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Protons effect of the isobars nuclei (Te^{126}, Xe^{126}, $Ba^{126}$and Ce^{126})

تأثير البروتونات على النوى الايزوبارية (Te^{126}, Xe^{126}, Ba^{126}, Ce^{126})

Heiyam Najy Hady Damin
Department of physics
Education college
Kufa University

Muhsen Cadem motleb
Department of physics
Science college
Babylon University

Abstract:

The protons effect on the nuclear structure of Isobars nuclei (Te^{126}, Xe^{126}, Ba^{126} and Ce^{126}) have been studied using the Interacting boson model-1.The present results have been appeared that the nuclei undergo from the vibration limit U(5) to O(6)- like nuclei toward the SU(3) limit with increase the proton number from (52) inTe^{126} nucleus to (58) in Ce^{126} nucleus. The calculated energy spectra and the properties of electric transition ratios are in reasonable agreement with experimental data.

الخلاصة:

تمت دراسة تأثير البروتونات على التركيب النووي للنوى المتكاتلات (Te^{126}, Xe^{126}, Ba^{126}, Ce^{126}) باستخدام نموذج البوزونات المتفاعلة-١. أظهرت النتائج الحالية انتقال النوى من التحديد الاهتزازي SU(5) إلى التحديد O(6) متجهة إلى نوى التحديد ألدوراني SU(3) بزيادة عدد البروتونات من (52) في نواة Te^{126} إلى (58) في نواة Ce^{126}.ان حساب طيف الطاقة وخصائص نسب الانتقالات الكهربائية متوافقة بشكل مقبول مع القيم العملية.

Introduction:

Many models have been developed to describe the collective properties of nuclei most of them, howevers, are applicable only to a limited part of a major shell. one of the strengths of the interacting boson model (IBM) of arima and iachello(1), is its ability to characterize isotopic chains extending across large sections of major shell with the same Hamiltonian(2,3). In the present work the even isobars (Te^{126}, Xe^{126}, $Ba^{126}$and Ce^{126}) are systematically studied using the IBM-1model. Many calculation have done one versions subset of the (Te^{126}, Xe^{126}, $Ba^{126}$and Ce^{126}) isotopes, based on a number of different theories, among the models used to describe the isotopic chains, are particle vibration coupling(4-6), pairing plus quadruple(7), boson expansion(8), traxial or asymmetric rotor(9,10). In order to investigate the effect of protons number on behavior and characteristics of nuclei, (Te^{126}, Xe^{126}, Ba^{126} and Ce^{126}) nuclei have been studied.

IBM:

One of the important concepts in nuclear structure is that of symmetries and one of the interesting aspects of the interacting boson approximation(IBM) model is that its inherent group structure leads to the appearance of three dynamical symmetries or limiting coupling schemes evolving from the parant group U(6)(1-3). these symmetries are usually labeled by their group notation, that SU(5)(11), SU(3)(12) and O(6)(13), the U(5) limit represents anharmonic vibrator; SU(3) is special case of deformed symmetric rotor and the O(6) limit is an axially asymmetric,γ–unstable(γ–independent)rotor. When the IBM was first proposed , it was thought that many examples of the U(5) and SU(3) symmetries were well known, and soon thereafter the O(6) limit was also discovered.(13)

In conclusion, there are three and only three possible chains.

$$\begin{tikzcd}
 & U(5) \supset O(5) \supset O(3) \supset O(2) \quad \text{I} \\
U(6) \arrow[ur] \arrow[r] \arrow[dr] & U(3) \supset O(3) \supset O(2) \quad \text{II} \\
 & O(6) \supset O(5) \supset O(3) \supset O(2) \quad \text{III}
\end{tikzcd}$$

The spectra of medium mass and heavy nuclei are characterized by the occurrence of low-lying collective quadruple states(14) .

The actual way in which these spectra appears is consequence of the interplay between pairing and quadruple correlations.(2)

This interplay changes form nucleus, giving rise to a large variety of collective spectra.(1)

The proton (neutron) boson in the IBM are identified with pairs of valance proton (neutron) coupled to J=0(s-boson) or J=2 (d-boson).

