STUDY THE NUCLEAR PROPERTIES OF EVEN – EVEN ²²⁶⁻²³⁴TH ISOTOPES USING THE INTERACTION BOSON MODELS (IBM-1) AND (IBM-2)

ALI MAHDI ABDUI HASSEIN

Department of science, College Basic Education, University of Misan, Iraq

ABSTRACT

The present work, we use the interacting boson models 1 and 2, for study the nuclear properties of Thorium isotopes which have the mass numbers between ($A = 226-234$). These isotopes lie in the region $SU(3)$ the rotational limit according to the energy rates (E_4/E_2) where the energy values for (2_1) level equal ($0.0722 - 0.0495$) MeV respectively. The calculated results for ground, Beta and Gamma bands, the energy ratios, and reduced transition probability $B(E2)$ and $B(M1)$ by IBM-1 and IBM-2 were compared with the experimental data and get a reasonable agreement.

KEYWORDS: Th Isotopes, $SU(3)$ Limit, $B(E2)$, $B(M1)$ & IBM-1, 2

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INTRODUCTION

The even –even Th isotopes with ($N > 126$) lie in the rotational region on nuclear deformation, where note the effect of back-bending has been observed experimentally [1] in the ground state rotational band of some deformed even – even nuclei. These isotopes have ($Z=90$), ($N= 136 - 144$), where the increase in the number of bosons from 9 to 12.

The interacting boson model (IBM) of Arima and Iachello [2, 4] is able to describe several types of nuclei, such as the enharmonic vibrator, the axially symmetric rotor, and the γ -unstable rotor, as well as the transitions between them. The collective excitations of even-even nuclei are described through s and d bosons with angular momentum 0 and 2, respectively. The total number of bosons ($n_s + n_d = N$) is a constant for a given nucleus; it is roughly equal to half the total number of nucleons (or holes) outside the last closed shells. For example, in ²²⁶Th₁₃₆ the proton pairs occupy the 82 to 126 shell so that we have 4 proton boson particles ($N_\pi = 4$) and the neutron pairs occupy the $N > 126$ shells so that we have 10 neutron boson particles ($N_\nu = 5$).

The interacting boson model (IBM) has been applied to the description of quadruple collective phenomena observed in the even-even medium-heavy nuclei.[5-7] In the simplest version of this model (IBM-1), the nuclear properties of nuclei are obtained from a system a fixed number of boson, and in this version, no distinction is made between proton boson and neutron boson, therefore all states in IBM-1 are symmetric[8]. Bosons are represented by creation and destruction operators ($s^\dagger, s$) for s-boson and ($d^\dagger, \tilde{d}$) for d-boson. The states in IBM-2 include all the symmetry states of the IBM-1, as well as the mixed symmetry states which are outside the IBM-1 spaces, i. e., states, are not completely symmetric with respect to the proton-neutron boson exchange.

The even-even mass Thorium isotopes have been a matter of study by several authors using different methods shown in references [9-14].

The aims of the present study are the following:

- The implementation IBM-1 and IBM-2 calculations of the even-even Th isotopes in the context of new experimental data.
- Study and discuss the structure of Thorium isotopes in the framework of the interaction boson model.

INTERACTION BOSON MODEL

IBM-1

The Hamiltonian of IBM-1 used is [15]

$$H = \varepsilon \cdot \hat{n}_d + a_0 \hat{P} \cdot \hat{P} + a_1 \hat{L} \cdot \hat{L} + a_2 \hat{Q} \cdot \hat{Q} + a_2 \hat{T}_3 \cdot \hat{T}_3 + a_4 \hat{T}_4 \cdot \hat{T}_4 \quad (1)$$

Where ε is the boson energy, the parameters a_0 's designate the strengths of the pairing, angular momentum, quadrupole, octupole, and hexadecapole interaction between bosons respectively. Where

$$\begin{aligned} \hat{n}_d &= (d^\dagger d) \hat{P} = \frac{1}{2} [(d^\dagger d) - (s^\dagger s)] \hat{L} = \sqrt{10} (d^\dagger \times d)^{(1)} \\ \hat{Q} &= (d^\dagger \times s + s^\dagger \times d)^{(2)} + \chi (d^\dagger \times d)^{(2)} \hat{T}_I = (d^\dagger \times d)^{(1)}, \quad I = 3, 4 \end{aligned} \quad (2)$$

The (s, d) and $(d^\dagger, s^\dagger)$ is the creation and annihilation operators of s and d . $\chi = \pm \frac{\sqrt{7}}{2}$ in the SU (3) limit. A successful nuclear model must yield a good description not only of the energy spectrum of the nucleus but also of its electromagnetic transitions.

