IMPROVEMENTS OF THE LEMS TECHNIQUE TO DETERMINE QUADRUPOLE MOMENTS OF HIGH-K ISOMERS* **

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Recent studies have shown examples of severe violations of the K-selection rule, raising questions about the usual understanding of the K-mixing process and the structure of the K-isomeric states. The LEMS technique enables us to measure the spectroscopic quadrupole moment of nuclei in high-K isomeric states, which allows to investigate the deformation of these isomers. As poor statistics is the main problem we face in these experiments, different improvements have been investigated to increase the sensitivity of the LEMS technique.

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1. Introduction

For axially symmetric nuclei, *i.e.* nuclei far away from closed shells, the projection of the total angular momentum along the axis of symmetry, K, is expected to be an approximately conserved quantum number. Electromagnetic transitions with $\Delta K > \lambda$, where λ is the multipolarity of the

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radiation, are forbidden and the degree of K-forbiddenness is defined as $\nu = \Delta K - \lambda$. The average hindrance factor grows exponentially with the degree of K-forbiddenness, $F_w = f^{\Delta K - \lambda}$, $f \approx 10$–100 [1]. As a consequence of the rapid decrease of the transition probability with ΔK, a high-K isomer decays into the band with the closest K value. While the K-isomers in the Hf nuclei exhibit the usual K-hindrance, this is not the case for the high-K isomers in the Os and the W nuclei. In ^{179}W, the $K^{\pi} = 35/2^{-}$ isomer decays with a 95% probability to the $K = 7/2^{-}$ ground state band with and not to the $K = 23/2^{-}$, although the latter transition is much less K-forbidden. Explanations about this anomalous decay include Coriolis mixing of different K-values [2, 3] or triaxial nuclear shapes [4, 5]. Experimental proof can be obtained by measuring the spectroscopic quadrupole moment. From the equations

$$\left\{ \begin{array}{l} Q_0 = \frac{3}{\sqrt{5\pi}} Z R^2 \beta_2 \\ Q = Q_0 \frac{3K^2 - I(I+1)}{(I+1)(2I+3)} \end{array} \right.$$

with Q_0 the intrinsic quadrupole moment, $R = a_0 A^{1/3}$, β_2 the nuclear deformation of the rotational band and Q the spectroscopic quadrupole moment, the corresponding value for K can be extracted. This enables us to test the current model predictions and to obtain insight on the structure of the K-isomeric states.

2. Experimental method

The LEMS method (Level Mixing Spectroscopy) is a powerfull method to measure quadrupole moments of high-spin isomers [6–9]. After production and orientation in a fusion-evaporation reaction, the nuclei are caught in a suitable host, often a polycrystal, where they are submitted to a combined electric quadrupole and magnetic dipole interaction. The magnetic field is oriented parallel to the beam axis. The anisotropy of the γ-radiation is measured as a function of the magnetic field strength. At zero magnetic field, only the quadrupole interaction is present and the initial orientation is decreased to the hard-core value. At high magnetic fields (several Tesla), the quadrupole interaction is negligible compared to the Larmor precession of the isomeric spins around $\bar{B}$. As the precession axis coincides with the initial orientation axis, the initial anisotropy is measured. At intermediate fields, a smooth change from the hard core anisotropy to the initial full anisotropy takes place.

In all former experiments, performed at the CYCLONE cyclotron, Louvain-la-Neuve (Belgium), thick targets (order of g/cm^2) which also served as a host, have been used. However, with the actual available beams, the K-isomers among others cannot be produced in a suitable host. To make the LEMS method applicable to a wider range of isomers, we separate target and host and use recoil-implantation. A disadvantage is that only thin targets and thus only a small fraction of the reaction cross-section is used. Inversing the reaction kinematics allows to increase the target thickness. Often nuclear reactions also occur on the host, which complicates the γ-spectra. Using a high-Z host and a low-Z target solves that problem [10]. The beam energy is then below the Coulomb-barrier of the host. Another way to clean the γ-spectra is by putting target and host at a distance of each other (further called recoil distance) and shielding the detectors from the target (Fig. 1), so that the prompt γ-rays coming from the target are not detected (recoil-shadow technique). However, as the nuclei are not fully stripped after a fusion-evaporation reaction, the interaction between the nuclear spin and the random oriented electron spin reduces the nuclear orientation during the flight through vacuum. Without nuclear spin orientation, nuclear moment measurements are not possible. The orientation can be restored by applying a high enough magnetic field parallel to the orientation axis (further called the decoupling field), so that the electron and nuclear spin are decoupled and both precess around this magnetic field. In this contribution we discuss the feasibility of LEMS with a recoil-shadow set-up.

