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O(6) Symmetry of Even $^{186-198}$Pt Isotopes Under the Framework of Interacting Boson Model (IBM-1)

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Abstract: ***The $^{186-198}$Pt isotopes with proton number Z=78 and neutron numbers (n) between 108 and 120 in O(6) region were investigated. The energy level, E2 transition probabilities, the square of rotational energy and the moment of inertia (backbending curve) and the potential energy surface have been calculated within the framework using interacting boson model (IBM-1). The calculated results are compared with the most resent experimental data. Good agreement is obtained between the theoretical and experimental results for all isotopes. The contour plot of the potential energy surfaces shows that the interested nuclei are deformed and have γ-unstable-like characters.***

Keywords: IBM-1, neutron-rich, B(E2) values, energy levels, potential energy surface.

1. Introduction

Platinum isotopes have always attracted much attention for physicists. Up to now, there have already been many experimental works, and abundant data are available [1, 2]. These nuclei are characterized by shape changes between spherical and deformed. Pt isotopes cited as the best example of an O(6) nuclei[3]. Accordingly, a number of theoretical investigations [4,5] have been presented to study the properties of these isotopes. Since Arima and Iachello [6] proposed the Interacting Boson Model (IBM) of nuclear structure, there has been much work on the IBM description of the even-even Pt isotopes. In the original version of the IBM, the proton- and neutron-boson degree of freedom is not distinguished. The O(6) symmetry of the IBM is, by now, well known through the examples in Pt isotopes[3]. A considerable effort has also been devoted to characterize Pt nuclei [1, 7], and several deformation regimes have been suggested. From the experimental point of view [8, 9], the energy ratio $E4^+/E2^+$is almost 2.5 for Pt nuclei with neutron number 108≤N ≤120 already pointing to γ-soft shapes. The application of this model to deformed nuclei is currently subject of considerable interested and controversy. It offers a simple Hamiltonian, capable of describing collective nuclear properties across a wide range of nuclei, and is founded on rather general algebraic group theoretical techniques, which have also been found after 1979s application for problems in, atomic, molecular and low-energy physics [6, 10]. Here, we apply the IBM to account for even-even Platinum isotopes. Detailed work has been done on the structure of Platinum nuclei in recent years. Garcìa *et al.* [11] studied the differences between the interacting boson model calculations with or without the inclusion of intruder states in $^{172-194}$Pt isotopes. Sethi *et al.* [12] measured the angular distributions of $d\sigma/d\Omega$ for low-lying collective states $J^\pi = 0_1^+, 2_1^+, 2_2^+, 4_1^+, 4_2^+ \; and \; 4_3^+$ in $^{194-198}$Pt nuclei using 135MeV-polarized protons. Nomura *et al.*[13]calculated the description of shape/phase transition in Pt nuclei in terms of the Interacting Boson Model Hamiltonian which derived from Hartree-Fock-Bogoliubov (HFB) calculations with the finite range and density dependent Gogny-DIS Energy Density Functional. Vergnes *et al.* [14] studied the ^{190}Pt (p,t) ^{188}Pt reaction at 25MeV on an enriched, and the low-lying 0^+ levels is weakly excited(5%) as compared with the ground state. Lie *et al.* [15] studied the excited states in ^{192} Pt and ^{194}Pt with high-energy resolution, in the (p, t) reaction, by using the Q3D magnetic spectrograph at the Munich MP tandem accelerator, and discussed the 0^+ states in ^{192,194}Pt in the context of the evolution of intruder states and shape coexistence in the light Pt isotopes. Borner *et al.* [16] measured the life time of the thread excited 0_3^+ state using the GRID method established the goodness of the σ quantum number in ^{196}Pt.Garcìa*et al.* [17] studied the evolution of the deformation parameter β and of the isotope shifts for a chain of Pt isotopes with the IBM-CM approach. Gyapong *et al.* [18] determined the static electric quadrupole moments of the $Q(2_1^+)$ of ^{194,196,198}Pt using Coulomb excitation by ^{4}He, ^{12}C, and ^{16}O projectiles. Ponomarev *et al.* [19] measured the differential cross sections for levels in the excitation-energy range from 0 to 3.0MeV in ^{196}Pt by inelastic electron scattering in a momentum-transfer range up to 2.5fm^{-1}. Todd Baker *et al.* [20] measured the angular distributions for 24MeV α-particle excitation of states in ^{192}Pt, determined relative signs and magnitudes of many E2, E3, and E4 matrix elements connecting the low-lying states. Deason *et al.*[21] measured many level energies in ^{194,196,198}Pt by using the(P, Ṕ) reaction at 35MeV, measured the angular distributions and comparisons to empirical shapes of angular distributions for levels with known J^π values allowed several new spin assignments. Gupta *et al.* [22] studied the ground band energies of medium mass shape transitional nuclei and noted a phase transition at N=110 (A=188), with lighter isotopes showing signification for Pt is maximum at N =104, (A=182). Irving *et al.*[23] studied the geometry of the Pt isotopes, found the absolute minimum of the potential for the Pt isotopes evolves from spherical to oblate and finally to prolate shapes when the neutron number decreases from N=126 to N=104. Bijker *et al.* [24] calculated excitation energies and electromagnetic properties and compared with experimental data. It has shown that the transition between the gamma unstable regions of the heavier Pt isotopes towards the more axially symmetric deformed features of the

lighter Os and Pt isotopes. The IBM Hamiltonian can describe these isotopes very well; qualitatively the properties of the transitional region are reproduced by the smooth change of one parameter, χ, which determines the character of the quadrupole-quadrupole interaction. The aim of the present work is to do a microscopic study of the Pt isotopes within the IBM-1 model and give a comprehensive view of these isotopes in a rather simple way. The paper will present only the results of the calculation and refer the reader to that paper for details of the model. The results of the IBM multilevel calculations for $^{186,188,\ 190,\ 192,\ 194,\ 196,\ 198}$Pt will be presented for energy levels for which transitions probabilities are compared with the corresponding experimental data. Furthermore, we will to calculate the square of rotational energy and the moment of inertia (backbending curve) and then study the nuclear structure described for Pt isotopes using the potential energy surface $E(N,\beta,\gamma)$.

