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Study of geometrical properties of 96Mo, 98Ru and 100Pd isotones within interacting boson model

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ABSTRACT

The software package for interacting boson model-1 and for the geometrical boson model has been used to calculate energy levels and potential energy surfaces for and by estimating a set of parameters which are used to predict the behavior of even-even and isotones. According to a framework, the interaction is prominent between the two parameters (and). This means that vibrational structures are constant rises with opposite of rotational. Thus, the potential energy surfaces are considered as a pointer of and distortions for even-even and isotones. The behaviors of the potential energy surfaces with minimum β (-0.84356,- 0.39928, and -0.19045) have circular contours centered at this point that indicates a good agreement with the typical axially symmetric limits. The results of the calculated energy levels were in acceptable agreement with the experimental data. There is no pure vibrational property of these isotones which is clearly shown in the behavior of potential energy surfaces.

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دراسة الصفات الهندسية للايزوتونات ^{96}Mo و ^{98}Ru و ^{100}Pd ضمن أنموذج البوزونات المتفاعلة

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الكلمات المفتاحية:

أنموذج البوزونات المتفاعلة-1
برنامج *IBM*
سطوح تساوي الجهد *PES*
برنامج *IBMP*

الـــخُـــلاصـــة

تـم اسـتخدام الحزمـة البرمجيـة *IBM* لنمـوذج البوزونـات المتفاعلـة الاول و الحزمـة البرمجيـة *IBMP* لنمـوذج البوزونـات المتفاعلـة الهندسـي لحسـاب مسـتويات الطاقـة وسـطوح تساوي الجهد للايزوتونـات ^{96}Mo و ^{98}Ru و ^{100}Pd من خلال تقدير مجموعـة من المعلمـات للتنبـؤ بسـلوك الايزوتونـات ^{96}Mo و ^{98}Ru و ^{100}Pd الزوجيـة -الزوجيـة. ووفقـا للعمـل ضـمن اطار *IBM*1 فان التفاعل بين المعاملين (ε و a_2) كان هو المهيمن. وهذا يعني ان الزيادة في التركيـب الاهتـزازي متعـاكس مـع التركيـب الـدوراني، بالتـالي فـان سـطوح تسـاوي الجهـد

$V(\beta,\gamma)$ اعتبرت β و γ كمؤشر لتشوه الايزوتونات ^{96}Mo و ^{98}Ru و ^{100}Pd الزوجية-الزوجية وان سلوك سطوح تساوي الجهد بقيمة صغرى لـ β (0.84356- و 0.39928 - و - 0.19045) تمتلك دوائر متحدة المركز عند هذه النقطة وهذا يشير الى توافق جيد مع التناظر المحوري النموذجي للتحديدين $U(5) - SU(3)$. كانت نتائج مستويات الطاقة المحسوبة في توافق مقبول مع البيانات العملية، لا توجد خاصية اهتزازية نقية لهذه الايزوتونات والذي يظهر بوضوح في سلوك سطوح تساوي الجهد.

1. INTRODUCTION

The structure of medium and heavy nuclei can be described based on the interacting boson model, which is mainly based on the well-known shell model and on the collective geometric model of the atomic nucleus. Besides, the dynamical symmetries of the nucleus can be shown by using Lie algebra [1-3]. The interacting boson model is convenient for studying the low-lying collective states in even- A system of interacting d and s bosons carrying angular momentum 2 and 0 is used to study low mass states in doubles [4-6]. In other words, the number of active nucleon-particle (N) or hole pairs outside the closed shell is the base for the total number of bosons. Therefore, the closed shell s-and d- boson has its own binding energy [7-9]. Thus, there is no significant difference between protons and bosons because the total number (N= Nπ+Nν) is limited and preserved in a certain nucleus, which gives half of the total number of nucleons. It is called a six-dimensional space because each person can describe it through a six-dimensional space. Through group theoretical methods many characteristics are analyzed and expressed. Even-even $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$, isotones considered as medium nuclei mass number, which are always referred to be as vibrational nuclei, due to the small bosons number outside the closed N and Z shells, probably what appears from the sequence of energy levels in the modern experimental decay schemes are stay away from their values of typical harmonic oscillator (pure vibration), which indicates to energy levels distortion such as 0_2^+, 2_2^+ , $4_1^+$and 6_1^+. For this reason, $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$, isotones have been re-examined in modern experimental decay schemes.

