Yanbu Journal of Engineering and Science

Volume 4 | Issue 1 Article 8

2012

EVIDENCE FOR πg9/2 ⊗ ν (h11/ 2) 2 DOUBLET BANDS IN 105Rh NUCLEUS

Nabeil Ibrahim Fawaz
University of Al-anbar, Al-anbar, Iraq, nifawaz@yahoo.com

Follow this and additional works at: https://yjes.researchcommons.org/yjes

The journal in which this article appears is hosted on Digital Commons, an Elsevier platform.

Recommended Citation

Fawaz, Nabeil Ibrahim (2012), EVIDENCE FOR πg9/2 ⊗ ν (h11/ 2) 2 DOUBLET BANDS IN 105Rh NUCLEUS, *Yanbu Journal of Engineering and Science*: Vol. 4: Iss. 1, 65-72.
DOI: https://doi.org/10.53370/001c.24048
Available at: https://yjes.researchcommons.org/yjes/vol4/iss1/8

This Research Article is brought to you for free and open access by Yanbu Journal of Engineering and Science. It has been accepted for inclusion in Yanbu Journal of Engineering and Science by an authorized editor of Yanbu Journal of Engineering and Science.

Yanbu Journal
of
Engineering
and Science
ISSN: 1658-5321

Vol. 4, April 2012 (1433H)
www.yjes.org.sa

EVIDENCE FOR $\pi g_{9/2} \otimes \nu (h_{11/2})^2$ DOUBLET BANDS IN ^{105}Rh NUCLEUS

Nabeil Ibrahim Fawaz

Department of Physics, College of Science, University of Al-anbar, Al-anbar, Iraq.
e-mail: nifawaz@yahoo.com

ABSTRACT

The existence of chirality in the positive-parity levels in ^{105}Rh nucleus has been confirmed by the theoretical model Interacting Boson-Fermion Model (IBFM). The IBFM succeeded in predicting the positive parity excitation energy and electromagnetic properties in the ^{105}Rh nucleus. The IBFM analysis suggest the coexistence of triaxial and axial shapes in the ^{105}Rh nucleus.

Keywords: *Nuclear structure, IBFM, chirality bands, Rh- odd nucleus.*

1. INTRODUCTION

The condition for the appearance of chiral doublet bands is that the proton and neutron Fermi levels are located in the lower part of the valence proton high-j (particle-like) and in the upper part of the valence neutron high-j (hole-like) subshells or vice versa, and the core is triaxial. The angular momenta of the valance particles are aligned along the short and the long axes of the triaxial core, while the angular momentum of the rotational core is aligned along the intermediate axis. The three angular momenta can be arranged to form two systems that differ by intrinsic static chirality, a left- and a right- hand system.

Theoretical work has suggested that chirality may exist in triaxial atomic nuclei[1,2] and can be manifested by the presence of pairs of nearly degenerated strongly coupled bands having the same parity. Chiral doublet band were first predicted by the particle-rotor model (PRM) and Tilted axis cranking (TAC) for triaxially deformed nuclei[3]. Later on, numerous efforts have been devoted to the development of TAC method[2], PRM models[4] and Interacting boson fermion-fermion model (IBFFM)[5] to describe chiral rotation in atomic nuclei.

In the A ≈ 100 mass region, bands formed by one $g_{9/2}$ quasiproton, with the proton Fermi level in the upper half of the $g_{9/2}$ subshell, present a large signature splitting (~ 200 keV). When two quasineutrons of the $h_{11/2}$ orbital are coupled to the $\pi g_{9/2}$ configuration, the signature splitting becomes small or disappears entirely and the B(M1)/B(E2) ratios become relatively large.

The chiral doublet bands in ^{106}Rh as well as other Rh isotopes were well reproduced and supported by many theoretical models[6-9].The experimental work on ^{105}Rh nucleus[10], suggested a new rotational band linked with many transitions to the previously known $\pi g_{9/2}$ ν $(h_{11/2})^2$ band. The observed $\Delta I=1$ rotational band doublets show a chiral characteristics and this is the first experimental evidence for $\pi g_{9/2} \otimes \nu (h_{11/2})^2$ three-quasipartical chiral structure in the A ≈ 100 mass region. They[10] conclude that the chiral partner bands in ^{103}Rh and ^{105}Rh depend strongly on the properties of the triaxial core while the dependence on the

Received: May 2011 Accepted: January 2012

valance quasiparticle coupling and on the Fermi level is weaker. However, many of the recent experiments and theoretical analysis do not support completely the chiral interpretation[11].

