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Octupole correlations in the $N = 56$ neutron-deficient ^{110}Xe

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Summary. — The neutron-deficient xenon isotopes have proved to be a good test bench to study octupole correlations. Nuclei around $N = Z = 56$, like ^{110}Xe, are indeed expected to show some of the largest octupole correlations in the whole Segré chart. An experiment aimed at studying the octupole correlations in the very exotic ^{110}Xe was performed in Jyväskylä, using the γ-ray detector array JUROGAM III coupled to the MARA separator. In this contribution, the preliminary results of the ongoing analysis will be presented.

1. – Introduction

The existence of nuclei with stable deformed shapes was realized early in the history of nuclear physics. The observation of large quadrupole moments led to the suggestion that some nuclei might have spheroidal shapes, while others present a reflection-asymmetric shape, as for example pear shape. The octupole correlations giving rise to reflection-asymmetric shapes are generated microscopically by the interaction between orbitals of opposite parity near the Fermi surface, differing by three units of angular momentum. In general, this situation occurs when the Fermi level lies between an intruder-orbital and the normal parity subshell. Nuclei in the region around $N = Z = 56$ are rather unique, since octupole correlations are predicted to happen both for protons and neutrons, where these nucleons occupy identical orbitals. Microscopically, in this case, the Fermi surface for both protons and neutrons lies between the $d_{5/2}$ and the $h_{11/2}$ orbitals, and the octupole correlation emerges from the coupling of these two orbitals from both valence neutrons and protons outside the ^{100}Sn core [1].

The aim of this study is to investigate the octupole correlations in the very exotic $N = Z + 2$ ^{110}Xe ($N = 56$) isotope, via the identification of the octupole band. Prior to this experiment, only the ground state band of ^{110}Xe is known up to the (6^+) [2], where the energies of the 2^+ and 4^+ states indicate an abnormal evolution towards spherical regime when approaching $N = 50$.

2. – Experimental details

The experiment was performed at the Accelerator laboratory of the University of Jyväskylä (Finland) in 2020. Neutron-deficient nuclei were produced via a fusion-evaporation reaction, with a beam of ^{58}Ni at 228 MeV impinging on a two-layer target of 0.75 mg/cm^2 ^{54}Fe and 1.0 mg/cm^2 ^{197}Au, the latter facing the beam. The fusion-evaporation products were separated in flight using the MARA separator [3]. The MARA separator consists on a quadrupole triplet employed to focus the ions and a combination of an electrostatic deflector and magnetic dipole to separate them according to different A/q ratios. The A/q ratios were obtained using a position sensitive Multi-Wire-Proportional Counter (MWPC) positioned at the MARA focal plane. Finally, the recoils were implanted in a Double-sided Silicon Strip Detector (DSSD) positioned after the MWPC. There, information about energy, position and time of the incident ions were obtained, allowing α-tagging for the reaction of interest. The γ rays emitted at the target position were detected by the JUROGAM III array [4], in coincidence with the implanted recoils in the DSSD detector. The JUROGAM III array consists of fifteen EUROGAM Phase1 and twenty-four EUROBALL Clover detectors arranged in four rings around the target chamber. The Phase1 type detectors were positioned at 157.6° and 133.57°, while the Clover detectors were arranged at 104.5° and 75.5° with respect to the beam axis. The Clover detectors have four crystals, coupled in two sub-rings at 109° and 100° for the first group of 12 Clovers and at 80° and 71° for the second group.

3. – Data analysis

The recoils were identified using the recoil-alpha tagging technique [5]. In this experiment, it was possible to clearly correlate several nuclei with high statistic, namely ^{110}Xe, ^{110}I, ^{109}I, ^{109}Te and ^{107}Te. In order to Doppler correct the raw spectra the velocity β of the identified recoils was determined, performing a fit of the Doppler-shifted energy versus the ring angle θ. For each nucleus, the fit was realized for the most intense γ-ray transitions and the average of the different β values obtained was used for the Doppler correction.

Figure 1(left) shows the least-squares fits for the energy of two of the most intense γ-ray transitions of ^{109}Te spectrum, respectively at 609 keV and 695 keV, as a function

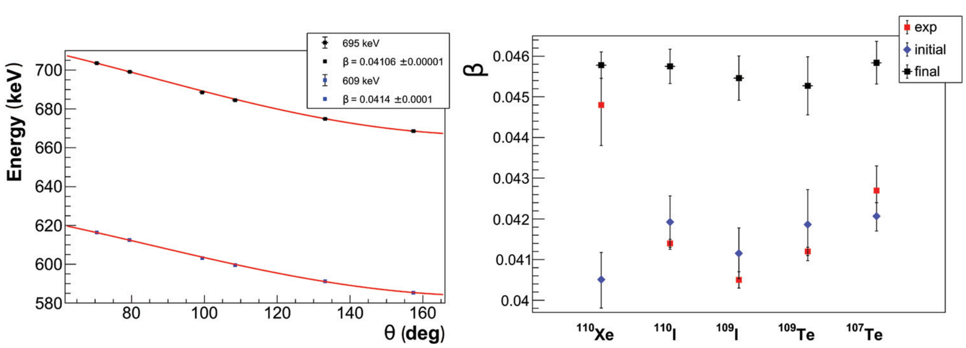

Fig. 1. – Left: fit of the energy Doppler-shift *versus* the ring angle for the two most intense peaks of ^{109}Te spectrum. Right: velocities for the different reaction products identified. The experimental values are in red, while the ones calculated with PACE4 are in blue and black, for the reaction taking place at the beginning and at the end of the target.

