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Evidence for a new region of chirality around $A \sim 104$

P Joshi[1], S Finnigan[2], D B Fossan[3], T Koike[4], E S Paul[2], G Rainovski[3], K Starosta[5], C Vaman[3] and R Wadsworth[1]

[1] Department of Physics, University of York, York, YO10 5DD, UK
[2] Oliver Lodge Laboratory, Department of Physics, University of Liverpool, L4 7ZE, UK
[3] Department of Physics and Astronomy, SUNY, Stony Brook, NY 11794-3800, USA
[4] Graduate school of science, Tohoku University, Sendai, 980-8578, Japan
[5] NSCL, Michigan State University, 164 S. Shaw Lane, East Lansing, MI 48824-1321, USA

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Abstract
Chirality in atomic nuclei is a direct consequence of the existence of triaxial nuclear shapes. This phenomenon is known to exist in the $A \sim 130$ region. We have now observed several pair of bands built upon the negative parity configuration, $\pi g_{9/2}^{-1} \otimes \nu h_{11/2}$, in Rh and Tc isotopes in the $A \sim 104$ region which can be understood in terms of the phenomenon of chiral symmetry breaking. Results of the search for chiral bands in ^{106}Ag are presented in the current paper.

1. Introduction

Theoretical work has suggested that chirality may exist in triaxial atomic nuclei [1, 2] and be manifested by the presence of pairs of nearly degenerate strongly coupled bands having the same parity. The first experimental evidence for such structures was found in the $A \sim 130$ region where nearly degenerate pairs of bands built on a unique positive parity $\pi h_{11/2} \otimes \nu h_{11/2}^{-1}$ configuration were observed [3]. For this configuration the high-j particle-like $h_{11/2}$ proton orbital has its angular momentum vector oriented along the short axis while the high-j hole-like $h_{11/2}$ neutron orbital has its angular momentum oriented along the long axis of the triaxial nucleus. The rotational angular momentum of the core points along the intermediate axis in order to minimize the energy, since this axis has the largest moment of inertia according to the irrotational flow model. This gives rise to left- and right-handed systems in the intrinsic frame of the nucleus and results in nearly degenerate doublet bands in these nuclei.

2. Characteristics of chiral bands in $A \sim 100$ region

The left- and right-handed geometry, described in the above section, can also exist in other mass regions of the nuclear chart provided triaxial nuclear shapes are present. In the

$A \sim 100$ region one finds such a situation where the chiral structures result from the occupation of $\pi g_{9/2}^{-1} \otimes \nu h_{11/2}$ configuration, which contains the unique parity orbitals. The first evidence for chiral structures in the $A \sim 100$ region was found in ^{104}Rh [4]. This study has been followed by a series of experiments undertaken by us to investigate the nature and extent of such structures in this mass region (^{102}Rh [5], ^{106}Rh [6], ^{100}Tc [7]). In addition to these experimental works there have also been theoretical studies [8, 9] which have suggested some key indicators as fingerprints of nuclear chirality. These indicators are as follows:

- The existence of nearly degenerate bands of the same parity, connected to each other via M1/E2 transitions.
- The bands should show a smooth variation of the parameter $S(I)$, defined as $S(I) = [E(I) - E(I-1)]/2I$ as a function of spin. $S(I)$ is related to the Coriolis force which is proportional to the scalar product of the three angular momentum vectors (of the two particles and the core). This scalar product vanishes for a perfect chiral geometry since in this case the three vectors are orthogonal to each other.
- A characteristic staggering of the in-band B(M1)/B(E2) values is predicted for the $\pi g_{9/2}^{-1} \otimes \nu h_{11/2}$ configuration in $A \sim 100$ region. The odd spin values are staggered lower compared to the even spin values while the effect is predicted to be reversed for the positive parity $\pi h_{11/2} \otimes \nu h_{11/2}^{-1}$ configuration in the $A \sim 130$ region. This results from the constraints imposed on the wave functions by the time reversal symmetry.

