# Chiral Bands in $^{105}$Rh

J.A. Alcántara-Núñez, J.R.B. Oliveira, E.W. Cybulska, N.H. Medina, M.N. Rao, R.V. Ribas, M.A. Rizzutto,W.A. Seale, F. Falla-Sotelo, K.T. Wiedemann

*Instituto de Física, Universidade de São Paulo, São Paulo, SP, C.P. 66318, 05315-970, Brazil*

V.I. Dimitrov, and S. Frauendorf

*Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556*

*Institute for Nuclear and Hadronic Physics, Research Center Rossendorf, PB 51 01 19, 01314 Dresden, Germany.*

Received on 3 November, 2003

The $^{105}$Rh nucleus has been studied by in-beam $\gamma$ spectroscopy with the heavy-ion fusion-evaporation reaction $^{100}$Mo($^{11}$B, $\alpha 2n\gamma$) at 43 MeV. A rich variety of structures was observed at high and low spin, using $\gamma - \gamma - t$ and $\gamma - \gamma -$ particle coincidences and directional correlation ratios. Four magnetic dipole bands have also been observed at high spin. Two of them are nearly degenerate in excitation energy and could be chiral partners, as predicted by Tilted Axis Cranking calculations.

The spontaneous breaking of chiral symmetry in the intrinsic system of triaxial nuclei is a very interesting phenomenon of nuclear structure. It has been predicted by the Tilted Axis Cranking (TAC) model [1, 2, 3] and was first identified experimentally in the odd-odd nuclei of the A $\sim$ 130 region [4, 5, 6, 7]. It is generated by a combination of geometry and dynamics, with particle, hole and collective angular momenta each aligning along a different principal axis of the triaxial deformation of the core, defining a left-handed or right handed intrinsic system.

In the mass 100 region, the role of particles and holes is played by the valence $h_{11/2}$ neutrons and and $g_{9/2}$ protons, respectively. The $^{105}$Rh nucleus is situated on the neutron–rich side of the stability line. Its population via a fusion evaporation reaction is hindered by a lack of suitable target–projectile combinations. In this work, we present the results of an investigation of $^{105}$Rh with the $^{100}$Mo($^{11}$B,$\alpha 2n\gamma$) reaction at 43 MeV beam energy. The beam was provided by the Pelletron Tandem Accelerator of the University of São Paulo. The target used was sufficiently thick in order to stop the recoils. Gamma rays and charged particles have been detected using the SACI–PERERE array. SACI [8] (*Sistema Ancilar de Cintiladores*) is a $4\pi$ charged particle telescope system consisting of 11 plastic phoswich scintillators, disposed in the geometry of a dodecahedron, and enabled the selection of the evaporated charged particle fold in coincidence with the observed $\gamma$–rays. PERERE [9] (*Pequeno Espectrômetro de Radiação Eletromagnética com Rejeição de Espalhamento*) is the $\gamma$–ray spectrometer consisting of 4 HPGe detectors with BGO Compton-shields.