In particular, in an ideal situation, i.e. perfectly orthogonal angular momentum vectors and stable triaxial nuclear shape, a perfect degeneracy between the identical spin states should be observed. In fact, the degeneracy, which is one of the key characteristics of chirality's, has not been observed in any of the chiral structures identified to data.

In this work, the chiral band in positive parity states will be examined according to the theoretical model and the Interacting boson-fermion model (IBFM). The $^{105}_{45}Rh$ nucleus is situated on the neutron rich side of the stability line. According to the simple shell model the π =50-82 proton shell contains $1g_{9/2}$ orbit only with positive parity. So, the ^{105}Rh nucleus is considered as resulting from coupling a proton hole to the even – even ^{104}Pd nucleus. The ^{104}Pd nucleus have already been studied with IBM[12] and considered as an U(5) vibration like nucleus.

2. THEORY :IBFM

In the IBFM, odd-A nuclei are described by the coupling of the odd fermionic quasiparticle to a collective boson core[13]. The total Hamiltonian can be written as the sum of three part

$$H = H_B + H_F + V_{BF} \quad (1)$$

where H_B is the usual IBM-2 Hamiltonian[14] for the even-even core, H_F is the fermion Hamiltonian containing only one-body terms.

$$H_F = \sum_{jm} \varepsilon_j \, a^*_{jm} \, a_{jm} \quad (2)$$

where ε_j are the quasiparticle energies and a^*_{jm} , a_{jm} are the creation (annihilation) operators for the quasiparticle in the eigen state jm.

The boson-fermion interaction, V_{BF} that describes the interaction between the odd quasi-nucleon and the even-even core nucleus, has been shown to be dominated by the following three terms[13]:

$$V_{BF} = \sum A_j [(\overset{+}{d} x \tilde{d})^0 \; x \; (\overset{+}{a}_j x \tilde{a}_j)^0 \;]^0$$

$$+ \sum_{jj'} \Gamma_{jj'} [Q^2 \; x((\overset{+}{a}_j x \tilde{a}_j)^2 \;]^0_0 \quad (3)$$

$$+ \sum_{jj'j''} \Lambda^{j''}_{jj'} :[(\overset{+}{d} x \tilde{a}_j)^{j''} \; x (\overset{+}{a}_j x \tilde{d})^{jj'}]^0_0 :$$

where Q is the core boson quadrupole operator

$$Q^2 = (\overset{+}{s} x \tilde{d} + \overset{+}{d} x \tilde{d})^2 + \chi (\overset{+}{d} x \tilde{d})^2 \quad (4)$$

and χ is a parameter shown by microscopic theory to lie through $\pm\frac{\sqrt{7}}{2}$, s,d, $\overset{+}{s}$ *and* $\overset{+}{d}$ are boson operators with $\tilde{a}_{jm} = (-1)^{j-m} a_{j-m}$ and : denotes normal ordering whereby contributions that arise from commuting the operators are neglected. The first term in V_{BF} is a monopole interaction which plays a minor role in actual calculations. The dominant terms are the second and third, which arise from the quadrupole interaction. The third term represents the exchange of the quasiparticle with one of the two fermion forming a boson[14] and has shown that this exchange force is a consequence of the Pauli principle on the quadrupole interaction between protons and neutrons. The remaining parameters in equation (3) can be related to the Bardeen, Cooper and Schrieffer (BCS)[15] occupation probabilities, u_j , v_j of the single particle orbits.

The Hamiltonian of equation (1) was digitalized by means of the standard program ODDA[16] in which the IBFM parameters are identified as: A_0 = BFM, Γ_0 = BFQ and Λ_0 = BFE . The electromagnetic transition

operators can be written as the sum of the two terms, the first of which acts only on the boson part of the wave function, and the second acts only on the fermion part in equation (1) .

