Nuclear structure of ^{74,76}Ge isotopes which have gamma unstable O(6) dynamical symmetry using interacting boson model

A.A.W. Redah
Physics Department, Science College, Thi-Qar University

Abstract

In this work we studied the nuclear properties (energy levels , gamma transitions , quadrupole electric transitions B(E2) and its reduced matrix elements T(E2) , dipole magnetic transitions B(M1) and its reduced matrix elements T(M1) , electric quadrupole moments for ground state (Q_I) , finally classified these transitions to its delta mixing ratio □(E2/M1) and reduced mixing ratio □(E2/M1).

All of these structure we calculated using IBM-1 programs for germanium isotopes (A=74,76) which have gamma unstable of the O(6) dynamical symmetry. Our results show a good agreement with the available experimental data.

التركيب النووي لنظائر الجرمانيوم ^{74,76}Ge ذات التناظر الديناميكي لكاما غير المستقرة O(6) باستخدام نموذج البوزونات المتفاعلة الأول

علي عبد الوهاب رضا
قسم الفيزياء – كلية العلوم – جامعة ذي قار

الخلاصة

تم في هذا البحث دراسة الخواص النووية (مستويات الطاقة ، انتقالات كاما ، الانتقالات الكهربائية رباعية القطب B(E2) وعناصر المصفوفة المختزلة لها T(E2)، الانتقالات المغناطيسية ثنائية القطب B(M1) وعناصر المصفوفة المختزلة لها T(M1)، العزوم الكهربائية رباعية القطب للمستويات الأرضية (Q_I) ، نسب الخلاط (E2/M1)□ ونسب الخلاط المختزلة (E2/M1)□.

قمنا باستخدام برامج نموذج البوزونات المتفاعلة (IBM-1) لحساب هذه الخواص النووية لنظائر الجرمانيوم ^{74,76}Ge ذات التناظر الديناميكي O(6) لكاما غير المستقرة حيث أظهرت النتائج تطابق جيد مع القيم العملية المتوفرة.

Introduction

The interacting boson model was introduced in an attempt to describe in a unified way collective properties of nuclei, this model is rooted in the spherical shell model which is the fundamental model for describing properties of nuclei[(1)](Bonatsos,1988).

In the simplest version of the interacting boson model (IBM-1), its assumed that low-lying collective states in even-even nuclei away from closed shells are dominated by excitation of the valence protons and the valence neutrons (particles outside the major closed shell) while the closed shell core is inert. Furthermore, its assumed that the particle configurations which are most important in shaping the properties of the low-lying states are these in which identical particles are coupled together forming pairs of angular momentum 0 and 2[(1,2)](Bonatsos,1988; Arima et al.,1987).

In addition, these proton (neutron) pairs are treated as boson, the boson with angular momentum (L=0) are denoted by s□ (s□) and are called s-bosons, while bosons with (L=2)[(3)](Casten et al.,1988) are denoted by d□ (d□) and are called d-bosons. The number of valence proton (neutron) pairs, N□ (N□) is counted from nearest magic number.

Interacting boson model was applied by two type of structures, the first is phenomenological structure which contain linear algebra and group theory, the second type is geometrical collective properties. In the present work, we used the (IBM-1) which deal with phenomenological structure underlying U(6)[(4)](Arema et al.,1981) groups basis leads to a simple Hamiltonian which is capable of describing the three specific limits of collective structure: vibrational U(5), rotational SU(3) and gamma unstable O(6).

Theoretical part

The hamiltonian operator according IBM-1can be written by creation and annihilation operators as follows[(2,5)](Arima et al.;Abrahams et al.1981):

$$\hat{H} = \in \hat{n}d + a_o(\hat{P}.\hat{P}) + a_1(\hat{L}.\hat{L}) + a_2(\hat{Q}.\hat{Q}) + a_3(\hat{T}_3.\hat{T}_3) + a_4(\hat{T}_4 + \hat{T}_4) \text{............(1)}$$

Where $\in = \in s + \in d$ is the boson energy

a_o, a_1, a_2, a_3, a_4 are the phenomenological parameters.

