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Short note

Identification of a high-K isomer in neutron-rich ^{185}Ta

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Abstract. A $t_{1/2}$>1 ms, high-K isomeric state feeding a strongly coupled rotational band has been identified following the deep inelastic reaction $^{238}_{92}$U + $^{186}_{74}$W at 1600 MeV. Examination of γ-ray and X-ray data combined with a g-factor analysis derived from in-band branching ratios suggests the assignment of the new states to the neutron-rich nucleus $^{185}_{73}$Ta.

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

In the A≈180 region, a large number of metastable states arise due to the occupation of both proton and neutron orbitals with large angular momentum projections K, on the prolate nuclear symmetry axis. The majority of the known K isomers lie on the neutron-deficient side of the valley of β-stability. Access to the stable and neutron-rich nuclei in this region has been limited because of the restriction of using fusion-evaporation reactions with stable beams and targets.

Recently, several studies [1–3] have employed the technique of deep inelastic reactions to populate high-K isomers in both stable and neutron-rich nuclei. In [2] we reported the results of an experiment using pulsed uranium beams to study isomers in the heaviest stable isotopes of ytterbium, lutetium, tantalum and tungsten. In addition to the strong inelastic excitation of the target nuclei, a large number of known isomers were observed from the multi-nucleon transfer channels. Here we report the identification of a new isomer in a neutron-rich tantalum isotope.

A 1600 MeV pulsed ^{238}U beam was provided by the ATLAS accelerator at Argonne National Laboratory. This was incident on thick targets (≥5 mg cm^{-2}) of $^{181}_{73}$Ta and $^{186}_{74}$W, each with a 43 mg cm^{-2} lead backing to stop all of the reaction products and the beam at the target position. The beam energy was chosen to be ≈15 % above the Coulomb barrier. The ATLAS beam, which has a natural micro-pulsing period of 82.5 ns, was macro-pulsed using a beam sweeper with ON/OFF conditions of 4/16, 40/160, 400/1600 and 4000/16000 micro-pulses, corresponding to time ranges from 1.65 μs to 1.65 ms. Delayed γ rays were detected using the Argonne/Notre-Dame BGO array with 12 Compton-suppressed Ge detectors and a 50 element BGO inner ball. Data were collected event-by-event with a master trigger of at least one Ge detector firing in the beam-off interval.

A large number of *nucleon-transfer* products in the target region have been observed in the ^{186}W target data. The strongest of these involves transition energies of 162, 175, 191, 218, 246 and 266 keV. Gamma-ray coincidences were used to order the transitions into a rotational sequence, shown in the inset of Fig. 1. The strong M1/E2 and accompanying weaker stretched E2 transitions in the band, can be seen in the γ-ray spectrum of Fig. 1. No accompanying crossover transition has been observed for the 175 keV γ ray. Intensity balancing for this transition gives an implied electron conversion coefficient of α_T(exp)=0.12 ±0.18 compared to theoretical values [4] of α_T(E1)=0.08, α_T(E2)=0.47 and α_T(M1)=0.91. This suggests that the 175 keV decay is an E1 transition, although an E2 assignment is not ruled out. The placement of this transition will be discussed later. The limit on the half-life for the new isomer is $t_{1/2}$>1 ms. This was found by examining the counts in several different time gated spectra on the 1.65 ms TAC range. (Random stopping effects and low statistics due to a limited beam time with the 1.65 ms range prevent a higher limit being set.)

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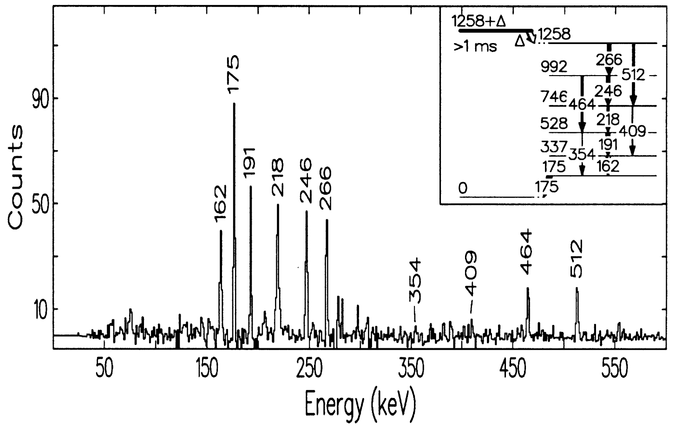

