P- ISSN 1991-8941 E-ISSN 2706-6703 Journal of University of Anbar for Pure Science (JUAPS) Open Access
2011,(5), (1) :41-48

Theoretical test for chirality's in negative parity states of Rhodium (Rh)-105

Nabeil I. Fawaz

University of Anbar - College of Science.

ARTICLE INFO

Received: 2 / 10 /2010
Accepted: 28 / 4 /2011
Available online: 14/6/2012
DOI: 10.37652/juaps.2011.15502

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

ABSTRACT

The chirality in the negative-parity levels in 105Rh nucleus has been examined by the theoretical model Interacting Boson-Fermion Model (IBFM). The IBFM succeed in prediction the negative parity excitation energy in the 105Rh nucleus. Including high-j orbits in the IBFM calculations or not gave nearly the same behavior. This nucleus could have static chirality but not vibration chirality. The negative parity bands dose not show the ideal chiral symmetry.

Introduction:

Chirality's in atomic nuclei is a direct consequence of triaxial nuclear shape. It is shown that triaxial deformation and high-j valence particles and valence holes are essential for the deformation of chirality in nuclei. 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. 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. All these models, suppose a rigid triaxial even-even core. On contrary, all nuclei in which chiral band have been observed have another characteristics in common, they are in regions of masses where even – even nuclei are γ-soft, i.e. triaxial but not rigid. It is evident that nuclei in these mass regions can not reach the full requirements needed for the existence of chirality, but they can approach them, or at least retain some fingerprints of chirality.

The intrinsic system of triaxial nuclei was first identified experimentally in the odd-odd nuclei of the A ~ 130 region[6-9]. The first evidence for chiral structure in A ~ 100 region was found in 104Rh[10].

* University of Anbar - College of Science.E-mail address: NIFAWAZ@yahoo.com

A series of experiments has been followed to investigate the nature and extent of such structure in this region such as 102Rh[11], 106Rh[12] and 100Tc[13]. In addition to the odd-odd nuclei, evidence has also been found in odd mass nucleus 105Rh[14] for the three quasiparticle chiral band. In A ~ 100 region, the chiral structure result from the occupation of πg-17/2 x υh11/2 configuration which contains unique parity orbital.

However, many of the recent experiments and theoretical analysis do not support completely the chiral interpretation[15]. 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 it is one of the key characteristics of chirality's, has not been observed in any of the chiral structures identified to data.

The experimental work on 105Rh nucleus[16], suggested two new bands labeled (7& 8) with negative parity and predicted to be the πg9/2 x υh11/2g7/2 intrinsic chiral band. Also, they suggested the need of measurement for transition probabilities to corroborate their suggestion.

In this work, the two bands (7 & 8) chiral band will examine according to the theoretical model, 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 the 2p1/2, 2p3/2 and 1f5/2 orbits with negative parity, and only 1g9/2 orbit with positive parity. So, the 105Rh nucleus is considered as resulting from coupling a proton hole to the even – even 104Pd nucleus. The 104Pd nucleus have already been studied with IBM[17] and considered as an U(5) vibration like nucleus.

Theory :IBFM

In the IBFM, odd-A nuclei are described by the coupling of the odd fermionic quasiparticle to a collective boson core[18]. The total Hamiltonian can be written as the sum of three part

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

where HB is the usual IBM-2 Hamiltonian[19] for the even-even core, HF is the fermion Hamiltonian containing only one-body terms.

$$H_F = \sum_{jm} \varepsilon_j \, \hat{a}_{jm} \, a_{jm} \qquad \text{..........(2)}$$

where εj are the quasiparticle energies and a+jm , ajm are the creation (annihilation) operators for the quasiparticle in the eigen state ׀jm>.

The boson-fermion interaction, VBF 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[18]:

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

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

$$+ \sum_{jj'j''} \Lambda_{jj'}^{j''} : [(\overset{+}{d} x \tilde{a}_j)^{j''} \; x (\overset{+}{\underset{j}{a}} x \tilde{d})^{jj'}]_0^0 : \qquad \text{........(3)}$$

Where Q is the core boson quadrupole operator

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

and χ is a parameter shown by microscopic theory to lie through $\pm \frac{\sqrt{7}}{2}$, s,d, $\overset{+}{s}$, $\overset{+}{d}$ are boson operators with $\tilde{a}_{jm}$ = (-1)j-m aj-m and : denotes normal ordering whereby contributions that arise from commuting the operators are neglected. The first term in VBF 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 and has shown[19] 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)[20] occupation probabilities, uj , vj of the single particle orbits.