In the $A \sim 100$ region, evidence has now been found in ^{106}Ag (see below), $^{102-106}$Rh [4–6], ^{98}Tc (currently being analysed) and ^{100}Tc [7], for spontaneous chiral symmetry breaking. These nuclei show an excited partner band built on the same configuration $\left(\pi g_{9/2}^{-1} \otimes \nu h_{11/2}\right)$ as that of the negative parity yrast band and connected to it through M1/E2 transitions. In ^{100}Rh [10], a partner band was identified which decays into the yrast $\pi g_{9/2}^{-1} \otimes \nu h_{11/2}$ band through M1/E2 transitions. This band was tentatively assigned a $\pi p_{\frac{1}{2}}^{-1} \bigotimes \nu\left(g_{\frac{7}{2}}\, d_{\frac{5}{2}}\right)$ configuration. We note, however, that the decay of this configuration would involve a change of more than one quasiparticle orbital, which is not allowed due to the one-body nature of electromagnetic operators. Furthermore, since there are no other possible negative parity configurations, it is most likely that this excited band is the chiral partner to the yrast band. Such an interpretation would be consistent with the systematic observation of chirality in the Rh isotopes.

In addition to the above odd–odd nuclei, evidence has also been found in the odd mass nucleus ^{105}Rh [11] for a three quasiparticle chiral band. All these results suggest the presence of a new region of chirality, and hence triaxiality. It would clearly be interesting to delineate the boundaries of such a region.

Figure 1 shows the systematic variation of the $S(I)$ parameter for several odd–odd Rh and Tc isotopes. It is noticable that there is a considerable staggering in the isotope ^{98}Rh ($N = 53$) suggesting that it is an axially rotating odd–odd nucleus. The values of $S(I)$ become much smoother in going from $N = 53$ towards $N = 55$. The plot seems to suggest that the boundary for chiral structures occurs at $N \sim 55$ in the odd–odd Tc and Rh isotopes. The $N > 55$ Rh and Tc isotopes also show evidence for a staggering of the B(M1)/B(E2) ratios for both the bands as well as a staggering for the $B(M1)_{in}/B(M1)_{out}$ values for the partner band. Clearly, it would be interesting to extend the data towards the heavier neutron-rich nuclei; however, these are difficult to populate through the conventional fusion–evaporation reactions. We therefore, decided to explore the higher-Z Ag isotopes. The results of the first experiment in ^{106}Ag are presented below.

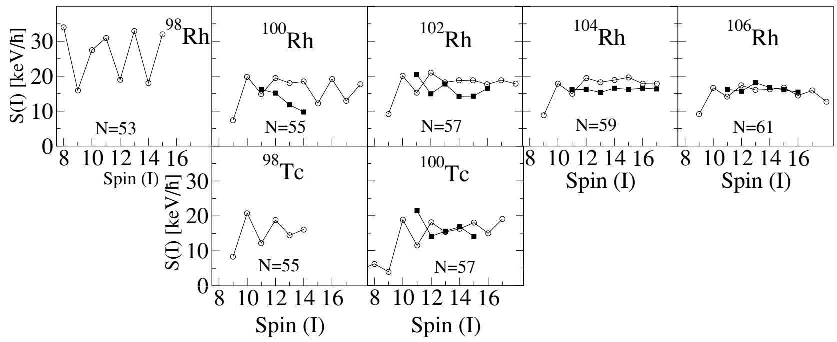

Figure 1. The plot of energy staggering defined as $S(I) = [E(I) - E(I-1)]/2I$ for the series of Rh and Tc isotopes. Open circles denote the yrast band while filled squares denote the partner band.