of θ. The obtained velocities are presented in fig. 1(right) with the label "exp". Furthermore, the expected velocities were calculated with PACE4 [6], considering two limits: the reaction taking place at the beginning ("initial") or at the end ("final") of the ^{54}Fe layer of the target. Except for ^{110}Xe, the velocities calculated for the reaction taking place at the end of the target agree, within the errors, with the experimental values. For ^{110}Xe, given the low statistics, the centroids of the peaks present larger uncertainties, resulting in a value of β considerably different from the one calculated for the reaction at the end of the target. This result suggests using $\beta \simeq 0.041 \pm 0.001$ as the optimal value for ^{110}Xe analysis.

4. – Experimental results

Once obtained the β values for the different nuclei, the corresponding spectra were Doppler corrected and analysed. For what concerns ^{110}Xe, all the transitions identified in [2] were observed, along with additional γ rays. In order to place them in the level scheme, both the γ-γ coincidences and the angular distribution of the γ rays observed were analysed. Indeed, since in fusion-evaporation reactions the compound nucleus is typically formed in a state with the angular momentum vector perpendicular to the axis defined by the direction of the beam, the relative intensities at different angles of the γ radiations emitted depend on the multipolarity of the transitions. Thus, studying the angular distribution of these γ rays it is possible to determine their multipolarity and confirm or disprove their placement in the level scheme. As a first step, we applied this technique to a well-produced nucleus, such as ^{109}Te, in order to identify the angular distributions for the most intense $\Delta L = 1$ and $\Delta L = 2$ transitions. The multipolarity of these transitions was previously established [7]: the γ rays of energy 695 keV and 609 keV are expected to show an E2 behaviour, while the 399 keV and 326 keV ones should be stretched E1.

The number of counts for each peak as a function of the angle of the Jurogam III rings with respect to the beam axis is shown in fig. 2. The angular distribution was fitted

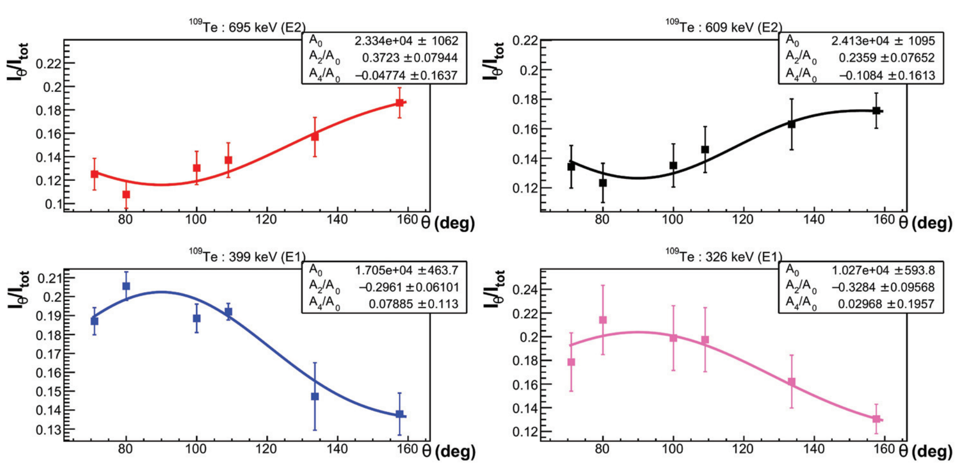

Fig. 2. – Angular distribution of four γ rays emitted by ^{109}Te: two E2 γ rays of 695 keV and 609 keV (top panels) and two E1 γ rays with energy 399 keV and 326 keV (bottom panels).

with the equation

(1) $$I(\theta)/I_{\text{tot}} = A_0[P_0(\cos\theta) + (A_2/A_0)P_2(\cos\theta) + (A_4/A_0)P_4(\cos\theta)]$$

with A_0, A_2 and A_4 as free parameters and P_i as the Legendre polynomial of order i. In this case, the value of A_2/A_0 is expected to be negative for $\Delta L = 1$ and positive for $\Delta L = 2$ [8]. The obtained A_2/A_0 values (see fig. 2) confirm the multipolarity previously established [7]. These results validate the methodology for studying the multipolarity of new transitions, which represents an invaluable tool to define the level scheme of ^{110}Xe and therefore to identify the octupole band.

5. – Conclusions

With the α-tagging technique it was possible to identify the γ rays of several neutron-deficient nuclei, including ^{110}Xe. Promising results of the ongoing analysis show the possibility to expand its level scheme and observe for the first time the octupole band, employing both the γ-γ coincidence technique and analysing the multipolarity of the observed transitions.

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