2. INTERACTING BOSON MODEL1

The interacting boson model (IBM) is suitable for describing the low-lying collective states in even-even nuclei by a system of interacting s-and d- bosons carrying angular momentum's 0 and 2, respectively .The IBM is built on a closed shell, Thus, it can be seen that the bosons are equal to the pairs of nucleons according to the most reliable atomic image. The s-boson is significant because of its shrill join with the nucleon and the nucleon in comparable elements[10-12]. In addition, the Hamiltonian results through this planetary using influential active group models and systems.The boson-boson interacting energy can be written as[1-5]:-

$$H = \varepsilon_s(s^\dagger s) + \varepsilon_d \sum_m d_m^\dagger d_m + \sum_{L=0,2,4} \frac{1}{2}(2L+1)^{\frac{1}{2}} C_L\left[(d^\dagger d^\dagger)^{(L)}.(dd)^{(L)}\right]^{(0)} + \frac{1}{\sqrt{2}}\upsilon_2\left[(d^\dagger d^\dagger)^{(2)}.(ds)^{(2)} + (d^\dagger s^\dagger)^{(2)}.(dd)^{(2)}\right]^{(0)} + \frac{1}{2}\upsilon_0\left[(d^\dagger d^\dagger)^{(0)}.(ss)^{(0)} + (s^\dagger s^\dagger)^{(0)}.(dd)^{(0)}\right]^{(0)} + \mathrm{u}_2\left[(d^\dagger s^\dagger)^{(2)}.(ds)^{(2)}\right]^{(0)} + \frac{1}{2}u_0\left[(s^\dagger s^\dagger)^{(0)}.(ss)^{(0)}\right]^{(0)} \dots\dots\dots\dots\dots (1)$$

where $\mathrm{C_L(L=0,2,4)}, \upsilon_\mathrm{L}(\mathrm{L}=0,2), \mathrm{u_L(L}=0,2)$ describe the boson interaction.

The utmost normally secondhand form of $IBM1$ Hamiltonian is [1-3]:-

$H = \varepsilon n_d + a_0 P^{\dagger} P + a_1 L.L + a_2 Q.Q + a_3 T_3 T_3 + a_4 T_4 T_4 \ldots (2)$

where $\varepsilon = \varepsilon_d - \varepsilon_s$ is the boson vigor, for ease ε_s is bundle equivalent to zero only $\varepsilon = \varepsilon_d$ seems, $a_0, a_1, a_2, a_3,$ and a_4 label the fortes of the quadrupole, boney impetus, trimming, octupole and hexadecapole interrelating among bosons correspondingly. It can be seen that the five mechanisms of d boson and the single constituent of the s boson are prolonged transversely a six dimensional planetary [13-15]. For a fixed number of boson N the collection construction of the tricky is$U(6)$. Having seen the diverse concessions of $U(6)$, three dynamical proportions appear, namely $U(5)$, $SU(3)$ and $O(6)$; these symmetries are related to the geometrical idea of the globular vibrator, distorted blade and a symmetric (γ −soft) distorted rotor, separately [16-18].

Potential Energy Surface (PES)

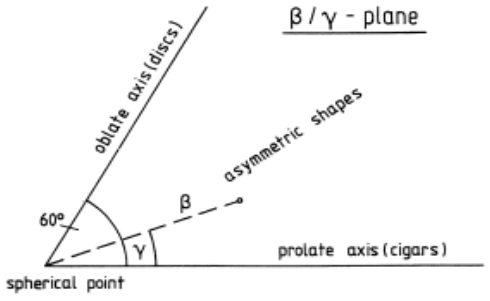
The general formula for the potential energy surface as a function of geometrical variables β and γ is given by [8-11]:-

$V(\beta,\gamma) = \frac{N(\varepsilon_s+\varepsilon_d\beta^2)}{1+\beta^2} + \frac{N(N+1)}{(1+\beta^2)^2}(\alpha_1\beta^4 + \alpha_2\beta^3 Cos3\gamma + \alpha_3\beta^2 + \alpha_4) \ldots (3)$