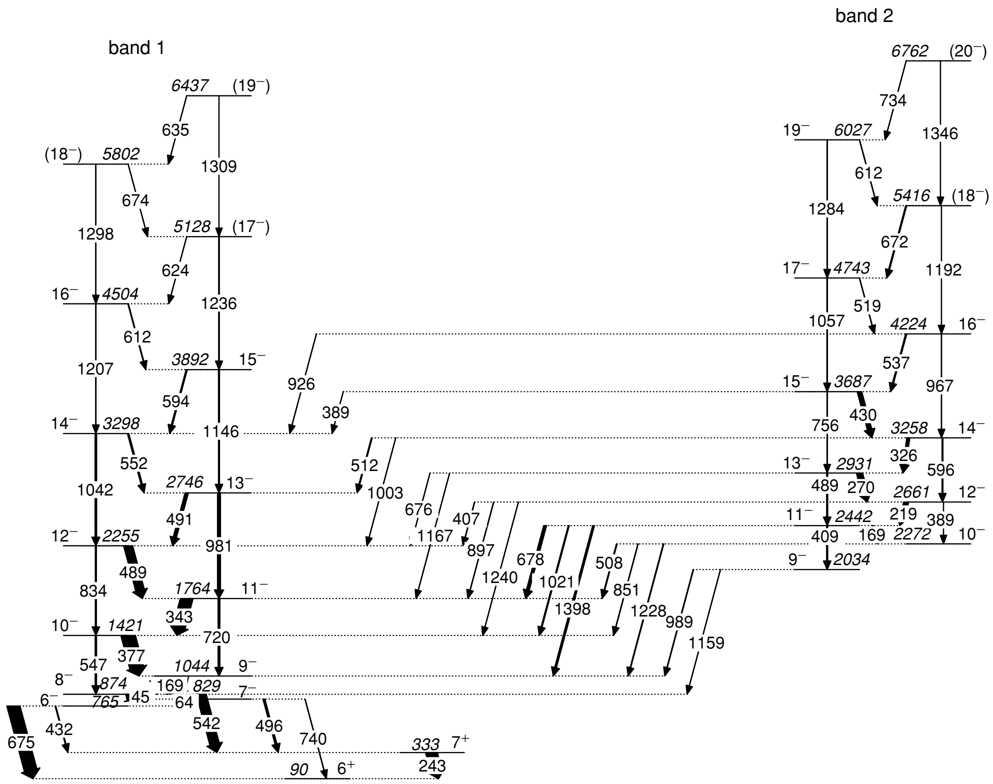

Figure 2. The level scheme of ^{106}Ag as studied in the present work.

3. Experiment for studying chirality in ^{106}Ag

The reaction ^{100}Mo(^{10}B, 4n)^{106}Ag at a beam energy of 42 MeV was used to populate excited states of ^{106}Ag. This experiment, which utilized a thin 550 μg/cm^2 ^{100}Mo target, was carried out using the Gammasphere array and the data were sorted into a γ–γ–γ cube and analysed using the Radware analysis package. Figure 2 shows the level scheme of ^{106}Ag deduced from this work. Band 1 is the yrast band which is understood to be built upon the $\pi g_{9/2}^{-1} \otimes \nu h_{11/2}$

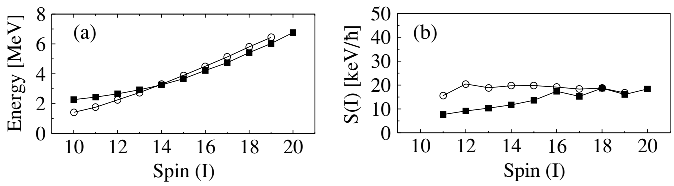

Figure 3. The plot of energy versus spin (left) and $S(I)$ plotted against I (right). Symbols used are open circles for the yrast band and filled squares for the partner band.

configuration [12, 13]. An excited band (band 2) which decays to the yrast band through E2, M1/E2 and non-stretched M1/E2 transitions is also seen in this work. The low spin states of these two bands were identified in previous works [12, 13]. However, the present work has extended the level scheme to higher spins and also established the spins and parities of the partner band. Most importantly, it has revealed a series of linking transitions between the two bands which indicate the inherent similarity of the configurations for the partner bands. More details will be presented in a longer paper [14].

It is interesting to look at the energy degeneracy (figure 3(a)) and the staggering $S(I)$ (figure 3(b)) for the two observed bands. The staggering $S(I)$ varies smoothly as a function of spin, which clearly indicates a possible triaxial rotation in this nucleus. From the plot of energy degeneracy versus spin we note that the two bands obtain degeneracy (within $\sim$30 keV) at spin 14. In $A \sim 100$ mass region, a better energy degeneracy has only been found in ^{104}Rh (within $\sim$1 keV), which is an isotone of ^{106}Ag. In principle, the higher proton number is expected to increase the hole character of protons and therefore, may give a better degeneracy. However, the triaxial shape may be influenced by the increase in proton number. Therefore, degeneracy may be a result of a delicate balance between these two effects. Most of the other nuclei in this region do not show such a good degeneracy.

4. Summary

The characteristics of nuclear chirality have been discussed in general. Current works suggest that there is a new region of chirality which appears around ^{104}Rh. New experimental data for the nucleus ^{106}Ag suggest the presence of chiral bands and hence triaxiality in this nucleus thereby extending the region to $Z = 47$ systems.

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