The electric quadrupole moment and the effective charge of even–even Sm(A=150 -154) isotopes

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Abstract

In the present work, the interacting boson model (IBM-1) was used in the calculations of the energy levels, energy ratios, electric quadrupole transitions probability B(E2), and their reduced matrix elements $\langle I_f \| \hat{T}^{(E2)} \| I_i \rangle$ for even-even of Sm (A=150-154). The dynamical symmetries SU(5)-O(6) and SU(5)-SU(3) for the isotopes under study have been determined. Through electric quadrupole moments $Q_{2_1^+}, Q_{2_2^+}$ state for ^{154}Sm have a prolate shape and the isotopes rest have an oblate shape, while 2_2^+ state have an oblate for ^{150,154}Sm .The program (IBSS1. For) and (IBMTT. For) were they had been written in fortran 77 used in the present calculations to calculate the eigen values, eigen vectors electric quadrupole probability B(E2), reduced matrix elements of the electric quadrupole $\langle I_f \| \hat{T}^{(E2)} \| I_i \rangle$ as a function of the boson effective charge (α_2,β_2). Our results confirmed good agreement for with available experimental data.

الزخم الرباعي الكهربائي و الشحنه الفعاله لنظائر (A=150−154) Sm الزوجيه – زوجيه

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المستخلص

في البحث الحالي استخدم نموذج البوزونات المتفاعله الاول (IBM−1) احتمالية الانتقالات الكهربائيه رباعية القطب B(E2) وحساب عناصر المصفوفه المختزله لمؤثر الانتقال الكهربائي لرباعي القطب $\langle I_f \| \hat{T}^{(E2)} \| I_i \rangle$ للنظائر الزوجية – زوجية ضمن الاعداد الكتليه Sm (A=150−154). واظهرت النتائج بان النظائر تنتمي الى التناظرات الديناميكيه SU(5)−O(6) و SU(5)−SU(3).

ومن خلال العزوم الكهربائيه $Q_{2_1^+}, Q_{2_2^+}$ تبين ان المستوي 2_1^+ للنظير ^{154}Sm يمتلك شكل متطاول (prolate) وبقية النظائر ذات المستوي 2_1^+ تمتلك الشكل المتقطع (oblate) بينما يتخذ المستوي 2_2^+ الشكل المتقطع (oblate) للنظير ^{150,154}Sm اما بقية النظائر المختاره فان 2_2^+ لها ، يمتلك الشكل المتطاول (prolate). وباستخدام برنامج (IBSS1.For) و برنامج (IBMTT.For)، اللذان تمت كتابتهما باستخدام لغة فورتران ٧٧ ،في حساباتنا الحاليه لحساب القيم الذاتيه (eigen values) والمتجهات الذاتيه (eigen vectors) و احتمالية الانتقالات الكهربائيه رباعية القطب B(E2) والمصفوفه المختزله لمؤثر الانتقال الكهربائي لرباعي القطب $\langle I_f \| \hat{T}^{(E2)} \| I_i \rangle$ كداله للشحنة الفعاله للبوزون (α_2,β_2). ونتائجنا اظهرت توافق جيد مع القيم العملية المتوفره.

1. Introduction

The nuclear spin is designated by a quantum number I such that the magnitude of the nuclear spin is $\hbar\sqrt{I(I+1)}$. The component of the nuclear spin in a given direction is given by $m_I \hbar$, where $m_I = \pm l, \pm(l-1), ... \pm 1/2, 0$ depending on whether I is a half – integer or an integer. Therefore there are 2I+1possible orientations of the nuclear spin. I are integers (if A is even) or half integer (if A is odd) ranging from zero or 1/2. All even – even nuclei have I=0, which indicates that identical nucleons tend to pair their angular moments in opposite directions. The electric quadrupole moment of a charge distribution relative to a given direction designated the Z-axis is defined by $Q' = \sum_i q_i (3z^2 - r_i^2)$.

