NEW REGION OF SIGNATURE INVERSION IN THE A $\approx$ 100 Rh AND Ag ISOTOPES*

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Study of high-spin bands in the $A \approx 100$ mass region revealed that signature inversion systematically occurs in the $\pi g_{9/2}\nu h_{11/2}$ bands and in the three-quasiparticle bands containing this configuration, establishing here a new region of signature inversion. The behaviour of the inversion spin in the $\pi g_{9/2}\nu h_{11/2}$ bands can qualitatively be understood as a competition between the Coriolis and the proton–neutron interaction, as it was proposed earlier for the analogous $A \approx 160$ region, if we take the variation of the moment of inertia into account.

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1. Introduction

In $\Delta I = 1$ rotational bands, the two signature branches are usually not equivalent energetically. Due to the Coriolis force acting on the valence particles, one of them, called favoured, is lower in energy than the other branch. The favoured signature is determined by the configuration and can be obtained in terms of a simple rule. Some two- and three-quasiparticle bands, however contradict this simple rule at low spin: the expected favoured signature branch becomes energetically unfavoured. This so-called signature inversion has recently attracted a lot of attention both in experimental and theoretical aspects.

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After the first observations of signature inversion in ^{76}Br and in the rare-earth nuclei [1] Bengtsson *et al.* interpreted the phenomenon by CSM as a consequence of triaxial deformation with positive γ-deformation parameter [2]. They have pointed out that signature inversion can be expected in two- and three-quasiparticle bands of γ-soft nuclei when one of the valence nucleons lies in a low-Ω orbital of a high-j shell and an other valence nucleon lies on a high- or medium-Ω orbital of a high-j shell. Following this prediction a large amount of experimental information has been collected showing that the $\pi g_{9/2}\nu g_{9/2}$ bands in the $A \approx 80$, as well as, the $\pi h_{11/2}\nu h_{11/2}$ bands in the $A \approx 130$ and the $\pi h_{11/2}\nu i_{13/2}$ bands in the $A \approx 160$ mass regions systematically show signature inversion. Reviews of the experimental facts are given in Ref. [3].

However, the γ-values necessary to account for the experimental data in many cases were much larger than the γ-values obtained from potential energy surface calculations indicating that triaxiality is not sufficient to interpret the phenomenon. Other mechanisms have also been suggested to explain it pointing out the role of the proton–neutron residual interaction [4] and recently the role of the mean-field contribution of the quadrupole pairing interaction [5]. These calculations describe reasonably well the behaviour of signature inversions within one or two regions. Zheng *et al.* suggested that the competition between the proton–neutron residual interaction and the Coriolis interaction could be a universal mechanism of signature inversion in doubly odd nuclei for different mass regions [6].

At present it is still not completely clear what mechanisms cause signature inversion in the different mass regions and if there exists a universal mechanism or not. Collecting more experimental data in new mass regions could help in answering these questions.

2. Signature inversion in the $A \approx 100$ mass region

In the $A \approx 100$ mass region the valence proton building the $\pi g_{9/2}\nu h_{11/2}$ configuration lies in the middle of the $g_{9/2}$ subshell while the neutron lies in the bottom at the $h_{11/2}$ subshell implying that signature inversion can be expected in these bands. However, experimentally these bands were not well known up to high spins until now. It has been pointed out by several authors that in this region the $\pi g_{9/2}\nu h_{11/2}$ bands and the three-quasiparticle bands containing this configuration have much smaller signature splitting than the one-quasiparticle $\pi g_{9/2}$ bands. This phenomenon was attributed to configuration dependent triaxiality [7] or to a drastic change in the deformation [8]. The relative position and the crossing of the favoured and unfavoured signature partners, however, have not been discussed. Signature inversion in the $A \approx 100$ region has been reported earlier only in one case, ^{98}Rh [9].

Our recent study on the $^{100-103}$Rh isotopes [10–12] and a close inspection at the known $\pi g_{9/2}\nu h_{11/2}$ bands of the Rh and Ag isotopes revealed that the signature splitting effects, earlier considered as quenchings of signature splitting, are not only quenchings but signature inversions. Moreover, these results show that signature inversion systematically occurs in this region in the $\pi g_{9/2}\nu h_{11/2}$ bands and in the three-quasiparticle bands containing this configuration. The obtained energy difference plots, showing the signature inversion, are presented in Fig. 1 for the $\pi g_{9/2}\nu h_{11/2}$ bands (left panel) and for the three-quasiparticle bands (right panel). The favoured–unfavoured order is inverted at low spin for all the $\pi g_{9/2}\nu h_{11/2}$ bands in the figure. The low-spin part of the ^{100,102}Rh bands and the ^{104,106}Ag bands are very similar to each other: the inverted signature splitting is small compared to the one in the neighbouring $\pi g_{9/2}$ bands, and it decreases gradually up to the inversion spin $I = 15\hbar$. This inversion spin is considerably larger than $j_n + j_p$=10$\hbar$. This behaviour is very similar to the behaviour of signature inversion in the $A \approx 130$ region. The best example among these four isotopes above mentioned is ^{102}Rh which shows the characteristics of signature

