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Nuclear structure of even-even Ge isotopes by means of interacting boson models

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Abstract

Interacting Boson Models IBM-1and IBM-2, have been used to calculate energy levels and nuclear properties of the even-even Ge isotopes from $A = 64$ to $A = 80$. Energy levels of the low lying states of these nuclei were produced, the electric quadruple reduced transition probabilities B(E2) were calculated as well. Mixing ratios $\delta(E2/M1)$ for transitions with $\Delta I = 0$, $I \neq 0$were calculated. All the results are compared with available experimental data and other IBM versions and calculations. Satisfactory agreements were produced.

Key Words: Interacting boson model, even-even Ge, energy levels, reduced transition probability, mixing ratio

1. Introduction

Even-even Ge isotopes with Z = 32 and $32 \leq N \leq 50$ have a collective quadrupole excitation strongly dependant on the number of nucleons outside the closed shells 28 and 50, and the neutron- proton interaction is known to have a great influence on nuclear properties. These isotopes are part of an interesting region including Se and Kr, which has and is likely to attract many experimental and theoretical works [1–4]. It is found that the spectra of those nuclei can not be explained in terms of simple versions of the rotational or vibrational models, with shape coexistance, for and there is a transition from spherical to weakly deformed shape with different types of deformations [5].

There is strong evidence that some kind of structural change takes place between $A \leq 70$ and heavy $A \geq 74$ Ge nuclei, as can be seen from irregular variation of nuclear properties from one isotope to an other, which cannot be explained in a simple way [6]. One of the peculiarities is the existence of the unusual low-lying excited 0^+ state which is sited just above 2^+, and in the case of ^{72}Ge it is below the first excited state. This can not be understood simply as the 0^+ member of two phonon triplet $(0, 2, 4)^+$ states. This is explained [7] by a rotational band member built on the excited 0^+ state.

Few known even-even nuclei have the 0 state as a first excited state. Investigation of the even mass Ge isotopes by means of the interacting boson model with fermium pair model has been done by Hsieh et al [5]. They took ^{56}Ni nucleus as a core for their study and, counting boson numbers, assumed that one of the bosons can be broken to form a fermion pair which may occupy the $f_{5/2}$ or $g_{9/2}$ orbitals. In this study a suggestion was made that there is complex shape coexistence in the ^{68}Ge nucleus. More complexity in the structure of these nuclei appears when the reduced transition probabilities are studied. The variation of the excitation energy of 0^+ was explained under the assumption of second minima in the potential energy surface [8]. The result of applying of the dynamic- deformation model (DDM) [9] on the Ge isotopes predicts that these nuclei were very soft and present as an oblate-prolate shape phase transition.

We have also found a strange feature of 2_1^+; it starts from 0.902 MeV in ^{64}Ge and pushes up to ^{70}Ge, and may be explained due to the effect of suggested closed shell at $N = 38$ [10], then pushed down after that, then up toward the second closed shell at $N = 50$.

2. The models

2.1. IBM-1

The early version of the Interacting Boson Approximation Model (IBA), or (IBM-1), in which there was no distinction made between proton and neutron bosons, and number of bosons taken to be the number of nucleons outside the closed shell divided by two, and the most general Hamiltonian written as [11]

$$H = \varepsilon n_d + a_0 P \cdot P + a_1 L \cdot L + a_2 Q \cdot Q + a_3 T_3 \cdot T_3 + a_4 T_4 \cdot T_4 \ldots, \tag{1}$$

where $\varepsilon, a_o, a_1, a_2, a_3, a_4$ are the model parameters, n_d is the d-boson number operator, P and Q represent pairing and quadrupole operators written in the language of second quantization s,s^+, d,d^+, where s, s^+, d, d^+ are the annihilation and creation operators of s- and d-bosons, respectively,

$$Q = (s^\dagger \tilde{d} + d^\dagger \tilde{s})^{(2)} + \chi (d^\dagger \tilde{d})^{(2)}, P = \frac{1}{2}(\tilde{d}.\tilde{d} + \tilde{s}.\tilde{s}) \tag{2}$$

and L and T are given by

$$L = \sqrt{10}(d^\dagger \tilde{d})^{(1)}, \quad T_l = (d^\dagger \tilde{d})^{(l)}, \quad l = 3, 4.$$