The Hamiltonian of equation (1) was digitalized by means of the standard program ODDA[21] in which the IBFM parameters are identified as: A0 = BFM, Γ0 = BFQ and Λ0 = 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

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

Where eB and eF are the boson and fermion effective charges

The M1 operator is

$$T^{(M1)} = \sqrt{\frac{30}{4\pi}} \, g_B (\overset{+}{d} \, x \tilde{d})^{(1)}$$

$$- \sum_{jj'} g_{jj'} [\, j(j+1)(2j+1) 4\pi \,]^{1/2} (a_j \, x \tilde{a})^{(1)} \qquad \text{.....(6)}$$

Where gB is the boson g-factor determined by the even-even core, and gjj' is the single particle contribution which depends on gℓ and gs (orbital and spin g-factor) of the odd nucleon.

Results and Discussion:

In the present work, the Interacting Boson-Fermion Model(IBFM) have been applied on this nucleus.

According to the simple shell model the N=28-50 proton shell contains the 2p3/2, 1f5/2, 2p1/2, and 1g9/2 orbits which play an active role in excitations of the 105Rh60 nucleus. In this work the 105Rh nucleus is considered as resulting from coupling a proton hole to the even-even 104Pd nucleus. The 104Pd nucleus has been studied in much detail by Sohair M. Diab[17] within the framework of the interacting boson approximation model (IBA-1).

For the negative- parity states, the negative parity orbital in this region N= 28-50 are 2p3/2, 1f5/2 and 2p1/2.

Since the occurrence of chirality in nuclear physics was expected to occur in nuclei having triaxial shapes in which there are a few high- j valence particles and a few high- j valence holes (such as g9/2 and h11/2), two sets of parameters have been used in order to describe the negative parity energy levels in this nucleus. One by including the negative parity orbits in this region only (3-levels calculation), and the another by including two more negative parity orbits with high –j, from (below π = 28) the 1f7/2 orbit, and from (above π = 50) the 1h11/2 (5-levels calculation).

Their BCS (Barden-Cooper-Schrieffer) parameters which provided the quasiparticle energies(εj) and shell occupancies(υj2) required as input for the IBFM calculations, are listed in table 1.

Table 1: BCS parameters used in the analysis for 105Rh nucleus.

	ε_j(MeV)		υ_j^2	
	3-levels	5-levels	3-levels	5-levels
$2p_{1/2}$	-1.15	-1.15	0.8820	0.8820
$2p_{3/2}$	-2.00	-2.00	0.9500	0.9200
$1f_{5/2}$	-2.35	-2.67	0.9800	0.9450
$1f_{7/2}$		-2.303		0.9890
$1h_{11/2}$		1.2950		0.0051

The IBFM Hamiltonian was diagonalised by means of the standard program ODDA[21]. The IBFM (boson-fermion interaction strength) parameters, adjusted such as to provide a good description to the experimental excited states, are listed in table 2.

Table 2: The IBFM parameters used in the analysis for 105Rh nucleus.

	3- Levels	5- Levels
BFQ	-0.0786	-0.6680
BFE	1.1987	2.1879
BFM	-0.255	-0.1789

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.[17].

Both sets of parameter shows very good agreements with experiment in the excitation energy. The average percentage deviation between experimental and the IBFM prediction have been found to be nearly 5% only for both sets.

The fingerprints for energy spectra, the chiral bands should contain a pair of nearly degenerate ΔI = 1 bands with same parity. Figures (1 & 2) shows the calculated degenerate bands for both analysis. From the plot of the energy degeneracy versus spin, it has been noticed that the two bands obtain degeneracy (within nearly 35 and 47 keV) at spin 8.5 and 11.5 respectively. In A ~ 100 mass region , a better energy degeneracy has only been found in 104Rh (within ~ 1 keV) and in most cases, the energy separation between the two partner band ranges from ~ 200 keV to ~ 400 keV.

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

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

Which 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. 3. The S(I) for 3- levels calculation shows smooth dependence with higher spin, while in 5- levels calculation do not. The S(I) values behaves nearly the same as the S(I) in the 106Rh nucleus rather than in the 104Rh nucleus.

