Role of Residual N- P interaction in K=0 bands of doubly odd rare earth nuclei

Kawalpreet Kalra[1]*, Uma V.S[1], Alpana Goel[2], Archana Yadav[2], A.K. Jain[3]
[1]*Department of Physics, Amity Institute of Applied Sciences (AIAS), Amity University, AUUP, Noida -201303, India*
[2]*Amity Institute of Nuclear Science and Technology (AINST), Amity University, AUUP, Noida-201303, India*
[3]*Department of Physics, Indian Institute of Technology (IIT), Roorkee- 247667, India*
*E-mail: kawal1211@gmail.com

Introduction:

The K = $|\Omega_p$-$\Omega_n|$= 0, 2qp rotational bands exhibit an odd-even staggering due to the Newby Shift [1]. The TQPRM calculations for K=0 bands had been done earlier by Goel et al. [2]. The odd-even shift of levels is used to get the empirical value of the Newby shift given by,

$$E_N = \frac{1}{2}(-1)^{I+1}[E_K(I) - E_K(I-1)] + \frac{\hbar^2}{2\Im}[(-1)^I . I - a_p a_n \delta_{\Omega_{p},\frac{1}{2}} \delta_{\Omega_{n},\frac{1}{2}}]$$

When $\Omega_p = \Omega_n = \Omega = 1/2$ orbital is involved, both the Newby term and decoupling parameter term present in the Newby shift expression become effective to get the required odd- even staggering pattern whereas in some cases decoupling parameter term does not play any role; only the Newby term is responsible for the staggering pattern. For $\Omega_p = \Omega_n \neq 1/2$ only the Newby term reproduces the odd-even staggering. A total of 36 cases have been analyzed for K=0 rotational bands in rare earth doubly odd nuclei. It has been observed that with $\Omega_p = \Omega_n = \Omega = 1/2$ orbital in ^{168}Tm and ^{172}Lu nuclei; the Newby term and decoupling parameter term both are significant but for other cases like **^{166}Ho, ^{168}Tm, ^{170}Tm, ^{172}Tm and ^{170}Lu** only the Newby term is important. The results of theoretical calculations are being reported in this paper.

Methodology:

A complete detail of the two quasiparticle plus rotor model (TQPRM) was presented by Jain et al. [3]. A brief outline necessary for this paper is given here.
The total Hamiltonian of the system in the framework of TQPRM is divided into two parts, the intrinsic Hamiltonian and the rotational Hamiltonian,

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

The intrinsic part is given by a deformed, axially symmetric average field H_{av}, a short range pairing interaction H_{pair} (pairing), a long range residual interaction H_{vib}, and a short range neutron - proton interaction V_{np}, so that

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

The effect of vibrational interaction has been neglected as the core is always in its vibrational ground state. For an axially-symmetric rotor, the rotational part of the Hamiltonian can be written as

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

The set of basis eigenvectors correspond to the eigenfunctions of H_{av}+ H_{pair} + $\frac{\hbar^2}{2\Im}$ (I^2- I_3^2) and may be written in the form of symmetrised product of Wigner function D^I_{MK} and intrinsic wavefunction |Kα> - $|IMK\alpha\rangle$ =

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

The Newby shift arises from the special nature of wave function for K=0 band may be written as $|IMK = 0, \alpha\rangle$ =

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

where K is the projection of the intrinsic angular momentum on symmetry axis [3] and $|K = 0, \alpha\rangle$ = $1/\sqrt{2}\{|\rho_p\Omega\rangle|\rho_n - \Omega\rangle - j_\alpha |\rho_p - \Omega\rangle|\rho_n\Omega\rangle\}$… (6)

Thus the total wave function is nonvanishing when j_α = +1, I=0, 2, 4..... and j_α = -1, I=1, 3, 5.....or j_α= $(-1)^I$. This splits the K=0 band into two sequences; j_α = +1 and j_α = -1 sequence corresponding to the different intrinsic wavefunction given by expression (6). The neutron - proton interaction V_{np} gives rise to a different diagonal contribution for j_α = ± 1 band members causing an odd-even shift given by the diagonal contribution,

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

The fitting procedure and selection of parameters:

The calculations can mix any number of bands representing the various two-quasiparticle states that are interacting strongly. The Newby shift enters as a parameter along with other parameters such as the quasiparticle energies E_{qp}, the moment of inertia $\Im$, and the single particle matrix elements $\langle j_+\rangle$. The single particle matrix elements $\langle j_+\rangle$ are initially taken from the Nilsson model wave functions [4]. The essential matrix elements and decoupling parameters are adjusted during the fitting process. We have used the MINUIT code to solve the least square fit problem [5]. The deformation parameters for each nucleus are taken from the paper by P.Mollar and J.R.Nix [6]. The energies of unidentified bands are estimated by using semi empirical formulation [7].

