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IDENTIFICATION OF MIXED SYMMETRY STATES IN$^{180\text{-}186}$ W ISOTOPES IN THE FRAMEWORK OF IBM-2

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ABSTRACT

In tungsten isotopes Z=74 (A=180-186), energy levels, B(E2), B(M1) and mixed symmetry states (MSS) have been discussed using the interacting boson model (IBM-2). The effect of the Majorana parameters on energy of the highly excited state have been investigated. The variation of these parameters have great effect on properties of MSS. All the calculated results were compared with the available experimental data and get reasonable agreement. It is found that the 2_5^+ in ^{180}W and ^{182}W are the first 2^+ mixed symmetry states, while the 2_4^+in ^{184}W and ^{186}W are the first 2^+ mixed symmetry states.

KEYWORDS: W Isotopes, IBM-2, Energy Level, Electromagnetic Transition, Mixed Symmetry States

INTRODUCTION

The proton-neutron interacting boson model (IBM-2) has been very successful in describing the collective properties of vas number of nuclei. The IBM-2 distinguishes between proton and neutron bosons can produce all the collective states of IBM-1 in addition it produced states called the mixed symmetry states (MSS). The presence of mixed symmetry states built on the basis of the properties of electromagnetic transitions [1]**.**

To understand the basis mechanism of how the interaction between protons and neutrons, which offers a complex formula for the nuclear structures, and it is the first task of the nuclear structures physics studies. That information can we get from studies of nuclear states and which are sensitive to the of the proton and the neutron degrees of freedom [2].

The even-even mass tungsten isotopes have been a matter of study by several authors using different methods shown in references [3-5].

The aims of the present study are the following:

- The implementation IBM-2 calculation of the even-even $^{180\text{-}186}$W isotopes in the context of new experimental data.
- Study of the mixed symmetry characters through a study of various quantities, the wave function, the F-spin values and the electromagnetic transition probabilities.
- Identification of the one – phonon and two – phonon mixed symmetry states.

Interaction Boson Model (IBM-2)

The IBM-2 Hamiltonian can be written as [6,7]

$$H = E_o + \varepsilon_d(\hat{n}_{d_\pi} + \hat{n}_{d_\upsilon}) + \kappa_{\pi,\upsilon}(\hat{Q}_\pi . \hat{Q}_\upsilon) + \hat{M}_{\pi\upsilon} + \hat{V}_{\pi\pi} + \hat{V}_{\upsilon\upsilon} \tag{1}$$

Where the index (υ) and (π) refer to neutron and proton bosons, respectively, E_o is a constant which contributes to the total binding energy only. Moreover:

$$\hat{n}_{d_\rho} = (d_\rho^\dagger . \tilde{d}_\rho) \quad (2)$$

$$\hat{Q}_\rho = [d_\rho^\dagger \times \tilde{s}_\rho + s_\rho^\dagger \times \tilde{d}_\rho]^{(2)} + \chi_\rho [d_\rho^\dagger \times \tilde{d}_\rho]^{(2)} \quad (3)$$

$$\hat{M}_{\pi\upsilon} = \frac{1}{2}\xi_2 \, [s_\upsilon^\dagger \times d_\pi^\dagger - s_\pi^\dagger \times d_\upsilon^\dagger]^{(2)} . [\tilde{s}_\upsilon \times \tilde{d}_\pi - \tilde{s}_\pi \times \tilde{d}_\upsilon]^{(2)}$$

$$- \sum_{k=1,3} \xi_k [d_\upsilon^\dagger \times d_\pi^\dagger]^{(k)} . [\tilde{d}_\pi \times \tilde{d}_\upsilon]^{(k)} . \quad (4)$$

The Majorana term $\hat{M}_{\pi\upsilon}$ is responsible for the location of mixed symmetry states with respect to fully symmetric ones. The term $\hat{V}_{\rho\rho}$ shows from microscopic considerations represents the interaction between same bosons, it given following form:

$$\hat{V}_{\rho\rho} = \frac{1}{2}\sum_{(L=0.2.4)} C_{L\rho} [d_\rho^\dagger \times d_\rho^\dagger]^{(L)} . [\tilde{d}_\rho \times \tilde{d}_\rho]^{(L)} \quad (5)$$

For the calculation of reduced transition probability and moments the following one-body electromagnetic operators were considered [8] :

$$\hat{T}(E2) = e_\pi \hat{Q}_\pi + e_\upsilon \hat{Q}_\upsilon \quad (6)$$

$$\hat{T}(M1) = \left[\frac{3}{4\pi}\right]^{1/2} (g_\pi \hat{L}_\pi + g_\upsilon \hat{L}_\upsilon) \qquad \text{where:} \qquad \hat{L}_\rho = \sqrt{10}[d_\rho^\dagger \times \tilde{d}_\rho]^{(1)} \quad (7)$$

Where e_π and e_υ the proton and neutron boson charges, g_π a and g_υ are g-factors for proton and neutron boson, $\hat{L}_\rho$ is the angular momentum operator.