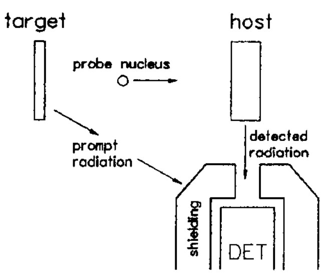

Fig. 1. Recoil-shadow configuration.

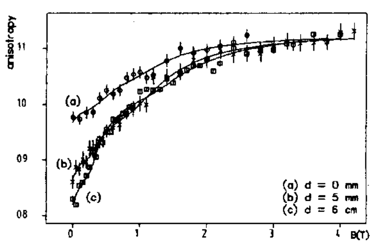

Fig. 2. LEMS curves for ^{69}Ge<u>Pt</u>.

3. Experimental innovations

The recoil-shadow technique has been tested in the ^{56}Fe(^{16}O,2pn)^{69}Ge reaction with a beam energy of 65 MeV, producing the isomeric state ($I^{\pi} = 9/2^{+}$, $Q = 2.4(5)$ efm^2, $\mu = 1.0011$ n.m.). The ^{56}Fe target with a thickness of 1.57 mg/cm^2 is thin enough to release all recoils. As host and beam stopper a thick ^{nat}Pt has been used. We have placed the Fe foil at 0 mm, 5 mm and 60 mm from the Pt host. For a distance of 60 mm the detectors are shielded from the prompt γ-rays produced on the target by a thick lead wall (Fig. 1). In the singles spectra for $d = 60$ mm the peak to background ratio is about a factor of five better than for spectra taken with a 0 mm and 5 mm recoil distance, because then only the radiation from long lived isomers ($\tau >$ flight time, order of 5 ns) is seen.

A value for the decoupling field B of the $\bar{I} \cdot \bar{J}$-interaction has also been derived. Since Pt has a fcc lattice structure, the Ge-recoils are not submitted to an EFG, unless defects are trapped. In an experiment with a 0 mm recoil distance — where no $\bar{I} \cdot \bar{J}$-interaction takes place — a change in the anisotropy of about 15% has been observed in the 398 keV M2 transition of ^{69m}Ge (Fig. 2a). So, a defect associated EFG, providing a quadrupole interaction, is present in the Pt host. From the LEMS fit two EFGs, belonging to two different defect structures, can be distinguished. This is in agreement with the results of later experiments on PoPt [9]. By comparing the curves for the three different recoil distances, we find an extra lowering of the anisotropy for $d = 5$ mm and $d = 60$ mm due to the $\bar{I} \cdot \bar{J}$-coupling (Fig. 2b and 2c). Only from a magnetic field of about 2 T the curves coincide again. For a 5 mm recoil distance the flight time (< 1 ns) is too short to allow a complete loss of orientation, while for a 60 mm recoil distance the hard-core value for the $\bar{I} \cdot \bar{J}$-interaction is reached, which explains the difference between both curves at low magnetic fields. For all recoil distances the same interaction frequencies within the error bar have been found. To obtain a better understanding of these results, a more detailed analysis, taking into account the $\bar{I} \cdot \bar{J}$-interaction before implantation, is being done.

4. Conclusion

Significant improvement of the quality of the γ-spectra can be obtained by using the recoil-shadow geometry. However, the loss of orientation during the flight through vacuum can highly influence a LEMS measurement. The method can only be applied when the decoupling field for the quadrupole interaction is much higher than the decoupling field for the $\bar{I} \cdot \bar{J}$-interaction, so that the$\bar{I} \cdot \bar{J}$-interaction can be neglected.

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