A Study for the Energy levels and Potential Energy Surface of $^{184}_{74}W_{110}$ Isotope

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Abstract

In the present work , The $^{184}_{74}W_{110}$ isotope in SU(3) – O(6) transition region were investigated . The Hamiltonian equation for this dynamical symmetry is used in the calculations of energy levels for $^{184}_{74}W_{110}$ isotope according to the interacting boson model version one (IBM-1) . The potential energy surface was also studied . As spin and parity for some energy levels, which were not exactly determined experimentally have been determined. It was assuring that spin and parity for energy levels number (5) . The results are compared with the most recent experimental data . Good agreement was obtained between our theoretical calculations for this under study isotope .

Key words: IBM-1 , nucleons tructure , potential energy surface

دراسة مستويات الطاقة وطاقة جهد السطح للنظير $^{184}_{74}W_{110}$

الخلاصة

في البحث الحالي ، النظير $^{184}_{74}W_{110}$ يقع في منطقة الانتقال SU(3) – O(6) . استخدمت معادلة الهاملتونين لهذا التناظر الديناميكي في حساب مستويات الطاقة للنظير $^{184}_{74}W_{110}$ وفقاً لأنموذج البوزونات المتفاعلة الأول (IBM-1) . تم أيضاً حساب طاقة جهد السطح . كما تم تحديد البرم والتماثل لبعض مستويات الطاقة غير المحددة عملياً بصورة أكيدة ، حيث تم تأكيد برم وتماثل لمستويات طاقة عدد (5) . وبمقارنة النتائج مع القيم العملية المتوفرة حصلنا على توافق جيد مع حساباتنا النظرية للنظير تحت الدراسة .

الكلمات المفتاحية : نموذج البوزونات المتقابلة ، التركيب النووي ، طاقة الجهد

1- Introduction :

In 1974 a nuclear model was proposed by Arima and Iachello[1,2], and was called Interacting Boson Model (IBM) in an attempt to describe in a unified way collective properties of nuclei (collective motion) .

The interacting boson model (IBM) was based on the well-known shell model and on geometrical collective model of the atomic nucleus . Which is suitable for describing the structure of intermediate and heavy nuclei . In addition , it is of a considerable theoretical interest since it shows the dynamical symmetries of the nuclei , which are made visible through using Lie algebra .

The basic idea of the interacting boson model is to assume that , the low-lying collective states in medium and heavy even –even nuclei away from closed shells, are dominated by excitations of the valence protons and the valence neutrons only , while the closed-shell core is inert[3,4,5] .

The (IBM) model , assumed that , the collective behavior arises from the coupling , through the nucleon - nucleon interaction of the separate low-lying systems of valence protons and neutrons defined with respect to a major shell closure . It can be able to describe nuclear properties such as spins and energies of the levels , decay probabilities for the emission of gamma quanta , probabilities of electromagnetic transitions and their reduced matrix elements for different transitions , multipole moments , and mixing ratios[3,6] .

Furthermore , it was assumed that the particle configurations which were very important in shaping the properties of the low-lying states were these in which identical particles were coupled together forming pairs of angular momentum L = 0 or 2 , In addition , these proton (neutron) pairs are treated as bosons . The bosons with angular momentum L=0 are denoted by s_π (s_υ) and are called s- boson, while proton (neutron) bosons with angular momentum L=2 are denoted by $d_\pi(d_\upsilon)$ and where they are called d-boson[7] .

The number of bosons depends on the number of active nuclear particle (or hole) pairs outside a closed shell, while the total boson number (N) is calculated by adding the partial numbers i.e. $N=N_\pi + N_\upsilon$,where N_π and N_υ are the number of proton and neutron bosons respectively[3,6] .

2 –Theoretical Basics :

2 –1: The Hamiltonian operator of the (IBM-1)

In the IBM-1, the Hamiltonian operator can be written in terms of (one –body and two –body interaction) as [8] .

$$\hat{H} = \sum_{i=1}^{N} \varepsilon_i + \sum_{i<j}^{N} V_{ij} \quad \text{.... (1)}$$

where

ε_i :- The Boson energy .

V_{ij}:- Boson–Boson interacting energy .

N :- Total number of bosons .