For a gamma ray decaying from J_i state to J_f state carried by a photon of multipole order L, the reduced transition probabilities, for electric B(EL) and magnetic transition B(ML) are defined as follows [9]:

$$B(EL{:}\, J_i \to J_f) = \frac{1}{2J_i+1} |\langle f|\hat{Q}|i\rangle|^2 \quad (8)$$

$$B(ML{:}\, J_i \to J_f) = \frac{1}{2J_i+1} |\langle f|\hat{M}|i\rangle|^2 . \quad (9)$$

Where $\hat{Q}$ and $\widehat{M}$ are the electric and magnetic multipole operators, respectively.

In IBM-2, the isospin formalism can be straight-forwardly applied on the boson level, i.e., the bosons are considered as elementary *particles* that form an isospin doublet with projections +1/2 (proton boson) and -1/2 (neutron boson). This "boson-isospin" is called F-spin. The lowest-energy nuclear states have the maximum F-spin quantum number, F=N/2, where N is the total number of bosons. Such states are symmetric with respect to the pairwise exchange of boson isospin labels. Boson states, that contain at least one-pair of bosons which is antisymmetric under the exchange of boson isospin labels, possess non-maximum values of the F-spin quantum number, F < N/2, and are called "mixed-symmetry states (MSS's)". Mixed symmetry states appear when the motions of the proton and neutron are not in phase. The signature of MSS's is the existence of strong F-vector M1 transitions to symmetric states with allowed M1 matrix elements of the order of 1 μ_N [10, 11]**.** In the IBM-2, F-spin operators written as:

$$F_+ = s_\pi^\dagger s_\upsilon + \left(d_\pi^\dagger . \tilde{d}_\upsilon\right) \quad (10)$$

$$F_- = s_\upsilon^\dagger s_\pi + \left(d_\upsilon^\dagger . \tilde{d}_\pi\right), \qquad F_z = \frac{(N_\pi - N_\upsilon)}{2}. \quad (11)$$

Both bosons form of (F-spin) multiplet written as;

$$|\pi >= \left|\frac{1}{2}, \frac{1}{2}\right\rangle |\upsilon >= \left|\frac{1}{2}, -\frac{1}{2}\right\rangle. \quad (12)$$

The total symmetry states have the maximum value of (F-spin) [12].

$$F_{max} = \frac{(N_\pi + N_\nu)}{2} \quad (13)$$

While the mixed symmetry states properties by decreasing (F-spin) value where:

$$F = F_{max} - 1\,, F_{max} - 2\,, \ldots \ldots, F_{min} = \frac{N_\pi - N_\upsilon}{2} \quad (14)$$

In the vibrational nuclei, lowest lying mixed symmetry state has spin–parity2^+, and the congruence is located at the levels around 2 MeV. It is decay to the 2_1^+ level by the basic strong M1 transition [13].

RESULTS AND DISCUSSIONS

For[180-186]W isotopes, there are four proton - boson holes and neutron hole bosons decrease gradually with mass number A. The calculated energy levels spectrum are obtained by diagonalizing the Hamiltonian in Eq.(1), using the NPBOS code[14].

The best fitted parameters are listed in Table 1. It can be seen from the table the values of $C_\nu^L = C_\pi^L (L = 0,2,4)$ for each isotope, the present of these terms corresponding to print out the sequences of levels. The parameter $\kappa_{\pi\upsilon}$ has been kept constant in all the isotopes. The parameters $x_\nu = x_\pi$ been kept constant in all set of the isotopes and equal to SU (3) limit value $=-\sqrt{7}/2$.

The values of the Majorana parameters will depress 2_{ms}^+ with respect first scissor mode state. The aim was to minimize the position of 2^+ mixed symmetry states in the W isotopes, and to monitor the effects of such a change on the calculated energy spectrum. On the other hand, we fixed the value of $\xi_1 = 0.24$ MeV for all isotopes and vary ξ_2 andξ_3.