The reduced quadrupole transition probability calculated from the relation

$$B(E2;\, I_f \to I_i) = \frac{1}{2I_f + 1} \left\langle I_f || T^{E2} || I_i \right\rangle^2, \tag{3}$$

where

$$T^{(E2)} = \alpha_2 \left(d^+ s + s^+ d\right)^{(2)} + \beta_2 \left(d^+ d\right)^{(2)}, \tag{4}$$

α_2 and β_2 are two parameters which refer to the effective charge.

2.2. IBM-2

In this version of the Interacting Boson Model, when there are distinctions between proton and neutron bosons, the Hamiltonian can be written as [12]

$$H = \varepsilon_d (n_{d\nu} + n_{d\pi}) + \kappa (Q_\nu \cdot Q_\pi) + V_{\nu\nu} + V_{\pi\pi} + M_{\nu\pi} \tag{5}$$

where Q is

$$Q_\rho = [d_\rho^\dagger s_\rho + s_\rho^\dagger d_\rho]^{(2)} + \chi_\rho [d_\rho^\dagger d_\rho]^{(2)}, \quad \rho = \pi \ or\ \nu. \tag{6}$$

The terms $V_{\pi\pi}$ and $V_{\nu\nu}$, which correspond to the interaction between like-boson, are sometimes included in order to improve the fit to experimental energy spectra.

The Majorana term, $M_{\nu\pi}$, which contains the three parameters ξ_1, ξ_2 and ξ_3, may be written as

$$M_{\nu\pi} = \frac{1}{2}\xi_2(\,[s_\nu^\dagger d_\pi^\dagger - d_\nu^\dagger s_\pi^\dagger]^{(2)}.[s_\nu d_\pi - d_\nu s_\pi]^{(2)}\,) - \sum_{k=1,3} \xi_k(\,[d_\nu^\dagger d_\pi^\dagger]^{(k)}.[d_\nu d_\pi]^{(k)}). \tag{7}$$

The Majorana term played a great role in producing the M1 matrix elements and the mixed symmetry states.

In IBM-2, the E2 transition operator is given by,

$$T^{(E2)} = e_\pi Q_\pi + e_\nu Q_\nu \tag{8}$$

where Q_ρ is the same as in equation (5) and e_π and e_ν are boson effective charges, depending on the boson number N_ρ, and they can take any value to fit the experimental results. The estimation method for these effective charges was explained in reference [13].

The M1 operator obtained by making $l = 1$ in the single boson operator of the IBM-2 and can be written as

$$T^{(M1)} = \left[\frac{3}{4\pi}\right]^{1/2} \left(g_\pi L_\pi^{(1)} + g_\nu L_\nu^{(1)}\right) \tag{9}$$

where g_π, g_ν are the boson g-factors in units of μN and $L^{(1)} = \sqrt{10}(d^+ \times \tilde{d})^{(1)}$. This operator can be written as

$$T^{(M1)} = \left[\frac{3}{4\pi}\right]^{1/2} \left[\begin{array}{l} \frac{1}{2}(g_\pi + g_\nu)(L_\pi^{(1)} + L_\nu^{(1)}) \\ +\frac{1}{2}(g_\pi - g_\nu)(L_\pi^{(1)} - L_\nu^{(1)}) \end{array}\right]. \tag{10}$$

The first term on the right hand side, in the above equation, is diagonal and therefore, for M1 transitions, the previous equation may be written as

$$T^{(M1)} = 0.77 \left[(d^+\tilde{d})_\pi^{(1)} - (d^+\tilde{d})_\nu^{(1)}\right](g_\pi - g_\nu). \tag{11}$$

The direct measurement of B(M1) matrix elements should be normally difficult, so the M1 strength of gamma transition may be expressed in terms of the multiple mixing ratio which can be written as [14]

$$\delta(E2/M1) = 0.835\, E_\gamma(MeV) \cdot \Delta, \tag{12}$$

where $\Delta = \frac{\langle I_f || T^{E2} || I_i \rangle}{\langle I_f || T^{M1} || I_i \rangle}$ in units of eb/μN.