The another 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. [16], shows that the measurement of transition probabilities would be very helpful in corroborate 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.
The effective boson and fermion charges and g-factors used in the calculation of the electromagnetic M1 and E2 transitions were as follows: eB =0.136 eb, eF =0.136 eb, gl = 1, gs = 3.899 µN and gd = 0.3 µN for both sets of calculation.

The only experimental values available to compare with are those reported in ref. [16]. They report, the experimental ratio of B(M1) reduced transition probabilities between in-band and interband transitions is between 1.2 and 2.4 for the 21/2 and 19/2 states of both bands. The calculated values found in the present analysis are 1.2 and 1 respectively in both sets of analysis. Also, they reported the experimental lower limits of the B(M1) / B(E2) (in band) ratio for the 21/2 states of bands 7 and 8 are around 6 µN/ e b, while the calculated value has been found to be 1.4 and 2.5 μN/ e b for the 3- levels and 5- levels calculations respectively. Moreover, they[16] are not confident about the values reported due to low statistics.

One of the most important signature on the electromagnetic properties of the chiral geometry is the B(M1)/B(E2) ratios in-band staggering as a function of spin. Figure 4 shows the staggering of the in-band B(M1)/B(E2) values as predicted by the IBFM. Both calculations (3& 5 levels) gives a values which are staggered nearly in the same miner.

Another important signature on the electromagnetic properties of the chiral geometry is that there should be very similar B(M1) transitions strength between the chiral partner states. Figure 5 shows the B(M1, I→ I-1) values calculated by the IBFM for both sets of analysis (3& 5 levels). However, the similarity is more clear in 3- levels calculation then on the 5- levels calculation.

In the ideal chiral symmetry, it is expected that interband B(E2, I→ I-2) transitions disappear in the chiral region. The IBFM values do not meet this criteria and shows a values for these transitions in both bands and for the two sets of calculation. However, the 5- levels calculation gives very small values for the B(E2, I→ I-2) interband transitions.

The B(E2) linking transitions between main band and side band are shown in fig. 6. The B(E2) linking values from 5- levels calculation are very small at high spin which indicate that it is not in an ideal chiral geometry. The B(E2) values calculated from 3- levels calculation shows different behavior.

Summary:

The excitation energy of the two negative parity bands (band 7 & 8) in 105Rh 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 shows that the possibility for chiral geometry in the negative parity states (bands 7 & 8) is present, but not dominant.

Electromagnetic transition probabilities using the IBFM were deduced for intra- and inter- band transitions in the two negative parity state bands in 105Rh nucleus that were previously identified as a chiral pair. The weak B(M1)/ B(E2) values staggering can be attributed to the static chirality for this nucleus rather than vibration chirality. Although, the results of the two sets of the analysis (3 & 5- levels) are close, the 5-levels calculation is more reasonable than 3- levels calculation. Due to the leak in experimental electromagnetic properties, the structure of the twin bands in the 105Rh nucleus could be determined by shape fluctuations and prolate- oblate coexistence than by chirality. This nucleus need more efforts from both experimental and theoretical sides.

References

1. S. Frauendorf and J. Meng : Nucl. Phys. A617 (1997) 131.
2. V.I. Dimitrov , S. Frauendorf and F. Donau: Phys. Rev. Lett. 84(2000)5732.
3. S. Frauendorf: Nucl. Phys. A557 (1993) 259c.
4. J. Peng, J. Meng and S.Q. Zhang: Phys. Rev. C68(2003) 044324.
5. S. Brant and D. Tonev: J. of Phys; Conference series 205(2010) 012026.
6. C. Petrache, D. Bazzacco, et al.: Nucl. Phys. A597(1996) 106.
7. K. Starosta, T, Koike,et al.: Phys. Rev. Lett. 86(2001) 971.
8. K. Starosta, T, Koike, G.T. Chiara, D.B. Fossan and D.R. LaFosse: Phys. Rev. A682(2001) 375c.
9. R. A. Bark, A.M. B axter, et al.: Nucl, Phys.. A691(2001) 577.
10. C. Vaman, D. B. Fossan, T. Koike, K. Starosta, I. Y. Lee nd A. O. Macchiavelli: Phys. Rev. Lett.: 92(2003) 032501.
11. C. Vaman, et al.: Phys. Rev. Lett. 92(2004) 032501.
12. P. Joshi, et al.: Phys. Lett. B595(2004) 135.
13. P. Joshi, et al.: Eur. Phys. J. A 24 (2005) 23.
14. J. Timar ,et a.: Phys. Lett. B 598 (2004) 178.
15. H.G. Ganev, A.I. Georgieva, S. Brant and A. Ventura: arXiv: 0901.3497 V1 [nucl-th] 22 Jan 2009.
16. J.A. Alcantara-Nunez, J.R.B. Oliveira, E.W. Cybulska, N.H. Medina, M.N. Rao, R.V. Ribas, M.A. Rizzuto, W.A. Seale, F. Falla-Sotelo, K.T. Wiedemann, V.I. Dimitrov and S. Frauendorf: Phys. Rev. C 69 (2004) 024317.
17. Sohair M.D., Prog. in Phys.: 1(2009)44.
18. Iachello F. and Scholten O.,(1979)," Description of odd-mass Nuclei" Phys, Rev. Lett. 43. 679-692.

