COULOMB EXCITATION OF AN ISOMERIC STATE IN ^{181}Ta VIA INTERMEDIATE STATES*

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$5/2^+[402]$ 10.8 ns isomeric level at 482 keV in ^{181}Ta was Coulomb-excited by 225 MeV ^{58}Ni, starting from $7/2^+[404]$ ground state. Particle–γ and particle–γ–γ events were collected. Excitation through newly observed gamma-vibrational $K^\pi = 3/2^+$ band turned out to be 50 times more efficient than direct excitation.

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1. Introduction

During the last years much theoretical and experimental research was devoted to the physics of K-isomers in atomic nuclei. In recent Coulomb excitation experiments a surprisingly strong population of these states was observed, which seems to be in contradiction to the retarded character of transitions connecting K-isomers to ground states. A possible explanation is that there are other ways of feeding the isomers, through some upper-lying intermediate states, but those states have not been identified yet.

In the present paper the mediating states are found in ^{181}Ta. However, the isomeric transitions here are forbidden due to asymptotic Nilsson quantum numbers rather than the K number.

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2. Experimental and theoretical approach

The experiment was held in the Tandem Accelerator Laboratory, Niels Bohr Institute, Risø, Denmark. It was actually designed to explore ^{180}Ta, which has a very strong K-isomer playing an important role in nucleosynthesis. But, as ^{180}Ta is extremely rare in nature, even an enriched target contained only 5% of it, the rest being ^{181}Ta. It was a unique occasion to collect a large statistics for ^{181}Ta and thus to observe weak effects.

A thin Ta_2O_5 target was bombarded with ^{58}Ni ions at 225 MeV. The scattered projectiles were detected in an array of 55 PIN-diodes of the size of 5×5 mm, placed at backward angles. Particle detection allowed to reproduce the kinematics necessary to calculate excitation cross-sections and to perform precise Doppler-correction. Gamma-rays were measured in the NORDBALL spectrometer with 20 germanium detectors.

The Coupled Channel Coulomb Excitation Code GOSIA [2], developed in Warsaw and Rochester, was used for data analysis. Given a set of matrix elements of electromagnetic transition operators, GOSIA can calculate excitation amplitudes and gamma intensities under particular experimental conditions. Furthermore, it can fit the matrix elements to experimental data using the least-squares method.

Calculations within the Quasiparticle-plus-Phonon Model (QPM) [1] were performed to describe the structure of the newly found mediating states.

3. Results

^{181}Ta lies at the borders of the rare earth region and has a stable deformation of $\beta \approx 0.28$, thus exhibiting the typical rotational structure with strongly coupled bands. Figure 1 shows the concerned part of the level scheme. The $7/2^+[404]$ and $5/2^+[402]$ bands are known from previous experiments, e.g. those incorporating fusion reactions [3, 5]. The state $5/2^+[402]$ is the isomer of interest. Its half-life is 10.8 ns and two decaying transitions to the ground state band were observed, namely 482 keV and 346 keV. Their reduced probabilities were measured mainly in β^- decay of ^{181}Hf, and values from the compilation [4] are adopted in this paper. They are given in Table I.

The forbidness of these transitions can be explained in terms of the Nilsson model. They require changes of K, Λ and Σ by values shown in Table I. According to the model such transitions are not allowed. However, the forbidness is not due to K, but rather to Λ and Σ.

In spite of the low probabilities, a surprisingly strong yield of the 482 keV line was observed in the present experiment. Also the 108 keV line which is the lowest transition within the isomer rotational band was visible. GOSIA

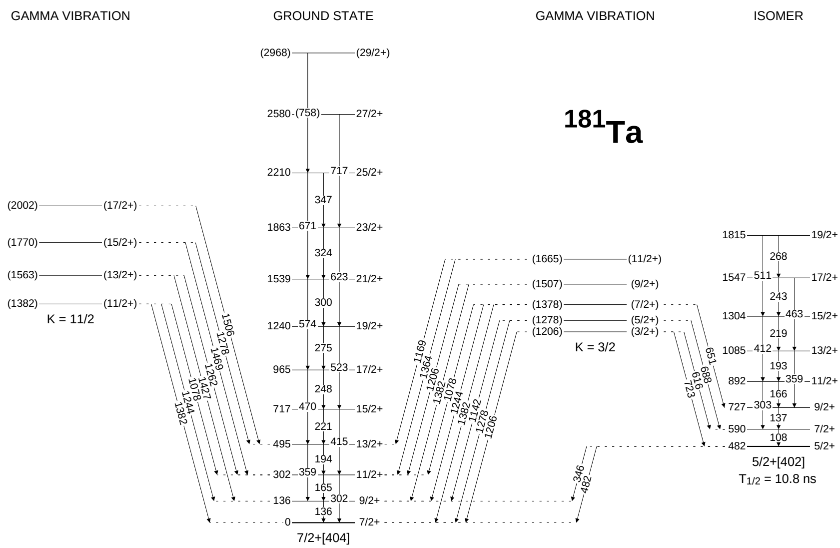

Fig. 1. Part of the ^{181}Ta level scheme. The ground-state and isomeric rotational bands are known from previous measurements. The remaining two bands are observed in the present work for the first time. Their bandheads are one-phonon gamma-vibrational states.

