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Theoretical study for some nuclear structure properties of even-even (^{170}Yb،^{228}Th) rotational nuclei using IBM-l,VMI models.

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ABSTRACT

The aim of the present work ، is to study some nuclear structure of even-even (^{170}Yb،^{228}Th) nuclei using IBM-I and VMI models such as ، energy states ، and their transition ، probability of electric transition ، electric quadrupole moments ، and the band intersection . The results obtained and the values of parameters used in this calculations indicated that these nuclei have a rotational SU(3) behaviour . It was found that the calculated positive parity of the low -lying energy levels spectra of these nuclei agree well with the experimental data. In actual study many of energy levels were ensure like(1.2253 , 1.7805 , 2.6038 and 2.8268) MeV have spin and parity $(3_1)^+$, $(7_1)^+$, $(11_1)^+$ and $(12_3)^+$ respectively which were not exactly determined experimentally for ^{170}Yb and we determined the experimentally energy level (1.0164) MeV has spin and parity (4_2^+) which were not exactly determined experimentally for ^{228}Th.

1-Introduction :

The interacting boson model (IBM) was created , firstly , in 1974 by , Arima and Iachello [1] . and it was developed after that by Arima and Iachello 1979 [2]. which is based on the well - known shell model and on geometrical collective model of the atomic nucleus and mainly rooted in the shell model [3] .The simplest version of the (IBM), called IBM-1 succeded to describe the even- even nucleus as an Inert core combined with bosons which represent pairs of identical nucleons . This model assumed that the low-lying collective states of nuclei away from closed shells are dominated by excitation of the valance protons or neutrons (particles outside major closed shell) while the closed shell core is inert[4,5]. In the work Levon et al (2009)[6] studied the excited state of deformed nucleus ^{230}Th using IBM and QPM for reaction (P,t).

They found that the experimental data are compared with spdf-IBM and QPM calculations giving an approximately correct number of o^+ states, these models provide different predictions for the structure of these states.

Variable moment of inertia (VMI) model was first proposed by Mariscotti et al to predict different level energies of ground state bands in even – even nuclei [7].

Wu et al (1979) [8] studied the rotational states in the normal ^{168}Yb nucleus by combining Hartree - Fock - Bogoliuboov theory and VMI model . They found no back bending in this nucleus .

2- Theoretical part :

The nuclei of the present work ,belong to SU(3) dynamical symmetry which can be represented by the form[2,9]

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$$U(6) \supset SU(3) \supset O(3) \supset O(2) \text{ .....(1)}$$

The general Hamiltonian form of IBM-1 is used[3] :

$$\hat{H} = \varepsilon \hat{n}_d + a_o(\hat{P}^{\dagger}.\hat{P}) + a_1(\hat{L}.^{\dagger}\hat{L}) + a_2(\hat{Q}^{\dagger}.\hat{Q}) + a_3(\hat{T}_3{}^{\dagger}.\hat{T}_3) + a_4(\hat{T}_4{}^{\dagger}.\hat{T}_4) \text{.....(2)}$$

where Ɛ is the boson energy .the parameters (a_0 , a_1 , a_2 , a_3 , a_4) designate the strengths of the , pairing , angular momentum , quadrupole , octupole , and hexadecapole , interaction between neutron or proton bosons respectively, and

$$\left.\begin{aligned} &\hat{n}_d = (\hat{d}^{\dagger}.\tilde{\hat{d}}) \\ &\hat{P} = 1/2[(\tilde{\hat{d}}^{\dagger}.\tilde{\hat{d}}) - 1/2(\tilde{\hat{s}}^{\dagger}.\tilde{\hat{s}})] \\ &\hat{L} = \sqrt{10}[\hat{d}^{\dagger} \times \tilde{\hat{d}}]^{(\ell)} \\ &\hat{Q} = [(\hat{d}^{\dagger} \times \tilde{\hat{s}}) + (\tilde{\hat{s}}^{\dagger} \times \tilde{\hat{d}})] - \frac{\sqrt{7}}{2}[\hat{d}^{\dagger} \times \tilde{\hat{d}}]^{(2)} \\ &\hat{T}_3 = [\hat{d}^{\dagger} \times \tilde{\hat{d}}]^{(3)} \text{ and } \hat{T}_4 = [\hat{d}^{\dagger} \times \tilde{\hat{d}}]^{(4)} \end{aligned}\right\} \text{....(3)}$$

The ($\hat{s}$, $\hat{d}$) and ($\hat{s}^{\dagger}$, $\hat{d}^{\dagger}$) are the creation and anninilatior operators of s and d bosons .