19.Talmi I.T., (1981)," In interacting Bose-Fermi system in Nuclei, ed. F. Iachello (New York: Plenum)".
20.Bardeen J., Cooper L.N. and Schrieffer J.R." Pairing Theory in Super Conductors" Phys. Rev.,(1957) 108.1175-1192.
21.Scholten O., (1980)," internal Report KVI 252, Computer code ODDA, Groningen".

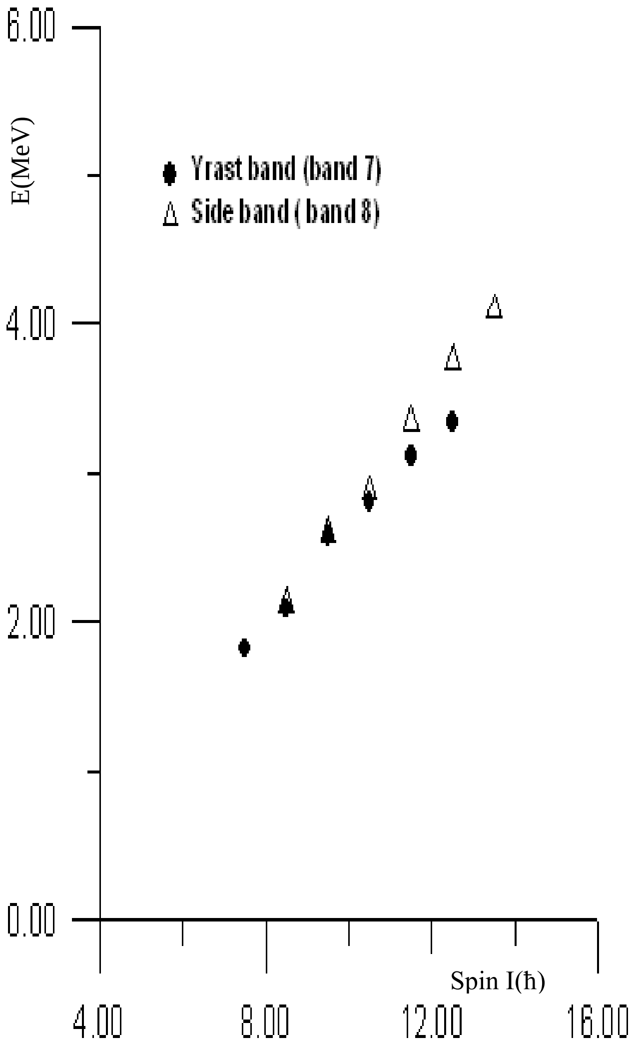

Fig. 1: Energy versus spin(I) for 3-levels IBFM calculation ^{105}Rh nucleus.

