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STUDY OF THE $B_{4/2}$ ANOMALY IN THE YRAST STATES OF ^{167}Os*

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In recent years, several cases of nuclei presenting the so-called "$B_{4/2}$ anomaly" have been observed in the neutron-deficient region close to $Z = 50$ and $Z = 82$. In the last region, the osmium isotopic chain is of particular interest, as three consecutive isotopes, ^{168,169,170}Os, have shown the

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presence of this peculiar phenomenon. An experiment aimed at extending the study to ^{167}Os was performed at the Accelerator Laboratory of the University of Jyväskylä, using a beam of ^{78}Kr at 360 MeV impinging on a ^{92}Mo target. Lifetimes of several low-lying states were measured using the Recoil-Distance Doppler Shift method. The preliminary analysis and the study of the influence of unobserved feeders are discussed.

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1. Introduction

The evolution of spectroscopic properties along the isotopic and isotonic lines is of great interest to study the change in the structure of nuclei when moving away from the valley of stability. Among these properties, the excitation energy of the first 2^+ state and the reduced transition probabilities, the $B(\mathrm{E2})$ values, from the first excited state to the ground state, play a key role in the study of the structure of even–even nuclei. In nuclei close to shell closures, a high-excitation energy of the first 2^+ state and a low $B(\mathrm{E2}; 2^+ \to 0^+)$ are expected. Conversely, in mid-shell nuclei, a low-excitation energy of the first 2^+ and large $B(\mathrm{E2})$ are observed, which is typically associated with collective behaviour [1]. In addition, one can define the quantities $R_{4/2} \equiv E_{4^+}/E_{2^+}$ and $B_{4/2} \equiv B(\mathrm{E2}; 4^+ \to 2^+)/B(\mathrm{E2}; 2^+ \to 0^+)$. In collective nuclei, these quantities are expected to be larger than two and one, respectively. However, in recent years, we observed the emergence of nuclei which exhibit a $B_{4/2} < 1$, despite otherwise presenting collective properties, such as an $R_{4/2} > 2$.

This “anomaly” in the $B_{4/2}$ ratio has already been observed in several neutron-deficient nuclei with $Z \approx 50$ such as ^{108,112,114}Sn [2–5], ^{114}Te [6], ^{112,114}Xe [7, 8], and $Z \approx 82$, such as ^{166}W [9], ^{168,170}Os [10, 11], and ^{172}Pt [12]. If we generalize the definition of $B_{4/2} \equiv B(\mathrm{E2}; J+4 \to J+2)/B(\mathrm{E2}; J+2 \to J)$ ratio to extend it to even–odd species, the same anomaly is observed also in ^{169}Os [13].

In this context, the osmium isotopic chain is of particular interest as this anomaly has been observed in three consecutive nuclei, allowing one to observe the evolution of this quantity as a function of the neutron number. In principle, the only theoretical explanation for this anomaly would be the presence of a seniority-like structure or shape coexistence. However, no indication of seniority-like structure nor of coexisting bands has been observed in neutron-deficient osmium isotopes. In order to further investigate the mechanism behind the $B_{4/2}$ anomaly, information on reduced transition probabilities between yrast states in lighter osmium isotopes is of key importance. We here present the preliminary analysis of the low-exciting states in the neutron-deficient ^{167}Os, studied via γ-ray spectroscopy. In particular, the selection of the channel of interest and the analysis of the influence of the unobserved feeders on the lifetime measurements of low-lying states will be discussed.

2. Experimental details

The nuclei of interest were populated via fusion–evaporation reactions. A beam of ^{78}Kr, provided by the K-130 cyclotron at the Accelerator Laboratory of the University of Jyväskylä, Finland, was accelerated to 360 MeV at an average intensity of 1–2 pnA, and impinged on a 1.3 mg/cm^2 ^{92}Mo target, producing the compound nucleus of ^{170}Pt at an average velocity of 4.7%. The fusion–evaporation recoils passed through a 1 mg/cm^2 ^{24}Mg degrader, decreasing the velocity by about $\Delta\beta \approx 1\%$. Both target and degrader were mounted in the APPA plunger setup [14], a device employed for the lifetime measurement of excited states in the range of picosecond by means of the Recoil Distance Doppler Shift (RDDS) method [15]. Around the target position, the jurogam 3 array [16] was placed to detect the γ rays emitted by the excited nuclei produced in the reaction. The germanium detectors were separated in two rings at 158° (5 detectors) and 134° (10 detectors). Downwards with respect to the degrader, the RITU separator was employed to separate the recoils from the beam [17]. At the RITU focal plane, a Double-Sided Silicon detector (DSSD) [14] was placed, where the recoils were implanted and the subsequent radioactive decays were detected.

