A STUDY FOR THE ENERGY LEVELS AND POTENTIAL ENERGY SURFACE OF $^{246}_{96}Cm_{150}$ ISOTOPE

ALYA'A ABDULKADHIM[1]

Abstract. *The $^{246}_{96}Cm_{150}$ isotope in SU(3) – O(6) transition region were investigated. For this nuclei, The interacting boson model (IBM-1) was used to study the nuclear structure of $^{246}_{96}Cm_{150}$ isotope. The (IBSS1. For) program was used to find the energy levels and calculate the energy ratios and quantum transitions depends on the total number for bosons (N). The energy levels was classified according to the $(g, \beta, \gamma - band)$, and determined the behavior of this isotope according to the experimental values of energy levels and their ratios and bands arrangement. 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 (3) and predication to spin and parity for the energy levels number (19).The results are compared with the most recent experimental data. Good agreement was obtained between our theoretical calculations for this under study isotope and simple different in some energy levels.*
Keywords: IBM-1, energy levels, nuclear structure, potential energy surface.

1. INTRODUCTION

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 (IBM) was developed by Iachello F. and Arima A. (1974) [1].

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 [2, 3].

According to (IBM) postulates, The nuclear pairs are represented by bosons with angular momentum $l = 0$ or 2, i.e. the number of bosons depend 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. $N = N_\pi + N_\nu$, where N_π and N_ν are the number of proton and neutron bosons respectively [2, 3].

[1] Muthanna University, Education Faculty For Pure Sciences, Department of Mathematics, Iraq.
E-mail: alyaa_ros@yahoo.com.

In IBM-1 the characteristic properties can be derived by group theoretical methods and expressed analytically. When we consider the different reductions of U(6), three dynamical symmetries emerge known as SU(5), SU(3) and O(6) [4], which are related to the geometrical idea of the spherical vibrator [5], deformed rotor and symmetric (γ-soft) [6].

The potential energy surface function $V(N, \beta, \gamma)$ depends on the shape variables β and γ, where β is the magnitude of the nuclear deformation and γ gives the deviations from axial symmetry (asymmetry angle), and they are different for different states of nucleus. This means that the rigidity of the shape is only a special case because of the natural dynamic of the nucleus.

The probability of finding the nucleus at ($\beta = 0$) or $\gamma = 0^{\circ}(60^{\circ})$ is always zero, and the nucleus is always deformed and nonaxial, but some nuclei are so to ($\beta = 0$) that we may call them (spherical), while those are close to $\gamma = 0^{\circ}$ may be called prolate and $\gamma = 60^{\circ}$ called oblate [7].

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].

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

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 [8, 9]:

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

$$\frac{1}{\sqrt{2}} V_2 \left[[\hat{d}^\dagger \times \hat{d}^\dagger]^2 \times [\hat{\tilde{d}} \times \hat{\tilde{S}}]^2 + [\hat{d}^\dagger \times \hat{S}^\dagger]^2 \times [\hat{d} \times \hat{\tilde{d}}]^2\right]^0 + \frac{1}{2} V_0 \left[[\hat{d}^\dagger \times \hat{d}^\dagger]^0 \times \right.$$

Sх   S   0+   S†х   S†0х   dх   d   0Ọ+   U2d†х   Ŝ†2х   dх   S   20+   12   UOŜ†х   Ŝ†0х   SхS   00

(2)

where the parameters
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 parenthesis denotes angular momentum couplings.

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

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

$$[\hat{d}_M, \hat{d}_M] = 0, [\hat{d}_M, \hat{d}_M^\dagger] = \delta MM$$
$$[\hat{d}_M^\dagger, \hat{d}_M^\dagger] = 0, [\hat{S}, \hat{d}_M] = 0, [\hat{S}, \hat{d}_M^\dagger] = 0, [\hat{S}^\dagger, \hat{d}_M] = 0, [\hat{S}^\dagger, \widehat{d}_M^\dagger] = 0 \qquad (3)$$

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].