The calculated energy spectrums of the 180-186W nuclei are shown in Figures 1-4. Reproduction of the trend in the experimental data [15] can be seen, the energy states have been grouped according to bands and F-spin values, and they provide an opportunity to study possible collective band structures that are predicted in these nuclei. As can be seen, our results agree well with the available experimental data. In particular, all symmetry states in different band are reproduced correctly, all second 0_2^+ and 2_2^+ states, except the 0_2^+ in the^{180}W isotope where the deviation is 0.276 MeV lower than the experimental value. The IBM-2 predictions of the γ- band of the selected set of W- isotopes are also satisfactory. Though the calculated 0_3^+ state at 1.651 MeV in the^{182}W isotope has not been observed, while the 0_3^+ states in the ^{180,184,186}W isotopes are very close to the experimental ones. All 3_1^+ states are fully symmetric states, i.e belong to γ-collective band. The deviations between theoretical and experimental data may be attributed to the mixing of the collective excitation with quasiparticle excitations.

Table 1: The Parameters of the IBM-2 Hamiltonian. $x_\nu = x_\pi = -\frac{\sqrt{7}}{2}$, $\xi_1 = 0.24$ Have Been Chosen for $^{180-186}W$ Isotopes, All Parameters are in Mev Unit except x_ν and x_π which are Dimensionless

A	N_ν	N_π	ε_d	κ	$C_\nu^0 = C_\pi^0$	$C_\nu^2 = C_\pi^2$	$C_\nu^4 = C_\pi^4$	ξ_2	ξ_3
180	10	4	0.28	-0.062	0.05	-0.10	0.13	0.10	0.10
182	9	4	0.28	-0.062	0.05	-0.10	0.13	0.10	0.10
184	8	4	0.30	-0.062	0.10	-0.10	0.15	0.04	0.04
186	7	4	0.33	-0.060	0.10	-0.20	0.20	0.04	0.04

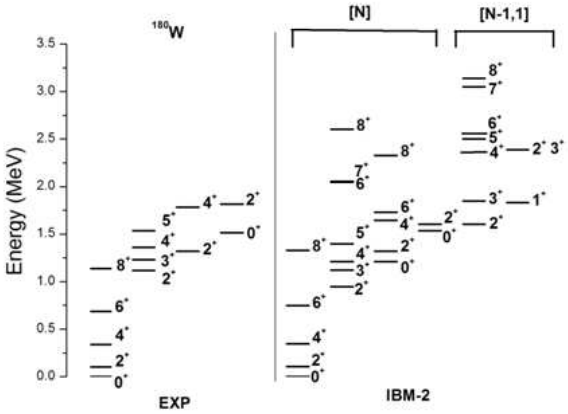

Figure 1: Comparison between Calculated Energy Levels and Experimental Data in (_74^180) W Isotope

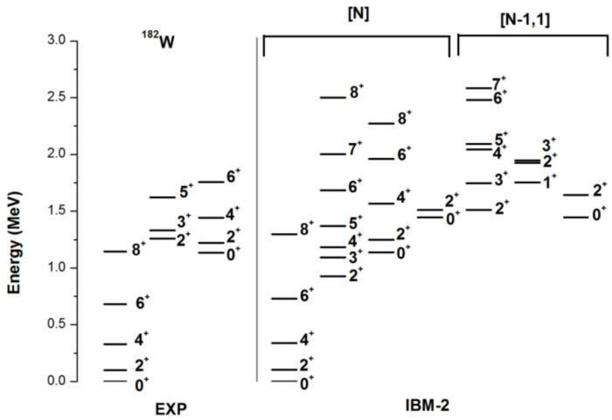

Figure 2: Comparison between Calculated Energy Levels and Experimental Data in $^{182}_{74}W$ Isotope

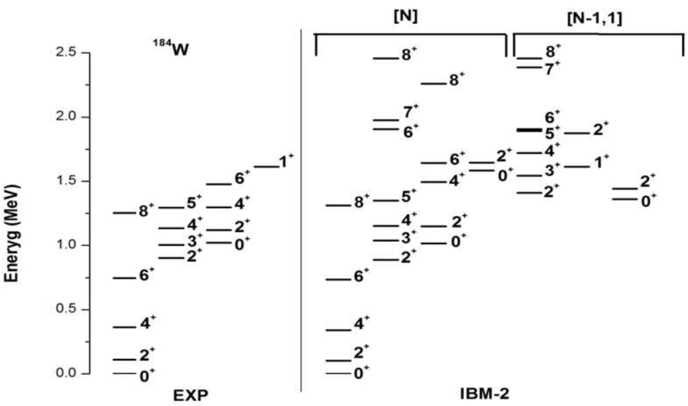

Figure 3: Comparison between Calculated Energy Levels and Experimental Data in $^{184}_{74}W$ Isotope