For O(6) dynamical symmetry, the hamiltonian operator becomes:

$$\hat{H} = a_o(\hat{P}.\hat{P}) + a_1(\hat{L}.\hat{L}) + a_3(\hat{T}_3.\hat{T}_3) ....(2)$$

The electric quadrupole transition operator in the IBM-1 can be written as:

$$\hat{T}^{(E2)} = \alpha_2\left[\hat{d}^+ \times \hat{\tilde{s}} + \hat{s}^+ \times \hat{\tilde{d}}\right]^{(2)}_{\mu} + \beta_2\left[\hat{d}^+ \times \hat{\tilde{d}}\right]^{(2)}_{\mu} .... (3)$$

Where α_2 is the effective charge of boson.

β_2 is the effective charge of one particle in d-boson.

While the electric quadrupole transition probability can calculated by:

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

Where I is angular momentum.

And the electric quadrupole moment (Q_I) is:

$$Q_I = \sqrt{\frac{16\pi}{5}}\begin{pmatrix} I & 2 & I \\ -I & 0 & I \end{pmatrix}\left\langle I_f \left\| \hat{T}^{(E2)} \right\| I_i \right\rangle .... (5)$$

The magnetic dipole transition operator in the IBM-1 can be written as:

$$\hat{T}^{(M1)} = \beta_1\left[d^+ \times \tilde{d}\right]^{(1)}_{\mu} + \alpha'_1\left[\left(d^+ \times \tilde{s} + s^+ \times \tilde{d}\right)^{(2)}_{\mu} \times \left(d^+ \times \tilde{d}\right)^{(1)}\right]^{(1)}_{\mu} +$$
$$\gamma'_1\left[\left(d^+ \times \tilde{d}\right)^{(0)} \times \left(d^+ \times \tilde{d}\right)^{(1)}\right]^{(1)}_{\mu} + \delta'_1\left[\left(d^+ \times \tilde{d}\right)^{(2)} \times \left(d^+ \times \tilde{d}\right)^{(1)}\right]^{(1)}_{\mu} +$$
$$\eta'_1\left[\left(s^+ \times \tilde{s}\right)^{(0)} \times \left(d^+ \times \tilde{d}\right)^{(1)}\right]^{(1)}_{\mu} .... (6)$$

Where $\beta_1, \alpha'_1, \gamma'_1, \delta'_1, \eta'_1$ are Linear Coefficients.

While the magnetic dipole transition probability can calculated by:

$$B(M1; I_i \rightarrow I_f) = \frac{1}{2I+1}\left|\left\langle I_f \left\| \hat{T}^{(M1)} \right\| I_i \right\rangle\right|^2 .... (7)$$

The mixing ratios δ(E2/M1) and reduce mixing ratios □(E2/M1) in IBM-1 can be founds from[(6)](Pfeifer,1998):

$$\delta(E2/M1; I_i \rightarrow I_f) = \sqrt{\frac{3}{100}}\, q\, \frac{\left\langle I_f \left\| \hat{T}^{(E2)} \right\| I_i \right\rangle}{\left\langle I_f \left\| \hat{T}^{(M1)} \right\| I_i \right\rangle} ....(8)$$

$$\Delta(E2/M1)=\frac{\delta(E2/M1)}{0.835\times E_{\gamma}}\ldots\ldots\ldots\ldots(9)$$

Where $q = E_{\gamma} / \hbar c$

Results and Discussion

In present work we had studied the nuclear properties of germanium Ge (A=74,76) isotopes where it belong to gamma unstable dynamical symmetry O(6) by using interacting boson model. At the first we classified all germanium isotopes to its dynamical symmetries by comparing the experimental energy levels of these isotopes with the ideal chart of U(5), SU(3) and O(6) in IBM-1, another test used also, which is the energy ratios E(4)/E(2) , E(6)/E(2) and E(8)/E(2) comparing with ideal values for the three dynamical symmetries, then choosing the isotopes which deal with gamma unstable O(6), as shown in table (1).

Table (1): theoretical and experimental data for branching ratios comparison with ideal values for IBM-1.

Dynamical Symmetry	$E(4_1^+)/E(2_1^+)$		$E(6_1^+)/E(2_1^+)$		$E(8_1^+)/E(2_1^+)$	
U(5)	2		3		4	
O(6)	2.5		4.5		7	
SU(3)	3.33		7		12	
Isotope	Exp.[7]	IBM-1	Exp.[7]	IBM-1	Exp.[7]	IBM-1
Ge-74	2.4563	2.6560	——	4.9679	——	7.9357
Ge-76	2.5053	2.6663	——	4.9989	——	7.9977

Table (2) listed the two isotopes were used in this work according to their atomic mass number, total number of boson (N) and corresponding hamiltonian parameters, reduced matrix element parameters for the electric quadrupole transitions (α_2,β_2) and magnetic dipole transitions ($\beta_1,\alpha_1',\gamma_1',\delta_1',\eta_1'$). The total number of bosons in ^{74}Ge is [2□(particle)+3□(hole)=6] and in ^{76}Ge is [2□(particle)+3□(hole)=5].

