particular nuclide. As can be seen in the bottom panel of Fig. 1, the α-particle spectrum obtained with the ^{157}Gd target is dominated by the group corresponding to the decay from the ground state of ^{188}Pb.

Time spectra were projected from a matrix of γ-ray energy *versus* the time difference between γ-rays and recoils. Out-of-beam γ-γ coincidence spectra were also obtained from these data, although the statistics were too low to provide definitive assignments.

2.2 Delayed coincidence measurements

High-spin states in ^{187}Tl were populated by bombarding a metallic terbium target with a nanosecond pulsed beam, with pulse separation of 1.7 μs, of 158-MeV ^{32}S ions from the 14UD Pelletron accelerator at the Australian National University. The target was 2 mg/cm^2 thick with a 5 mg/cm^2 layer of lead evaporated on the back to stop recoiling evaporation residues at the target position. Gamma radiation was detected by the six Compton-suppressed Ge detectors and two planar Ge detectors of the CAESAR array. Prompt γ rays were rejected by a 37-ns-wide veto encompassing the beam pulse so that data were acquired only during the interval between beam pulses. This arrangement selected transitions in the decay paths from isomers with lifetimes greater than about ten nanoseconds.

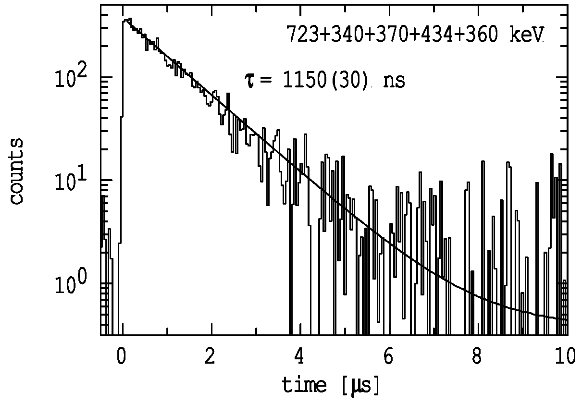

Fig. 2. Time spectrum for ^{188}Pb

3 Results

3.1 ^{187}Pb

No γ-ray line in the E_{γ}-time data could be identified with any known transition [1] in ^{187}Pb, leading to the conclusion that the total decay time must be short relative to the transit time (0.9 μs) of evaporation residues in the recoil separator. The non-observation of lines in the previous experiment [1] provides a lower limit on the meanlife; consequently, if an isomeric state is significantly populated in the yrast or near-yrast level scheme of ^{187}Pb, its meanlife must be between 20 and 600 ns.

3.2 ^{188}Pb

Figure 2, shows a time spectrum which is a sum of gates on several known [2, 7] transitions in ^{188}Pb. The lifetimes associated with the individual gates are consistent with each other and together they give a mean lifetime of 1150(30) ns. The properties of this isomer are consistent with it being identified with the 1200(300) ns isomer at 2576 keV in ^{188}Pb reported by Dracoulis *et al.* [2].

3.3 ^{187}Tl

Gamma-ray coincidence spectra with gates set on known lines in ^{187}Tl [8] are shown in Fig 3. As these data are collected in the out-of-beam period they indicate clearly