The number of bosons for a given nucleus is $N=N\pi + N\nu$ where $N\pi(N\nu)$ is the number of proton (neutron) pairs out side the nearest major closed shell. If the shell is more then half filled $N\pi(N\nu)$ is the number of proton (neutron) hole pairs, reflecting the particle- hole(1-3) symmetry of the nuclear shell model. In a simpler version of the IBM, in which the neutron boson and proton boson degrees of freedom are not treated separately. The Hamiltonian which includes boson- boson interaction is(1):

$$H = \in \hat{n}_d + a_0\hat{P}^{+}.\hat{P} + a_1\hat{L}^2 + a_2\hat{Q}^2 + a_3\hat{T}_3^{\,2} + a_4\hat{T}_4^{\,2} \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where $\hat{n}_d = (d^{\dagger}.d)$, $\hat{T} = (d^{\dagger}\times d)$, $\hat{p} = \frac{1}{2}(d^{\dagger}.d\,)-(s.s)$, $\hat{L} = \sqrt{10}\,(d^{\dagger}\times d)$

was set equal to zero only $\in_s$ is the boson energy. For simplicity, $\in = \in_d + \in_s$ Also appears. $\in = \in_d$

The parameters a0, a1, a2, a3 and a4 designate the strengths of pairing, angular momentum, quadruple, octupole and hexadecapole interacting between bosons, respectively. In order to calculate the transition rates, one most specify the transition operators. In the simplest form of the IBM-1, the one body Transition operator which has the second quantized form is:(1-3)

$$T_m^{(1)} = \alpha_2\delta_{12}\,[d^{\dagger}\times s+s^{\dagger}\times d]^{(1)}{}_m+\beta_1[d^{\dagger}\times d]^{(1)}{}_m+\gamma_0\delta_{1o}\delta_{mo}\,[s^{\dagger}\times s]^{(0)}{}_0 \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where α2 , βl and γ0 are the coefficients of the various terms in the operator. This equation yields transition operator. for E0, M1, E2, M3 and E4 transitions with appropriate values of the corresponding parameters.

The Tm $^{(E2)}$ operator, which has enjoyed a widespread application in the analysis of $\gamma - ray$ Transitions , can thus take the form:(2)

$$T_m^{(E2)} = \alpha_2\;[d^{\dagger}\times s+s^{\dagger}\times d]^{2}{}_m+\beta_2[d^{\dagger}\times d]^{2}{}_m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Its clear, for the E2 multpolarity, two parameters α2 and β2 are needed in addition to the wave functions of the initial and final states.

The three limits discussed above are useful since they provide a set of analytic solutions which are easily tested by experiment. However only few nuclei can be discussed by limiting cases. Most of the nuclei belong to these regions and are difficult to explain in traditional models(15).for the purpose of classification, the transitional nuclei can be divided in to four classes.(1-3)

(A) nuclei with spectra intermediate between SU(3) and SU(5).
(B) nuclei with spectra intermediate between O(6) and SU(3).
(C) nuclei with spectra intermediate between O(6) and SU(5).
(D) nuclei with spectra intermediate among all three limiting cases.

Much simpler studies can be done for nuclei belonging to the transitional classes A,B and C. (2,3) The limiting symmetries can now be expressed in terms of Eq.(1) with only some non zero parameters.(1)

I) SU(5) :$a_0=0$,$a_1=0$
II)SU(3): $\epsilon=0,a_0=0=a_3=0$
III) O(6) : $\epsilon=0,a_2=0=a_4=0$

A useful pictorial representation of this is shown in fig. (1) called casten's triangle where the limiting cases are placed at the vertices of a triangle with the sides representating the transition from one limit to another.

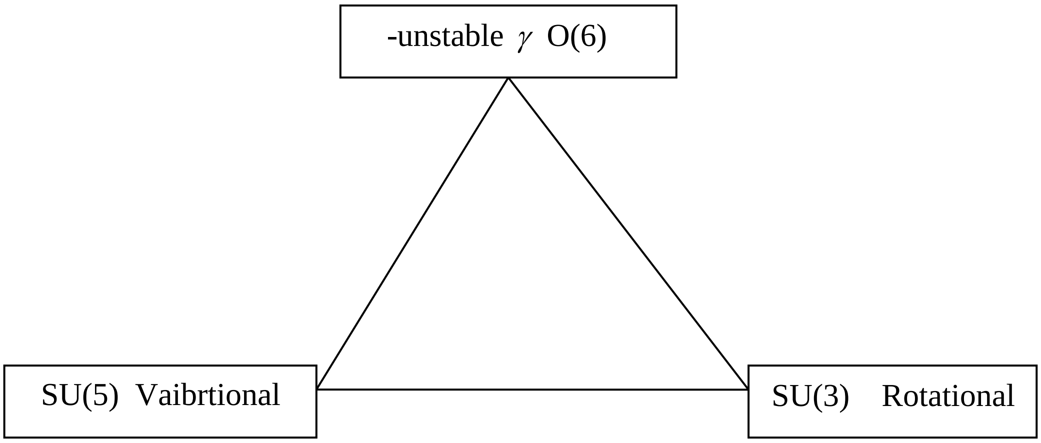

Fig.(1) symmetry triangle, illustrating Three direct transitions between them.(15)