In the IBFM the E2 operator is

$$T^{(E2)} = e_B Q^{(2)} + e_F \sum Q_{jj'} (a_j x \tilde{a}_{j'})^2 \quad (5)$$

Where e_B and e_F are the boson and fermion effective charges

The M1 operator is

$$T^{(M1)} = \sqrt{\frac{30}{4\pi}} g_B (\overset{+}{d} x \tilde{d})^{(1)} - \sum_{jj'} g_{jj'} [j(j+1)(2j+1)4\pi]^{1/2} (a_j x \tilde{a})^{(1)} \quad (6)$$

Where g_B is the boson g-factor determined by the even-even core, and $g_{jj'}$ is the single particle contribution which depends on g_ℓ and g_S (orbital and spin g-factor) of the odd nucleon.

The transition strengths B(E/Mλ) between levels with spin J and J' are obtained from the operators of equation (5) as

$$B(E/M\lambda; J \to J') = \frac{\left| \langle J' \| T^{(E/M\lambda)} \| J \rangle \right|^2}{(2J+1)} \quad (7)$$

The magnetic dipole moments (μ_J) and the electric quadruple moment(Q_J) for a state with spin J can be calculated from M1 and E2 operators respectively. From the matrix elements of $T^{(M1)}$ and $T^{(E2)}$ one can

$$\mu_J = \sqrt{\frac{4\pi}{3}} \sqrt{\frac{J}{(2J+1)(J+1)}} \left| \langle J \| T^{(M1)} \| J \rangle \right| \quad (8)$$

$$Q_J = \sqrt{\frac{16\pi}{5}} \sqrt{\frac{J(2J-1)}{(2J+1)(J+1)(2J+3)}} \left| \langle J \| T^{(E2)} \| J \rangle \right| \quad (9)$$

3. RESULTS AND DISCUSSION:

In the present work, the Interacting Boson-Fermion Model(IBFM) has been applied on this nucleus. According to the simple shell model the N=28-50 proton shell contains the $2p_{3/2}$, $1f_{5/2}$, $2p_{1/2}$, and $1g_{9/2}$ orbits which play an active role in excitations of the $^{105}Rh_{60}$ nucleus. The ^{105}Rh nucleus is considered as resulting from coupling a proton hole to the even-even ^{104}Pd nucleus. The ^{104}Pd nucleus has been studied in much detail by Sohair[12] within the framework of the interacting boson approximation model (IBA-1).

For the positive- parity states, the only positive parity orbital in this region is $1g_{9/2}$. Including the $1g_{9/2}$ orbit only in the IBFM calculation does not give a good agreement with experimental for both excitation energy and electromagnetic transitions. Hence, the orbit $2d_{5/2}$ form above π =50 has been included in the IBFM calculations.

The BCS (Barden-Cooper-Schrieffer) parameters which provided the quasiparticle energies(εj) and shell occupancies(υ_j^2) required as input for the IBFM calculations for the orbits included in the calculation, are listed in Table 1.

TABLE 1: BCS PARAMETERS USED IN THE ANALYSIS FOR POSITIVE PARITY STATES IN ^{105}RH NUCLEUS.

	ε_j(Mev)	υ_j^2
$1g_{9/2}$	0.50	0.5653
$2d_{5/2}$	4.50	0.0279

The IBFM Hamiltonian was diagonalised by means of the standard program ODDA[16]. The IBFM (boson-fermion interaction strength) parameters used in the analysis of the positive-parity states in ^{105}Rh was adjusted such as to provide a good description to the experimental excited states. These parameters are, BFQ= 0.1992 Mev, BFE= 1.4501 Mev and BFM= -0.4321 Mev. The χ- value is taken to be 1.323 and OMEGA= 1.5 Mev. The boson core parameters chosen in this work are those reported in ref.[12]. This set of parameters were in good agreement with the experiment in the excitation energy. The

average percentage deviation between experimental and the IBFM prediction for both bands have been found to be nearly 7% in average.

The fingerprints[17,18,19] for energy spectra, the chiral bands should contain a pair of nearly degenerate ΔI = 1 bands with same parity. Figure 1 shows the calculated degenerate bands in comparison with experimental excitation energy[10,20]. From the plot of the energy degeneracy versus spin, it has been noticed that the calculated separation energy between the two bands is in agreement with first requirements for chirality.

