Some recent experimental results related to nuclear chirality

J Timár[1], I Kuti[1], D Sohler[1], K Starosta[2], T Koike[3] and E S Paul[4]

[1] Institute for Nuclear Research, Hungarian academy of Sciences, H-4026 Debrecen, Hungary
[2] Department of Chemistry, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada
[3] Graduate School of Science, Tohoku University, Sendai, 980-8578, Japan
[4] Oliver Lodge Laboratory, Department of Physics, University of Liverpool, Liverpool L69 7ZE, UK

E-mail: timar@atomki.mta.hu

Abstract. Detailed band structures of three chiral-candidate nuclei, ^{134}Pr, ^{132}La and ^{103}Rh have been studied. The aim of the study was twofold. First, to try to explore the reasons behind the contradiction between the theoretically predicted chirality in these nuclei and the recently observed fingerprints that suggest non-chiral interpretation for the previous chiral candidate band doublets. Second, to search for multiple chiral bands of different types in these nuclei. In ^{134}Pr a new $\pi h_{11/2}\nu h_{11/2}$ band has been observed besides the previously known chiral-candidate $\pi h_{11/2}\nu h_{11/2}$ doublet. This new band and the yrare $\pi h_{11/2}\nu h_{11/2}$ band show the expected features of a chiral doublet structure. This fact combined with the observed similarity between the band structures of ^{134}Pr and ^{132}La suggests that chirality might exist in these nuclei. The detailed study of the ^{103}Rh band structure resulted in the observation of two new chiral-doublet looking structures besides the previously known one. This is indicative of possible existence of multiple chiral doublet structure in this nucleus.

1. Introduction

Chiral-candidate doublet bands in the triaxial A≈105 and A≈130 nuclei attracted great interest in the past decade. Many such doublet structures corresponding to particular configurations have been identified in these mass regions. These doublets were subjects of numerous theoretical and experimental studies, which either confirmed or contradicted with the chiral interpretation of the actual bands. The performed studies have focused mainly on the observed chiral-candidate doublet band structures while a major part of the rotational bands has remained unexplored. However, recent theoretical studies indicated that study of the whole band structure in a nucleus can be important from chirality point of view.

It has been shown in Ref. [1] that the expected fingerprints in non-ideal chiral cases can change considerably. Thus, it is not enough to compare the observed properties with the fingerprints derived for ideal cases. Realistic calculations are needed to identify chirality, especially in cases of controversial observed chiral fingerprints. However, realistic calculations require knowledge on the whole band structure, not only on the particular doublet.

Also, recent theoretical studies have shown that chirality in nuclei can also be manifested in features that are beyond the properties of the firstly observed nearly-degenerate doublet bands.

It has been proposed that more than one configuration in a nucleus can have chiral properties [2], or more than one pair of degenerate bands corresponding to the same configuration can exist in case of chirality [3, 4].

Motivated by these predictions, we have studied the detailed band structures of several chiral-candidate nuclei in the A≈105 and A≈130 mass regions, of which we discuss here the cases of ^{134}Pr, ^{132}La and ^{103}Rh.

2. Possible chirality in ^{134}Pr and ^{132}La

^{134}Pr and ^{132}La were the first nuclei in which chiral candidate doublet band structures have been observed [5, 6]. These observations were in agreement with theoretical results that confirmed the existence of chirality in these nuclei. However, results of subsequent lifetime experiments for these doublet bands contradicted with the chiral interpretation [7, 8].

We have studied the detailed band structures of these nuclei based on high-statistics experiments. Excited states of ^{134}Pr were populated following the ^{116}Cd(^{23}Na,5n) reaction at a beam energy of 115 MeV and the gamma transitions were detected using the GAMMASPHERE spectrometer. The bands of ^{132}La were excited in the ^{100}Mo(^{36}S,p3n) reaction at 160 MeV beam energy, and studied with the EUROBALL IV spectrometer. In both cases the off-line analysis of coincident γ rays was carried out using the RADWARE software package and an angular-correlation analysis, based on the DCO (directional correlation of oriented states) was performed for γ-ray multipolarity assignments. In the case of the EUROBALL experiment, the clover detectors, placed at 90 degrees relative to the beam direction, also allowed of linear polarization analysis.

