The Prediction of the Electromagnetic Properties and the δ(E2/M1) of $^{110-116}$Cd-Isotopes in IBM Model

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Abstract:

The Nuclear structure of $^{110-116}$Cd isotopes was studied theoretically in the framework of the interacting boson model of IBM-l and IBM-2. The properties of the lowest mixed symmetry states such as the 1^+, 2^+ and 3^+ levels produced by the IBM-2 model in the vibrational-limit U(5) of Cd - isotopes are studied in details. This analysis shows that the character of mixed symmetry of 2^+ is shared between 2_2^+ and 2_3^+ states in $^{110-114}$Cd – isotopes, the large shar goes to 2_2^+s, while in ^{116}Cd isotope, the 2_3^+ state is declared as a mixed symmetry state without sharing. This identification is confirmed by the percentage of F-spin contribution.

The electromagnetic properties of E2 and Ml operators were investigated and the results were analyzed. Various values of e_B in the IBM-l and fixed e_π= 0.104 eb and e_ν=0.093 e.b in the IBM-2 are used to generate the B(E2) and Q(2^+). Fixed values of $g_\pi = 0.31\mu_N$ and $g_\nu = -0.31\mu_N$ were adopted to generate the B(Ml) and δ(E2/ Ml) mixing ratios. The small values of δ(E2/Ml) which obtained for transition from MS- states to those of full symmetry support the conclusion that there may be a strong Ml transition between these states.

Key words: energy levels, B(E2), B(M1), mixing ratios, Mixed-symmetry, IBM-1, IBM-2

Introduction:

The even-even cadmium isotopes are part of an interesting region near the closed proton shell at Z=50, while the number of neutrons in the open shell is larger, as such these nuclei have been commonly considered to exhibit vibrational-like properties.

The even-mass cadmium isotopes have been extensively investigated both theoretically and experimentally in recent years with special emphasis on interpreting experimental data via collective models. Energy levels, electric quadrupole moments, B(E2) values of ^{106}Cd, ^{112}Cd and ^{118}Cd isotopes were calculated within the frame work of IBM-1[1]. The three – phonon structure of ^{110}Cd has been studied with the $(n,\overline{n}\gamma)$ reaction [2]. Multi pole mixing ratios and transition strengths of gamma rays from excited states of ^{112}Cd and ^{113}Cd were following angular distribution study [3]. Life times of levels below 4 MeV in ^{112}Cd have been measured using the Doppler shift attenuations technique following inelastic scattering of monoenergetic neutrons [4].

The energy levels of ^{114}Cd has been studied by using ^{113}Cd (n,γ) reaction, the energies and the relative intensities of the γ- rays were determined [5]. The interaction boson model (IBM-2) was used for describing the Cadmium isotopes $^{110-116}Cd$ [6].

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Theory: In IBM-1, proton- and neutron-boson degrees of freedom are not distinguished. The model has an inherent group structure, associated with it. In terms of s- and d-boson operators the most general IBM Hamiltonian can be expressed as [7]

$$\hat{H} \quad \varepsilon_s(s^+.\tilde{s})+\varepsilon_d(d^+.\tilde{d})+\sum_{L\ 0,2,4}\sqrt{2L+1}\,c_L$$
$$\left[\left[d^+\otimes d^+\right]\otimes\left[\tilde{d}\otimes\tilde{d}\right]^L\right]^0+\frac{\tilde{v}_2}{\sqrt{2}}$$
$$\left[[d^+\otimes d^+]^2\otimes[\tilde{d}\otimes\tilde{s}]^2+[d^+\otimes s^+]^2\otimes[\tilde{d}\otimes\tilde{d}]^2\right]^0+$$
$$\frac{\tilde{v}_0}{2}\left[[d^+\otimes d^+]^0\otimes[\tilde{s}\otimes\tilde{s}]^0+[s^+\otimes s^+]^0\otimes[\tilde{d}\otimes\tilde{d}]^0\right]^0+$$
$$u_2\left[[d^+\otimes s^+]^2\otimes[\tilde{d}\otimes\tilde{s}]^2\right]^0+\frac{u_0}{2}\left[[s^+\otimes s^+]^0\otimes[\tilde{s}\otimes\tilde{s}]^0\right]^0$$

… (1)

This Hamiltonian contains 2 one-body term, (ε_s and ε_d), and 7 two-body interactions [c_L (L=0,2,4), v_L (L=0,2), u_L (L=0,2)], where ε_s and ε_d are the single-boson energies, and c_L, v_L and u_L describe the two-boson interactions. Hamiltonian can be rewritten in terms of the Casimir operators of U(6) group. In that case, one says that the Hamiltonian H has a dynamical symmetry. These symmetries are called U(5) vibrational, SU(3) rotational and O(6) γ-unstable.