The three limiting symmetries of IBM-1 and the similar changes also occur in the electromagnetic transition rates. Particularly important are the ratios(1-3)

$$\mathrm{R}=\frac{B(E2:4_1^+\rightarrow 2_1^+)}{B(E2:2_1^+\rightarrow 0_1^+)}$$

$$\mathrm{R'}=\frac{B(E2:2_2^+\rightarrow 2_1^+)}{B(E2:2_1^+\rightarrow 0_1^+)}$$

$$=\frac{B(E2:0_2^+\rightarrow 2_1^+)}{B(E2:2_1^+\rightarrow 0_1^+)}\,\mathrm{R''}$$

Which changes from R = R'= In U(5) $2\left[(\mathrm{N}-1)/\mathrm{N}\right]\mathrm{R''}=$

To

In SU(3) $=\frac{10}{7}\frac{(N-1)(2N+5)}{2(2N+3)}\approx 1.4,\ \mathrm{R'}=\mathrm{R''}\ =0\,\mathrm{R}$

and to

In O(6) $= \frac{10}{7} \frac{(N-1)(N+5)}{2(N+4)} \approx 1.4, \mathrm{R}'' = 0\,\mathrm{R}'$

R=

$(\varepsilon/a_2\ )$ The control parameter in class A is when this is large the eigenfunctions of H are these appropriate to symmetry SU(5), and when it is small, the eigenfunctions are those appropriate to symmetry SU(3). While in the B and C .(15) $(a_0/\varepsilon\ )$ and $(a_0/a_2\ )$classes the control parameters are

Calculation:

Calculation were performed in the complete Hamiltonian using the IBM-1 computer code IBM for energies and IBMT- code for B(E2) values.

For (Te^{126}, Xe^{126}, $Ba^{126}$and Ce^{126}) there are (five, seven, nine and eleven) active bosons, formed by (one, two, three and four) proton (particle) pairs and (four, five, six and seven) neutron (hole) pairs out side of the closed shells (50, 50) respectively. The values of the parameters which gave the best fit to the experimental date(16-23) are given in table (1) and fig (2) and calculated level energies are compared with the experimental in fig (3).

For the calculation of the absolute B(E2) the two parameters α_2 and β_2 (equ. (3)) the equivalent $\mathrm{E2}SD = \alpha_2, \mathrm{E2}DD = \sqrt{5}\beta_2$ parameters in IBMT- code are Where

$$\beta_2 = \frac{-0.7}{5}\alpha_2, \beta_2 = -\sqrt{7/2}\,\alpha_2 \text{ And } \beta_{=0}$$

in SU(5), SU(3) and O(6) respectively.

value $\mathrm{B}(\mathrm{E2}: 2_1^+ \to 0_1^+)$ Were adjusted according to the experimental (table(1)), the B(E2), $Q21^+$and B(E2) ratios values calculated these parameters are shown in table(2) together with experimentally determind(16-23) values see figs:(4-6).

Table (1): The parameters obtained from the programs IBM- code and IBMT- code using the IBM-1 Hamiltonian.

Table (2): experimental(16- 23) B(E2) values (e^2b^2) and Q_{21}+(eb) in Te, Xe, Ba and Ce isobars nuclei

Isobars	The parameters									
	Eps	**a_o**	**a_1**	**a_2**	**a_3**	**a_4**	**CHI**	**$B(E_{2;}2_1^+ \rightarrow 0_1^+)$ (e^2b^2)**	**E2SD (eb)**	**E2DD (eb)**
$^{126}_{52}Te$	**0.5940**	**0.0**	**0.0050**	**0.0**	**-0.0305**	**0.0480**	**0.0**	**0.0994**	**0.1410**	**-0.09880**
$^{126}_{54}Xe$	**0.0**	**0.0206**	**0.0181**	**-0.0586**	**0.0001**	**0.0019**	**-0.0590**	**0.1511**	**0.09973**	**0.0**
$^{126}_{56}Ba$	**0.0**	**0.0745**	**0.0256**	**-0.0370**	**0.0**	**0.0**	**-0.2900**	**0.2226**	**0.10398**	**0.0**
$^{126}_{58}Ce$	**0.0**	**0.0**	**0.0157**	**-0.0202**	**0.0**	**0.0**	**-0.0590**	**0.5405**	**0.09976**	**-0.29580**

are compared with IBM-1 results.