Also the Hamiltonian can be written in terms of Creation and Annihilation operators as [5, 8] :-

$$\hat{H} = \varepsilon_s (\hat{S}^\dagger . \hat{\tilde{S}}) + \varepsilon_d \left(\hat{d}^\dagger . \hat{\tilde{d}} \right) + \sum_{L=0,2,4} \frac{1}{2} \sqrt{2L+1}\, C_L \, [[\hat{d}^\dagger \times \hat{d}^\dagger]^L \times [\hat{d} \times \hat{\tilde{d}}]^L]^0 + \frac{1}{\sqrt{2}} V_2 \, [[\hat{d}^\dagger \times \hat{d}^\dagger]^2 \times \left[\hat{\tilde{d}} \times \hat{\tilde{S}}\right]^2 + [\hat{d}^\dagger \times \hat{S}^\dagger]^2 \times \left[\hat{d} \times \hat{\tilde{d}}\right]^2]^0 + \frac{1}{2} V_0 \, [[\hat{d}^\dagger \times \hat{d}^\dagger]^0 \times \left[\hat{\tilde{S}} \times \hat{\tilde{S}}\right]^0 + \left[\hat{\tilde{S}}^\dagger \times \hat{S}^\dagger\right]^0 \times \left[\hat{\tilde{d}} \times \hat{\tilde{d}}\right]^0]^0 + U_2 [[\hat{d}^\dagger \times \hat{S}^\dagger]^2 \times \left[\hat{\tilde{d}} \times \hat{\tilde{S}}\right]^2]^0 + \frac{1}{2} U_0 [[\hat{S}^\dagger \times \hat{S}^\dagger]^0 \times \left[\hat{\tilde{S}} \times \hat{\tilde{S}}\right]^0]^0 \quad \text{.... (2)}$$

Where

ε_L(L = 0, 2), C_L(L = 0, 2, 4), V_L(L = 0, 2), U_L (L = 0, 2) represents the boson energies and interactions .

The creation operators ($\hat{d}^\dagger$, $\hat{S}^\dagger$) , and the annihilation operator ($\hat{s}$, $\hat{d}$) can obey the commutation relations [4,8] .

$[\hat{S} , \hat{S}^\dagger] = 1$, $[\hat{S} , \hat{S}] = 0$, $[\hat{S}^\dagger , \hat{S}^\dagger] =0$

$[\hat{d}_M , \hat{d}_M] = 0$, $[\hat{d}_M , \hat{d}_M^\dagger] = \delta MM$,

$[\hat{d}_M^\dagger, \hat{d}_M^\dagger] = 0$, $[\hat{S}, \hat{d}_M] = 0$, $[\hat{S}, \hat{d}_M^\dagger] = 0$,
$[\hat{S}^\dagger, \hat{d}_M] = 0$, $[\hat{S}^\dagger, \hat{d}_M^\dagger] = 0$ .... (3)

The general formula of the IBM-1 Hamiltonian, which contains one- body and two-body terms , can be written explicitly in terms of s and d bosons [8] .

$$\hat{H} = \varepsilon_s \ (\hat{S}^\dagger . \hat{\tilde{S}}) + \varepsilon_d \ \sum_m (\hat{d}_m^\dagger . \hat{\tilde{d}}_m) \ + \ \hat{V} \quad \text{.... (4)}$$

where :

ε_s , ε_d are the s- and d- boson energies .
The index m = 0, ±1, ±2 .
$\hat{V}$:- boson-boson interaction , which can be written as :-