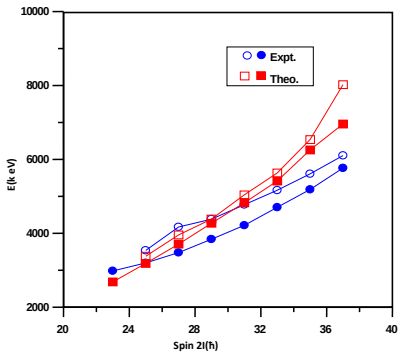

Fig. 1: Experimental and theoretical energy levels versus spin(2I) for positive parity (side(S) and partner(P)) bands in ^{105}Rh nucleus

The separation energy between the two bands under investigation is smaller than the experimental separation energy except at higher spin states I ≥ 35/2 state of the side band, the separation energy becomes approximately linear spin-dependent in which the collective rotation of core becomes dominate.

The energy staggering parameter S(I), is given by:

$$S(I)=\frac{[E(I)-E(I-1)]}{2I}$$

is indicative of the degree of mutual orthogonality of the three vectors involved. The S(I) for the two observed bands are shown in Fig. 2.

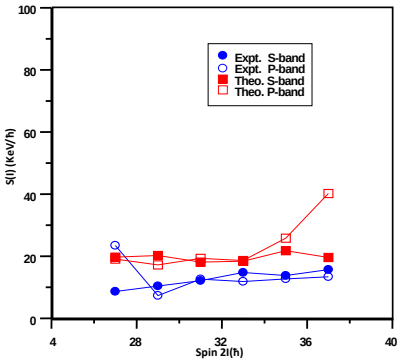

Fig. 2: Comparison of Signature Splitting S(I) versus spin (2I) between experimental and IBFM prediction for side(S) and partner(P) bands in ^{105}Rh.

The smoothness of the signature splitting S(I) support the chiral structure of the two bands. However, the S(I) plot Fig. (2) suggest a triaxial nature for partner band while the staggered nature of the side band at I ≥ 35/2 suggest it contains a large planar component of the collective rotation. This situation for the two bands in ^{105}Rh positive parity states appear to suggest the coexistence of triaxial and axial shapes. The same situation had been noticed in ^{106}Ag nucleus[19]. Moreover, and according to the triaxial particle rotor model [21], it have been found that the least energy separation between the doublet bands happens around I = 37/2 . They[21] suggested that the chiral doublet bands start as a chiral vibration, both in ^{103}Rh and ^{105}Rh, and becomes static chirality around I=37/2. After that the two band again develop into a chiral vibration.

The other fingerprint of the chirality in atomic nuclei, is the electromagnetic transition in doublet bands which becomes a hot topic in identifying the chiral bands. The most recent experimental work on this nucleus ref. [20], shows that the measurement of transition probabilities would be very helpful in corroborating their suggestion of the chirality in this nucleus.

The wave function obtained by diagonalization of the IBFM Hamiltonian by

the computer code ODDA have been used by the code PBEM to calculate the reduced transition probabilities for E2 and M1. Because of the leakage in experimental data for the electromagnetic transitions in this nucleus, the effective boson and fermion charges have been chosen to give for B(E2; 9/21 →7/21) a value 0.106 $e^2.b^2$ same as that for B(E2;21 → 01) transition of the ^{104}Pd even core. Moreover, the magnetic moments of the 7/2 ground state has been calculated and found to be 4.10 μ_N compared with the experimental value reported before[22]of 4.36(± 0.12) μ_N. These parameters and the g-factors used in the calculation of the electromagnetic M1 and E2 transitions were as follows:

e_B =0.0485 eb,
e_F =0.0485 eb,
g_l = 1,
g_s = 3.798 μ_N and
g_d = -0.3 μ_N.

One of the most important signature on the electromagnetic properties of the chiral geometry is the staggering of the intra-band and inter-band M1 and the ΔI = 1 E2 transitions. The reduced transition probabilities of the ΔI = 1 intra-bands have been shown in figures 3 and 4. The M1 transition, Fig.4 shows very regular and strong staggering while the staggering in E2 transition, Fig.3 is not regular.

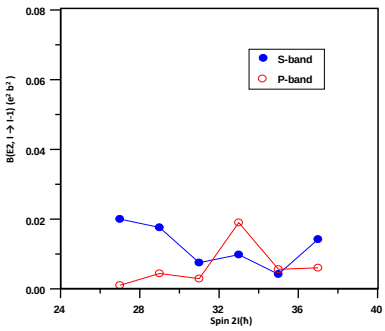

Fig. 3: B(E2) values predicted by the IBFM in ^{105}Rh nucleus.

