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# STUDY OF $\boldsymbol{K}$ SELECTION RULES IN WARM ROTATING NUCLEI*

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The problem of the conservation of the $K$-quantum number at high spin and high-excitation energy is investigated making use of a large statistics data set on the $^{163}$Er nucleus, obtained with the EUROBALL array. In particular, the ridge structure, observed in $\gamma$–$\gamma$ coincidence matrices and typical of the rotational motion, is analysed for high and low values of the $K$ quantum number. The experimental results are compared with cranked shell model calculations taking into account the residual interaction and for which the $K$-quantum number of the band can be traced also in the warm rotation.

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## 1. Introduction

The $\gamma$-decay among cold rotational bands is governed by selection rules associated with the quantum numbers of the intrinsic structures. At excitation energies high above the yrast line, such selection rules are expected to be lost as a consequence of the gradual transition into the compound nucleus regime, where the only quantum numbers surviving are energy, spin and parity. The question is at which energy such selection rules vanish and what is the role played by the residual interaction.

A useful probe for these studies is the $K$-quantum number, defined as the projection of the angular momentum on the symmetry axis of a prolate nucleus. The selection rules on $K$ are known to be strong for low energy transitions, but can be broken at higher energies due to both the Coriolis force and the residual interaction. Two previous investigations were made: the first indicated that the $K$-quantum number is conserved at high excitation energy in the neutron resonance region [1]. The second investigated lower excitation energy at higher rotational frequencies through the $\gamma$-emission in the quasi-continuum region, and suggested that selection rules on $K$-quantum number still persist at excitation energy around 1 MeV [2].

## 2. Experiment and data analysis

A good case for studying the conservation of $K$-quantum number selection rules is $^{163}$Er nucleus. This system is characterised, in the same spin region, by rotational bands with small and large ($K = 19/2$) values of $K$. The high-$K$ bands, in particular, lie at rather high excitation energy above yrast, between 0.8 and 1.4 MeV, which is the region that is expected to be dominated by the mixing of rotational bands due to both the large level density and the two-body residual interaction.

High fold $\gamma$-ray coincidence data have been collected with the EUROBALL IV array at IReS (France). The reaction employed was $^{18}$O+$^{150}$Nd with $E_{\rm beam}$= 87–93 MeV, which leads to the population of $^{162,163}$Er as the main evaporation residua. Although the level scheme of $^{163}$Er is quite complicated, the selection of low-$K$ and high-$K$ bands can be done by means of standard gating procedure: in particular high-$K$ bands can be selected due to the presence of low-energy M1 transitions connecting states of same parity and different signature [3].

The collected data have been sorted into a number of double and triple-$\gamma$ coincidence matrices obtained by gating on different nuclear configurations, characterised by low and high $K$-values. After subtraction of the background under the gate-selected peaks and reduction of Compton and other uncorrelated events using the COR procedure [4], the double coincidence matrices have been projected into one-dimensional cuts perpendicular to the main diagonal $E_{\gamma_1} = E_{\gamma_2}$, for the analysis of the ridge-valley structures which characterise the rotational pattern in two dimensions. These cuts have been performed at increasing transition energy with a width of $4\hbar^2/\mathrm{Im}^{(2)} \approx 60$ keV, in order to guaranty that at least one rotational transition is deposited in the energy window.

Figure 1 illustrates the ridge-valley structure for the E low-$K$ gate (panel (a)) and the K1 high-$K$ gate (panel (b)) corresponding to $\langle E_\gamma \rangle = (E_{\gamma_1} + E_{\gamma_2})/2 = 880$ and 820 keV slicing energies, respectively. The ridge structure, marked by arrows in the figures, is created by transitions that follow regular rotational bands lying above the yrast line which cannot be resolved experimentally. The different line shape of the ridges corresponding to the two