2. Interacting Boson Model (IBM-1)

IBM-1 has become possible to give a simple and consistent to the transition region [25]. The model is described the low-lying collective excitations of even-even nuclei in terms of the s(L=0) and d(L=2) bosons. Casten and Warner [26] have been given a comprehensive review of model and its application to the transition region. As the s and d bosons span a six-dimensional Hilbert space, the Hamiltonian corresponding to the IBM-1 has a group structure U(6). The three limiting symmetries of this Hamiltonian are called SU(5) vibrational, SU(3) rotational, and O(6) γ-unstable [25, 26]. The IBM-1 Hamiltonian can be expressed as [27, 28]

$$H=\varepsilon_s(s^+.\tilde{s})+\varepsilon_d(d^+.\tilde{d})+\sum_{L=0,2,4}\frac{1}{2}(2L+1)^{\frac{1}{2}}c_L[(d^+\times d^+)^{(L)}\times(\tilde{d}\times\tilde{d})^{(L)}]^{(0)}$$
$$+\frac{1}{\sqrt{2}}\tilde{v}_2[(d^+\times d^+)^{(2)}\times(\tilde{d}\times\tilde{s})^{(2)}+(d^+\times s^+)^{(2)}\times(\tilde{d}\times\tilde{d})^{(2)}]^{(0)}$$
$$+\frac{1}{2}\tilde{v}_0[(d^+\times d^+)^{(0)}\times(\tilde{s}\times\tilde{s})^{(0)}+(s^+\times s^+)^{(0)}\times(\tilde{d}\times\tilde{d})^{(0)}]^{(0)}$$
$$+u_2[(d^+\times s^+)^{(2)}\times(\tilde{d}\times\tilde{s})^{(2)}]^{(0)}+\frac{1}{2}u_0[(s^+\times s^+)^{(0)}\times(\tilde{s}\times\tilde{s})^{(0)}]^{(0)} \quad (1)$$

Where it can be written in general form as [26, 27]

$$\hat{H}=\varepsilon\hat{n}_d+a_0\hat{p}.\hat{p}+a_1\hat{L}.\hat{L}+a_2\hat{Q}.\hat{Q}+a_3\hat{T}_3.\hat{T}_3+a_4\hat{T}_4.\hat{T}_4 \quad (2)$$

Where:
$\hat{n}_d=(d^+.\tilde{d})$ is the total number of d_{boson} operator
$\hat{p}=^1/_2\,[(d^+.\tilde{d})$ is the pairing operator, $\hat{L}=\sqrt{10}(d^+\times\tilde{d})^{(1)}$ is the angular momentum operator, $\hat{Q}=(d^+\times\tilde{s}+s^+\times\tilde{d})^{(2)}+\chi(d^+\times\tilde{d})^{(2)}$ is the quadrupole operator, $\hat{T}_r=(d^+\times\tilde{d})^{(r)}$ is the octoupole and hexadecapole operator, and $\varepsilon=\varepsilon_d-\varepsilon_s$ is the boson energy. The parameters a_0, a_1, a_2, a_3 and a_4 designated the strength of the pairing, angular momentum, quadrupole, octoupole and hexadecapole interaction between the bosons. The O(6) symmetry of the IBM-1is based on the chain U(6) ⊃O(6) ⊃O(5) ⊃O(3) of nested sub-algebra with quantum numbers N, σ, τ, and L, respectively [26]. In the O(6)limit, the energies of collective states are given by [26]

$$E(\sigma,\tau,L)=A(N-\sigma)(N+\sigma+4)+B\,\tau(\tau+3)+CL(L+1) \quad (3)$$

Where: $A=a_0/4$, $B=a_2/2$ and $C=a_1-a_2/10$)
Where N is the number of bosons, σ=N,N-2,N-4,……,0,and τ=0,1,……,σ.L takes on the values 2λ, $2\lambda-2$, $2\lambda-3$,……., $\lambda+1$, λ where λ is non-negative integer defined by $\lambda=\tau-3v_\Delta$ for v_Δ=0,1,2,……[28] .

3. Results and Discussion

The calculated results can be discussed separately for energy levels, the square of rotational energy and the moment of inertia (backbending curve), the B(E2) values, and potential energy surface.

3.1 Energy Levels

The IBM-1 has been used to calculate the energy levels of the $^{186\text{-}198}$Pt isotopes using the experimental energy ratios [24]$E_2:E_4:E_6:E_8$=1:2.5:4.5:7. It has been found that the$^{186\text{-}198}$Pt isotopes were deformed nuclei and they have a dynamical symmetry O(6). For the analysis of excitation energies in Platinum isotopes, it is tried to keep a minimum number of free parameters in Hamiltonian. The adopted Hamiltonian is expressing as [24].

$$\hat{H}=a_0\hat{P}.\hat{P}+a_1\hat{L}.\hat{L}+a_2\hat{T}_3.\hat{T}_3 \quad (4)$$

In the framework, the isotopic chains of (Z=78) nuclei have a number of proton bosons holes 2, and a number of neutron bosons particles varies from 5 to 11 for$^{186\text{-}198}$Pt nuclei. The parameters value used in the present work are presented in Table 1. The calculated ground (gr–), β– and γ–bands and the experimental data of low-lying states were plotted in Figures1-4 for even-even $^{186\text{-}198}$Pt isotopes. These figures show that the IBM calculations (energies, spin and parity) are in good agreements with the experimental data [29-36]. However, it is deviated in the high spin (energies) of the experimental data. Levels with '( )' correspond to cases for which the spin and/or parity of the corresponding states are not well established experimentally. Furthermore, from figure1 we can see the levels$14_1^+,5_1^+,7_1^+,10_2^+,6_3^+$ and$8_3^+$with energies 3.570, 1.321, 1.912, 2.624, 1.495 and 2.006MeV, respectively for ^{186}Pt isotope and $3_1^+,4_3^+,6_3^+$ and $8_3^+$with energies 1.1085, 1.464, 2.028 and 2.767MeV, respectively for ^{188}Pt isotope correspond to cases for which the spin and/or parity of the corresponding states are not well established experimentally [29-31].