As a result, we have observed many new rotational bands in ^{134}Pr, assigned single-particle configurations to them, and identified one of the previously known two long-halflife isomers as the ground state [9]. One of the new bands (band 3 in Fig. 1) has $\pi h_{11/2}\nu h_{11/2}$ configuration and is linked by many transitions to the previously known $\pi h_{11/2}\nu h_{11/2}$ doublet (bands 1 and

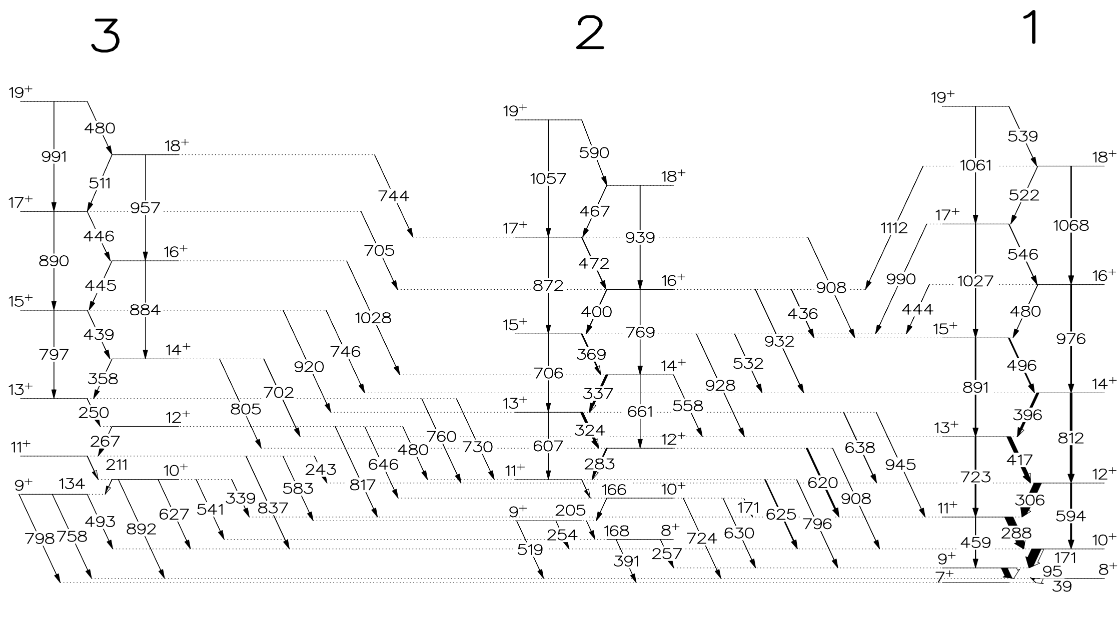

Figure 1. Partial level scheme of ^{134}Pr, showing the three $\pi h_{11/2}\nu h_{11/2}$ bands up to spin 19.

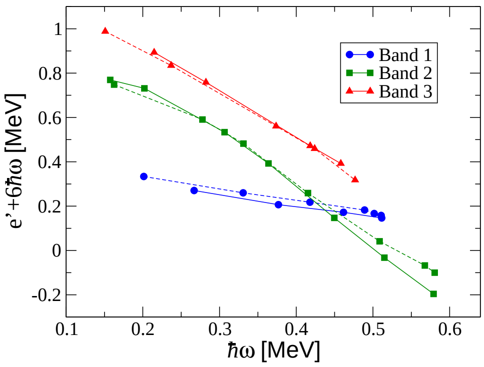

Figure 2. Routhian+$6\hbar\omega$ for the three $\pi h_{11/2}\nu h_{11/2}$ bands in ^{134}Pr as a function of the rotational frequency.

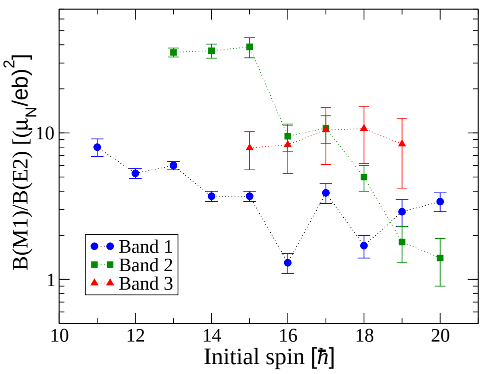

Figure 3. B(M1)/B(E2) values for the three $\pi h_{11/2}\nu h_{11/2}$ bands in ^{134}Pr as a function of the spin.