The general E2 transition operator must be a hermitian tensor of rank two and therefore the number of bosons must be conserved. Since, with these constraints there are two operators possible in the lowest order, the general E2 operator can be written as [7]

$T_m(E2)=\alpha_2[d^\dagger s+s^\dagger d]^{(2)}_m+\beta_2[d^\dagger d]^{(2)}_m$, …(2)

where α_2 plays the role of the effective boson charge and β_2 $\sqrt{7}/2\alpha_2$. The B(E2) strength for the E2 transitions is given by $B(E2;L_i\rightarrow L_f)=$

$$\left|\langle L_f\|T_m(E2)\|L_i\rangle\right|^2/(2L_i+1)\ldots(3)$$

Similarly, the M1 operator would be just $\beta_1[d^\dagger d]_1$.

However, in this work another form of the Hamiltonian of IBM-1 is used, which was introduced by Scholtan [8] in terms of multipole expansion, and is given by

$$\hat{H}=\varepsilon(n_d)+a_0$$
$$(\hat{P}\bullet\hat{P})+a_1(\hat{L}\bullet\hat{L})+a_2(\hat{Q}\bullet\hat{Q})+a_3(\hat{T}_3\bullet\hat{T}_3)+a_4(\hat{T}_4\bullet\hat{T}_4)$$

…(4)

The parameters a_o, a_1, a_2, a_3, a_4 represent the strength of the pairing, angular momentum, quadruple, octupole and hexadecapole interactions respectively. P, L, Q, T_3 and T_4 represent the operators for each interaction respectively.

The Hamiltonian operator in IBA-2, has three parts [9], one for proton bosons, one for neutron bosons and the third one describing the interaction between unlike bosons:

$$H \quad H_\pi+H_\nu+H_{\pi\nu} \quad \ldots(5)$$

The Hamiltonian generally used in phenomenological calculations can be written as

$$H \quad \varepsilon_d(n_{d\nu}+n_{d\pi})+\kappa(Q_\nu.Q_\pi)+V_{\nu\nu}+V_{\pi\pi}+M_{\nu\pi}$$

… (6)

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 ν (neutron) bosons. The second term denotes the quadrupole-quadrupole interaction between neutron and proton bosons with the strength κ. The quadrupole operator is given by

$$Q_\rho \quad [d_\rho{}^+ s_\rho+s_\rho{}^+ d_\rho]^{(2)}+\chi_\rho[d_\rho{}^+ d_\rho]^{(2)}$$

…(7)

where χ_ρ determines the structure of the quadrupole operator and is

determined empirically. The square bracket in Eq. (7) denotes angular momentum coupling. The terms $V_{\pi\pi}$ *and* $V_{\nu\nu}$ correspond to the interaction between like-boson. They are of the form

$$V_{\rho\rho} \quad \frac{1}{2}\sum_{L\ 0,2,4} C_L{}^{\rho}([d^{+}{}_{\rho}d^{+}{}_{\rho}]^{(L)}.[d_{\rho}d_{\rho}]^{(L)}). \quad ..(8)$$

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

$$M_{\nu\pi} \quad \frac{1}{2}\xi_2([s_{\nu}{}^{+}d_{\pi}{}^{+} - d_{\nu}{}^{+}s_{\pi}{}^{+}]^{(2)}.[s_{\nu}d_{\pi} - d_{\nu}s_{\pi}]^{(2)}) - \sum_{k\ 1,3}\xi_k([d_{\nu}{}^{+}d_{\pi}{}^{+}]^{(k)}.[d_{\nu}d_{\pi}]^{(k)}) \quad ...(9)$$

Calculations and Results:

1- Energy Spectra

To produce the low –lying energy levels of a nucleus by IBM-1 model, it is necessary to specify the symmetry shape of the nucleus, which can be predicted from the energy ratio $E4_1{}^{+}$ to $E2_1{}^{+}$. $R_{4/2}$ has a limit value of 2 for the vibrational nuclei U(5), 2.5 for γ-unstable nuclei O(6) and finally 3.33 for rotational nuclei SU(3). The variation of the experimental $E4_1^{+}/E2_1^{+}$ value with the neutron numbers is given in Figure (1). It is clear that the $^{110-116}Cd$ isotopes are transitional U(5)- O(6) nuclei, but they are close to U(5) symmetry. The best fit values for the Hamiltonian parameters in IBM-1 are given in Table-1 and those in IBM-2 are given in Table-2.