Previous to the present work, only four bands were known [10]. Four new structures with rotational characteristics were identified. Two bands (labelled 7 and 8 in Fig. 1) with strong M1 transitions and negligible signature splitting are nearly degenerate and present considerable cross-talk at low spin, which suggests a chiral doublet (Fig. 2) in a fashion similar to those observed in the A≈130 mass region [4, 5]. Two types of 3 quasiparticle negative parity configurations are available at low excitation energy: from $\pi 1/2^{-}[301](g_{9/2})^2$ (with $K \approx 8$) and $\pi g_{9/2} \otimes \nu h_{11/2}(g_{7/2}, d_{5/2})$ parentage. Total Routhian Surfaces (TRS) calculations show for the second configuration a very shallow minimum as a function of $\gamma$ deformation (Fig. 3). The TRS calculation however assumes a PAC (Principal Axis Cranking) rotation. From a more general approach, considering a tilted axis rotation [1], one would expect that the combined polarization of $g_{9/2}$ proton hole, $h_{11/2}$ neutron particle, and the collective rotation could lead to a rather stabilized collective triaxial deformation ($\gamma = -30°$). This condition is suitable for the appearance of chirality in the intrinsic system, generating a pair of nearly degenerate bands. Hybrid TAC model [11] calculations were performed for $^{105}$Rh which indeed present a chiral solution ($\varphi \neq 0$ or 90°) for the $\pi g_{9/2} \otimes \nu h_{11/2}(g_{7/2}, d_{5/2})$ basic configuration, assuming a triaxial shape with: $\varepsilon_2 = 0.21$, $\gamma = 30°$ (with pairing gaps: $\Delta_p = 0.97$ MeV and $\Delta_n = 1.12$ MeV), but for an excited proton $g_{9/2}$ state, while the lowest state is planar. Table I presents the results for the tilting angles and total angular momentum as a function of rotational frequency.

The total energy minimum as a function of the parameters is very shallow. Fig. 4 presents the comparison of these results with the experimental values from bands 7 and 8. The agreement is reasonable with the theoretical values lying roughly between the experimental values for the two bands due to the absence of tunneling (the chiral vibration[5]) in the model. In addition, the calculations reproduce the cross-talk between the bands at low spin. Chirality develops already at low spin which is unusual, and is probably related to the presence of a Fermi-aligned quasiparticle ($\nu g_{7/2}$), besides the particle-like and hole-like excitations ($\nu h_{11/2}$ and $\pi g_{9/2}$, respectively). Normally some amount of collective rotation is necessary for the aplanar (or chiral) configuration to become favorable [2]. It is suggested, therefore, that

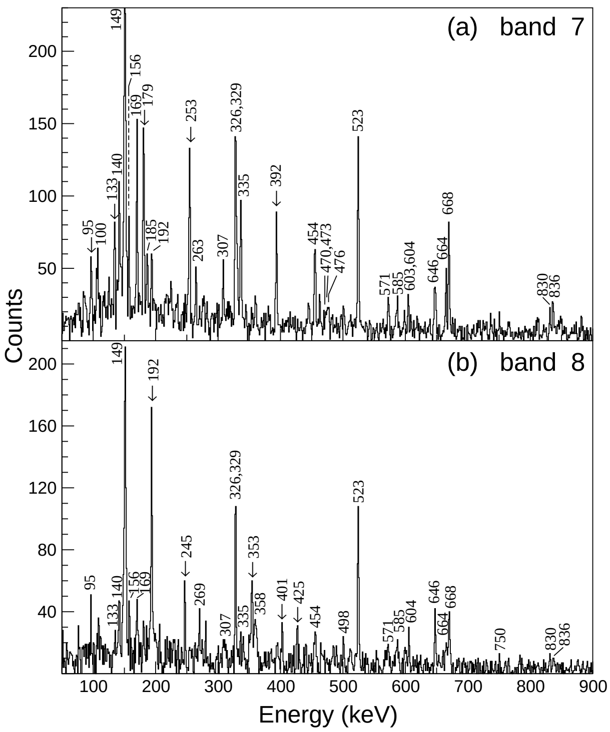

Figure 1. Gamma–ray spectra from the $1\alpha$ gated matrix. Sum of gates on (a) 179, 253 and 392 keV transitions belonging to band 7 and (b) 245, 307 and 353 keV transitions belonging to band 8, in $^{105}$Rh.

