Transition Strengths $|M(E2)|^2$ for γ- Transition in Even $_{56}$Ba Nuclei 122 ≤A≤146

Zahida Ahmmed Dakhil   Fatima Abdel Amir Jassim
Physiscs Department College of Science Physics Department ,College of Education University of Baghdad Baghdad (Ibn Al-Haithem), University
Yousif Hashem Jaber
Physics Department ,College of Education
(Ibn Al-Haithem), University of Baghdad

Abstract:

Transition strength $|M(E2)|^2$ for gamma transition from excited 2^+ states to the ground states 0^+ that produced by pure electric quadruple emission for even –even nuclei such as $_{56}$Ba nuclide with $122 \leq A \leq 146$
have been calculated as a function of neutron number (N) .Gamma ray intensities for γ_o -transitions with half life times for the 2^+ states reported in ref .[2] are used together with γ_o -energy .The results thus obtained are shown the isotopes with magic neutron number N=82 has minimum values for $|M(E2)|^2$ for γ_{o}- transition . The good agreement of the reduced transition probability B(E2) e^2 b^2 values calculated in the present work with those of experiment in ref . [7] , are provided the most accurate results for comparison with the values predicted by different nuclear models.

Introdiction:

The Electromagnetic transition nuclei have a powerful tool for nuclear structure. The study of electromagnetic transition & strengths in nuclei provides a valuable information on the ability of current models to describe details of nuclear structure and transition properties. Measurements of the electric quadruple transition strengths $|M(E2)|^2$ for gamma transitions in even – even nuclei provide important tests to nuclear-models. The experimental $|M(E2)|^2$ for transitions in even – even nuclei have been surveyed to provide accurate results for comparisons with theoretical calculations based on different nuclear– models , especial for even –even nuclei included isotopes with neutron magic number .

THEORY

The partial width of γ – ray transition from an initial state with spin J_i to final state with spin J_f is given by Ref. [1];

$$\Gamma_{\gamma i} = \frac{8\pi[(l+1)]}{l[(2l+1)!!]^2}\left[\frac{E_\gamma}{\hbar c}\right]^{2L+1} B(L) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where

$\hbar = \text{Dirac constant} = \frac{h}{2\pi}$, $h = \text{plank constant}$

C= spead of light

E_γ = Gamma energy

L= angular momentum of the γ – transition, $L \neq 0$

B (L) = Reduced transition probability

The weisskopf single –particle reduced transition probability is defined in Ref. [2] by:

$$B(EL)(W.u) = \frac{t^{\gamma}{}_{1/2}(EL)_{sp}}{t^{\gamma}{}_{1/2}(EL)_{exp}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

Partial half life

$t^{\gamma}{}_{1/2} =$ for γ-ray transition

If the total width is

$$\Gamma_\gamma = \sum \Gamma_{\gamma i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Then $\Gamma_\gamma T = \hbar = 0.65822\times10^{-15}\,\text{eV.s}$ ………………...………………(4)

Where T is the mean life time of initial state $= \frac{\tau_{1/2}}{\ln 2}$ …………….…….(5)

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The γ –ray transition strength $[M]^2$ is defined as [1]

$[M]^2 = \frac{\Gamma_\gamma}{\Gamma_{\gamma w}}$ Weisskopf unit (W.u)……………..…………………..(6)

$\Gamma_{\gamma w} =$ Width in weisskopf unit

By using single particle model, weisskopf derived the following relation $\Gamma_{\gamma w}[(E2)]$ for

………………………...…………..(7) $\Gamma_{\gamma w}(E2) = 4.790\times10^{-23} A^{4/3} E_\gamma{}^5$

Where A is nuclear mass number, $E_\gamma$in KeV, $\Gamma_{W.u}$ in eV .