Having fit E2 matrix elements, one can then use them to obtain M1 matrix elements and then the mixing ratio $\delta(E2/M1)$, and compare them with the prediction of the model using the operator (10). If they had not been measured in the case of Ge isotopes, factors g_π and g_ν have to be estimated. The g factors may be estimated from experimental magnetic moment (μ) of the 2_1^+ state ($\mu = 2g$). In phenomenological studies g_π

and g_ν are treated as parameters and kept constant for a whole isotope chain. The total g factor is defined by Sambataro et al [15] as

$$g = g_\pi \frac{N_\pi}{N_\pi + N_\nu} + g_\nu \frac{N_\nu}{N_\pi + N_\nu}. \tag{13}$$

Many relations could be obtained for a certain mass region and then the average g_π and g_ν values for this region could be calculated.

3. Calculations and results

Before starting the calculation and choosing the models fitting the parameters, one has to look for a systematic trend in the experimental energy level of these isotopes. Figure 1 shows the low-lying energy levels of the series of Ge isotopes. It looks like a clear phase transition, from ^{64}Ge to ^{82}Ge. The ratio $E4_1/E2_2$ changes from vibrational $\sim$2 toward gamma soft at $\sim$2.5, as shown in Table 1. This phase coexistence is suggested by Yosuka Toh et al, as well as in [16]. This gives us a good indication for choosing the model parameters.

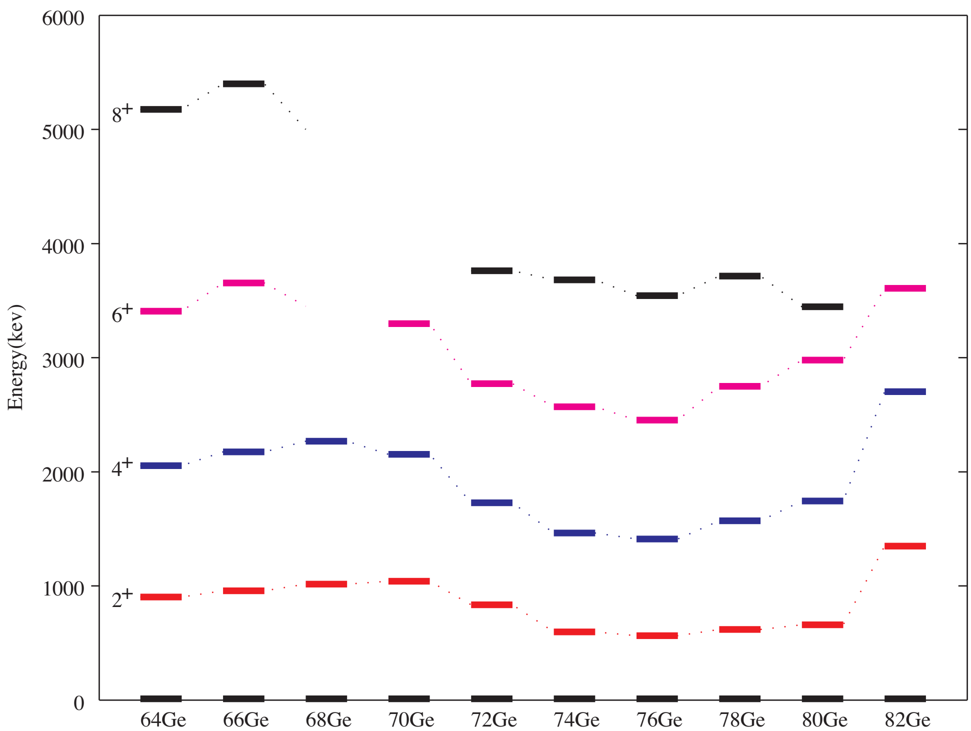

Figure 1. Variation of experimental excitation energies [17] of low-spin, even-parity states of Ge isotopes.

