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Decay-out of the yrast superdeformed band in ^{136}Nd: towards an experimental extraction of the neutron pairing gap in the second well

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The ^{136}Nd nucleus has been studied using the EUROBALL III γ-multidetector to establish the decay-out of the yrast superdeformed band. Three discrete γ-ray transitions linking superdeformed and normally deformed states have been observed, providing the excitation energies and the spin of the superdeformed states. Neutron pairing gap parameters for superdeformed shapes have been tentatively extracted in Nd isotopes.

1. INTRODUCTION

One of the most exciting questions concerning the superdeformation phenomenon is the decay-out of the superdeformed (SD) bands and the determination of excitation energies, spins and parities for the SD states. These quantities can be reached through the observation of discrete γ transitions linking the lowest levels of the SD band to the normally deformed (ND) ones. The first experimental breakthrough in the knowledge of the decay-out process has been achieved in the odd ^{133,135,137}Nd nuclei of the A$\sim$130 mass region [1–4]. In even-even Nd nuclei, such transitions have been only recently observed in ^{132,134}Nd [5,6]. The study of the superdeformation phenomenon is also fruitful for answering questions about pairing correlations. The strength of neutron pairing correlations in the second minimum of SD nuclei can be estimated by a phenomenological analysis from the knowledge of the excitation energies for a given series of isotopes. The identification of linking transitions for the yrast SD band in ^{136}Nd will fix its excitation energy and will offer the possibility to estimate the SD neutron pairing gap.

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2. EXPERIMENT AND RESULTS

The experiment was performed at the Legnaro National Laboratory with the XTU Tandem accelerator. The ^{110}Pd(^{30}Si,4n) reaction at a beam energy of 130 MeV was used to populate high angular momentum states in ^{136}Nd. The target consisted of a foil of 1 mg/cm^2 of ^{110}Pd deposited on a 15 mg/cm^2 gold backing. A backed target was used to unambiguously identify the transitions which depopulate the SD band. The γ-ray transitions were measured with the EUROBALL III array [7] which consisted of 239 germanium crystals.

For the analysis, a variable Doppler correction, built with extracted attenuation factors for the superdeformed transitions, has been used for the gating conditions. So, we have obtained two kinds of spectra : i) with the Doppler correction to check the superdeformed gates, ii) and without correction to search and study linking transitions. We have also extracted the directional correlation from oriented states (DCO) ratio of the transitions.

From this analysis, clear coincidence relationships have been observed, establishing unambiguously the position of three linking transitions 754, 1456 and 1493 keV. Figure 1 displays the level scheme associated with the decay-out of the yrast SD band in ^{136}Nd. The directional correlation from oriented states ratio measurements of the linking transitions show that 1456 keV transition is dipolar while the 754 keV transition is quadrupolar. Assuming the electric character of these transitions, the decay-out proceeds via E2 and E1 transitions. Therefore the lowest state of the SD band is proposed to have spin and parity (17^-) at an excitation energy of 7028 keV. In Figure 1 are also indicated the intensities of the decay flow (dotted arrows), the reference being taken for the 857 keV transition (100%). The observed discrete linking transitions collect about 20% of the SD decay-out intensity via the two transitions of 754 and 1493 keV. The extracted intensities provide also information on the fragmentation of the decay-out. The decay-out flow of the SD band is distributed towards three structures with $\sim$ 30% each and a fourth band receives only about 4% of the decay-out. The full SD intensity is completely recovered at spin $15 - 16\hbar$.

3. DISCUSSION

The Nd series represent a very appropriate laboratory for the decay-out study of SD bands because its evolution with the neutron number N can be now analysed, including our results, in six isotopes $^{132-137}$Nd from N=72 to N=77 [1–6]. The SD minimum occurs in the Nd isotopic series when the $i_{13/2}$ (6_1) intruder orbital is occupied and the SD bands in even isotopes are built on two quasiparticle (qp) configurations.