These parameters were used in (IBS1.For, IBMT.For and M5.For) programs of interacting boson model, which help us to calculate the energy levels, electric moments (Q_I) for ground state, electric quadrupole transitions probability B(E2) and magnetic dipole transitions probability B(M1) comparing with experimental data for Ge-74,76 were shown in table (3,4). Figure (1) explains the agreement between the available experimental data and theoretical calculation of IBM-1 for energy levels with the angular momentums of the levels. Figure (2) shows which transitions or spin sequences has a high values of electric quadrupole transitions probability B(E2) for Ge-74,76. In figure (3) we found the same behavior of magnetic transitions B(M1) for Ge-74, while in Ge-76 there are high and low probabilities in the some spin sequences. The electric quadrupole moments (Q_I) is one of many methods to predict the deformations from the spherical shape of nuclear structure. In the present work, we were used IBM-1 analysis, that's mean when Q_I=0 , the nuclei or levels has a spherical shape while Q_I>0 for prolate and Q_I<0 for oblate, therefore figure (4) shows the two isotopes in this work has a prolate shape and the levels which has odd angular momentums has a low deformation and the spherical shape for 3_1 level.

Table (2): total number of boson and the parameters of energy levels, electric transitions and magnetic transitions used in programs of IBM-1.

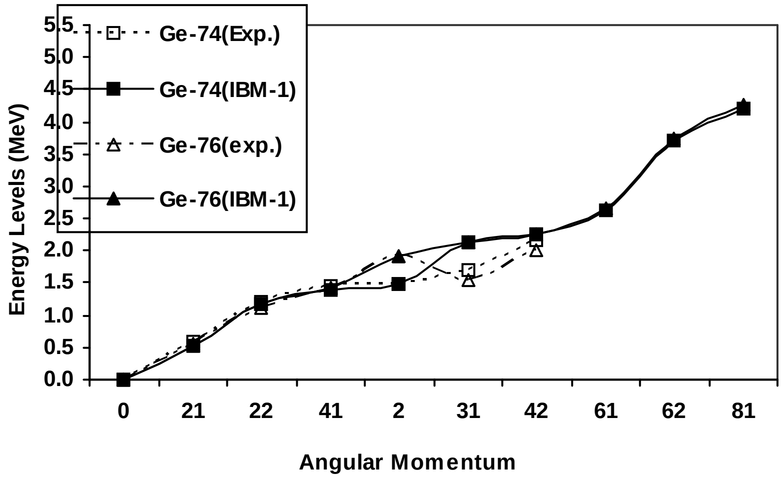
Isotope	N	$\hat{p}.\hat{p}$ (MeV)	$\hat{I}.\hat{I}$ (MeV)	$\hat{T}_3.\hat{T}_3$ (MeV)	α_2 (eb)	β_2 (eb)	β_1' (μ_N)	α_1' (μ_N)	γ_1' (μ_N)	δ_1' (μ_N)	η_1' (μ_N)
Ge-74	**6**	**0.2125**	**0.0380**	**0.2150**	**0.4274**	**5.1200**	**0.1720**	**0.0156**	**0.3896**	**0.3583**	**0.1294**
Ge-76	**5**	**0.4300**	**0.0390**	**0.2130**	**0.5464**	**5.5702**	**0.2513**	**0.4832**	**0.0165**	**0.2744**	**-0.3723**

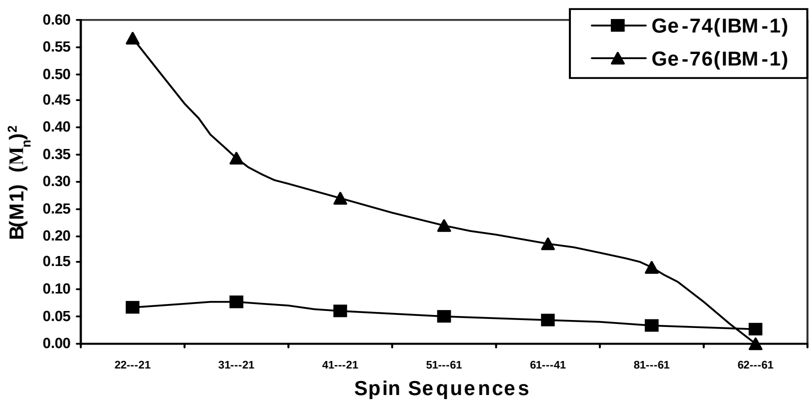
Table (3): energy levels, electric moments for ground state, electric quadrupole transitions probability and magnetic dipole transitions probability comparison with experimental data for Ge-74 isotope.