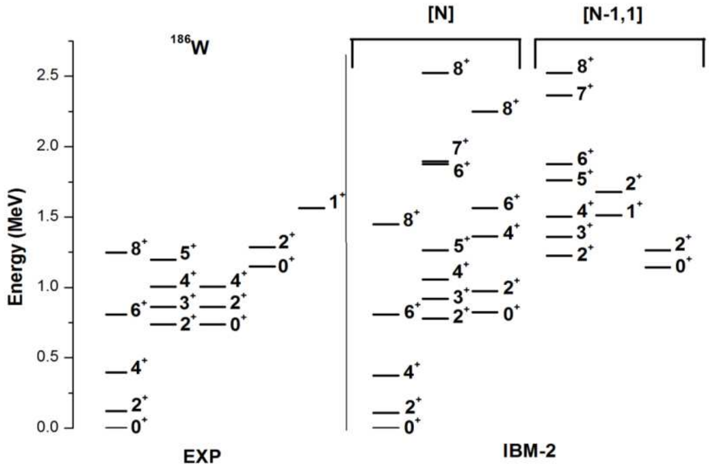

Figure 4: Comparison between Calculated Energy Levels and Experimental Data in $^{186}_{74}W$ Isotope

Mixed Symmetry States

The excitation energy of the mixed symmetry states are depend on the Majorana terms. In which we can found the ratio by [16]

$$R = \frac{\langle J|F^2|J\rangle}{F_{max}(F_{max}+1)} \tag{15}$$

Where: $|J\rangle = \alpha|F_{max}\rangle + \beta|F_{max} - 1\rangle$, $\alpha^2 + \beta^2 = 1$ (16)

We can be calculate

$$\langle J|F^2|J\rangle = \alpha^2 F_{max}(F_{max} + 1) + \beta^2 (F_{max} - 1)F_{max} \tag{17}$$

The values ofα and $\beta$are playing an important role in the measurement of symmetry in each state. We found that N depends on the energy excitation, this the energy of the mixed symmetry states increases with the N to deformed nuclei [17]. In the SU(3) limit that the difference in the excitation energies for two different Majerona force are important. Can be noted in most of the deformed nuclei by mixing the quotient of the wave function of the proton and the neutron. 1_1^+ states can be observed in rotational nuclei SU(3) [18].

The ξ_2 component of Mojorana interaction should has an extreme effect on the energy of the MSS. We set, as starting point, the three parameters ξ_1, ξ_2 and ξ_3 which obtained the best fit to experimental data and then allow ξ_2 to vary. The completely symmetric 2^+ states do not effected by changing ξ_2, or reach the saturation value very quick, while the energy of the MSS increase (decrease) rapidly by changing the ξ_2 value and become constant at a certain energy as shown in figures 5 and 6. The energy of the 1_{ms}^+ shows a linear increase with ξ_2. The 3_{ms}^+ and 4_{ms}^+ behave in the same manner of the2_{ms}^+. The F-spin projection calculation confirm this criteria, in other word, we recommended the two methods in searching for the mixed symmetry states. The values (F*F/max) of low lying states which reflect of the amount of the symmetry in the state can is shown in Figure 7.

According to the above discussion, it is found that the 2_5^+ and 2_6^+ at calculated energy around 2 MeV in$^{180}_{74}W$ isotope are mixed symmetry states, plus the 1_1^+ and 1_2^+at 2.130 MeV and 2.877 MeV respectively. The same states in^{182}W isotopes are mixed symmetry states. In 184W isotope, it is found that the 2_4^+ and 2_5^+ states at experimental and theoretical energies (1.386, 1.431) and (1.408, 1.441) MeV respectively are the mixed symmetry states. In ^{186}W has the similar behavior as previous isotope, i.e the 2_4^+ and 2_5^+ states at experimental and theoretical energies (1.285, 1.322) and (1.226, 1.254) MeV respectively are mixed symmetry states.