$$\hat{V} = \sum_{L=0,2,4} \frac{1}{2} (2L+1)^{\frac{1}{2}} C_L \left[\left(\hat{d}^\dagger \times \hat{d}^\dagger\right)^{(L)} \times \left(\hat{\tilde{d}} \times \hat{\tilde{d}}\right)^{(L)} \right]_0^{(0)} + \frac{V_2}{\sqrt{2}} \left[\left(\hat{d}^\dagger \times \hat{d}^\dagger\right)^{(2)} \times \left(\hat{\tilde{d}} \times \hat{\tilde{S}}\right)^{(2)} + \left(\hat{d}^\dagger \times \hat{S}^\dagger\right)^{(2)} \times \left(\hat{\tilde{d}} \times \hat{\tilde{d}}\right)^{(2)} \right]_0^{(0)} + \frac{V_0}{2} \left[\left(\hat{d}^\dagger \times \hat{d}^\dagger\right)^{(0)} \times \left(\hat{\tilde{S}} \times \hat{\tilde{S}}\right)^{(0)} + \left(\hat{S}^\dagger \times \hat{S}^\dagger\right)^{(0)} \times \left(\hat{\tilde{d}} \times \hat{\tilde{d}}\right)^{(0)} \right]_0^{(0)} + U_2 \left[\left(\hat{d}^\dagger \times \hat{S}^\dagger\right)^{(2)} \times \left(\hat{\tilde{d}} \times \hat{\tilde{S}}\right)^{(2)} \right]_0^{(0)} + \frac{1}{2} U_0 \left[\left(\hat{S}^\dagger \times \hat{S}^\dagger\right)^{(0)} \times \left(\hat{\tilde{S}} \times \hat{\tilde{S}}\right)^{(0)} \right]_0^{(0)} \quad \text{....(5)}$$

Where the parameters C_L (L = 0, 2, 4) , V_L (L = 0, 2) , U_L (L = 0, 2) describe the boson interaction and the parenthesis denotes angular momentum couplings .

The most commonly used form of the IBM-1 Hamiltonian is [4, 8] .

$$\hat{H} = \varepsilon \, \hat{n}_d + a_0(\hat{p}.\hat{p}) + a_1(\hat{L}.\hat{L}) + a_2(\hat{Q}.\hat{Q}) + a_3(\hat{T}_3.\hat{T}_3) + a_4(\hat{T}_4.\hat{T}_4) \quad \text{.... (6)}$$

Where $\varepsilon = \varepsilon_d - \varepsilon_s$ is the boson energy .

The operators :

$\hat{n}_d = (\hat{d}^\dagger . \hat{\tilde{d}})$ the boson number operator

$\hat{P} = \frac{1}{2} (\hat{\tilde{d}} . \hat{\tilde{d}}) - \frac{1}{2} (\hat{\tilde{S}} . \hat{\tilde{S}})$ the pairing bosons operator

$\hat{L} = \sqrt{10} \, [\hat{d}^\dagger \times \hat{\tilde{d}}]^{(1)}$ the angular momentum operator

$\hat{Q} = \left[\left(\hat{d}^\dagger \times \hat{\tilde{S}}\right) + \left(\hat{S}^\dagger \times \hat{\tilde{d}}\right) \right]^{(2)} - \frac{1}{2}\sqrt{7} \left[\hat{d}^\dagger \times \hat{\tilde{d}}\right]^{(2)}$ the quadrupole operator

$\hat{T}_3 = \left[\hat{d}^\dagger \times \hat{\tilde{d}}\right]^{(3)}$ the octupole operator

$\hat{T}_4 = \left[\hat{d}^\dagger \times \hat{\tilde{d}}\right]^{(4)}$ the hexadecapole operator

....(7)

And a0 , a1 , a2 , a3 , a4 are the phenomenological parameters .

CHI = $-\sqrt{\frac{7}{2}}$ for rotational dynamical symmetry and CHI = Zero for vibrational and γ – soft dynamical symmetry .

2-2: Potential Energy Surface (P.E.S.)

The general formula for the potential energy surface as a function of geometrical variables β and γ is given by[3, 8] :-

$$V(N,\beta,\gamma) = \frac{N(\varepsilon_s + \varepsilon_d \beta^2)}{1+\beta^2} + \frac{N(N-1)}{(1+\beta^2)^2} (\alpha_1 \beta^4 + \alpha_2 \beta^3 \cos 3\gamma + \alpha_3 \beta^2 + \alpha_4) \quad \text{.... (8)}$$

Where

N= is the total boson number .

$\hat{\beta}^2$ = is the quadrupole deformation parameter operator from 0 → 2.4 .

$\hat{\gamma}$ = is the distortion parameter operator or (asymmetry angle) for 0° → 60° .

The variables (α_1 , α_2 , α_3 , α_4) are related to the parameters C_L , V_L and U_L which is given in equation (3) .