The dynamical symmetry SU(3) occurs wherever the quadrupole- quadrupole interacting between bosons are dominating , Ɛ = a_0 = a_3 = a_4 = 0 , the reduced Hamiltonian in eq . (2) of this chain can be written as [2,10]. $\hat{H}_{II} = a_1(\hat{L}^{\dagger} \times \hat{L}) + a_2(\hat{Q}^{\dagger} \times \hat{Q})$...(4) The electric quadrupole transition operator of B(E2) in the IBM-1 of this chain has the form [11]

$$\hat{T}(E2) = \alpha_2 Q \text{.....(5)}$$

while the VMI energy levels can be calculated from the form [12] : $E(L) = \frac{1}{2}[\frac{\ell(\ell+1)}{\vartheta(L)} + C(\vartheta(L) - \vartheta_0)^2]$.....(6)

the rotational energy squared $(\hbar\omega)^2$ as a function of angular momentum (L)for g-band can be calculated from the form [13] :

$$(\hbar\omega)^2 = [\frac{E(L \to L-2)}{\sqrt{L(L+1)} - \sqrt{(L-2)(L-1)}}]^2 \text{.....(7)}$$

and for ϫ-band as :

$$(\hbar\omega)^2 = [\frac{E(L \to L-1)}{\sqrt{L(L+1)} - \sqrt{L(L-1)}}]^2 \text{...(8)}$$

3- The calculations and discussion:

The energy levels of ^{170}Yb ,and ^{228}Th nuclei are calculated from the parameters in table (1) by fit them with the experimental values and exhibit in figures (1 and 2).

These figures show that the IBM-1 calculated results are agree well with experimental data at low-laying states , but small large in high excited state because in the first version of IBM , no distinction is made between neutron and proton degress of freedom.

In this work , we determined the experimentally energy levels (1.2253 ,1.7805 , 2.6038 and 2.8268) MeV have spin and parity $(3_1)^+$, $(7_1)^+$, $(11_1)^+$ and $(12_3)^+$ respectively which were not exactly determined experimentally for ^{170}Yb [14,15].

We found the new theoretical energy levels (1.8028, 2.1885, 2.6410, 3.1709 and 4.4396) MeV for ^{228}Th nucleus have spin and parity(10_2^+, 12_2^+, 14_2^+, 16^+_2 and 18_2^+) respectively for β_1 - band which never determined experimentally, energy levels (1.8933 , 2.1961 , 2.5945 , 3.1132 ,3.2409 and 3.9810)MeV, which have spin and parity (6_3^+ , 8_3^+ , 10_3^+, 12_3^+, 14_3^+ and 16_3^+) respectively for β_2 - band which never determined experimentally , also the theoretical energy levels (2.0072 , 2.1212 , and 2.2957) MeV which have spin and parity (5_1^+ , 6_4^+ and 7_1^+) respectively for ϫ$_1$ - band , which never determined experimentally , and we determined the experimentally energy level (1.0164) MeV has spin and parity (4_2^+)

which were not exactly determined experimentally [14,16].

figures. (3 , 4) show the comparison between experimental data [14,15,16] and VMI , IBM-1 calculations for these nuclei , it is found that the VMI calculations are very agreement with experimentally values than IBM-1 calculations in some bands.

In the present work , we calculated the electric transition probability B(E2) as in figure (5) compared with experimental data . This figure shows the theoretical results to be in a very good agreement with experimental data, also we found that B(E2) increase rapidly with the increase angular momentum and has max .value at L=8_1^+ for g-band and decreases after that. The theoretical values of electric quadrupole moments Q_L as a function of angular moments L_{2_1} to $L_{2_{10}}$are shown in fig. (6).This figures shows that the ^{170}Yb nucleus has a "Prolate shape" deformation at states (2_1^+ , 2_2^+ , 2_4^+ , 2_6^+ , 2_7^+ and 2_{10}^+)but has an " oblate shape" deformation at states (2_3^+ , 2_5^+ , 2_8^+ and 2_9^+) while the ^{228}Th nucleus has an" oblate shape" at states (2_1^+ , 2_3^+ , 2_4^+ , 2_6^+ , 2_8^+ and 2_{10}^+) but has a "Prolate shape" at states (2_2^+ , 2_5^+ , 2_7^+ and 2_9^+)

In order to study the energy band intersection we will draw the energy levels E(L) as a function of angular momentum (L) for all bands as in figure (7) . This figure shows that the band (g , β_1) for ^{170}Yb intersection at Lc=22^+ but the bands β_1 , β_2 , γ_1, γ_2 not intersection, while the bands (g , β_1) and (β_2 , γ_1) for ^{228}Th nucleus intersection at Lc= 16^+ and 4^+ respectively

This study shows that there is no effect to the moment of inertia on nuclear structure on the nuclei understudy, because the back bending is not occur.