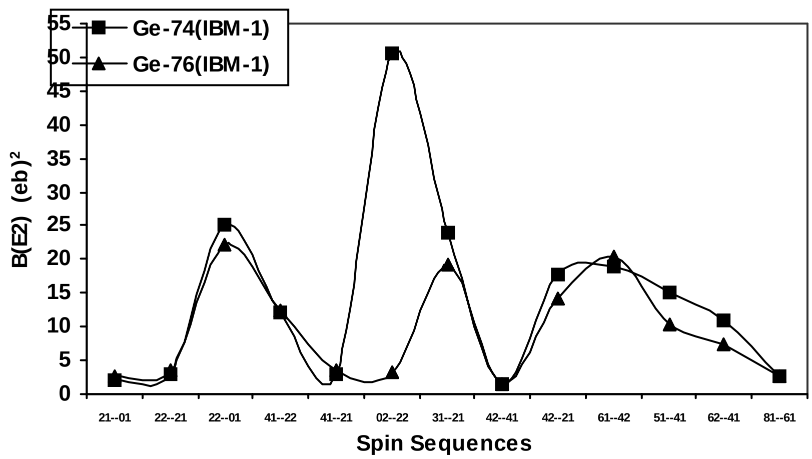
I^{π}	Energy Levels (MeV)		Q_I	I_i^+—I_f^+	$B(E2)\ (eb)^2$	$B(M1)\ (\mu_N)^2$
	Exp.[8,9,10,11]	IBM-1				
0_1^+	0.0000	0.0000		——	——	——
2_1^+	0.5959	0.5290	10^{+2}×0.1612	2_1^+—0_1^+	10^{+1}×0.2192	0.0000
2_2^+	1.2043	1.1740		2_2^+—2_1^+	10^{+1}×0.2871	10^{-1}×0.6737
4_1^+	1.4637	1.4050	10^{+2}×0.2740	2_2^+—0_1^+	10^{+2}×0.2522	0.0000
0_2^+	1.4826	1.4875		4_1^+—2_2^+	10^{+2}×0.1213	——
3_1^+	1.6972	2.1330	10^{-6}×0.4133	4_1^+—2_1^+	10^{+1}×0.2871	10^{-1}×0.6151
0_3^+	1.9130	1.9350		0_2^+—2_2^+	10^{+2}×0.5044	——
4_2^+	2.1658	2.2650		0_2^+—2_1^+	10^{-11}×0.1802	0.0000
2_3^+	2.1980	2.0165		3_1^+—4_1^+	0.8351	10^{-1}×0.7908
0_4^+	2.2270	2.5500		3_1^+—2_2^+	10^{+1}×0.2088	10^{-1}×0.3828
6_1^+	2.5720	2.6280	10^{+2}×0.4025	3_1^+—2_1^+	10^{+2}×0.2402	10^{-1}×0.7908
2_4^+	2.6460	2.6615		0_3^+—2_2^+	10^{+1}×0.2923	0.0000
4_3^+	——	2.8925		0_3^+—2_1^+	10^{+2}×0.3363 Exp.[11]=30.00±3.2	——
2_5^+	——	3.0790		4_2^+—4_1^+	10^{+1}×0.1392	10^{-1}×0.3743
2_6^+	——	3.1090		4_2^+—2_2^+	10^{+1}×0.1531	10^{-2}×0.1264
0_5^+	——	3.1875		4_2^+—2_1^+	10^{+2}×0.1761	10^{-1}×0.3743
4_4^+	——	3.3400		2_3^+—2_2^+	0.0000	10^{-14}×0.6658
5_1^+	——	3.5050	10^{+2}×0.1832	2_3^+—4_1^+	10^{-13}×0.4306	10^{-14}×0.5555
3_2^+	——	3.6205		2_4^+—4_1^+	0.0000	10^{-2}×0.3617
6_2^+	——	3.7030		0_4^+—2_2^+	10^{-11}×0.1322	——
2_7^+	——	3.7240		0_4^+—2_1^+	10^{-11}×0.4689	——
4_5^+	——	3.7525		6_1^+—4_2^+	10^{+2}×0.1899	0.0000
4_6^+	——	3.9550		6_1^+—4_1^+	10^{+1}×0.2923	10^{-1}×0.4258
6_3^+	——	4.1155		2_4^+—4_2^+	0.0000	10^{-1}×0.6755
8_1^+	——	4.1980		2_4^+—2_3^+	10^{+1}×0.1409	——
2_8^+	——	4.3990		8_1^+—6_1^+	10^{+1}×0.2591	10^{-1}×0.3256
5_2^+	——	4.7950		4_3^+—2_4^+	10^{+2}×0.1544	0.0000
7_1^+	——	5.2240		2_5^+—0_4^+	0.4384	——
8_2^+	——	5.4880		5_1^+—6_1^+	0.6123	10^{-1}×0.5033
3_3^+	——	6.0030		5_1^+—4_1^+	10^{+2}×0.1517	10^{-1}×0.5033
10_1^+	——	6.1150		6_2^+—6_1^+	0.8243	10^{-1}×0.2591
7_2^+	——	6.7290		6_2^+—4_1^+	10^{+2}×0.1084	10^{-1}×0.2591