For γ- transition with mixed multi polarities L and L+1 and by theoretical calculation from Ref. [2]

……………………………………….…………………..(8) $\delta^2 = \frac{\tau_{1/2}(\gamma)^{l}}{\tau_{1/2}(\gamma)^{l+1}}$

Where δ is the mixing ratio by using Eq.(4) and (5)

$$\delta^2 = \frac{\Gamma(l+1)}{\Gamma(l)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where Γ (L) +Γ (L+1) =Γ_γ ……………………………………….. (10)
Partial width of each γ –ray can be calculated as follows Ref. [3]
BRi×Γ_γ ………………………………………(11) $_{\gamma i}$ =Γ
BR_i the branching ratio of (γ_i) can be calculated as in Ref. [4] form:

$$BR(\gamma_i) = \frac{I_{\gamma I}}{I_{tot}} \times 100 \,{}^{0}\!/\!_{0}$$ ………………………………………. (12)

$I_{\gamma i}$ = the relative intensity of γ_i

∑ I_i (summation for all γ, s dexcit certain level)
Also the square of the mixing ratio δ^2 may be defined as follows [4]:

$$\delta^2 = \frac{I_{\gamma i}(L+1)}{I_{\gamma i}(L)}$$ ………………………...…(13)

I_γ (L)+ I_γ (L+1)= I_γ …………….............……………………………..(14)

For pure E2 transition, δ =0and hence
Γ(E) =Γ_γ …………………………………………………….…….(15)
And the transition strength of this transition .can be calculated by using Eq.(6), the corresponding $\Gamma_{W.u}$ (E2) values calculated for the transition .
So that the Eq.(6) can be then used in the form of
4

$$[M(E2)]^2 = \frac{\Gamma(E2)_{esp}}{\Gamma(E2)_{W.u}}$$ …………………………………..(16)

From the relations (2) ,(4) and (16) for E2 transition can be calculated ; the ratio values for single – particle half – life to the experimental half –life can be considered as the ratio values for the experimental gamma width to the gamma width calculated in weisskopf unit.

The Relation Between B (E2) e^2 b^2 ↑, B (E2) e^2 b^2 ↓
and $|M(E2)|^2_{W.u}$

The relation between B(EL)↑ and B(EL)↓ is given by ref .[5] :-

………………………………(17) $$B(E2)\uparrow = \frac{(2J_f+1)}{(2J_i+1)} B(EL)\downarrow$$

In the case of an E2 transition between ground state o^+_{gs} and the first excited state 2^+ the Eq.(17) can be written in the form

$B(E2, 0^+_{gs} \rightarrow 2^+_1) \uparrow = 5\times B(E2, 2^+ \rightarrow o^+_{gs}) \uparrow$............................(18)

While the relation of B(EL) in $e^2 b^2$ unit with the B(EL) in W.u is given by [6] ;

For E2 transition, 23.96 e^2 fm4 =1W.u.. (19)

For E1 transition, 1.29 e^2 fm^4 = 1W.u.. (20)

Where;

$Fm^4 = 10^{-4}\ 1b^2$

So

$B(E2)\ e^2 b^2 = 23.96 \times 10^{-4}\ B(E2)_{W.U}$

Hence from Eq.(18) and (19)

$B(E2)\ e2\ b^2 \uparrow = 5 \times 23.96\ 810^{-4}\ B(E2)_{W.u} \downarrow$

or

$B(E2)\ e^2 b^2 \uparrow = 5\times 23.\ 96 \times 10^{-4}\ \left|M(E2)\right|^2_{W.u} \downarrow$ …………………(21)

or

$$M^2_{w.u.}(E2) = \frac{16.8}{A^{4/3}} \cdot \frac{B(E2)}{e^2.fm^4} = \frac{16.8\times10^4}{A^{4/3}} \cdot \frac{B(E2)}{e^2b^2} \qquad \text{…………………(22)}$$

CALCULATIONS AND RESULTS

The transition strengths $|M(E2)|^2_{W.u}$ for γ -turansition from first excited 2^+states to the ground states 0^+ that produced by pure electric quadruple transition as a function of neutron number in $_{56}$Ba nuclei with calculated as follows: $122 \leq A \leq 146$

1- Mean life times τ_m for excited states calculated by Eq.(5) from half life times related to those states measuring by ref . [2] are presented in table (1) togather with total gamma widths Γ_γ calculated by Eq.(4) .

2- The partial γ - width Γ(E2) for γ-transitions is calculated as follows :-

According to the electromagnetic γ - transition selection rules for parity and total angular mome there is only one transition for gamma from $J^\pi = 2^+$ state to $J^\pi = 0^+$ state is γ_0 with intensity (100%) E2 for each even nuclide under consideration . According to Eq.(11and 12) the values of gamma width Γ_γ for $2^+ \rightarrow o^+$ can be considered as pure Γ (E2) values for γ_0 -transitions .