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Table (1): The parameters values of Hamiltonian operator

parameters / Nuclei	N_π	N_ν	N	ε (MeV)	$\hat{P}.\hat{P}$ (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)
$^{170}_{70}Yb_{100}$	6	9	15	0.0001	-0.0211	0.0020	0.1100	0.0650	0.0030	0.1600
$^{228}_{90}Th_{138}$	4	6	10	0.0000	0.0000	0.0061	-0.0090	0.0500	0.0710	-3.6500

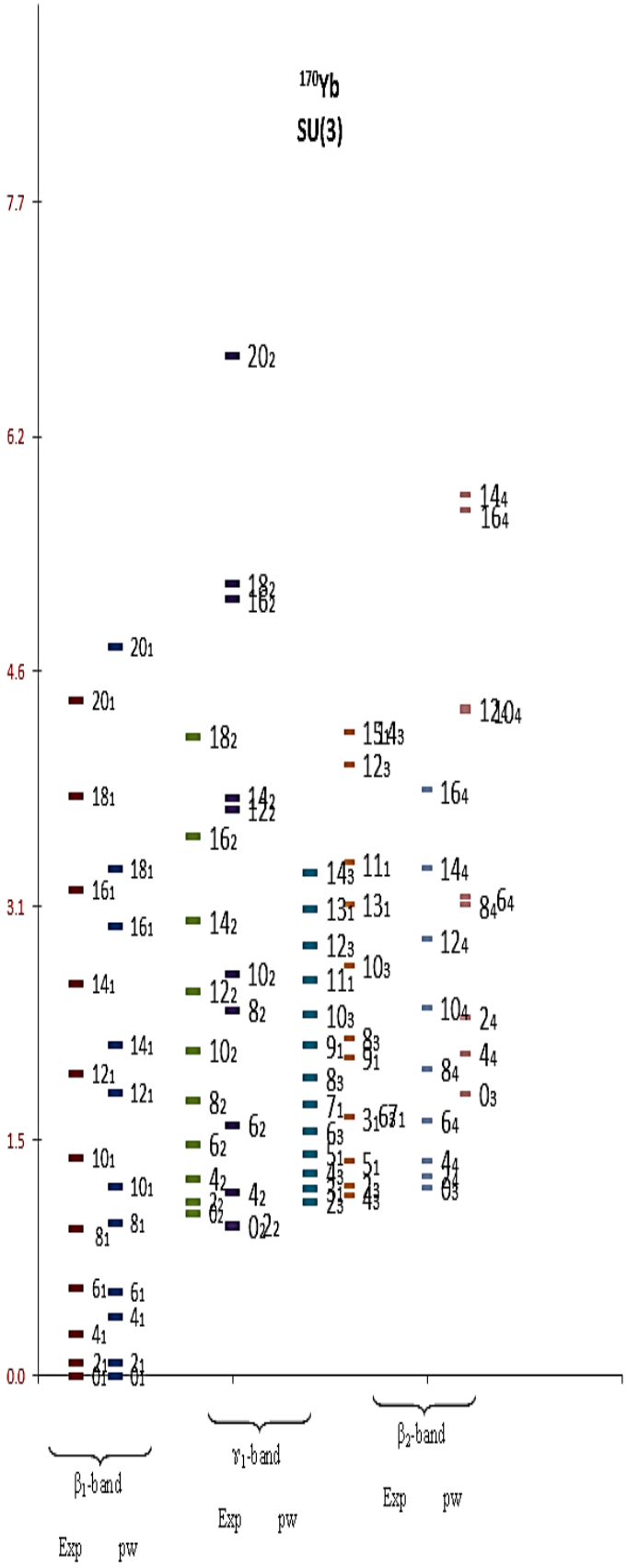
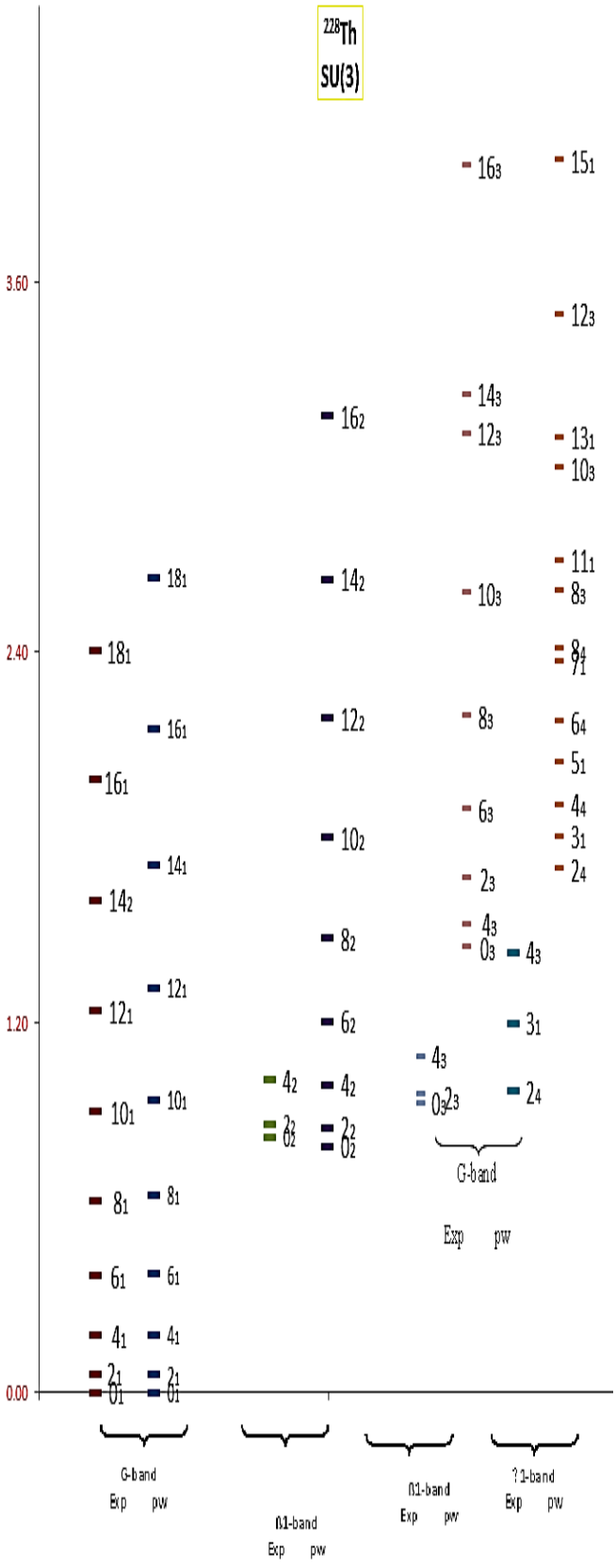
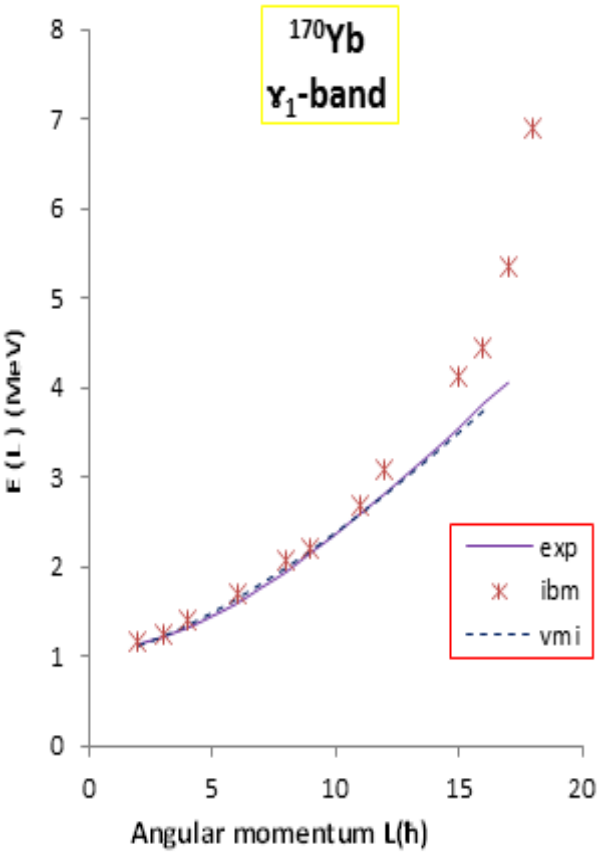