Table (4): energy levels, electric moments for ground state, electric quadrupole transitions probability and magnetic dipole transitions probability comparison with experimental data for Ge-76 isotope.

I^{π}	Energy Levels (MeV)		Q_I	$I_i^+ — I_f^+$	B(E2) $(eb)^2$	B(M1) $(\mu_N)^2$
	Exp.[8,9,10,11]	IBM-1				
0_1^+	0.0000	0.0000		——	——	——
2_1^+	0.5628	0.5322	10^{+2}×0.1601	$2_2^+—2_1^+$	10^{+1}×0.3412	0.5647
2_2^+	1.1090	1.1712		$2_2^+—0_1^+$	10^{+2}×0.2216	0.0000
4_1^+	1.4100	1.4190	10^{+2}×0.2782	$4_1^+—2_2^+$	10^{+2}×0.1251	——
3_1^+	1.5394	2.1294	10^{-6}×0.3110	$4_1^+—2_1^+$	10^{+1}×0.3412	0.2683
0_2^+	1.9111	1.9170		$3_1^+—4_1^+$	0.9383	0.3450
4_2^+	2.0199	2.2710		$3_1^+—2_1^+$	10^{+2}×0.1935	0.3450
0_3^+	——	2.5800		$0_2^+—2_1^+$	10^{+2}×0.2709 Exp. [11]=27.00±2.0	——
6_1^+	——	2.6604	10^{+2}×0.4185	$4_2^+—4_1^+$	10^{+1}×0.1564	10^{-15}×0.3137
2_3^+	——	3.0882		$4_2^+—2_2^+$	10^{+1}×0.1720	10^{-1}×0.1035
2_4^+	——	3.1122		$4_2^+—2_1^+$	10^{+2}×0.1419	10^{-15}×0.3137
4_3^+	2.0140	3.3360		$6_1^+—4_2^+$	10^{+2}×0.2053	0.0000
5_1^+	——	3.5130	10^{+2}×0.1950	$6_1^+—4_1^+$	10^{+1}×0.3284	0.1858
6_2^+	——	3.7254		$2_3^+—0_2^+$	0.9554	——
2_5^+	2.5030	3.7512		$2_3^+—3_1^+$	10^{+1}×0.1194	0.0000
4_4^+	2.7330	3.9990		$2_3^+—4_1^+$	10^{+1}×0.3870	0.3644
8_1^+	——	4.2564		$2_3^+—2_2^+$	10^{+2}×0.1238	10^{-15}×0.9923
0_4^+	——	4.3000		$2_4^+—4_1^+$	0.0000	10^{-1}×0.1941
2_6^+	——	4.3662		$4_3^+—3_1^+$	——	0.2124
0_5^+	——	4.4970		$4_3^+—2_4^+$	0.0000	0.3548
4_5^+	——	4.6140		$4_3^+—4_1^+$	10^{+1}×0.1626	0.2024
3_2^+	——	4.7094		$4_3^+—2_2^+$	10^{+2}×0.1118	10^{-15}×0.5513
5_2^+	——	4.7910		$4_3^+—2_1^+$	10^{-14}×0.8273	0.2024
2_7^+	——	4.8322		$5_1^+—6_1^+$	0.6159	0.2195
4_6^+	——	4.8510		$5_1^+—4_1^+$	10^{+2}×0.1034	0.2195
6_3^+	——	5.0034		$6_2^+—6_1^+$	0.8290	10^{-15}×0.2172
6_4^+	——	5.2404		$4_4^+—2_3^+$	0.0000	10^{-1}×0.8871
7_1^+	——	5.2512		$6_2^+—4_1^+$	10^{+1}×0.7387	10^{-15}×0.2172
8_2^+	——	5.5344		$8_1^+—6_2^+$	0.0000	10^{-15}×0.6719
10_1^+	——	6.2070		$8_1^+—6_1^+$	10^{+1}×0.2606	0.1420