3- The partial gamma widths Γ(E2) in W.u were calculated for γ_0 - transition using Eq.(7)are listed column 8 from table (1) .

4- The transition strength. $\left|M(E2)\right|^2_{w.u.} \downarrow$ for each γ_0 –transition was then calculated by dividing the partial width Γ(E2) by the corresponding partial gamma width in W.u $\Gamma_{W.u}(E2)$ Eq .(16) was used ,the results

Thus obtained are presented in table (2) For Convince the Γ(E2) valus are also presented in table(2).

5- The transition strength are plotted as a function of neutron number (N) for $_{56}$Ba nuclei as shown in Fig (1) .

6- For the sake of comparison, the transition strengths $|M(E2)|^{2}_{w.u.}\downarrow$ values are converted to reduced transition probabilities B (E2) e2 b$^2\uparrow$ using Eq.(21) or Eq(22).
7- The calculated B(E2) e^2 $b^2\uparrow$values of γ_0 -transitions for $_{56}$Ba nuclei are compared with the experimental values as well as with other various theoretical models ref .[7] . This comparison are tabulated in table (3)
8- The B(E2) e^2 $b^2\uparrow$ values are plotted as a function of neutron number (N) with the comparison (in7) as in Fig (2) . Fig (2) includes two part ; A for present work with experimental and Global Best Fit (GLOBAL)

Data ref .[7] and B for comparison with the prediction values from Single – Shell Asymptotic Nilson Model (SSANM) and Finit – Range Droplet Model (FRDM) ref .[7] .

Discussion:

In view of tables (1) one can point out that the experimental values of partial gamma widths Γ(E2) are larger than that estimated by Weisskopf unit $\Gamma_{W.u}$(E2) especially when the nucleon number deviated more and more from the magic neutron number ,since the cooperative effects appear between nucleons and the rotational motion must be taken in regard .Also, it appears that the single particle shell model is valid
Particularly near the closed shell, minimum difference between
Γ (E2) and $\Gamma_{W.u}$(E2) occurs at magic neutron number so that the calculated for $_{56}$Ba $|M(E2)|^{2}_{w.u.}\downarrow$ Nuclei which are shown in Fig .(1) is
reproduce the diffraction minimum at the magic neutron number N= 82.

The discrepance of the calculated $|M(E2)|^{2}_{W.u}\downarrow$ for $2^+\rightarrow 0^+$ transition
from 196.1 KeV level in $^{122}_{56}Ba$ is indication that the half life times for 2^+
State reported in ref . [2] is inaccurate and the values of $|M(E2)|_{W.u}{}^{2}\downarrow$
may be ruled out .

The behavior for B (E2) e^2 $b^2\downarrow$ versus neutron number (N) for $_{56}$Ba nuclei Fig(2) A, B can be discussed as this , in part A the present results (black solid curve) to gather with GLOBAL (blue solid curve) are in good agreement with the experimental data ref .[7]. The observed location of the diffraction minimum is very well reproduced at N=82 for these curves .

The part B of this Figuer shown the comparison of the present results of B(E2) (black-solid curve) with GLOBAL (blue –solid curve) , SSANM (red solid curve) and with FRDM (green –solid curve) ref .[7] , the present results with the other results seen to be in good behavior at all region of N and close to each other , the observed diffraction minimum are very well reproduced by all models except for FRDM results.

Conclusions

The transition strengths $|M(E2)|^2$ values is experimental quantity that do not depend on nuclear models . It can be calculated if the mean or half life times for first excited 2_1^+ states with intensities of γ_0 – transition have been calculated . The present work is provided a compilation of experimental values of B(E2) $e^2 b^2 \uparrow$to $_{56}$Ba nuclei with $122 \leq A \leq 146$ for comparison with experimental values extracted from half –lives corrected for internal conversion ref .[8] and with the values are predicted by theoretical model

Table (1) : Experimental value for $_{56}$Ba isotopes reported in ref. [2] [mass number A, neutron number N, initial energy E_i half life times for initial level $t_{1\backslash 2}$ and γ–energy $E_{\gamma 0}$] are used in present work