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

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:

$$\hat{V} = \sum_{L=0,2,4} \frac{1}{2} (2L+1)^{\frac{1}{2}} C_L \left[\left(\hat{d}^\dagger \times \hat{d}^\dagger \right)^{(L)} \times \left(\hat{\tilde{d}} \times \hat{\tilde{d}} \right)^{(L)} \right]_0^{(0)} + \frac{V_2}{\sqrt{2}} \left[\left(\hat{d}^\dagger \times \hat{d}^\dagger \right)^{(2)} \times$$

$d \times S \, 2+ \, d\dagger \times \hat{S}\dagger 2 \times \, d \times d \, 200 + V02 \, d\dagger \times d\dagger 0 \times S \times S \, 0+ \hat{S}\dagger \times \hat{S}\dagger 0 \times d \times d \, 000 + U2 d\dagger \times \hat{S}\dagger 2 \times d \times S200+ \, 12U0\hat{S}\dagger \times \hat{S}\dagger 0 \times S \times S000$

(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].

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

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 a_0, a_1, a_2, a_3, a_4 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. TRANSITIONAL REGION IN IBM-1 [SU(3) – O(6)]

The breaking of SU(3) symmetry in the direction of O(6) symmetry can be treated in this transitional region by adding the term $\hat{P}.\hat{P}$, so that the Hamiltonian form can be written as [3]:

$$\hat{H} = a_0\hat{P}^\dagger.\hat{P} + a_1\hat{L}^2 + a_2\hat{Q}^2 + a_3\hat{T}_3^2 \tag{8}$$

The solution of equation (8) depends on the ratio a_0/a_2, when it is large, the eigenfunction of the Hamiltonian $[\hat{H}]$ are appropriate to O(6) symmetry, but if it is small, the eigenfunction are appropriate to SU(3) symmetry. In this region the change in the electromagnetic rates can be seen from the branching ratios R which takes the values [8].

$$R = \frac{7}{10} \qquad\qquad \text{in SU(3) symmetry}$$

$$R = 0 \qquad\qquad \text{in O(6) symmetry}$$

2.3. 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 [2, 8]:

$$V(N,\beta,\gamma) = \frac{N(\varepsilon_s+\varepsilon_d\beta^2)}{1+\beta^2} + \frac{N(N-1)}{(1+\beta^2)^2}(\alpha_1\beta^4 + \alpha_2\beta^3\cos 3\gamma + \alpha_3\beta^2 + \alpha_4) \tag{9}$$

where
  N= is the total boson number.
  $\hat{\beta}^2 = $ is the quadrupole deformation parameter operator from $0 \rightarrow 2.4$.
  $\hat{\gamma} = $ is the distortion parameter operator or (asymmetry angle) for $0^\circ \rightarrow 60^\circ$.

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 [10]:

$$\alpha_1 = \frac{C_0}{10} + \frac{C_2}{7} + \frac{9}{35}*C_4 \tag{10}$$

$$\alpha_2 = -SQRT\left(\frac{8}{35}\right)*V_2 \tag{11}$$

$$\alpha_3 = (V_0 + U_2)/SQRT(5) \tag{12}$$

$$\alpha_4 = U_0 \tag{13}$$

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

Thus, the energy surfaces has minima only at $\gamma = 0°$ and $60°$. The energy expressions in their limits, can display the essential dependence on β and γ, which are been given as [2]:

$$E(N, \beta, \gamma) = \varepsilon_d \, N \frac{\beta^2}{1+\beta^2} \qquad \text{in SU(5) limit} \qquad (14)$$

$$E(N, \beta, \gamma) = KN(N-1) \frac{1+\frac{3}{4}\beta^4 - \sqrt{2}\beta^2 \cos 3\gamma}{(1+\beta^2)} \qquad \text{in SU(3) limit} \qquad (15)$$

$$E(N, \beta, \gamma) = K'N(N-1) \left[\frac{1-\beta^2}{1+\beta^2} \right] \qquad \text{in O(6) limit} \qquad (16)$$

3. RESULTS AND DISCUSSION

3.1. ENERGY RATIOS AND DYNAMICAL SYMMETRY

To introduce a comprehensive description for a nuclear structure of the $^{246}_{96}Cm_{150}$ 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 [2, 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

Table 2 shows the comparison between the experimental values and theoretical values for energy ratios and from the experimental energy ratios, we known the dynamical symmetry for the isotope under study.

Table 2. 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 $^{246}_{96}Cm_{150}$ isotope.

Isotope	$E(4_1^+)/E(2_1^+)$		$E(6_1^+)/E(2_1^+)$		$E(8_1^+)/E(2_1^+)$	
$^{246}_{96}Cm_{150}$	Exp.[11]	IBM-1	Exp.[11]	IBM-1	Exp.[11]	IBM-1
	3.31396	3.33547	6.88182	7.01143	11.67740	12.03547

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 $^{246}_{96}Cm_{150}$ isotope is belonging to the dynamical symmetry SU(3) – O(6) and the equation of the Hamiltonian operator function as shown in table 3.

