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TITLE: UNIQUE PARITY STATES IN ^{109}Pd AS A TEST OF PARTICLE-ROTOR AND IBFA MODELS

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UNIQUE PARITY STATES IN ^{109}Pd AS A TEST OF PARTICLE-ROTOR AND IBFA MODELS

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Unique parity levels in odd mass heavy nuclei arise, in each shell, from that isolated orbit lying amidst others of opposite parity. Their effective isolation leads to high purity and therefore such states offer an ideal testing ground for nuclear models.

Usually, the known unique parity states are high spin, aligned states disclosed in neutron deficient nuclei through heavy ion, in-beam studies. A simple geometrical picture of these states, valid for moderately deformed nuclei is illustrated in fig. 1. When the Fermi surface is amongst the low K orbits, the coupling scheme approximates a decoupled band picture[1] in which the yrast states of spin I are obtained by a nearly parallel coupling of the particle

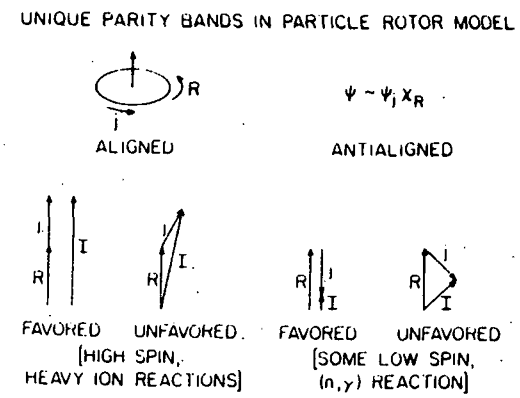

Fig. 1. Decoupled band picture of particle rotor alignment, with indication of typical empirical means of access.

angular momentum $\vec{j}$ and the core rotational angular momentum $\vec{R}$. Successively higher spin states occur for successively larger R values and thus the yrast energies follow those of the ground band in the adjacent even nucleus. These are the favored, aligned levels. At slightly higher energies, unfavored aligned levels are occasionally identified: because of the angle between $\vec{R}$ and $\vec{j}$, a larger R value (hence energy) is required for a given I.

Seldom observed, but a more sensitive means of discriminating various models, are the low spin states arising from the anti-parallel coupling of $\vec{R}$ and $\vec{j}$. As shown in fig. 1, these can be either favored or unfavored. They arise only for $\vec{R} \sim -\vec{j}$ and so are rather restricted in number. Thus, for an $h_{11/2}$ particle, there are only two $3/2^-$ levels compared to six states for each spin $I \geq 11/2$. Due to this and the fact that one expects these levels to occur lower in energy than their high spin counterparts with the same R, they may indeed be expected to be even purer in character.

Unfortunately, they are rarely observed and, until the present study, never has the complete set been established. Exploiting the inherent non-selectivity[2] of the (n,γ) reaction, we have studied the low spin levels in ^{109}Pd and located[3] the complete set of low lying, low spin anti-aligned states of $h_{11/2}$ parentage.

One might not expect, a priori, that the particle-rotor (PR) model would be a suitable framework for interpreting unique parity levels in the A∿100 mass region. However, it is in just such moderately deformed nuclei that the greatest successes[1] of this approach have been achieved since such nuclei have large Coriolis coupling constants, $h^2/2I$, which favor parallel R, j alignment. Furthermore, it has been shown[4] (see fig. 2 (left)) that the model indeed works

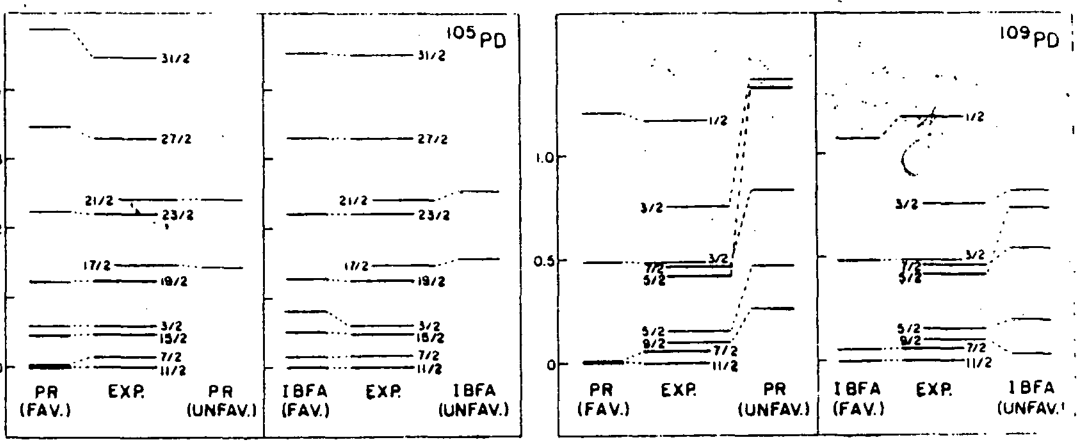

Fig. 2. Unique parity states in ^{105,109}Pd compared with PR and IBFA models. For convenience the favored and unfavored states are compared separately.

exceedingly well for the aligned high spin ($h_{11/2}$ based) states in the even less deformed nucleus ^{105}Pd.