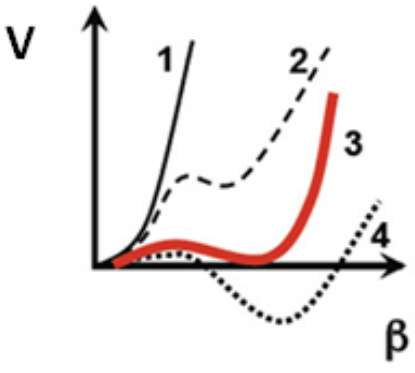
where $\alpha_1 = \frac{C_0}{10} + \frac{C_2}{7} + \frac{9C_4}{35}, \alpha_2 = -\sqrt{\frac{8}{35}}\upsilon_2,$ $\alpha_3 = \frac{(\upsilon_0+u_2)}{\sqrt{5}}, \alpha_4 = u_0 \ldots (4)$

where N is the total boson number β is the quadruple deformation parameter operator from $\beta = 0 - 2.4$, γ is asymmetry angle for $0^{\circ} \le \gamma \le 60^{\circ}$. The variables $\alpha_1, \alpha_2, \alpha_3$ and α_4 are related to the parameters $C_L, \upsilon_L,$ and $u_L$which are given in equation (1).

All deformations can be described by N, which is the quaternary distortion modulus of operator from β=0-2.4, γ, the interval 0°≤γ≤60°. Thus, multiplying spherical bodies are produced through these deformed quadrilateral shapes, while flattened shapes are produced from triangular shapes. It can be seen that $\alpha_1, \alpha_2, \alpha_3,$ and α_4 are linked to the limits $C_L, \upsilon_L,$ and $u_L$which are shown in equivalence (1). These parameters can be used as variables $(\alpha's)$ to be expressed by F. Iachello [19-22] as one must take into justification the irregularity viewpoint happens only in the term $cos3\gamma$.Thus, the energy surfaces has minima only at $\gamma = 0^{\circ}$and 60°. These terms give at large N, $\beta_{min} = 0, \sqrt{2}, 1$ for $U(5), SU(3)$, and $O(6)$ respectively. According to figure (1), The first curve has a minimum at $\beta = 0$ (spherical equilibrium shapes). Noticeably, it will provide a rise to a vibrational-like spectrum with phonon energy depending on the softness in β of the potential. The second curve displays the emergence of a second, higher energy, minimum at finite deformation. This minimum denotes the onset of a co-existing deformed shape. With additional valence nucleons, the third curve is reached by which the deformed minimum has become degenerate with the spherical one, denoting true equilibrium phase coexistence. For curve number four and beyond, the nuclei are obviously well deformed.



(a)



(b)

Figure 1 a-The $\beta-\gamma$ plane with different types of nuclear shape indicated[9].**b-** Dissimilar statistics of valence nucleons can be demonstrated through the potential as a purpose of the deformation β [22].

3. CALCULATIONS AND RESULTS

The $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$, isotones have neutron number $N=54$ which equivalent(two particles bosons) and atomic number (Z=42,44 and 46) respectively, which equivalent (4,3 and 2) hole proton boson number. The software bundle IBM computer code for interacting boson model-1 and $IBMP-code$ for geometrical boson model GBM were used to calculate energy levels for $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$, through approximating a bundle of strictures designated in the Hamiltonian operative as it is shown in equations (1) and balances(3) for possible dynamism surface. The parameters estimated $IBM1\&PES$ calculations for three isotones are prearranged in Table (1).

Table 1. The parameters have been used in the interacting boson model-1 and geometrical boson model GBM for even-even $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$, isotones (in MeV).

IBM1-Parameters in MeV, except χ			
Isotopes / **The parameters**	**^{96}Mo**	**^{98}Ru**	**^{100}Pd**
N	6	5	4
ε	0.44	0.57	0.61
a_0	0.0	0.0	0.0
a_1	0.02	0.008	0.008
a_2	-0.04	-0.018	-0.01
a_3	0.001	0.001	0.001
a_4	0.001	0.001	0.001
χ	-0.8	-0.8	-0.8
Potential energy surface (PES) Parameters in MeV			
Isotopes / **The parameters**	**^{96}Mo**	**^{98}Ru**	**^{100}Pd**
ε_s	0.2	0.09	0.05
ε_d	0.629	0.651	0.678
α_1	0.008	0.004	0.002
α_2	0.068	0.031	0.017
α_3	0.16	0.072	0.04
α_4	0	0	0
B.E	0.84356	0.39928	0.19045
B.E is Binding Energy			

The levels of the calculated energy compared with the experimental data[24-27] for $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$,isotones are shown in Figure (2), however, the calculated potential energy surfaces PES as a function of β rustles are shown in Tables (2), illustrated in Figure (3) with contour diagrams.

