A Semi-classical Approach to Signature Splitting and Signature Inversion in Odd-Odd Nuclei

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Introduction

The signature quantum number is associated with symmetry under a rotation of a deformed nucleus around a principal axis by 180°. A rotational band splits into two sequences according to the signature, where I is the total angular momentum and $j_n(j_p)$ is the spin of odd neutron (proton) quasiparticle. The specific action in the rotating system in general is to decrease $I - j_n - j_p=$ even states with respect to the others in almost all the experimentally known cases, and for this reason it receives the name of favoured band and the other one the unfavoured partner. The energy shift between both bands at a given rotational frequency is called the signature splitting (SP), and it is characterized by a energy staggering. This shift is well understood in terms of the Coriolis coupling. The evolution of the energy staggering these couple of bands as a function of spin or angular frequency one may observe that sometimes the favoured and unfavoured bands cross each other producing the so-called signature inversion (SI) phenomenon.

The signature splitting and signature inversion have been studied so far in several nuclei. In this report we examine mass region 80, 100, 130 and 160. The energy staggering function is given as $(E_x(I)–[E_x(I+1)+E_x(I−1)]/2)$. The energy staggering values for even spins were plotted for mass 80 and 100, and are shown in Fig 1 and 2. The following experimental observations have been observed.

(i) Staggering values smoothly increase (starts from negative value to reaches positive value) for the levels of given configurations in mass 80 and 130, except few cases in 130.
(ii) Staggering values smoothly decrease (starts from positive value to reaches negative value) for the levels of given configurations in mass 100 and 160, except few cases in 100.
(iii) The states, which have staggering values below zero are called energetically favoured and above zero are called unfavoured. The spin at zero value is called critical spin (*Ic*). The even spin states at low spin, are favoured in mass 80, 130 and unfavoured in mass 100, 160.
(iv) The analysis of the individual trend of Ic versus N, reveals that for the mass 80, 130 region the critical spin shows a tendency to increase with increasing neutron number. On the other hand, the mass 100, 160 region present the reverse direction, the critical spin decreases with increasing neutron number. Mass region 100 and 130, except few cases, show a sort of intermediate. On the other word we can say that the critical spin (*Ic*) depends on valence neutron and proton number.

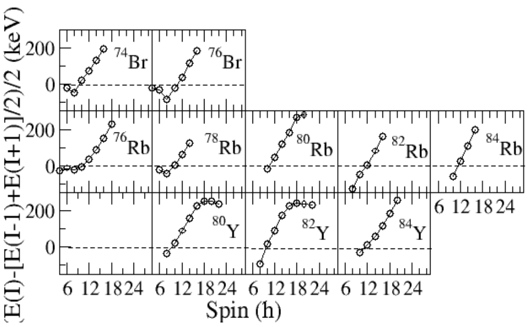

Fig.1: Energy staggering, defined in the text, as a function of spin for the $\pi g_{9/2}\otimes\nu g_{9/2}$ bands in odd-odd nuclei in mass 80.

The model Hamiltonian H for odd-odd nucleus could be written as $H = H_R + Hsn + Hsp$ [1,2]. The coupling between the particles and the rotation comes as $R = I - j_n - j_p$. In this case, another terms arises in addition to even-even system, called n-p interaction (H_{np}) and coriolis (H_c) will be given as

$$H_{np} = (\hbar^2/2\eth)[j_{n+}j_{p-} + j_{n-}j_{p+}]$$
$$H_c = -(\hbar^2/2\eth)[I_+j_{n-} + I_-j_{n+} + I_+j_{p-} + I_-j_{p+}]$$

The competition between n-p interaction and Coriolis interaction are main cause to energy staggering in Hamiltonian H.

$$H_{stagg} = H_c + H_{np}.$$
$$H_{stagg} = -A_1\,(-1)^{I-jp-jn}(Ij_n + Ij_p) + A_2(-1)^{jp+jn}j_n\,j_p$$