Encouraged by this and by the opportunity presented to perform the first test of the PR model for an extensive set of anti-aligned levels, we performed calculations for ^{109}Pd exactly analogous to those of Rickey and co-workers[4] for the $h_{11/2}$ neutron system in ^{105}Pd. A Nilsson model with pairing, variable moment of inertia and Coriolis coupling was used. The results are shown in fig. 2 (right). As with ^{105}Pd, the favored levels are well reproduced. However, the low spin unfavored states exhibit serious disagreements which cannot be rectified by parameter changes. This is most obvious for the three close lying pairs of states, of spins 3/2, 5/2 and 7/2. The two 3/2 levels, for example, form an isolated pair: Thus, their minimum separation is twice their mixing matrix element. But, in the PR model, the Coriolis interaction is (schematically) given by $h^2/2I\langle f|j_-|i\rangle \times \sqrt{(I-K)(I+K+1)}$. The first factor is ∿60 keV, the j_- matrix elements are ∿5 and the square root is 1.5-2. Thus the Coriolis matrix element is approximately 500-600 keV and the closest separation for the $3/2^-$ levels is ∿1 MeV. Yet, empirically, they occur <300 keV apart. Strongly attenuating the Coriolis interaction is not an acceptable solution because the other levels could not then be reproduced: in particular, the $11/2^-$ state would not lie lowest.

In view of this, it seemed apt to attempt an IBFA calculation[5] using the code ODDA, written by O. Scholten. For this single j shell ($h_{11/2}$) case, only two parameters, Γ, the strength of the direct or $Q_B.q_F$ interaction, and Λ, the multiplier of the exchange term, were required. The parameters for the even-even Pd core were taken from a systematic survey.[6] The results[7] are shown in fig. 2, where we have also shown the comparison for the high spin states in ^{105}Pd to verify that the agreement for low spin levels in ^{109}Pd is not at the expense of a discrepancy elsewhere. The IBFA calculations are a significant improvement, in particular as regards the splitting of states of common spin.

It is interesting to study the source of this improvement by inspecting the resulting wave functions: their composition, in terms of core states, is summarized in Table I. In the PR model, the odd particle is coupled only with the core states of the quasi ground band. The IBFA, however, allows the full participation of all collective core levels. It is striking (see Table I) that the quasi ground band in fact accounts for only ∿40% of the IBFA wave functions. It is therefore not surprising that the PR model could not reproduce the empirical low spin level energies. What is intriguing is why it succeeded for any levels since the core structure of high and low spin states is similar.

One might question whether it is fair to utilize the simple Nilsson PR model instead of, for example, the asymmetric rotor model

Table 1. Probability Distribution Ranges (in %) of Different Categories of Core States in the IBFA and PR Wave Functions (see ref. 7)

^{105,109}Pd States	Core State Category			
	Quasi-ground band		Other	
	PR	IBFA	PR	IBFA
Low spin states in ^{109}Pd	100	28-49	0	72-51
High spin states in ^{105}Pd	100	42-56	0	58-44

so successfully employed in other mass regions. There are two responses appropriate here. First, the same IBFA wave functions show that core states involving the quasi-γ band are rather unimportant (probabilities $\lesssim$10%). Coupling to the quasi β band in fact is far more important (~40%). Secondly, we performed[3] asymmetric rotor calculations for all γ values and found that, while for γ~30° it was possible to reduce the splitting between $3/2^-$ states, at the same time the $5/2^-$ splitting increased. For no γ value could a satisfactory fit be obtained.

To conclude, (n,γ) techniques were used to study, for the first time, an essentially complete set of low spin, anti-aligned, unique parity levels in ^{109}Pd. The particle rotor model, notably successful[4] for high spin states of the same $h_{11/2}$ parentage in this mass region, did not, and could not, explain the empirical energy levels, even when core asymmetry was included. IBFA calculations involving only two parameters accounted well for both the high spin levels in ^{105}Pd and the low spin states of ^{109}Pd. Analysis of the resulting IBFA wave functions showed large probabilities for core states other than those of the quasi ground band, in particular those associated with the quasi-β band.

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