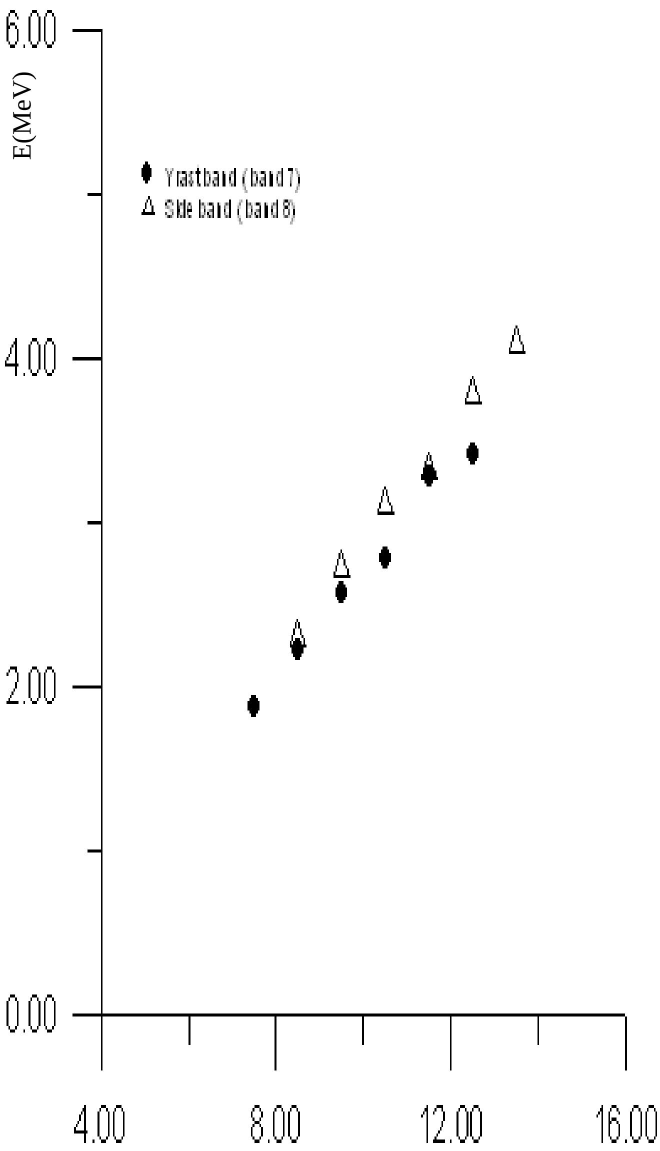

Fig. 2: Energy versus spin(I) for 5-levels IBFM calculation ^{105}Rh nucleus.

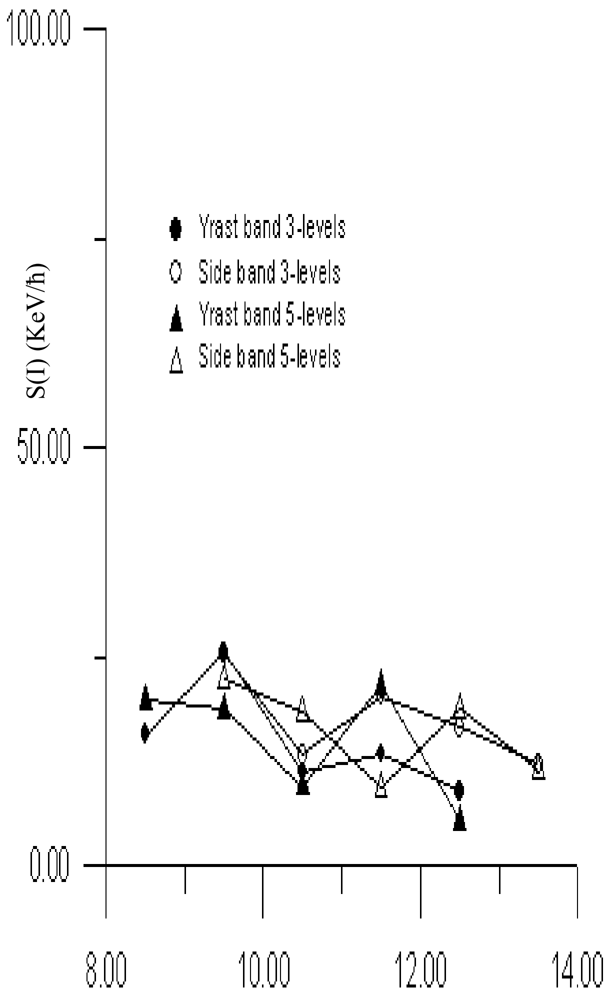

Fig. 3: Signature Splitting S(I) versus spin (I) from the IBFM calculations in ^{105}Rh