Since thorium isotopes are in SU(3) limit, the rotational Hamiltonian function of this limit is given as follows: [16]

$$H = a_1 (\hat{L} \cdot \hat{L}) + a_2 (\hat{Q} \cdot \hat{Q}) \quad (3)$$

The eigen value for this limit. [8]

$$E(\lambda, \mu, L) = k_2 (\lambda^2 + \mu^2 + 3(\lambda + \mu) + \lambda\mu) + k_3 L(L + 1) \quad (4)$$

The electric quadrupole transition B(E2) operator in the IBM-1 has the form:

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

The parameters (α_2) and (β_2) are adjusted to fit the experimental data. The classic limit of IBM-1 Hamiltonian can be obtained through the IBM coherent intrinsic state (boson condensate) introduced in references [17-19]

The transition probability B(E2) strength for the E2 transition is given by:

$$B(E2; L_i \rightarrow L_f) = \frac{|\langle L_i || T(E2) || L_f \rangle|^2}{(2L_i + 1)} \quad (6)$$

IBM-2

In the IBM-2 Hamiltonian, the s and d pairs of valance nucleons have angular momentum J=0 and J=2, respectively. These pairs correspond intuitively to the s and d bosons, respectively. The building block of the IBM-2 is the proton bosons s_π, d_π and neutron s_v, d_v . The Hamiltonian is written as [3]

$$H = \varepsilon_d(\hat{n}_{d_\pi} + \hat{n}_{d_v}) + \kappa_{\pi,v}(\hat{Q}_\pi \cdot \hat{Q}_v) + \hat{M}_{\pi v} + \hat{V}_{\pi\pi} + \hat{V}_{vv} \quad (7)$$

where the dot denoted the scalar product. The first term represents the single-boson energies for neutron and protons, ε_d is the energy difference between s- and d- boson and $n_{d\rho}$ is the number of d-bosons, where ρ correspond to π (proton) or v (neutron) bosons. The second term denotes the main part of the boson-boson interaction, i. e. the quadrupole-quadrupole interaction between neutron and proton bosons with the strength κ . The quadrupole operator is

$$\hat{Q}_\rho = [d_\rho^+ \times \tilde{s}_\rho + s_\rho^+ \times \tilde{d}_\rho]^{(2)} + \chi_\rho [d_\rho^+ \times \tilde{d}_\rho]^{(2)} \quad (8)$$

Where χ_ρ determines the structure of the quadrupole operator and is determined empirically. The square bracket in Eq. (8) denotes angular momentum coupling.

The terms $V_{\pi\pi}$ and V_{vv} , in equation (7) which correspond to an interaction between like-boson, are sometimes included in order to improve the fit to experimental energy spectra. They are of the form

$$\hat{V}_{\rho\rho} = \frac{1}{2} \sum_{(L=0,2,4)} c_{L\rho} [d_\rho^+ d_\rho^+]^{(L)} \cdot [\tilde{d}_\rho \tilde{d}_\rho]^{(L)} \quad (9)$$

For the simplicity sake, one can halve the number of the free parameters C_L^ρ by requiring $C_L^\pi = C_L^v = C_L$

The Majorana term, M_{vp} , which contains three parameters ξ_1, ξ_2 and ξ_3 may be written as

$$\hat{M}_{vp} = \frac{1}{2} \xi_2 [s_v^+ d_\pi^+ - d_v^+ s_\pi^+]^{(2)} \cdot [s_v d_\pi - d_v s_\pi]^{(2)} - \sum_{k=1,3} \xi_k [d_v^+ d_\pi^+]^{(k)} \cdot [d_v d_\pi]^{(k)} \quad (10)$$

The B(E2) were calculated by using the operator

$$\hat{T}(E2) = e_\pi \hat{Q}_\pi + e_v \hat{Q}_v \quad (11)$$

Where Q_ρ is the same as in equation (8) and e_π and e_v are boson effective charges depending on the boson number N_ρ and they can take any value to fit the experimental results. The M1 operator is

$$\hat{T}(M1) = \left[\frac{3}{4\pi} \right]^{1/2} (g_\pi \hat{L}_\pi + g_v \hat{L}_v) \quad (12)$$

where g_π, g_v are the boson g-factors in units of μ_N and $\hat{L} = \sqrt{10}(d^+ \times d)^{(1)}$.