$i \rightarrow f$	B(E2) e^2b^2							
	Te^{126}		**Xe^{126}**		**Ba^{126}**		**Ce^{126}**	
	p.w	**Exp**	**p.w**	**Exp**	**p.w**	**Exp**	**p.w**	**Exp**
$2_1^+ \rightarrow 0_1^+$	**0.0994**	**0.095**	**0.1511**	**0.154**	**0.2226**	**0.245**	**0.5405**	**0.54**
$2_1^+ \rightarrow 0_2^+$	**0.0318**	**-**	**0.0001**	**-**	**0.0005**	**-**	**0.0753**	**-**
$2_2^+ \rightarrow 0_1^+$	**0**	**0.0008**	**0.0018**	**0.002^***	**0.0222**	**0.0212**	**0.1154**	**0.1624**
$2_2 \rightarrow 0_2^+$	**0**	**-**	**0.0428**	**-**	**0.0578**	**-**	**0.0388**	**-**
$2_1 \rightarrow 2_2$	**0.159**	**0.1314**	**0.1871**	**0.2064**	**0.0757**	**-**	**0.01566**	**-**
$4_1 \rightarrow 2_1$	**0.159**	**-**	**0.2029**	**-**	**0.3148**	**0.3275**	**0.035**	**0.0443**
$4_2 \rightarrow 2_1$	**0**	**-**	**0.0001**	**-**	**0.0038**	**-**	**0.0136**	**-**
$4_2 \rightarrow 2_2$	**0.0937**	**-**	**0.1134**	**-**	**0.1665**	**0.0987**	**0.0171**	**0.0261**
$Q21^+$	**0. 22 -eb**	**-0. 2 eb**	**-0.29**	**-**	**-1.15**	**-**	**-2.0783**	**-**

Discussion and conclusion:

Te^{126} nucleus :

Te^{126} nucleus expected for a vibration nuclei. See fig (7). The experimental(4-7,16-20) energy level structure of Te^{126} suggests avibrational nature at least in the low energy region and exhibit rather complex structures at higher spins due to the strong mixing collective quadruple excitations and levels of bands based on quasi particle states. The Te^{126} nuclease has an energy ratios.

$E_{4_1^+}/E_{2_1^+} = 2.04, E_{6_1^+}/E_{2_1^+} = 2.66$ *and* $E_{8_1^+}/E_{2_1^+} = 4.1$ *closer to the values of* $(2,3 and 4)$

The vibrational SU(5) limit of the IBM-1 and has been applied to describe the level structure of Te^{126}. In Te^{126} the experimental$^{(4-7,16-20)}$ 2^+ and 4^+ states at (1420 and 1361) kev which are commonly

$2^+ \otimes 2^+$ considered as members of the two- phonon triplet a two- quadruple phonon triplet with states having spin and parity quantum number ($J^{\pi}= 0^+,2^+$and 4^+)$^{(2,17)}$ are well described in the frame work of the IBM-1.

This is not the case for the only experimentally found 0^+ state (1873 kev) in this energy region. Figs. (3,7) which can be considered as an intruder state. Concerning the three- phonon quintuplet it is easy to identify the experimental$^{(4-7, 16-20)}$ $0^+,2^+$ and 3^+ states at 2114 kev, 2045 kev and 2128 kev, respectively, as member of this multiple, the situation of the 6^+ state of the quintuplet is more complicated. The behaviour of the 6^+ level in the approach to the (N=82) closed shell could not reproduced by the calculation reported. This behavior may be due to the increasing importance of the g7/2 proton configuration and hence significant non- collective effects.

The interpretation of the level scheme in the frame work of the U(5) limit of the IBM-1 gave good agreement between experiment$^{(4-7, 16-20)}$ and theory for the low- lying levels the calculated B(E2) values, $Q21^+$ and B(E2) ratios gave reasonable agreement with experimental $^{(4-7, 16-20)}$ date and U(5) limit predication.

Xe^{126} nucleus :

The occurrence of axially asymmetric features can be expected in cases where the neutrons are particles and the protons holes or vice versa.

From the eigenvalue equation for O(6) limit the energy ratios [R4/2=2.5, R6/2=4.5, R8/2=7 and E22=2.5 E21], the four experimental$^{(7-9, 20,22)}$ observables [R4/2, R6/2, R8/2 and E22] for Xe^{126} isotope are plotted in figs. (3,7). As can be seen from these figures, the discussed levels$^{(7-9, 20, 22)}$ become more and more equidistance [O(6)- like] from U(5) limit, where R4/2=2.4, R6/2=4.27, R8/2=6.34 and E^+22= 2.25 E^+21.

In the frame work of the interaction boson model Xe^{126} has been suggest to lie within the U(5) $\longrightarrow$ O(6) transition region.