The most striking feature of the discrete linking transitions discovered in the Nd series is that the total intensity of the observed discrete decay-out transitions decreases when increasing the mass number A, with a stronger absolute value for odd isotopes: 100% for ^{133}Nd, 65% for ^{135}Nd, 30% for ^{137}Nd and 100% for ^{132}Nd, 50% for ^{134}Nd, 20% for ^{136}Nd. This behavior can be understood by an increase of the excitation energy with A, as can be seen in Figure 2, which presents the ^{136}Nd SD excitation energy found in this work in comparison with those recently determined in the neighboring Nd isotopes [2–6]. A simple explanation of this pattern can be given in terms of the location of the $i_{13/2}$ (6_1) intruder orbital. When increasing A, its excitation energy above the Fermi surface

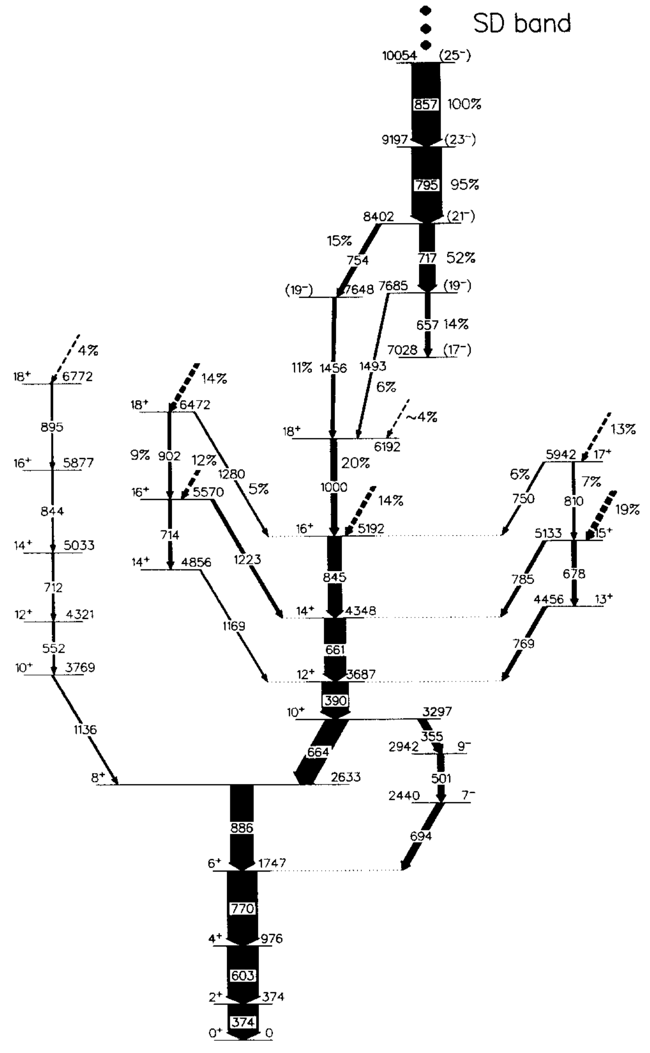

Figure 1. Level scheme associated with the decay-out of the ^{136}Nd yrast SD band.

