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Study the properties of the low-lying energy states for ^{184,186}Os isotopes using IBM-1

دراسة خصائص مستويات الطاقة الواطئة لنظائر الاوزيميوم ^{184,186}Os بأستخدام IBM-1

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بحث مستل

Abstract:-

The energy levels, B(E2) values, the square of rotational energy and the moment of inertia, staggering in γ- band energies andthe potential energy surface for^{184,186}Osisotopes have been investigated using IBM-1. The calculated results good agreement with experimental data.

Keywords: IBM; Energy levels;B(E2) values; Staggering in γ- band energies; Potential energy surface

الخلاصة

تم حساب مستويات الطاقة, قيم B(E2), طاقة الدوران للحزمة الارضية لنظائر الاوزيميوم ^{184,186}Os بأستخدام نموذج تفاعل البوزونات الاول. وكانت النتائج متوافقة مع القيم العملية. كذلك تم حساب تمايل في حزمة γ وجهد طاقة السطح حيث اظهرت النتائج ان هذه النظائر تقع ضمن المنطقة الانتقالية SU(3)-O(6) وقريبة من التحديد SU(3).

1.Introduction

The interacting boson model (IBM-1) was proposed by Arima and Iachello in (1974)[1, 2], it has become widely accepted to describe and predicting low-energy collective properties of complex nuclei.This model adopted in terms ofthe group U(6)[2], it has three dynamical symmetries correspondingto different nuclear shapes: U(5) a spherical nucleusthat can vibrate,SU(3) an ellipsoidal deformed axiallysymmetric rotor, and O(6) an axially asymmetric rotor. Even-even osmium isotopes are in interesting because it's lies in complex region and hard to populated experimentally.Many studies have been conducted on thestructure of Osmium nucleus in recent years,P. Sarriguren et. al. were studied the evolution of shapes with the number of nucleons in various chains of Yb, Hf,W, Os, and Pt isotopes from neutron number N = 110 up to N = 122, in (2008)[3]. K. Nomura. et al in(2011)[4], used interacting boson model (IBM) to calculate the transitions from prolate to oblate ground-state shapes. The energy levels (positive parity), the reduced probability of E2 transitions, the intrinsic quadrupole moment Q_0, and the potential energy surface for ^{184}W and ^{184}Os nuclei were calculated using IBM-1 by F. I. Sharrad et al. in (2013)[5].In (2015) [6],

the energy levels for the ground-state band, the properties of the ground and excited-state bands, negative parity band , the γ-band and β-band states for$^{178-188}$Os isotopes, have been calculated using Interacting Boson model by I. Mamdouh and M, Al-Jubbori.

In this present work were investigated the energy levels, probability of electromagnetic transitions B(E2),and potential energy surface for $^{184-194}$Os isotopesusing IBM-1

2. Theory

2.1. The Interacting Boson Model (IBM-1) :-

The Hamiltonian operator according to IBM- 1 describes the system of s (L= 0) and d (L= 2) boson can be written as follows[1, 7]

$$\hat{H} = \varepsilon\hat{n}_d + a_0\hat{p}^{\dagger}.\hat{p} + a_1\hat{L}.\hat{L} + a_2\hat{Q}.\hat{Q} + a_3\hat{T}_3.\hat{T}_3 + a_4\hat{T}_4.\hat{T}_4 \quad (1)$$

where:-

$(\varepsilon, a_0, a_1, a_2, a_3, and\ a_4)$ are parameter used in IBM-1 ,

$\varepsilon = (\varepsilon_d - \varepsilon_s)$ is the boson energy

$\hat{n}_d = (d^{\dagger}.\tilde{d})$ Boson number type of (d-boson)

$\hat{p} = 1/2\left[(\tilde{d}.\tilde{d}) - (\tilde{s}.\tilde{s})\right]$ Pairing bosons operator

$\hat{L} = \sqrt{10}\left[d^{\dagger} \times \tilde{d}\right]^{1}$ Angular momentum operator

$\hat{Q} = \left[d^{\dagger} \times \tilde{s} + s^{\dagger} \times \tilde{d}\right]^{(2)} + CHI\left[d^{\dagger} \times \tilde{d}\right]^{(2)}$ Quadrupole operator

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

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

A form of the IBM Hamiltonian suitable for the study of shape phase transitions from SU(3) to O(6) as follows[7, 8]:-

$$\hat{H} = a_0\hat{p}^{\dagger}.\hat{p} + a_1\hat{L}.\hat{L} + a_2\hat{Q}.\hat{Q} \quad (2)$$

The ratio $a_0/4a_2$ is closed to (-1), the equation above is used, but if it's larger the appropriate Hamiltonian is [2]:-

$$\hat{H} = a_0\hat{p}^{\dagger}.\hat{p} + a_1\hat{L}.\hat{L} + a_2\hat{Q}.\hat{Q} + a_3\hat{T}_3.\hat{T}_3 \quad (3)$$

The parameters a_2 and a_1 determine only features of the eigenvalue spectrum. Furthermore, χ (CHI) can be used as a single parameter describing the O(6)- SU(3) transition, since χ=0 corresponds to O(6) eigenfunctions and $\chi = -\frac{\sqrt{7}}{2}$ corresponds to SU(3) eigenfunctions[9].

The $n_d\varepsilon_d$ term were added to the equation (2) so the Hamiltonian Writes as follows [10]:-

$$\hat{H} = \varepsilon\hat{n}_d + a_0\hat{p}^{\dagger}.\hat{p} + a_1\hat{L}.\hat{L} + a_2\hat{Q}.\hat{Q} \quad (4)$$

The terms in $n_d\varepsilon_d$ or $\hat{T}_3$ will to reduce the ratio $E4_1^+/E2_1^+$ and thus must be kept small for well deformed nuclei [8].