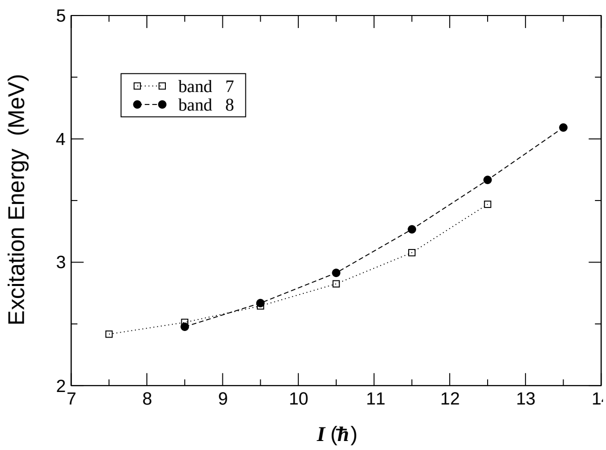

Figure 2. Experimental excitation energy as a function of angular momentum for bands 7 and 8 in $^{105}$Rh.

TABLE I. Tilting angles $(\theta, \varphi)$ and angular momentum $(J)$ as a function of rotational frequency $(\hbar\omega)$ from TAC calculations for the excited $\pi g_{9/2} \otimes \nu h_{11/2} g_{7/2}$ configuration in $^{105}$Rh.

| $\hbar\omega$(MeV) | $\theta$ | $\varphi$ | $J(\hbar)$ |
|---|---|---|---|
| 0.15 | 55° | 0° | 9.0 |
| 0.20 | 60° | 23° | 9.8 |
| 0.25 | 65° | 38° | 10.0 |
| 0.30 | 65° | 43° | 11.9 |
| 0.35 | 65° | 48° | 12.7 |
| 0.40 | 65° | 54° | 13.8 |

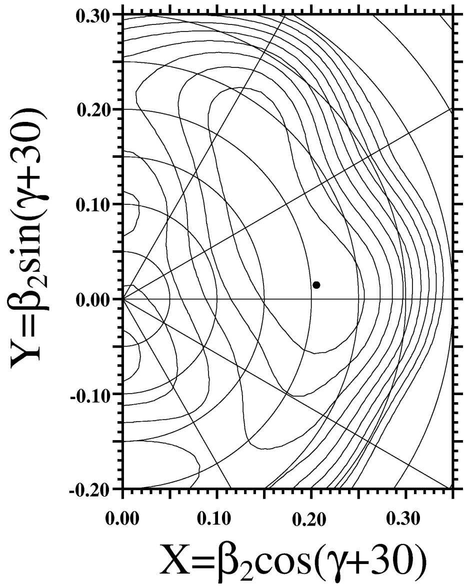

Figure 3. Total Routhian Surface calculations for the and $\pi g_{9/2} \otimes \nu h_{11/2}(g_{7/2}, d_{5/2})$ configuration at $\hbar\omega$ = 0.190 MeV in $^{105}$Rh. The thick dot indicates the position of the equilibrium deformation.

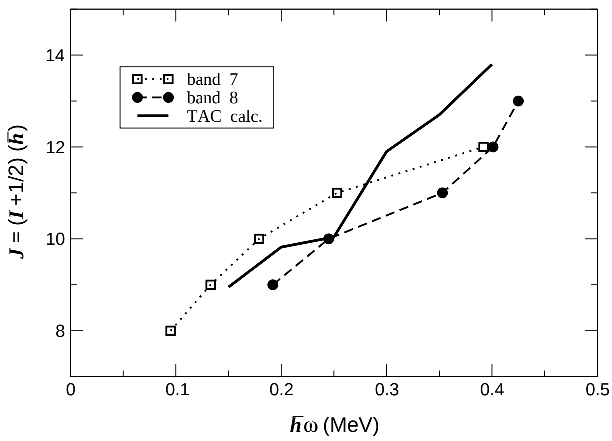

Figure 4. Total angular momentum as a function of rotational frequency. The open squares and closed circles are the experimental data for bands 7 and 8, respectively, in $^{105}$Rh. The thick line corresponds to the TAC calculations for the chiral $\pi g_{9/2} \otimes \nu h_{11/2} g_{7/2}$ excited configuration.