Table (1): The Hamiltonian parameters IBM-1 used for Cd-isotopes.

Param-eters	^{110}Cd	^{112}Cd	^{114}Cd	^{116}Cd
N	7	8	9	8
ε (MeV)	0.712	0.650	0.580	0.490
a_0 (MeV)	-0.0023	-0.002	-0.0080	-0.0077
a_1 (MeV)	0.000	0.000	0.0047	0.0068
a_2 (MeV)	-0.0125	-0.009	-0.0026	-0.0058
a_3 (MeV)	0.0018	0.0300	0.0003	0.0010
a_4 (MeV)	0.0190	0.007	0.0058	0.050
CHI	0.000	-0.100	-0.0310	-0.250
e_B (eb)	0.1003	0.1	0.1095	0.1135

Table (2): The Hamiltonian parameters IBM-2 used for Cd-isotopes.

Parameters	^{110}Cd	^{112}Cd	^{114}Cd	^{116}Cd
N_{ν}	6	7	8	7
ε_d (MeV)	0.84	0.78	0.76	0.735
k (MeV)	-0.057	-0.060	-0.063	-0.085
χ_{υ}	-1.00	-1.00	-1.500	-0.050
χ_{π}	-1.500	-1.500	-1.600	-0.620
ξ_1 (MeV)	-0.100	-0.100	-0.180	-0.140
ξ_2 (MeV)	0.185	0.130	0.080	0.170
ξ_3 (MeV)	-0.020	-0.080	-0.120	-0.090
e_{π} =0.093 eb,		e_{ν} = 0.104 eb		

In Figure (2) a comparison between the experimental and IBM-2 energy spectra were shown for the investigated Cd- isotopes. The interesting point in this figure is that the IBM-2 has preserved the image of the experimental spectrum such as the sequences of states, even in the cases where the fit is not good enough. It must be noticed that the goal in this study is to obtain global reasonable predications of several properties and not only the energy spectra.

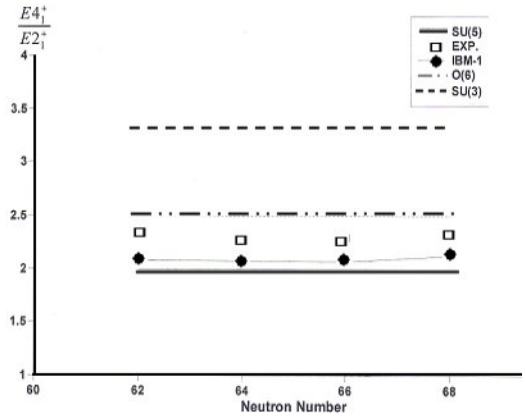

Fig. (1): shows the variation of $E4_1^{+}/E2_1^{+}$ in Cadmium isotopes.