Ref. [2]							
A	N	E_i(kev)	$E_{\gamma 0}$(kev)	$t_{1/2}$(Ps)	τ_m (Ps)	Γ_{tot}($\times 10^{-6}$)eV	$\Gamma(E2)_{W.u}$ ($\times 10^{-6}$)eV
122	66	196.1	196.1	0.297±0.027	0.42857 ± 0.039	1535.828±139.620	0.0084
124	68	229.89	229.9	297 ± 26	428.571 ± 37.518	1.5358 ±0.1344	0.01902
126	70	256.09	256.1	108 ± 4	155.844 ± 5.772	4.2235 ± 0.1564	0.03333
128	72	284	284	100 ± 4.5	144.3 ± 6.4935	4.5614 ± 0.2052	0.05709
130	74	357.38	357.41	37 ± 4	53.3911 ± 5.772	12.3281±1.3327	0.18392
132	76	464.588	464.55	15.1 ± 1.1	21.7893 ± 1.5873	30.2080±2.2005	0.6969
134	78	604.723	604.72	5.12 ± 0.09	7.38817 ± 0.1299	89.09 ± 1.5660	2.6565
136	80	818.515	818.514	1.93 ±0.015	2.78499 ± 0.0216	236.3424±1.8368	12.3097
138	82	1435.82	1435.795	0.195±0.005	0.28139 ± 0.0072	2339.184±59.979	208.4817
140	84	602.35	602.35	9.7±4.1	13.9971 ± 5.9163	47.0248 ±198764	2.7615
142	86	354.597	354.598	66 ± 44	95.2381 ± 5.772	6.9112± 4.188	0.21338
144	88	199.32	199.326	700± 30	1010.1 ± 43.29	0.6516 ±0.0279	0.01137
146	90	181.05	181.02	860 ± 30	1240.98 ± 43.29	0.5303± 0.0185	0.00715

Table (2): Transition strengths $|M(E2)|^2_{W.u}\downarrow$ of γ_0 - ray from excited levels of $_{56}$Ba nuclei

Ref [2]					
Mass number A	N	E_i (keV)	$E\gamma_0$ (keV) $2^+ \rightarrow 0^+$	$\Gamma(E2)_{exp}$ ($\times 10^{-6}$) eV .	$[M(E2)]^2_{W.u}\downarrow$
122	66	196.1	196.1	1535.828 ± 139.620	182702 ± 16609
124	68	229.89	229.89	1.53583 ± 0.134	80.745 ± 7.069
126	70	256.09	256.09	4.22353 ± 0.156	126.71 ± 4.693
128	72	284	284	4.56141 ± 0.205	79.89 ± 3.595
130	74	357.38	357.38	12.3281 ± 1.333	67.028 ± 7.246
132	76	464.59	464.55	30.208 ± 2.201	43.346 ± 3.158
134	78	604.723	604.721	89.09 ± 1.566	33.536 ± 0.589
136	80	818.52	818.51	236.342 ± 1.837	19.2 ± 0.149
138	82	1435.8	1435.79	2339.18 ± 59.98	11.22 ± 0.288
140	84	602.35	602.35	47.0248 ± 19.88	17.029 ± 7.198
142	86	359.59	359.59	6.91123 ± 0.419	32.389 ± 1.963
144	88	199.326	199.326	0.65163 ± 0.028	57.275 ± 2.455
146	90	181.05	181.02	0.5304 ± 0.019	74.03 ± 2.582

Table (3): The present reduced transition probabilities B (E2) e2 $b^2\uparrow$ values are compared with the of experimental, Global best fit and, theoretical predications for $_{56}$Ba nuclei.

A	N	E_{γ_0} (keV)	B(E2; $2^+_1 \rightarrow 0^+_1$) $e^2 b^2$				
			Experimental of Ref[31]	Theoretical			
				Present work	Global Best fit of Ref[31]	SSANM	FRDM
118	62	194			1.72 ± 0.30	1.882	2.448
120	64	183			1.82 ± 0.32	1.881	2.254
122	66	196	2.81 ± 0.28	(3289.63±299.05)	1.67 ± 0.29	1.854	2.06
124	68	229	2.09 ± 0.10	1.486± 0.130	1.41 ± 0.25	1.821	2.031
126	70	256	1.75±0.09	2.382±0.088	1.25 ±0. 22	1.787	1.753
128	72	284	1.48 0.07	1.533± 0.690	1.11 ± 0.19	1.595	1.287
130	74	357	1.163±0.016	1.313± 0.142	0.88 ± 0.15	1.336	0.797
132	76	464	0.86 ±0.06	0.867 ± 0.063	0.67 ±0.12	1.092	0.555
134	78	604	0.658±0.007	0.684± 0.012	0.51 ±0.09	0.874	0.281
136	80	818	0.410±0.008	0.400± 0.065	0.37 ± 0.06	0.682	< 0.001
138	82	1435	0.230±0.009	0.238 ± 0.006	0.210±0.037	0.468	< 0.001
140	84	602	0.45±0.19	0.368± 0.156	0.50 ± 0.09	0.907	< 0.001
142	86	359	0.699±0.037	0.714 ± 0.021	0.82 ± 0.14	1.256	0.631
144	88	199	1.05 ±0.0 6	1.286± 0.055	1.47 ± 0.26	1.634	0.989
146	90	181	1.355±0.048	1.694± 0.059	1.60 ±0.28	1.886	1.584
148	92	141			2.03 ± 0.35	2.115	2.467