For electric B(EL) and magnetic transitions B(ML), are defined as follows:[20]

$$B(EL; I_i \rightarrow I_f) = \frac{1}{2I_i+1} |\langle f || \hat{Q} || i \rangle|^2 \quad (13)$$

$$B(ML; I_i \rightarrow I_f) = \frac{1}{2I_i+1} |\langle f || \hat{M} || i \rangle|^2 \quad (14)$$

The 2_1^+ electric quadrupole moments were predicted. Since it is not available, one can calculate it by using, the relation related to the deformed nuclei written in reference [21].

$$B(E2; 2_1 \rightarrow 0_1) = \frac{5}{16\pi} Q_0^2 Q(2_1^+) = -\frac{2}{7} Q_0 \quad (15)$$

where Q_0 is the static quadrupole moment.

RESULTS AND DISCUSSIONS

In this work, we using the interaction boson models 1 and 2, [22, 23], for compare between the calculation results of these models and experimental data[24]. And for study the nuclear properties to Thorium isotopes which belong to SU(3) limit, where the best-fitted parameters in IBM-1 are listed in the table (1), while the best-fitted parameters in IBM-2 are listed in the table (2). From the table the value ($C_{0\pi} = C_{2\pi} = 0,2$), ($C_{4\pi} = -0.1$) and ($C_{4\nu} = 0.20$) for all isotopes. The calculated energy spectrum of the $^{226-234}\text{Th}$ nuclei is shown in Figures (1-5).

As for the energy ratios are calculated to confirm these isotopes belong to rotation limit and shown in the table (3), and the agreement between three values for the ratio ($\frac{E_{4_1^+}}{E_{2_1^+}}$).

Energy Levels

From table (1) Note that variable (a_2) in (IBM-1) increases with increasing number of neutrons which move away from the closed shell (126) this shows to increase the amount of deformation in the nucleus, this is consistent with experimental results. As we note from the table (2) for values used in (IBM-2) to the variable values (E_d) below with the number of neutrons and also the increase in a variable (K) this means a perfect match for variables used in the models with the nature of the deformation in nuclei studied. The figures (1-5), we note the correspondence between the values calculated by the models for the ground band as well as for levels ($0_2, 2_2, 4_2$) in a beta band with levels in the two models did not appear experimental data consequences and that proof of ability in analyzing levels of nuclei under study. Convergence results of two models emphasize the isotopes eariler in rotational limit SU(3).

Table 1: The Parameters of the IBM-1 Hamiltonian for $^{226-234}\text{Th}$ Isotopes, All Parameters

Nucleus	N	ϵ	a_0	a_1	a_2	a_3	a_4	CHI	SO6
$^{226}_{90}\text{Th}$	136	0.0	0.0	0.0055	-0.0165	0.0	0.0	-1.3	1
$^{228}_{90}\text{Th}$	138	0.0	0.0	0.0040	-0.0155	0.0	0.0	-1.22	1
$^{230}_{90}\text{Th}$	140	0.0	0.0	0.0048	-0.0102	0.0	0.0	-1.31	1
$^{232}_{90}\text{Th}$	142	0.0	0.0	0.0043	-0.0105	0.0	0.0	-1.32	1
$^{234}_{90}\text{Th}$	144	0.0	0.0	0.0040	-0.0109	0.0	0.0	-1.32	1

Table 2: The Parameters of the IBM-2 Hamiltonian for $^{226-234}\text{Th}$ Isotopes, $CHP = 1.32$ all Parameters are in MeV Unit Except CHN and CHP Which are Dimensionless

Nucleus	N_v	N_π	ϵ_d	κ	CHN	C_{0v}	C_{2v}	F_s	F_k
$^{226}_{90}\text{Th}$	5	4	0.065	-0.155	1.22	0.40	0.50	-0.160	-0.40
$^{228}_{90}\text{Th}$	6	4	0.060	-0.174	1.22	0.40	0.60	-0.160	-0.40
$^{230}_{90}\text{Th}$	7	4	0.055	-0.140	1.32	0.45	0.60	-0.160	-0.48
$^{232}_{90}\text{Th}$	8	4	0.040	-0.140	1.30	0.35	0.50	-0.174	-0.51
$^{234}_{90}\text{Th}$	9	4	0.040	-0.137	1.32	0.45	0.53	-0.165	-0.50