TABLE I

Reduced probabilities of selected transitions in ^{181}Ta. Changes in asymptotic Nilsson quantum numbers in each transition are indicated assuming the $3/2^{+}[402]$ label for the $3/2^{+}$ bandhead. Multipolarities allowed by Nilsson selection rules are shown in the last column.

Transition	Reduced probability in Weisskopf units	ΔK	$\Delta\Lambda$	$\Delta\Sigma$	Type
482 keV $5/2^{+} \to 7/2^{+}$	M1: $6.21(12) \cdot 10^{-7}$ E2: 0.0256(3)	1	2	-1	Forbidden
346 keV $5/2^{+} \to 9/2^{+}$	E2: 0.0264(3)	1	2	-1	Forbidden
1206 keV $3/2^{+} \to 7/2^{+}$	E2: 6.6(3)	2	2	0	E2
723 keV $3/2^{+} \to 5/2^{+}$	M1: 0.015(1)	1	0	1	M1
616 keV $3/2^{+} \to 7/2^{+}$	E2: 8(2)	1	0	1	M1

calculations were done with the probabilities of the 482 keV and 346 keV transitions from Table I and it turned out that the experimental intensity of the 108 keV line was about 50 times stronger than expected.

Several lines not observed before were obtained in the experiment. In order to find their place in the level scheme it is proposed to add two new rotational bands. They are marked in Fig. 1 as GAMMA VIBRATION. The new transitions are the ones depopulating these bands. With such placement of levels all new gamma energies fit the scheme. Another indication for the correctness of this interpretation is that two new lines of 1142 keV and 1244 keV were visible in coincidence with the 136 keV transition in the ground-state band. Insufficient statistics did not allow checking other coincidence relations.

The QPM calculations indicate, that the two new bandheads are one-phonon gamma-vibrational states. Their energies are typical for vibrational excitations. As the phonon changes K by 2, their spins are $11/2^+$ and $3/2^+$, respectively.

Assuming the spin assignment from Fig. 1, a fit of matrix elements was performed with GOSIA. All experimental gamma intensities were involved except for the 482 keV line, since the isomer lives 10.8 ns and it decayed far behind the target, often out of the detectors visibility area. Therefore, the probabilities from Table I were assumed for the 482 keV and 346 keV transitions and not varied in the fit. The branching ratios inside the isomer band, measured in fusion experiment [5], were also included as data points. There was not enough data to find each matrix element independently and within each group of transitions, *i.e.* connecting the same bands, the matrix elements of the same multipolarity were coupled through Clebsch–Gordan coefficients, following the rotational model.

The fitting procedure succeeded in reproducing the experimental data very well and its main results are the reduced probabilities of the transitions depopulating the $3/2^+$ gamma-vibrational bandhead, namely the $B(\mathrm{E2})$ of the 1206 keV one leading to the ground state and the $B(\mathrm{M1})$ of the 723 keV one leading to the isomer. It was impossible to obtain the probabilities for other multipolarities because of insufficient sensitivity of the χ^2 to the corresponding elements. Apart from the GOSIA fit, the $B(\mathrm{E2})$ of the 616 keV transition from the $3/2^+$ bandhead to the second state in the isomer band was extracted from the branching ratio relative to 723 keV. These results are listed in Table I. Values of the order of a few Weisskopf units for $B(\mathrm{E2})$ are typical for vibrational transitions.

According to the QPM, the leading single-particle component of the $3/2^+$ collective bandhead is $3/2^+[402]$. A simple interpretation within the Nilsson model is obtained by considering this label, namely, the transitions depopulating the $3/2^+$ band to the ground-state and isomeric bands are then allowed by the selection rules respectively as E2 and M1. This is in agreement with the measured reduced probabilities. The B(E2) of the 616 keV line must be due to another component.

4. Summary

Now the mechanism of the strong population of the isomer becomes clear. Coulomb excitation can easily populate the $3/2^+$ vibrational band via E2 from the ground-state band, and then the decay via M1 and E2 feeds the isomer band. Calculations indicate that this way is almost 50 times more efficient than through the direct but forbidden Coulomb excitation of the 482 keV level.

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