In addition, from figure 2 the levels $4_2^+,6_2^+$and$4_3^+$with energies 1.385, 1.842 and 1.628MeV, respectively for ^{190}Pt isotope and$8_2^+,4_3^+$,$6_3^+$and 8_3^+ with energies 2.950, 1.800, 2.732 and 3.883MeV, respectively for ^{192}Pt isotope correspond to cases for which the spin and/or parity of the corresponding states are not well established experimentally [29, 32, 33]. In addition, from figure 3 and 4 the levels$8_1^+,5_1^+,6_2^+,7_1^+,8_2^+$ and 4_3^+ with energies 2.424, 2.03, 2.072, 2.982, 3.057 and 1.911MeV, respectively for ^{194}Pt isotope, $10_1^+$with energy 3.044MeV for ^{196}Pt isotope and$5_1^+,6_2^+,4_3^+$ and $6_3^+$with energies 2.573, 2.666, 2.155 and 3.170MeV, respectively for ^{198}Pt isotope correspond to cases

for which the spin and/or parity of the corresponding states are not well established experimentally [29, 34-36].

The β_2- band are calculated in this work as indicated in Table 2. This table shows the comparison between of the experimental and the IBM-1 calculations energy levels of $^{186-198}$Pt isotopes. From this comparison, we can see a good agreement between experimental data and the IBM-1 calculation. Levels with '*' correspond to cases for which the spin and/or parity of the corresponding states are not well established experimentally.

Table 1: Adopted values for the parameters used for IBM-1 calculations. All parameters are given in MeV except N and CHI (CHI is a constant depended on the dynamical symmetry).

Isotope	N	ε	a_0	a_1	a_2	a_3	a_4	CHI
^{186}Pt	11	0.000	0.0400	0.0113	0.000	0.0900	0.000	0.000
^{188}Pt	10	0.000	0.1104	0.0160	0.000	0.1175	0.000	0.000
^{190}Pt	9	0.000	0.1660	0.0213	0.000	0.1110	0.000	0.000
^{192}Pt	8	0.000	0.1700	0.0220	0.000	0.1150	0.000	0.000
^{194}Pt	7	0.000	0.184	0.0226	0.000	0.1210	0.000	0.000
^{196}Pt	6	0.000	0.1753	0.0230	0.000	0.1300	0.000	0.000
^{198}Pt	5	0.000	0.2468	0.0275	0.000	0.1550	0.000	0.000

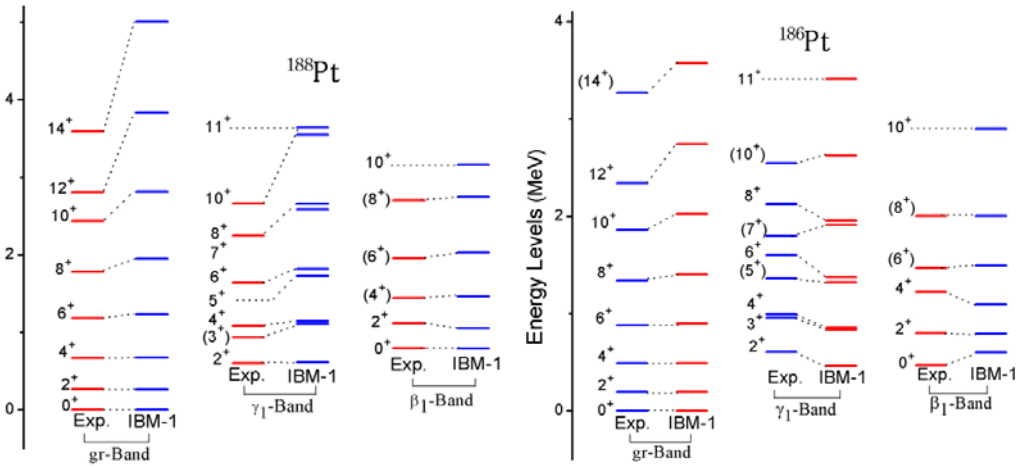

Figure 1: (Color online) Comparison the IBM-1 calculations with the available experimental data [29-31] for ^{186,188}Pt nuclei.

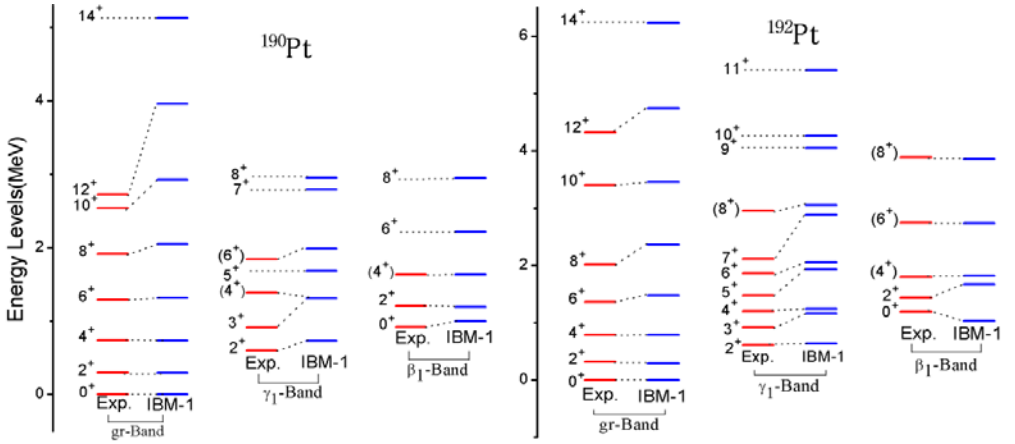

Figure 2: (Color online) Comparison the IBM-1 calculations with the available experimental data [29,32,33] for ^{190,192}Pt nuclei.