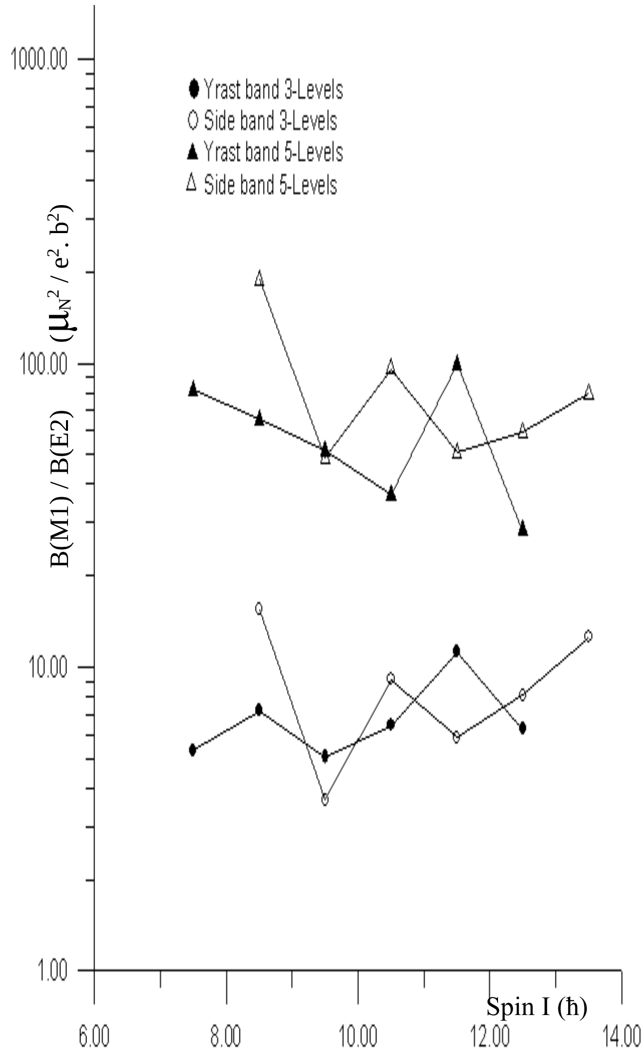

Fig.4: The calculated B(M1)/B(E2) ratios as functions of the spin in ^{105}Rh.

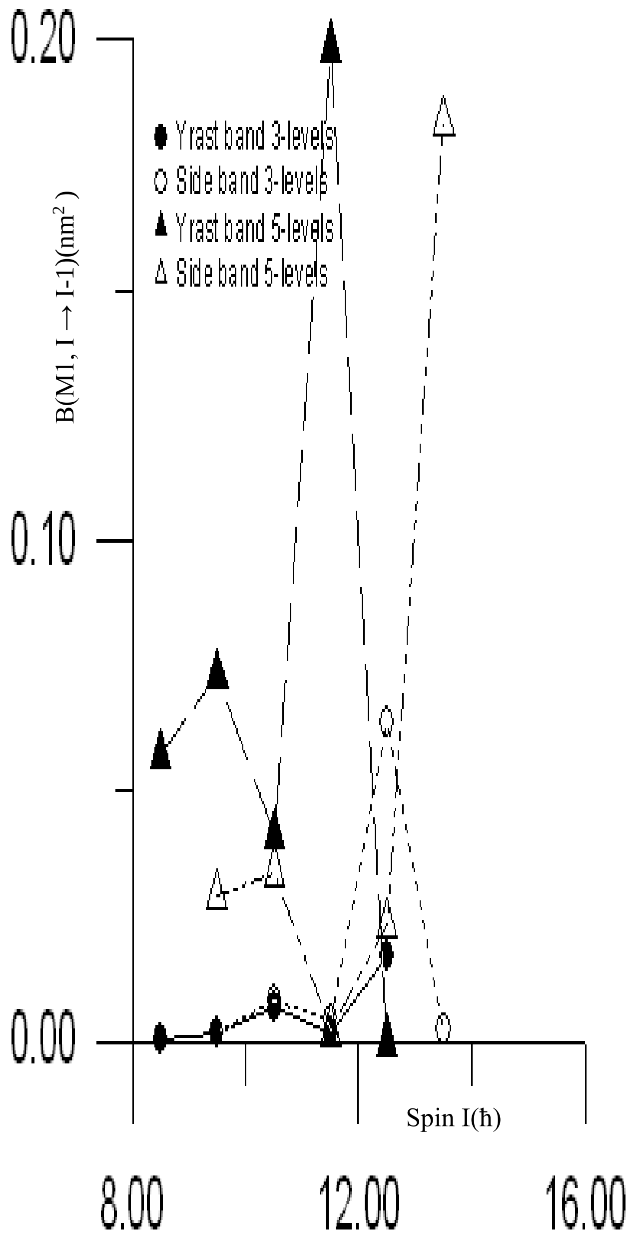

Fig. 5: B(M1) values predicted by the IBFM in ^{105}Rh nucleus.

