The Gadolinium Isotopes Properties (152-160) in the beginning of the deformed region 150<A<190

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:Abstract

In the present research the $^{152-160}$ Gadolinium Isotopes have been studied using the interacting boson model -1, From the experimental and calculated energy levels ,electromagnetic transition B(E2),B(E2) ratios(R,R' and R")& $Q2_1^+$ values we consider that there are three modes of behavior to the $^{152-160}$Gd isotopes

i-The level structure of ^{152}Gd which in the beginning of the transitional region between spherical and O(6) symmetry

ii-The ^{154}Gd nucleus has SU(3)-O(6) character

iii- The $^{156-160}$Gd are at the SU(3)-O(6) transition region and more closer to O(6) character with A increases .

Then we can conclude that the $^{152-160}$ Gd nuclei are at the beginning of the deformation region 150<A<190 where the pairing and the quadrupole forces are competing .

خصائص نظائر الكادلينيوم (152-160) في بداية المنطقة المشوهة A<190>150

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الخلاصة:

في البحث الحالي تمت دراسة نظائر الكادلينيوم (152-160) باستعمال نموذج البوزونات المتفاعلة -1 ومن خلال القيم العملية والنظرية لمستويات الطاقة ,الانتقالات الكهرومغناطيسية B(E2) ,ونسب الانتقالات (R,R', R")وقيم العزم الكهربائي للمستوي 2^+_1 نعتقد أن هناك ثلاث أنماط من السلوك لنظائر الكادلينيوم (160-152)

i. تركيب المستويات في نواة ^{152}Gd في بداية المنطقة الانتقالية بين SU(5) و O(6)

ii. تكون خصائص نواة ^{154}Gd بين التحديدين SU(3) وO(6).

iii. تكون نوى $^{156-160}$Gd عند المنطقة الانتقالية بين SU(3) و O(6) مع الاقتراب أكثر لصفات O(6) مع زيادة العدد الكتلي

ومن هذا يمكن أن نستنتج أن نوى الكادلينيوم (152-160) هي في بداية منطقة النوى المشوه ما بين A<190>150 حيث تتنافس قوى الازدواج ورباعية القطب فيما بينها.

:Introduction

In 2000, K. Zajak et. al. describe quadrupole excitation of even-even $^{148-162}$ Gd isotopes within a microscopic approach based on the general collective Bohr Hamiltonian(GBH) model which include the effect of coupling with the pairing vibrations [1].In 2008 (154,158) Gd have been studied by Harun et al .[2]using the interacting boson model .

To explain the form of these nuclei ,the energy levels ,the transition probabilities between different energy levels the quadrupole moments and the transition ratios must be known properties .

-:(Interacting Boson Model (IBM

Interacting Boson Model (IBM) had been introduce by Iachello [3]and then developed by Arima and Iachello [4-7]in the field of nuclear low –energy phenomena .The model has already gained a significant success in both single particle and .collective behaviuor of nuclei

Countless interaction boson approximation (IBM)calculations have been done over the last 20 years ,and the model has proved to be a valuable interpretive and predictive aid in understanding nuclear structure and its evolution as a function of N,Z and A .the model has entered the lexicon of standard approaches to nuclear structure .

In the IBM ,Axially symmetric rotors and spherical vibrators are schematically described in the IBM[8]by the analytically solvable dynamical symmetries SU(3)and U(5) .Besides these there exists a third analytical solution of dynamical symmetry O(6) with schematically describes γ –soft nuclei[9] .The three possible chains are as shown in fig:

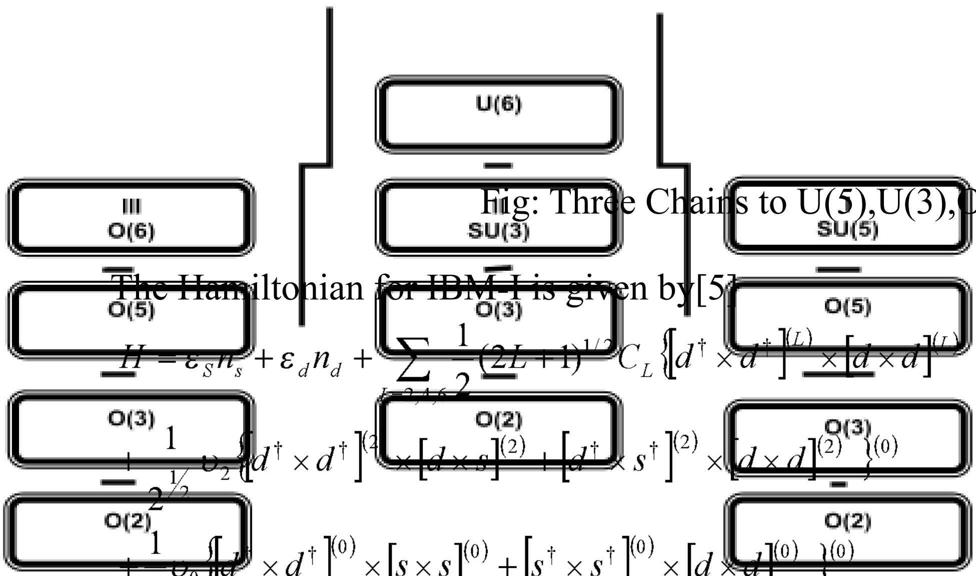


Fig: Three Chains to U(5),U(3),O(6).

The Hamiltonian for IBM-I is given by[5]

$$H = \varepsilon_S n_s + \varepsilon_d n_d + \sum_{L=2,4,6} \frac{1}{2}(2L+1)^{1/2} C_L \left\{ \left[d^\dagger \times d^\dagger\right]^{(L)} \times \left[d \times d\right]^{(L)} \right\}^{(0)}$$

$$+ \frac{1}{2^{1/2}} \upsilon_2 \left\{ \left[d^\dagger \times d^\dagger\right]^{(2)} \times \left[d \times s\right]^{(2)} + \left[d^\dagger \times s^\dagger\right]^{(2)} \times \left[d \times d\right]^{(2)} \right\}^{(0)}$$

$$+ \frac{1}{2} \upsilon_0 \left\{ \left[d^\dagger \times d^\dagger\right]^{(0)} \times \left[s \times s\right]^{(0)} + \left[s^\dagger \times s^\dagger\right]^{(0)} \times \left[d \times d\right]^{(0)} \right\}^{(0)}$$

$$+ u_2 \left\{ \left[d^\dagger \times s^\dagger\right]^{(2)} \times \left[d \times s\right]^{(2)} \right\}^{(0)}$$

$$+ \frac{1}{2} u_0 \left\{ \left[s^\dagger \times s^\dagger\right]^{(0)} \times \left[s \times s\right]^{0} \right\}^{(0)} \quad \text{..............................(1)}$$

where n_s and n_d are number operators, ε_s and , ε_d are single boson energies for s- and d boson respectively. The C_L, V_2, V_0, u_2 and u_0 are corresponding interaction parameters.

This form of Hamiltonian is the most direct form which includes all allowed one-body and two-body interactions in the second quantization formalism. Alternatively, another form of Hamiltonian which emphasizes its multipole character is also adopted [9].

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

where P, L,Q,T_3 and T_4 are the pairing, angular momentum, quadrupole, octopole and hexadecapole operators respectively.

A successful nuclear model must yield a good description not only of the energy spectrum of the nucleus but also of its electromagnetic properties.

The one body transition operator which has the second quantized form is[8] :

$$T_m^{(l)} = \alpha_2\delta_{l2}\left[d^+s + s^+d\right]_m^{(l)} + \beta_l\left[d^+d\right]_m^{(l)} + \gamma_0\delta_{l0}\delta_{m0}\left[s^+s\right]_0^{(0)} \quad \text{..........................(3)}$$

Where α_2,$\beta_l$and γ_0 are coefficient 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 most important electromagnetic features are the E2 transitions. The B(E2) values were calculated by using the E2 operator. The E2 transition operator must be a hermitian tensor of rank two and therefore the number of bosons must be conserved. Since, with these constraints the general E2 operator can be written as [7]

$$T_m^{(E2)} = \alpha_2\left[d^+s + s^+d\right]_m^2 + \beta_2\left[d^+d\right]_m^2 \quad \text{..........................(4)}$$

The $T_m^{(E2)}$ operator ,which has enjoyed a widespread application in the analysis of γ-Ray transitions .

Calculation :

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

For $^{152-160}$Gd there are (10-14) active bosons ,the values of the parameters which gave the best fit to experimental data [10-15] are given in tables (1) and fig.(1)for energy levels, and table (2)for B(E2) transition, in figs.(2:a&b) the calculated energy levels are compared with the experimental data.