The positive states have been interpreted interims of the IBM-1, in general, the ground state band is fitted very well. The most characteristic and easily recognizable signature of U(5) $\longrightarrow$ O(6) has been the appearance of nearly degenerate 2^+2 and 4^+1 states at an energy of roughly 2.5 times that of the2^+1 levels with the 02 state lying significantly higher and decaying to the second 2^+ state $\left[B(E2): 0_2^+ \to 2_2^+ = 0.214\ e^2b^2\right]$

. $\left[B(E2): 0_2^+ \to 2_1^+ = 0.0005\right] e^2b^2$ rather than to the 2^+1 level

appear to be small about 10^{-3}. $\left[B(E2): 0_2 \to 2_1\right]$ See- fig (4) one can observed that The values for R, R' and R" ratios are [1.34, 1.23 and 0.003] near from the O(6) limit values of (R= R' =1.4 and R"=0) as shown in table (2) and fig: (6).

Ba^{126} nucleus :

The Ba^{126} nucleus has an energy ratios(7-9, 20-23) [E4/2= 2.77, E6/2= 5.2 and E8/2= 8.16] closer to the values of (2.5, 4.5 and 7) expected for a γ–unstable nucleus rather then the SU(3) values (3.33, 7 and 12).

The Ba^{126} Spectra change from the γ–unstable shapes to the rather strongly deformed and was considered in terms of the IBM-1 between O(6) to SU(3).

In the present IBM-1 calculation transitional Hamiltonian between O(6) to SU(3) was performed all parameters in the Hamiltonian were varied to give good fits to the energy levels in Ba^{126} nucleus table (1), fig (3, 7) in fig. (6) one can observed that B (E2) ratios (R=1.4, R' =0.34 and R"=0.011) lie between the two limits, O(6)[R=1.4 and R' = R"=0] and SU(3) [R= R' ~1.4 and R"=0], and closer to O(6) limit. The theoretical values of electric quadruple moment $Q^{+}21$ and B (E2) transition which are assumed to be pure E2 gives in table (2) fig. (5), from $Q^{+}21$ value we can assume that Ba^{126} has slightly deformed.

Ce^{126} nucleus :

The nuclear structure of Ce^{126} nuclei seems to show a rotational nature more than "γ–unstable" .

In fact and due to lack of data(7,8,21`,22) for $Ce^{126}$ is more difficult to interpret . from the data that exist, though, it seems to evolve from O(6) to near SU(3) limit. The rotational theory expects R=3.33 for the first two excited states ($2^{+}$ and $4^{+}$) of the ground state band whereas the experimental(7,8,21`,22) value is 3.06 and [R6/2=5.98 and R8/2=9.58] are closer to values (3.33, 7 and 12) for SU(3) from (2.5, 4.5 and 7) for O(6) limit. The nucleus and from the values of B (E2) ratios and $Q^{+}21$ figs.(6, 5) are believed to be deformed nucles, and therefore show rotational – like spectra the even- even Ce^{126} nucleus lies on the edge of this deformation region.

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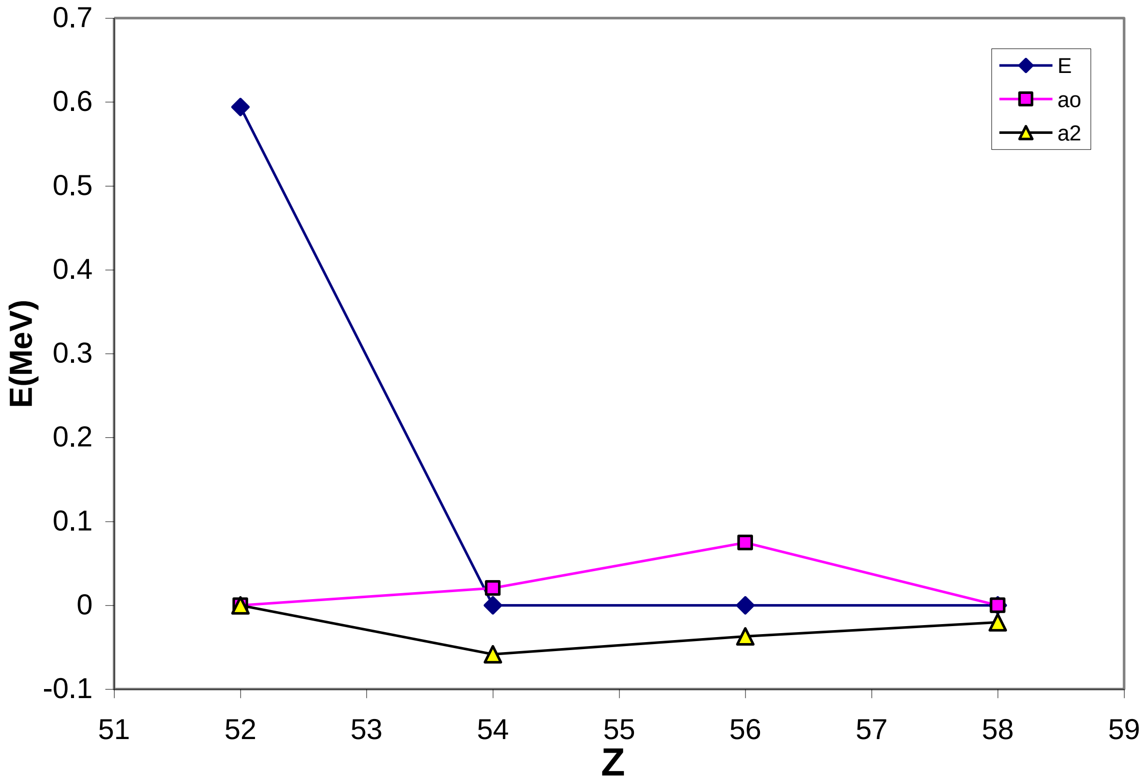