Fig. 1. The γ-ray spectrum gated on transitions in the new band. A level scheme is proposed (see inset panel), with a well formed rotational structure being fed by an isomeric state. The low energy isomeric transition has not been observed leading to an offset of Δ for the isomeric level. See text for details

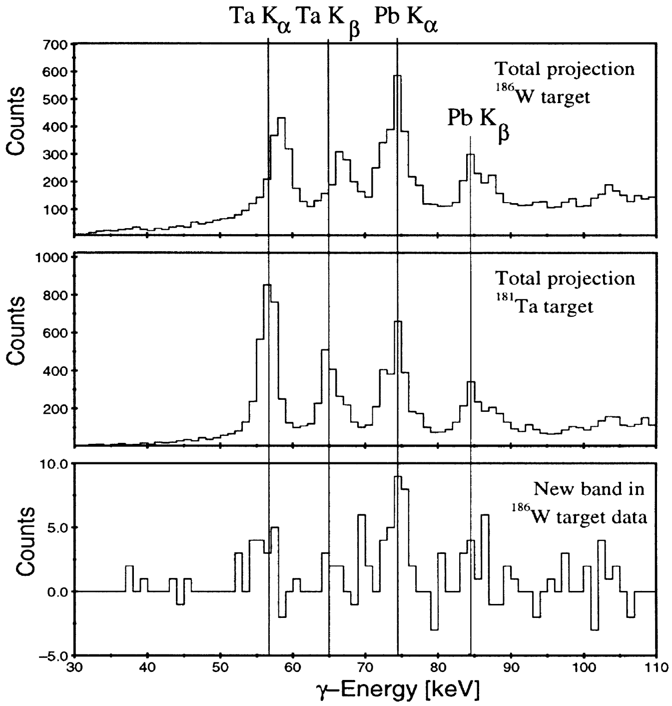

Fig. 2. X-rays from 3 different γ-ray coincidence spectra. The top panel shows the total out-of-beam spectrum for the ^{186}W target data. The middle panel is the corresponding plot for the ^{181}Ta target data. The lower panel shows the X-ray region of a spectrum gated by transitions in the new band. The vertical lines (left to right) are at the K_α and K_β X-ray energies of tantalum and lead respectively. The X-rays in the lower spectrum match with the energies of the tantalum lines, but are offset compared with the tungsten X-rays

In an attempt to assign this band to a particular nucleus, the X-ray spectrum region was examined in detail. Although the use of absorbers blocked a high proportion of the low energy events, there are significant counts in this domain in the gated spectra. Figure 2 shows the X-ray region for the total projections using the ^{186}W and ^{181}Ta targets, together with the spectrum gated by transitions in the new band. The X-rays from the lead backing can be seen clearly in all three spectra and though there are few counts in the lower spectrum (for the new band), small X-ray peaks do lie at the same energy as tantalum X-rays. Therefore, this new band is considered to belong to a tantalum isotope.

The relatively strong population of this isomer with respect to other transfer products suggests that a 1-particle transfer is responsible, due to the higher cross-section for such processes over multi-nucleon transfer. This, together with the X-ray information, points towards the isotope ^{185}Ta as being the most likely candidate, produced by 1-proton transfer from the ^{186}W target. The possible quasiparticle configurations of these states are discussed below.