fig.(1) companions between theoretical and experimental values of energy levels for ^{170}Yb nucleus [14,15]





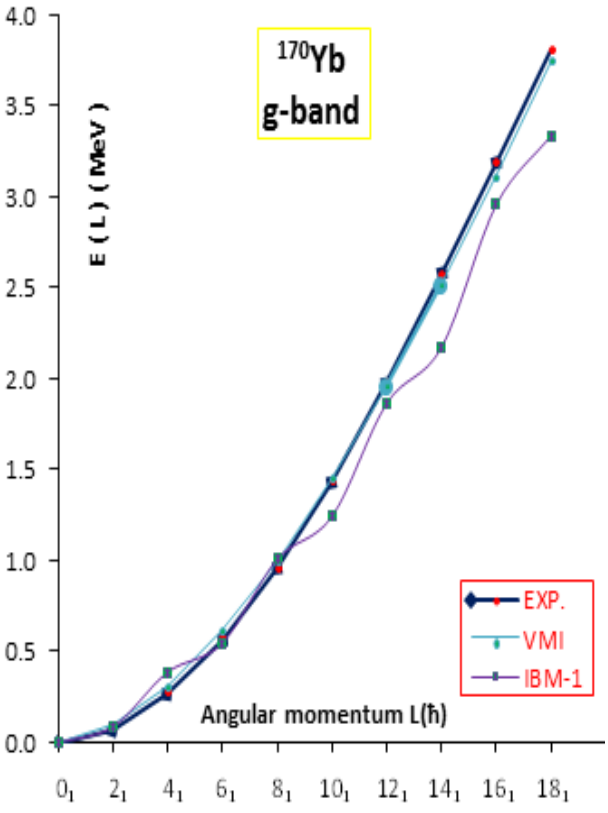


fig.(2) companions between theoretical and experimental values of energy levels for ^{228}Th nucleus [14,16]

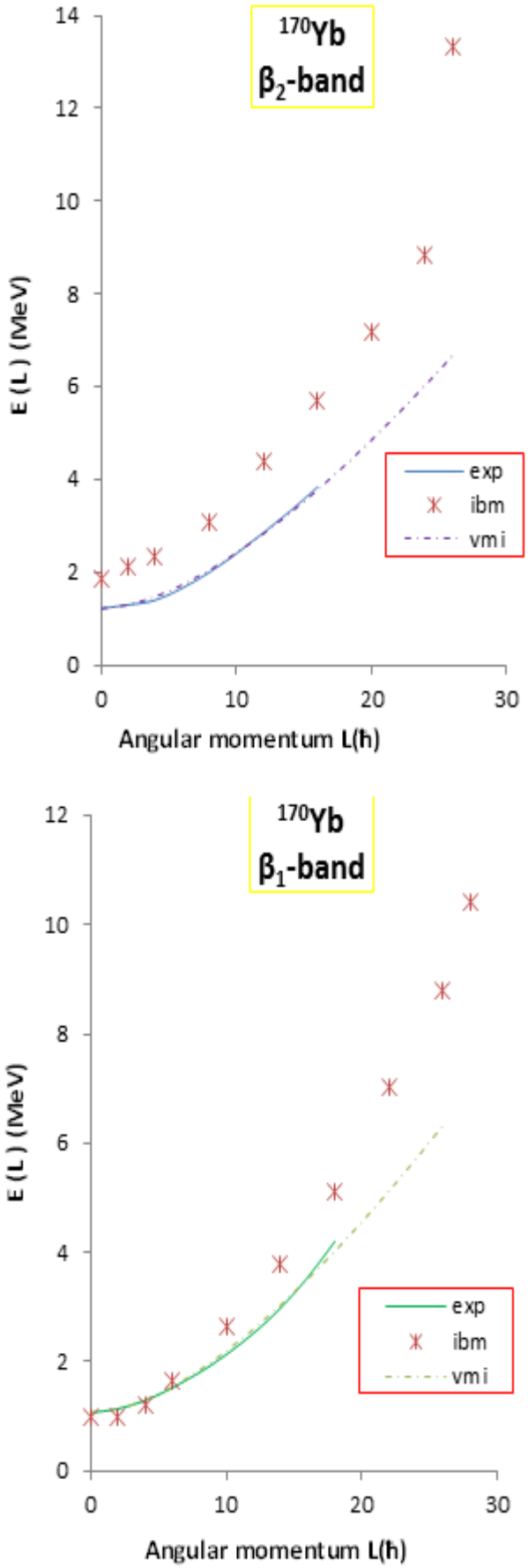


fig.(3) The comparison between the theoretical IBM-1,VMI model and experimental energy levels of ^{170}Yb nucleus

