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Important Role of Newby Shift in Odd-Even Staggering

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ABSTRACT: We have investigated the role of Newby shift in the odd-even staggering observed in doubly odd deformed nuclei within the framework of the Two quasi particle rotor model (TQPRM). We have done Coriolis coupling calculation for odd-odd and even-even nuclei in rare earth region. With these calculations, we have well reproduced the odd-even staggering and also signature inversion. In the present paper, we will show the results of 180Ta, where Newby Shift play very important role in explaining the signature dependence and odd-even staggering observed in this nucleus. Comparison of the calculated results with experimental data evidences the importance of this effect in explaining the signature dependence observed in nuclei of this region.

Keywords: Two quasi particle rotor model (TQPRM), Gallaher-Moszkowski (GM) splitting, Newby-Shift (N), signature dependence, signature inversion.

I. INTRODUCTION

The behaviour of the rotational bands should be smooth because of large moment of inertia and decreased pairing but it is not so. Large signature dependence has been reported so far. The odd spins behave differently as the even spins called odd-even staggering. The Coriolis force plays an important role in influencing the structure of deformed nuclei both at low and high energy. Many new and unusual features have been discovered in the high spin rotational spectra of deformed even-even and odd-odd nuclei during the past few decades. Attempts have been made to understand this phenomenon using several models. We have done Two-quasi particle rotor model calculations to explain features like signature dependence, odd-even staggering, signature inversion and signature reversal. In our previous work we have identified the mechanisms responsible for these features [1-4].

II. MECHANISM

The most important effect is of n-p interaction in odd-odd nuclei. The Gallaher-Moszkowski (GM) splitting and the Newby-Shift (N) are the two factors of n-p interaction which play important role. The Newby shift play role only for K = 0 bands, which staggered energies of this band [6]. A lot of the work has been done to emphasize the importance of n-p interaction in explaining the odd-even staggering in K≠0 bands; the most important mechanism responsible for it being the direct Coriolis mixing with K = 0 band. Also, the signature inversion phenomenon and the odd-even staggering can be reasonably explained by the two-quasi particle plus rotor model (TQPRM). Both, the Newby shift and the decoupling parameter of K = 0 band are responsible for such features. The perturbation in K = 0 band is transmitted to higher K bands through Coriolis and particle-particle coupling.

We have done TQPRM calculations to explain the odd-even staggering observed in $K_{-} = 1^{+}\{7/2[404]_p$ x $9/2[624]_n\}$ band of ^{180}Ta. This is highly staggered band. The magnitude of the staggering is well reproduced by our calculation. There is a strong mixing between $K_{-} = 1^{+}\{7/2[404]_p$ x $9/2[624]_n\}$and $K_{-} = 0^{+}\{7/2[404]_p$ x$7/2[633]_n\}$ band . The wave function of the states of the K = 1 band contain significant components (almost 35%-40%) of the states of the K = 0 band. The Newby Shift of K = 0 band plays an important role in explaining staggering feature in K = 1 band of ^{180}Ta. Although the K = 0 band is not an experimentally known band but this K = 0 band is important to obtain the magnitude of odd-even staggering in K = 1 band. The comparison with the experimental data of K = 1 band with and without Newby Shift of K = 0 band is as shown in Fig. 1. This unknown K = 0 band is found to be lying at an energy of E_α = 945.4Kev and Newby shift E_N = 97.9KeV, which is obtained after fitting. In the figure, the experimental plot is shown by solid line and TQPRM calculations by dashed line. When the Newby shift E_N = 0 for K = 0 band, the odd-even staggering of K = 1 band disappeared. Therefore Newby shift is responsible for the behaviour of K = 1 band in ^{180}Ta and there is no role of decoupling parameter and matrix elements of high- j orbital.

III. MODEL AND METHODOLOGY

We have used the two-quasi particle plus rotor model (TQPRM) where an axially symmetric core is assumed. A detailed description of the model may be found in many our papers [4-6]. A brief description is, however, presented here for completeness.