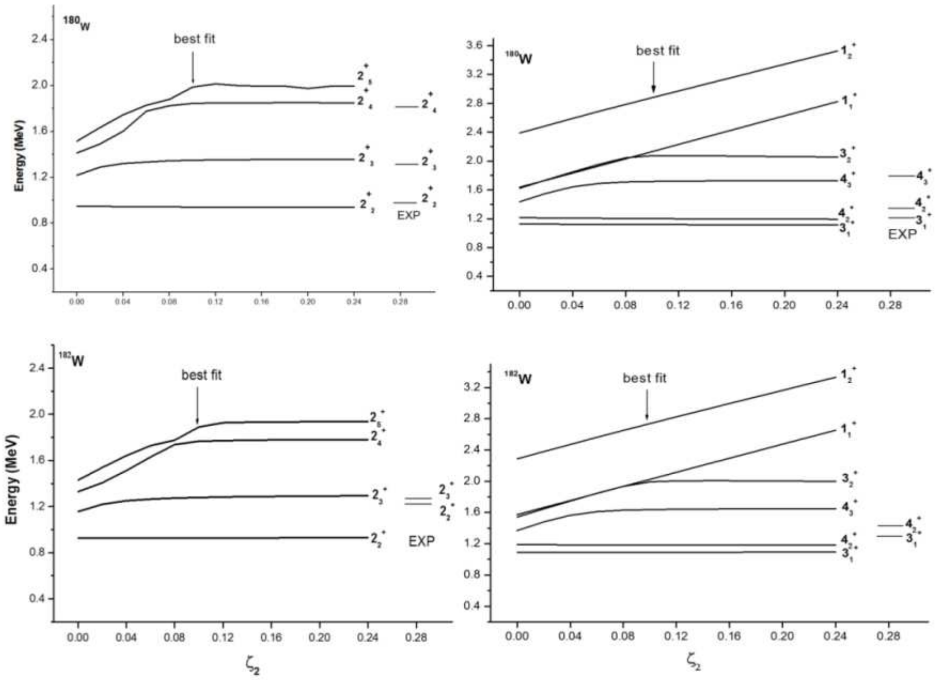

Figure 5: The Variation in Levels Energy of ^{180,182}W Isotopes as a Function of ξ_2

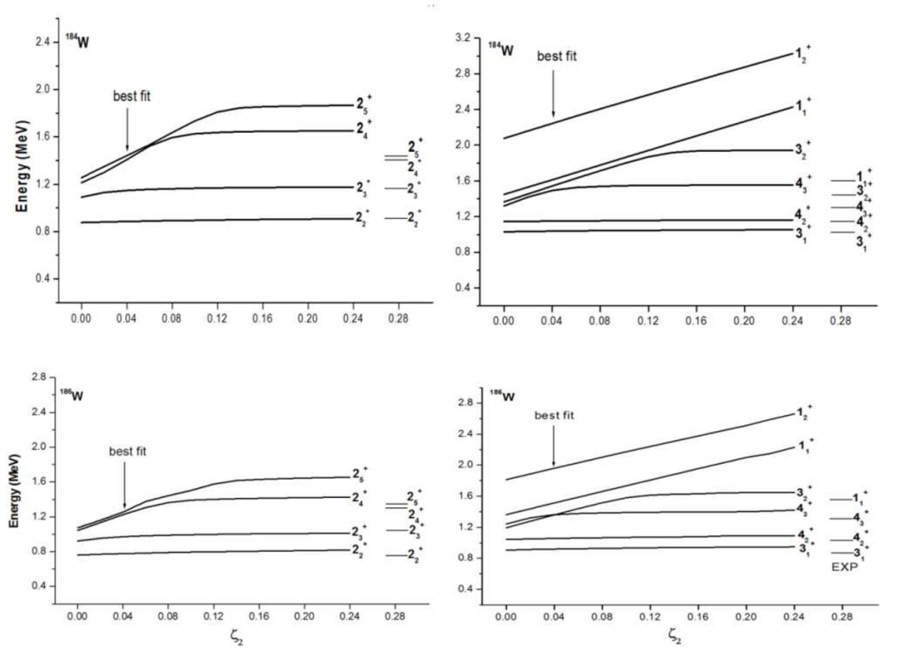

Figure 6: The Variation in Levels Energy of ^{184,186}W Isotopes as a Function of ξ_2

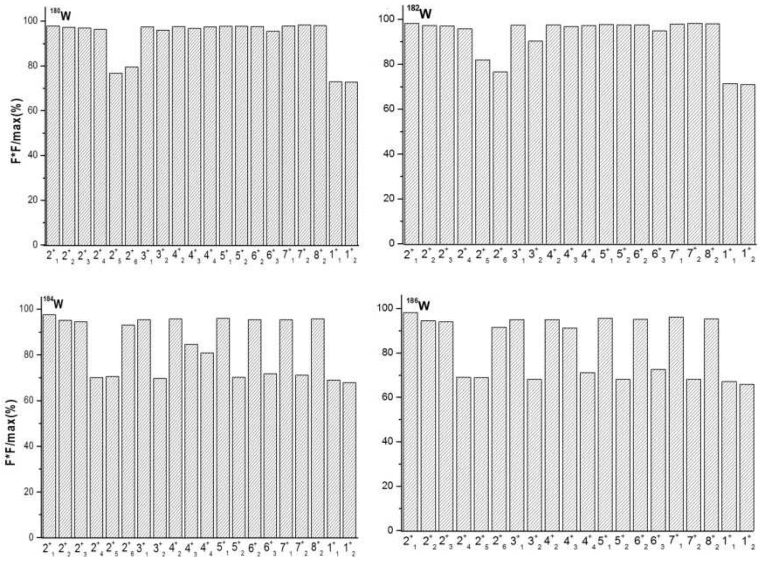

Figure 7: The F*F/Max (%) Values of the Low-Lying Positive Parity States in IBM-2, Lower Numbers Denote the Order of the States