Table 1. The experimental energy ratios of Ge isotopes [17].

Energy Ratio ↓	^{64}Ge	^{66}Ge	^{68}Ge	^{70}Ge	^{72}Ge	^{74}Ge	^{76}Ge	^{78}Ge	^{80}Ge	^{82}Ge
$E4_1/E2_2$	2.28	2.27	2.23	2.07	2.07	2.46	2.50	2.54	2.64	2.000
$E6_1/E2_1$	3.78	3.81	-	-	3.32	4.31	4.36	4.44	4.51	2.68

The IBM-1 model parameters are listed in Table 2. Here, the TT's parameters are taken to be zero for best fit. The above discussion is taken into consideration in order to initiate the first run of the IBM-1 program. Five parameters are used to fit the experimental data [17].

Table 2. The IBM-1 Parameters of Ge isotopes, with $T_3 \cdot T_3 = T_4 \cdot T_4 = 0.0$.

Isotope	N	eps	P · P	L · L	Q · Q	chi	α_2	β_2
^{64}Ge	4	0.76	0.0038	0.032	-0.019	0.76	0.100	-0.130
^{66}Ge	5	0.84	0.0020	0.034	-0.017	0.65	0.058	-0.110
^{68}Ge	6	0.88	0.0022	0.036	-0.015	0.40	0.065	-0.110
^{70}Ge	7	0.94	0.0028	0.030	-0.013	0.65	0.065	-0.110
^{72}Ge	7*	0.75	0.0030	0.029	-0.020	0.60	0.065	-0.110
^{74}Ge	6*	0.61	0.0060	0.022	-0.025	0.50	0.085	-0.110
^{76}Ge	5*	0.55	0.0080	0.020	-0.029	0.50	0.082	-0.110
^{78}Ge	4*	0.54	0.0052	0.021	-0.029	0.50	0.095	-0.110
^{80}Ge	3*	0.52	0.0037	0.021	-0.033	0.50	0.090	-0.110

*Denotes holes for neutron bosons

The program NPBOS [18] was used to dogmatize the IBM-2 Hamiltonian in equation (5). The Ge isotopes have $N_\pi = 2$ and N_ν varies from 2 to 5 as a particle boson relative to the magic number 28 and 5 to 1 as a hole boson relative to the magic closed shell at 50. The model parameters are listed in table-3. The parameter $\chi_\pi = -1.2$ is taken to be constant for all the series isotopes. The rest of the parameters are free parameters that have been determined so as to reproduce as closely as possible to experimental excitation energy of the low-lying positive parity states. The parameters of ref.[8] are taken to be the starting parameters. Altogether, the six fitting free parameters used.

Table 3. The IBM-2 parameters, $(N_\pi = 2)$.

Isotope	N_ν	EPS	RKAP	CHN	CLN	CLP	$\zeta_{1,3}$	ζ_2
^{64}Ge	2	1.22	-0.25	1.4	0.0	0.0	0.05	-0.05
^{66}Ge	3	1.39	-0.28	1.5	0.0	0.0	0.05	-0.05
^{68}Ge	4	1.4	0.20	1.45	0.0	0.0	0.05	-0.05
^{70}Ge	5	1.45	-0.19	1.45	0.0	0.0	0.02	-0.03
^{72}Ge	5*	1.40	-0.28	1.3	0.0	0.0	-0.05	-0.03
^{74}Ge	4*	0.98	-0.22	1.20	0.0	0.0	-0.01	-0.01
^{76}Ge	3*	0.96	-0.22	1.20	0.0	0.0	-0.01	-0.01
^{78}Ge	2*	0.96	-0.22	1.20	0.0	0.0	-0.01	-0.01
^{80}Ge	1*	1.55	-0.22	1.2	0.0	0.0	-0.01	-0.01

*Denotes holes for neutron bosons

Table 4 contains energy values compared with the predictions of the three versions are of the interacting boson approximation.

