SHAPE EVOLUTION IN THE NEUTRON-RICH OSMIUM ISOTOPES: PROMPT γ-RAY SPECTROSCOPY OF ^{196}Os*

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In order to investigate the shape evolution in the neutron-rich osmium isotopes, the first in-beam γ-ray spectroscopic measurement of ^{196}Os was performed at the Laboratori Nazionali di Legnaro, Italy. ^{196}Os was populated in the two-proton-transfer channel ^{198}Pt(^{82}Se, ^{84}Kr)^{196}Os with a beam energy of 426 MeV. The beam-like recoils were detected in the large-acceptance magnetic spectrometer PRISMA and the coincident γ rays were measured by the AGATA demonstrator. The de-excitation of the two lowest-lying yrast states was observed for the first time and a candidate for the 6_1^+-level was found. The comparison with state-of-the-art beyond mean-field calculations reveal the γ-soft character of ^{196}Os.

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1. Introduction

The existence of different equilibrium shapes in atomic nuclei is due to the complex interplay of the closed shells and sub-shells, which tend to stabilise a spherical shape, the residual interaction between protons and neutrons and the correlation energy gain in the proton–neutron interaction, which drives the nucleus towards deformation. The proton–neutron interaction energy is a major contribution to the correlation energy, which is largely multiplicative in the number of interacting protons times the number of interacting neutrons. Hence, regions of the nuclear chart, where shape transition occur are an essential testing-ground for nuclear models [1].

The shape of a nucleus is not a direct observable. However, the low-lying excitations of many atomic nuclei can be explained as oscillations and/or rotations of macroscopic objects with different deformation. The spectra can be compared with the expectation values of the different solutions of the geometric collective model: spherical vibrator, γ-soft/triaxial rotator and axial-deformed rotor [2].

The isotopic chain of the neutron-rich osmium isotopes is an example of shape transition: ^{194}Os, populated up to $J^\pi = (10^+)$ [3], has a level scheme that suggests a prolate deformation, at variance with the interpretation of previous experimental results [4]. In an isomer-decay spectroscopy experiment using fragmentation reactions at relativistic energies, the first two excited yrast states of ^{198}Os were identified. From the energies of the (2_1^+) and (4_1^+) levels, a weak oblate deformation was deduced [5]. In the eighties, Bond *et al.* [6] established two excited states (300 (20) keV and 760 (20) keV) in the even–even nucleus between those two, ^{196}Os, populated via the two-proton transfer reaction ^{198}Pt(^{14}C, ^{16}O)^{196}Os. The first excited state was proposed to be the 2_1^+ state. For the second excited state, a 2_2^+, 4_1^+ or doublet of these two states was suggested. In the present study, the recently published first measurement of excited states in ^{196}Os through in-beam γ-ray spectroscopy [7] is reported.

2. Experiment and data analysis

In order to study ^{196}Os, a multi-nucleon-transfer experiment using a 426 MeV ^{82}Se beam impinging on a ^{198}Pt target and the binary partner method was performed at the Laboratori Nazionali di Legnaro (LNL), Italy. The beam-like recoils were detected and identified with the large-acceptance magnetic spectrometer PRISMA [8–10] and the coincident γ rays were detected with the Advanced Gamma Tracking Array (AGATA) demonstrator [11, 12]. The momentum vector, necessary for the Doppler correction, of the unidentified heavier target-like recoil is calculated using a two-body reaction kinematics.

A pulse shape analysis is applied to the digitized AGATA signals. The obtained interaction points and energies are passed to a tracking algorithm in order to reconstruct the γ rays. The first interaction defines the interaction time and the angle of emission for the Doppler correction. The atomic charge number, charge state and mass are uniquely identified in the PRISMA spectrometer.

3. Results

The spectrum, gated on the binary partner of ^{196}Os, ^{84}Kr, and Doppler corrected for ^{84}Kr is shown in figure 1 (a). The $2^+_1 \rightarrow 0^+_{\mathrm{gs}}$ transition at 882 keV is the most intense peak in the spectrum. When the Doppler correction is performed for the target-like recoil (figure 1 (b)), γ rays not only for the binary partner, but also from less neutron-rich isotopes are present in the spectrum. They are produced after the evaporation of neutrons. Besides known transitions of lighter Os isotopes, a peak at 324 keV appears. A condition on a low reconstructed Q-value of the reaction limits reduces the contribution of γ rays from isotopes populated after neutron evaporation. In figure 1 (c), a condition on the reconstructed Q-value lower than 12 MeV and