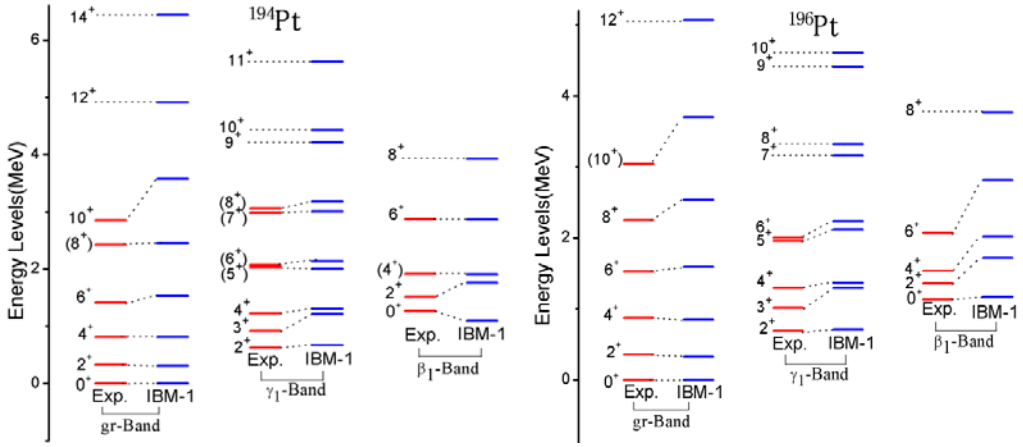

Figure 3: (Color online) Comparison the IBM-1 calculations with the available experimental data [29,34,35] for ^{194,196}Pt nuclei.

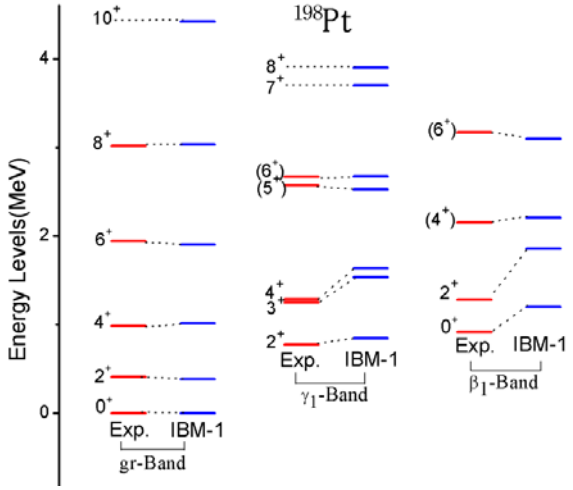

Figure 4: (Color online) Comparison the IBM-1 calculations with the available experimental data [29,36] for ^{198}Pt nuclei.

Table 2: β_2– bands for Pt isotopes (in MeV). The experimental data are taken from [29-36].

J^π	IBM-1	EXP	IBM-1	EXP	IBM-1	EXP
	^{186}Pt		^{188}Pt		^{190}Pt	
0^+	0.8100	------	1.057	-----	1.305	1.395
2^+	1.0622	1.176	1.405	1.312	1.626	1.670
4^+	1.300	1.671	1.730	1.685*	2.035	-----
6^+	1.885	1.814*	2.524	2.525*	2.911	-----
8^+	2.506	-----	3.391	------	3.669	-----
10^+	3.124	-----	4.257	4.282*	4.549	-----
J^π	IBM-1	EXP	IBM-1	EXP	IBM-1	EXP
	^{192}Pt		^{194}Pt		^{196}Pt	
0^+	1.530	1.546*	1.472	1.479	1.227	1.402
2^+	1.823	1.576	1.777	1.622	1.880	1.604
4^+	2.315	2.300*	2.287	2.275*	2.077	1.754
6^+	3.006	-----	3.002	3.057*	3.020	2.084
8^+	3.896	-----	4.023	-----	4.230	-----
10^+	5.180	-----	5.390	-----		
J^π	IBM-1	EXP				
	^{198}Pt					
0^+	1.395	1.481				
2^+	2.047	2.059*				
4^+	2.410	2.387*				
6^+	3.604	-----				

3.2 Backbending Curve

The collective rotation motion for nucleus depends on the valence nucleons motion with nucleus motion. It's causes rotation numeral of nucleons around axis which is different from the nuclear symmetry axis. In some nuclei occurs a sudden change in the value of the moment of inertia at the high angular momentum relatively leads to landing in the rotational energy of the nuclei. These sudden changes (curvatures) like Z character in opposite shape [38].

The formulas for calculating all the square of rotational energy and the moment of inertia are [37, 38].

$$\frac{2\vartheta}{\hbar^2}=\frac{4L-2}{E(L)-E(L-2)}=\frac{4L-2}{E_\gamma}(MeV)^{-1} \quad (5)$$

$$(\hbar\omega)^2=\left[\frac{E(L)-E(L-2)}{\sqrt{L(L+1)}-\sqrt{(L-2)(L-1)}}\right]^2(MeV)^2 \quad (6)$$

After finding the energy levels using IBM-1 and angular moment to the yrast energy levels, the square of rotational energy and the moment of inertia can be calculated from equations (5 and 6). Figure 5 shows the relation of the moment of inertia $\frac{2\vartheta}{\hbar^2}$as a function of the square of the energy $(\hbar\omega)^2$(backbending curve) of the emitted photon for whole Pt isotopes under study. When the nuclei transition from the (L) state to the (L-2) state, they don't have any backbending, which means there's no change in properties for Pt isotopes under study.