Fig: (2) The Values of the parameters Which gave the best fit to the experimental(16-23) data.

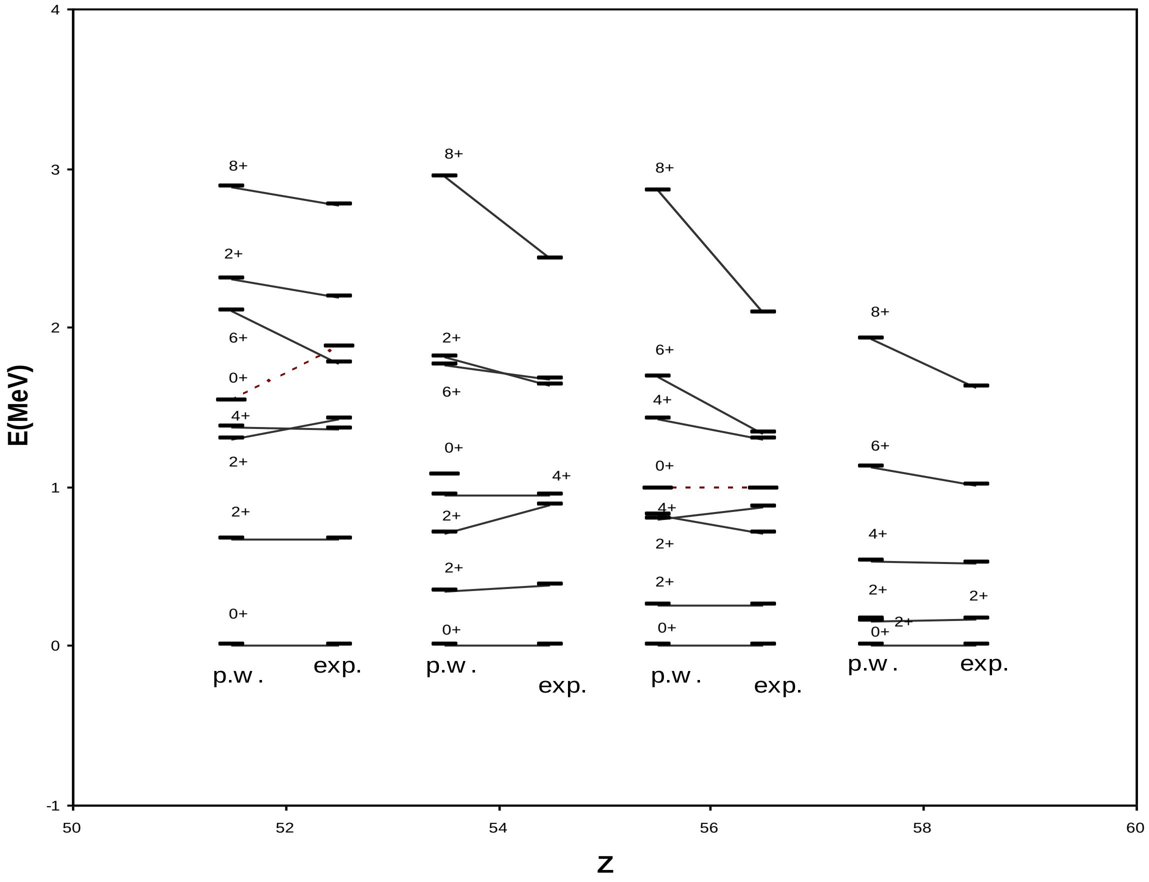

Fig:(3) Comparision of experimental(16-23) **and theoretical energy levels of Te** ^{126} **.Xe** ^{126}**.Ba** ^{126}**. and Ce** ^{126}**.**