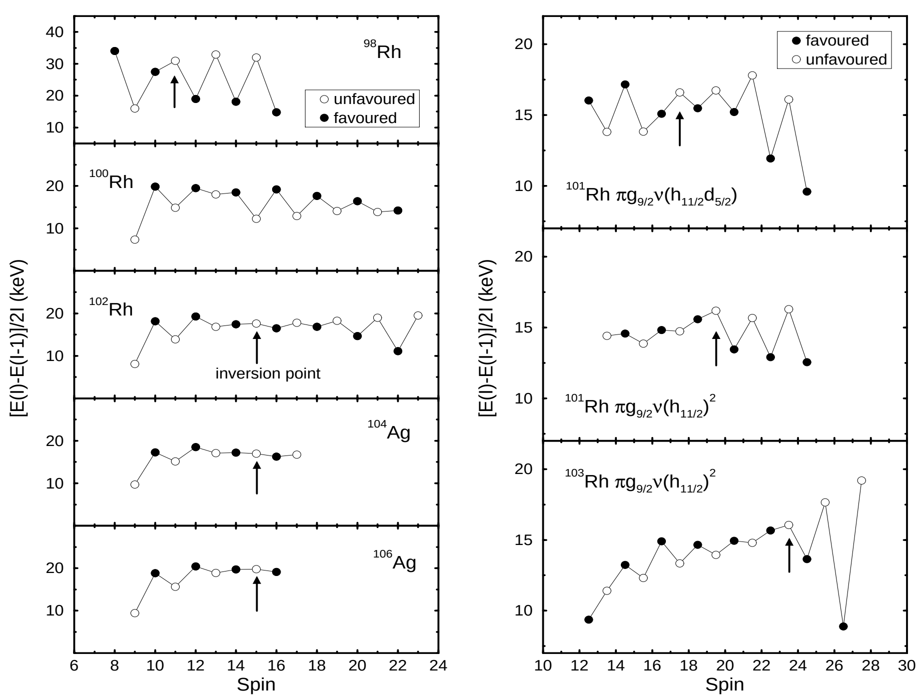

Fig. 1. Energy difference plots of $\pi g_{9/2}\nu h_{11/2}$ bands (left panel) and for three-quasiparticle bands (right panel) in the $A \approx 100$ mass region.

inversion well established in the other mass regions also above the inversion spin. As the bands in the Ag isotopes in the known spin region behave similarly to the ^{102}Rh band, one can expect similar behaviour also for the spin region above the inversion spin which is not known experimentally. In the case of ^{100}Rh the normal signature order does not restore in the known spin region because from about spin $15\hbar$ this band is disturbed by another, probably four-quasiparticle band [10]. However, on the basis of its low-spin behaviour, one can expect I$\approx 15\hbar$ inversion spin for this band, too. The ^{98}Rh band behaves differently from the others. It has a larger signature splitting, the inversion is much more abrupt than in the other cases and the inversion takes place at spin $I = 11\hbar$, very close to $j_n + j_p$=$10\hbar$. The three-quasiparticle bands containing the $\pi g_{9/2}\nu h_{11/2}$ configuration also show signature inversion (see the right panel of Fig. 1). Contrary to the doubly odd cases the inversion spin in the $\pi g_{9/2}\nu(h_{11/2})^2$ bands seems to show a pronounced neutron number dependence when moving from ^{101}Rh to ^{103}Rh.

3. Competition between the Coriolis and the proton–neutron interactions

The observed systematic occurrence of signature inversion in the $A \approx 100$ region can qualitatively be understood assuming large positive-γ triaxiality as it was discussed in Ref. [11]. However, Total Routhian Surface calculations based on Woods–Saxon potential [13] and configuration dependent Nilsson–Strutinsky cranking calculations [14] both predict $\gamma \approx 6°$ for the $\pi g_{9/2}\nu h_{11/2}$ band in ^{102}Rh. This small γ value is not sufficient to explain the observed signature inversion [12]. Other causes *e.g.* proton–neutron interaction probably also play important role.