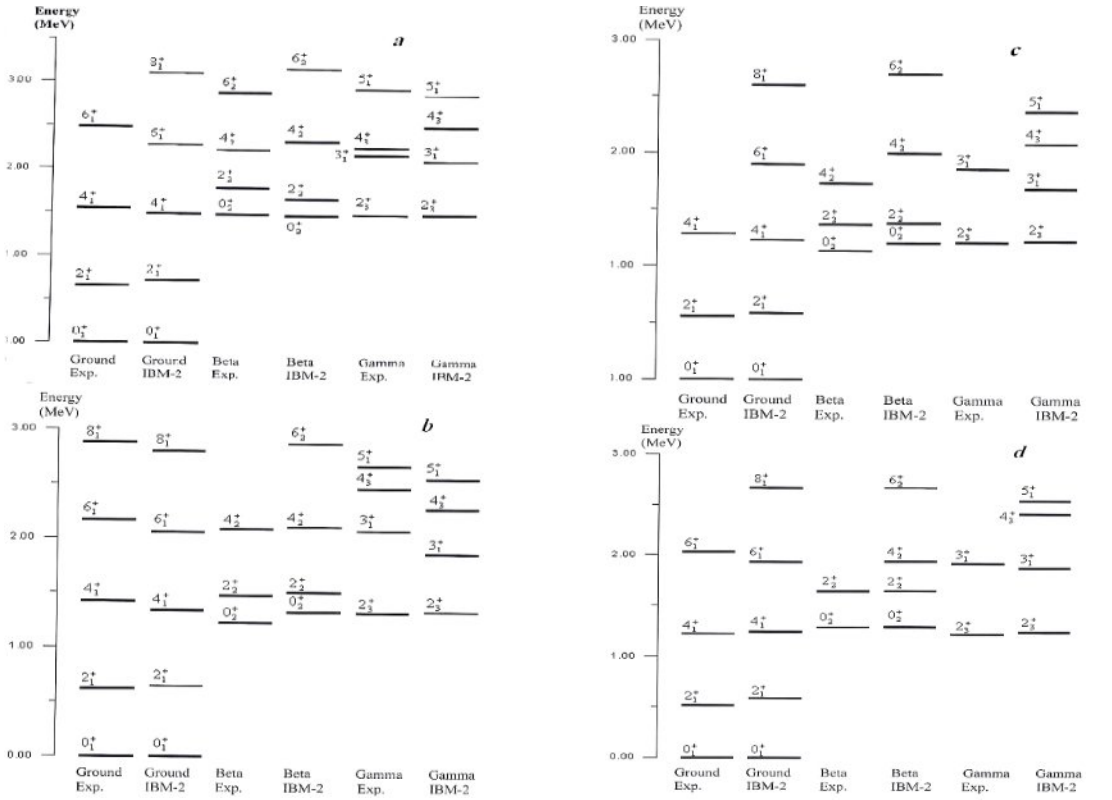

Fig. (2): A comparison between the experimental low-lying positive parity states and those obtained by IBM-2a) ^{110}Cd **[2,10,11],b)** ^{112}Cd **[4, 10, 11], c)** ^{114}Cd **[5,10,12], d)** ^{116}Cd **[10,13].**

2-B (E2) transition properties:

In principle that the value of the effective charge (e_B) of the IBM-1 was determined by normalization to the experimental data of $B(E2;2_1^+ \rightarrow 0_1^+)$ of each isotopes. While in IBM-2 the e_ν and e_π in the present work were given fixed values (e_ν=0.104 eb, e_π=0.093 eb) and have been used for all treated set of Cd-isotopes.

In tables 3 and 4, the calculated result of the IBM-1 and IBM-2 and the experimental data for B(E2; $j_i \rightarrow j_f$) transitions in (e^2b^2) are compared. As the neutron number is increasing the experimental $B(E2;2_1^+ \rightarrow 0_1^+)$ increases as well.

The quadrupole moments of the first excited 2_1^+ state for Cd-isotopes were calculated in this work and presented in tables 3 and 4 in comparison with the experimental data.

Table (3): The experimental B(E2; $j_i \to j_f$) (e^2b^2) values[2,4,6, 10], and the $Q_{2_1^+}$ ($e.b$), for $^{110,112}Cd$ isotopes are compared with those obtained by IBM-1 and IBM-2 results.