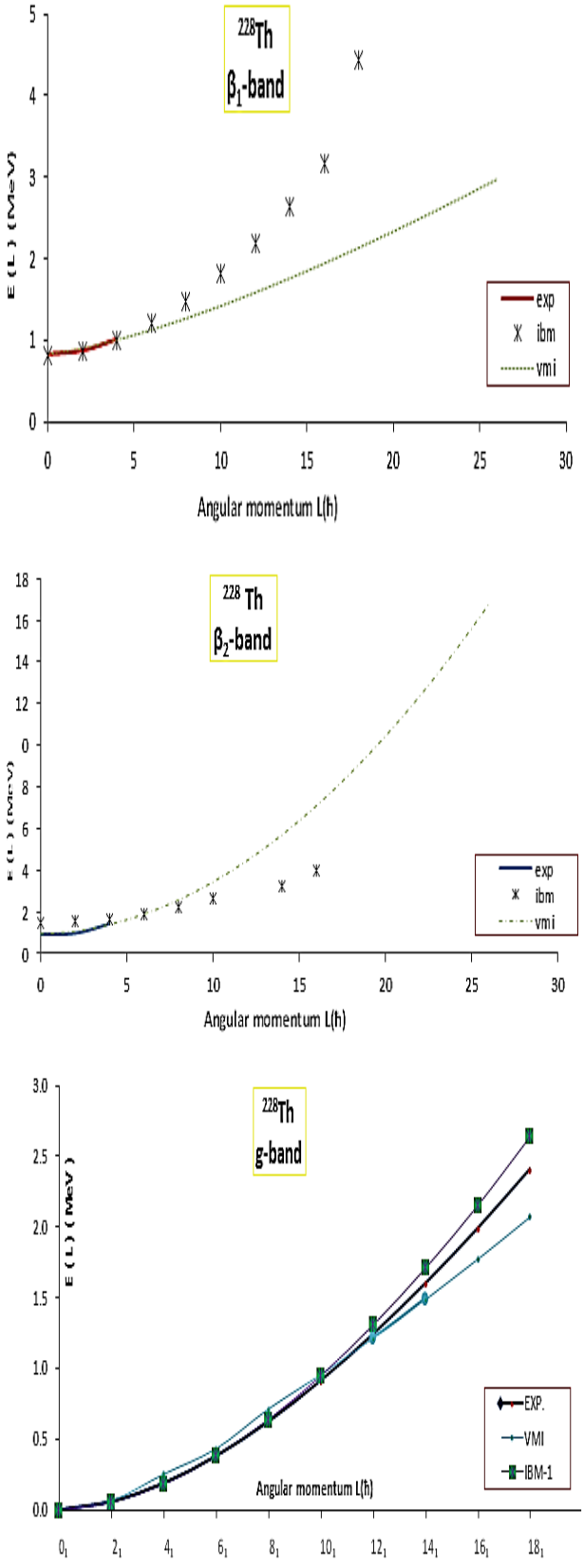


fig.(4) The comparison between the theoretical IBM-1,VMI model and experimental energy levels of ^{170}Yb nucleus

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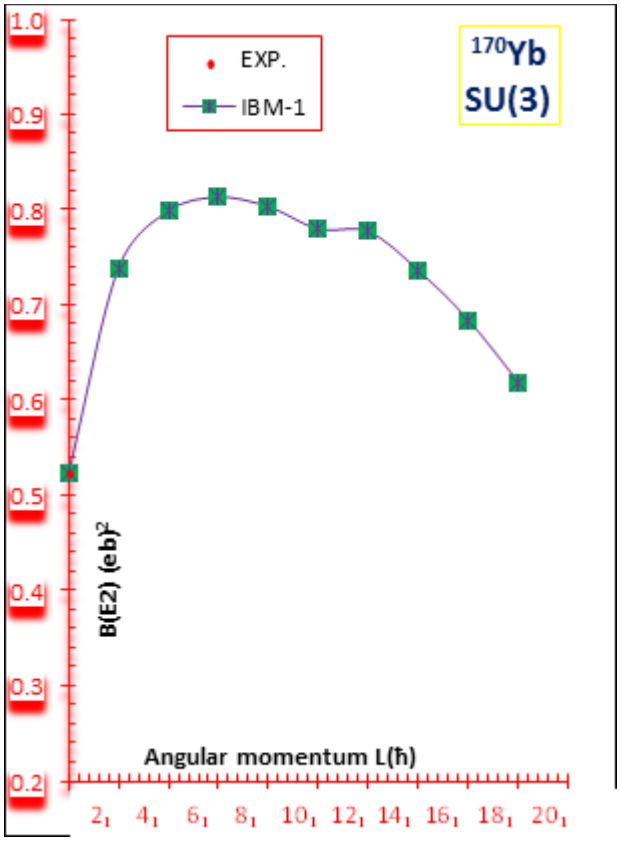