These terms are in arbitrary magnitude and shown theirs sign in Fig. 5 with respect to ($H_{remain} \equiv H_r$). The experimental observations from (i) to (iii) could be explained by competition between Coriolis and n-p interaction. The experimental observation (iv) could be explained by adding N_nN_p parameter.

$$H = H_r(\gamma) - A_1\,(-1)^{I-jp-jn}(Ij_n + Ij_p) + A_2(-1)^{jp+jn}j_n\,j_p - A_3N_nN_p$$

Figure 3 shows the behaviour of Coriolis interaction term $(-1)^{I-jp-jn}(Ij_n + Ij_p)\ (-1)$, n-p interaction $(-1)^{jp+jn}\ j_n\ j_p$ and valence nucleon factor *NpNn*. The $H^I stagg$ is due to only Coriolis and *n-p* interaction and the $H^{II} stagg$ includes the effect of number of valence nucleon. The energy staggering vary for valence proton and neutron are in same *j* orbit as shown in Fig.3 (a), by assuming the $\pi g_{9/2}\otimes\nu g_{9/2}$ configuration, and in different *j* orbit as in Fig.3 (b), by assuming the $\pi h_{11/2} \otimes \nu i_{13/2}$ configuration, for even spin states. *NnNp* shows the effect of valence nucleon on critical spin *(Ic)*. The magnitude of interaction is in arbitrary magnitude and shows only sign of magnitude with respect to H_r, which is given in text.

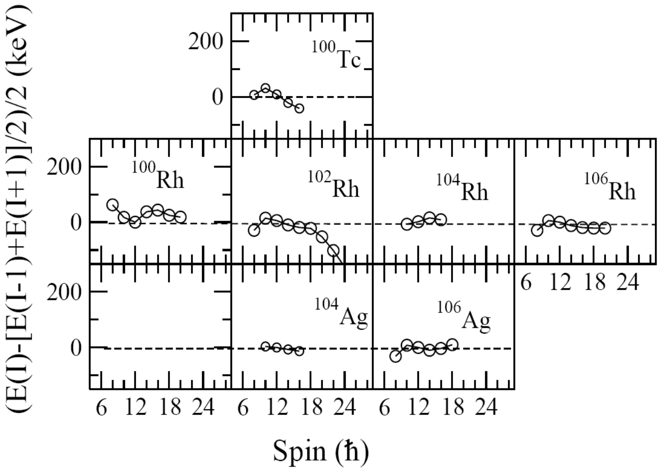

Fig.2: Energy staggering, defined in the text, as a function of spin for the $\pi g_{9/2}\otimes\nu h_{11/2}$ bands in odd-odd nuclei in mass 100.

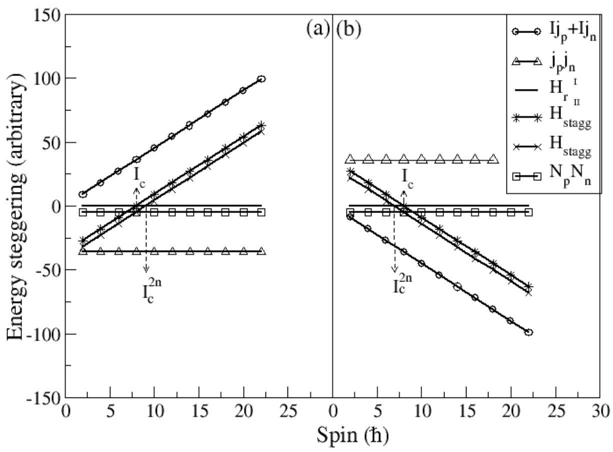

Fig.3 : The energy staggering vary for valence proton and neutron are in same *j* orbit as shown in (a), by assuming the $\pi g_{9/2}\otimes\nu g_{9/2}$ configuration, and in different *j* orbit as in (b), by assuming the $\pi h_{11/2}\otimes\nu i_{13/2}$ configuration, for even spin states.

References

[1] F.S. Stephens, Rev. Mod. Phys. Vol 47, 43 (1975).
[2] Renrong Zheng et al., Phys. Rev. C64, 014313 (2001).