^{110}Cd				^{112}Cd			
$j_i \to j_f$	EXP.	IBM-1	IBM-2	$j_i \to j_f$	EXP.	IBM-1	IBM-2
$2_1^+ \to 0_1^+$	0.085	0.085	0.0826	$2_1^+ \to 0_1^+$	0.0968	0.0967	0.097
$2_1^+ \to 4_1^+$	0.1436(23)	0.1391	0.1445	$2_1^+ \to 4_1^+$	0.1956	0.1627	0.173
$6_1^+ \to 4_1^+$	$0.194^{+0.056}_{-0.053}$	0.1673	0.1816	$0_2^+ \to 2_1^+$	0.1635	0.1355	0.169
$2_2^+ \to 2_1^+$	0.101(29)	0.1391	0.0939	$2_2^+ \to 2_1^+$	0.048(1)	0.1624	0.098
$4_2^+ \to 4_1^+$	$0.053^{+0.025}_{-0.019}$	0.0797	0.0636	$4_2^+ \to 4_1^+$	0.08017	0.0961	0.073
$4_2^+ \to 2_2^+$	0.10331	0.0877	0.024	$4_2^+ \to 2_2^+$	0.1924	0.1058	0.085
$2_3^+ \to 0_2^+$	$0.072^{+0.084}_{-0.056}$	0.0730	0.0118	$2_3^+ \to 0_2^+$	$0.143^{+0.031}_{-0.022}$	0.0888	0.0183
$3_1^+ \to 4_1^+$	$0.0219^{+0.0187}_{-0.0125}$	0.0478	0.0171	$3_1^+ \to 4_1^+$	0.08017	0.0576	0.0205
$3_1^+ \to 2_2^+$	$0.078^{+0.040}_{-0.034}$	0.1195	0.0889	$3_1^+ \to 2_2^+$	0.20203	0.1442	0.1118
$Q_{2_1^+}$	-0.40	0.0	-0.337	$4_3^+ \to 2_2^+$	$0.0067^{+0.001}_{-0.002}$	0.0	0.0059
				$Q_{2_1^+}$	-0.37	-0.043	-0.385

3 - B (M1) transition properties:

The B(M1) transition in IBM-2, is influenced by the parameters of g_ν and g_π. A fixed values for g_π=0.31 and g_ν=-0.31 were used to produce these properties through out all Cd-isotopes. The comparison between the calculated result for B(M1) transitions and ($\mu_{2_1^+}$) moments of the IBM-2 model and those of experimental data are presented in table 5 for ^{110}Cd, since the available experimental data are restricted only for ^{110}Cd, and no experimental data are excited for other isotopes. Therefore a clear picture could not be drawn for the properties of the B(M1) transitions in Cd-isotopes. However, the good agreement could be noted for the available experimental data with calculated B(M1) transitions.

Table (4): The experimental B(E2; $j_i \to j_f$) (e^2b^2) values[5,6,10], and the $Q_{2_1^+}$ ($e.b$), for ^{114}Cd and ^{116}Cd isotopes are compared with those obtained by IBM-1 and IBM-2 results.

^{114}Cd				^{116}Cd			
$j_i \to j_f$	EXP.	IBM-1	IBM-2	$j_i \to j_f$	EXP.	IBM-1	IBM-2
$2_1^+ \to 0_1^+$	0.102	0.102	0.112	$2_1^+ \to 0_1^+$	0.112	0.112	0.104
$2_1^+ \to 4_1^+$	0.201	0.181	0.211	$2_1^+ \to 4_1^+$	0.197(50)	0.193	0.172
$0_2^+ \to 2_1^+$	.1350	0.179	0.221	$2_2^+ \to 2_1^+$	0.0730	0.192	0.167
$2_2^+ \to 2_1^+$	0.0875	0.181	0.057	$Q_{2_1^+}$	-0.42	-0.100	-0.124
$2_3^+ \to 4_1^+$	0.207	0.081	0.039				
$Q_{2_1^+}$	-0.34	-0.009	-0.544				

Table (5): The experimental B(M1; $j_i \to j_f$) (μ_N^2) values[2,10], and the $\mu_{2_1^+}$ (μ_N), for ^{110}Cd isotope are compared with those obtained by IBM-1 and IBM-2 results.

$j_i \to j_f$	EXP.	IBM-2	$j_i \to j_f$	EXP.	IBM-2
$2_2^+ \to 2_1^+$		0.0269	$3_1^+ \to 2_2^+$	0.010	0.0341
$2_3^+ \to 2_1^+$	0.026	0.0691	$4_2^+ \to 4_1^+$	0.103	0.0075
$2_4^+ \to 2_1^+$	0.031	0.0006	$4_3^+ \to 4_1^+$	$0.148^{+0.73}_{-0.68}$	0.0947
$3_1^+ \to 2_1^+$	0.002	0.0023	$\mu_{2_1^+}$	+0.56	-0.1700
$3_1^+ \to 4_1^+$	0.027	0.0347			

4- δ – mixing ratios:

The δ – mixing ratios in the considered Cd-isotopes were have been studied in the present work using the relation of δ with the ratio of the reduced matrix elements of the E2 and M1, which given as

$$\delta(E2/M1) \quad 0.835 E_\gamma \times \Delta(E2/M1) \quad \ldots (10)$$

where E_γ is the transition energy in (MeV), and $\Delta(E2/M1)$ in (eb/μ_N) and defined as the ratio of the reduced E2 matrix element to the M1 matrix elements. i.e.

$$\Delta(E2/M1) \quad \frac{\langle J_f \| T(E2) \| J_i \rangle (eb)}{\langle J_f \| T(M1) \| J_i \rangle (\mu_N)} \ldots (11)$$

In table 6, the comparison between the available experimental δ(E2/M1) mixing ratio for ^{110}Cd and ^{112}Cd isotopes with their counterpart which calculated in the frame work of IBM-2.