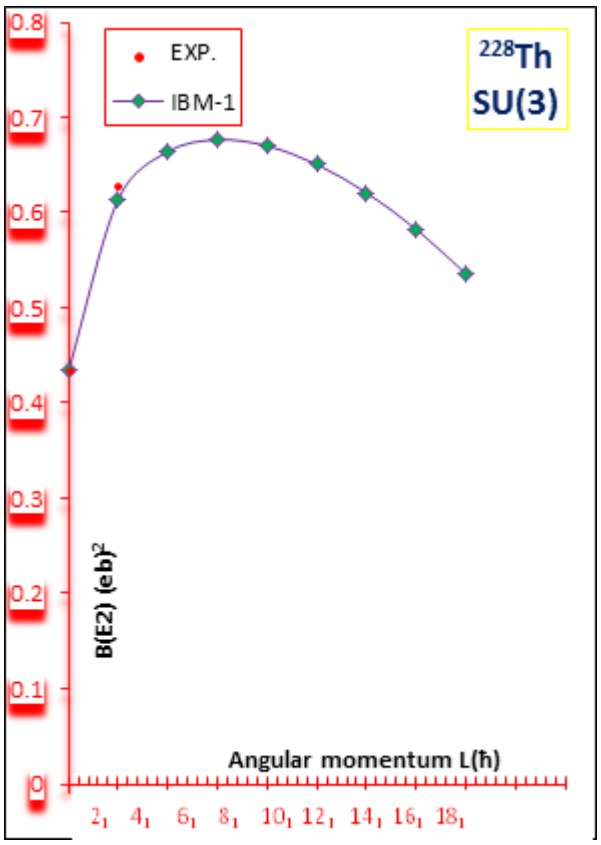
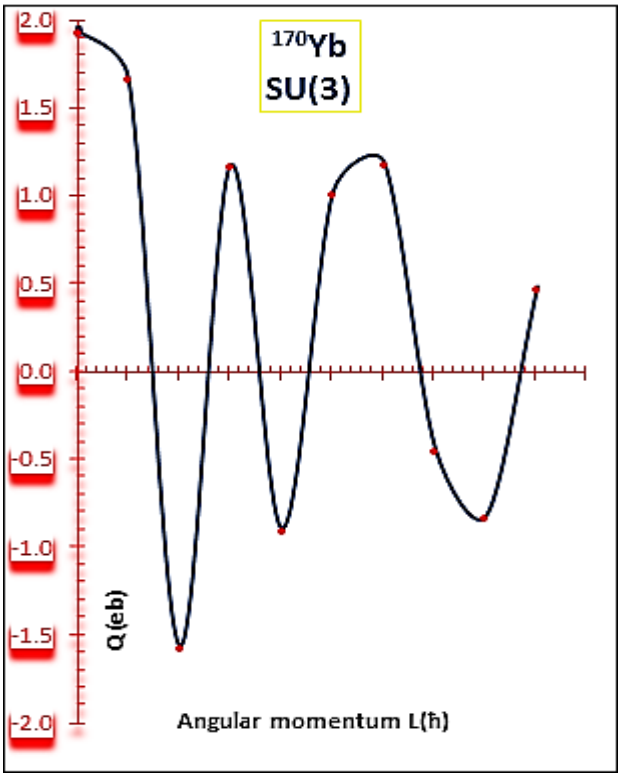


Fig. (5) :Electric transition probability B(E2) as a function of angular momentum(L)for g-band