.Table(1):The parameters obtained from the programs IBM-1 code

Isotopes	**(Parameters in(Mev**						
	.Eps	P.P	L.L	Q.Q	T3.T3	T4.T4	CHI
Gd^{152}	0.427	0.04	0.0051	0.0	0.0472	0.0	0.0
^{154}Gd	0.0	0.259	0.0009	0.0378-	0.0	0.0	0.01-
^{156}Gd	0.0	0.895	0.110	0.0092-	0.0	0.0	1.32
^{158}Gd	0.0	0.895	0.015	0.0096-	0.0	0.0	1.32
Gd^{160}	0.0	0.895	0.0096	0.0101-	0.0	0.0	1.32

.Table(2):The parameters obtained from the programs IBMT code

Isotopes	Parameters		
	(B(E2:$2_1^+\rightarrow0_1^+$)(e^2b^2	(E2SD(eb	(E2DD(eb
Gd^{152}	0.3429	0.185	-0.1296
^{154}Gd	0.7241	0.1482	0.0
^{156}Gd	0.928	0.165	0.0
^{158}Gd	1.0098	0.1607	0.0
Gd^{160}	1.159	0.1607	0.0

The three electromagnetic transition rates. Particularly important are the ratios[9]

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

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

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

Which changes from

$R = R' = R'' = 2[(N-1)/N]$ IN U(5)

To

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

to and

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

are illustration in the fig.(3) ,see table (3) ,while Q_{21}^+ and the experimental[10-15] and calculated $B(E2:2^+_1 \rightarrow 0^+_1)$are shown in figs,(4)&(5)

Table(3):Experimental[10-15]B(E2) values (e^2b^2) and $Q2_1^+$ (eb) in $^{152-160}$Gd nuclei are compared with IBM-1 results.

i→f	B(E2)e^2b^2									
	^{152}Gd		^{154}Gd		^{156}Gd		^{158}Gd		^{160}Gd	
	P.w	Exp.	P.w	Exp.	P.w	Exp.	P.w	Exp.	P.w	Exp.
$2_1^+ \rightarrow 0_1^+$	0.342	0.394	0.724	0.77	0.928	0.924	1.009	1.004	1.159	1.038
$2_1^+ \rightarrow 0_2^+$	0.12	-	0.0001	0.043	0.0002	-	0.0002		0.0002	-
$2_2^+ \rightarrow 0_1^+$	0.0	-	0.001	0.02	0.058	-	0.059	0.089	0.063	0.098
$2_2^+ \rightarrow 0_2^+$	0.0134	-	0.223	-	0.0638	-	0.064	-	0.068	-
$2_1^+ \rightarrow 2_2^+$	0.617	-	0.993	-	0.089	-	0.089	-	0.096	-
$4_1^+ \rightarrow 2_1^+$	0.617	-	1.003	1.062	1.3	1.43	1.42	1.6	1.63	-
$4_2^+ \rightarrow 2_1^+$	0.0	-	0.0	-	0.03	-	0.031	-	0.034	-
$4_2^+ \rightarrow 2_2^+$	0.43	-	0.587	-	0.467	-	0.515	-	0.598	-
Q21$^+$	-0.289	-	0.238	-	-2.55	-1.96	-2.67	-2.01	-2.86	-2.08

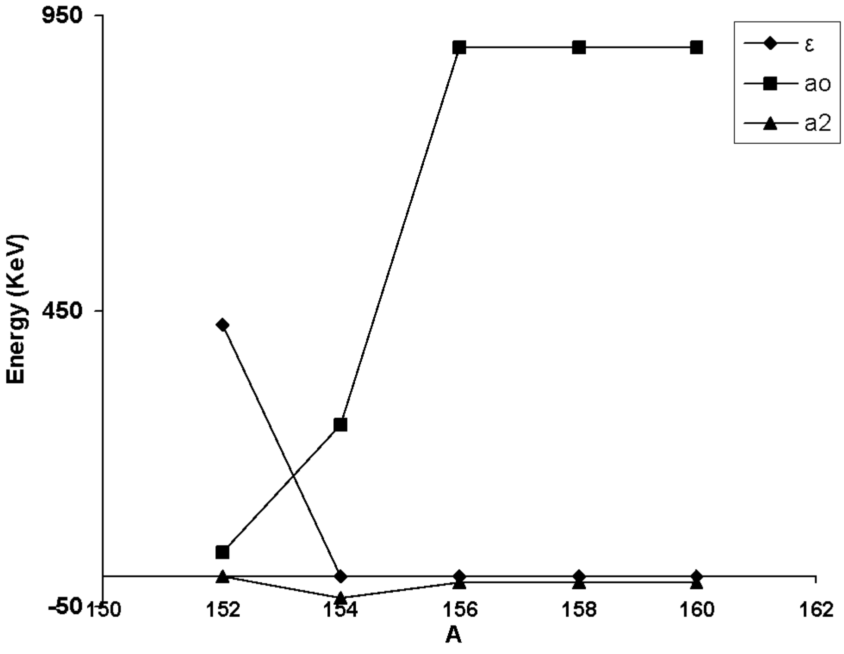


Fig.(1):The values of the (Eps., a0 and a2) parameters which give the best fit to the expermental [10-15] data.