From the details of Table 4, one can see that all IBM versions reproduce the first excited state very well, while IBM-1 version misses the energy value of the three phonon triplet $(2_2, 4_1, 0_2)$. The IBM-3 does not work on nuclei when the total boson number exceeds 7 bosons [19].

Table 4. Calculated energy levels from the present work (IBM-1 and IBM-2) and IBM-3, compared with the experimental data [17].

Ge Isotope	calculations	2_1	4_1	6_1	8_1	0_2	2_2	3_1	2_3
^{64}Ge	Exp. =	**0.902**	**2.052**	**3.406**	**5.175**		**1.572**		
	IBM-1=	0.901	2.133	3.659	5.587		1.712	2.770	
	IBM-2=	0.908	2.139	3.814	5.770	2.250	1.533	2.482	2.489
	*IBM-3=	0.907	2.117	3.628		1.215	1.627	2.578	2.081
^{66}Ge	Exp. =	**0.957**	**2.174**	**3.655**	**5.399**		**1.663**	**2.495**	
	IBM-1=	0.937	2.225	3.860	5.840	1.618	1.771	2.840	2.732
	IBM-2=	0.954	2.256	3.821	6.000	2.352	1.669	2.709	2.852
	IBM-3=	0.957	2.126	3.504		1.334	1.776	2.754	2.185
^{68}Ge	Exp. =	**1.016**	**2.268**			**1.755**	**1.778**	**2.429**	**2.457**
	IBM-1=	1.002	2.354	4.054	6.107	1.659	1.858	2.989	2.790
	IBM-2=	0.986	2.239	3.703	5.315	2.462	1.778	2.831	2.686
	IBM-3=	0.995	2.183	3.565		1.670	1.889	2.935	2.462
^{70}Ge	Exp. =	**1.039**	**2.153**	**3.290**	**4.024**	**1.216**	**1.708**	**2.452**	**2.156**
	IBM-1=	1.000	2.293	3.881	5.760	1.708	1.892	3.010	2.826
	IBM-2=	0.999	2.257	3.706	5.247	2.493	1.762	2.767	2.649
	IBM-3=	1.004	2.238	3.396		1.217	1.801	3.307	2.224
^{72}Ge	Exp. =	**0.834**	**1.728**	**2.772**	**3.761**	**0.691**	**1.464**	**2.065**	
	IBM-1=	0.774	1.814	3.006	4.109	1.284	1.457	2.389	2.224
	IBM-2=	0.891	1.926	2.705	3.188	1.974	1.403	2.212	2.181
	IBM-3=								
^{74}Ge	Exp. =	**0.596**	**1.464**	**2.569**	**3.681**	**1.483**	**1.204**	**1.697**	**1.913**
	IBM-1=	0.591	1.469	2.629	4.060	1.129	1.211	2.029	1.941
	IBM-2=	0.604	1.439	2.348	3.169	1.522	1.077	1.708	1.905
	IBM-3=								
^{76}Ge	Exp. =	**0.563**	**1.410**	**2.453**	**3.543**	**1.911**	**1.108**	**1.539**	
	IBM-1=	0.563	1.409	2.531	3.921	1.116	1.178	1.976	1.917
	IBM-2=	0.642	1.513	2.466	3.973	1.585	1.099	1.733	1.867
	IBM-3=								
^{78}Ge	Exp. =	**0.619**	**1.570**	**2.748**	**3.714**	**1.547**	**1.186**		**1.842**
	IBM-1=	0.619	1.523	2.704	4.157	1.169	1.259	2.102	2.006
	IBM-2=	0.705	1.648	2.980	4.516	1.684	1.144	1.798	1.876
	IBM-3=								
^{80}Ge	Exp. =	**0.659**	**1.743**	**2.978**	**3.446**		**1.574**		
	IBM-1=	0.660	1.611	2.849		1.230	1.339	2.236	2.117
	IBM-2=	0.658	1.732	3.791		1.783	1.898	2.884	2.564
	IBM-3=								