It is worth noting that for ^{114}Cd and ^{116}Cd isotopes only the experimental data of $2_2^+ \to 2_1^+$ transitions is available; where it is $\delta = -1.4^{+0.7}_{-0.3}$ in ^{114}Cd and $\delta = -1.5^{+0.7}_{-0.4}$ in ^{116}Cd , while their correspondent in IBM-2 are δ = -0.5 for ^{114}Cd and δ = -5.17 for ^{116}Cd . In general the results are in good agreement with the available experimental data. However, the prediction of the sign of δ(E2/M1) ratios is a common problem in theoretical nuclear models. Some authors prefer to use the absolute value of the ratio |Δ(E2/M1)| to overcome this problem.

Table (6): A comparison between the experimental δ– mixing ratios [10,14,15,16] and those obtained by IBM-2(e_ν =0.104 eb, e_π =0.093 eb, g_π =0.31 μ_N and g_ν =- 0.31 μ_N) for ^{110}Cd and ^{112}Cd isotopes.

Transitions	^{110}Cd		^{112}Cd	
$j_i \to j_f$	δ Exp.	δ IBM-2	δ Exp.	δ IBM-2
$2_2^+ \to 2_1^+$	-1.2	-1.2112	$-1.6^{+0.8}_{-0.5}$	-0.96
$2_3^+ \to 2_1^+$	$0.13^{+0.03}_{-0.02}$	0.46248	0.22	0.55
$2_4^+ \to 2_1^+$	-0.01	0.42185	0.15	0.38
$2_5^+ \to 2_1^+$	-0.07	-0.4926	$-0.6^{+0.2}_{-0.4}$	-0.38
$3_1^+ \to 2_1^+$	$-1.52^{+0.11}_{-0.14}$	-0.9663	-1.2	-0.90
$3_1^+ \to 2_2^+$	$-1.66^{+0.09}_{-0.08}$	-0.8331	-1.5	-0.83
$4_2^+ \to 4_1^+$	-0.41	-2.2112	-0.47	-1.83
$4_3^+ \to 4_1^+$	$0.13^{+0.04}_{-0.03}$	0.16048	0.40	0.20

5- Mixed symmetry states (MS):

The energy fits of several levels are very sensitive to the parameters of the Majorana terms. This sensitivity urges us to conduct a search for low –lying states with mixed symmetry character in the vibrational Cd-isotopes. Figure -3 and Figure -4 demonstrate the influence of the Majorana parameters ξ_1, ξ_2 and ξ_3 on the mixed symmetry states or those contained mixed symmetry components.

Figure -3 shows that the term ξ_2 affects the energies of all levels that considered to have a mixed symmetry components in ^{114}Cd, and ^{116}Cd

isotopes, but its strong influence is on the 2^+ states and control the shearing of the mixed-symmetry character between 2_2^+ and 2_3^+. It should be notified that plots of ^{110}Cd and ^{112}Cd are similar to Figure-3a of ^{114}Cd. At starting point the ξ_2 influences the 2_2^+ energy level and then transfers this influence to 2_3^+, but this character for the 2_2^+ state is less pronounced than that for 2_3^+ states which can be seen in Figure -3a for ^{114}Cd. Such behavior of shearing disappeared in Figure - 3b for ^{116}Cd isotope. F- spin indications agree with the assignment of 1_1^+ and 3_1^+ states to have a mixed-symmetry character, give evidence that 2_2^+ and 2_3^+ are sharing the mixed symmetry properties in ^{110}Cd, ^{112}Cd and ^{114}Cd, and that 2_3^+ represents the 2_M^+ in ^{116}Cd isotope. From Figure - 4a and -4b, 1_1^+ and 3_1^+ levels in ^{112}Cd, can be assigned as 1_M^+ and 3_M^+, since they are strongly affected by ξ_1 and ξ_3 respectively.