Table 3: The Energy Ratios are Calculated and Experimental Data

Nucleus	$\frac{E4_1^+}{E2_1^+}$	$\frac{E6_1^+}{E2_1^+}$	$\frac{E8_1^+}{E2_1^+}$	$\frac{E4_1^+}{E2_1^+}$	$\frac{E6_1^+}{E2_1^+}$	$\frac{E8_1^+}{E2_1^+}$	$\frac{E4_1^+}{E2_1^+}$	$\frac{E6_1^+}{E2_1^+}$	$\frac{E8_1^+}{E2_1^+}$
	EXP.			IBM-1			IBM-2		
²²⁶ ₉₀ Th	3.33	7	12	3.13	6.19	10.27	3.15	6.15	9.65
²²⁸ ₉₀ Th	3.33	6.99	11.99	3.23	6.54	10.77	3.15	6.11	9.52
²³⁰ ₉₀ Th	3.33	7	12	3.27	6.69	11.15	3.18	6.19	9.53
²³² ₉₀ Th	3.33	6.99	11.99	3.28	6.75	11.28	3.15	6.07	9.02
²³⁴ ₉₀ Th	3.33	6.99	11.99	3.29	6.79	11.39	3.21	6.41	10.19

Figure 1: Comparison between Calculated Energy Levels by IBM-1 and IBM-2 with Experimental Data in ²²⁶Th Isotope

Figure 2: Comparison between Calculated Energy Levels by IBM-1 and IBM-2 with Experimental Data in ²²⁸Th Isotope

Figure 3: Comparison between Calculated Energy Levels by IBM-1 and IBM-2 with Experimental Data in ²³⁰Th Isotope

Figure 4: Comparison between Calculated Energy Levels by IBM-1 and IBM-2 with Experimental Data in ^{232}Th Isotope

Figure 5: Comparison between Calculated Energy Levels by IBM-1 and IBM-2 with Experimental Data in ^{234}Th Isotope

Figure 6: Comparison between Calculated Energy Levels for Ground Band by IBM-1 and IBM-2 with Experimental Data

Figure 7: Comparison between Calculated Energy Levels for Beta Band by IBM-1 and IBM-2 with Experimental Data

Figure 8: Comparison between Calculated Energy Levels for Gamma Band by IBM-1 and IBM-2 with Experimental Data

Electromagnetic Transition

The reduced electric transition probability $B(E2)$ is calculated in the (IBM-1) model after the select the values of variables (β , γ) consistent with experimental values to transition ($2_1^+ \rightarrow 0_1^+$), where we choose a value ($\beta = 0.05$) while values (γ) was worth (0.2567–0.2339 – 0.2352–0.2184 –0.1942), respectively. In (IBM-2) model calculate the transition probability depended to found the matrix elements are calculated by the program and then the transition probability calculate from equations (11.13) after selecting the values of the effective charges (e_π , e_ν) using the following relationship [25]:

$$B(E2: 2_1^+ \rightarrow 0_1^+) = \frac{(2N+3)(e_\pi N_\pi + e_\nu N_\nu)}{5N} \quad (16)$$

To identify the effective charges of proton and neutron, we used the equation (16) for isotopes (²²⁶Th, ²²⁸Th) with experimental values to transition ($2_1^+ \rightarrow 0_1^+$), where he found that the values ($e_\pi = 0.5$) ($e_\nu = 0.13$), experimental and theoretical values calculated are shown in tables (4,5). Either the magnetic transition probability $B(M1)$, there are no experimental values for transitions is described and the program (IBM-1) cannot calculate this probability of transition (M1) is proportional to the angular momentum.

In (IBM-2) the magnetic transition probability is calculated by equations(12, 14) after we the selector two g- factor from the equation:[26]

$$g = g_\pi \frac{N_\pi}{N_\pi + N_\nu} + g_\nu \frac{N_\nu}{N_\pi + N_\nu} \text{ where } g = \frac{Z}{A} \quad (17)$$

Where the values for g- factor were ($g_\pi = 0.4419$) ($g_\nu = 0.3632$), respectively. The experimental and calculation values of the magnetic transition probability were listed in the table (6).