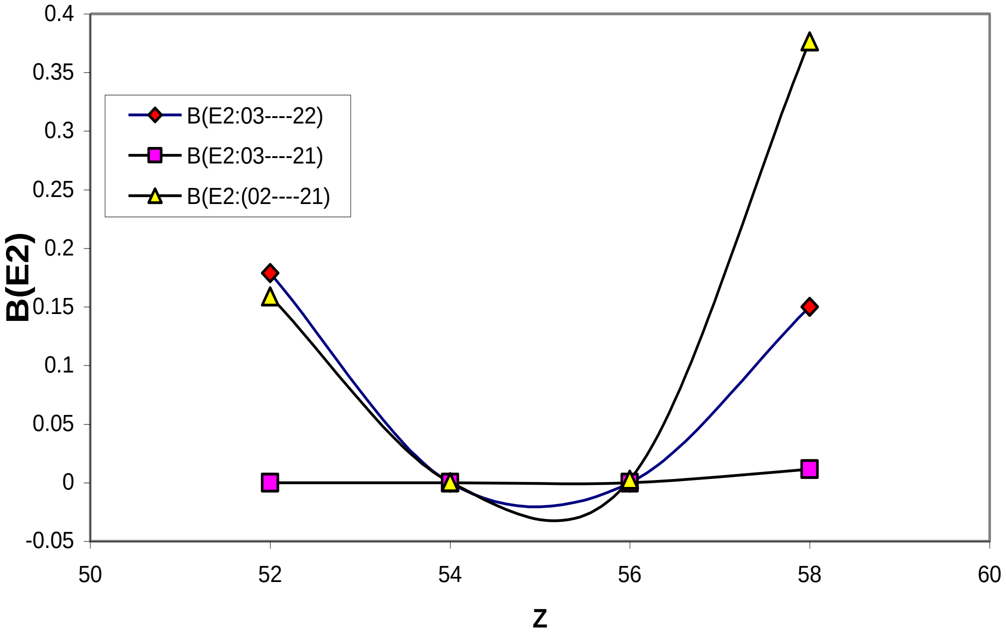

Fig:(4) Calculated reduced transition probabilities B(E2).

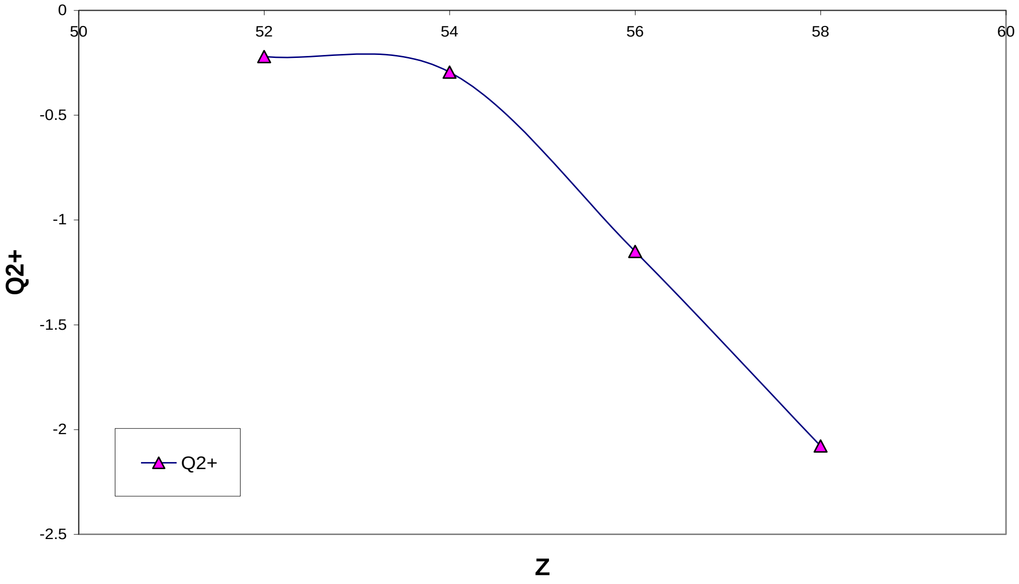

Fig :(5) Calculated electric quadrupole moments in (eb) of the first excited 2^{+}state