In the nuclear case only the proton contribute to the electric quadrupole since $q_i = e$, we get $Q' = e\sum_p (3z_p^2 - r_p^2)$. Normally the nuclear quadrupole is defined as $Q = Q'/e$. Where Q is defined by:
$Q = \sum_p (3z_p^2 - r_p^2) m_i = I$.

If the protons are distributed with spherical symmetry, Q = 0, if Q is positive the nucleus must resemble a prolate ellipsoid and if Q is negative the nucleus must look like an oblate ellipsoid, when some nuclei have abnormally large electric quadrupole moments indication very large deformations[1, 2].

In the present work the IBM-1 has been used widely by different authors [5, 6, 7]. This model is assumed that low – lying collective states in medium and heavy even-even nuclei away from closed shells are denoted by excitations of valance protons and neutrons.

2. Theoretical part

2.1. Electromagnetic Transitions

The interacting boson model (IBM) is able to describe the electromagnetic rates, besides the excitation energy spectra. In order to do so, one has to specify the transition operators in terms of the boson operator will be [3]:

$$\hat{T}_m^L = \alpha_2 \left[\hat{d}^+ \otimes \hat{\tilde{S}} + \hat{S}^+ \otimes \hat{\tilde{d}}\right]_m^2 + \beta_L \left[\hat{d}^+ \otimes \hat{\tilde{d}}\right]_m^l + \gamma_0 \left[\hat{S}^+ \otimes \hat{\tilde{S}}\right]_0^0 \qquad (1)$$

where: γ_o, α_2, β_I = (I=0, 1, 2, 3, 4) are parameters specifying the various terms in corresponding operator of E0, M1, E2, M3, E4.

2.2. Electric Quadrupole Transition Operator $\hat{T}^{(E2)}$

The electric quadrupole transition operator has widespread applications in the analysis of gamma-ray transitions and can be obtained from equation (1) [4]:

$$\hat{T}^{(E2)} = \alpha_2 \left[\hat{d}^+ \otimes \hat{\tilde{S}} + \hat{S}^+ \otimes \hat{\tilde{d}}\right]_\mu^2 + \beta_2 \left[\hat{d}^+ \otimes \hat{\tilde{d}}\right]_\mu^{(2)} \qquad (2)$$

These transition operators obey the selection rules as follows [3]:

$$\left.\begin{array}{ll} SU(5): \Delta n_d = 0, \pm 1; \quad \Delta\upsilon = \pm 1; \quad \Delta n_\Delta = 0; & |\Delta I| \le 2 \\ SU(3): \Delta\lambda = 0; & \Delta\mu = 0 \\ O(6): \Delta\sigma = 0; & \Delta\tau = \pm 1 \end{array}\right\} \qquad (3)$$

Knowing the matrix elements, one can calculate the electromagnetic transition rates and moments. Electromagnetic transition rates are governed by B(E2) values. These are defined as [3]:

$$B(E2; I_i \rightarrow I_f) = \frac{1}{(2I+1)} \left| \left\langle I_f \left\| \hat{T}^{(E2)} \right\| I_i \right\rangle \right|^2 \qquad (4)$$

The quadruploe moments are defined by:

$$Q_{2_1^+} = \sqrt{\left[\frac{16\pi}{5}\right]} \begin{bmatrix} I & 2 & I \\ -I & 0 & I \end{bmatrix} \left\langle I_f \left\| \hat{T}^{(E2)} \right\| I_i \right\rangle \qquad (5)$$

2.3. Selection Rules of Gamma-Decay

The selection rule for electric transitions provides that the angular momentum, the parity of the initial and final states and multipolarity should obey the relations [4]:

$\Delta\pi = (-1)^{L+1}$ for magnetic transition (6)

$\Delta\pi = (-1)^{L}$ for electric transition (7)

Where (L) values must obey the condition:

$$\left|I_i - I_f\right| \le L \le (I_i + I_f) \qquad (8)$$

3. Results and discussion

The interacting boson approximation version one (IBM-1) has been used in this work to study the effect of the effective charge on the nuclear structure of the transitional nuclei from vibrational SU(5) to gamma – unstable O(6) dynamical symmetries of ${}^{150}_{62}\boldsymbol{Sm}_{88}$ or from rotational SU(3) to vibrational SU(5) to gamma-unstable O(6) dynamical symmetry of ${}^{152}_{62}Sm_{90}, {}^{154}_{62}Sm_{92}$ respectively .