Table 4: Experimental and Calculated $B(E2)$ (In Unit $e^2 b^2$) for ²²⁶⁻²³⁰Th Isotopes

$J_i^+ \rightarrow J_f^+$	²²⁶ ₉₀ Th			²²⁸ ₉₀ Th			²³⁰ ₉₀ Th		
	B(E2)			B(E2)			B(E2)		
	EXP	IBM-1	IBM-2	EXP	IBM-1	IBM-2	EXP	IBM-1	IBM-2
$2_1^+ \rightarrow 0_1^+$	1.3411	1.3414	1.4921	1.3818	1.3819	1.4785	1.6407	1.6405	1.4629
$2_2^+ \rightarrow 2_1^+$		0.1008	0.0254		0.0926	0.0669			0.0470
$2_3^+ \rightarrow 2_1^+$			0.0123			0.0139			0.0138
$3_1^+ \rightarrow 2_1^+$		0.1064	0.2087		0.0989	0.0411		0.1053	0.0522
$4_1^+ \rightarrow 2_1^+$		1.8656	1.9370		1.9313	1.8954		2.3010	1.8828
$4_2^+ \rightarrow 2_1^+$		0.0304	0.0772		0.02828	0.1047		0.0306	0.1128
$4_2^+ \rightarrow 2_2^+$		0.6330	1.0387		0.6670	0.9923			0.9789
$4_2^+ \rightarrow 4_1^+$		0.1108	0.0434		0.1042	0.0516		0.1105	0.0562

Table 5: Experimental and Calculated B(E2) (In Unit e^2b^2) for $^{232-234}\text{Th}$ Isotopes

$J_i^+ \rightarrow J_f^+$	$^{232}_{90}\text{Th}$			$^{234}_{90}\text{Th}$		
	B(E2)			B(E2)		
	EXP	IBM-1	IBM-2	EXP	IBM-1	IBM-2
$2_1^+ \rightarrow 0_1^+$	1.6767	1.6766	1.5677	1.5675	1.5674	1.4296
$2_2^+ \rightarrow 2_1^+$	0.0004		0.0571			0.0637
$2_3^+ \rightarrow 2_1^+$			0.0161			0.0148
$3_1^+ \rightarrow 2_1^+$		0.0956	0.0360		0.0777	0.0465
$4_1^+ \rightarrow 2_1^+$		2.3582	1.7649		2.2095	1.8484
$4_2^+ \rightarrow 2_1^+$		0.0280	0.1314		0.0229	0.1262
$4_2^+ \rightarrow 2_2^+$			0.9626			0.9999
$4_2^+ \rightarrow 4_1^+$		0.1004	0.0616		0.0815	0.0650

Table 6: The Calculated Values B(M1) by(IBM-2)(In Unit μ_N^2) for $^{226-234}\text{Th}$ Isotopes

$J_i^+ \rightarrow J_f^+$	$^{226}_{90}\text{Th}$	$^{228}_{90}\text{Th}$	$^{230}_{90}\text{Th}$	$^{232}_{90}\text{Th}$	$^{234}_{90}\text{Th}$
	B(M1)				
$2_2^+ \rightarrow 2_1^+$	0.0000749	0.0000527	0.0000351	0.0000242	0.0000019
$2_3^+ \rightarrow 2_1^+$	0.00008487	0.0000842	0.0000355	0.0000145	0.0000194
$3_1^+ \rightarrow 2_1^+$	0.0002012	0.0000174	0.0000012	0.0000018	0.00000007
$4_2^+ \rightarrow 4_1^+$	0.0001816	0.0001480	0.0001113	0.0000804	0.0000066

Electric Quadrupole Moment

From equation (15), we can be the calculated the electric quadruple moment by using the experimental and calculation values of transition probability for transition ($2_1^+ \rightarrow 0_1^+$), these values listed in the table (6).

Table 7: Experimental and Calculated Q (In Unit efm^2) for $^{226-234}\text{Th}$ Isotopes

Nucleus	$Q(E2: 2_1^+ \rightarrow 0_1^+)$		
	EXP.	IBM-1	IBM-2
$^{226}_{90}\text{Th}$	-1.0748	-1.0492	-1.1065
$^{228}_{90}\text{Th}$	-1.0648	-1.0649	-1.1015
$^{230}_{90}\text{Th}$	-1.1603	-1.1602	-1.0956
$^{232}_{90}\text{Th}$	-1.1730	-1.1729	-1.1342
$^{234}_{90}\text{Th}$	-1.1341	-1.1341	-1.0831

CONCLUSIONS

In the present paper, the IBM-1 and IBM-2 models are used for the calculation of the energy levels, ratios ($\frac{E_{4_1^+}}{E_{2_1^+}}$), transition probability and quadruple moment for Th isotopes, where the shape nuclei in these isotopes are deformation nuclei lie in SU(3) limit. This investigation increases the theoretical knowledge of these isotopes the theoretical results have a satisfactory agreement with the available experimental data.

