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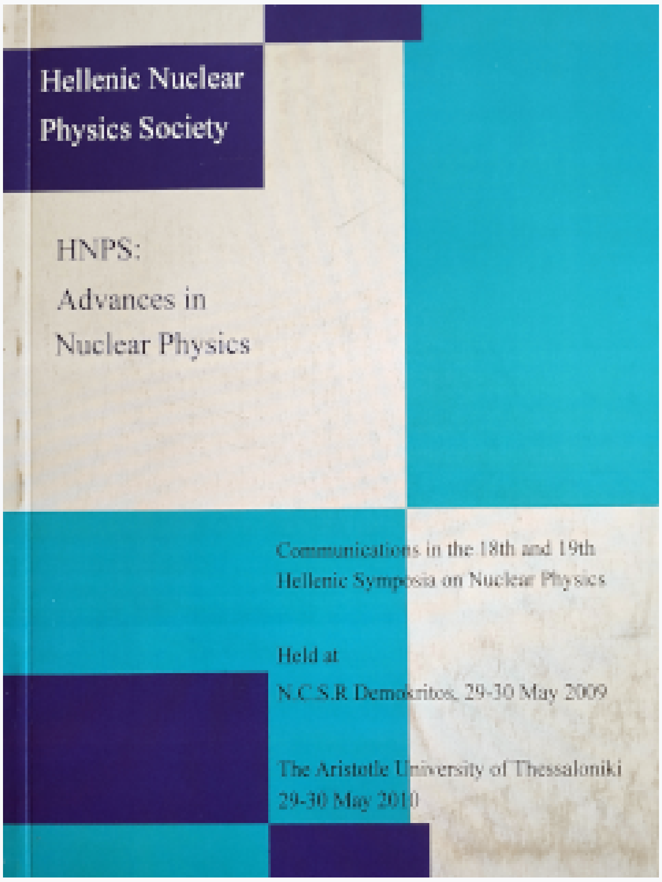

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Search for $E(5)$ Symmetry in ^{102}Pd

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Abstract

Lifetimes of the excited states in the yrast band of ^{102}Pd have been determined using the Recoil-Distance Doppler Shift experiment at INFN, Laboratori Nazionali di Legnaro. Excited states in ^{102}Pd were populated by the ^{92}Zr(^{13}C,3n)^{102}Pd fusion-evaporation reaction. Lifetimes were deduced using the Differential Decay Curve method and the corresponding $B(E2)$ values were compared to the $E(5)$ critical-point symmetry, and also the $U(5)$ and $O(6)$ limits of the Interacting Boson Model-1. It is evident that ^{102}Pd agrees poorly with the predicted $E(5)$ symmetry but has a very good (and somewhat surprising) agreement with the $O(6)$ limit.

1. Introduction

Within the classical limit of the Interacting Boson Model, two shape-phase transitions have been predicted. Firstly, between the spherical vibrator and γ-soft rotor limits (referred to as the $E(5)$ symmetry [1]). Secondly, between the spherical vibrator and rigid rotor limits (referred to as $X(5)$ symmetry [2]). These "dynamical" symmetries both occur when the spherical and deformed potentials coexist at the same depth, and both symmetries are modelled around infinite square-wells. In the case of $X(5)$ symmetry,

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numerous nuclei show good agreement, both in terms of level energies and $B(E2)$ values, to level scheme predicted in Ref. [2] (see for example [3–5]). A survey for potential $E(5)$ candidates has been performed [6], and with the exception of ^{134}Ba [7], information is lacking on the $B(E2)$ values of the yrast-band transitions in the majority of the candidate nuclei. This paper focusses on the determination of lifetimes in ^{102}Pd, a candidate for $E(5)$ symmetry [6, 8], such that $B(E2)$ values could be extracted and a more inclusive comparison to $E(5)$ symmetry can be made.

2. Experimental Technique and Data Analysis

Intrinsic state lifetimes of various excited states in ^{102}Pd were determined by a Recoil Distance Doppler-Shift experiment that was performed at INFN, Laboratori Nazionali di Legnaro (LNL). Excited states in ^{102}Pd were populated using the ^{92}Zr(^{13}C,3n)^{102}Pd fusion-evaporation reaction, with E(^{13}C) = 48 MeV. An enriched ^{92}Zr target foil, of ≈ 1 mg/cm^2, was mounted inside the Cologne plunger along with a separate 4 mg/cm^2 Au stopper foil. The average recoil velocity of the evaporation residues was $\sim 0.8\%$ c. Measurements involving twenty-four different target-to-stopper distances were performed, with this distance being regulated by a piezoelectric feedback loop housed in the plunger. Reaction γ rays were detected using the GASP array [9] (in configuration "I"), which consisted of forty, large-volume, Compton-suppressed HPGe detectors coupled to a BGO inner ball. Valid events, which were recorded for offline analysis, consisted of coincident γ rays being detected in (at least) two different HPGe detectors. The HPGe detectors were grouped such that there were seven "rings" at angles of 34.5°, 59.4°, 72.0°, 90.0°, 108.0°, 120.6° and 145.4°, with respect to the beam axis. These valid events were then sorted offline into γ-ray energy vs. γ-ray energy matrices for all ring permutations and for each individual distance.