The general form of B(E2) operator in IBM-1 is given by reduce electric quadrupole transition probability B(E2) operator as follows [11,12, 13]:-

$$\hat{T}_{\mu}^{E2} = \alpha_2\left[d^{\dagger} \times \tilde{s} + s^{\dagger} \times \tilde{d}\right]_{\mu}^{(2)} + \beta_2\left[d^{\dagger} \times \tilde{d}\right]_{\mu}^{(2)} \quad (5)$$

The reduced $E2$ transition probability ($E2$) is given by [11,12] :-

$$B(E2; I_i \rightarrow I_f) = \frac{1}{(2I_i+1)} \left|\langle I_f \| T^{(E2)} \| I_i \rangle\right|^2 \qquad (6)$$

2.2. Staggering in γ- band Energies

The staggering in γ - band energies S(J) and the transition between different structural symmetries in nucleican be written as follows [7, 14] :-

$$S(J) = \frac{\{E(J_\gamma^+) - E[(J-1)_\gamma^+]\} - \{E[(J-1)_\gamma^+] - [(J-2)_\gamma^+]\}}{E(2_1^+)} \qquad (7)$$

The odd–even staggering is quite strongly pronounced in nuclear regions characterized by SU(5) and O(6) and relatively weaker in nuclei near the SU(3) region[15].

2.3. The square of rotational energy and the moment of inertia

The moment of inertia and the square of rotational energy are [7,16,17]

$$\frac{2\vartheta}{\hbar^2} = \frac{4L-2}{E(L)-E(L-2)} = \frac{4L-2}{E_\gamma}\,(\mathrm{MeV})^{-1} \qquad (8)$$

where:

ϑ is moment of inertia, E_γ is transition energy and L is angular momentum. Also,

$$(\hbar\omega)^2 = \left[\frac{E(L)-E(L-2)}{\sqrt{L(L+1)} - \sqrt{(L-2)(L-1)}}\right]^2 (\mathrm{MeV})^2 \qquad (9)$$

2.4. Potential energy surface

The calculation the potential energy surface is one of methods to knowledge the deformation of nuclear structure. The general formula for the potential energy surface as a function of geometrical variables β and γ is given by[1, 8]:-

$$E(N,\beta,\gamma) = \frac{N\varepsilon_d\beta^2}{(1+\beta^2)} + \frac{N(N+1)}{(1+\beta^2)^2}(\alpha_1\beta^4 + \alpha_2\beta^3\cos 3\gamma + \alpha_3\beta^2 + \alpha_4) \quad (10)$$

Where:

N is the total boson number, $\beta^2$is the quadrupole deformation parameter and γ : is a symmetry angle.

3. Results and discussion

The energy levels, reduced electric transition probabilities B(E2), relative B(E2) values, the square of rotational energy and the moment of inertia, the staggering in γ- band energies, and potential energy surface, for ^{184,186}Osisotopes have been studied and compared with the experimental data using IBM-1 code PHINT [18].

3.1. Energy levels

The ^{184,186}Osisotopes, with Z=76 and N=108, 110, have ratio R4/2 equals 3.21, 3.16, and the β-band above the γ- band which is incompatible with the SU(3) limit. So the equations 1, 2, and 3 are suitable usedto get better results and comparing with experimental data. The parameters of ^{184,186}Osisotopes are shown in Tables (1, 2 ,3). The calculated of the energy levels are shown in Fig. (1), can see when we added EPS and OCT terms better than without them, generally the calculations are in agreement compare with experimental data.

3.2. Reduced probability of electric quadrupole transition B(E2)

Electromagnetic properties were described by IBM-1[2, 8], to calculatedthe absolute B(E2) values of^{184,186}Osisotopesthe E2SD and E2DD were estimatedcorrespond to selection rules[2, 8], and it's shown in Table 4. The calculated and experimental values of absolute B(E2) values given in Table 4, shows the values of $BE(2;2_1^+ \rightarrow 0_1^+), BE(2;4_1^+ \rightarrow 2_1^+)$ decreases with increasing atomic mass number, from this Table can see the results are in agreement with experimental values.The relative B(E2) values of the^{184,186}Osisotopes were calculated, the intraband and interband transitions from $2_\gamma^+, 4_\gamma^+, 5_\gamma^+$, and 6_γ^+ states were compare the calculated values with experimental data [19], as see in Fig. (3, 4), shows the results are in agreement with experimental data[19].

3.3. Staggering in γ- band energies

Can observed the effect odd-even staggering in the γ-bands it is among the mostsensitive phenomena carrying information about the symmetry changes[15],as see in Fig.(5, 6 and 7), in Fig. (5)the^{184,186}Os isotopes S(J) not appear but in Fig.(6 and 7) the S(J) is weak because it's close to SU(3) limit. This results agreement with previous study in Ref.[14].

3.4. The square of rotational energy and the moment of inertia

Fig.(8, and 9) shows the square of rotational energy and the moment of inertia for^{184,186}Os isotopes. As see the ^{184}Osappears a gradual increase in moment of inertia between the lower angular momentum states, then change in behavior and then again extends gradually, this effect is known as back bending[2], that is occurs in some heavy nuclei because the rotational energy increases the energy required to break a pair of coupled nucleons. When this effect occurs, the unpaired nucleons go into different orbits and change the nuclear moment of inertia [16]. But in^{186}Osdose not appear any back bending, namely the properties for ^{186}Osisotope nochange.

3.5. Potential energy surface

The potential energy surface were calculated using equation (10) to determined the laste shap for^{184,186}Os isotopes. Fig. (10 and 11), shows the isotopes under study have prolate deformed deeper than oblate shape.where the β_{min} =1.4 for ^{184,186}Os isotopes as for SU(3) limit.

4. Conclusions

In this work, the IBM-1 modelwasapplied for ^{184,186}Osisotopes, this isotopes lie in transition region SU(3)-O(6)limits.The energy levels have been calculated in three different procedures.The results of added the OCT or EPS term to the eq. 2 are in agreement with experimental data and better than without them. B(E2)values, relative B(E2) values are in agreement with experimental data. The square of rotational energy and the momentof inertia were produced reasonably with experimental values, where the ^{184}Osisotope has the backbending. odd-even staggering in the γ-bands has been studied,the S(J) is weak because it's close to SU(3) limit.The final shape for ^{184,186}Osisotopes were found by calculatingpotential energy surfaces. They have prolate shape more than oblate.

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Table .1.Adopted values for the parametersused for IBM-1 calculations. All parameters are given in MeV except CHI. using eq. 2

Isotopes	N	EPS	PAIR	ELL	Q Q	OCT	HEXA	CHI
^{184}Os	12	0.0	0.0110	0.0312	-0.0238	0.0	0.0	-2.958
^{186}Os	11	0.0	0.300	0.0389	-0.0200	0.0	0.0	-2.898

Table .2. Adopted values for the parametersused for IBM-1 calculations. All parameters are given in MeV except CHI. using eq. 2+OCT term.

