Full-symmetry and mixed-symmetry states in ^{110,112,114}Cd

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An analysis of low-lying collective states in ^{110,112,114}Cd has been performed within the framework of the interacting proton-neutron boson model. The influence of model parameters on level schemes and electromagnetic properties has been investigated, in particular, as far as the breaking of F-spin symmetry is concerned. The 2_3^+ state is suggested as a relatively pure $F=F_{\max}-1$ ("mixed-symmetry") state in the three isotopes.

Low-energy collective spectra of even-even nuclei with mass number $A\simeq 110$ and atomic number approaching the $Z=50$ shell closure show the peculiar features of an anharmonic vibrator. This is particularly evident in ^{110,112,114}Cd isotopes on which the analysis presented in this paper is mostly focused. In the interacting boson model (IBA) approach, they have often been described by an approximate U(5) dynamical symmetry [1]. It is important to realize, however, that even in the framework of a normal vibrationlike picture, one has to consider the so-called mixed-symmetry states which, in the IBA language, break F-spin symmetry and carry a large fraction of $F=F_{\max}-1$ amplitude [1]. These states, which are due to collective motions of neutrons and protons out of phase [1,2], arise naturally in going from the IBA-1 to the IBA-2 model, which distinguishes between neutron and proton bosons. In spherical nuclei they are expected to occur at an excitation energy of about 2 MeV [3,4], the lowest one having $J^\pi=2^+$. Its main signature is given by a strong $M1$ component and a weak $E2$ component in the decay to the 2_1^+ state [2], contrary to what happens for transitions between 2^+ states having $F=F_{\max}$. It follows that a first hint at the identification of a 2^+ mixed-symmetry state is provided by a particular small value of the mixing ratio for a $2_i^+\rightarrow 2_1^+$ transition. In ^{110,112,114}Cd mixing ratios $\ll 1$ have indeed been measured for some transitions between low-lying 2^+ states.

An unambiguous identification of this state is made difficult by the appearance, at excitation energies as low as 1.5 MeV, of intruder bands with rotational-like character. These bands have been recognized many years ago [5,6] and interpreted as due to a possible γ softness [7] or to proton particle-hole excitations across the $Z=50$ shell closure [8]. The latter mechanism has recently been studied in detail and extensive calculations have been carried out in the frame of a truncated shell model [8–10] and in the frame of the IBA-2 model with configuration mixing [9–11]. While the role played by proton excitations across a closed shell is widely recognized in the relevant literature, a still-controversial matter is the amount of mixing between normal and intruder configurations needed to explain the observed features of the nuclear spectra and transition strengths. Indeed, on one hand, several theoretical analyses [12–14] imply a sizable amount of mixing so as to dim simple vibrational or rotational characters of the relevant states; on the other hand, information from (t,p) transfer intensities to 0^+ levels in cadmium isotopes [15,16] seems to support an interpretation of these states as having relatively pure vibrational or rotational structure.

The present investigation, performed in the framework of the standard IBA-2 model, is focused on low-lying levels in ^{110,112,114}Cd in order to (a) try to identify the lowest-lying 2^+ mixed-symmetry state by its decay via $E2$ and $M1$ transitions and (b) provide a reliable set of model parameters to be used in future calculations extended to include intruder bands. Such calculations, which are in progress, are based on a modified version of the IBA-2-plus configuration mixing code [17] which diagonalizes the complete IBA-2 Hamiltonian, thus avoiding possible mistakes due to phase inconsistencies among wave functions of given spin J.

We adopted the usual Talmi Hamiltonian [1] in the following form:

$$H=E_0+\varepsilon(\hat{n}_{d_\pi}+\hat{n}_{d_\nu})+\kappa\hat{Q}_\pi\cdot\hat{Q}_\nu+\hat{M}_{\pi\nu}+\hat{V}_{\pi\pi}+\hat{V}_{\nu\nu}\ , \quad (1)$$

where the indexes ν and π refer to neutron and proton bosons, respectively, and E_0 is a constant which contributes to the total binding energy only. Moreover,

$$\hat{n}_{d_\rho}=(d_\rho^\dagger\cdot\tilde{d}_\rho)\ , \quad (2)$$

$$\hat{Q}_\rho=[d_\rho^\dagger\times\tilde{s}_\rho+s_\rho^\dagger\times\tilde{d}_\rho]^{(2)}+\chi_\rho[d_\rho^\dagger\times\tilde{d}_\rho]^{(2)}\ , \quad (3)$$

$$\hat{M}_{\pi\nu}=\xi_2[s_\nu^\dagger\times d_\pi^\dagger-s_\pi^\dagger\times d_\nu^\dagger]^{(2)}\cdot[\tilde{s}_\nu\times\tilde{d}_\pi-\tilde{s}_\pi\times\tilde{d}_\nu]^{(2)}-2\sum_{k=1,3}\xi_k[d_\nu^\dagger\times d_\pi^\dagger]^{(\kappa)}\cdot[\tilde{d}_\nu\times\tilde{d}_\pi]^{(\kappa)}\ . \quad (4)$$