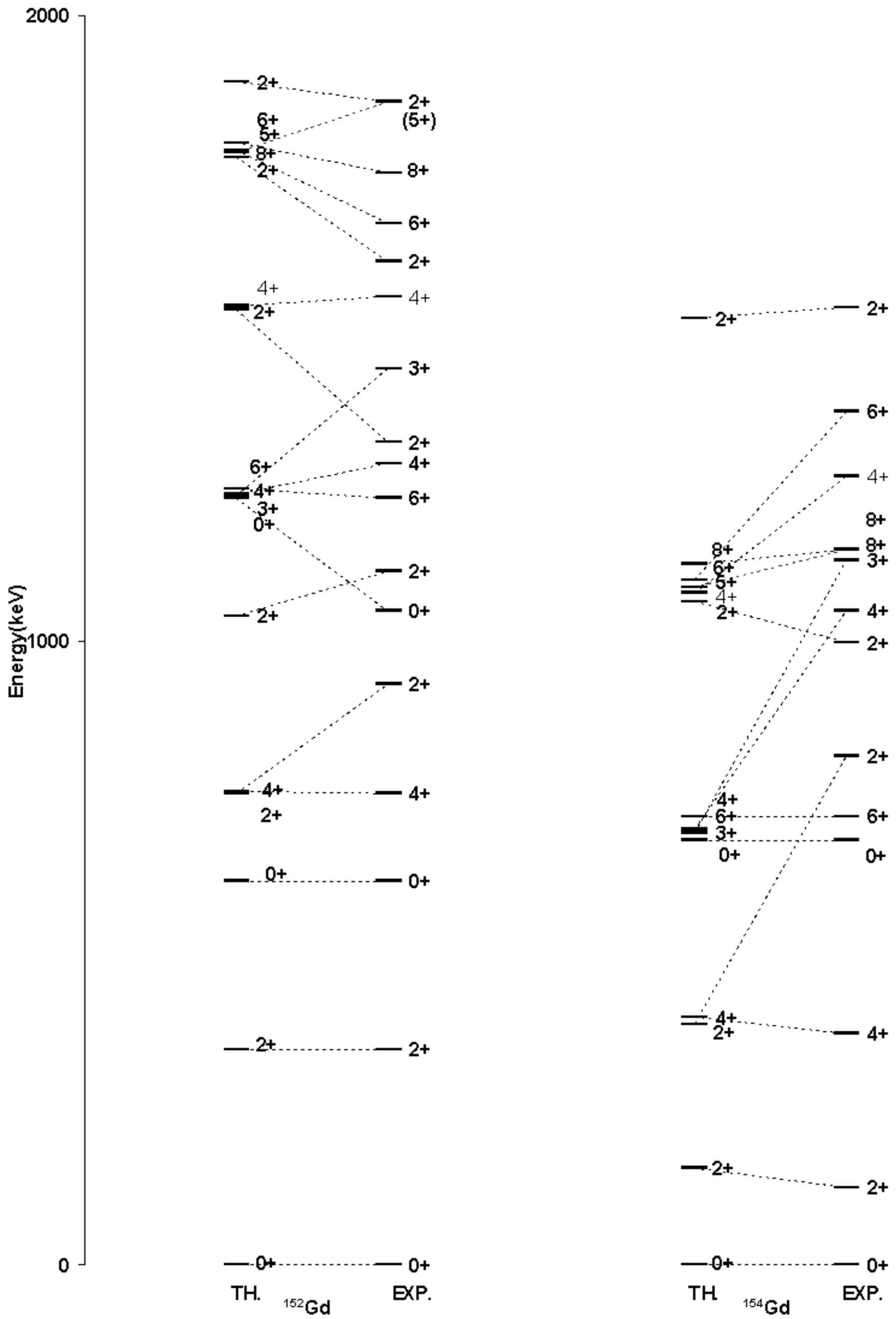


Fig. (2a): Comparsion of experemental [10-15] and theortical energy levels of $^{152-160}$Gd Isotopes.