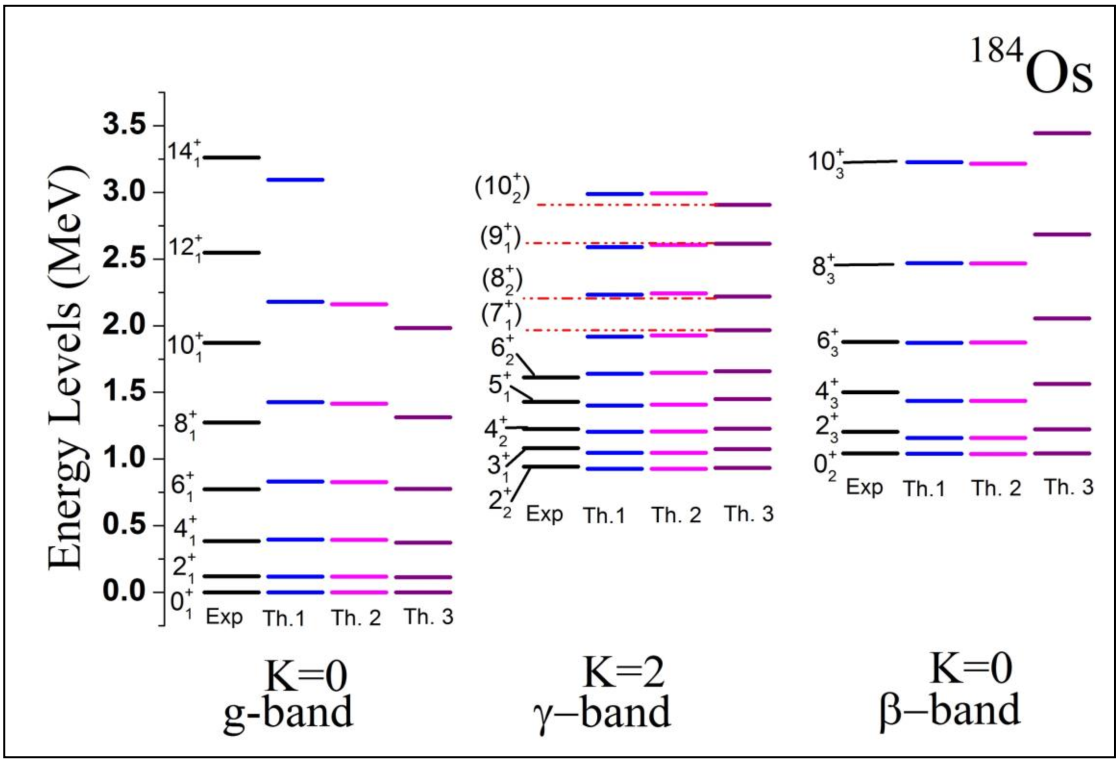
Isotopes	N	EPS	PAIR	ELL	Q Q	OCT	HEXA	CHI
^{184}Os	12	0.0	0.0139	0.0300	-0.0219	0.0020	0.0	-2.9580
^{186}Os	11	0.0	0.242	0.0328	-0.0178	0.0046	0.0	-2.7325

Table .3. Adopted values for the parametersused for IBM-1 calculations. All parameters are given in MeV except CHI. using eq. 2 + EPS term.

Isotopes	N	EPS	PAIR	ELL	Q Q	OCT	HEXA	CHI
^{184}Os	12	0.383	0.0223	0.0172	-0.0239	0.0	0.0	-2.7680
^{186}Os	11	0.383	0.300	0.0245	-0.0173	0.0	0.0	-2.7485

Table .4.The values of parameters (E2SD, E2DD in (e^2b^2)) of B(E2) for $^{184-186}Os$ isotopes.

Isotopes	E2SD	E2DD
^{184}Os	1	-1.088
^{186}Os	1	-0.686



igure . 1. (color online) The calculatedlow-lying energy levels(Th.1: using eq.2, Th. 2: using eq. 2+a_3 term, Th. 3: using eq. 2+ $\varepsilon\hat{n}_d$ term) and the experimental data of ^{184}Os, taken from Ref. [19].

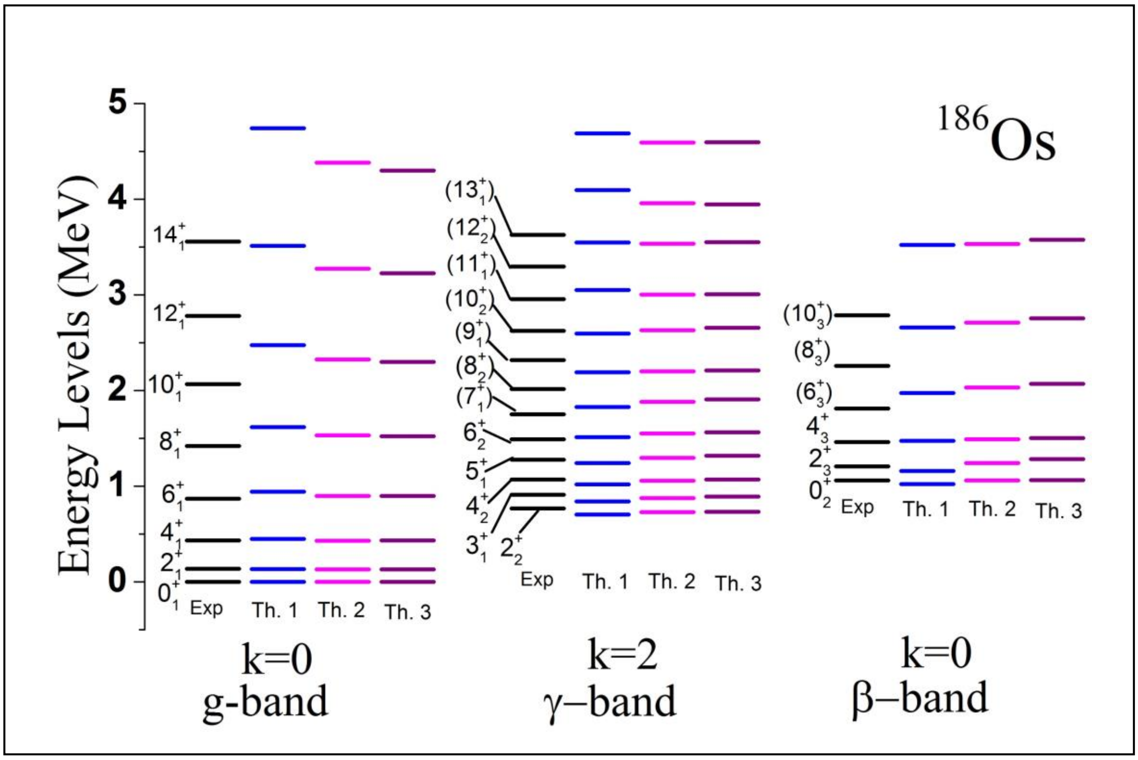


Figure . 2. (color online) The calculated low-lying energy levels (Th.1: using eq.2, Th. 2: using eq. 2+a_3 term, Th. 3: using eq. 2+ $\varepsilon\hat{n}_d$ term) and the experimental data of ^{186}Os, taken from Ref. [19].