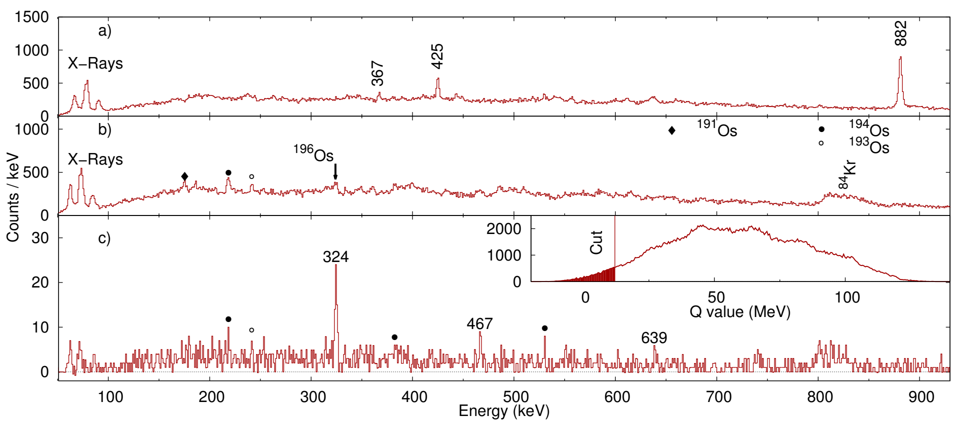

Fig. 1. Gamma-ray spectra obtained after gating on the beam-like recoils ^{84}Kr. (a) The Doppler correction is performed for ^{84}Kr. The strongest γ-ray transitions of ^{84}Kr are labelled. (b) The spectrum is Doppler corrected for ^{196}Os, the binary partner of ^{84}Kr. The wrongly Doppler corrected $2^+_1 \rightarrow 0^+_{\mathrm{gs}}$ γ transition of ^{84}Kr and the $(2^+_1) \rightarrow 0^+_{\mathrm{gs}}$ of ^{196}Os are indicated. The strongest transitions from other Os isotopes, populated after neutron evaporation, are indicated by different symbols. (c) The same as (b) with an additional gate on the reconstructed Q-value < 12 MeV (see the inset) and a multiplicity of the γ rays of one. The peaks labelled by the energy are assigned to ^{196}Os.

on the multiplicity of tracked γ rays of one is placed. Three peaks appear clearly in this spectrum: 324 keV, 467 keV and 639 keV. In general, the most intense transitions in nuclei populated via multi-nucleon-transfer reactions are the de-excitation of the yrast states. Hence, the observed transitions are tentatively assigned based on previously reported level energies and intensities to originate from the de-excitation of the three lowest-lying levels of the yrast band in ^{196}Os. The energy of the two lowest-lying levels agree with the excitation energies measured by Bond *et al.* [6] (see figure 2 (left)).

State-of-the-art self-consistent beyond mean-field calculations based on the Gogny D1S interaction were performed for the even–even $^{188-198}$Os isotopes. The potential energy surface (PES) for ^{196}Os is plotted in figure 2 (middle). It reveals a shallow oblate deformed minimum with a degeneracy in the γ-direction. The spectrum calculated from configuration mixing calculations based on this PES is shown in figure 2 (right) together with the predictions given by axial rotor, γ-soft/triaxial rotor and vibrator limits [13].

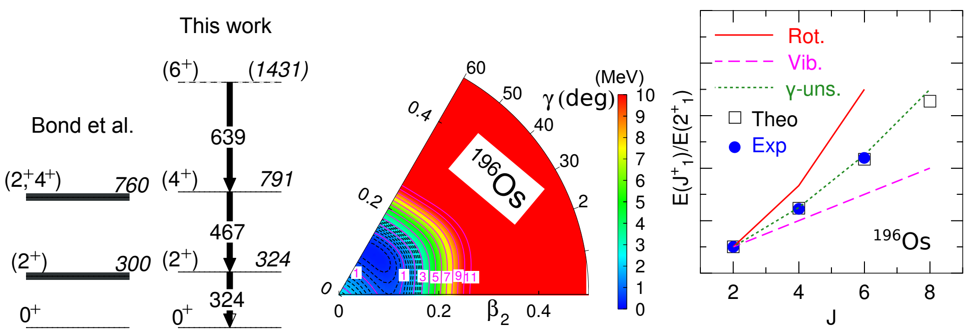

Fig. 2. (Left) Level scheme of ^{196}Os compared to the previously reported levels [6]. (Middle) Particle number projected potential energy surfaces in the triaxial plane for ^{196}Os calculated with the Gogny D1S interaction. Solid and dashed contour lines are separated by 1.0 MeV and 0.2 MeV, respectively. The solid contour lines are labelled with their energy. (Right) Yrast band excitation energies of ^{196}Os, normalised to the corresponding 2_1^+ energies. Dots (blue) and boxes (black) are the experimental points and theoretical beyond mean-field predictions respectively. Theoretical limits for axial rotor (continuous/red line), vibrator (dashed/magenta line) and γ-soft/triaxial rotor (dotted/green line) geometrical models are also given.

The proposed level scheme is in perfect agreement with both the beyond mean-field calculations and the predictions of the γ-soft/triaxial rotor geometric model.

4. Conclusions and outlook

The de-excitation of the yrast band in ^{196}Os was observed for the first time using the AGATA demonstrator in a multi-nucleon-transfer reaction using a ^{82}Se beam with 426 MeV impinging on a ^{198}Pt target. The yrast band exhibits the characteristics of an almost perfect γ-soft/triaxial rotator, as predicted by state-of-the-art beyond mean-field calculations. Additional spectroscopic information for neutron-rich Os isotopes would help to further understand the shape evolution. An approved experiment in the forthcoming AGATA campaign at Ganil, France using AGATA coupled with $LaBr_3$ detectors and the VAMOS++ spectrometer might provide new in-beam transitions and the quadrupole transition strength from the $(2_1^+) \to 0_1^+$ transition for ^{194}Os.

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