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E0 transitions and the depopulation of SD bands

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1. Introduction

The decay out of super-deformed (SD) bands is still a puzzle. While the most likely explanation is in terms of multi-decay path statistical γ process, other mechanisms may contribute as well.

One of such mechanisms is the contribution of E0 transitions to the decay strength. The E0 transitions are not observable as γ-rays, proceed mainly through internal conversion of K-shell electrons and are followed by the emission of K X-rays. The measurement of the K X-ray yield in coincidence with the SD band is then the easiest way of verifying the E0 hypothesis.

In the first part of this work we present the results of calculations showing that E0 transitions may successfully compete with other types of electromagnetic transitions in the decay out of SD bands. This is followed by the report on the search of highly converted transitions in coincidence with the SD band in ^{143}Eu.

2. Transition probability calculations

The aim is to calculate the E0 transition probability from a SD state to normal deformed (ND) states and to compare this with E1 and E2 transition probabilities. It is assumed that the SD state is separated from the ND potential well by a potential barrier. The barrier is penetrated by a transition of energy E. The excitation energy of the SD state in respect to the bottom of the ND well is E_x. The transmission coefficient through the barrier is calculated according to the formula:

$$B = \frac{e^{-\alpha I} K}{E^2}, \quad K \cong 0.006, \quad \text{E in MeV}$$

where I is the spin of the decaying state, α is a parameter adjusted to reproduce the change of the SD band intensity in its decay region and the $1/E^2$ factor reflects the dependence of the wave functions overlap on the transition energy ([1], [2]).

Standard formulas are used for E1 and E2 transition strengths (T_{E1},T_{E2}), as well as for the level density η [3]. The E0 transition strength is expressed as:

$$T_{E0}(E) = \rho^2 \Omega(E)$$

where ρ is the E0 matrix element and Ω is the electronic factor [4]. The integrated transition probability is:

$$P_{El}(E_x) = \int_{E_0}^{E_x} BT_{El}\eta(E_x - E)dE$$

where E_0 is equal 0 for E1 and E2 transitions and is equal to the K-binding energy in the case of E0 transition.

The value of the E0 matrix element is unknown. It is however proportional to the change of the mean square radius between the initial and final state. Assuming such scaling, which is equivalent to the scaling with the square of the deformation parameter β, one may get a rough estimate of ρ using the matrix element values obtained for the known $E0$ transitions and taking

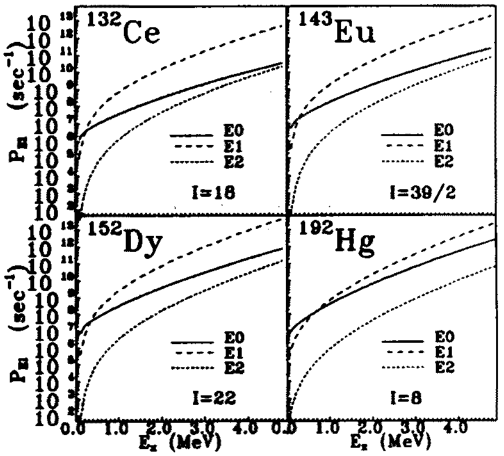

Figure 1: Probability of a transition from a SD state as a function of the excitation energy. The spin values correspond to the SD decay region.

into account the larger deformation change in the case of transitions from SD to ND states [5]. This leads to unrealisticly large enhancement factors, e. g. of the order of 10^5 for the SD to ND transition as compared to the β-band to ground state band E0 transitions in the rare earth region [5]. The enhancement is largely offset by poor overlap of the wave functions for states with large deformation difference. Still, the values of $\rho > 1$ are not unexpected. The results of calculations with $\rho = 1$ are presented in fig. 1. We conclude that the comparison of E0, E1 and E2 transition probabilities makes the possible contribution of E0 to the decay out of the SD band worth to be searched for.