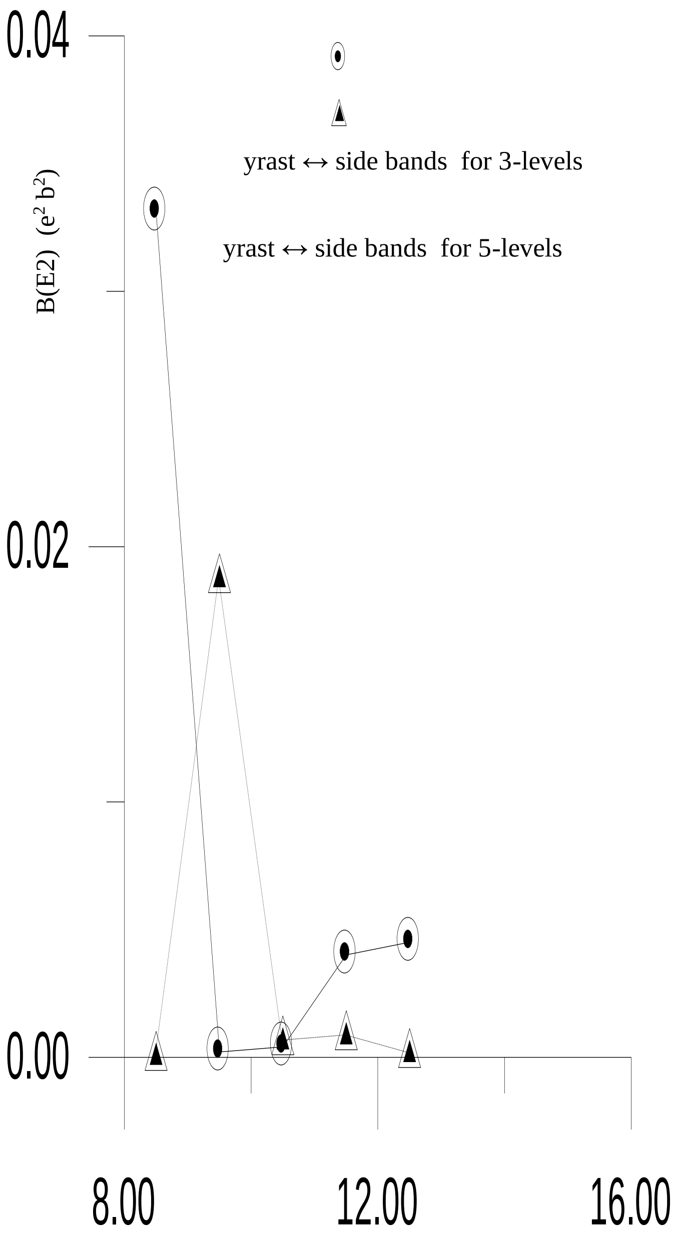

Fig. 6: The B(E2) values for transitions de-exciting states in the yrast and the side bands as predicted by the IBFM in ^{105}Rh nucleus.

P- ISSN 1991-8941 E-ISSN 2706-6703 *Journal of University of Anbar for Pure Science (JUAPS)* Open Access
2011,(5), (1) :41-48

أختبار نظري للتماثل اليدوي لمستويات البرم السالب في نواة إل 105Rh

نبيل ابراهيم فواز

e-mail: NIFAWAZ@yahoo.com

الخلاصة :

التماثل اليدوي لمستويات البرم السالب في نواة ال 105Rh تم اختبارها بأستخدام نموذج تفاعل البوزون – فرميون. نجح نموذج تفاعل البوزون – فرميون في تحديد مستويات الطاقه ذات البرم السالب. أضافة المدارات العليا في حسابات نموذج تفاعل البوزون – فرميون لا يغير من تصرف المستويات. يمكن تصنيف هذه النواة على انها تمتلك تماثل يدوي ساكن وليس تماثل اهتزازي . حزم التماثل السالب لا تظهر تماثل يدوي مثالي .