The total Hamiltonian is divided into two parts, the intrinsic and the rotational,

$$H = H_{intr} + H_{rot} \quad ...(1)$$

The intrinsic part consists of a deformed axially symmetric average field H_{av}, a short range residual interaction H_{pair}, and a short range neutron-proton interaction V_{np}, so that

$$H_{intr} = H_{av} + H_{pair} + V_{np} \quad ...(2)$$

The vibrational part has been neglected in this formulation. For an axially symmetric reflection – symmetric rotor

$$H_{rot} = \hbar^2 / 2\Im\,(I^2 - I_3^2) + H_{cor} + H_{ppc} + H_{irrot} \quad ...(3)$$

Where,

$$H_{cor} = -\hbar^2 / 2\Im (I_+ j_- + I_- J_+),$$

$$H_{ppc} = \hbar^2 / 2\Im\, (j_{p+} j_{n-} + j_{p-} j_{n+}),$$

$$H_{irrot} = \hbar^2 / 2\Im [(j_p^2 + j_{pz}^2) + (j_p^2 - j_{pz}^2)].$$

The particle angular momentum j is given by the sum of the angular momentum of the odd proton j_p and the odd neutron j_n. The operators $I_\pm = I_1 \pm iI_2$, $j_\pm = j_1 \pm ij_2$, $j_{n\pm} = j_{n1} \pm j_{n2}$ and $j_{p\pm} = j_{p1} \pm j_{p2}$ are the usual shifting operators. $\Im$ is the moment of inertia with respect to the rotation axis.

The set of basis Eigen functions of $H_{av} + \hbar^2 / 2\Im\,(I^2 - I_3^2)$ may be written in the form of the symmetrised product of the rotational wave function D^I_{MK} and the intrinsic wavefunction |Kαρ> can be written as –

$$|IMK\alpha_p\rangle = \left[\frac{2I+1}{16\pi^2(1+\delta_{K0})}\right]^{1/2} \left[D^I_{MK}|K\alpha_p\rangle + (-1)^{I+K} D^I_{M-K} R_i |K\alpha_p\rangle\right] \quad ...(4)$$

Where the index α_ρ characterizes the configuration ($\alpha\rho = \rho_p\rho_n$) of the odd neutron and the odd proton.

The correct choice of the set of basis function is very important as all the states which may couple together and influence each other should be included in the calculations.

Diagonalization of the total Hamiltonian matrix for each value of the angular momentum I gives the energies E_{th} (I, α_ρ,σ) for all the bands built on the two-quasi particle (2qp) configuration $|K\alpha_\rho\rangle$ present in the basis set of the eigen functions. The Newby shift enters as a parameter along with other parameters such as the quasi particle energies E_α, the moment of inertia $\Im$ and the single matrix elements. The results are shown in Fig. 1. In the Fig. 1 we have shown both the results with and without Newby Shift. The Newby Shift is very important in explaining the odd-even staggering and also the magnitude of the staggering in 180Ta. The Newby Shift arises from the special nature of the wave function for a K=0 band which may be written as [6-9].

$$|IMK = 0, \alpha\rangle = (2I+1/32\pi^2)\, D^I_{M0}\ \{|K = 0, \alpha\rangle + (-1)^I R_i\, |K = 0, \alpha\rangle \quad ...(5)$$

Where R_i is the rotation operator exp(-iπj_α) with eigenvalues $j_\alpha = \pm 1$ and