Table .5.B(E2) values for ^{184,186}Osisotopes in (e^2b^2)

Isotopes	$J_i \rightarrow J_f$	EXP B(E2) [19]	Th. 1 B(E2)	Th. 2 B(E2)	Th. 3 B(E2)
^{184}Os	$2_1^+ \rightarrow 0_1^+$	0.610	0.610	0.610	0.610
	$4_1^+ \rightarrow 2_1^+$	0.870	0.850	0.870	0.870
	$6_1^+ \rightarrow 4_1^+$	-----	0.910	0.930	0.940
	$2_2^+ \rightarrow 0_1^+$	-----	0.011	0.013	0.023
	$2_2^+ \rightarrow 2_1^+$	-----	0.018	0.020	0.052
	$2_2^+ \rightarrow 4_1^+$	-----	0.001	0.001	0.002
	$3_1^+ \rightarrow 2_1^+$	-----	0.019	0.020	0.040
	$3_1^+ \rightarrow 4_1^+$	-----	0.008	0.010	0.025
	$4_2^+ \rightarrow 2_1^+$	-----	0.010	0.005	0.007
	$4_2^+ \rightarrow 4_1^+$	-----	0.021	0.020	0.050
	$4_2^+ \rightarrow 2_2^+$	-----	0.290	0.040	0.320
^{186}Os	$2_1^+ \rightarrow 0_1^+$	0.580	0.580	0.580	0.580
	$4_1^+ \rightarrow 2_1^+$	0.840	0.820	0.820	0.820
	$6_1^+ \rightarrow 4_1^+$	1.160	0.860	0.880	0.880
	$2_2^+ \rightarrow 0_1^+$	0.063	0.024	0.028	0.031
	$2_2^+ \rightarrow 2_1^+$	0.140	0.035	0.057	0.073
	$2_2^+ \rightarrow 4_1^+$	0.0075	0.002	0.005	0.006
	$3_1^+ \rightarrow 2_1^+$	-----	0.040	0.050	0.057
	$3_1^+ \rightarrow 4_1^+$	-----	0.020	0.038	0.049
	$4_2^+ \rightarrow 2_1^+$	0.020	0.010	0.010	0.010
	$4_2^+ \rightarrow 4_1^+$	0.155	0.040	0.064	0.080
	$4_2^+ \rightarrow 2_2^+$	0.450	0.279	0.298	0.320
	$4_2^+ \rightarrow 3_1^+$	-----	0.610	0.587	0.556

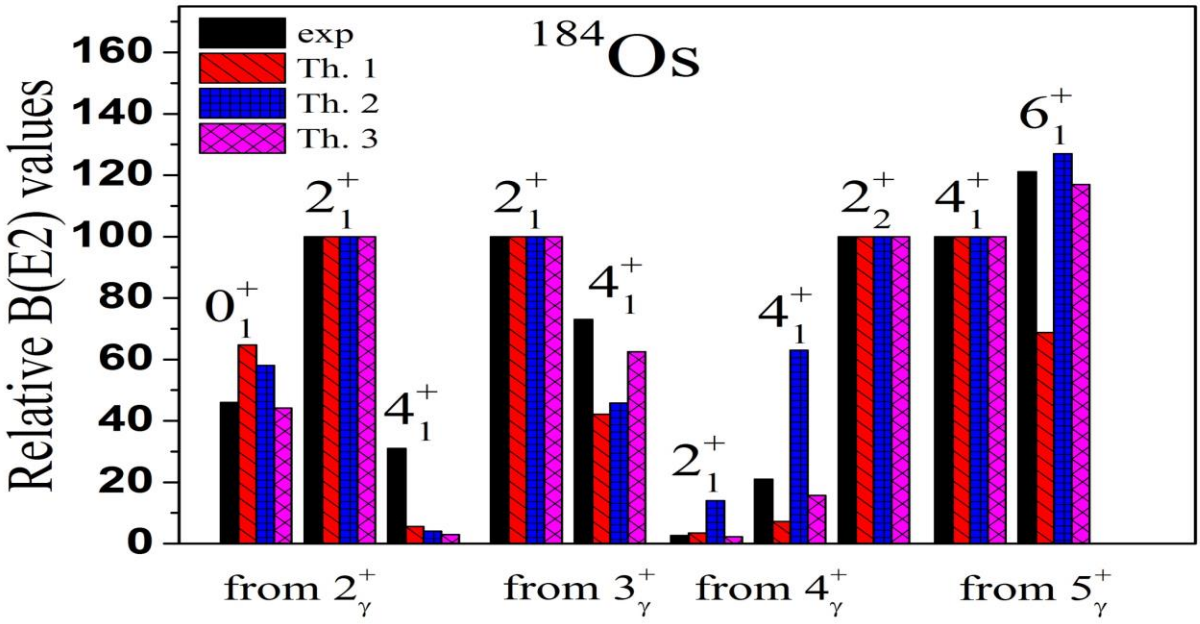


Figure.3. (color online) Calculated (Th.1 is using eq.2, Th. 2 is using eq. 2+a_3 term, Th. 3 is using eq. 2+ $\varepsilon\hat{n}_d$ term) and experimental values of relative B(E2) for^{184}Os, experimental values taken from Ref. [19].