Figure -5 shows the influence of ξ_2 Majorana parameter on the δ(E2/M1) of gamma transitions between $(2_i^+ \to 2_1^+,\ i = 2,3,4)$ in ^{112}Cd isotope. The value of δ varies with the change in Δ(E2/M1) and the later reflects the variation in the mixed-symmetry character in the initial levels. This variation is introduced by ξ_2 which effects the M1 component in the transition.

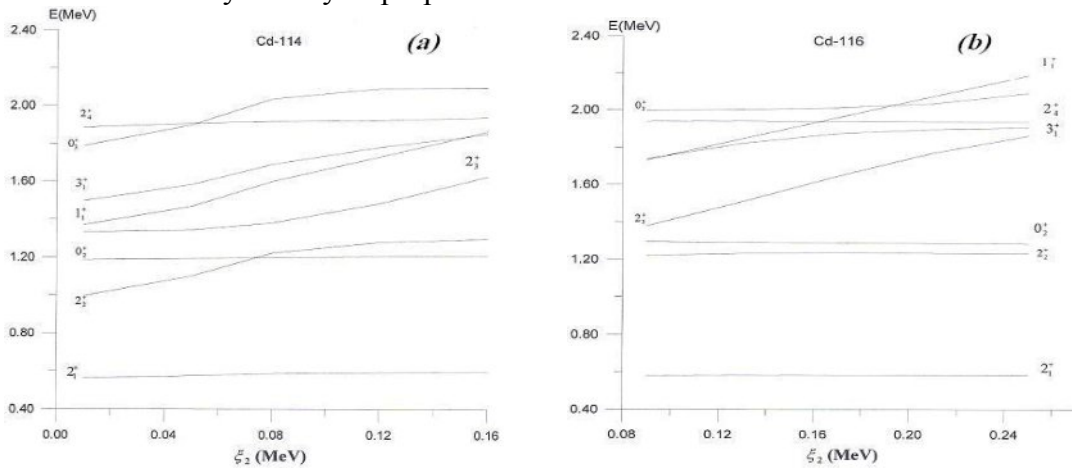

Fig. (3) : the change of the level energy in ^{114}Cd and ^{116}Cd as: ξ_2 is varied while the two remaining Majorana parameters are hold constant.

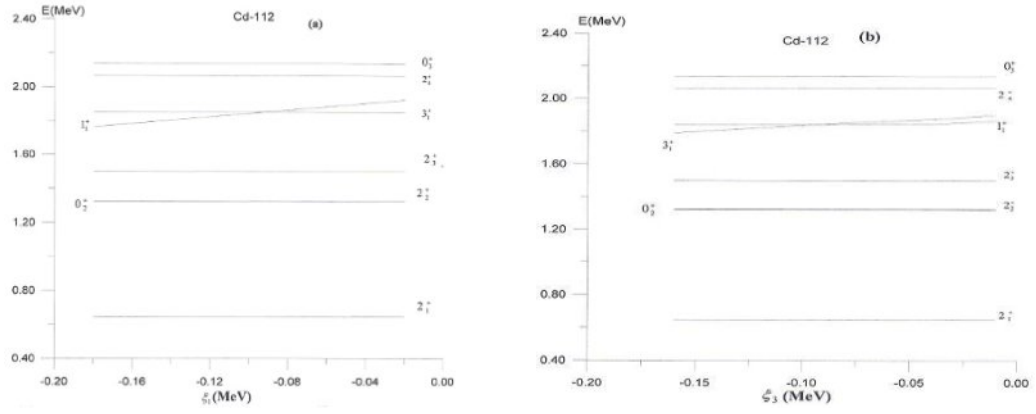

Fig. (4): the change of the level energy in ^{112}Cd as: (a) ξ_1 is varied (b) ξ_3 is varied while the two remaining Majorana parameters are hold constant.