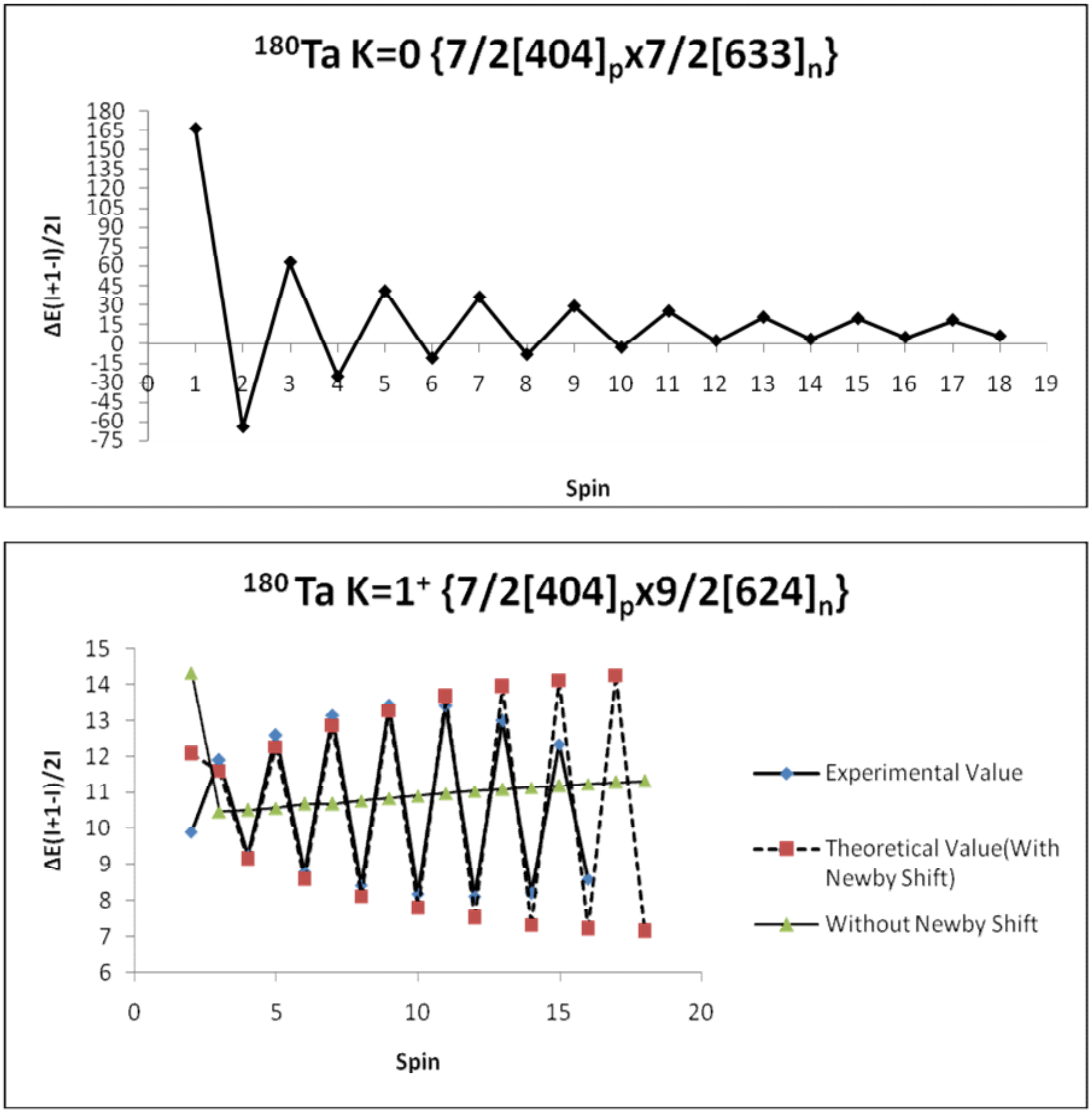
$$K = 0, \alpha\rangle = 1/\sqrt{2}\,\{|\rho_p\,\Omega\rangle\,|\rho_n\,-\Omega\rangle - j_\alpha|\rho_p\,-\Omega\rangle\,|\rho_n\,\Omega\rangle\} \quad ...(6)$$

The index α denotes the single particle configuration ($\alpha = \rho_n\,\rho_p$) of the odd neutron and the odd proton and K is the projection of the intrinsic angular momentum on the symmetry axis also $\Omega_p = \Omega_n = \Omega$. Thus the total wave function is non vanishing when j = +1, I = 0, 2, 4..... and j = -1, I = 1, 3, 5.....or j = $(-1)^I$. This splits the K=0 band into two sequences. The residual interaction V_{np} gives rise to a different diagonal contribution which causes an odd-even shift given by

$$E_N = (-1)^{I+1} \langle \rho_p\,\Omega; \rho_n\,-\Omega\,|\,V_{np}|\,\rho_p\,-\Omega; \rho_n\,\Omega\rangle \quad ...(7)$$

This Newby Shift of K = 0 band contribute to K = 1 band of 180Ta. The large odd-even staggering is well reproduced by the effect.

Fig. 1: The TQPRM calculation for 180Ta. K = 1 (Experimentally observed) and K = 0 (unknown) are shown in figure. The Odd-even staggering of K = 0 band is transmitted to K = 1 band.



IV. RESULTS

The odd-even staggering observed in K = 1 band of 180Ta is well reproduced by Two quasi-particle rotor model calculations. We conclude that only Newby Shift of K = 0 band is responsible for large odd-even staggering in K = 1 band. The results are compared with experimental data.

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