Electromagnetic Transitions

Most characteristics and measurable quantities of MSS states is the electromagnetic decay by allowed F-vector any M1 transition to symmetric states. This is an important feature because the M1 transitions between FSS are prohibited and therefore M1 transition is a distinct of MSS states. The M1 transitions between MSS and FSS are proportional to the quantity $[(g_\pi - g_\upsilon)^2 N_\pi N_\upsilon]$, while, E2 transitions between FSS are proportional to the quantity $[(e_\pi N_\pi + e_\upsilon N_\upsilon)^2]$ and E2 transition between MSS and FSS are proportional to the quantity $[(e_\pi - e_\upsilon)^2 N_\pi N_\upsilon]$. The proportionality factors depend on the structures of the wave functions are included.

From equation (6) we note that an E2 transition mainly depends on identifying proton and neutron bosons effective charges and in the case of the mixed symmetry states $(e_\pi \neq e_\nu)$ [19]. The relationship between (e_π , e_ν) and the reduced transition probability B(E2) for rotational limit SU(3) is given in the form [20]:

$$\boldsymbol{B(E2: 2_1^+ \rightarrow 0_1^+) = \frac{(2N+3)(e_\pi N_\pi + e_\upsilon N_\upsilon)}{5N}} \tag{18}$$

This relation was used to estimate the effective charges for proton and neutron bosons. It was found that the values $e_\pi = 0.12\, eb$ and $e_\nu = 0.14\, eb$ are suitable values for the selected W isotopes order to calculate the reduced electric transition probability B (E2).

In order to calculate the M1 transition probabilities, one has to estimate the two g-factors in Eq.(7) and to do so, we used relation for the total g-factor written as[21]

$$\boldsymbol{g = g_\pi \frac{N_\pi}{N_\pi + N_\upsilon} + g_\upsilon \frac{N_\upsilon}{N_\upsilon + N_\pi}} \tag{19}$$

The predicted values were$g_\pi = 0.75\, \mu_N$ and$g_\upsilon = 0.15\, \mu_N$. These parameters were kept constant for the whole series of isotopes. The model results and experimental values of the electromagnetic transition probabilities have been listed in tables 2 and 3.

From the calculated values for the transition probability B(E2) and B(M1) in ^{180}W and^{182}W in table 2 , it found that the 2_5^+ state is a mixed symmetry state and represent $2_{1,ms}^+$, because B(E2) < B(M1) as well as the 2_7^+ state which represents the mixed symmetry for the same reason. Whereas 2_4^+ state is a totally symmetric state because of B (M1) < B(E2). While, in the case of $^{184-186}$W, the 2_4^+ represent the $2_{1,ms}^+$ according to the values of B(E2) and B(M1).

In most cases the values of B(M1) and their ratios are very helpful in nuclear shape coexistence. Normally the value of B(M1;$1^+ \rightarrow 0^+$) is the largest value in the M1 transition probability between states, so we applied the B(M1) ratio normalized to the value of this transition, according to the fallowing relations;

$$\boldsymbol{R_1} = \frac{B(M1;\, 1_1^+ \rightarrow 0_1^+)}{B(M1;\, J_i \rightarrow J_F)}, \boldsymbol{R_2} = \frac{B(M1;\, 1_1^+ \rightarrow 2_1^+)}{B(M1;\, J_i \rightarrow J_F)}, \boldsymbol{R_3} = \frac{B(M1;\, 1_1^+ \rightarrow 2_2^+)}{B(M1;\, J_i \rightarrow J_F)} \quad (20)$$

Figure 8, represents the relationship between the ratio R_1 and the mass number (A) by the following formula;

$$\boldsymbol{R_1} = \frac{B(M1;\, 1_1^+ \rightarrow 0_1^+)}{B(M1; 2_i^+ \rightarrow 2_f^+)} \quad \text{where: i= 4 , 5 , 6 , 7 and f=1,2.} \quad (21)$$