Table 3. Hamiltonian representation for the dynamical symmetry corresponding to the $^{246}_{96}Cm_{150}$ isotope used in the present work.

Isotope	Dynamical Symmetry	Hamiltonian
$^{246}_{96}Cm_{150}$	SU(3) – O(6)	$\hat{H} = a_0\hat{P}^\dagger.\hat{P} + a_1\hat{L}^2 + a_2\hat{Q}^2 + a_3\hat{T}_3^2$

3.2. ENERGY LEVELS AND ENERGY TRANSITIONS

To find the energy levels and energy transition for any isotope, first of all we need parameters from the Hamiltonian operator with the equivalent dynamical symmetry, as input in the program to obtain the best fitting results from the energy levels and consequently find the energy transitions.

Table 4 shows the corresponding parameters obtained with the best fitting from the Hamiltonian operator with the convenient dynamical symmetry.

Table 4. The parameters values of Hamiltonian operator for the $^{246}_{96}Cm_{150}$ isotope by using (IBSS1. For) program.

Isotope	N_π	N_ν	N	EPS (Mev)	$\hat{P}^\dagger.\hat{P}$ (Mev)	$\hat{L}.\hat{L}$ (Mev)	$\hat{Q}.\hat{Q}$ (Mev)	$\hat{T}_3.\hat{T}_3$ (Mev)	$\hat{T}_4.\hat{T}_4$ (Mev)	CHI (Mev)
$^{246}_{96}Cm_{150}$	7	12	19	0.00000	0.01920	0.00572	-0.00620	0.00791	0.00000	-0.68900

Table (5) shows the energy levels and their transitions were obtained from the program (IBSS1. For) for the $^{246}_{96}Cm_{150}$ 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 (2).

Table 5. Theoretical energy levels and energy transitions compared with the experimental data for the $^{246}_{96}Cm_{150}$ isotope by using (IBSS1. For) program.

Isotope	I_i^+	Energy level (MeV)		Spin sequences I_i^+-I_f^+	Transition Energy (MeV)	
		Exp.[11,12]	IBM-1		Exp.[11,12]	IBM-1
$^{246}_{96}Cm_{150}$	$0_1^+(g)$	0.00000	0.00000	–	–	–
	$2_1^+(g)$	0.04285	0.04200	$2_1^+-0_1^+$	0.04285	0.04200
	$4_1^+(g)$	0.14201	0.14009	$4_1^+-2_1^+$	0.09920	0.09809
SU(3)-O(6)	$6_1^+(g)$	0.29490	0.29448	$6_1^+-4_1^+$	0.15350	0.15439
	$8_1^+(g)$	0.50040	0.50549	$8_1^+-6_1^+$	0.20500	0.21101
	$10_1^+(g)$	–	0.77358	–	–	–
	$2_2^+(\gamma_1)$	1.12427	0.98445	–	–	–
	$3_1^+(\gamma_1)$	1.16549	1.02767	–	–	–
	$12_1^+(g)$	–	1.09934	–	–	–
	$0_2^+(\beta_1)$	1.17474	1.17190	$0_2^+-2_1^+$ $0_2^+-0_1^+$	1.13190 1.17470	1.12990 1.17190
	$2_3^+(\beta_1)$	1.21053	1.21467	$2_3^+-2_1^+$ $2_3^+-0_1^+$	1.16774 1.21040	1.17267 1.21467
	$4_2^+(\gamma_1)$	(1.21990)	1.27898	$4_2^+-2_1^+$	1.17720	1.23638
	$0_3^+(\beta_2)$	1.28940	1.28182	$0_3^+-0_1^+$	1.28940	1.28182
	$4_3^+(\beta_1)$	–	1.31460	–	–	–