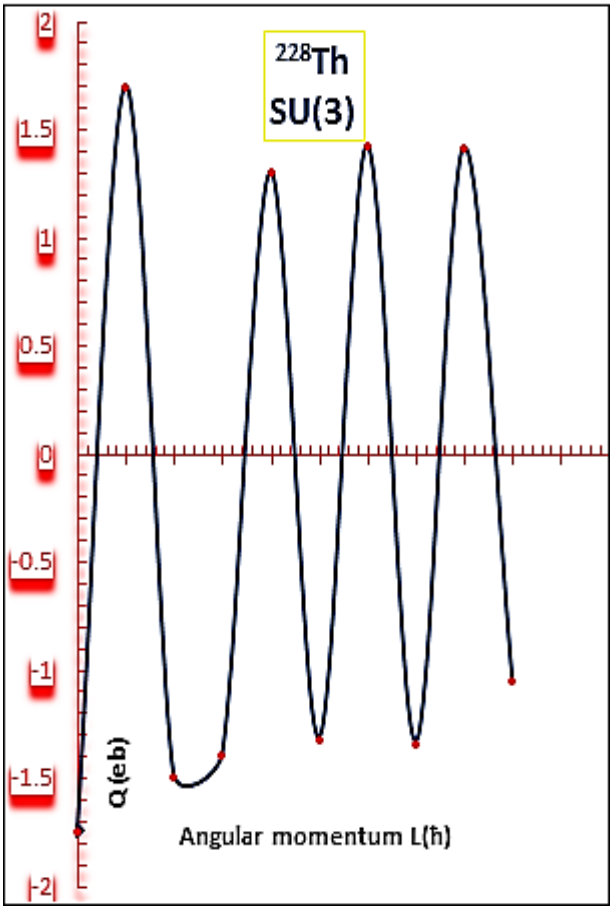


Fig. (6): The electric quadrupole moment as a function of angular momentum

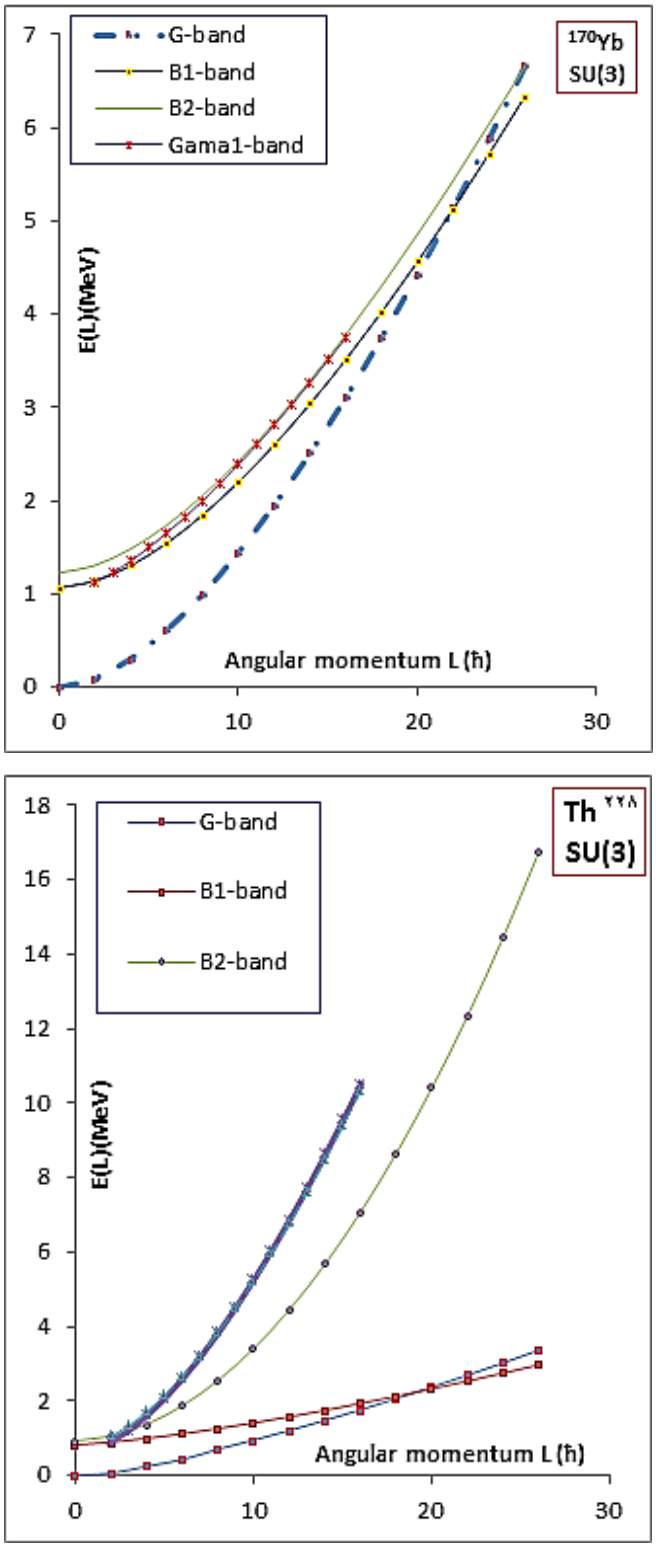


Fig.(7) :The energy band crossing E(L) as a function of angular momentum L using VMI model

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دراسة نظرية لبعض خواص التركيب النووي للانوية الدورانية (^{228}Th,^{170}Yb) الزوجية – الزوجية بأستعمال نموذج IBM-1 و VMI

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الخلاصة:

في البحث الحالي تمت دراسة بعض خواص التركيب النووي للنوى (^{170}Yb، ^{228}Th) الزوجية – الزوجية باستخدام نموذج البوزونات المتفاعلة الاول ونموذج عزم القصور الذاتي المتغير مثل مستويات الطاقة والطاقة الانتقالية واحتمالية الانتقالات الكهربائية رباعية القطب وعزوم رباعية القطب وتقاطع الحزم . اظهرت النتائج توافقا جيدا مع القيم العملية الحديثة وأظهرت قيم المعاملات المستخدمة في هذه الحسابات ان هذه النوى تمتلك صفات دورانية.وفي هذه الدراسة تم تاكيد عدد من مستويات الطاقة لم تكن مؤكدة عمليا مثل المستويات (1.2253، 1.7805، 2.6038، 2.8268) بوحدات MeV بزخم زاوي وتماثل $(3_1)^+$ و $(7_1)^+$ و $(11_1)^+$ و $(12_3)^+$ على الترتيب لنواة يتربيوم ^{170}YB ومستوي الطاقة (1.0164)MeV بزخم زاوي وتماثل (4_2^+) لنواة الثوريوم ^{228}Th.