Since the value of the $B(M1;\ 1_1^+ \rightarrow 0_1^+)$ in the above equation, is constant, which means, that the R_1 ratio depends on the $B(M1;\ \boldsymbol{2_i^+} \rightarrow \boldsymbol{2_f^+})$. The large value of R_1 means that the 2_i^+ state is a totally symmetric state and this is consistent with the values calculated in the program and with the F-spin values. For small R_1 values the $B(M1;\ \boldsymbol{2_i^+} \rightarrow \boldsymbol{2_1^+})$ is large (>>1), means that, the state $\boldsymbol{2_i^+}$is a mixed symmetry state and it has the strong M1 decay to the $\boldsymbol{2_1^+}$ state and one must take into account that the states in which the M1 decay are one-phonon or two-phonon differences. The relationship between the (R_1) for the ($2_i \rightarrow 2_2$) transition with the (A) number can be seen in the figure also. The ratio will be different in values depending on the amountB(M1; $2_i \rightarrow 2_2$). It can be seen that (R_1) is small (<<1) when ($N_\upsilon = 12$), because this isotope has larger value of B(M1) than the other isotopes. The procedure was applied to identify the totally symmetric sates using the ratios R_2 and R_3; the results are presented in figures 9 and 10.

Table 2: Experimental and Calculated B (E2) (In Unite^2b^2) and B (M1) (in Unitμ_N^2) for $^{180-182}$W Isotopes

$J_i^+ \rightarrow J_f^+$	$^{180}_{74}W$				$^{182}_{74}W$			
	B(E2)		B(M1)		B(E2)		B(M1)	
	Exp.	Cal.	Exp.	Cal.	Exp.	Cal.	Exp.	Cal.
$2_1^+ \rightarrow 0_1^+$	0.8328	0.9285			0.8390	0.8536		
$2_2^+ \rightarrow 0_1^+$		0.0185			0.0208	0.0151		
$2_2^+ \rightarrow 2_1^+$		0.0118		0.0001	0.0412	0.0118	0.0001	0.0001
$0_2^+ \rightarrow 2_1^+$		0.0152				0.0148		
$0_3^+ \rightarrow 2_1^+$		0.0001				0.0001		
$3_1^+ \rightarrow 2_1^+$		0.0289		0.0002		0.0239		
$3_1^+ \rightarrow 4_1^+$		0.0134		0.0002		0.0107		0.0002
$4_1^+ \rightarrow 2_1^+$		1.2909			1.2004	1.1856		
$4_2^+ \rightarrow 2_1^+$		0.0043				0.0039		
$4_2^+ \rightarrow 2_2^+$		0.3309				0.3070		
$4_2^+ \rightarrow 3_1^+$		0.8821		0.0072		0.8031		0.0001
$5_1^+ \rightarrow 4_1^+$		0.0207		0.0003		0.0178		0.0003
$6_1^+ \rightarrow 4_1^+$		1.3382			1.2249	1.2283		
$8_1^+ \rightarrow 6_1^+$		1.2696			1.2800	1.1642		
$1_1^+ \rightarrow 2_1^+$		0.0029		0.1128		0.0025		0.1132
$1_1^+ \rightarrow 2_2^+$		0.0002		0.0029		0.0002		0.0034
$1_1^+ \rightarrow 0_1^+$				0.1872				0.1869

Table 3: Experimental and Calculated B (E2) (in Unit e^2b^2) and B (M1) (Inunit μ_N^2) for $^{184-186}$W Isotopes

$J_i^+ \rightarrow J_f^+$	$^{184}_{74}W$				$^{186}_{74}W$			
	B(E2)		B(M1)		B(E2)		B(M1)	
	Exp.	Cal.	Exp.	Cal.	Exp.	Cal.	Exp.	Cal.
$2_1^+ \rightarrow 0_1^+$	0.7395	0.7559			0.6998	0.6711		
$2_2^+ \rightarrow 0_1^+$	0.0274	0.0131			0.0291	0.0101		
$2_2^+ \rightarrow 2_1^+$	0.0522	0.0123	0.0001	0.0002	0.0636	0.0083	0.0002	0.0001
$0_2^+ \rightarrow 2_1^+$		0.0250				0.0206		
$0_3^+ \rightarrow 2_1^+$		0.0013				0.0001		
$3_1^+ \rightarrow 2_1^+$		0.0218		0.0005		0.1720		
$3_1^+ \rightarrow 4_1^+$		0.0090		0.0006		0.0033		0.0001
$4_1^+ \rightarrow 2_1^+$	0.9943	0.0514			0.9078	0.9294		
$4_2^+ \rightarrow 2_1^+$		0.0038				0.0064		
$4_2^+ \rightarrow 2_2^+$		0.2807			0.0023	0.2383		
$4_2^+ \rightarrow 3_1^+$		0.7018		0.0131		0.6232		0.0001
$5_1^+ \rightarrow 4_1^+$		0.0173		0.0009		0.0179		0.0003
$6_1^+ \rightarrow 4_1^+$	1.1372	1.0936			1.1789	0.9660		
$8_1^+ \rightarrow 6_1^+$		1.0421				0.9206		
$1_1^+ \rightarrow 2_1^+$		0.0029		0.1116		0.0024		0.0998
$1_1^+ \rightarrow 2_2^+$		0.0006		0.0003		0.0001		0.0017
$1_1^+ \rightarrow 0_1^+$				0.1837				0.1616