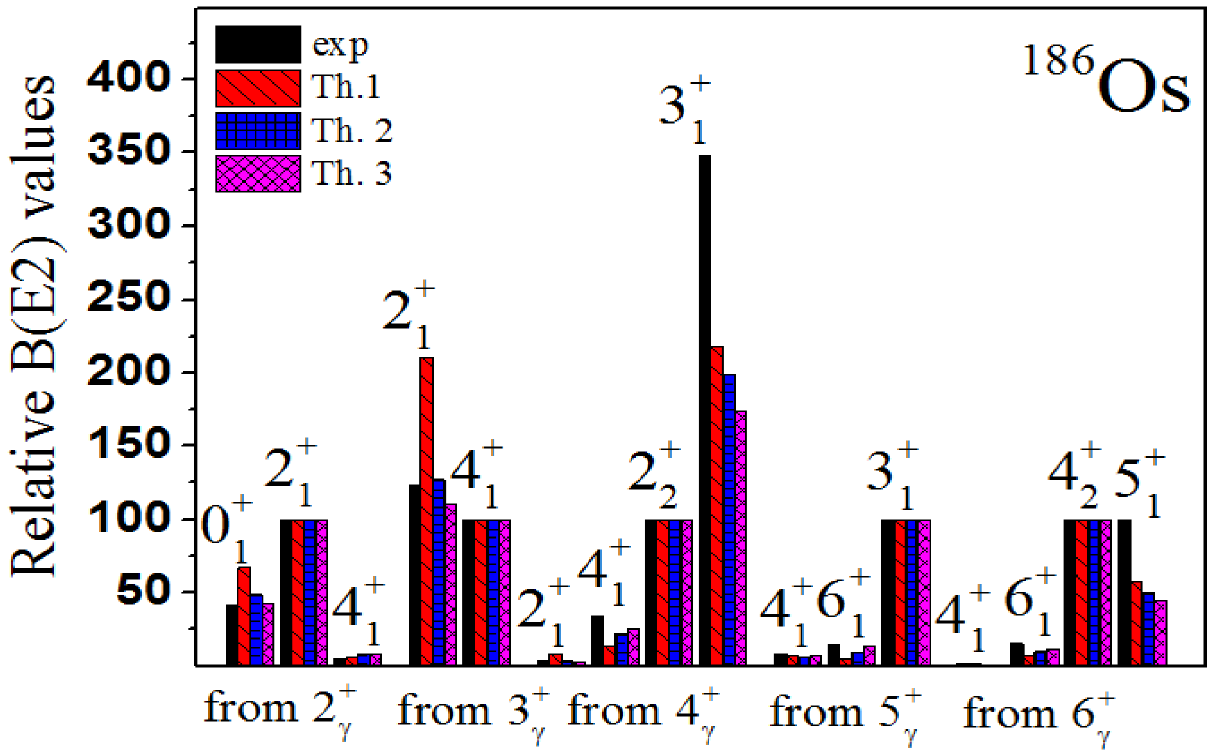


Figure.4. (color online) Calculated (Th.1:using eq.2. Th. 2: using eq. 2+a_3 term. Th. 3: using eq. 2+ $\varepsilon\hat{n}_d$ term) and experimental values of relative B(E2) for ^{186}Os, experimental values taken from

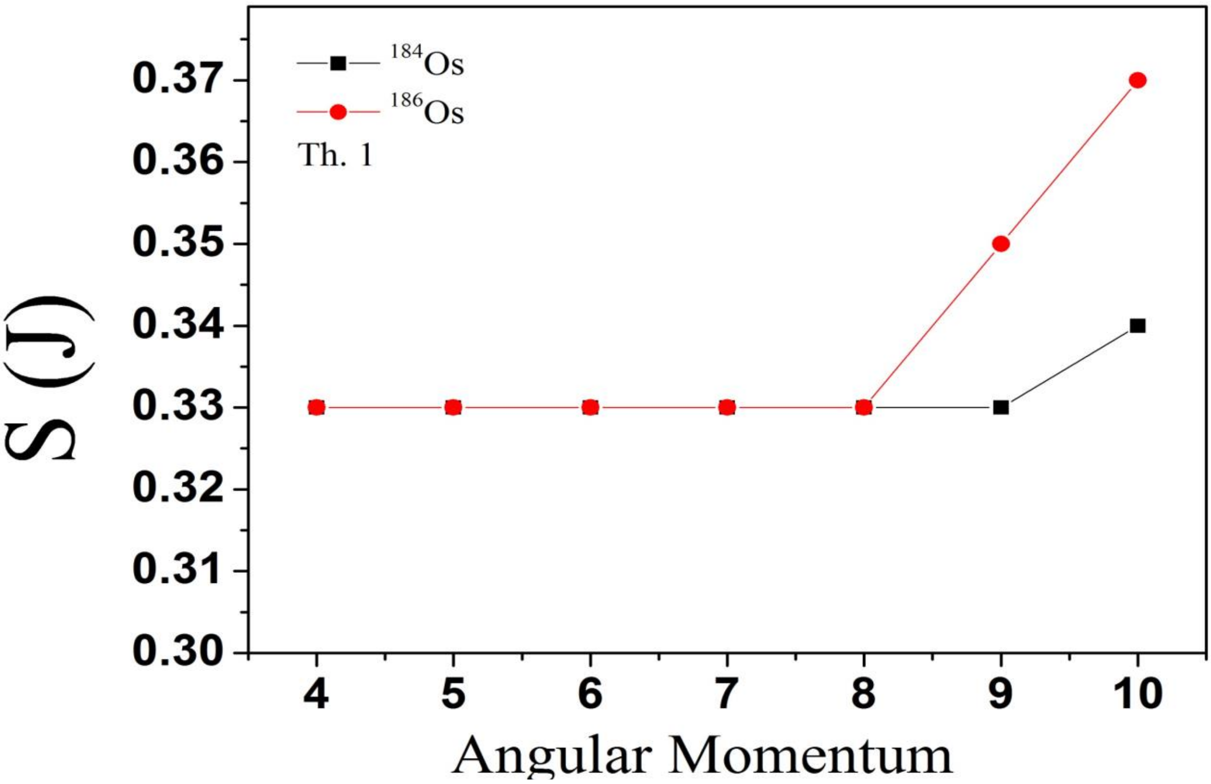


Figure. 5. Staggering S(J) in γ- band calculations for $^{184-186}$Os isotopes, using eq. 2