Lifetimes were extracted using the Differential Decay Curve Method [10, 11]. In a nutshell, by placing a gate on the shifted component of a transition feeding the state of interest, the lifetime can be extracted by Equation 1:

$$\tau = \frac{I_U^{out}(x)}{v \cdot dI_S^{out}(x)/dx} \tag{1}$$

where $I_U^{out}(x)$ is intensity of the unshifted component depopulating the state, v is the recoil velocity and $dI_S^{out}(x)/dx$ is the rate of change of the shifted component as a function of target-stopper distance. In the case of indirect

Table 1: Lifetimes and corresponding $B(E2)$ values of excited states populated in the ^{92}Zr(^{13}C,3n)^{102}Pd RDDS experiment.

I_i^π	E_x (keV)	τ (ps)	$I_i^\pi \rightarrow I_f^\pi$	E_γ (keV)	$B(E2)$ (W.u.)
2_1^+	556.4	17.5 (6)	$2_1^+ \rightarrow 0_1^+$	556.4	30.8 (10)
4_1^+	1275.9	3.7 (3)	$4_1^+ \rightarrow 2_1^+$	719.4	40.7 (29)
6_1^+	2111.4	1.93 (8)	$6_1^+ \rightarrow 4_1^+$	835.5	36.8 (16)
8_1^+	3013.1	1.78 (15)	$8_1^+ \rightarrow 6_1^+$	901.7	27.3 (23)

feeding, one has to account for the feeding into the excited state of interest, as shown in Equation 2:

$$\tau = \frac{I_U^{out}(x) - I_U^{in}(x)}{v \cdot dI_S^{out}(x)/dx} \cdot \frac{[I_U^{out}(x) + I_S^{out}(x)]}{[I_U^{in}(x) + I_S^{in}(x)]} \tag{2}$$

where $I_U^{in}(x)$ and $I_S^{in}(x)$) are the unshifted and shifted components feeding the state. Gaussian peaks were fitted to the shifted and unshifted peaks to ascertain their intensities (using the program TV [12]) and a series of second-order polynomials were fitted to the intensities of both the unshifted and shifted peaks (using the program NAPATAU [13]). From these fits, the lifetime of the excited state was extracted. In this work, numerous direct and indirect gates were placed on yrast-band transitions, the weighted average of these results yielded the final lifetimes. The corresponding $B(E2)$ values were compared to $E(5)$ symmetry, and also the $U(5)$ and $O(6)$ limits of the IBM-1.

3. Results

Figure 1 shows the total projection spectrum seen in the detectors at 34.5° with respect to the beam-axis, where the target and stopper are in contact. The transitions labelled in Figure 1 are the yrast-band transitions of ^{102}Pd populated in this experiment. An example of a complete set of gated-projection spectra is shown in Figure 2, which shows the 556-keV $I^\pi = 2_1^+ \rightarrow 0_1^+$ transition (seen in the detectors at 140.6°), from a gate placed on the forward-shifted component of the 719-keV, $I^\pi = 4_1^+ \rightarrow 2_1^+$ transition (seen in the detectors at 34.5°). The results for the yrast-band transitions are tabulated in Table 1.

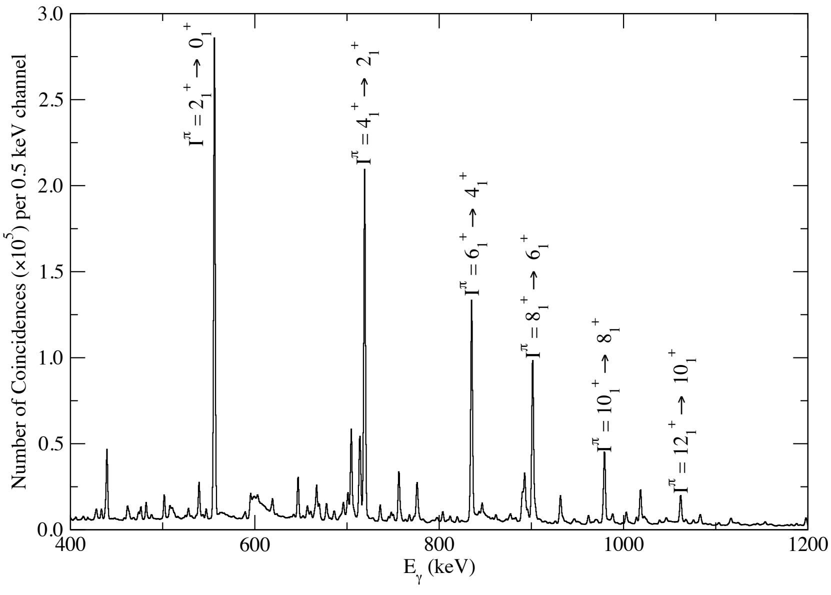

Figure 1: Total projection spectrum of the γ rays observed at 34.5° from the ^{92}Zr(^{13}C,3n)^{102}Pd reaction.