Results and Discussion:

The experimental data (level scheme) for K=0 rotational bands in rare earth region have been analyzed [8]. Total 36 cases of K=0 bands of doubly odd rare earth nuclei are observed. The results of TQPRM calculations are categorized in the following three cases:

(a) For configuration $\{1/2[411]_p - 1/2[400]_n\}$ in ^{168}**Tm** nuclei, the decoupling parameters of proton and neutron, both are effective to obtain the odd-even staggering but the magnitude of staggering is not completely reproduced. On incorporating the Newby term =10.43keV the magnitude of staggering has been well reproduced.
In ^{172}**Lu**, K=0, $\{1/2[541]_p - 1/2[521]_n\}$ band; with decoupling parameter but without the Newby term reverse staggering pattern is obtained i.e. even spins are favored. On incorporating the Newby term in the calculations; required staggering pattern is obtained.
The results are compared with the experimental odd-even staggering as shown in figure 1 and also with the previously calculated value by Goel et al. [2] as shown in Table 1.

(b) In ^{166}**Ho,** ^{168}**Tm,** ^{170}**Tm,** ^{172}**Tm,** ^{170}**Lu** for K=0, $\{1/2[411]_p - 1/2[521]_n\}$ band; only the Newby term in the Newby shift expression is responsible for the obtained odd-even staggering, decoupling parameter term is not having any effect. The results of calculation are shown in Table 1.

(c) For the remaining cases where $\Omega_p = \Omega_n \neq 1/2$, solely the Newby term is responsible for the odd-even staggering in K = 0 bands.

Table 1: Newby shift: TQPRM calculated value are compared with the experimental value and previously quoted value by Goel et al. [2, 8].

Configuration	Nucl.	Newby shift (keV) Exp.	Our	Previous Goel et al.	Deformation ϵ_2	ϵ_4
1	2	3	4	5	6	7
$1/2[411]_p - 1/2[400]_n$	^{168}Tm	25	10.43	22.3	0.267	0.033
$1/2[541]_p - 1/2[521]_n$	^{172}Lu	-92	-43.00	-68.0	0.267	0.053
$1/2[411]_p - 1/2[521]_n$	*^{166}Ho	_	47.61	_	0.267	0.020
	^{168}Tm	28	24.77	42.9	0.267	0.047
	^{170}Tm	37	31.56	37.9	0.267	0.047
	^{172}Tm	_	22.19	16.5	0.267	0.060
	^{170}Lu	_	22.22	16.8	0.267	0.040

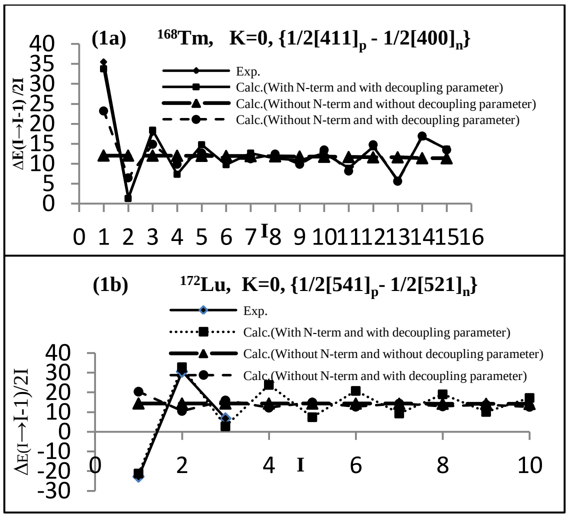

Fig. 1: The TQPRM plots between ΔE (I→I-1) / 2I (keV) versus I showing the importance of the Newby term (N-term) and decoupling parameter term.

Conclusion:

The experimental data of K=0 bands in the rare earth region has been analyzed. The Newby term in the expression of Newby shift is solely responsible for the observed odd-even staggering in K=0 bands except for the cases where $\Omega_p = \Omega_n = \Omega = 1/2$ orbital is involved and it shows the importance of decoupling parameter term as well as the Newby term.

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http://www.nndc.bnl.gov/chart/