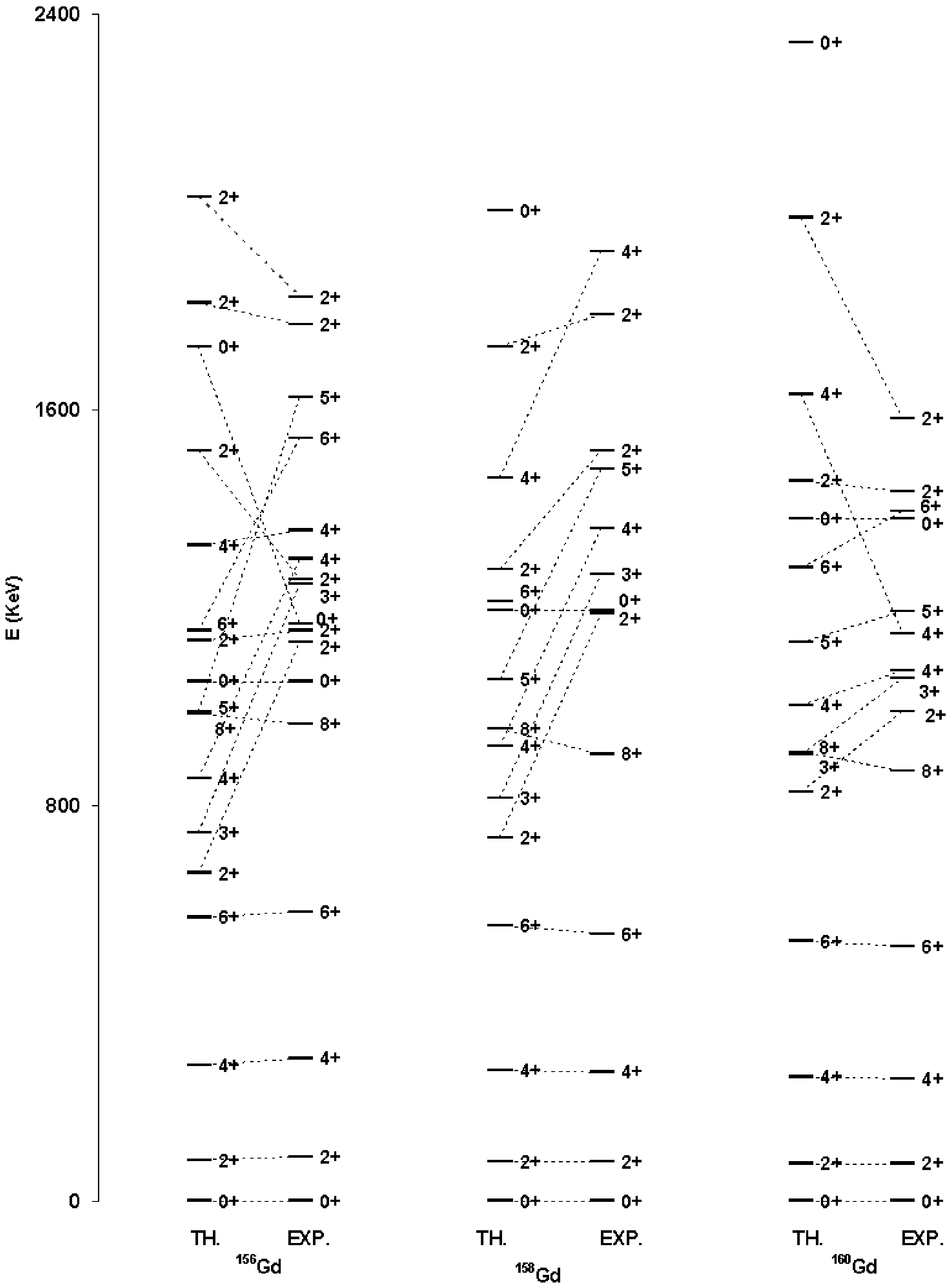


Fig.(2b):COUN.