Ge-74(Exp.)
Ge-74(IBM-1)
Ge-76(exp.)
Ge-76(IBM-1)
Energy Levels (MeV)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
0 21 22 41 2 31 42 61 62 81
Angular Momentum


Ge-74(IBM-1)
Ge-76(IBM-1)
B(M1) (Mn)2
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
22---21 31---21 41---21 51---61 61---41 81---61 62---61
Spin Sequences


Ge-74(IBM-1)
Ge-76(IBM-1)
B(E2) (eb)2
0
5
10
15
20
25
30
35
40
45
50
55
21--01 22--21 22--01 41--22 41--21 02--22 31--21 42--41 42--21 61--42 51--41 62--41 81--61
Spin Sequences

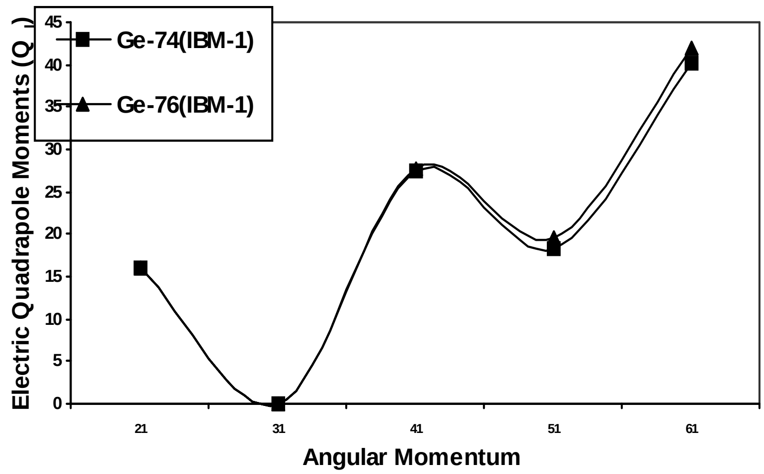


Table (5,6) listed gamma energy transitions by using IBS1.For program from IBM-1, reduced matrix elements $T^{(E2)}$, $T^{(M1)}$ (equation-3,6) using IBMT.For and M5.For which help us to calculate delta mixing ratios δ(E2/M1) and reduced mixing ratios □(E2/M1). For knowledge of gamma transition, is the transition either to be electric, magnetic, or mixed transition, the delta mixing ratios for the transitions belonging to the present isotopes have been calculated from the electric quadrupole transition probabilities and the magnetic dipole transition probabilities (equation-8,9). The delta maxing ratios δ(E2/M1) equality (E2) that means the transition is pure electric transition, while the delta equal to zero, we will found two probabilities, the first probability occurs nonbeing any transition that means inside change (E0), the second probability occurs the magnetic transition is pure. However, the appearance value of delta maxing ratio is existence the mixture between electric and magnetic components in the transition.