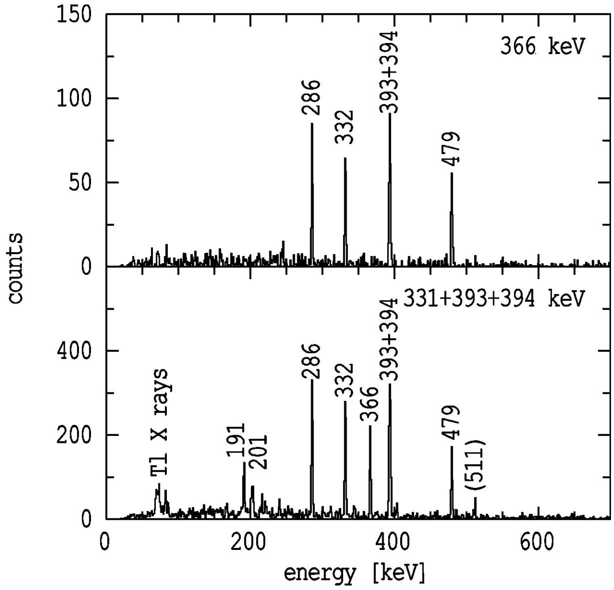

Fig. 3. γ-γ coincidence spectra of transitions in ^{187}Tl delayed relative to the beam pulses. Transitions assigned to ^{187}Tl are marked, as is the contaminant 511 keV line

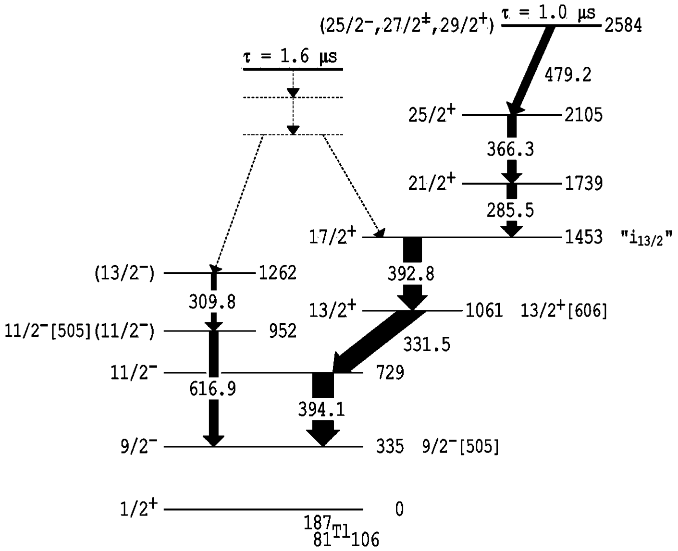

Fig. 4. Partial level scheme for ^{187}Tl showing decay paths for the two isomers. One-quasiparticle configurations from [8] are indicated

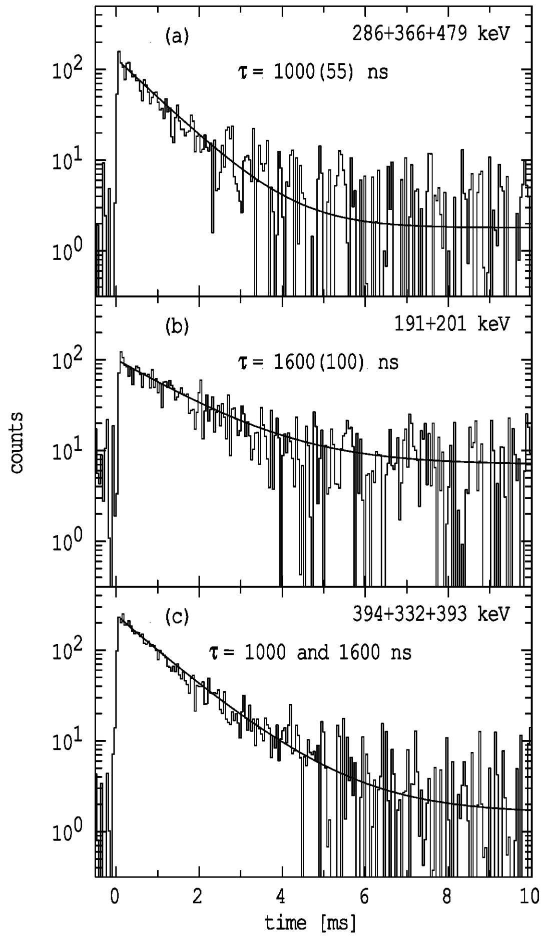

Fig. 5. Time spectra for ^{187}Tl

an isomer at excitation energy 2584 keV with the decay path shown on the right of the partial level scheme in Fig 4. As the data collected in the current experiments excluded prompt feeding contributions, we have adopted the ordering of transitions from the work of Lane *et al.* [8].