3.3 The B (E2) Values

More information can be obtained by studying the reduced transition probabilities B(E2). The reduced matrix elements of the E2 operator $\hat{T}^{E2}$have the form [6].

$$\hat{T}(E2)=\alpha_2[d^\dagger\tilde{s}+s^\dagger\tilde{d}]^{(2)}+\beta_2[d^\dagger\tilde{d}]^{(2)}$$
$$=\alpha_2([d^\dagger\tilde{s}+s^\dagger\tilde{d}]^{(2)}+\chi[d^\dagger\tilde{d}]^{(2)})$$
$$=e_B\hat{Q} \quad (7)$$

where ($s^\dagger$, $d^\dagger$) and ($\tilde{s}$, $\tilde{d}$) are creation and annihilation operators for *s* and *d* bosons respectively [26].

while $\alpha_2$and β_2 are two parameters and $(\beta 2=\chi\alpha_2,\ \alpha_2=e_B\,\text{(effective charge)})$, and the quadrupole operator

$$\hat{Q}=([d^\dagger\tilde{s}+s^\dagger\tilde{d}]^{(2)}+\chi[d^\dagger\tilde{d}]^{(2)})$$

Then the B(E2) values are given as:

$$B(E2,J_i\rightarrow J_f)=\frac{1}{2J_i+1}|\langle J_f\|T^{E2}\|J_i\rangle|^2 \quad (8)$$

The values of effective charge (e_B) are estimated to reproduce the experimental B(E2;$2_1^+\rightarrow 0_1^+$) and as given in Table 3. In addition, the comparison of calculation of B(E2) values with experimental data [2,11, 29-36, 39,40] are given in Table 4 for all nuclei under study.

Table 3: Effective charge used to reproduce B (E2) values for $^{186\text{-}198}$Pt nuclei.

A	e_B(eb)
^{186}Pt	0.1340
^{188}Pt	0.1369
^{190}Pt	0.1246
^{192}Pt	0.1397
^{194}Pt	0.1460
^{196}Pt	0.1513
^{198}Pt	0.1550

Table 4 shows that, in general, most of the calculated results in IBM-1 reasonably consistent with the available experimental data, except for few cases that deviate from the experimental data. The number of absolute *B(*E2*)* values known in the $^{186-198}$Pt nuclei is quite restricted, then can be cover relative *B(*E2*)* values. The relative *B(*E2*)* values are presented in Table 5, there, we give all data used in order to extract these relative values starting from the intensities of γ - transitions, specifying the decay of specific levels. In a number of transitions that have been taken as a reference transition to derive the relative *B(*E2*)* values, then the $3_1^+\rightarrow 2_2^+$ transition can (if present) be taken as the reference transition when deriving relative *B(*E2*)* values, and in a number of cases, the mixing ratio $\boldsymbol{\delta}$ helps substantially in deciding to fix a reference transition in order to derive relative *B(*E2*)* values. Using the criteria discussed before, we have extracted the experimental relative *B(*E2*)* values. The expression used is given by [11]:

$$B(E2)=100\left(\frac{I_\gamma}{I_\gamma^{ref}}\right)\left(\frac{E_\gamma^{ref}}{E_\gamma}\right)^5\left(\frac{1+\frac{1}{\delta^2_{ref}}}{1+\frac{1}{\delta^2}}\right) \quad (9)$$

where 'ref' stands for the reference transition.

3.4 Potential Energy Surface *(E(N, β, γ))*

The potential energy surface gives a final shape to the nucleus that corresponds to the function of Hamiltonian [43], as the equation [28]:

$$E(N,\beta,\gamma)=\frac{\langle N,\beta,\gamma|\hat{H}|N,\beta,\gamma\rangle}{\langle N,\beta,\gamma|N,\beta,\gamma\rangle} \quad (10)$$

The expectation value of the IBM-1 Hamiltonian with the coherent state $(|N,\beta,\gamma\rangle)$is used to create the IBM energy surface [27, 28].

The state is a product of boson creation operators ($b_c^\dagger$), with

$$|N,\beta,\gamma\rangle=\frac{1}{\sqrt{N!}}(b_c^\dagger)^N|0\rangle \quad (11)$$

$$b_c^\dagger=(1+\beta^2)^{-1/2}\{s^\dagger+\beta[\cos\gamma(d_0^\dagger)+\sqrt{1/2}\sin\gamma(d_2^\dagger+d_{-2}^\dagger)]\} \quad (12)$$

The energy surface, as a function of βandγ, has been given by [26]

$$E(N,\beta,\gamma)=\frac{N\varepsilon_d\beta^2}{1+\beta^2}+\frac{N(N-1)}{(1+\beta^2)^2}(\alpha_1\beta^4+\alpha_2\beta^3\cos 3\gamma+\alpha_3\beta^2+\alpha_4) \quad (13)$$

Where theα_i's are related to the coefficients C_L, ν_2, ν_0, u_2 and u_0 of equation (1).And $\beta$is a measure of the total deformation of nucleus, where$\beta = 0$ the shape is spherical, and is distorted when $\beta \neq 0$, and $\gamma$is the amount of deviation from the focus symmetry and correlates with the nucleus, if γ = 0the shape is prolate, and if γ = 60the shape becomes oblate. In the figure 6, the contour plots in the γ-β plane resulting from $E(N,\beta,\gamma)$ are shown for 186-198Pt isotopes. For most of the considered Pt nuclei the mapped IBM energy surfaces are triaxial shape. Triaxial shape is associated with intermediate values $0 < \gamma < \pi/3$. The triaxial deformation helps to understand the prolate-to-oblate shape transition that occurs in the considered Pt isotopes. The Pt nuclei considered here do not display any rapid structural change but remain γ-soft. This evolution reflects the triaxial deformed as one approaches the neutron shell closure N = 126.

