Contrasting behavior of Signature Inversion in Rubidium Isotopes

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Introduction:

Among the features exhibited by the rotational spectra of doubly odd nuclei, signature inversion has attracted a lot of attention in both theory and experiments. Near the end of the last century many new experimental results were added in doubly odd nuclei of A=80 region, e.g. $^{76-82}_{37}$Rb [1-3, 8], ^{78}Br [4], ^{82}Y [5]. Although these studies have shown that the low-spin structure of these nuclei could be complex, very interesting systematic behaviors have been identified. One of the most striking features occurs in the behavior of the differences in energy between the odd and even spin states (signature splitting). In last few years, it has been observed that in different mass regions at A = 160, 130 and 80 [6-8] for doubly odd nuclei, signature inversion is a common phenomenon. Over the years, sufficient data have been accumulated by researchers to enable a meaningful study of the systematic of the signature inversion phenomenon to be undertaken. In the present paper the experimental data for isotopic chain of Rubidium (Rb) has been examined and analysis of the staggering pattern is presented.

Results and Discussion:

The positive parity levels in $^{76-82}$Rb nuclei result from the occupation of unique parity high-$g_{9/2}$ orbitals. The band configuration are same i.e. $[(g_{9/2})_p \otimes (g_{9/2})_n]$ but the band head spins are different between nuclei. As a rule, the energetically favored signature sequence in an odd-odd nucleus may have the signature $\alpha_f = 1/2(-1)^{j_p-(1/2)} + 1/2(-1)^{j_n-(1/2)}$ while the unfavored signature is determined by $\alpha_{uf} = 1/2(-1)^{j_p-(1/2)} + 1/2(-1)^{j_n+(1/2)}$ or $\alpha_{uf} = 1/2(-1)^{j_p+(1/2)} + 1/2(-1)^{j_n-(1/2)}$, where j_p and j_n are angular momentum of the valence proton and neutron respectively. Generally the levels with α_f are expected to lie lower in energy than the levels with α_{uf}. But in some of the bands with high-j configuration, favored signature branch lies higher in energy than the unfavored signature at low spin. But after a certain spin I_c called critical spin, the favored signature branch lies lower in energy than the unfavored signature at high spins. This feature is termed as **signature inversion.** According to the rule, the favored signature is $\alpha_f = 1$ so odd spins should be lower in energy than the even spin states. The signature splitting and inversion are best visualized by plotting the experimental quantity $\Delta E(I \rightarrow I - 1)/2I$ as a function of the spin (I). The plot of $[E(I) – E(I-1)]/2I$ versus I for the positive parity bands observed in different isotopes for $^{76-82}$Rb are presented in Figure 1. The critical spin I_c of inversion is indicated by the arrow in the plots. We have defined the critical spin I_c as the point where the abnormal phase of staggering sets in as we move from the higher spin side of the bands to the bandhead. This definition seems to be quite appropriate in view of the fact that the normal phase of staggering prevails at the higher spin side. With this definition in mind, we summarize in Table 1 the most important indicators of signature inversion from the experimental data. The experimental observations for Rb isotopes have revealed the following:

(i) The energy staggering values increase smoothly for the levels of given configurations in the chain of isotopes.

(ii) The even spin states at low spin and odd spin states at high spin are favored in the whole chain of isotopes.

(iii) The analysis of critical spin (I_c) in a chain of Rubidium isotopes reveals that the critical spin has a tendency to increase with increasing neutron number. The point of signature inversion I_c shifts towards higher spin with increasing neutron number in a chain of isotopes [9] in contrast to the rare earth nuclei. In the mass 160 region [6, 7] for rare earth nuclei, the opposite behavior is observed, i.e. the critical spin decreases with increasing neutron number. The point of signature inversion I_c shifts towards lower spin with increasing neutron number in a chain of isotopes for A ~ 160.

Calculations:

To study the underlying mechanism of signature inversion in the positive-parity yrast band in mass *A* ~ 80 region we have performed the TQPRM calculations for ^{78}Rb by incorporating rotational bands based on $g_{9/2}$ proton and $g_{9/2}$ neutron configuration. A detailed description of the model may be found in many papers [10]. The single particle matrix elements $\langle j_+ \rangle$ and excitation energies of these bands have been calculated by using the Nilsson wave functions [11]. The Nilsson model parameters, κ and μ for protons and neutrons are calculated by using the following relations respectively: κ_p= {0.0766-0.0779(A/1000)}, μ_p= {0.493+0.649(A/1000)} and κ_n = {0.0641-0.0026(A/1000)}, μ_n = {0.624-1.234(A/1000)} [9]. We are unable to find any signature inversion from our preliminary calculations, even if we set the quadrupole deformations equal to ε_2 = 0.30 for the low spin region and ε_2 = −0.280 for the high spin region.