3. Analysis and discussion

The region populated in the reaction presents many nuclei with a significant, if not predominant, branching ratio of α decay. This characteristic allows for the identification of the different reaction channels using the so-called recoil-α-decay tagging [18] technique. After the implantation of the recoil in the DSSD detector, the α-decaying nuclei decay emitting an α particle at a characteristic energy that is detected by the same detector. By gating on the α-decay channel and observing the γ rays emitted in coincidence, it is possible to select a specific reaction channel and obtain a clean single-γ spectrum. The γ-ray spectrum in coincidence with the α decay of ^{167}Os is presented in figure 1.

The γ-ray spectra obtained in particle–γ coincidence was used for the analysis. The lifetimes of the yrast states of ^{167}Os were extracted using the Differential Decay Curve Method (DDCM) [15], following the equation:

$$\tau_i(t) = -\frac{R_i(t) - \sum_k b_{ki}\alpha_{ki}R_k(t)}{\frac{\mathrm{d}}{\mathrm{d}t}R_i(t)}\,, \tag{1}$$

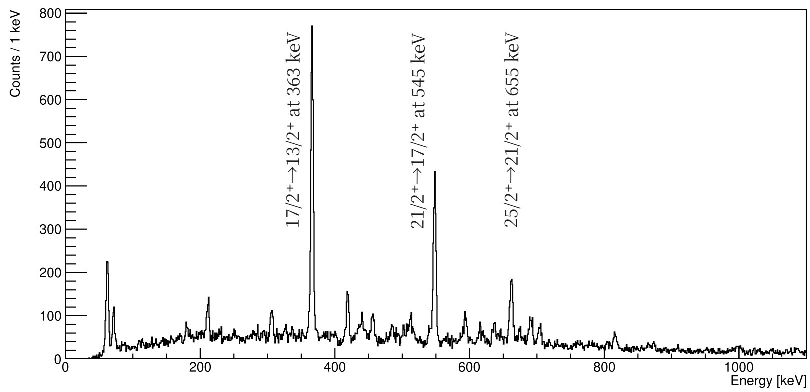

Fig. 1. γ-ray spectrum obtained by requiring the coincidence with the α-decay of ^{167}Os. The main γ-ray transitions of the nucleus of interest are easily identified in the spectrum with respect to the background.

where R_i is the shifted components of the transition of interest i and R_k of its direct feeders k, both normalized to the sum of the two components, b_{ki} is the branching ratio and α_{ki} is a correcting factor that takes into consideration the efficiency and intensity of the two transitions. In the case of a gate on the shifted component of the direct feeder, the second term of the numerator in Eq. (1) can be neglected. However, in the present work, it was not possible to perform the analysis in γ–γ coincidence mode due to the lack of statistics. Therefore, the contribution of the feeders must be carefully assessed in the analysis in order to correctly compute the lifetime of the state of interest.

A preliminary measurement of the $17/2^+$ state in ^{167}Os, corresponding to the first excited state over the $13/2^+$ isomeric state based on the $\nu i_{13/2}$ orbital, points to a lifetime of 21(2) ps [19], in agreement with a previous measurement [20] reporting a lifetime of 20(4) ps. The only observed feeder for the $17/2^+$ state was the $21/2^+ \to 17/2^+$ transition at 543 keV. The contribution of this transition was measured and included in the analysis and it was observed that, if neglected, it would lead to an overestimation of the lifetime of about 30%. However, this transition accounts for 68% of the total intensity of the $17/2^+ \to 13/2^+$ transition, leaving a 32% of the intensity associated with unobserved feeders.

A generally accepted assumption is to consider the unobserved feeders as prompt, as stated in reference [21]. However, due to the large intensity of the unobserved feeder, a thorough analysis was conducted to test the validity of this assumption for the present case and to evaluate the potential influence of the feeding transition on the final lifetime measurement for the $17/2^+$ state.

A Monte Carlo simulation was performed using the AGATA simulation code [22], modified in order to take into consideration the different geometry of the jurogam 3 array. The θ angle of the jurogam 3 detectors, the thickness of the target and degrader, the target-to-plunger distances, and the statistics of the full spectrum were adjusted in order to be comparable to the experimental conditions. The intensity of the $21/2^+ \rightarrow 17/2^+$ transition and the measured lifetime of the $21/2^+$ were included in the simulation. A feeding transition at high energy with an intensity corresponding to 32% of the $17/2^+ \rightarrow 13/2^+$ transition was also simulated for different lifetime values in a range from 1 ps to 1 ns. The simulated spectra were analyzed using the same functions and tools as in the case of the experimental data. An example of simulated spectra for different lifetime values of the feeder is presented in figure 2 for $\theta = 157°$ and a target-to-degrader distance of 300 μm.