Information on the nature of signature inversion could be inferred in other mass regions from the systematic behaviour of the inversion spin in function of the neutron and proton numbers. Considering that the j-Ω structure of the $\pi g_{9/2}\nu h_{11/2}$ bands in the $A \approx 100$ region is very similar to that of the $\pi h_{11/2}\nu i_{13/2}$ bands in the $A \approx 160$ mass region, we can expect a similar behaviour of the inversion spin. In the $A \approx 160$ region the inversion spin increases with increasing proton number and decreases with increasing neutron number in agreement with the calculations of Zheng *et al.* [6]. In their model this behaviour is attributed to a competition between the Coriolis and the proton–neutron interactions. Stronger Coriolis interaction decreases while stronger proton–neutron interaction increases the inversion spin. The observed variation of the inversion spin in the $A \approx 160$ region is mainly due to the variation of the proton–neutron interaction strength as the Fermi level moves. Increasing proton Fermi level increases while increasing neutron Fermi level decreases the interaction strength and consequently the inversion spin. Similar behaviour can be expected in the $A \approx 100$ region, too.

In the $A \approx 100$ Rh nuclei, however, the observed inversion spins of the $\pi g_{9/2} \nu h_{11/2}$ bands behave differently. In ^{98}Rh it is $10\hbar$ while in ^{100}Rh and ^{102}Rh the inversion spin is $15\hbar$. Although this behaviour seems to contradict the above model, it can be understood qualitatively by this model if we take also the variation of the moment of inertia into account. The Coriolis interaction is inversely proportional to the moment of inertia at a certain spin, thus an increasing moment of inertia decreases the Coriolis interaction and, in this way, increases the inversion spin. Indeed, the experimental kinetic moment of inertia is $20\hbar^2$/MeV, $29\hbar^2$/MeV and $30\hbar^2$/MeV for ^{98}Rh,^{100}Rh and ^{102}Rh, respectively, at spin $12\hbar$. The obtained big increase in the kinetic moment of inertia from ^{98}Rh to ^{100}Rh is very probably due to a big increase in the β deformation parameter. Then the deformation does not change too much from ^{100}Rh to ^{102}Rh. This scenario is supported also by the β=0.13 and β=0.19 deformation parameters proposed for ^{98}Rh [9] and ^{102}Rh [12], respectively. The experimental kinetic moment of inertia is increased by 45% from the ^{98}Rh band to the ^{100}Rh band. The effect of this large decrease of the Coriolis interaction could overcome the effect of the smaller decrease of proton–neutron interaction and rises the inversion spin from $10\hbar$ to $15\hbar$. The large decrease of the signature splitting is also in agreement with the large decrease of Coriolis interaction. In the next step from the ^{100}Rh band to the ^{102}Rh band, the increase of the experimental moment of inertia is much smaller, *i.e.* only 4%. This might be just enough to compensate the effect of the small decrease of the proton–neutron interaction and to leave the inversion spin at $15\hbar$. The bands in the Ag isotopes have similar moment of inertia and the same inversion spin: $15\hbar$.

The observed large increase of the inversion spin in the $\pi g_{9/2} \nu (h_{11/2})^2$ bands when moving from ^{101}Rh to ^{103}Rh, however, does not fit to this scenario as the experimental moment of inertia increases only by 5%. It might be caused by a sudden change in the γ shape parameter of these nuclei.

4. Conclusion

$\pi g_{9/2} \nu h_{11/2}$ and $\pi g_{9/2} \nu (h_{11/2})^2$ bands were studied in the $A \approx 100$ region. It has been revealed that signature inversion systematically occurs in these bands. Two types of signature inversion have been observed in this region. The first one is found only in the $\pi g_{9/2} \nu h_{11/2}$ band of ^{98}Rh. It has a large signature splitting and the inversion spin is close to the $j_n + j_p$=$10\hbar$ value. All the other cases belong to the second type which has a small signature splitting and an inversion spin considerably higher than $j_n + j_p$=$10\hbar$. The $\pi g_{9/2} \nu h_{11/2}$ bands belonging to this type are very similar to each other, they all have the same inversion spin of $I = 15\hbar$. The behaviour of the inversion spin can be qualitatively understood as a competition between the

Coriolis and the proton–neutron interaction, as it was proposed by Zheng *et al.* for the $A \approx 160$ region, if we take the variation of the moment of inertia into account. According to this scenario the big difference between the signature inversions in ^{98}Rh and in the other doubly odd nuclei is caused by a big change in the deformation.

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