*IBM-3 values are from reference [19]

4. Electromagnetic properties

Calculations of electromagnetic properties give us a good test of the nuclear models prediction. The electromagnetic matrix elements between eigenstates were calculated using the programs IBMT in IBM-1 and

NPBMTRN for IBM-2 model.

In the IBM-1 version the strength was calculated by equations (4) and (3), using the parameters α_2 and β_2 are listed in Table 1.

In the IBM-2 version the effective charges calculated by for Ge isotopes were $e_\nu = 28.33\ e\,fm^2$ and $e_\pi = 2.58\,e\,fm^2$ and kept constant for all Ge isotopes. The results of the calculation are listed in Table 5.

The B(M1) reduced transition probabilities were calculated using equations (11), and the gyromagnetic ratios by making use of equation (13) and one of the experimental B(M1) values. It is found that $g_\pi - g_\nu = 0.17\ \mu N$. The estimated values of the parameter are $g_\pi = 0.58\ \mu N$ and $g_\nu = 0.0.41\ \mu N$. These were used to calculate the ratio $\Delta(E2\backslash M1)$ and then the mixing ratio $\delta(E2\backslash M1)$.

Table 5. B(E2) transitions for the Ge isotopes (unit e^2b^2).

Nucleus	$I_i \rightarrow I_f$	Present work IBM-1	Present work IBM-2	Experimental [17]	IBM-3 [18]
^{64}Ge	$2_1 \rightarrow 0_1$	0.045	0.0125	0.0410 (60)	0.03826
	$2_2 \rightarrow 0_1$	0.0015	0.0028	0.00015(5)	0.00036
	$2_2 \rightarrow 2_1$	0.0728	0.0166	0.0620 (210)	0.05995
	$2_3 \rightarrow 0_1$	0.0000	0.0018		0.00001
	$2_3 \rightarrow 2_1$	0.0004	0.0012		0.00013
	$4_1 \rightarrow 2_1$	0.0605	0.0121		0.05991
^{64}Ge	$2_1 \rightarrow 0_1$	0.0143	0.0212	0.01896(362)	0.01879
	$2_2 \rightarrow 0_1$	0.0004	0.0029	0.00016(6)	0.00008
	$2_2 \rightarrow 2_1$	0.0321	0.0283	0.02686(1264	0.03102
	$2_3 \rightarrow 0_1$	0.0000	0.0018		0.0000
	$2_3 \rightarrow 2_1$	0.0001	0.0225		0.00905
	$4_1 \rightarrow 2_1$	0.0285	0.0325	$\geq$ 0.01517	0.03102
^{68}Ge	$2_1 \rightarrow 0_1$	0.0300	0.0273	0.02912(329)	0.03096
	$2_2 \rightarrow 0_1$	0.0006	0.0048	0.00023(4)	0.00010
	$2_2 \rightarrow 2_1$	0.0510	0.0406	0.00086(34)	0.05289
	$2_3 \rightarrow 0_1$	0.0000	0.0038		0.0
	$2_3 \rightarrow 2_1$	0.0002	0.0076		0.00004
	$4_1 \rightarrow 2_1$	0.0460	0.0446	0.02287(29)	0.05292
^{70}Ge	$2_1 \rightarrow 0_1$	0.0355	0.0340	0.03593(68)	0.03360
	$2_2 \rightarrow 0_1$	0.0009	0.0069	0.00171(85)	0.00000
	$2_2 \rightarrow 2_1$	0.0630	0.0500	0.0497(189)	0.05760
	$2_3 \rightarrow 0_1$	0.0000	0.0030	-	0.00000
	$2_3 \rightarrow 2_1$	0.0003	0.0010	-	0.00000
	$4_1 \rightarrow 2_1$	0.0564	0.0579	0.04112(11)	0.05760
^{72}Ge	$2_1 \rightarrow 0_1$	0.0338	0.0330	0.040(3)	
	$2_2 \rightarrow 0_1$	0.0035	0.0099		
	$2_2 \rightarrow 2_1$	0.0708	0.0478	0.114(12)	
	$2_3 \rightarrow 0_1$	0.0010	0.0017		
	$2_3 \rightarrow 2_1$	0.0006	0.0190		
	$4_1 \rightarrow 2_1$	0.0566	0.0565	0.0641(71)	