4. Discussion

The ratios of measured $B(E2)$ values to those predicted for a harmonic vibrator, γ-soft rotor, $E(5)$ limit [14], the $U(5)$ limit (see Eqn. 4 in Ref. [15]) and $O(6)$ limit (see Eqn. 5.14 in Ref. [16]) both with $N = 5$ bosons are shown in Figure 3. It is evident that a very good agreement is observed between the experimentally deduced $B(E2)$ values and the $O(6)$ limit. Furthermore, in the $O(6)$ limit, the $B(E2; 0_2^+ \rightarrow 2_1^+) = 0$, this compares to an upper limit of 0.004 [17]. IBA calculations to show the nature of the excited level scheme and for all inter- and intraband transitions are currently being performed.

5. Conclusion

Lifetimes of the yrast-band states in ^{102}Pd have been determined using the Recoil-Distance Doppler Shift technique. Significant deviations from the $E(5)$ symmetry are noted and it is apparent that from the yrast-band transitions, ^{102}Pd is a good candidate for $O(6)$ symmetry. A fuller account of this work is being prepared for publication [18] and will also be found in the Ph.D. thesis of T. Konstantinopoulos [19].

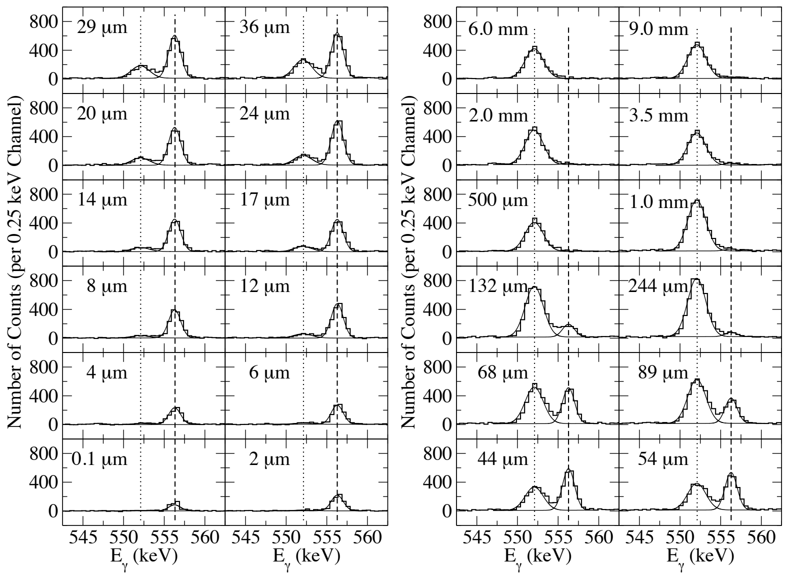

Figure 2: Deconvoluted spectra for all separate target-stopper distances of the stopped and backward-shifted component of the 556-keV, $I^\pi = 2_1^+ \rightarrow 0_1^+$ transition, from a gate placed on the forward-shifted component of the 719-keV, $I^\pi = 4_1^+ \rightarrow 2_1^+$ transition. The centroids of the stopped and backward-shifted peaks are shown by the dashed and dotted lines respectively.

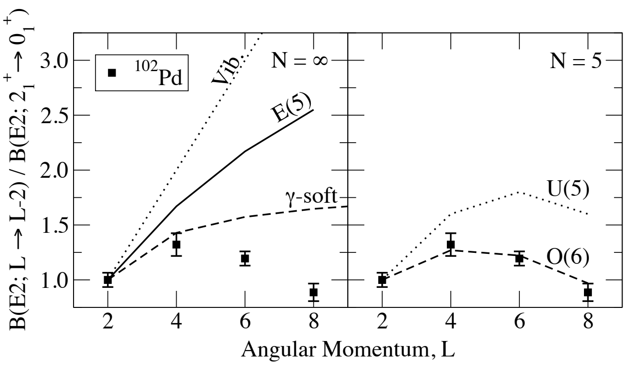

Figure 3: Left: Comparison of the experimentally deduced $B(E2; L \rightarrow L-2)/B(E2; 2_1^+ \rightarrow 0_1^+)$ ratios of the yrast-band transitions in ^{102}Pd to the classical harmonic vibrator, γ-soft rotor and $E(5)$ limit. Right: Comparison of the experimentally deduced $B(E2; L \rightarrow L-2)/B(E2; 2_1^+ \rightarrow 0_1^+)$ ratios of the yrast-band transitions in ^{102}Pd to the $U(5)$ and $O(6)$ limits with $N = 5$ bosons.

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