Shift in Signature Inversion in high-j bands of doubly odd Ho isotopes

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Introduction:

A systematic of the signature Inversion in high–j ($h_{11/2}$ proton and $i_{13/2}$ neutron) bands in odd –odd nuclei in rare earth region is presented. We have analyzed the experimental data for rare earth region from Pm to Re isotopes.The point of inversion shifts to lower /higher spin with the increase in neutron/proton numbers. Calculations are carried out within the frame work of Two Quasiparticle Rotor Model (TQPRM). The point of inversion and odd-even staggering is well reproduced by TQPRM calculations. We present the calculations for Ho isotopic chain.

The phenomenon of signature inversion observed at low spins in the high–K rotational bands of odd-odd nuclei has been discussed by earlier by us [1-4].These bands are composed of high-j, $h_{11/2}$ proton and $i_{13/2}$ neutron orbitals. It is now well known that the coupling of the odd proton and the odd neutron gives rise to a pair of bands with band quantum numbers $K_+= (\Omega_p + \Omega_n)$ and $K_-= (\Omega_p-\Omega_n)$. The K_+ bands composed of high-j configuration, display a very strong odd-even staggering in their rotational energy spacing, implying a signature dependence. For ($h_{11/2}$ x $i_{13/2}$) configuration bands, the even members should lie lower in energy. It has been observed that the odd-spin members lie in energy up to a certain spin I_c; the normal signature dependence is restored afterwards. This anomalous effect is known as **signature inversion.**

As was earlier suggested by Goel et.al [2], it is necessary to include the 1/2[541] proton orbital belonging to the $h_{9/2}$ orbit in order to explain point of inversion and strong odd-even staggering in 152Eu and 156Tb. But the point of inversion is well reproduced in 160Ho without including $h_{9/2}$ orbital. The experimental plots are shown in the fig.1 showing shifting in the point of inversion towards lower spin as we are moving toward higher isotopes in Ho chain. We have done calculations for the Ho chain and concluded that point of inversion is indeed reproduced without including 1/2[541] orbital. The results are shown in figure 2.

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 papers [5, 6]. A brief description is, however, presented here.

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

$H=H_{intr} + H_{rot}$ .... [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

$H_{intr}=H_{av}+ H_{pair} + V_{np}$ …... [2]

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

$H_{rot}=\hbar^2/ 2\Im(I^2-I_3^2) + H_{corv}+ H_{ppc} + H_{irrot}$ …..[3]

Where,

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

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

$H_{irro\,t}= \hbar^2 / 2\Im\left[\left(j_p^2 + j_{pz}^2\right) + \left(j_p^2 - j_{pz}^2\right)\right]$.

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_{MK}^I and the intrinsic wavefunction $|K\alpha\rho>$ can be written as -

$$|IMK\propto_p\rangle = \left[\frac{2I+1}{16\pi^2(1+\delta_{KO})}\right]^{½} \left[D^I_{MK}|K\alpha_p\rangle + (-1)^{I+K}D^I_{M-K}R_i|K \propto_p\rangle\right]$$

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. We have included all the orbitals of $h_{11/2}$ and $i_{13/2}$ for calculations. The magnitude of the odd-even staggering is very large as actual fitting of the data is not done.

Result and Discussion:

We have analyzed the experimental data for $h_{11/2}$ and $i_{13/2}$ orbitals for rare earth region from Pm to Re nuclei. **Table 1** present the experimental systematic of Ho nuclei [7,8]. The point of inversion is shifting towards lower spin as increase in neutron number i.e. normal feature is restored.

Table 1: Experimental systematic of 67Ho where each box list the following information:

Top row: K (observed), I_c (Inversion), **Middle row:** K and configuration from systematic, **Bottom row:** lowest observed spin & its energy in kev. xxx denotes energy unknown.

Configurations are abbreviated as: **protons**: B=7/2[523],]
Neutrons: U=1/2[660], V=3/2[651], W=5/2[642].

*N signifies no Inversion, Normal behaviour. *NS signifies Smooth Behaviour, no odd-even staggering. **NC signifies energy is not conformed, it is in the form of W+,X+,Y+.

67 Ho	**?, N 4,BU 11,NC****	**?, N 4,BU 9, xxx**	**5, 17 5,BV 8,208**	**6, 15 6,BW 6,118**	**6, N 6,BW 6,106**	**6, NS* 6,BW 6,140**
N	**87**	**89**	**91**	**93**	**95**	**97**

In Fig.1 Staggering plots of gamma energies Eγ(keV) with angular momentum (I) for experimental data are shown. In Fig 2 the results of the TQPRM calculations are shown by plotting graphs ΔE (I→I-1)/2I versus I for four Ho isotopes with A=158 to 164. The critical spin I_c of inversion is indicated by the arrow in the plots.