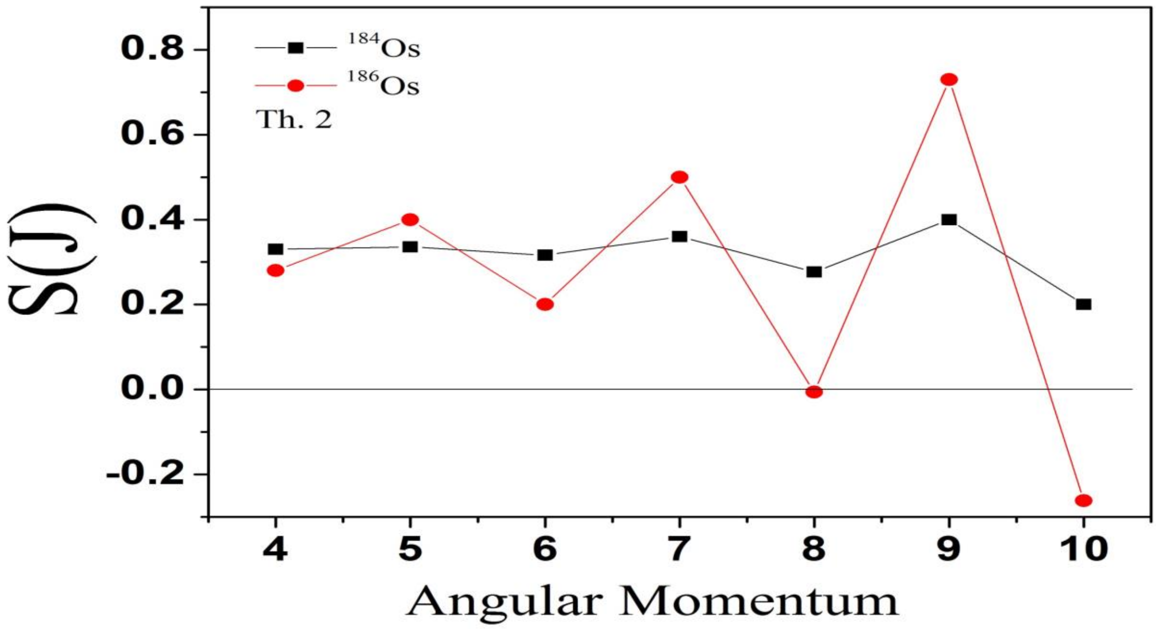


Figure. 6. Staggering S(J) in γ- band calculations for $^{184-186}$Os isotopes, using eq. 2 + OCT term.

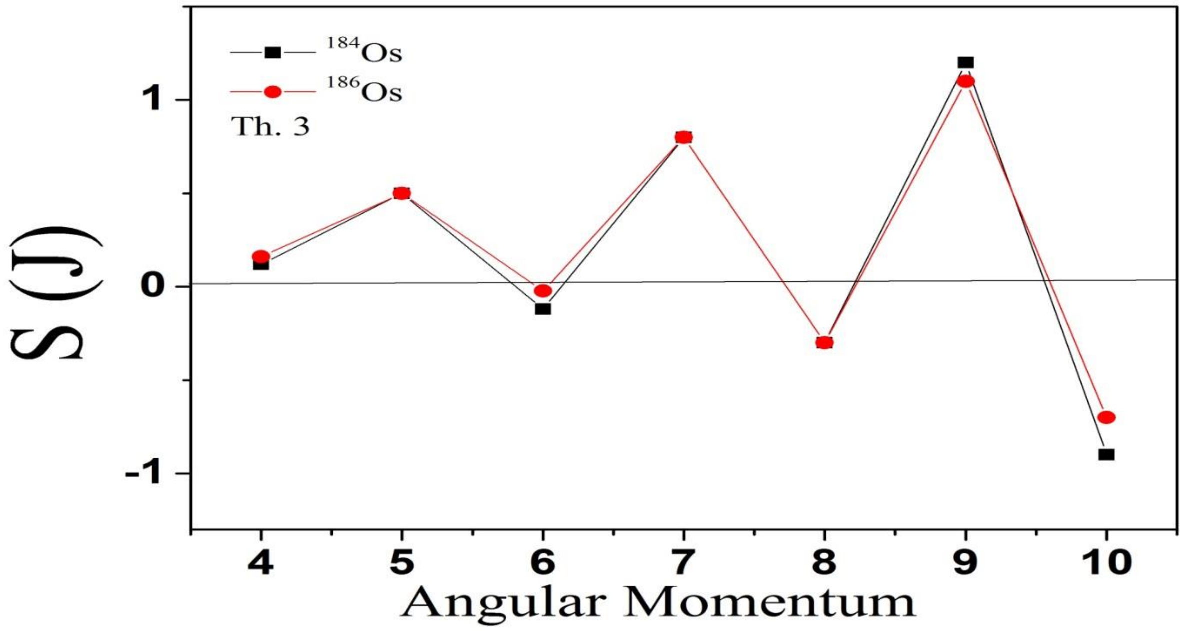


Figure. 7. Staggering S(J) in γ- band calculations for $^{184-186}$Os isotopes, using eq. 2 +EPS term.