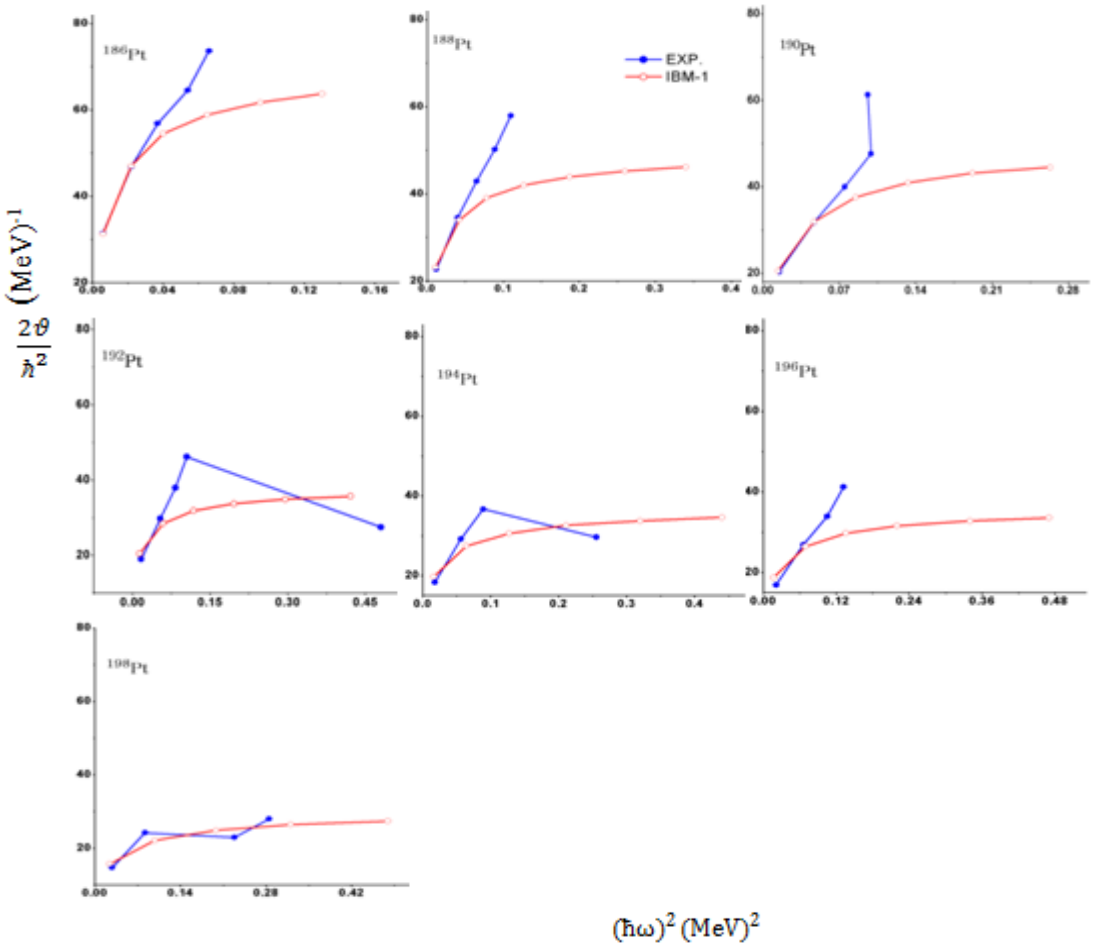

Figure 5: The calculated and observed moment of inertia $\frac{2\vartheta}{\hbar^2}$ vs. $(\hbar\omega)^2$ for yrast levels of $^{186\text{-}198}$Pt. Open circles represents the calculated values and it solid are observed ones. The experimental data are taken from [29-36].

Table 4: B(E2) values for platinum nuclei (in $e^2.b^2$).

$I_i \rightarrow I_f$	IBM-1	EXP. [29,30]	IBM-1	EXP. [29,31]	IBM-1	EXP. [29,32]
	^{186}Pt		^{188}Pt		^{190}Pt	
$2_1^+ \rightarrow 0_1^+$	0.5925	0.5931	0.5248	0.5248	0.3633	0.3635

$2_2^+ \to 0_1^+$	0.0823	--	0.0732	--	0.0504	1.3950
$2_2^+ \to 4_1^+$	0.0285	--	0.0584	--	0.0189	--
$4_1^+ \to 2_1^+$	0.8208	--	0.0263	--	0.4920	--
$4_2^+ \to 2_1^+$	0.0666	--	0.4189	--	0.0395	--
$4_2^+ \to 6_1^+$	0.0397	--	0.0447	--	0.0272	--
$6_1^+ \to 4_1^+$	0.9158	--	0.0371	--	0.5382	--
$6_2^+ \to 4_1^+$	0.0520	--	0.5530	--	0.0040	--
$6_2^+ \to 8_1^+$	0.0462	--	0.0331	--	0.0208	--
$8_1^+ \to 6_1^+$	0.9402	--	0.0439	--	0.5368	--
$10_1^+ \to 8_1^+$	0.9185	--	0.7785	--	0.0139	--
$10_2^+ \to 8_2^+$	0.5870	--	0.0496	--	0.3574	--
$10_3^+ \to 12_2^+$	0.0008	0.0007	0.7122	--	0.0880	--
$12_1^+ \to 10_1^+$	0.8619	--	0.0234	--	0.4428	0.1104
$12_2^+ \to 10_1^+$	0.0000	0.0003	0.5747	--	0.0434	0.0519
$0_2^+ \to 2_1^+$	0.0254	--	0.0223	--	0.0755	--
$5_1^+ \to 4_1^+$	0.0728	--	0.0797	--	0.0139	--
$7_1^+ \to 6_1^+$	0.0564	--	0.0626	--	0.3574	--
$11_1^+ \to 10_1^+$	0.0300	--	0.0336	--	0.0434	--