3. Multiplicity of K X-rays in coincidence with the SD band in ^{143}Eu

In April 1991 a long run experiment aiming at the study of SD phenomena in ^{142,143}Eu was performed at the Tandem Accelerator Laboratory, Risø. The SD band of 22 transitions was observed in ^{143}Eu. The absolute excitation energy of a superdeformed band was determined directly for the first time [6]. The Nordball array of Ge Compton suppressed detectors used in the experiment included one Low Energy Photon detector (LEP). The presence of LEP detector and the unique data set with high statistics (10^9 of triple coincidence events, 1/30 of them with LEP detector) made it worthwhile to test the E0 hypothesis even though this odd-A nucleus, with large number of low energy, highly converted M1 transitions [7], was not optimal for the purpose.

The method is based on the comparison of the excess multiplicity (M^{exc}) of K X-rays between spectra gated on the SD and ND bands. The M^{exc} is defined as the difference of the measured K X-rays multiplicity and the multiplicity expected from the conversion of γ-lines observed in the spectrum. The term multiplicity refers to the intensity of the peaks in the spectrum normalized to the intensity of the ground state transitions.

The quantitative analysis (e. g. determination of K X-rays multiplicities) of spectra gated on weak transitions is strongly sensitive to the background subtraction technique. The background is due mainly to the unsupressed Compton scattered events. In the unsubtracted spectra more than 95 % of gate selected events originate from the background and all these events contribute to the intensity of the K X-rays. The M^{exc} value in the background spectrum is larger than in the spectra gated on lines from the nucleus of interest because of the contribution of neighbouring isotopes to the intensity of K X-rays. A determination of the content of background within the gate (i.e. number of counts to be subtracted) is therefore crucial. We have found that the quantitative background subtraction can not be performed properly for the single SD gated spectra. An attempt of determination of the M^{exc} for double gated spectra has been done. Unfortunately the statistics in these double gated spectra are too low for background subtraction. Unsubtracted spectra have been analyzed (fig. 2). The positive difference in M^{exc} for the SD and ND gated spectra has been found: $M^{exc}(SD) - M^{exc}(ND) = 0.64 \pm 0.26$. This, however, can be understood as a result of the larger background content in the SD gated spectrum than in the ND gated one (about 80 % and 13 % respectively) and can not be treated as a signature of the E0 presence.

5. Conclusion

The results of transition probabilities calculations show that E0 transitions are likely to carry an important fraction of the SD decay strength. The determination of the K X-ray multiplicities in coincidence with SD bands requires higher fold gating conditions. In the optimal situation background subtraction should be avoidable and we estimate that triple gating would match this requirement (expected background content is less than 50 %).

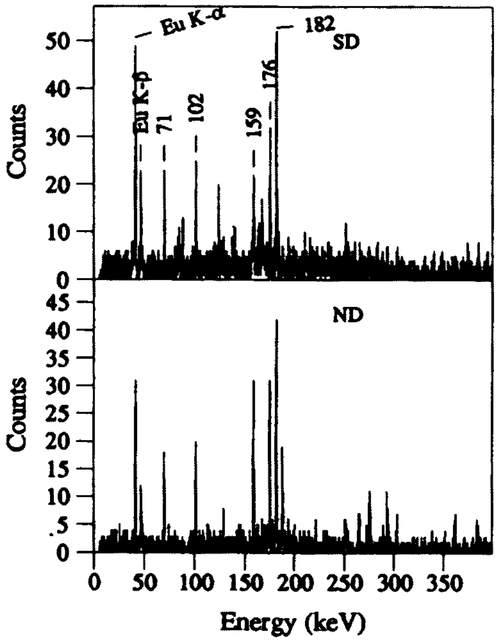

Figure 2: Double SD and ND gated LEP detector spectra.

4. Comment

Research similar to the one described here has been performed with negative result for ^{192}Hg [8]. We note that single gating was used in [8]. The SD peaks in mercury region are significantly better discernible from the background than in the rare-earth nuclei — the content of the background in the single SD gated spectra is about 90 % [9].

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