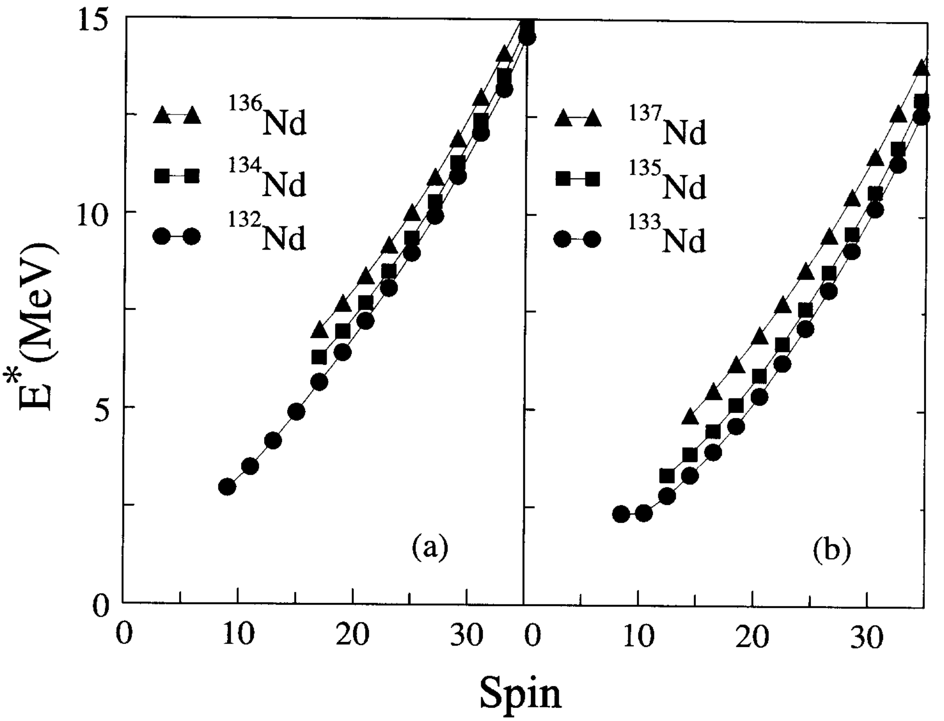

Figure 2. Comparison of the SD states excitation energies versus the spin, for even-even (a) and odd Nd isotopes (b).

increases. Indeed this orbital which provides the basis for SD shell gaps approaches the Fermi surface in the N=72 isotope. Thus the excitation energy of the SD bands is higher in the heavier isotopes. Moreover, the excitation energy of the SD bands is systematically higher in even isotopes than in the odd ones confirming that 2-qp configurations are involved in the first case.

The knowledge of the SD absolute excitation energy for an extended series of Nd isotopes, allows the pairing strength to be estimated in the second minimum. Indeed, it is well known for ND matter that the neutron pairing gap Δ_n can be estimated from the odd-even mass differences using a first-order Taylor expansion. The experimental neutron pairing gap takes the following expression :

$$\Delta_n = \frac{(-)^N}{2} [M(N+1) - 2M(N) + M(N-1)] \qquad (1)$$

The same extraction of the neutron pairing gap can be applied to the SD nuclei. If the even SD ground states correspond to 2-qp states and the odd one to 1-qp state, the neutron pairing strength is given by the same formula with opposite sign. In the framework of the particle-plus-rotor model in the strong coupling scheme, for axial symmetry the excitation energy of a state at spin I is the sum of the collective rotational energy and of the intrinsic energy which is the sum of the individual quasiparticle energies. If we assume that the rotational contribution is the same for three Nd isotopes, it is justified to suppose that the same formulae remain valid at a given spin I. The application of the strong coupling scheme is valid only for moderate spin values up to $\sim 30\hbar$ and for large deformations.

The most striking feature of our results is that the pairing gap value is reduced approximately by a factor 2 to a value $\Delta_n(SD) \sim 0.6$ MeV, but that pairing correlations still exist in SD matter. Our extraction is very rough because we have made crude assumptions but in spite of this phenomenological analysis our results are in agreement with the theoretical results of R.A. Wyss *et al.* [8] in the Cranked Shell Model framework. K. Tanabe *et al.* [9] have also predicted in Cranked HFB calculations that the neutron pairing gap remains finite even at spin 60 in the ^{136}Nd SD band.

4. CONCLUSION

We have observed for the first time, by using the EUROBALL III array, discrete γ-ray linking transitions de-exciting the SD band in ^{136}Nd. A level scheme associated with the decay-out of the SD band has been proposed. The SD structure has been placed and extends from a level with spin (17^-) and excitation energy of 7.03 MeV up to spin (49^-) at 25.7 MeV. We have also extracted the first experimental estimation of the neutron pairing gap in the SD matter, using the strong coupling model with restrictive hypothesis. The conclusion of this phenomenological analysis is that pairing correlations still exist in the SD bands of the A$\sim$130 mass region.

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