bands 7 and 8 have the $\pi g_{9/2} \otimes \nu h_{11/2} g_{7/2}$ intrinsic chiral configurations. This will then be the first candidate reported on the experimental observation of a chiral doublet in an odd nucleus in this mass region (another candidate in an odd nucleus is recently reported in $^{135}$Nd[13]). Due to the shallowness of the potential energy minima, the theoretical results become rather sensitive to the single particle energy parameters. It would be desirable as more high-spin data from this mass region become available, to revise these parameters and improve the accuracy of the calculations. The measurement of transition probabilities would also be very helpful to corroborate this suggestion, and additional cases in this mass region should be sought.

**Acknowledgments**

We thank the technical staff of the Pelletron Tandem Accelerator of the University of São Paulo. This work was partially supported by the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil. V.I.D. and S.F. acknowledge DOE Grant No. DE-FG02-95ER40934.

# References

[1] S. Frauendorf, Nucl. Phys.A **557**, 259c (1993).

[2] S. Frauendorf and Jie Meng, Nucl. Phys.A **617**, 131 (1997).

[3] V.I. Dimitrov, S. Frauendorf, and F. Dönau, Phys. Rev. Lett. **84**, 5732 (2000).

[4] C. Petrache, D. Bazzacco, S. Lunardi, C. Rossi Alvarez, G. De Angelis, M. De Poli, D. Bucurescu, C.A. Ur, P.B. Semmes, and R. Wyss, Nucl. Phys. A**597**, 106 (1996).

[5] K. Starosta, T. Koike, C. J. Chiara, D.B. Fossan, D. R. LaFosse, A.A. Hecht, C. W. Beausang, M. A. Caprio, J. R. Cooper, R. Krcken, J.R. Novak, N.V. Zamfir, K.E. Zyromski, D.J. Hartley, D.L. Balabanski, Jing-ye Zhang, S. Frauendorf, and V.I. Dimitrov, Phys. Rev. Lett. **86**, 971 (2001).

[6] K. Starosta, T. Koike, C. J. Chiara, D.B Fossan, and D.R. LaFosse, Nucl. Phys. A**682**, 375c (2001).

[7] R.A. Bark, A.M. Baxter, A. P. Byrne, G.D. Dracoulis, T. Kibédi, T.R. McGoram, and S.M. Mullins, Nucl. Phys. A**691**, 577 (2001).

[8] J.A. Alcántara-Núñez, J.R.B. Oliveira, E.W. Cybulska, N.H. Medina, M.N. Rao, R.V. Ribas, M.A. Rizzutto, W.A. Seale, F. Falla-Sotelo, F.R. Espinoza-Qiñones, and C. Tenreiro, Nuclear Instrum. Methods A**497**, 429 (2003).

[9] R.V. Ribas, J.R.B. Oliveira, E.W. Cybulska, M.N. Rao, W.A. Seale, M.A. Rizzutto, and N.H. Medina, Ann. Rep. of the Nucl. Phys. Dept., Institute of Physics, University of São Paulo, p. 63 (1996).

[10] F.R. Espinoza-Quiñones, E.W. Cybulska, J.R.B. Oliveira, R.V. Ribas, M.N. Rao, M.A. Rizzutto, N.H. Medina, L.G.R Emediato, W.A. Seale, and S. Botelho, Phys. Rev. C **55**, 2787 (1997).

[11] V.I. Dimitrov, F. Dnau, and S. Frauendorf, Phys. Rev. C **62**, 024315 (2000).

[12] F.R. Espinoza-Quiñones, E.W. Cybulska, J.R.B. Oliveira, R.V. Ribas, N.H. Medina, M.N. Rao, M.A. Rizzutto, L.G.R Emediato, W.A. Seale, and S. Botelho, Phys. Rev. C **55**, 1548 (1997).

[13] S. Zhu *et al.*, Phys. Rev. Lett. **91**, 132501 (2003).