The relationships between the variables (α's) and these parameters have been expressed by Van Isacker and Chen (1981) as[9] :-

$$\alpha_1 = \frac{C_0}{10} + \frac{C_2}{7} + \frac{9}{35} * C_4 \quad \text{.... (9)}$$

$$\alpha_2 = -SQRT\left(\frac{8}{35}\right) * V_2 \quad \text{.... (10)}$$

$$\alpha_3 = (V_0 + U_2)/SQRT(5) \quad \text{.... (11)}$$

$$\alpha_4 = U_0 \quad \text{.... (12)}$$

One must take into account that the asymmetry angle which occurs only in the term cos3γ .

Thus, the energy surfaces has minima only at $\gamma = 0^{\circ}$ and 60° . The energy expressions in their limits, can display the essential dependence on β and γ, which are been given as [3] :-

$$E(N,\beta,\gamma) = \varepsilon_d\, N \frac{\beta^2}{1+\beta^2}$$

in SU(5) limit .... (13)

$$E(N,\beta,\gamma) = KN(N-1)\frac{1+\frac{3}{4}\beta^4 - \sqrt{2}\beta^2 \cos 3\gamma}{(1+\beta^2)}$$

in SU(3) limit .... (14)

$$E(N,\beta,\gamma) = K'N(N-1)\left[\frac{1-\beta^2}{1+\beta^2}\right]$$

in O(6) limit .... (15)

3- Results and Discussion :

3-1: Energy levels and energy ratios

To introduce a comprehensive description for a nuclear structure of the $^{184}_{74}W_{110}$ isotope, we have to emphasize first of all on finding the dynamical symmetry of this isotope , by comparing the energy ratios with their identical and experimental values as shown in table (1) .

Table (1) : The energy ratios of corresponding limits[3,4,8] .

Limit	$R4 = E(4_1^+)/E(2_1^+)$	$R6 = E(6_1^+)/E(2_1^+)$	$R8 = E(8_1^+)/E(2_1^+)$
SU(5)	2	3	4
SU(3)	3.33	7	12
O(6)	2.5	4.5	7

For each dynamical symmetry there is an equivalent equation of the Hamiltonian operator function , which is used to calculate the energy levels, their ratios and the (g , β , γ) –energy bands .

Show that , the $^{184}_{74}W_{110}$ isotope is belonging to the dynamical symmetry SU(3) – O(6) and the equation of the Hamiltonian operator function as shown in table (2) .

Table (2) : Hamiltonian representation for the dynamical symmetry corresponding to the $^{184}_{74}W_{110}$ isotope used in the present work .

Isotope	Dynamical Symmetry	Hamiltonian
$^{184}_{74}W_{110}$	SU(3) – O(6)	$\hat{H} = a_0\hat{P}^{\dagger}.\hat{P} + a_1\hat{L}^2 + a_2\hat{Q}^2 + a_3\hat{T}_3^2$

Table (3) shows the corresponding parameters obtained with the best fitting from the Hamiltonian operator with the convenient dynamical symmetry .

Table (3) : The parameters values of Hamiltonian operator for the $^{184}_{74}W_{110}$ isotope by using (IBSS1. For) program .

Isotope	$^{184}_{74}W_{110}$
N_{π}	4
N_{ν}	8
N	12
EPS (Mev)	0.0000
$\hat{P}^{\dagger}.\hat{P}$ (Mev)	0.0127
$\hat{L}.\hat{L}$ (Mev)	0.0100
$\hat{Q}.\hat{Q}$ (Mev)	-0.0144
$\hat{T}_3.\hat{T}_3$ (Mev)	0.0280
$\hat{T}_4.\hat{T}_4$ (Mev)	0.0000
CHI (Mev)	-0.9000

Table (4) shows the energy levels and their transitions were obtained from the program (IBSS1. For) for the $^{184}_{74}W_{110}$ isotope . The results have been used for calculating the energy ratios and compared them with the identical and available experimental values as shown in table (5) .

Table (4) : Theoretical energy levels and energy transitions compared with the experimental data for the ${}^{184}_{74}W_{110}$ isotope by using (IBSS1. For) program .