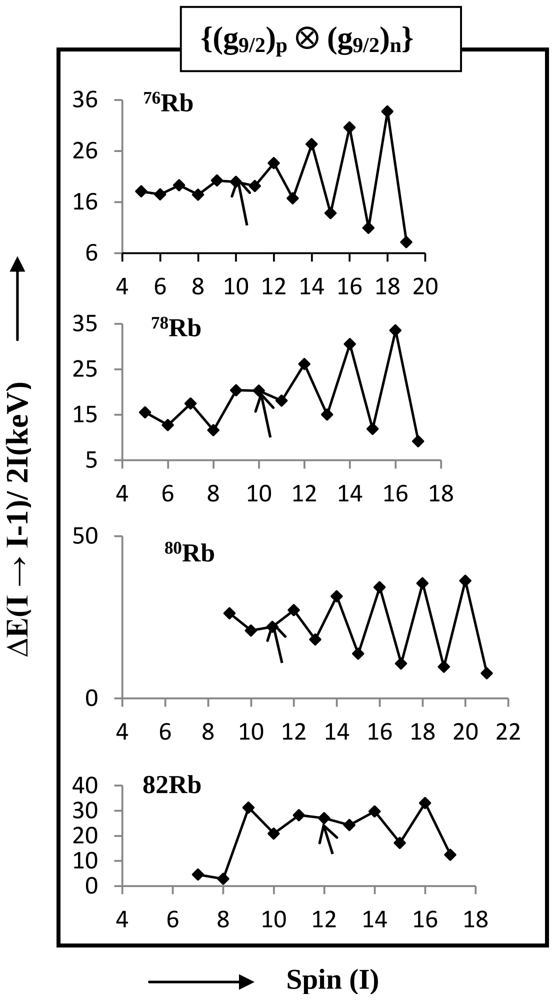

Figure 1: The experimental values of ΔE (I → I - 1) / 2I vs spin (I) of odd-odd nuclei and a comparison of the signature splitting and signature inversion in $\{(g_{9/2})_p \otimes (g_{9/2})_n\}$ positive parity band for $^{76-82}$Rb.

The results of calculations for the yrast states of positive parity are obviously in satisfactory agreement with the experimental results in the high spin region but in the low spin region the point of signature inversion could not reproduced. According to the projected shell model calculations for ^{78}Rb [2] , this signature pattern is a result of a shape change that occurs as the spin increases. This is a novel observation which suggests that the nucleus changes from a prolate shape at low spin to an oblate shape at high spin i.e. there is shape coexistence.

Table 1: Point of inversion for $^{76-82}_{37}$Rb. N represents the neutron number and I_c represents the point of inversion.

$_{37}$**Rb**	I_c=10	I_c=10	I_c=11	I_c=12
N	39	41	43	45

It is observed from the above drawn table that when we move from ^{76}Rb to ^{82}Rb, the point of inversion is shifting towards higher spin. It is shifting from I_c =10 (in^{76}Rb) to I_c = 12 (in ^{82}Rb).

Conclusion:

An analysis of the experimental data for Rb isotopes has been presented. The point of signature inversion is observed to shift to higher spin with increase in neutron number in a chain of isotope which is just opposite in nature when compared to A~ 160 mass region. TQPRM calculations for yrast positive parity band for $\{(g_{9/2})_p \otimes (g_{9/2})_n\}$ in ^{78}Rb shows that the phenomenon of signature inversion which was observed in high-j orbitals of rare earths is also present in low mass region. The odd- even staggering is well reproduced in high spin region by calculations and further investigations are required to reproduce the exact point of signature inversion in low spin region.

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References:

[1] A. Harder et al. Phys. Rev. C **51**, 2932, 1995.
[2] R. A. Kaye, Phys. Rev. C **54**, 1038, 1996.
[3] R. Schwengner, Phys. Rev. C **66**, 024310, 2002.
[4] E. Landulfo, Phys. Rev. C **54**,626, 1996.
[5] S. D. Paul, Phys. Rev. C **51**, 2959, 1995.
[6] A. Goel and A.K. Jain, Nucl. Phys. A 620: 265, 1997
[7] K. Kalra et al. Pramana- J. of Phys. 84(1): 87, 2015.
[8] He Chuangye et al. Phys. Rev. C **87**, 034320, 2013.
[9] Renrong Zheng, Phys. Rev. C, 64, 014313, 2001.
[10] A. K. Jain et al., Phys. Rev. C 40, 432 (1989); A. K. Jain et al., Rev. Mod. Phys. 62, 393 (1990).
[11] S. G Nillson et al., Nucl. Phys. A 131, (1969).