Role of N-P residual interaction in $K = 0$ band in actinide region

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Introduction

The important characterstic of the rotational band with $K = 0$ in deformed nuclei is odd-even shift in rotational energy levels. The shifting in energy of $K = 0$ band caused by residual interaction among odd neutron and odd proton is known as Newby shift [1, 2].

The two most significant effects associated with the residual interaction between the odd neutron and the odd proton in doubly odd deformed nuclei are the Gallagher-Moszkowski (GM) splitting [3] and the Newby (N) shift [4]. Several efforts have been made to obtain detailed information on the effective n-p interaction in the rare-earth region from the empirical values of GM splitting and N-shift.

In the present paper we have done TQPRM calculations to quote correct sign and value of Newby shift in $K = 0$ band in actinide region and also compare it with the experimental data and other theoretical value available in literature.

Model Description

A detailed description of the two quasiparticle rotor model has been given in Ref. [5]. Here the total Hamiltonian of the system for odd-odd nuclei is usually expressed as:

$$H = H_{int} + H_{rot} \tag{1}$$

The above Hamiltonian is well explained in the given Ref. [5]. In the given Hamiltonian, the set of basis eigenvectors corresponds to the eigen-functions of $H_{av} + H_{pair} + \frac{\hbar^2}{2\jmath}(I^2 - I_3^2)$ and may be product of written in the form of the symmetrized Wigner functions D^I_{MK} and the intrinsic wave functions as,

$$|IMK\alpha> = \sqrt{\frac{2I+1}{16\pi^2(1+\delta_{ko})}} \times \left[D^I_{MK}|K\alpha_p> + (-1)^{I+K} D^I_{M-K} R_i |K\alpha_p>\right] \tag{2}$$

where the index α_p characterizes the $2qp$ configuration ($\alpha_p \equiv \rho_n\rho_p$) of the odd neutron and the odd proton. The single particle energies are used to calculate the one-quasiparticle ($1qp$) energies (E_{qp}) for all cases by formula,

Configuration / *Nucleus*	E_N^{Exp} [7]	E_N^{Th}	I_F Exp	I_F Rule	TQ-PRM	Frisk [4]
$[530\ 1/2]_p - [631\ 1/2]_n$						
^{238}Np	38	39.17	0	1	0	1
$[523\ 5/2]_p - [622\ 5/2]_n$						
^{238}Np	-29	-23.22	1	1	1	1
^{240}Am	-28	-40.82	1	1	1	1
^{242}Am	-27	-26.82	1	1	1	1
^{244}Am	-26	-26.10	1	1	1	1
$[400\ 1/2]_p - [631\ 1/2]_n$						
^{238}Np	-6	-6.24	1	0	1	0
$[642\ 5/2]_p - [622\ 5/2]_n$						
^{238}Np	-13	-50.84	1	1	1	1
^{242}Am	-60	-59.87	1	1	1	1
$[633\ 7/2]_p - [624\ 7/2]_n$						
^{244}Am	32	45.35	0	0	0	0

TABLE I: Empirical values of Newby Shift (experimental & theoretical) and comparison of spin with rule, experimental and other work.

$E_{qp}(\Omega) = [(\varepsilon_\Omega - \lambda)^2 + \Delta^2]^{1/2} - \Delta$ with pairing gap $\Delta = 1\ MeV$. These $1qp$ energies are used to calculate the two-quasiparticle ($2qp$) excitation energies by using the formula:

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$$E_{qp}(\Omega_p, \Omega_n) = E_{qp}(\Omega_p) + E_{qp}(\Omega_n) + (\frac{\hbar^2}{2\Im}) \pm \frac{1}{2} E_{GM} - \delta_{K,0} E_N . \quad (3)$$

E_{GM} is the Gallagher-Mosczkowski (GM) splitting energy and GM splitting of $\pm 100 keV$ is used here for the calculations, E_N is the Newby shift parameter for $K = 0$ bands. The values of the Newby shifts for $K = 0$ bands have been adopted from experimental data compiled by Jain et al. This definition of E_N is identical to the quantity B of Elmore and Alford (1976) but differs by a phase factor $(-\pi)$ with the quantity E_N of Boisson et al. [2]. It is also opposite in sign to the similar quantity discussed by Frisk [4], Jain et al. [5], and Goel et al. [6].

Results

In this section, we discuss the cases where the favoured spins by experimental data differ from rule. Our TQPRM calculation also support experimental data:

(i) The $[530\ 1/2]_p - [631\ 1/2]_n$ configuration in ^{238}Np, it is observed that the rule favours odd spin which is in accordance to Frisk while our TQPRM calculations favours even spin which supports experimental spins but it is opposite to the rule:

(ii) The $[400\ 1/2]_p - [631\ 1/2]_n$ configuration in ^{238}Np is again found mismatch in favoured spin by rule and calculations. The rule favours even spin which is in accordance to Frisk but TQPRM calculations give odd spin which can be observed experimentally.

In our calculations with TQPRM model, we have observed that Newby shift of $K = 0$ band plays an important role in explaining staggering feature. The odd-even staggering disappeared when Newby shift $E_N = 0$ for $K = 0$ band. It shows the importance of N-P residual interaction.

The $[530\ 1/2]_p - [631\ 1/2]_n$ and $[400\ 1/2]_p - [631\ 1/2]_n$ configurations in ^{238}Np, the theoretical value supports the spin assignments. Thus, the rule should be taken with caution when the orbitals are mixed.

$Configuration$ $Nucleus$	E_{Exp} (keV)	E_α (keV)	A (keV)	E_N (keV)
$[530\ 1/2]_p - [631\ 1/2]_n$				
^{238}Np	217.95	326.17	12.57	39.17
$[523\ 5/2]_p - [622\ 5/2]_n$				
^{238}Np	299.79	342.02	5.37	-23.22
^{240}Am	346	379.93	5.23	-40.82
^{242}Am	44.092	35.54	5.22	-26.82
^{244}Am	333.7	328.52	5.21	-26.10
$[400\ 1/2]_p - [631\ 1/2]_n$				
^{238}Np	243.96	236.96	4.49	-6.24
$[642\ 5/2]_p - [622\ 5/2]_n$				
^{238}Np	250.33	322.09	4.62	-50.84
^{242}Am	341.58	296.62	4.73	-59.87
$[633\ 7/2]_p - [624\ 7/2]_n$				
^{244}Am	375.2	472.53	3.32	45.35

TABLE II: Experimental energy $E_{Exp}(keV)$, Band head energy $E_\alpha(keV)$, Rotational parameter $A(keV)$ and Newby shift $E_N(keV)$ from our calculations.

Discussion

In 3 out of 5 configurations the rule works sufficiently well. However, in 2 of the remaining configurations, the favoured spin by experimental data differ from rule. Our TQPRM calculation also supports the experimental results. The Newby shift in all the cases changes marginally except two cases where the Frisk rule fails. The detail study is under process and will be produced later.

References

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