Isotope	I_i^+	Energy level (MeV)		Spin sequences I_i^+ - I_f^+	Transition Energy (MeV)	
		Exp.[10,11]	IBM-1		Exp.[10,11]	IBM-1
${}^{184}_{74}W_{110}$	$0_1^+(g)$	0.0000	0.0000	–	–	–
	$2_1^+(g)$	0.1112	0.1090	$2_1^+ - 0_1^+$	0.1112	0.1090
	$4_1^+(g)$	0.3641	0.3606	$4_1^+ - 2_1^+$	0.2528	0.2516
	$6_1^+(g)$	0.7483	0.7500	$6_1^+ - 4_1^+$	0.3842	0.3894
	$2_2^+(\gamma_1)$	0.9033	0.9602	$2_2^+ - 4_1^+$ $2_2^+ - 2_1^+$ $2_2^+ - 0_1^+$	0.5392 0.7921 0.9033	0.5996 0.8512 0.9602
	$0_2^+(\beta_1)$	1.0025	1.0005	$0_2^+ - 2_1^+$	–	0.8915
	$3_1^+(\gamma_1)$	1.0060	1.0859	$3_1^+ - 4_1^+$ $3_1^+ - 2_1^+$	0.6419 0.8948	0.7253 0.9769
	$2_3^+(\beta_1)$	1.1214	1.1160	$2_3^+ - 4_1^+$ $2_3^+ - 2_1^+$ $2_3^+ - 0_1^+$	0.7574 1.0102 1.1214	0.7554 1.0070 1.1160
	$4_2^+(\gamma_1)$	1.1338	1.2382	$4_2^+ - 3_1^+$ $4_2^+ - 2_2^+$ $4_2^+ - 4_1^+$ $4_2^+ - 2_1^+$	0.1277 0.2305 0.7698 1.0226	0.1523 0.2780 0.8776 1.1292
	$8_1^+(g)$	1.2520	1.2721	–	–	–
	$5_1^+(\gamma_1)$	1.2941	1.4434	$5_1^+ - 4_1^+$	0.9309	1.0828
	$0_3^+(\beta_2)$	(1.3221)	1.5910	$0_3^+ - 2_2^+$	–	0.6308
	$4_3^+(\beta_1)$	(1.3590)	1.3777	–	–	–
	$2_4^+(\gamma_2)$	1.3863	1.7458	$2_4^+ - 3_1^+$ $2_4^+ - 2_2^+$ $2_4^+ - 2_1^+$ $2_4^+ - 0_1^+$	0.3803 0.4830 1.2751 1.3867	0.6599 0.7856 1.6368 1.7458
	$2_5^+(\beta_2)$	1.4310	1.8147	$2_5^+ - 2_1^+$ $2_5^+ - 0_1^+$	– –	1.7057 1.8147
	$6_2^+(\gamma_1)$	(1.4790)	1.6498	–	–	–
	$3_2^+(\gamma_2)$	(1.5233)	1.9555	$3_2^+ - 2_1^+$	–	1.8465
	$0_4^+(\beta_3)$	1.6149	1.8792	$0_4^+ - 2_2^+$ $0_4^+ - 2_1^+$	– –	0.9190 1.7702
	$4_4^+(\gamma_2)$	(1.6960)	1.8760	–	–	–
	$10_1^+(g)$	1.8610	1.9219	–	–	–

Table (5) : Theoretical energy ratios values $E(4_1^+)/E(2_1^+)$, $E(6_1^+)/E(2_1^+)$, $E(8_1^+)/E(2_1^+)$ and their comparison with the experimental data according to the (IBM-1) for the $^{184}_{74}W_{110}$ isotope .

Isotope	$^{184}_{74}W_{110}$	
$E(4_1^+)/E(2_1^+)$	Exp.[10]	3.2737
	IBM-1	3.3076
$E(6_1^+)/E(2_1^+)$	Exp.[10]	6.7290
	IBM-1	6.8793
$E(8_1^+)/E(2_1^+)$	Exp.[10]	11.2583
	IBM-1	11.6673

3 – 2: (g, β, γ) – Energy bands spectrum

The researcher classifies the energy levels of the $^{184}_{74}W_{110}$ isotope, according to the energy bands (g , β , γ – bands) .

