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$\Delta I = 4$ BIFURCATION: ORIGINS AND CRITERIA

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$\Delta I = 4$ Bifurcation: Origins and Criteria

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Abstract

An alternative approach for the $\Delta I = 4$ bifurcation phenomenon has been presented without introducing either a Y_{44} deformation or an I^4 term in the Hamiltonian explicitly. The optimal criteria for observing the phenomenon have been discussed as well.

The new γ-ray detector arrays have demonstrated that rotational sequences in certain superdeformed bands with angular momentum differing by two can split into two branches [1–3]. This is commonly called $\Delta I = 4$ *bifurcation,* and has attracted considerable interest in the nuclear structure community (for instance, see [4–10]). Because this phenomenon depends on the variation of E_γ values, the bifurcation appears as an oscillation in the dynamic moment of inertia, $J^{(2)}$ as well. Fig. 1 shows the bifurcation in both E_γ and $J^{(2)}$ for the yrast superdeformed band in ^{149}Gd [1]. The reference for $J^{(2)}$ is simply the average value of the two neighboring ones.

Intuitively, these observations suggest a fourfold symmetry in the nuclear system, cor-

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responding to an invariance of the shape under rotations by $\frac{\pi}{2}$ [1]. This has motivated theoretical investigations that have included a C_4 symmetry piece in the Hamiltonian statically or dynamically, with the rotation axis either along or vertical to the symmetry axis [6,8]. In another approach, the influence of $\Delta K = 4$ coupling through the inclusion of an I^4 operator in the Hamiltonian has been investigated [9].

Recently, we have proposed an alternative approach that is based on the angular momentum projected shell model [11]. We have shown that such staggering can emerge naturally in an angular-momentum preserving system when two almost isolated rotational bands are mixed by *ordinary two-body shell model interactions.* Angular momentum projection transforms intrinsic states to the laboratory system and shell-model configuration mixing provides coupling between different intrinsic K-states. The quantum mechanical interference of this projection and the associated configuration mixing can lead to $\Delta I = 4$ bifurcation in the resulting laboratory-frame spectrum. Under such a mechanism [11], there should be four distinct features in the resulting bifurcations:

1. The existence of this effect should be independent of the difference in K values between two bands which mix.

2. There is a "beat" envelope localized in the crossing region; the largest amplitude of the oscillation corresponds to where the two bands come the closest, as shown on Fig. 2.

3. If the two bands that mix are well isolated from other bands, this bifurcation should be observed in both mixed bands with opposite phase structure (see Fig. 2).

4. There may exist phase reversals in a long oscillation sequence because the following band mixture occurs normally independent of the previous band crossing.

According to calculations and analysis using this approach, the optimal conditions for observing $\Delta I = 4$ bifurcation experimentally can be summarized as follows:

1. The effect is most clearly seen if two bands that are close to the yrast line dominate the mixing. If too many bands mix, the interference effects may cancel out the visible bifurcation. Thus, nuclei for which the Fermi surfaces lie in regions of low level density for states of a given parity are particularly favored. Since superdeformed bands are generally found for nuclei having Fermi surfaces lying near gaps in the deformed single-particle spectrum, this condition is fulfilled rather automatically for superdeformed cases.

2. In principle, mixing between bands with different qp-numbers could give such bifurcation effects, but such a mixing will usually result in a distortion of the regular band structure. Thus, observation of this bifurcation fine-structure is more likely if the two bands that mix have the same qp-number.

3. There must be long enough sequences of transitions (say eight transitions or more). This condition is more easily fulfilled in superdeformed systems. In the normally deformed case, odd–odd nuclei are other possible candidates because blocking of both neutron and proton pair alignment ensures a longer regular band.

4. For realistic coupling, the interacting bands must be close in energy to generate observable bifurcation amplitudes. Thus, nearly degenerate parallel bands, or bands that cross at very shallow angles, favor the survival of the oscillations for long angular momentum sequences. Such bands are likely to be more common for superdeformation than for normal deformation, while for normally deformed bands we may expect that high-K bands are more likely to fulfill this condition than low-K bands.

5. The interacting pair of bands should not be too similar in structure (for example, they should not be built on quasiparticles from the same single j-shell). The reason may be understood qualitatively from the matrix element $\left\langle K|\hat{H}\hat{R}(\beta)|K'\right\rangle$ entering the projection integral. For states that are too similar in structure, the angular dependence of this matrix element is strongly peaked near zero (loosely, only a small rotation is

required to bring the two states into strong Hamiltonian overlap) and this kills the oscillation.

6. Energy measurements with uncertainty of 0.1 keV (or less) are required, because the expected amplitude of the oscillation is about or even less than 0.5 keV in most cases.

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FIGURES

FIG. 1. $\Delta I = 4$ bifurcation in both E_γ and $J^{(2)}$ values for the yrast SD band in ^{149}Gd [1]. The top curve is ΔE_γ in units of keV (shifting up by 1 keV), while $\Delta J^{(2)}$ is in units of $\hbar^2$/MeV, with a multiplication factor of 0.5 so that these two curves can be put in the same figure.

FIG. 2. Schematic picture of the "beat" structure resulting from a two-band mixture mechanism. Two mixed bands should show staggering of opposite phase, if they are isolated well enough from other bands.

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