To get more information about the nuclear structure of any isotope under studying we have to study the following:

3.1. Electric quadrupole moments Q_I

The deformed nuclei of prolate shape have a positive electric quadrupole moment ($Q_I > 0$), and the nuclei of oblate shape have a negative electric quadrupole moment ($Q_I < 0$). Table (1) shows the electric quadrupole moments of the ground level (2_1^+) and the excited states (2_2^+), also $Q4_1^+$, $Q4_2^+$, $Q6_1^+$ and $Q6_2^+$ according to their dynamical symmetry for Sm(A=150-154) isotopes. Table (1) listed the values of Q_I for the selected nuclei in the present work that have large electric quadrupole moments indicating very large deformations. Figure (1) shows that Q_I changes the states of nuclei Sm (A=150-154) between prolate and oblate shape. The theoretical $Q2_1^+$ values obtained for the Sm (A=150-145) are $Q2_1^+$= -0.1298, -2.2080, 1.7410, $Q2_2^+$ = 0.1175, -1.1249, -1.6090 respectively. Figure (1) The Q_L quadrupole moment as a function of atomic mass number for even-even Sm (A=150-145) isotopes.

The compilation of B(E2) values has helped to establish clearly the smooth dependence of nuclear deformations on the product $N_p.N_n$ of the valence protons and neutrons especially for heavier nuclei the main point to emerge from these comparisons is that the physical parameters governing the B(E2) values that increase with Np.Nn. Where the experiment B(E2) values showing saturation.

The nuclei lie in a region of transition from deformed shapes, corresponding to nuclei near the middle of the Z= 50-82 and N=82-126 shells, to spherical shapes. The nuclei of this region undergo a prolate – oblate transition as Z, N increase (before becoming spherical in the vicinity of Z=82, N=126). One indication of a prolate –oblate transition is the change of the sign of Q_2, the quadrupole moment of the first 2_1^+.The comparison of the theoretical.

Table (1): The theoretical values of electric quadrupole moments (pw) of even – even Sm (A=150 – 154) isotopes.

Q (eb)^2	${}^{150}_{62}Sm_{88}$	${}^{152}_{62}Sm_{90}$	${}^{154}_{62}Sm_{92}$
$Q2_1^+$	-0.1298	-2.2080	1.7410
$Q2_2^+$	0.1175	-1.2490	-1.6090
$Q4_1^+$	-0.1727	-2.5470	2.1490
$Q4_2^+$	0.09177	-1.4700	0.6812
$Q6_1^+$	-0.1525	-2.6380	2.4260
$Q6_2^+$	0.1391	-1.4480	1.3260