Table (6) shows the energy band values for the $^{184}_{74}W_{110}$ isotope and their comparison with the available experimental values , the results shows that, there are good agreement of the levels of the present work comparison with the experimental results , as assuring the energy levels of the spins (6_2^+, 4_3^+ , 0_3^+, 3_2^+, 4_4^+) from (1.479, 1.359, 1.3221, 1.52326, 1.696) in experimental results to (1.6498, 1.3777, 1.5910 , 1.9555 , 1.8760) in the present work respectively, as well as the isotope belongs to the dynamical symmetry SU(3) – O(6) , that the (β – band) is widely appearance than the (γ – band) .

Figure (1) shows the energy levels for the $^{184}_{74}W_{110}$ isotope, where that obey the typical energy bands spectrum . Noticed that , there are good agreement of the level sequences of each band with the typical sequence of ground band (0^+, 2^+, 4^+ ....) , β – band (0^+, 2^+ , 4^+ ....) and γ – band (2^+, 3^+ , 4^+, 5^+ .....) . There are good agreement between the present results and the experimental values of the energy bands .

Table (6) : The comparison between the theoretical (pw) and experimental [10] energy bands (g, β, γ-bands) for the $^{184}_{74}W_{110}$ isotope by using IBM-1 .

Isotopes	Spin / Band	0^+ 2^+	2^+ 3^+	4^+ 4^+	6^+ 5^+	8^+ 6^+	10^+ 7^+
$^{184}_{74}W_{110}$	g- exp.	0.0000	0.1112	0.3641	0.7483	1.2520	1.8610
SU(3) – O(6)	g-pw	0.0000	0.1090	0.3606	0.7500	1.2721	1.9219
	γ_1-exp.	0.9033	1.0060	1.1338	1.2941	(1.4790)	_
	γ_1-pw	0.9602	1.0859	1.2382	1.4434	1.6498	_
	β_1-exp.	1.0025	1.1214	(1.3590)	_	_	_
	β_1-pw	1.0005	1.1160	1.3777	_	_	_
	β_2-exp.	(1.3221)	1.4310	_	_	_	_
	β_2-pw	1.5910	1.8147	_	_	_	_
	γ_2-exp.	1.3863	(1.5233)	(1.6960)	_	_	_
	γ_2-pw	1.7458	1.9555	1.8760	_	_	_
	β_3-exp.	1.6149	_	_	_	_	_
	β_3-pw	1.8792	_	_	_	_	_

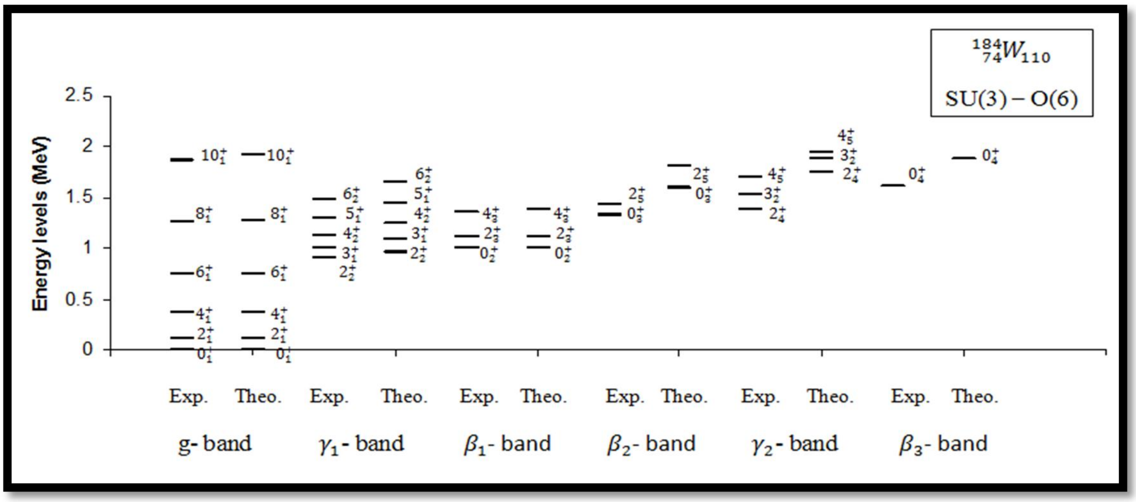

Figure (1) : Comparison between calculated IBM (pw); and experimental[10] energy bands states (g, β, γ- bands) in $^{184}_{74}W_{110}$ isotope of the dynamical symmetry SU(3) – O(6) .