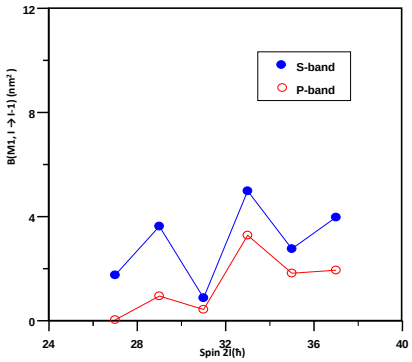

Fig. 4: B(M1) values predicted by the IBFM in ^{105}Rh nucleus.

The inter-band E2 and M1 transitions behave in a similar way as shown in figures 5 and 6. Although, the electromagnetic transitions behaves in the same minor with that reported in reference [21], the IBFM results show more obvious staggering. The chirality fingerprints for electromagnetic transitions have been fulfilled in these bands in ^{105}Rh nucleus.

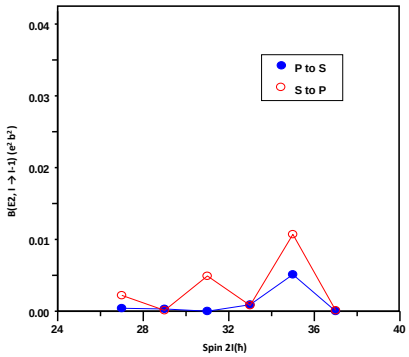

Fig. 5: The B(E2) values for transitions de-exciting states between partner and the side bands as predicted by the IBFM in ^{105}Rh nucleus.

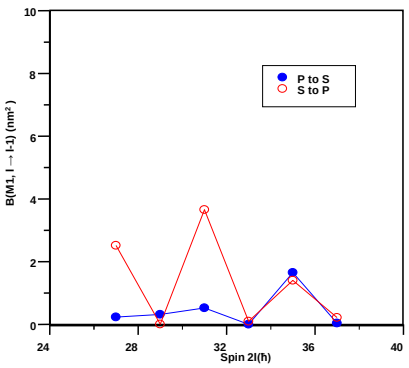

Fig. 6: The B(M1) values for transitions de-exciting states between partner and the side bands as predicted by the IBFM in ^{105}Rh nucleus.

4. SUMMARY:

The excitation energy of the two positive parity bands in ^{105}Rh nucleus were predicted very well by the Interacting Boson-Fermion Model (IBFM). The analysis of the wave function of the chiral candidates in the framework of the IBFM confirms the existence of chiral bands in the positive parity states. The IBFM analysis suggests the coexistence of triaxial and axial shapes in the ^{105}Rh nucleus.

Electromagnetic transition probabilities using the IBFM were deduced for intra- and inter-band transitions in the two positive parity state bands in ^{105}Rh nucleus which agrees very well with the chirality characteristics requirement.

REFERENCES

[1] Frauendorf, S. and Meng J., Tilted rotation of triaxial nuclei, Nuclear Physics, A 617, 1997, pp 131-147.

[2] Dimtrov, V.I., Donau, F. and Frauendorf, S., A hybrid version of the tilted axis cranking model and its application to ^{128}Ba, Physical Review C62, 024315, 2000.

[3] Frauendorf, S., Tilted cranking, Nuclear Physics A 557, 1993, pp 259-276.

[4] Peng, J., Meng, J. and Zhang, S.Q., Description of Chiral doublets in A=130 nuclei and possible chiral doublets in A= 100 nuclei, Physical Review C 68, 044324, 2003.

[5] Brant , S. and Tonev, D., Dynamic chirality in the interacting boson model, Journal of Physics: Conference Series, 205, 012026, 2010.

[6] Meng, J., Peking, U., Peng, J. and Zhou, S.G., Possible existence of multiple chiral doublet in Rh-106, Physical Review C73, 037303, 2006.

[7] Peng, J., Sagaw, H., Zhang, S.Q., Yao, J.M., Zhang, Y. and Meng, J. , Search for multiple chiral doublet in rhodium isotopes, Physical Review C77, 024309, 2008.