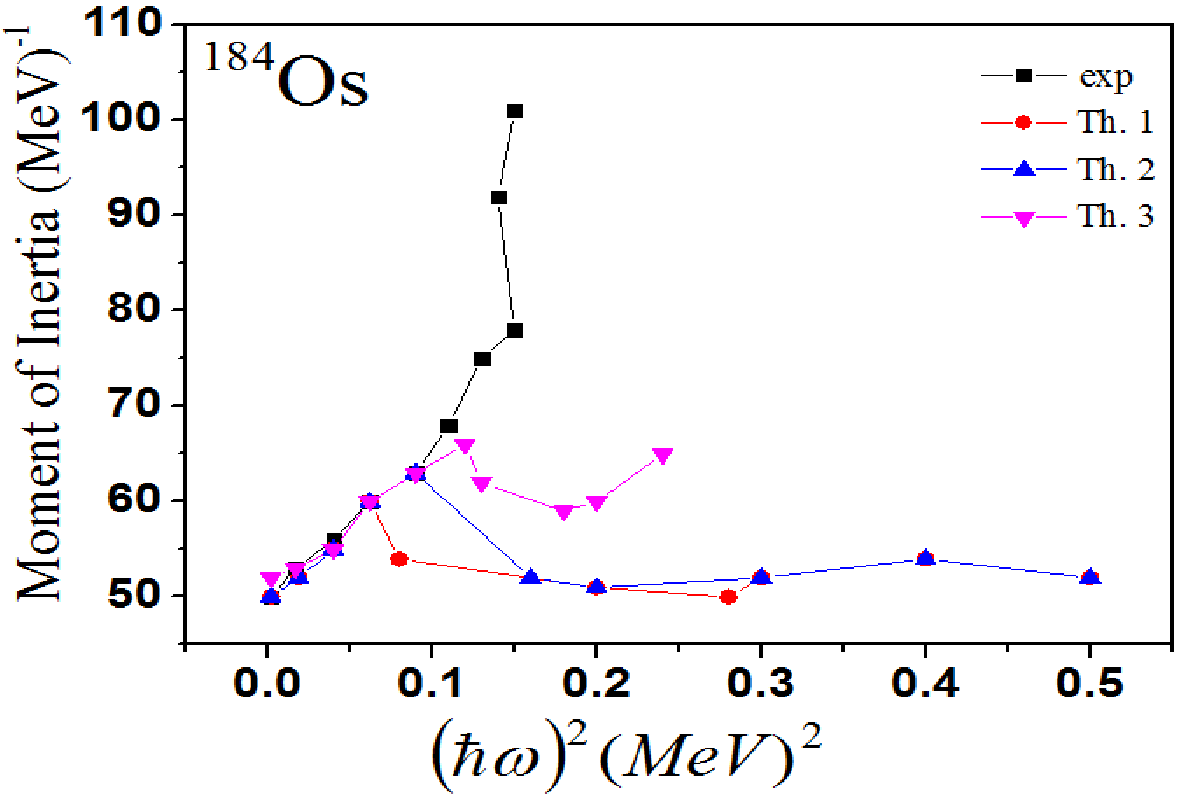


Figure.8. (color online)The calculated moment of inertia $\frac{2\vartheta}{\hbar^2}$ versus the square of rotational energy $(\hbar\omega)^2$ (Th.1: using eq.2, Th. 2: using eq. 2+a_3 term, Th. 3: using eq. 2+ $\varepsilon\hat{n}_d$ term)for ^{184}Os isotope, the experimental data taken from Ref.[19].

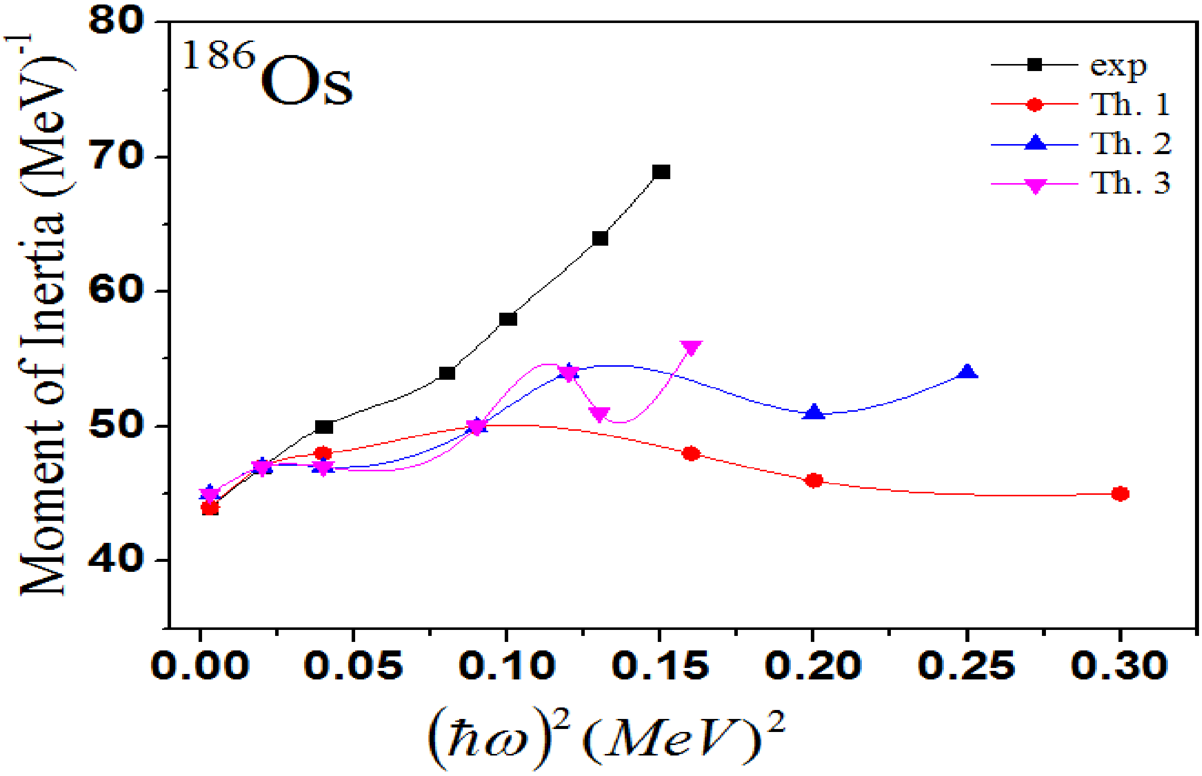


Figure. 9. (color online)The calculated moment of inertia $\frac{2\vartheta}{\hbar^2}$ versus the square of rotational energy $(\hbar\omega)^2$ (Th.1: using eq.2, Th. 2: using eq. 2+a_3 term, Th. 3: using eq. 2+ $\varepsilon\hat{n}_d$ term)for ^{186}Os isotope, the experimental data taken from Ref.[19].