Table 5. Continued.

Nucleus	$I_i \rightarrow I_f$	Present work		Experimental [17]	IBM-3 [18]
		IBM-1	IBM-2		
^{74}Ge	$2_1 \rightarrow 0_1$	0.0542	0.0296	0.060(3)	
	$2_2 \rightarrow 0_1$	0.0014	0.0055	$\leq$ 0.078	
	$2_2 \rightarrow 2_1$	0.0860	0.0470	0.0997(203)	
	$2_3 \rightarrow 0_1$	0.0014	0.0017		
	$2_3 \rightarrow 2_1$	0.0183	0.0056		
	$4_1 \rightarrow 2_1$	0.0012	0.0464	0.0664(55)	
^{76}Ge	$2_1 \rightarrow 0_1$	0.059	0.026	0.046(3)	
	$2_2 \rightarrow 0_1$	0.0059	0.0041		
	$2_2 \rightarrow 2_1$	0.0994	0.0308	0.0746(96)	
	$2_3 \rightarrow 0_1$	0.0001	0.0011		
	$2_3 \rightarrow 2_1$	0.0012	0.000		
	$4_1 \rightarrow 2_1$	0.0823	0.0373	0.073(13)	
^{78}Ge	$2_1 \rightarrow 0_1$	0.0444	0.0230	0.044(30)	
	$2_2 \rightarrow 0_1$	0.0029	0.0033		
	$2_2 \rightarrow 2_1$	0.0686	0.0164	0.0396(238)	
	$2_3 \rightarrow 0_1$	0.0000	0.0040		
	$2_3 \rightarrow 2_1$	0.0009	0.0007		
	$4_1 \rightarrow 2_1$	0.0566	0.0160	$\geq$ 0.0218	
^{80}Ge	$2_1 \rightarrow 0_1$	0.0282	0.034	0.028(5)	
	$2_2 \rightarrow 0_1$	0.0015	0.0012		
	$2_2 \rightarrow 2_1$	0.0397	0.0019		
	$2_3 \rightarrow 0_1$	0.0000	0.000		
	$2_3 \rightarrow 2_1$	0.0003	0.000		
	$4_1 \rightarrow 2_1$	0.0318	0.0036		

Looking at the details of Table 5, we can see the good agreement between the theoretical values and the available experimental data for all the versions, except the cases when we are close to the neutron core (at $N = 82$).

The $E2/M1$ multiple mixing ratios for this nucleus, $\delta(E2/M1)$, were calculated for some selected transitions between states of $\Delta I = 0$. The sign of the mixing ratio must be chosen according to the sign of the reduced matrix elements. The equations used are (11) for M1 transitions and (12) for the mixing ratios. The results are listed in Table 6. The agreement with available experimental data [17] is more than good especially in the sign of the mixing ratio. However, there is a large disagreement in the mixing ratios of $3_1 \rightarrow 2_1$, due to the small value of M1 matrix elements.