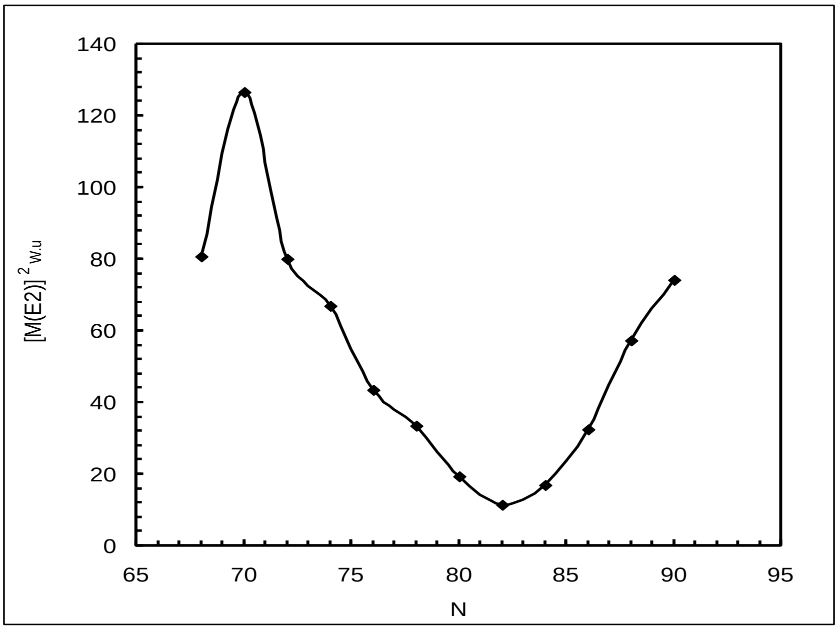


Fig (1): Transition strengths the $|M(E2)|^2_{w.u}$for γ_0-transition as a function of neutron number (N) in ${}_{56}$Ba nuclei