Continued

$I_i \to I_f$	IBM-1	EXP. [29,33,40]	IBM-1	EXP. [11,29,34,39]	IBM-1	EXP. [2,29,35,39]
	^{192}pt		^{194}pt		^{196}pt	
$2_1^+ \to 0_1^+$	0.3747	0.3752	0.3283	0.3283	0.2747	0.2747
$2_2^+ \to 0_1^+$	0.0526	0.0102	0.0462	0.0022	0.0385	--
$2_2^+ \to 2_1^+$	0.5074	0.5100	0.4385	0.4230	0.3597	0.3410
$2_2^+ \to 4_1^+$	0.0209	--	0.0199	--	0.0185	--
$0_2^+ \to 2_1^+$	0.0153	--	0.0130	0.0102	0.0515	0.0400
$0_2^+ \to 2_2^+$	0.1093	--	0.0924	0.0573	0.3660	0.2190
$3_1^+ \to 2_1^+$	0.0548	0.0052	0.0464	--	0.0367	--
$3_1^+ \to 4_1^+$	0.1560	0.1214	0.1026	--	0.0814	--
$3_1^+ \to 2_2^+$	0.3903	0.370	0.3299	--	0.2616	--
$4_1^+ \to 2_1^+$	0.5074	0.5529	0.4385	0.4490	0.3597	0.3800
$4_2^+ \to 2_1^+$	0.0287	--	0.0340	0.0286	0.0269	0.0052
$4_2^+ \to 2_2^+$	0.3629	--	0.2419	0.2800	0.1919	0.1962
$4_2^+ \to 4_1^+$	0.2602	--	0.2199	0.2150	0.1744	0.1800
$4_2^+ \to 6_1^+$	0.0308	--	0.0300	--	0.0418	--
$6_1^+ \to 4_1^+$	0.5464	0.4607	0.4618	0.4800	0.3663	0.3800
$6_2^+ \to 4_1^+$	0.0287	--	0.0230	--	0.0166	0.0053
$6_2^+ \to 4_2^+$	0.3629	--	0.2960	0.2800	0.2213	0.2435
$6_2^+ \to 6_1^+$	0.1694	--	0.1381	--	0.1033	0.1082
$6_2^+ \to 8_1^+$	0.0380	--	0.0382	--	0.0383	--
$8_1^+ \to 6_1^+$	0.5323	--	0.4341	0.4272	0.3246	0.4601
$8_2^+ \to 6_1^+$	0.0192	--	0.0139	--	0.0085	--
$8_2^+ \to 6_2^+$	0.3651	--	0.2802	0.2869	0.1874	--
$8_2^+ \to 8_1^+$	0.1153	--	0.0885	--	0.0592	--
$8_2^+ \to 10_1^+$	0.0448	--	0.0464	--	0.0482	--
$10_1^+ \to 8_1^+$	0.5325	--	0.3689	0.2869	0.2464	--
$10_2^+ \to 8_1^+$	0.0116	--	0.0071	--	0.0029	--
$10_2^+ \to 8_2^+$	0.3213	--	0.2202	0.2002	0.1108	--
$10_2^+ \to 10_1^+$	0.0768	--	0.0527	--	0.0265	--
$12_1^+ \to 10_1^+$	0.3981	0.3817	0.2728	--	0.1374	--

$I_i \to I_f$	IBM-1	EXP. [2,29]
	^{198}pt	
$2_1^+ \to 0_1^+$	0.2165	0.2166
$2_2^+ \to 0_1^+$	0.0301	--
$2_3^+ \to 0_1^+$	0.0000	0.0001
$2_2^+ \to 4_1^+$	0.0170	--
$2_2^+ \to 2_1^+$	0.2749	0.2620
$2_3^+ \to 2_1^+$	0.0041	0.0041
$0_2^+ \to 2_1^+$	0.0074	0.0045
$4_1^+ \to 2_1^+$	0.2749	0.2723
$4_2^+ \to 2_1^+$	0.0193	--
$4_2^+ \to 2_2^+$	0.1386	--
$4_2^+ \to 4_1^+$	0.1260	--
$4_2^+ \to 6_1^+$	0.0279	--

$6_1^+ \rightarrow 4_1^+$	0.2646	0.3900
$6_2^+ \rightarrow 4_1^+$	0.0100	--
$6_2^+ \rightarrow 6_1^+$	0.0668	--
$6_2^+ \rightarrow 8_1^+$	0.0385	--
$8_1^+ \rightarrow 6_1^+$	0.2099	--
$8_2^+ \rightarrow 8_1^+$	0.0289	--
$10_1^+ \rightarrow 8_1^+$	0.1203	--

Table 5: Comparisons of IBM-1 calculate relative *B(*E2*)* values with the experimental data [29–36], complemented with Refs. [7,41,42].