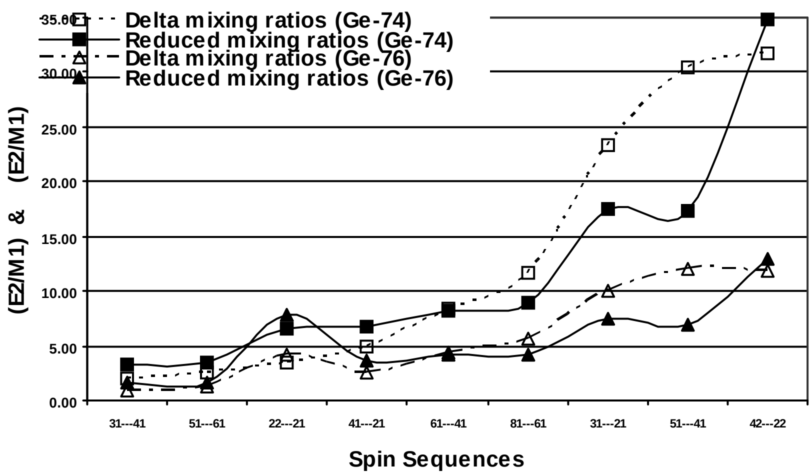
Figure (5) show the gamma energy transitions as a function of spin sequences, the transitions (3_1---2_1 , 8_1---6_1) has a very high reduced probability of gamma ray by using IBM-1 comparison with experimental data. Figure (6) explain the relationship between delta mixing ratios and reduced mixing ratios as a function of spin sequences for Ge-74,76.

Table (5): gamma transitions, reduced matrix elements for electric and magnetic transitions, delta mixing ratios and reduced mixing ratios compare with experimental data for Ge-74 isotope[7].

I_i---I_f	E_γ (MeV)		$\langle I_f \Vert \hat{T}^{(E2)} \Vert I_i \rangle$ (eb)	$\langle I_f \Vert \hat{T}^{(M1)} \Vert I_i \rangle$ (μ_N)	δ(E2/M1)	Δ(E2/M1)
	Exp.	IBM-1				
2_1^+—0_1^+	0.5959	0.5290	-0.3106	0.0000	∞	∞
2_2^+—2_1^+	0.6084	0.6450	3.7885	0.5804 Exp. [11]=0.5	3.5155 Exp. [11]= 3.3	6.5274 Exp. [11]=6.4
2_2^+—0_1^+	1.2043	1.1740	-11.2296	0.0000	∞	∞
4_1^+—2_1^+	0.8678	0.8760	5.0828	0.7440	4.9971	6.8317
0_2^+—0_1^+	1.4826	1.4875	0.0000	0.0000	——	——
3_1^+—4_1^+	0.2335	0.7280	-2.4177	0.7440	-1.9754	-3.2497
3_1^+—2_2^+	0.4929	0.9590	3.8228	-0.5176	-5.9142	-7.3857
3_1^+—2_1^+	1.1013	1.6040	-12.9668	0.7440	-23.3427	-17.4285
4_2^+—4_1^+	0.7021	0.8600	-3.5392	0.5804	-4.3789	-6.0979
4_2^+—2_2^+	0.9615	1.0910	-3.7119	0.1066	-31.7213	-34.8209
4_2^+—2_1^+	1.5699	1.7360	-12.5909	0.5804	-31.4460	-21.6935
2_3^+—2_2^+	0.9937	0.8425	0.0000	0.1825×10^{-6}	0.0000	0.0000
2_3^+—4_1^+	0.7343	0.6115	0.0000	-0.1667×10^{-6}	0.0000	0.0000
6_1^+—4_1^+	——	1.2230	6.1640	0.7440	8.4606	8.2849
2_4^+—4_1^+	——	1.2565	0.0000	-0.1345	0.0000	0.0000
2_4^+—4_2^+	——	0.3965	0.0000	-0.5812	0.0000	0.0000
5_1^+—6_1^+	——	0.8770	-2.5953	0.7440	-2.5545	-3.4883
5_1^+—4_1^+	——	2.1000	-12.9196	0.7440	-30.4496	-17.3650
6_2^+—6_1^+	——	1.0750	-3.2735	0.5804	-5.0627	-5.6401
8_1^+—6_1^+	——	1.5700	6.6363	0.7440	11.6934	8.9198

Table (6): gamma transitions, reduced matrix elements for electric and magnetic transitions, delta mixing ratios and reduced mixing ratios comparison with experimental data for Ge-76 isotope[7].