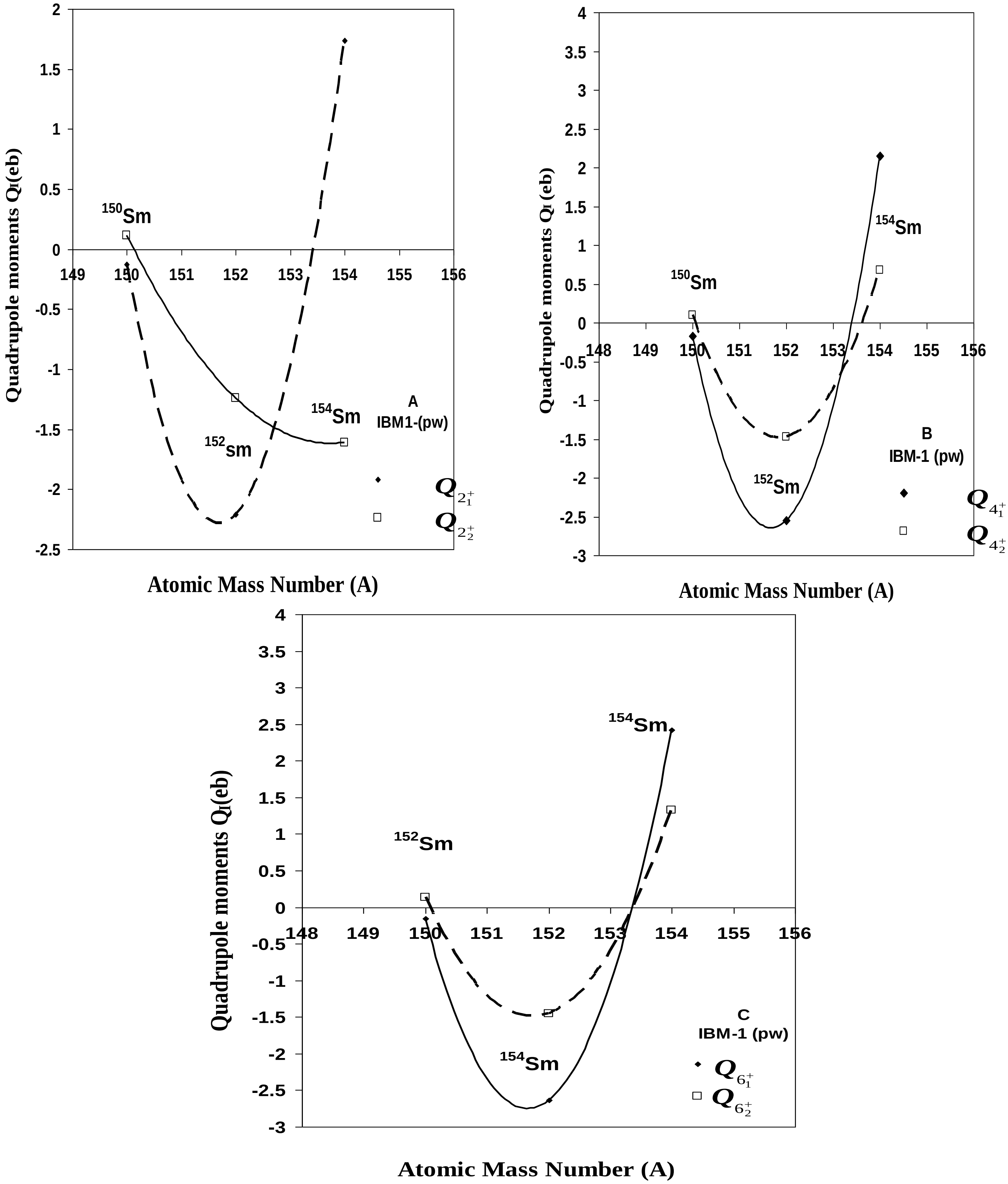

Figure (1-A,B,C) The Q_I quadrupole moment as a function of atomic mass number for even-even Sm (A=150-154) isotopes.

3.2. Effective Charge

When the neutron or proton transports from a higher level to lower level to eliminate nuclei excitation leads to a change in the value of the neutron or proton charge acquiring effective charge resulting in an electromagnetic transition.

To be sure that the calculations of B(E2) values obtained are correct we calculate the electric quadrupole probabilities B(E2). According to (IBM-1) model through application a new method to select the effective charge values for the bosons (α_2,β_2) in which (α_2) characterized by the effective charge for boson (due to interaction of S-boson with d-boson).Where the B(E2) values had been calculated depending on calculation of $\left|\left\langle I_f \left\| \hat{T}^{(E2)} \right\| I_i \right\rangle\right|$ as a function of the effective charge of the boson (β_2,α_2) were (β_2) represent the effective charge for the boson as result of the interaction of d-boson with d-boson .

Table (2) shows the parameters values (α_2, β_2) of the Hamiltonian operator function for the selected isotopes under study by using (IBMTT. For) program. With the restrictions that only s and d bosons are present and that only one - body terms are included in the transition operators these are only possible transitions in IBM-1. The dynamical symmetry SU(5), notice that in this limit only the first term of $\hat{T}^{(E2)}$ operator contributes. This is due to the fact that the states in this limiting symmetry are characterized by a fixed number of d-bosons in particular B(E2;2_1^+-0_1^+)depends on N where N = n_s+n_d. Comparing this result with the corresponding result in dynamical symmetry SU(3), B(E2) of this symmetry depend on N^2. Deformed nuclei where the SU(3) symmetry applied show much higher B(E2; 2_1^+-0_1^+) than spherical nuclei where U(5) symmetry applies.