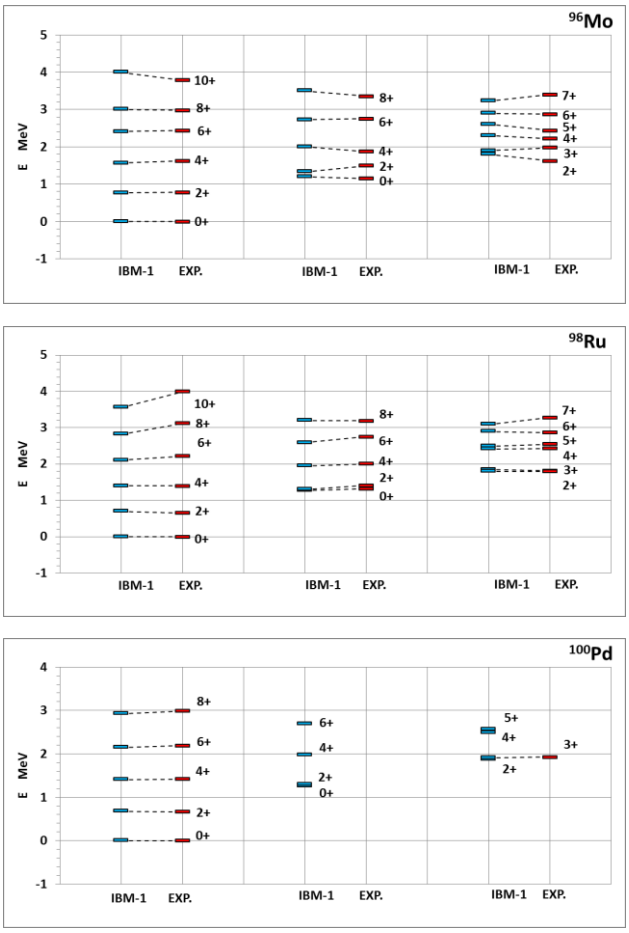


Figure 2 The levels of the calculated energy in comparison with experimental[24-27] for $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$, isotones.

Table 2. Calculated potential energy surfaces using IBMP code even-even $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$, isotones (in MeV).