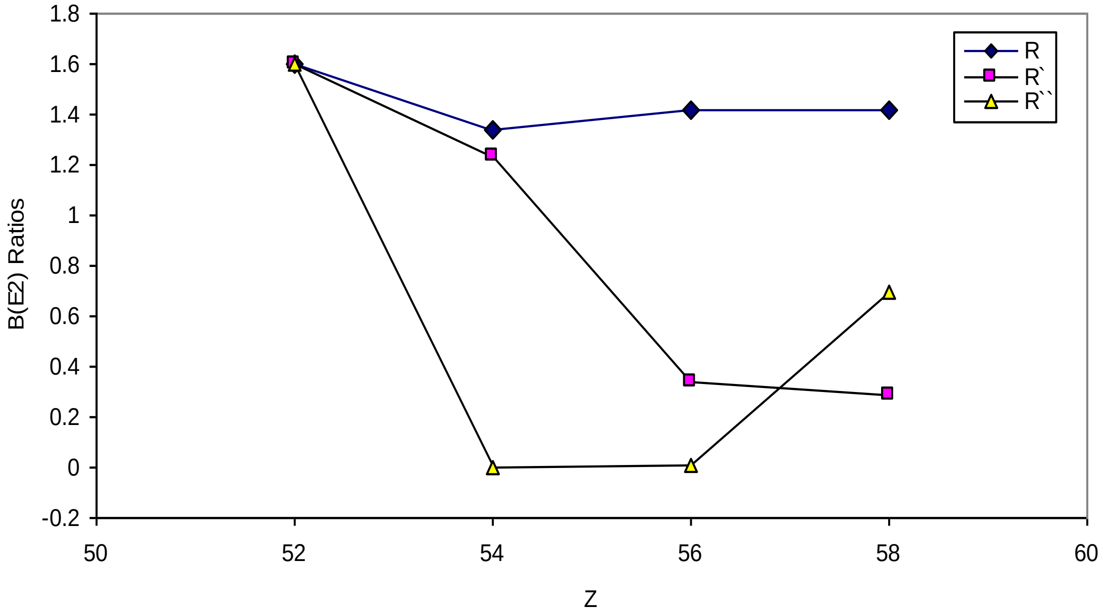

Fig:(6) Calculated B(E2) Ratios of Te , Xe , Ba and Ce (126) isobar.

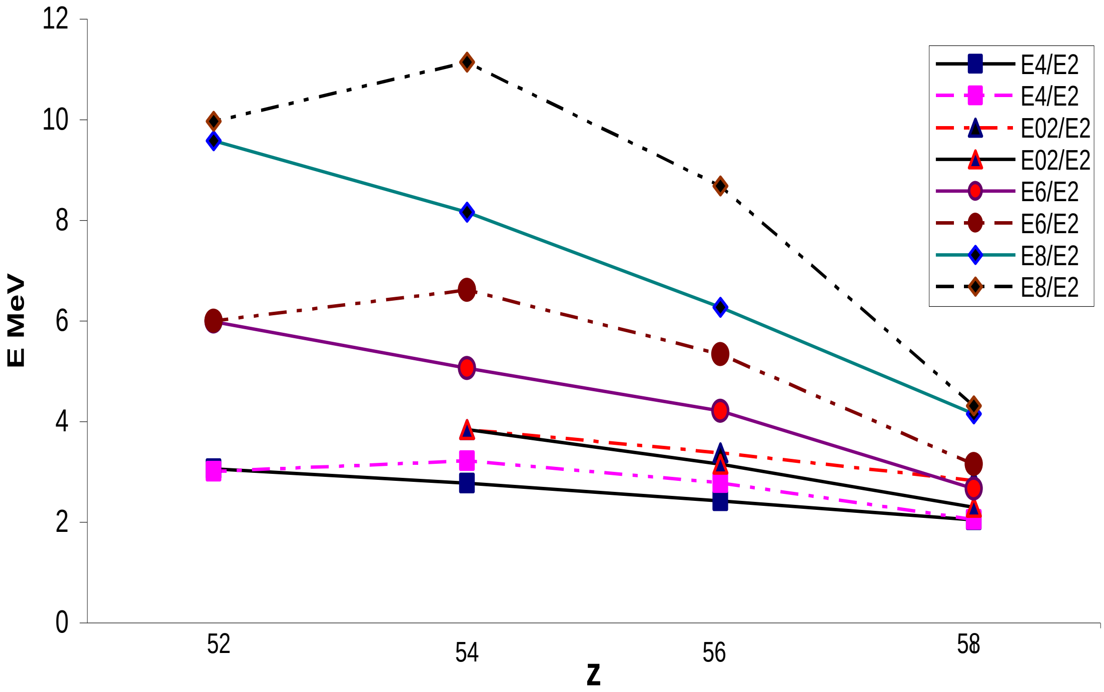

Fig:(7)Calculated and experimental$^{(16-23)}$ ratios $R_{4/2}$, $R_{0/2}$, $R_{6/2}$ and $R_{8/2}$ for Te , Xe ,Ba and Ce (126) isobars.