$2_4^+(\beta_2)$	(1.31757)	1.32579	$2_4^+ - 2_1^+$	1.27472	1.28379
$5_1^+(\gamma_1)$	–	1.35427	–	–	–
$4_4^+(\beta_2)$	(1.37923)	1.35657	$4_4^+ - 4_1^+$ $4_4^+ - 2_1^+$	1.23720 1.33640	1.21648 1.31457
$6_2^+(\gamma_1)$	–	1.44189	–	–	–
$2_5^+(\gamma_2)$	1.47844	1.45611	$2_5^+ - 2_3^+$ $2_5^+ - 4_1^+$ $2_5^+ - 2_1^+$	0.26730 1.33640 1.43560	0.24144 1.31602 1.41411
$6_3^+(\beta_1)$	–	1.47200	–	–	–
$3_2^+(\gamma_2)$	1.50924	1.50252	$3_2^+ - 4_2^+$ $3_2^+ - 4_1^+$ $3_2^+ - 2_1^+$ $3_2^+ - 0_1^+$	0.28930 1.36790 1.46630 1.50900	0.22354 1.36243 1.46052 1.50252
$6_4^+(\beta_2)$	–	1.52413	–	–	–
$7_1^+(\gamma_1)$	–	1.54936	–	–	–
$8_2^+(\gamma_1)$	–	1.55737	–	–	–
$9_1^+(\gamma_1)$	–	1.59385	–	–	–
$8_3^+(\beta_1)$	–	1.66256	–	–	–
$8_4^+(\beta_2)$	–	1.68751	–	–	–
$10_2^+(\gamma_1)$	–	1.74087	–	–	–
$10_3^+(\beta_1)$	–	1.84825	–	–	–
$11_1^+(\gamma_1)$	–	1.90223	–	–	–
$12_2^+(\gamma_1)$	–	1.92779	–	–	–
$10_4^+(\beta_2)$	–	1.94017	–	–	–
$12_3^+(\beta_1)$	–	2.08009	–	–	–
$12_4^+(\beta_2)$	–	2.20086	–	–	–

3.3. (g, β, γ) – ENERGY BANDS SPECTRUM

The researcher classifies the energy levels of the $^{246}_{96}Cm_{150}$ isotope, according to the energy bands (g, β, γ – bands).

Table 6 shows the energy band values for the $^{246}_{96}Cm_{150}$ isotope and their comparison with the available experimental values, the results shows that, there are good agreement for some levels and simple different for another levels of the present work comparison with the experimental results, as assuring the energy levels of the spins (4_2^+, 2_4^+, 4_4^+) from (1.21990, 1.31757, 1.37923) in experimental results to (1.27898, 1.32579, 1.35657) in   the present work respectively, as predication to spin and parity for some energy levels, which were not determined experimentally have been determined (10_1^+, 12_1^+, 4_3^+, 5_1^+, 6_2^+, 6_3^+, 6_4^+, 7_1^+, 8_2^+, 9_1^+, 8_3^+, 8_4^+, 10_2^+, 10_3^+, 11_1^+, 12_2^+, 10_4^+, 12_3^+, 12_4^+) that (0.77358, 1.09934, 1.31460, 1.35427, 1.44189, 1.47200, 1.52413, 1.54936, 1.55737, 1.59385, 1.66256, 1.68751, 1.74087, 1.84825, 1.90223, 1.92779, 1.94017, 2.08009, 2.20086) 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).

Table 6. The comparison between the theoretical (pw) and experimental [11] energy bands (g, β, γ-bands) for the $^{246}_{96}Cm_{150}$ isotope by using IBM-1.

Isotopes	Spin / Band	0^+ 2^+	2^+ 3^+	4^+ 4^+	6^+ 5^+	8^+ 6^+	10^+ 7^+	12^+ 8^+	14^+ 9^+	16^+ 10^+	18^+ 11^+	20^+ 12^+
SU(3) − O(6) $^{246}_{96}Cm_{150}$	g-exp.	0.00 000	0.0428 5	0.1420 1	0.294 90	0.500 40	–	–	–	–	–	–
	g-pw	0.00 000	0.0420 0	0.1400 9	0.294 48	0.505 49	0.773 58	1.099 34	–	–	–	–
	γ_1-exp.	1.12 427	1.1654 9	(1.2199 0)	–	–	–	–	–	–	–	–
	γ_1-pw	0.98 445	1.0276 7	1.2789 8	1.354 27	1.441 89	1.549 36	1.557 37	1.593 85	1.740 87	1.902 23	1.927 79
	β_1-exp.	1.17 474	1.2105 3	–	–	–	–	–	–	–	–	–
	β_1-pw	1.17 190	1.2146 7	1.3146 0	1.472 00	1.662 56	1.848 25	2.080 09	–	–	–	–
	β_2-exp.	1.28 940	(1.3175 7)	(1.3792 3)	–	–	–	–	–	–	–	–
	β_2-pw	1.28 182	1.3257 9	1.3565 7	1.524 13	1.687 51	1.940 17	2.200 86	–	–	–	–
	γ_2-exp.	1.47 844	1.5092 4	–	–	–	–	–	–	–	–	–
	γ_2-pw	1.45 611	1.5025 2	–	–	–	–	–	–	–	–	–