The calculated of potential energy surface (P.E.S) for ^{96}Mo													
γ° / β	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	0.384	0.384	0.382	0.38	0.377	0.373	0.369	0.365	0.362	0.359	0.356	0.355	0.354
0.4	1.358	1.355	1.345	1.33	1.31	1.286	1.261	1.236	1.213	1.193	1.177	1.168	1.164
0.6	2.506	2.498	2.474	2.436	2.387	2.329	2.268	2.206	2.149	2.099	2.061	2.038	2.029
0.8	3.508	2.495	3.456	3.394	3.314	3.22	3.12	3.019	2.926	2.845	2.783	2.745	2.731
1	4.257	4.24	4.189	4.108	4.002	3.879	3.747	3.615	3.492	3.386	3.305	3.254	3.237
1.2	4.772	4.752	4.693	4.599	4.476	4.333	4.18	4.027	3.884	3.761	3.667	3.608	3.588
1.4	5.111	5.09	5.026	4.924	4.792	4.638	4.473	4.307	4.153	4.021	3.919	3.855	3.834
1.6	5.33	5.307	5.241	5.137	5	4.841	4.67	4.5	4.341	4.204	4.1	4.034	4.011
1.8	5.468	5.445	5.379	5.274	5.137	4.977	4.806	4.635	4.475	4.338	4.233	4.167	4.144
2	5.554	5.531	5.466	5.362	5.227	5.07	4.901	4.732	4.574	4.439	4.335	4.27	4.248
2.2	5.605	5.584	5.52	5.419	5.287	5.133	4.968	4.803	4.65	4.518	4.417	4.353	4.331
2.4	5.635	5.614	5.552	5.454	5.326	5.177	5.017	4.858	4.709	4.581	4.483	4.421	4.4
The calculated of potential energy surface (P.E.S) for ^{98}Ru													
γ° / β	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	0.2	0.2	0.2	0.199	0.198	0.197	0.196	0.195	0.194	0.193	0.192	0.191	0.191
0.4	0.713	0.712	0.709	0.705	0.699	0.691	0.684	0.676	0.669	0.663	0.658	0.655	0.654
0.6	1.339	1.337	1.329	1.318	1.303	1.285	1.267	1.248	1.23	1.215	1.204	1.197	1.194
0.8	1.919	1.915	1.903	1.884	1.86	1.831	1.801	1.77	1.742	1.717	1.698	1.687	1.683
1	2.388	2.382	2.367	2.342	2.31	2.273	2.232	2.192	2.155	2.123	2.098	2.083	2.078
1.2	2.743	2.737	2.719	2.69	2.653	2.609	2.563	2.516	2.473	2.435	2.407	2.389	2.383
1.4	3.005	2.998	2.979	2.948	2.908	2.861	2.811	2.76	2.713	2.673	2.642	2.623	2.616
1.6	3.197	3.19	3.17	3.138	3.097	3.048	2.997	2.945	2.896	2.855	2.823	2.803	2.796
1.8	3.339	3.332	3.312	3.28	3.238	3.189	3.137	3.085	3.037	2.995	2.963	2.943	2.936
2	3.444	3.437	3.417	3.386	3.345	3.297	3.246	3.194	3.146	3.105	3.074	3.054	3.047
2.2	3.523	3.517	3.498	3.467	3.427	3.38	3.33	3.28	3.233	3.193	3.162	3.143	3.136
2.4	3.584	3.578	3.559	3.529	3.49	3.445	3.397	3.348	3.303	3.264	3.234	3.215	3.209
The calculated of potential energy surface (P.E.S) for ^{100}Pd													
γ° / β	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	0.131	0.131	0.131	0.131	0.131	0.13	0.13	0.129	0.129	0.129	0.128	0.128	0.128
0.4	0.469	0.469	0.468	0.466	0.464	0.462	0.459	0.457	0.454	0.452	0.451	0.85	0.449
0.6	0.89	0.889	0.887	0.883	0.878	0.872	0.866	0.86	0.854	0.849	0.845	0.843	0.842
0.8	1.293	1.292	1.288	1.282	1.274	1.264	1.245	1.244	1.235	1.227	1.221	1.217	1.215
1	1.633	1.631	1.626	1.618	1.607	1.595	1.582	1.569	1.556	1.546	1.538	1.533	1.531
1.2	1.902	1.9	1.894	1.885	1.873	1.858	1.843	1.828	1.813	1.801	1.792	1.786	1.784
1.4	2.11	2.108	2.101	2.091	2.078	2.063	2.046	2.03	2.014	2.001	1.991	1.984	1.982
1.6	2.269	2.267	2.26	2.25	2.236	2.22	2.203	2.186	2.17	2.157	2.146	2.14	2.137
1.8	2.392	2.39	2.383	2.373	2.359	2.343	2.326	2.309	2.293	2.279	2.268	2.262	2.26
2	2.487	2.485	2.478	2.468	2.454	2.439	2.422	2.405	2.389	2.376	2.365	2.359	2.356
2.2	2.562	2.559	2.553	2.543	2.53	2.514	2.498	2.481	2.466	2.453	2.443	2.436	2.434
2.4	2.621	2.619	2.613	2.603	2.59	2.575	2.559	2.543	2.528	2.516	2.506	2.5	2.497