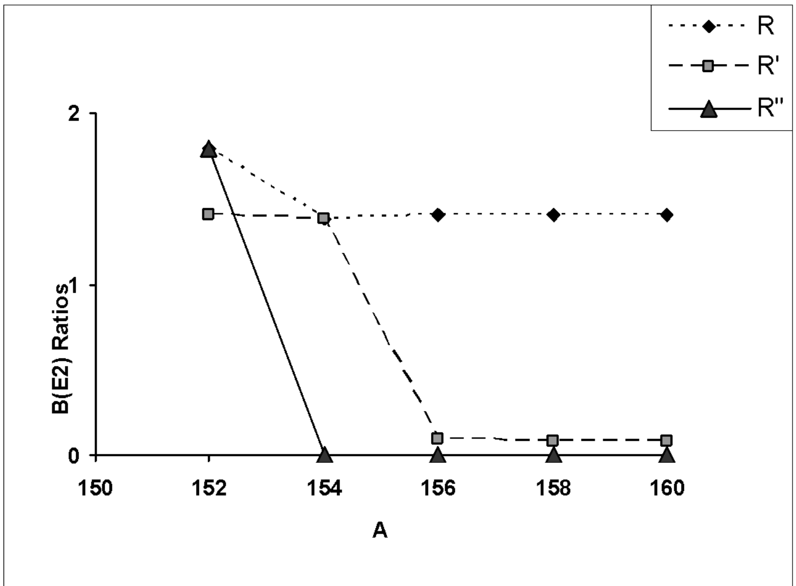


Fig.(3) :Calculated B(E2) ratios of $^{152-160}$Gd isotopes.

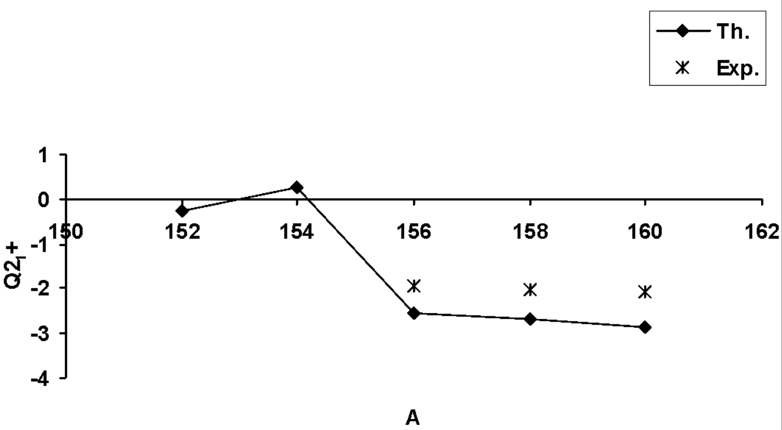


Fig.(4):Experemental [16] and Calculated electric quadrupole moments in (eb)of the first excited 2+ state for 152-160 Gd isotopes.

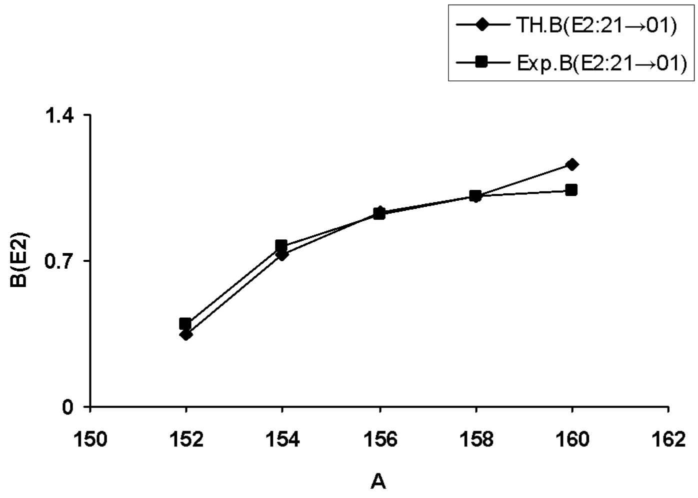


Fig.(5): Calculated and experimental[10-15] Reduced transition probabilities B(E2).

Discussion and conclusion:

The even-even Gadolinium isotopes have been described by the IBA-1 Hamiltonian yields a good description of the energy levels in addition to the excitation energies and the electric quadrupole transition probability B(E2; Ii →If) of the $^{152-160}$Gd isotopes. The $^{152-160}$Gd nuclei have 7 bosons proton(particles) and (3-7)boson neutron (particles) then the total number of bosons is (10-14) respectively.

The pairing and the quadrupole forces are important in deformed nuclei .These forces especially influence the particles in the unfilled states .The pairing force keeps the nuclei in spherical symmetry .The quadrupole charge distribution causes what is known as the quadrupole force . This force take the nuclei to the deformed state .The relation between the pairing and the quadrupole forces determines the form of the nuclei.