I_i---I_f	E_γ (MeV)		$\langle I_f \| \hat{T}^{(E2)} \| I_i \rangle$ (eb)	$\langle I_f \| \hat{T}^{(M1)} \| I_i \rangle$ (μ_N)	δ(E2/M1)	Δ(E2/M1)
	Exp.	IBM-1				
$2_2^+ — 2_1^+$	0.5462	0.6390	-4.1304	-0.5314 Exp. (11)=0.5	4.1472 Exp. (11)= 3.5	7.7726 Exp. (11)=7.7
$2_2^+ — 0_1^+$	1.1090	1.1712	10.5267	0.0000	∞	∞
$4_1^+ — 2_1^+$	0.8472	0.8868	5.5415	$-0.1554 \times 10^{+1}$	-2.6405	-3.5659
$3_1^+ — 4_1^+$	0.1294	0.7104	-2.5628	$-0.1554 \times 10^{+1}$	0.9783	1.6492
$3_1^+ — 2_1^+$	0.9766	1.5972	-11.6377	$-0.1554 \times 10^{+1}$	9.9876	7.4889
$0_2^+ — 0_1^+$	1.9111	1.9170	0.0000	0.0000	——	——
$4_2^+ — 4_1^+$	0.6099	0.8520	-3.7516	0.0000	∞	∞
$4_2^+ — 2_2^+$	0.9109	1.0998	3.9347	-0.3052	-11.8393	-12.8922
$4_2^+ — 2_1^+$	1.4571	1.7388	-11.3003	0.0000	∞	∞
$6_1^+ — 4_1^+$	——	1.2414	6.5340	$-0.1554 \times 10^{+1}$	-4.3584	-4.2046
$2_3^+ — 4_1^+$	——	1.6692	4.3986	$-0.1350 \times 10^{+1}$	-4.5413	-3.2583
$2_3^+ — 2_2^+$	——	1.9170	-7.8685	0.0000	∞	∞
$2_4^+ — 4_1^+$	——	1.6932	0.0000	0.3115	0.0000	0.0000
$4_3^+ — 2_4^+$	——	1.0650	-3.2829	$0.1332 \times 10^{+1}$	-2.1917	-2.4646
$4_3^+ — 4_1^+$	——	1.9170	-3.8255	$-0.1350 \times 10^{+1}$	4.5359	2.8337
$4_3^+ — 2_1^+$	——	2.8038	00.000	$-0.1350 \times 10^{+1}$	0.0000	0.0000
$5_1^+ — 6_1^+$	——	0.8526	-2.6028	$-0.1554 \times 10^{+1}$	1.1924	1.6749
$5_1^+ — 4_1^+$	——	2.0940	-10.6661	$-0.1554 \times 10^{+1}$	12.0010	6.8636
$6_2^+ — 6_1^+$	——	1.0650	-3.2829	0.0000	∞	∞
$4_3^+ — 3_1^+$	——	1.2066	0.0000	$-0.1350 \times 10^{+1}$	0.0000	0.0000
$8_1^+ — 6_1^+$	——	1.5960	6.6554	$-0.1554 \times 10^{+1}$	-5.7075	-4.2828


Delta mixing ratios (Ge-74)
Reduced mixing ratios (Ge-74)
Delta mixing ratios (Ge-76)
Reduced mixing ratios (Ge-76)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
(E2/M1) & (E2/M1)
31---41
51---61
22---21
41---21
61---41
81---61
31---21
51---41
42---22
Spin Sequences

References

Abrahams. K. Allaart and A.E.L. Dieperink nuclear structure: Ed. Pub. PLENUM press. New York and London P.P. 67. 53. (1981).

Arima A. and Iachello F.: Ann.phys. ,vol.21,No.75, NewYork (1981).

Arima A. and Iachello F.: Interacting Boson Model. Ed. Iachello F., Pub. University of Cambridge, England. pp. 3-236 (1987).

Bonatsos D.: Interacting Boson Models of nuclear structure Ed. Hodgson P.E., Pub. Oxford University press, NewYork. pp.1-264 (1988)..

Casten R. F. and Warner D. D. : Rev. Mod. Phys. 60, 391 (1988).

Ensdf, nuclear data sheet (2006).

Lany J., Kumark and Hamilton J.H.: Rev. of Mod. Phys., Vol. 54, 119 (1982).

Lederer G. M., Brown E., and Snihab: Table of Isotopes, 7th edition (1978).

Mitsuo Saka I.: Atomic data and nuclear data tables Vol. 31. 399(1984).

Pfeifer W.: (Introduction to interacting boson model of atomic (nuclei) V1, PP. 5, (1998).

Pramana , j. phys.G: Vol.64, No.2, P.214 (2005).

Raghavan et al., Atom. Nucl. Data Tables, Vol.42, No.189 (1989).