2 in Fig. 1). This new band has an approximately constant ~200 keV energy separation from band 2 and their Routhians have approximately the same slopes as a function of the rotational frequency, thus their single particle alignments are approximately equal (Fig. 2). We could not derive lifetime values for the levels of this new band; however it has been observed that the B(M1,$I\to I-1$)/B(E2,$I\to I-2$) ratios of bands 2 and 3 are close to each other in the 16 - 18 spin region (Fig. 3). These observations suggest that bands 2 and 3 may be chiral partner bands in a geometry corresponding to a chiral vibration. Therefore, the presence of chirality in this nucleus may not be excluded in spite of the lifetime results. We note that the occurrence of more than two bands close to each other corresponding to the chiral candidate configuration is predicted by calculations in this mass region [3]. In these predictions the first two and the second two bands are chiral partners of each other. However, the observed bands in ^{134}Pr are different from these predicted band structures because here the second and third bands show the chiral doublet features. In our case a possible scenario is that two shapes coexist in the $\pi h_{11/2}\nu h_{11/2}$ configuration, as it is discussed in Ref. [10], one of which is less triaxial while the other is close to the maximal triaxiality. In this case band 1 corresponds to the less triaxial shape, and is not chiral, while bands 2 and 3 correspond to the triaxial shape, and they are chiral.

As a byproduct of the lifetime experiment published in Refs. [11, 8], a new band has also been observed in ^{132}La, which is linked by many transitions to the yrast $\pi h_{11/2}\nu h_{11/2}$ band. Although the spins and the parity of the levels of this band could not be determined unambiguously, the authors tentatively assigned positive parity and spins that suggested a small energy separation between the new band and the previously known candidate chiral doublet. Moreover, the observed B(E2) values in the new band were found to be close to that of the yrast $\pi h_{11/2}\nu h_{11/2}$ band. Therefore, the scenario of the two bands being members of a chiral vibrational doublet, similarly to the case of ^{134}Pr, seemed to be possible. Our aim was to determine the spins and parities in order to confirm or reject this possibility. As a result of our studies, we built a corrected version of the new band and determined its parity and the spins of its levels [12]. The parity turned out to be negative, and the spins indicated a four-quasiparticle configuration. Thus, the possibility that this band is the chiral partner of the yrast band has been rejected. On the other hand, the results of our detailed study on the band structures of ^{134}Pr and ^{132}La revealed a strong similarity between both the low-lying states and the high-spin bands of the two nuclei. Based on this similarity, it is probable that ^{132}La also has more than two $\pi h_{11/2}\nu h_{11/2}$ bands close to each other in energy, and two of them may show the features of a chiral doublet. Although the observed hints for chirality are needed to be confirmed by higher-statistics experiments in case of ^{132}La, as well as by lifetime measurements and realistic calculations for both nuclei, the existence of chirality may not be excluded in ^{134}Pr and ^{132}La.

3. Possible multiple chiral doublet bands in ^{103}Rh

A chiral candidate doublet band structure, based on the three-quasiparticle $\pi g_{9/2}\nu(h_{11/2})^2$ configuration, has been observed previously in ^{103}Rh and ^{105}Rh [13]. In ^{105}Rh another chiral candidate doublet structure has been reported corresponding to the $\pi g_{9/2}\nu h_{11/2}(g_{7/2}, d_{5/2})$ configuration [14]. In agreement with these observations, diabatic and configuration-fixed constrained triaxial relativistic mean-field calculations predicted the existence of a new phenomenon, the multiple chiral doublet (MχD) in ^{105}Rh [15]. These calculations predicted two chiral doublet band structures with the $\pi g_{9/2}\nu h_{11/2}d_{5/2}$ and $\pi g_{9/2}\nu(h_{11/2})^2$ configurations.

We have studied the detailed band structure of the neighbouring ^{103}Rh to search for MχD in this nucleus, too. High-spin states in ^{103}Rh were populated using the ^{96}Zr(^{11}B,4n) reaction at 40 MeV beam energy. The emitted γ-rays were detected by the GAMMASPHERE spectrometer. A total of $\sim 9\times10^8$ quadruple- and higher-fold events were accumulated using a thin target, and sorted off-line into 2-d, 3-d, and 4-d histograms.

As a result of the analysis, we have observed several new bands. According to the preliminary configuration assignments, four of the observed negative-parity bands have the $\pi g_{9/2}\nu h_{11/2}(g_{7/2}, d_{5/2})$ configuration and form two pairs which show the characteristics of chiral doublets. There is a very small energy difference between the members of the doublets (less then 100 keV), and their B(M1)/B(E2) ratios are also close to each other. This is the configuration for which chirality has been predicted in ^{105}Rh. If the calculations confirm the chirality for these configurations also in ^{103}Rh, then the existence of three chiral doublet bands will be probable including the previously known chiral candidate band in this nucleus.

Acknowledgments

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