Fig. 1 shows the energy levels for the $^{246}_{96}Cm_{150}$ isotope, where that obey the typical energy bands spectrum. Noticed that, there are good agreement for some level sequences and simple different for another 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 proportional good agreement between the present results and the experimental values of the energy bands.
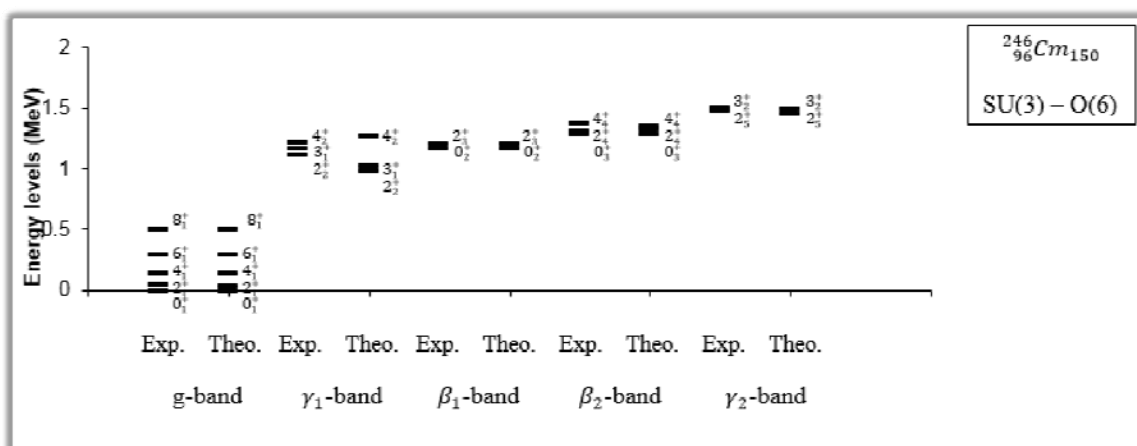
Figure 1. Comparison between calculated IBM (pw); and experimental [11] energy bands states (g, β, γ-bands) in $^{246}_{96}Cm_{150}$ isotope of the dynamical symmetry SU(3) – O(6).

3.4. THE POTENTIAL ENERGY SURFACE (P.E.S)

The potential energy surface is one of the nuclei properties, and it gives a final shape of nuclei. The PES.FOR program is used to calculate the potential energy surface $V(N, \beta, \gamma)$.

In the present work, the researcher has applied the geometrical model of the IBM-1 for the $^{246}_{96}Cm_{150}$ 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 $V(N, \beta, \gamma)$ is calculated by using the parameters (α's) that was deduced from (IBSS1. For) program, as shown in table 7.

Table 7. The parameters values of the potential energy surface (P.E.S) for the $^{246}_{96}Cm_{150}$ isotope.

Isotope	N_π	N_ν	N	ε_s	ε_d	α_1	α_2	α_3	α_4
$^{246}_{96}Cm_{150}$	7	12	19	-0.03100	0.36000	0.00400	-0.00900	-0.02500	0.00000

Fig. 2 (b) 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 ($\gamma = 0°$, $\gamma = 30°$, $\gamma = 60°$) plots of the potential function is calculated in the present work, for the $^{246}_{96}Cm_{150}$ isotope show that:

The axially symmetric for the isotope $^{246}_{96}Cm_{150}$ of the dynamical symmetry SU(3) – O(6), Fig. 2 (a) shows the behaviors of the potential energy surfaces of (2.566 MeV) on the prolate shape at β = 1, γ= 0° and for oblate shape at β = 0.8, γ= 60° which is (1.239 MeV). Also it shows good agreement with the typical axially symmetric of SU(3) – O(6) limits.
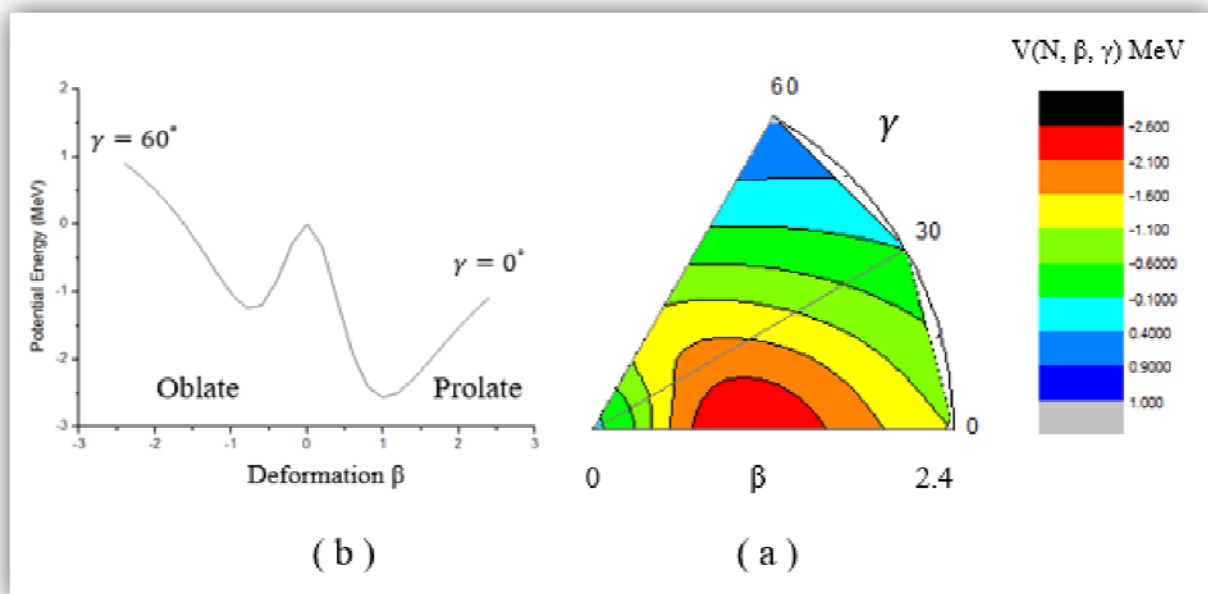
Figure 2. The Contour plots (b) and the axial symmetric (a) for the $^{246}_{96}Cm_{150}$ isotope of the SU(3) – O(6) limit.

4. CONCLUSIONS

From all calculations, we can conclude the following:

- Determine the dynamical symmetry to the isotope under study, Show that, the $^{246}_{96}Cm_{150}$ isotope is belonging to the dynamical symmetry $SU(3) - O(6)$.
- The calculating values for energy levels, their ratios, transition energies using IBM-1 for the $^{246}_{96}Cm_{150}$ isotope is in a proportional good agreement with the experimental values.
- Determining spin and parity for some energy levels, which were not exactly determined experimentally and predication to spin and parity for some the energy levels.
- Predication to spin and parity for some the energy levels, which were not determined experimentally.
- Determined the nuclei shape by the potential energy surface for the $^{246}_{96}Cm_{150}$ isotope.

REFERENCES

[1]   Iachello, F., Arima, A., *Phys. Lett. B*, **53**, 309,1974.
[2]   Bonatsos, D., *Interacting Boson Models of Nuclear Structure*, Pub. Oxford University Press, New York, 1988.
[3]   Pfeifer, W., *Introduction to interacting boson model of atomic nucleus*, PI, 1998.
[4]   Casten, R.F., Warner, D.D., *Rev. Mod. Phys.,* **60**, 391, 1988.
[5]   Scharff Goldhaber, G., Weneser, J., *Phys. Rev.*, **98**, 212, 1955.
[6]   Willets, L., Jean, M., *Phys. Rev. C*, **102**, 788, 1956.
[7]   Kumar, K., *The Electric Interaction in Nuclear physics,* North Holland, Amsterdam, 1975.
[8]   Iachello, F., Arima, A., *Interacting boson model*, Pub. Cambridge University press, Cambridge, England, 1987.
[9]   Arima, A., Iachello, F., *Ann. Phys.*, **123**, 468, 1979.
[10]   Van Isacker, P., Chen, J.Q., *Phys. Rev. C*, **24**, 684, 1981.
[11]   Sakai, M., *Atomic Data and Nuclear Data   Tables*, **31**(3), 399, 1984.
[12]   Lederer, C.M., Shirley, V.S., *Table of isotopes,* 7th Ed., Wiley, New York, 1978.