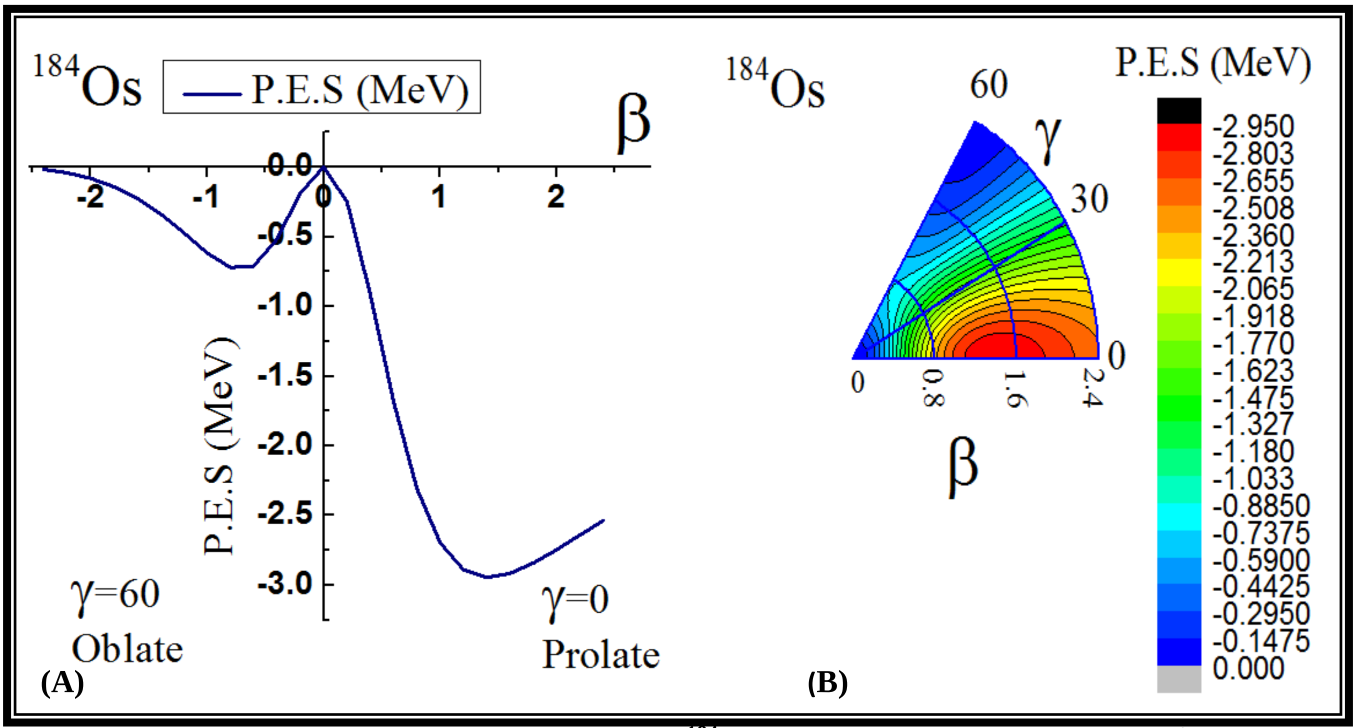


Figure. 10. (A) The potential energy surface for **^{184}Os** as a function of β at γ=0 and 60°. **(B)** The potential energy surface in β-γ plane for **^{184}Os** Nucleus.

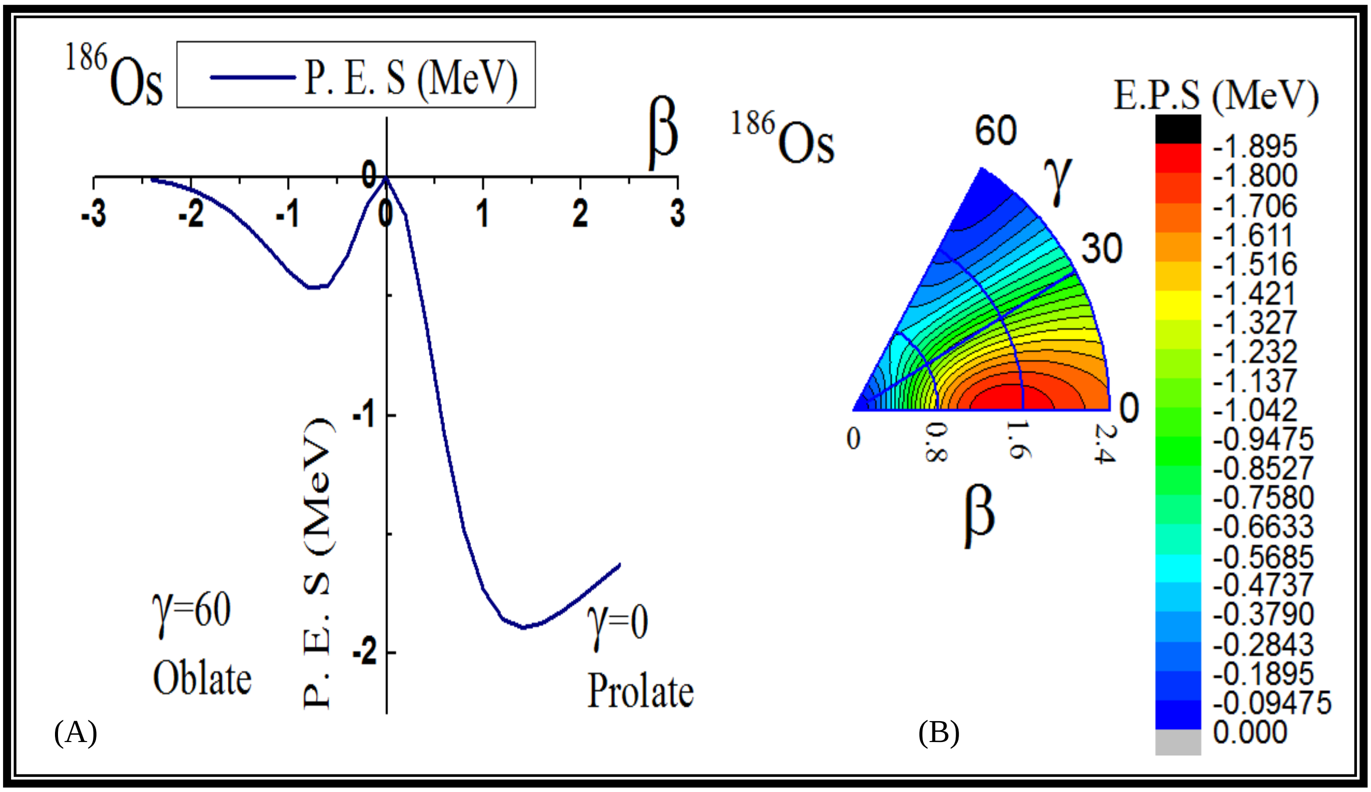


Figure. 11. : (A) The potential energy surface for **^{186}Os** as a function of β at γ=0 and 60°. **(B)** The potential energy surface in β-γ plane for **^{186}Os** Nucleus.