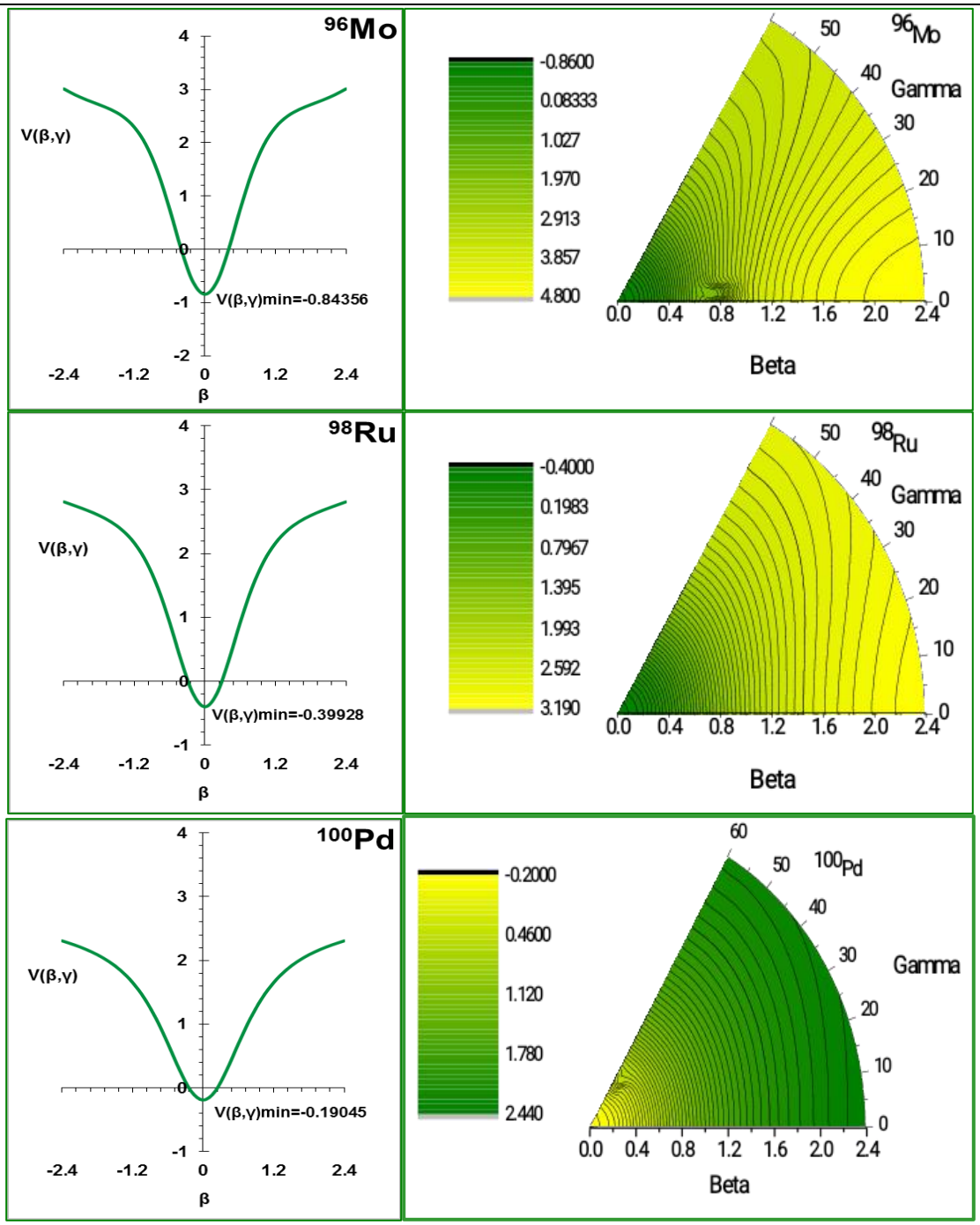


Figure 3 The surface of the potential energy as a function to β with contour diagrams for even-even $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$,isotones .

4. DISCUSSION AND CONCLUSIONS

It is demonstrated that (ε and a_2) are compared $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$,isotones according to the IBM1 framework. The decreases of a_2 is linked with the increases of ε. Thus, the increases of vibrational characteristics keep continuous with opposite of rotational possessions, $^{100}_{46}Pd$, which is presented as a different mode of characteristics where the number of proton is around 50. Due to the lacking of the data, the calculated value of states cannot be compared with the U(5) to SU(3). The nuclear distortion can be defined as a shape which is one of the most fundamental characteristic of an atomic nucleus. It is controlled by the mutual effect of macroscopic, liquid-drop like characteristics of the nuclear matter and the effects of microscopic shell. It can be seen that It is distributed due to the

nucleons outside the closed shells. The behaviors of the potential energy surfaces for the $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$, isotones with minimum β (-0.84356,- 0.39928 and -0.19045) have circular contours centered at this point that shows a respectable covenant with the standard axially symmetric of U(5)-SU(3) limits, as seen in figure (3). A contour plot of V (β,γ) for $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$, isotones have shown the minimum potential that occurs at approximately β near 0 for all nuclei potential implies that the $^{96}_{42}Mo$, $^{98}_{44}Ru$ and $^{100}_{46}Pd$,isotones display the appearance of a additional, advanced dynamism, least at limited distortion. This least means the start of a present distorted, as in figure(1).

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