Conclusions:

The structure of the Cd - isotopes with neutron's number N =62, 64, 66 and 68 have been studied theoretically using the framework of the interacting boson approximations IBM-1 and IBM-2. The fitting parameters were chosen to be consistent with geometrical and dynamical symmetries

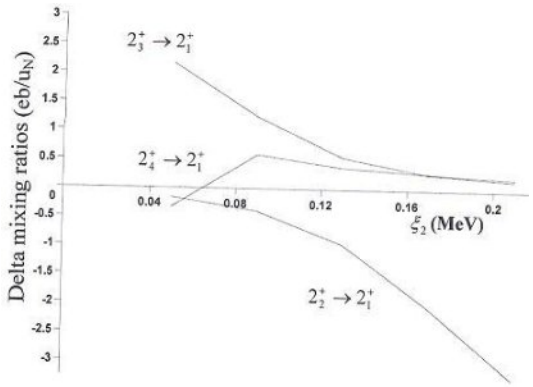

Fig. (5): the delta mixing ratio, δ(E2/M1) of $2_i^+ \to 2_1^+$ transitions is plotted against ξ_2, in ^{112}Cd.

That predicated for these isotopes. The properties of the low-lying collective states which have been predicated by these models for the Cd - isotopes are studied and compared with those available experimental data. The properties of the lowest mixed Symmetry states such as the 1_M^+, 2_M^+ and 3_M^+ states produced by IBM-2 model, which are out of the space of IBM-l model, are carefully examined.

The energy levels are well reproduced in the results of the IBM-2 than those of IBM-1. However, it can be concluded that the investigated Cd - isotopes can be considered as almost vibrational nuclei and have U(5) symmetry, but there transitional U(5) – O(6) character can not be neglected. Therefore, these nuclei still draw attention of researchers. It is concluded that the mixed symmetry character of 1_M^+ and 3_M^+ levels are confined to one level only whereas the 2_M^+ states may share this character with their neighboring levels. Their identification was confirmed by the F-spin contribution, since each of these MS states has the lowest percentage among the other 2^+ levels in each isotope. Accordingly, 2_2^+ and 2_3^+ were considered shearing this character in ^{110,112,114}Cd isotopes, but in ^{116}Cd, the 2_3^+ was declared as a mixed symmetry state. The IBM-2 result for $Q(2_1^+)$ are in good agreement with experimental data. The calculated delta mixing ratios of IBM-2 model are in reasonable agreement with the available experimental data. However, the sign and magnitude of δ(E2/M1) are real challenge to all nuclear models.

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حساب الخصائص الكهرومغناطيسية و نسب المزج δ(E2/M1) لنظائر $^{110-116}$Cd في أنموذج البوزونات المتفاعلة

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الخلاصة :

لقد تم دراسة التركيب النووي لنظائر نواة الكادميوم (Z=48) ($^{110-116}$Cd) نظريا بأستخدام أنموذج البوزونات المتفاعلة (IBM-2 , IBM-1). قد درست خصائص و صفات المستويات الأوطأ ذات التناظر المختلط مثل $^{+}1$ و $^{+}2$ و$^{+}3$ التي أستخرجت في فضاء IBM-2 لنظائر الكادميوم ذات التناظر الأهتزازي. أن صفة المستوى 2^{+}_{MS} مشتركة بين المستويين 2^{+}_{2} و 2^{+}_{3} في نظائر الكادميوم ذات العدد الكتلي 110 و 112 و 114 مع ان الجزء الأكبر كان من نصيب المستوى 2^{+}_{2} بينما انفرد المستوى 2^{+}_{3} بصفة التناظر المختلط في النظير 116. أن هذا التحديد للمستوى 2^{+}_{MS} قد عزز بنتائج نسب تأثير (F - spin). أن الخصائص الكهرومغناطيسية للمؤثرين E2 و M1 قد درست و حللت نتائجها. أن قيمة e_B في IBM-1 قد أختيرت متغيرة لكل نظير في حين أستخدمت قيم ثابته e_π=0.104 eb و e_ν=0.093 eb في IBM-2 لتوليد قيم B(E2) و ($Q(2^{+})$. أختيرت قيم g_ν و g_π في IBM-2 لتكون ثابته (g_π=0.31 μ_N , g_ν=-0.31 μ_N) في حسابات توليد B(M1) و $\mu 2^{+}_{1}$ ونسب المزج δ(E2/M1) في هذه النظائر. أن صغر قيمة نسب المزج في الأنتقالات من المستويات ذات التناظر المختلط الى المستويات ذات التناظر التام يعزز امكانية تحديد المستوى ذي التناظر المختلط من بين تلك المستويات $^{+}2$ المشتركه بالصفه في نظائر الكادميوم.