A conversion coefficient of 0.15(18) was determined for the 479 keV line from a balance of intensities and hence multipolarities of E1, M1 and E2 are possible, restricting the isomeric 2584 keV level to $J^{\pi} = 25/2^{-}$, $27/2^{\pm}$ or $29/2^{+}$. The $29/2^{+}$ possibility is the least likely as the isomer, and the states built on it, would then be near yrast, and should have been observed in the work of Lane *et al.* [8]. The $25/2^{+}$ possibility has been excluded because of the lack of a transition from the 2584 keV state to the $21/2^{+}$ state at 1739 keV.

The coincidence spectrum shown in the lower panel of Fig. 3 shows some lines not associated with the decay of the 2584 keV isomer, notably those at 191 keV and 201 keV. These lines are evidence for an additional isomeric state which feeds both the $17/2^{+}$ state at 1453 keV and other known negative parity states. The decay of this isomer is fragmented and we were unable to place all transitions de-exciting it.

Further evidence for the presence of two isomeric states comes from the lifetime measurements, some of which are shown in Fig. 5. The top panel shows the sum of gates for the first three transitions depopulating the isomer at 2584 keV, from which a meanlife of 1000(55) ns was deduced. Fig. 5(c) is the sum of the next three transitions in the cascade. This spectrum cannot be fitted with a single lifetime with the value deduced from the upper spectrum. The fit shown in Fig. 5(c) assumes feeding from two isomers, with one meanlife fixed at 1000 ns and the meanlife of the second isomer obtained from the fit to the 191 and 201 keV transitions. (Note that both these transitions are contaminated by activity lines, largely from ^{184}Ir, ^{187}Ir and ^{186}Pt, and this is reflected in the decay curve shown in Fig. 5(b).) The fit indicates that the longer isomer contributes approximately one third of the population of the 1453 keV level, in rough agreement with the observed γ–ray intensities.

4 Discussion

The isomer identified at an excitation energy of 2584 keV has assignments constrained to the range $J^\pi = 25/2^-$, $27/2^\pm$, or $29/2^+$ suggesting a three-quasiparticle configuration. The configurations expected for ^{187}Tl are likely to reflect the co-existence of oblate and prolate minima already identified in the one-quasiparticle structures observed at low excitation energy [8]. A variety of structures has also been observed in the "core" nucleus, ^{188}Pb, where prolate, oblate and spherical configurations are seen to compete [2], so that it is not immediately clear which excitations will be lowest in ^{187}Tl.

For prolate deformation the lowest energy high-K, three-quasi-particle state is likely to arise from the coupling of the $11/2^-[505]$ proton configuration, observed at 952 keV, to a two-quasineutron configuration. Isomeric 8^- states, attributed to the $9/2^+[624]\otimes 7/2^-[514]$ two-quasineutron configuration have been observed in the N= 106 isotopes with Z between 70 and 80, and this configuration has been suggested for one of the isomeric states observed in ^{188}Pb [2]. The resulting three-quasiparticle configuration in ^{187}Tl would have $K^\pi = 27/2^+$.

In the oblate well a number of two-quasineutron, one-quasiproton configurations can be produced involving couplings to either of the $9/2^-[505]$ or $13/2^+[606]$ quasiprotons. These can give several low-lying three-quasiparticle states with a range of K values encompassing the 25/2 to 29/2 range of the isomeric state at 2584 keV. The lowest high-K, three-quasiproton state is likely to arise from the coupling of the $\pi h^2_{9/2}$ configuration, seen as an 8^+ isomer in the Pb isotopes, with the oblate $13/2^+[606]$ quasiproton configuration.

At this stage the lack of firm spin and parity assignments prevents a more definite attribution to any of the above possibilities.

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