3 – 3 : The potential energy surface (P.E.S)

In the present work , the researcher has applied the geometrical model of the IBM-1 for the $^{184}_{74}W_{110}$ isotope, since the IBM-1 geometrical model of nuclear collective motion is provided as with an alternative description of nuclear collective excitations , which are more sensitive than the phenomenological model .

The IBM-1 analysis of the counter plots of the potential energy function V(N, β, γ) is calculated by using the parameters (α's) that was deduced from (IBSS1. For) program , as shown in table (7) .

Figure (2a) elucidates the potential energy surface as a function of deformed parameters (β , γ) , the contour lines are in good agreement with the typical plots .

The axially symmetric ($\gamma = 0^\circ$, $\gamma = 30^\circ$, $\gamma = 60^\circ$) plots of the potential function is calculated in the present work , for the $^{184}_{74}W_{110}$ isotope show that :

The axially symmetric for the isotope $^{184}_{74}W_{110}$ of the dynamical symmetry SU(3) – O(6) , Figure (2b) shows the behaviors of the potential energy surfaces of (3.109 MeV) on the prolate shape at β=1.2 , γ= 0° and for oblate shape at β=0.8 , γ= 60° which is (1.302 MeV) . Also it shows good agreement with the typical axially symmetric of SU(3) – O(6) limits .

Table (7) : The parameters values of the potential energy surface (P.E.S) for the $^{184}_{74}W_{110}$ isotope .

Isotope	$^{184}_{74}W_{110}$
N_π	4
N_ν	8
N	12
ε_s	-0.0720
ε_d	0.0730
α_1	0.0000
α_2	-0.0280
α_3	-0.0640
α_4	0.0000

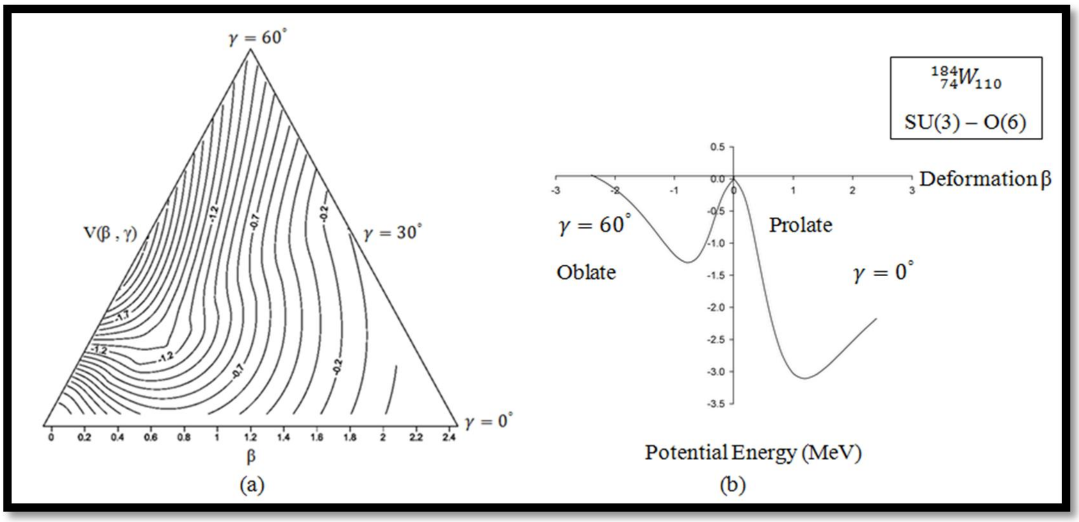

Figure (2 a, b) : The Contour plots and the axial symmetric for the $^{184}_{74}W_{110}$ isotope of the SU(3) – O(6) limit .

3 – 4: Conclusions

The following results are the outcome of this research :

1– The calculating values for energy levels , their ratios , transition energies using IBM-1 for the $^{184}_{74}W_{110}$ isotope is in a good agreement with the experimental values .

2 – Determining spin and parity for some energy levels , which were not exactly determined experimentally .

3– Determined the nuclei shape by the potential energy surface for the $^{184}_{74}W_{110}$ isotope .

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