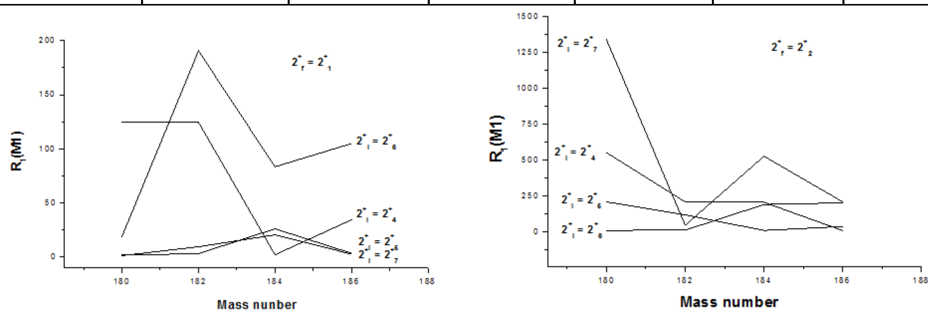

Figure 8: Ratio (2_1) for ($2_i^+ \rightarrow 2_f^+$) (I= 4, 5, 6, 7 and F =1, 2) Transitions with Mass Number

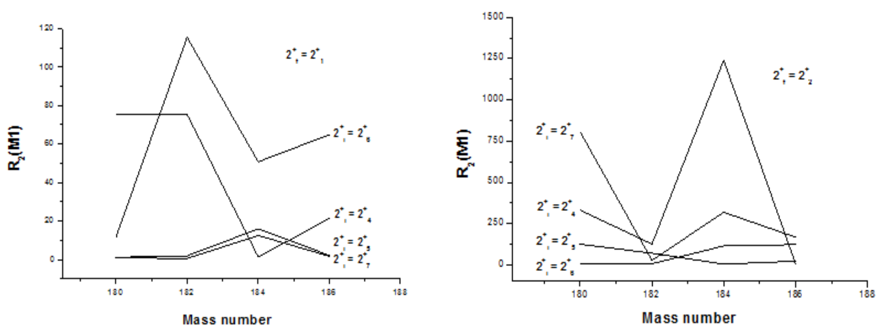

Figure 9: Ratio (2_2) for ($2_i^+ \rightarrow 2_f^+$) (I= 4, 5, 6, 7 and F =1, 2) Transitions with Mass Number

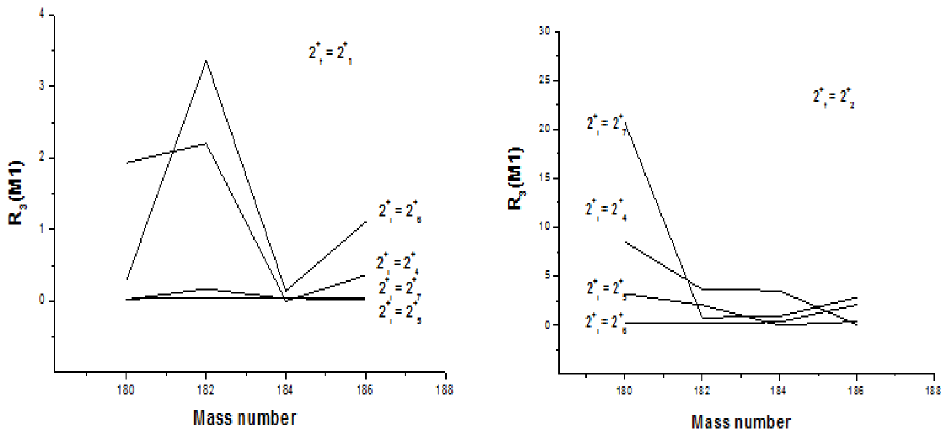

Figure 10: Ratio (2_3) for ($2_i^+ \rightarrow 2_f^+$) (I= 4, 5, 6, 7 and F =1, 2) Transitions with Mass Number

CONCLUSIONS

In this work, a satisfactory description of the mixed symmetry states properties in tungsten isotopes A=180 to 186 has been obtained using M1 transition strength. The calculation was done in the framework of IBM-2. These properties provided us with an example of details of nuclear structure of the selected nuclei. The analyses demonstrate the sensitivity of the mixed symmetry states energy to the model parameters F-spin and the Majorana term 2_2. The comparison with experimental data shows that, we still lacking of experimental data on the B(M1; $1^+ \rightarrow 0^+$) in order to focus on these aspect.

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