In the present work and from the first sight we can see that the Gadolinium isotopes leave the SU(5) to SU(3) toward the O(6) because of the experimental and calculated ratio values E^+_4/E^+_2, E^+_6/E^+_2 & E^+_8/E^+_2 which occur near SU(5) for ^{152} Gd and between O(6)& U(3) for ^{154}Gd then closer to SU(3) characteristics to$^{156-160}$Gd isotopes (see figs.(6,7)&[5] then, when we look to the B(2) ratios, (fig:3) we can observed that the ^{152} Gd nuclei have U(5) features when R=R'=R"=1.79 which close to 2[(N-1)/N]≈1.8 see [8] while^{154}Gd have R=R'=1.37≈1.4 &R"=0 which means the characteristics of O(6) limit and SU(3) limit for $^{156-160}$Gd when R=1.4 &R' ≈R"=0.As well as that the quadrupole moments values will be give the same impression where $Q2_1^+$ which measures the deviation of the nuclear charge distribution from a spherical shape advance step by step to SU(3) from SU(5).It's clear that there are three modes of behavior to the $^{152-160}$Gd isotopes

i-The level structure of ^{152}Gd which in the beginning of the transitional region between spherical and O(6) symmetry on the basis of assuming Z=64 is a good sub shell closer for N<90.

ii-The ^{154}Gd nucleus has SU(3)-O(6) character as we can see the location on the casten triangle [9] fig.(8).

iii-When we taking into account the dynamic symmetry location of the $^{156-160}$Gd nuclei at the IBM phase triangle where their parameter sets are at the SU(3)-O(6) transition region and more closer to O(6) character with A increases.

Then we can conclude that the $^{152-160}$ Gd nuclei are at the beginning of the deformation region 150<A<190. Nuclei are expected to be soft and flexible, i.e. the shape of a nucleus may strongly deviate from a sphere. Experimentalists found many nuclei with a remarkably deformed charge distribution in large regions of N and Z between the magic numbers

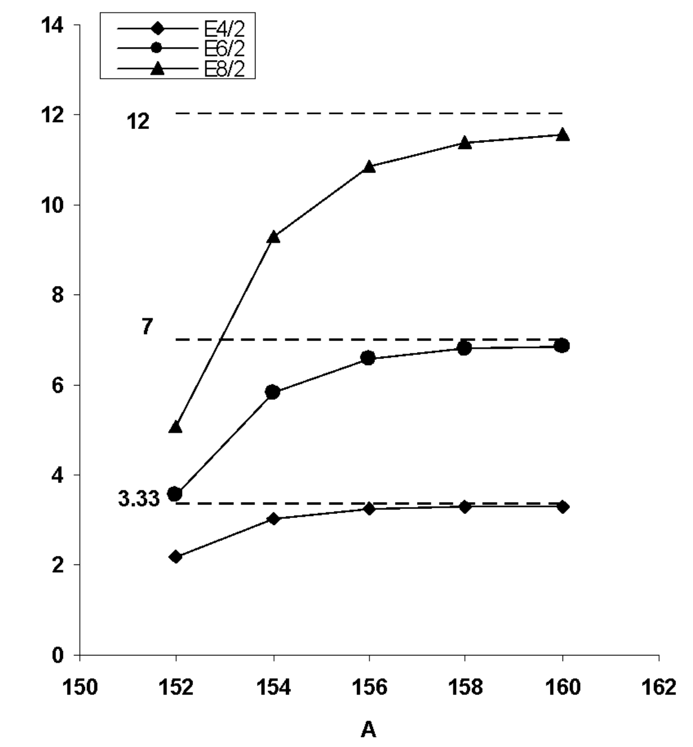


Fig.(6):Experimental [10-15] ratios $R_{4/2}$,$R_{6/2}$ and $R_{8/2}$ for $^{152-160}$ Gd isotopes with SU(3) prospects.