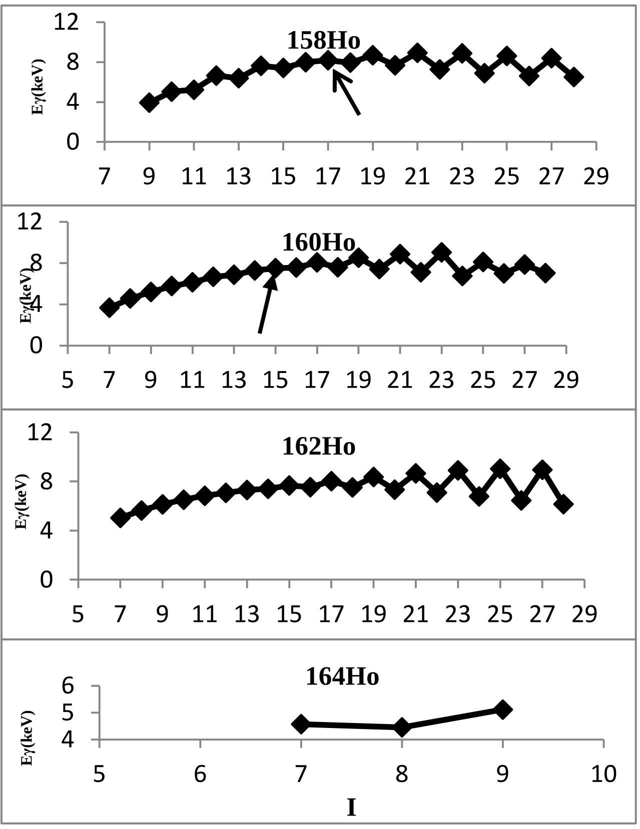

Fig.1: Experimental plot for Eγ(keV) vs. I .In the figure the point of Inversion is shown by arrow.

The unknown band head energies are estimated from neighbouring odd-A nuclei [9]. From the plots and calculations we can specify the following points:

(i) The point of signature Inversion I_c shifts towards lower spin with increasing neutron number in a chain of isotopes.

(ii) The magnitude of staggering before the inversion point becomes smaller with increasing neutron number in a chain of isotopes.

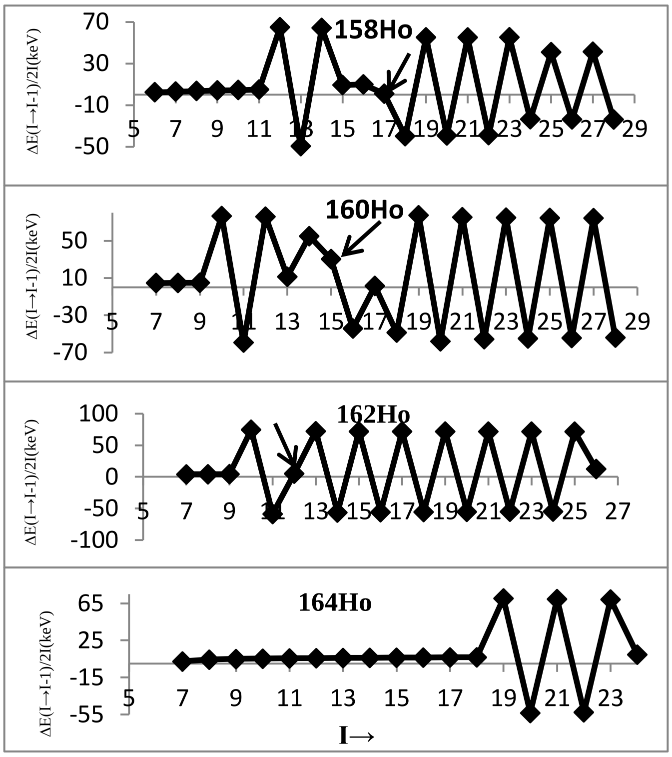

Fig.2: The TQPRM plots between ΔE (I→I-1) / 2I vs. I for Ho chain of isotopes. The point of Inversion I_c is shown by arrow.

References:

[1] Goel, Alpana and Jain A.K., Phys. Lett. B337, 240 (1994)
[2] Goel, Alpana and Jain A.K., Nucl. Phys. A 620,265 (1997).
[3] Kalra Kawalpreet, Alpana Goel, A.K.Jain, IJSRP, 2 (2012)
[4] Jain A.K. and Alpana Goel Phys. Lett.B277, 233(1992)
[5] Jain A.K..et al., Phys. Lett. B 209, 19(1988)
[6] Jain A.K..et al., Phys. Rev. C 40, 432 (1989)
[7] NNDC(National Nuclear Data Center).Brookhaven National Laboratory. [Cited on July 2013] http://www.nndc.bnl.gov/chart/
[8] Sirag Manal Mahmoud,Turk J Phys., 33,330(2009)
[9] Jain A.K..et al., Rev. .Mod. Phys., 62, .2(1990)