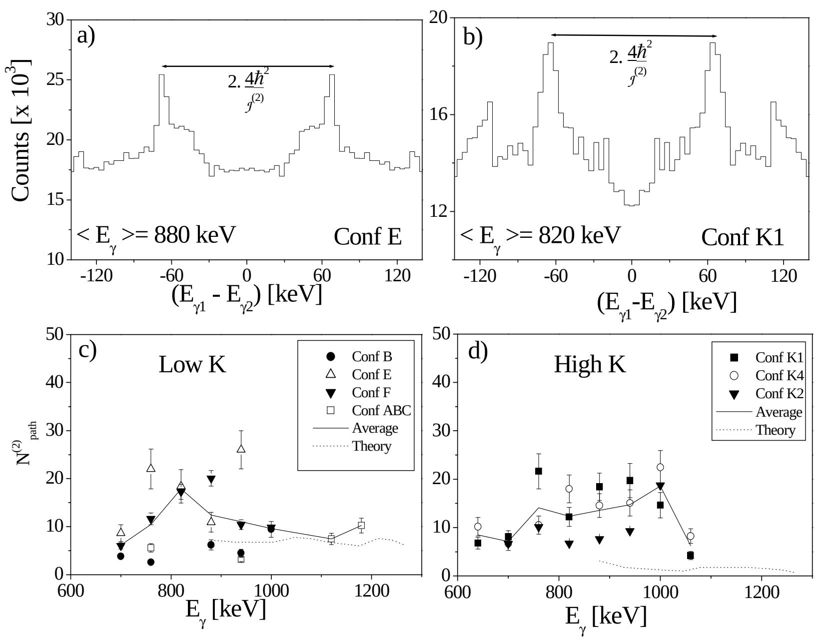


Fig. 1. The top panels show the ridge-valley structure obtained through cuts perpendicular to the main diagonal in matrices gated on low-$K$ configurations (panel (a), conf. E) and high-$K$ configurations (panel (b), conf. K1) at the average energy of 880 and 820 keV respectively. The first ridge, indicated by the arrows, is well defined in both configurations. The bottom panels show the number of paths extracted using the fluctuation analysis on the first ridge of matrices gated on different configurations. Panel c) shows the results for low-$K$ configurations, while panel (d) for high-$K$ ones. In both pictures (panel (c) and (d)) the solid lines represent the average experimental value and the dotted lines the theoretical predictions for the number of discrete lines that populate the ridge structure.

different configurations might be related to a different spreading of the moment of inertia of the interacting bands, and possibly to a different strength of the residual interaction in the two cases.

By studying the statistical fluctuations of the counts in the coincidence spectrum it is possible to determine the number of *decay paths* populating the ridges and corresponding to the number of such unresolved bands [5]. In order to obtain a good estimate of the number of paths it is necessary to subtract the most intense transitions present in the matrices, since they strongly affect the evaluation of the fluctuations. The number of paths obtained from the analysis of the first ridge for different configurations is also shown in figure 1: panel (c) refers to low-$K$ bands and panel (d) to high-$K$ bands. The solid lines correspond to the average values.

For each of the configurations 10–20 unresolved bands are found both for low-$K$ and high-$K$ structures. In addition, a rather strong configurations dependence is observed, although the average value of number of paths is very similar for low and high-$K$ bands, in agreement with the previous analysis [2].

### *2.1. Comparison between experiment and theory*

The experimental results have been compared to theoretical calculations based on a cranked shell model including the residual interaction and an additional term which takes into account the angular momentum carried by the $K$-quantum number [6, 7]. Such calculations show that the $K$-mixing is produced by the interplay of the Coriolis interaction and the residual interaction: it is expected to be weak in the region of the discrete bands ($U \leq 1$ MeV), but it gradually increases until a complete violation of $K$ is predicted to be reached around $U \approx$ 2-2.5 MeV, over a wide spin region (30–60 $\hbar$). The model shows that although the Coriolis force is essential to produce the mixing of $K$, without the residual interaction this mixing is very weak.

In order to compare the experimental values with theoretical predictions we have calculated the number of discrete bands populating the ridge structure by counting the number of two consecutive transitions (*e.g.* decay-paths) which branch out to less than two levels [5]. The selection between low-$K$ and high-$K$ configurations is made by requiring that the $K$-quantum number associated to a given state is smaller (greater) than 10.5. The results of the comparison are shown as dotted lines in figure 1, for low-$K$ (panel (c)) and high-$K$ (panel (d)) configurations. While a rather good agreement is obtained for the low-$K$ number of paths, a larger discrepancy is observed for the high-$K$ states. This is most probably related to the complexity of the $K$-mixing process, which is expected to be better understood by a simulation the $\gamma$-decay of the rotational nucleus which takes into account also the role of the feeding of the different configurations [8].

### *2.2. Conclusion*

Preliminary results addressing the problem of a possible conservation of the $K$-quantum number at high spin and high-excitation energy have been presented and discussed.

The large statistics of the EUROBALL experiment on the $^{163}$Er nucleus allows to study in details the ridge-valley structures typical of the rotational motion in connection with high and low values of the $K$-quantum number. The ridge structures, populated by discrete unresolved rotational bands, have been analysed and compared to new theoretical calculations taking into account the importance of both the residual interaction and of the $K$-quantum number. While for the low-$K$-quantum number a rather good agreement between data and predictions is found the results on the high $K$-quantum number are not yet understood within the same model.

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