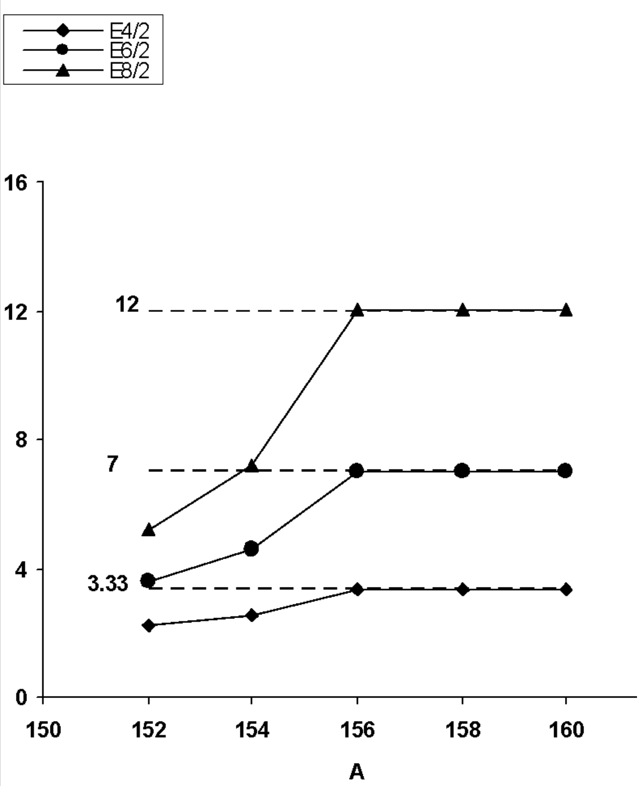
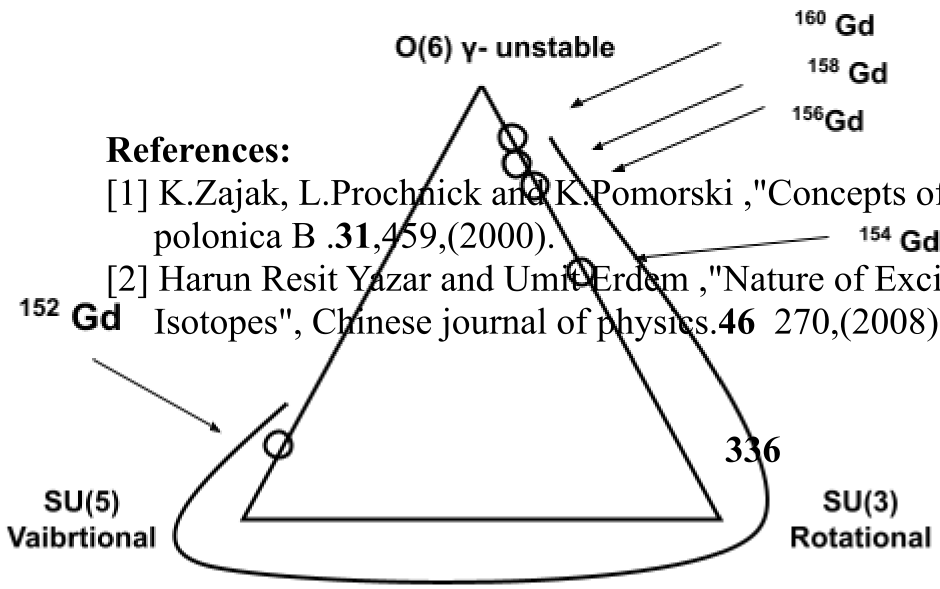


Fig.(7):Calculated ratios $R_{4/2}$,$R_{6/2}$ and $R_{8/2}$ for $^{152-160}$ Gd isotopes with SU(3)



References:

[1] K.Zajak, L.Prochnick and K.Pomorski ,"Concepts of Moden Phys.",Acta physics polonica B .**31**,459,(2000).

[2] Harun Resit Yazar and Umit Erdem ,"Nature of Excited States of Gadolinium Isotopes", Chinese journal of physics.**46** 270,(2008).

[3] F.Iachello, Collective aspects of the shell –model ,Proc. Int. Conf. on Nucl. Structure and Spectroscopy, Amsterdam , 1974 .
[4] A. Arima,F. Iachello ,"Interacting Boson Model",Ann. Phy. **99**,293 (1976).
[5] A. Arima,F. Iachello,"Interacting Boson Model",Ann. Phy. **111**,201 (1978).
[6] O.Scholten, F. Iachello, A. Arima,"Apairing of Force", Ann. Phy. **115**,325 (1979).
[7] A. Arima,F. Iachello ,"Interacting Boson Model", Ann. Phy. **123**, 468 (1976).
[8] K. Abrahams, K. Allaart and A. Dieperink ,"Nuclear Structure", B. Physics. **67**, 53,(1980).
[9] R.Casten and P. Brentano ,"Interacting BosonModel",Phys.Lett.,**152**B,22,(1985).
[10] N. Zamfir and R. Casten , J. Res. Natl. ,"Concepts of Moden Phys.", Inst. Stand. Technol. **105**, 147 (2000)
[11] J. Tuli ,"Atomic Data and Nuclear Data", Nuclear Data Sheets ,**79**, 1, (1996).
[12] C. W. Reich and R. G. Helmer Nuclear Data Sheets **85**, 171 (1998).
[13] C. W. Reich , Nuclear Data Sheets **99**, 753 (2003).
[14] R. G. Helmer, Nuclear Data Sheets **101**, 325 (2004).
[15] C. W. Reich, Nuclear Data Sheets **105**, 557 (2005).
[16] N.J.Stone "Table of Nuclear Magnetic Dipole and Electric Quadrupole Moments"OXFORD OX1 3PU ,U.K.,(1998).