REFERENCES

1. E. Grosse, F. S. Stephens, and R. M. Diamond, *Phys. Rev. Lett.* 31, (1973) 840.
2. A. Arima and F. Iachello, *Ann. Phys. (N. Y.)* 99, (1976) 253.
3. A. Arima and F. Iachello, *Ann. Phys. (N. Y.)* 111, (1978) 201.
4. A. Arima and F. Iachello, *Phys. Bev. Lett.* 40, (1978) 201.

5. P. Van Isacker and G. Puddu, *Nucl. Phys.* A348, (1980) 125.
6. A. Sevrin, K. Heyde, and J. Jolie, *Phys Rev.* C36, (1987) 2621.
7. Ka-Hac Kim, Adrian Gelberg, Takkahiro Mizusaki, Takaharu Otsuka, and Peter Von Brentano, *Nucl. Phys.* A604, (1996) 163.
8. F. Iachello and A. Arima, *The Interacting Boson Model*, Cambridge University Press, Cambridge, England (1987).
9. H. Ower, Th. Elze, J. Idzko, K. Stelzer, H. Emling, P. Fucks, E. Grosse, D. Schwalm, H. Wollersheim, N. Kaffrell, et. al., *HAL Id: jpa- 00220630*, 1980.
10. Lian- Ao Wu and Hiroshi Toki, *Phys. Rev.* C56, (1997).
11. S. Kuyucak and S. C. Li, *Nucl. – th*, 9506002.
12. V. P. Garistov, Al. Georgieva, A. T. Solnyshkin, *Nucl. Theor. Vol.* 31, (2012).
13. P. Jaclimowicz, M. Kawa, and J. Skalaki, [*nucl. – th*], VI, (2013).
14. A. M. Khalaf, M. M. Sirag and M. Kotb, *Commun Theor. Phys.* 64, (2015) 90-94,.
15. Walter Pfeifer. “An Introduction to The Interacting Boson Model of The Atomic Nucleus” (1998).
16. A. R. Subber. W. D. Hamilton, P. Van Isacker and Scherckenbach. *J. phys. G. nucl. phys.* 14, (1978)p(87)
17. J. N. Ginocchio and M. W. Kirson” relationship between the Bohr collective Hamiltonian and the Interacting boson model”, *Phys. Rev. Lett.* 44, (1980) 1744.
18. A. E. L. Dipernik, O. Scholten and F. Iachello,” Classical limit of the Interacting boson model”, *Phys. Rev. Lett.* 44, (1980) 1747.
19. K. Abrahams, k. Allaart and A. E. L. Dieperinnk “Nuclear structure” *B. Phys.* 67, (1981) 53.
20. M. J. A. V. H. Ejiri, "Gamma-Ray and Electron Spectroscopy in Nuclear Physics" Oxford Science Publications, (1989).
21. S. J. Q. Robinson, A. Escuderos, L. Zamick et al, *Phys. Rev.* C73, (2006) 037306.
22. O. Scholton. "The program – package, PHINT, Kernfysish Versneller institute (Groningen) KVI-63" (1979).
23. T. Otsuka and N. Yoshida, Program NPBOs, Japan Atomic Energy Research Institute Report JAERI-M85-094, (1985).
24. ENSDF 2014 Nuclear Data sheet, www.nndc.bnl.gov/ensdf.
25. P. ValSacker, K. Heyder, J. Lolie and A. Seyrin, *Ann of phys.* Vol. 171, no. (15), (1986) (253 - 296).
26. C. Goodin, J. R. Stone, N. J. Stone, A. V. Ramayya, A. V. Daniel, J. H. Hamilton, K. Li, J. K. Hwang, G. M. Ter- Akopian and J. O. Rasmnssen *phys. Rev. C* 79, (2009) 034316.
27. Akila, E., Usharani, M., & Rajavel, R. (2013). Inspired Research on the DNA Binding and Cleavage Ability: Design, Synthesis, Characterization and Properties of Their Dinuclear Metal (II) Complexes. *International Journal of Bio-Technology and Research*, 3(2), 61-70.