In ^{183}Ta (and also in ^{181}Ta), the ground-state band is built on a $\frac{7}{2}^+$[404] 1-quasiproton configuration [5]. The ^{183}Ta ground-state is fed by an isomeric yrast $\frac{9}{2}^-$[514] bandhead with $t_{1/2} = 0.11$ μs [5] at 73 keV. In ^{185}Ta (the favoured isotope for the new band) the ground-state band has been tentatively assigned the same $K^\pi = 7/2^+$ proton orbital [6]. As neutrons are added, the trend of the $K^\pi = 9/2^-$ bandheads in the odd-A tantalum isotopes is for increasing excitation energy and shorter half-lives. The 175 keV transition is of the right multipolarity and approximately the right energy to continue the systematics. The half-life limit for this transition with respect to the band members is $t_{1/2} \leq 5$ ns, based on a time difference analysis (a second TAC was started by the Ge signal and stopped by the electronically delayed BGO signal). This fits well with the B(E1) rates observed in the lighter odd-A isotopes. A state at approximately 163 keV has been observed with a tentative spin of 9/2 [6] from proton pick-up reactions. The uncertainty in this energy is likely to be large due to the low energy resolution and relatively poor statistics, and the assignment of a 175 keV transition here is not inconsistent with the previous study.

To gauge whether the new band could be built on either a $7/2^+$ or $9/2^-$ 1-quasiproton configuration the in-band branching ratios, T_2/T_1 are calculated. The rotational model expressions [7] can be used to derive an experimental intrinsic g-factor to compare with the calculated values for each configuration. The parameters $Q_0 = 6.5$ e·b and $g_R = 0.3$ are chosen as these reproduce the intrinsic g-factors for the $K^\pi = 7/2^+$ and $9/2^-$ bands in ^{181}Ta [8].

Table 1 shows the results based on two assumptions for the K values at the bandhead, namely $K^\pi = 7/2^+$ and $9/2^-$. The g-factors fluctuate very little over the range of spins. However, the calculated quantities using the asymptotic Nilsson quantum numbers are

$$\begin{aligned}(g_K - g_R)/Q_0 &= +0.06 \text{ for } K^\pi = \tfrac{7}{2}^+ \\ &= +0.16 \text{ for } K^\pi = \tfrac{9}{2}^-\end{aligned}$$

Table 1. Gamma-ray branching ratios and g-factors for the new band

I ($\hbar$)		E_2	E_1	T_2/T_1	$\|(g_K - g_R)/Q_0\|$ (e·b)$^{-1}$	
7/2[a]	9/2[b]	(MeV)			7/2[a]	9/2[b]
11/2	13/2	0.354	0.191	0.11±0.10	0.21±0.50	0.15±0.36
13/2	15/2	0.409	0.218	0.33±0.17	0.18±0.08	0.13±0.06
15/2	17/2	0.464	0.246	0.72±0.23	0.15±0.04	0.11±0.03
17/2	19/2	0.512	0.266	0.60±0.17	0.20±0.04	0.15±0.03

[a] Assuming $K = 7/2$
[b] Assuming $K = 9/2$

For $K = 9/2$ the experimentally determined g-factors agree, within the uncertainties, with the calculated value based on the $\pi\frac{9}{2}^-[514]$ Nilsson orbital. The $|(g_K - g_R)/Q_0|$ values assuming $K = 7/2$ do not agree with the calculated quantity. This provides evidence for a $\frac{9}{2}^-[514]$ assignment, and supports the placement of this band and its associated isomer in ^{185}Ta.

Adding one unit of spin for each level above an $I^\pi = 9/2^-$ bandhead would mean that the transition directly depopulating the isomer feeds the $19/2^-$ member of the band. This transition has not been observed but can be given energy limits of <100 keV (M1) and <80 keV (E1) on the basis of detection-efficiency and conversion-coefficient considerations. Comparison with Nilsson model calculations favours a $K^\pi = 21/2^-$ $\{\frac{5}{2}^+[402], \frac{7}{2}^+[404], \frac{9}{2}^-[514]\}$ 3-quasiproton configuration for the isomer, consistent with an isomeric M1 transition. It should be noted that the 175 keV transition could itself be the isomeric decay, as the ordering cannot be unambiguously determined in this work. This would lead to a probable $K^\pi = 21/2^+$ assignment for the $t_{1/2}$>1 ms isomer, but would not alter the proposed configuration of $\frac{9}{2}^-[514]$ for the observed rotational band, or its placement in ^{185}Ta.

This work extends the systematics of the 3-quasiparticle tantalum isomers to the neutron-rich side of β stability for the first time.

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