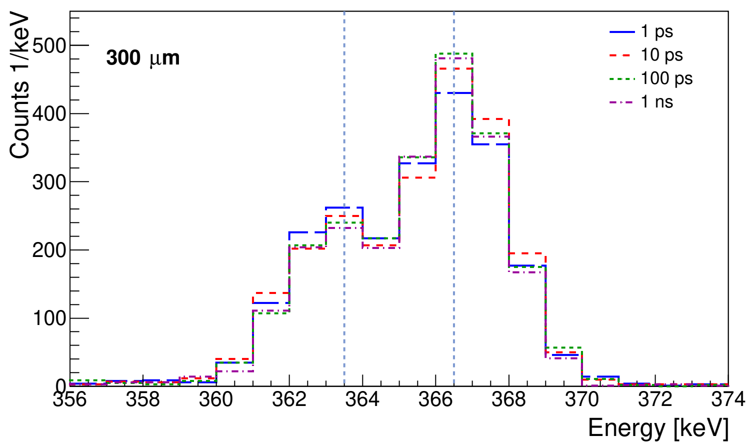

Fig. 2. Simulated spectra for different lifetime values of the unobserved feeder at a target-to-degrader distance of 300 μm. The two components of the $17/2^+ \rightarrow 13/2^+$ transition are marked by the vertical dashed line.

The decay curve obtained from the analysis of the two components of the transitions in the simulated spectra was compared to the experimental decay curve using the maximum likelihood method [23], assuming that uncertainties follow a Gaussian distribution. The maximum likelihood $\mathcal{L}$ was found for a feeder of negligible lifetime, and it decreased with the increasing lifetime of the feeding transition. The dependence of the $-\ln\mathcal{L}$ on the lifetime of feeding transition is presented in figure 3. The uncertainty was obtained considering a $\Delta\ln\mathcal{L} = -\ln\mathcal{L}_{\max} + \ln\mathcal{L} = 1/2$ [23], corresponding to a feeding transition with a lifetime of around 1 ps or shorter. The presence of such a transition would affect the lifetime measurement of the $17/2^+$

state by adding a systematic error of 5% towards longer lifetimes. Therefore, a systematic error of 5% is added to the statistical error in the evaluation of the lifetime for the $17/2^+$ state.

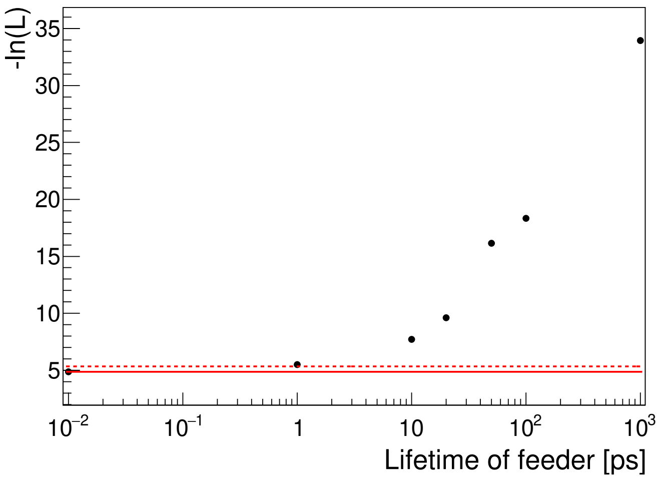

Fig. 3. Maximum likelihood $(-\ln\mathcal{L})$ as a function of the lifetime of the unobserved feeder. The best agreement with experimental data was found for the shortest lifetime. The $\Delta\ln\mathcal{L} = 1/2$ limit is marked by the two horizontal lines.

4. Conclusion

In the present experiment, the ^{167}Os nucleus was successfully populated using a fusion–evaporation reaction. The channel of interest was selected using the recoil-α-decay tagging technique, obtaining a low-background spectrum where the $17/2^+ \rightarrow 13/2^+$ and $21/2^+ \rightarrow 17/2^+$ transitions were identified. The γ-ray spectrum was analysed in order to extract the lifetime of the $17/2^+$ and $21/2^+$ states. The influence of unobserved feeding transitions was investigated via Monte Carlo simulations that were optimized to reproduce the experimental conditions. The assumption of a prompt feeding transition was found to be valid for the present analysis. The influence of an unobserved feeding transition with a lifetime shorter than 1 ps was attested at 5% and the systematic error was included in the final result along with the statistical error.

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