The B(E2; 2_1^+-0_1^+) in the dynamical symmetry O(6) depends on N^2 the rates of E2 transitions in the three dynamical symmetry depend on the selection rules that dominated on .

The deformed nuclei exist only in regions far from filled neutron and proton shells. Just as the cooperative effect of a few nucleon pairs outside of a filled shell was responsible for the microscopic structure of the vibrations of spherical nuclei, the cooperative effect of many valance nucleon pairs can distort the “core” of nucleons until the equilibrium shape becomes strongly deformed.

Figure (2) shows the relation between the effective charge calculated according to IBM-1 as function of total boson number (N) for Sm (A=150-154). It shows the increment of deformity parameter α_2 in corresponding to the increment of the total boson number (N) for A=150-154, in contrast the sharp decrement of deformity parameter α_2 in corresponding to the increment of the total boson number (N) for (A=152-154). In the other hand the deformity parameter β_2 decreases gradually as total boson number (N) increases for (A=150-154).

Table (2) The values of the parameters (α_2, β_2) of B(E2) and $\langle L_f \| \hat{T}^{(E2)} \| L_i \rangle$ for even-even isotopes Sm(A=150-154), by using (IBMTT.For) program.

Isotopes	N_π	N_υ	N_{tot}	α_2(eb)	β_2(eb)
${}^{150}_{62}\boldsymbol{Sm}_{88}$	6	3	9	0.1391	0.0505
${}^{152}_{62}\boldsymbol{Sm}_{90}$	6	4	10	0.1870	0.0383
${}^{154}_{62}\boldsymbol{Sm}_{92}$	6	5	11	0.1148	0.0322

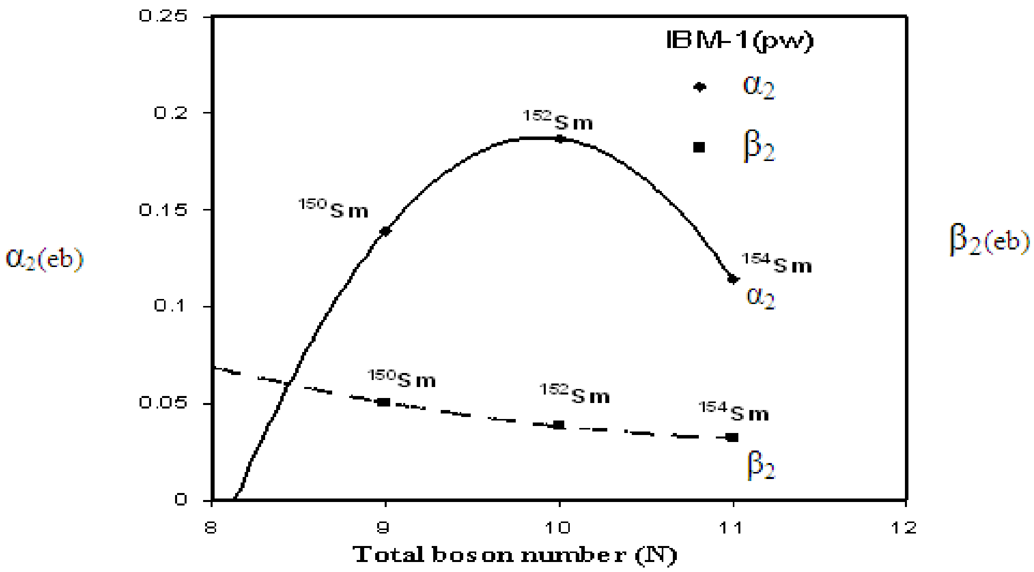

Figure (2): Parameters α_2 and β_2 as a function of total boson number (N) for the even-even Sm (A=150-154) isotopes.

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