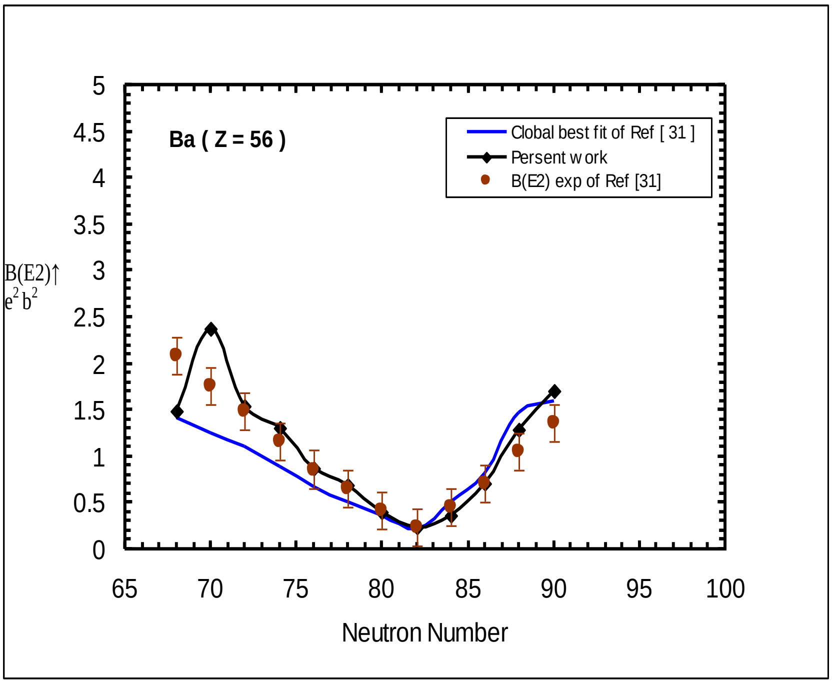
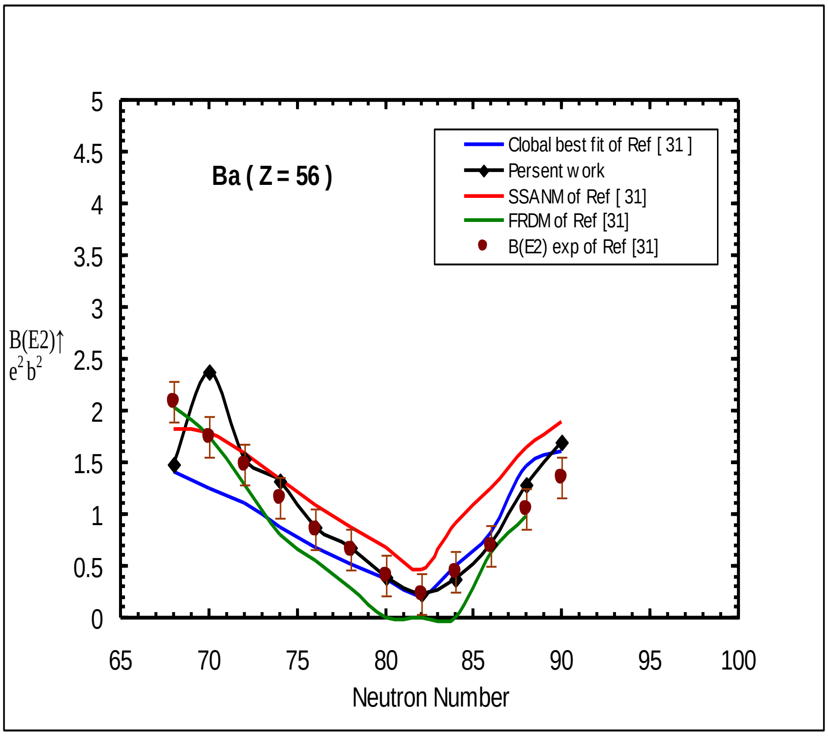


Fig (2) : Comparison between the B(E2) ↑ values of the present work for ($_{56}$Ba) nuclei with (A) Global and experimental (B) other theoretical models



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قوى الانتقال $|M(E2)|^2$ لاشعة كاما لنوى الباريوم الزوجية ذات العدد الكتلي (146-122)

زاهدة احمد دخيل جامعة بغداد - كلية العلوم - قسم الفيزياء
فاطمة عبد الأمير جاسم جامعة بغداد - كلية التربية(ابن الهيثم) - قسم الفيزياء
يوسف هاشم جابر جامعة بغداد - كلية التربية(ابن الهيثم) - قسم الفيزياء

الخلاصة :

تم في هذا البحث حساب قوى الانتقال $|M(E2)|^2$ لانتقالات أشعة كاما من المستوي المتهيج الأول 2^+ إلى المستوي الأرضي والناتج عن إشعاع رباعي قطب كهربائي نقي للنظائر الزوجية لنواة الباريوم $_{56}Ba$ حيث $122\leq A\leq 146$ كدالة إلى عدد نيوترونات النظير (N) وذالك بالاعتماد على حساب معدل العمر للمستوي المتهيج الأول 2^+_1 وعلى الشدة النسبية لأشعة كاما المنتقلة في ذالك المستوي وكذالك بالاعتماد على طاقة اشعة كاما المنتقلة بين المستويين γ_o حيث برهنت النتائج التي تم الحصول عليها لأشعة كاما ان نظير الباريوم الذي له العدد النيتروني السحري $N=82$ يمتلك اقل قيمة لقوة انتقال كاما . ان التوافق الجيد بين قيم احتمالية الانتقال المختزل $B(E2)$ والتي تم حسابها في بحثنا الحالي وبين القيم المنشورة في المصدر [7] تعطي دعما كافيا لتقديم نتائجنا الحالية للمقارنة مع النتائج التي يتم الحصول عليها من الموديلات النووية النظرية .