5. Concluding remarks

In this work a systematic study of most nuclear properties of even mass germanium isotopes have been performed. IBM calculations have been presented and all the results were compared with the available experimental data. The good agreement between the theoretical and experimental energy spectra , B(E2) values, and mixing ratios support the hypothesis of phase transitions between vibrational to O(6) in these nuclei.

Table 6. The calculated mixing ratios for selected transitions in Ge isotopes compared with the available experimental data.

Nucleus	$I_i \rightarrow I_f$	Present work $\delta(E2/M1)$	Experimental [17]
^{64}Ge	$2_2 \rightarrow 2_1$	-5.6	-
	$2_3 \rightarrow 2_1$	2.3	-
	$3_1 \rightarrow 2_1$	+10.74	-
	$3_1 \rightarrow 2_2$	-2.027	-
^{66}Ge	$2_2 \rightarrow 2_1$	-1.591	-3.5(+18-26)
	$2_3 \rightarrow 2_1$	-1.56	-
	$3_1 \rightarrow 2_1$	20.9	-
	$3_1 \rightarrow 2_2$	2.61	-
^{68}Ge	$2_2 \rightarrow 2_1$	-1.9346	-0.2(0.1)
	$2_3 \rightarrow 2_1$	-1.734	-
	$3_1 \rightarrow 2_1$	-36.78	0.16(2)
	$3_1 \rightarrow 2_2$	-0.31	-0.2(0.3)
^{70}Ge	$2_2 \rightarrow 2_1$	-1.76	-5.0(3.0)
	$2_3 \rightarrow 2_1$	-5.78	-
	$3_1 \rightarrow 2_1$	-16.7	-2.2(+5-3)
	$3_1 \rightarrow 2_2$	-0.35	-0.05(8)
^{72}Ge	$2_2 \rightarrow 2_1$	-3.45	-10.3(13)
	$2_3 \rightarrow 2_1$	-3.89	-
	$3_1 \rightarrow 2_1$	-7.88	-
	$3_1 \rightarrow 2_2$	+3.92	$\approx$ +4.0
^{74}Ge	$2_2 \rightarrow 2_1$	-3.67	+3.4(4)
	$2_3 \rightarrow 2_1$	-1.222	-2.8(3)
	$3_1 \rightarrow 2_1$	7.44	0.34(5)
	$3_1 \rightarrow 2_2$	3.02	+1.3(4)
^{76}Ge	$2_2 \rightarrow 2_1$	-5.789	+3.5(15)
	$2_3 \rightarrow 2_1$	3.500	-
	$3_1 \rightarrow 2_1$	-11.58	-
	$3_1 \rightarrow 2_2$	2.44	-
^{78}Ge	$2_2 \rightarrow 2_1$	-6.78	-
	$2_3 \rightarrow 2_1$	0.98	-
	$3_1 \rightarrow 2_1$	29.5	-
	$3_1 \rightarrow 2_2$	1.96	-
^{80}Ge	$2_2 \rightarrow 2_1$	-1.2	-
	$2_2 \rightarrow 2_1$	-1.6	-
	$3_1 \rightarrow 2_1$	-1.37	-
	$3_1 \rightarrow 2_2$	-0.511	-

For most Ge isotopes, it is found that the changing of Majorana interaction does not effect levels of energy of the ground band states and B(E2) values, but it has a great effect on the energy of the 2_2 and 2_3 and transitions linking them.

The 2_2 could be interpreted as a band-head of gamma- band linked with a strong B(E2) transition, which suggests that they are collective or forming gamma rotational band based on the 2_2 band head.

The intruder 0_2 which becomes the first excited state in ^{70}Ge is a band head of strongly deformed band, coexisting with a less deformed structure of nucleus.

The IBM-2 version was able to reproduce $\delta(E2/M1)$ for most transitions especially $2_2 \rightarrow 2_1$, with its sign.

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