Isotopes	Transition	E_γ (keV)	I_γ	Δ	Exp.	IBM-1
^{186}Pt	$2_2^+ \rightarrow 0_1^+$	607	62(15)		9.4(23)	12.5
	$2_3^+ \rightarrow 0_1^+$	799	100(12)		7.6(11)	0.0
	$2_3^+ \rightarrow 0_2^+$	327	15.1(12)		100	64.2
	$2_2^+ \rightarrow 2_1^+$	416	100(4)	19^{+20}_{-8}	100	125
	$3_1^+ \rightarrow 2_1^+$	765	100(5)	16^{+4}_{-3}	18(4)	13.44
	$3_1^+ \rightarrow 4_1^+$	466	12.4(6)	0.42	4.0(16)	3.11
	$3_1^+ \rightarrow 2_2^+$	349	12.4(8)	2.8(3)	100	100
	$4_2^+ \rightarrow 2_1^+$	800	79(16)		3.2(7)	10.18
	$4_2^+ \rightarrow 2_2^+$	384	63(5)		100	73.33
	$4_2^+ \rightarrow 4_1^+$	501	100(16)	-0.85(9)	18(5)	66.6
^{188}Pt	$2_2^+ \rightarrow 0_1^+$	605	66(3)		3.7(2)	12.81
	$2_3^+ \rightarrow 0_1^+$	1115	100(4)		1.0(1)	0.0
	$2_3^+ \rightarrow 0_2^+$	316	19(2)		100	62.99
	$2_2^+ \rightarrow 2_1^+$	340	100(4)	Unknown	100	126
	$3_1^+ \rightarrow 2_1^+$	671	100(4)		<5	13.95
	$3_1^+ \rightarrow 2_2^+$	331	63(3)	Unknown	100	100
	$4_2^+ \rightarrow 2_1^+$	820	21(2)		1.43(17)	10.22
	$4_2^+ \rightarrow 2_2^+$	479	100(7)		100	73.33
	$4_2^+ \rightarrow 4_1^+$	415	45(4)		<92	66.66
^{190}Pt	$2_2^+ \rightarrow 0_1^+$	598	40(3)		1.3(1)	13.11
	$2_3^+ \rightarrow 0_1^+$	1203	14(2)		0.019(3)	0.0
	$2_3^+ \rightarrow 0_2^+$	282	51(4)		100	51.19
	$2_2^+ \rightarrow 2_1^+$	302	100(3)	Unknown	100	128
	$3_1^+ \rightarrow 2_1^+$	621	56(5)	$1.0^{+2.0}_{-0.6}$	$1.0^{+0.6}_{-0.7}$	14.25
	$3_1^+ \rightarrow 4_1^+$	180	3.1(3)	$3^{+2.0}_{-1.0}$	49^{+9}_{-10}	31.12
	$3_1^+ \rightarrow 2_2^+$	319	100(5)	Unknown	100	100
	$4_2^+ \rightarrow 2_2^+$	531	100(8)		100	73.33
	$4_2^+ \rightarrow 4_1^+$	391	30(3)		<140	66.68
^{192}Pt	$2_3^+ \rightarrow 0_1^+$	1439	4.6(5)		0.023(3)	0.00
	$2_3^+ \rightarrow 2_1^+$	1123	100(4)		<1.7	0.00
	$2_3^+ \rightarrow 4_1^+$	655	3.3(4)		0.85(11)	1.195
	$2_3^+ \rightarrow 3_1^+$	518	26.8(35)		<22	31.8
^{194}Pt	$3_1^+ \rightarrow 2_1^+$	594	18.4(6)	>10	<0.64	14.06
	$3_1^+ \rightarrow 4_1^+$	111	0.49(15)		<75	39.98
	$3_1^+ \rightarrow 2_2^+$	301	100.0(10)	>5	100	100
^{196}Pt	$3_1^+ \rightarrow 2_1^+$	659	4.4(9)	0.0379	0.13	14.02
	$3_1^+ \rightarrow 4_1^+$	138	1.3(4)	2.65	95	40
	$3_1^+ \rightarrow 2_2^+$	326	100(8)	0.0769	100	100

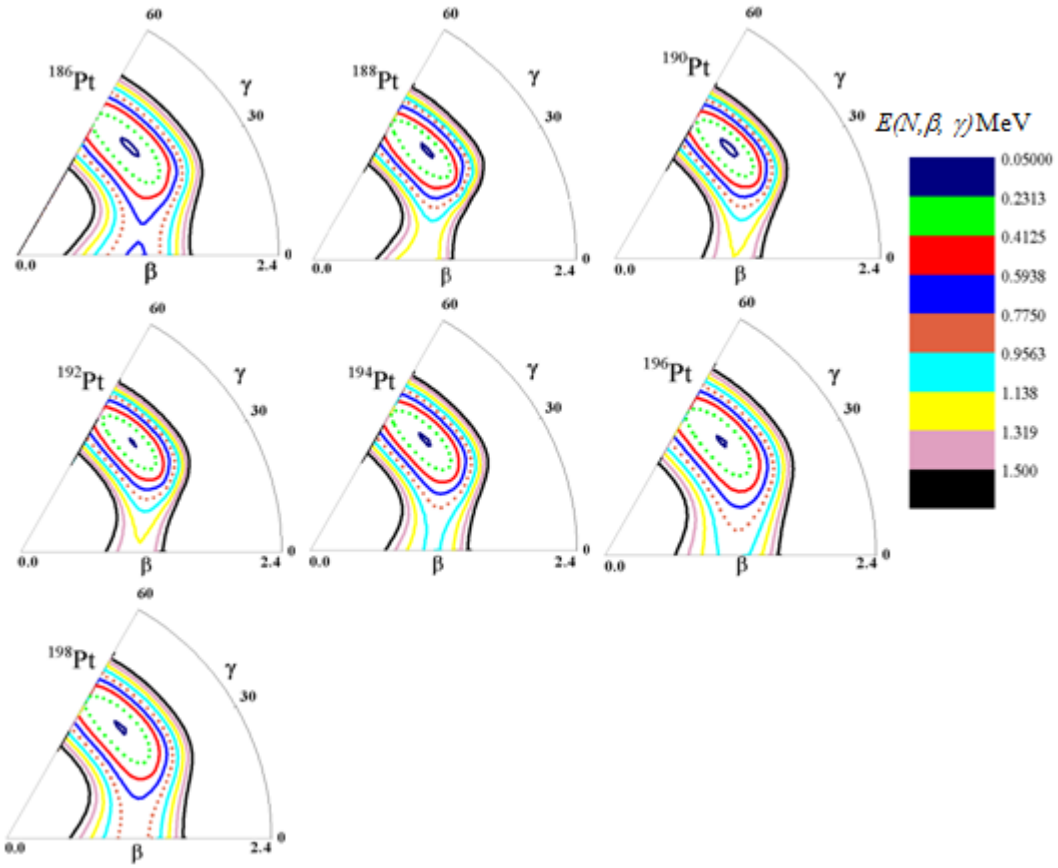

Figure 6: (Color online) The potential energy surface in γ-β plane for $^{186-198}$Pt nuclei.

4. Conclusions

Theoretical calculations using IBM-1 model are performed for $^{186-198}$Pt isotopes with proton number of 78. The $^{186-198}$Pt isotopes have bosons total numbers between 5 and 11 are considered fully deformed nuclei, and the dynamical symmetry of these isotopes is O(6). The calculated energy levels including the ground (gr-), β- and γ-bands are in satisfactory agreement with the observed values for the whole Pt isotopes. The square of rotational energy and the moment of inertia of the yrast states can be reproduced reasonably well. The calculated values of electric transition probabilities B(E2) for these isotopes using IBM-1 model are in good agreement with the experimental data. The potential energy surfaces for platinum isotopes shows that all nuclei are deformed and have dynamical symmetry O(6) characters.

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