[8] Wang, S.Y., Zhang, S.Q., Qi, B., Peng, J., Yao, J.M. and Zhang, J.m., Description of $\pi g_{9/2} \otimes \nu h_{11/2}$ doublet bands in ^{106}Rh, Physical Review C77, 034314, 2008.

[9] Yao, J.M., Qi, B., Zhang, S.Q., Peng, J., Wang, S.Y. and Meng, J., Candidate multiple chiral doublets nucleus ^{106}Rh in a triaxial relativistic mean-field approach with time-odd fields, Physical Review C79, 067302, 2009.

[10] Timar, T., Koike, T., Pietralla, N., Rainonski, G., Sohler, D., Ahn, T., Berek, G., Costin, A., Dusling, K., Li, T. C., Paul, E.S., Starosta, K., and Vaman, C., High-spin structure of ^{105}Ag , search for chiral doublet bands, Physical Review C73, 011301(R), 2006.

[11] Ganev, H.G., Georgieva, A. I., Brant, S., and Ventura, A., New description of the doublet bands in doubly odd nuclei, Physical Review C79, 044322, 2009.

[12] Sohair, M.D., Phase transition in even-even palladium isotopes, progress in physics, Vol. 1, 2009.

[13] Iachello, F. and Scholten, O., Description of odd-mass Nuclei, Physical Review Letters, Vol.43, 1979, pp 679-692.

[14] Talmi, I.T. : In interacting Bose-Fermi system in Nuclei; ed. F. Iachello (New York: Plenum), 1981.

[15] Bardeen, J., Cooper, L.N. and Schrieffer, J.R., pairing theory in super conductors, Physical Review 108, 1957, pp 1175-1192.

[16] Scholten O., internal report KVI 252; Computer code ODDA, Groningen, 1980.

[17] Joshi, R., Finningon, S., Fossan, D.B., Koike, T., Paul, E.S., Rinovski, G., Starosta, K., Vaman, C. and Wadsworth, R., Evidence for a new region of chirality around A~ 104, Journal of Physics G: Nuclear and Particle Physics, Vol.31, 2005, pp 1895- 1898.

[18] Meng, J. and Zhang, S.Q., Open Problems in understanding the Nuclear chirality, Journal of Physics G37, 064025, 2010.

[19] Joshi, P., Carpenter, M.P., Fossan, D.B., Koike, T., Paul, E.S., Rianovski, G., Stovosta, K., Vaman, C. and Wadsworth, R. , Effect of γ softness on the stability of chiral geometry: spectroscopy of ^{106}Ag, Physical Review Letters PRL 98, 102501, 2007.

[20] Alcantara-Nunez,J.A., Oliveira, J.R.B., Cybulska, E.W., Medina, N.H., Rao, M.N., Ribas, R.V., Rizzuto, M.A., Seale, W.A., Falla-Sotelo, F., Wiedemann, K.T.,. Dimitrov, V.I. and S. Frauendorf, S., Magnetic dipole and electric

quadrupole rotational structures and chirality in ^{105}Rh, Physical Review C 69, 024317, 2004.

[21] Qi, B., Zhang, S.Q., Wang, S.Y., Meng, J. and Koike, T. , Chirality in odd-A Rh isotopes within triaxial particle rotor model, Physical Review C83, 034303, 2011.

[22] Stone, N. J., Table of Nuclear Magnetic dipole and electric Quadrupole moments; Oxford OX1 3PU U.K., 2001.

Yanbu Journal of Engineering and Science Vol. 4 (2012)

تاكيد وجود حزمتين مزدوجه في نواة ال ^{105}Rh

نبيل ابراهيم فواز
قسم الفيزياء، كلية العلوم، جامعة الأنبار، الأنبار، العراق

الملخص:

وجود التماثل اليدوي لمستويات البرم الموجب في نواة الـ ^{105}Rh تم تأكيده بأستخدام نموذج تفاعل البوزون – فرميون. نجح نموذج تفاعل البوزون – فرميون في تحديد مستويات الطاقه والخصائص الكهرومغناطيسيه في نواة إلـ ^{105}Rh ذات البرم الموجب. يقترح نموذج تفاعل البوزون – فرميون وجود مشترك للشكلين المحوري والثلاثي المحاور في هذه النواة .