The Majorana term $\hat{M}_{\pi\nu}$ is responsible for the location of mixed-symmetry states with respect to fully symmetric

ones. The term $V_{\rho\rho}$ (with $\rho=\pi,\nu$), which arises from microscopic considerations, represents the interaction between identical bosons. It reads

$$\hat{V}_{\rho\rho}=\sum_{L=0,2,4}\tfrac{1}{2}\sqrt{2L+1}c_{L\rho}[d_\rho^\dagger\times d_\rho^\dagger]^{(L)}\cdot[\tilde{d}_\rho\times\tilde{d}_\rho]^{(L)}\ . \tag{5}$$

In cadmium isotopes ($Z=48$), which have just one π boson, only the $V_{\nu\nu}$ term has to be considered.

For the calculation of transitions and moments, the following one-body electromagnetic operators were considered:

$$\hat{T}(E2)=e_\pi\hat{Q}_\pi+e_\nu\hat{Q}_\nu\ , \tag{6}$$

$$\hat{T}(M1)=\left[\frac{3}{4\pi}\right]^{1/2}(g_\pi\hat{L}_\pi+g_\nu\hat{L}_\nu)\ , \tag{7}$$

with

$$\hat{L}_\rho=\sqrt{10}[d_\rho^\dagger\times\tilde{d}_\rho]^{(1)}\ . \tag{8}$$

The Hamiltonian (1) is not F scalar because of the quadrupole-quadrupole interaction, whose strength is driven by κ, χ_ν, and χ_π. They determine a sharing of different F-spin components into excited states originally belonging to full- and mixed-symmetry bands. Diagonal matrix elements of operators (6) and (7) give, apart from usual numerical factors, electric quadrupole and magnetic dipole moments, respectively. Off-diagonal matrix elements of (7) are very sensitive to mixed-symmetry components in the wave function. As a consequence, the mixing ratio $\delta(E2/M1)$ is also very sensitive to the presence of different F-spin components.

Since ^{110,112,114}Cd spectra show strong anharmonicities even in the ground-state band, their investigation cannot be accomplished by means of analytical or approximate formulas so that numerical calculations have to be performed. Moreover, for Cd isotopes the effective boson numbers for neutrons (N_ν) and protons (N_π) differ considerably and the condition $|N_\pi-N_\nu|\ll(N_\pi+N_\nu)$ does not hold. As a consequence (see Ref. [2]), excitation patterns as well as $B(E2)$ transition strengths are influenced by all the IBA-2 parameters, not only by quadrupole-quadrupole interaction strengths and quadrupole effective boson charges. Therefore, the adjustable parameters of the Hamiltonian and electromagnetic transition operators have to be determined by a global fit to level energies and electromagnetic moments and transitions.

The calculations have been performed by means of the code NPBOS [18].

The following procedure has been utilized to determine the parameters of the Hamiltonian, the effective boson charges e_π,e_ν, and g factors g_π,g_ν.

(a) Two sets of values have been considered for the parameters κ and χ_ν, namely, (I) $\kappa=-0.15$ MeV, $\chi_\nu=-1.1$, -0.9, and -0.7, and (II) $\kappa=-0.173$, -0.169, and -0.165 MeV, $\chi_\nu=-0.4$, -0.2, and 0 for the isotopes ^{110,112,114}Cd, respectively. They will be referred to as sets (I) and (II) in the following. Set (I) is close to values already found by Sambataro [11] for cadmium isotopes and by van Isacker and Puddu [19] for neighboring ruthenium and palladium isotopes.

Set (II) has been derived on the basis of microscopic calculations in Ref. [20], assuming a schematic single-J shell model.

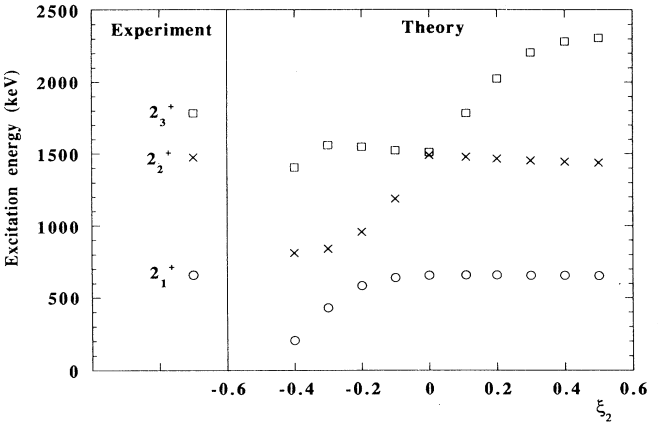

FIG. 1. Calculated excitation energies of the lowest 2^+ states in ^{110}Cd as a function of the parameter ξ_2 in the Majorana term. The other Hamiltonian parameters are frozen to the values given in Table I.

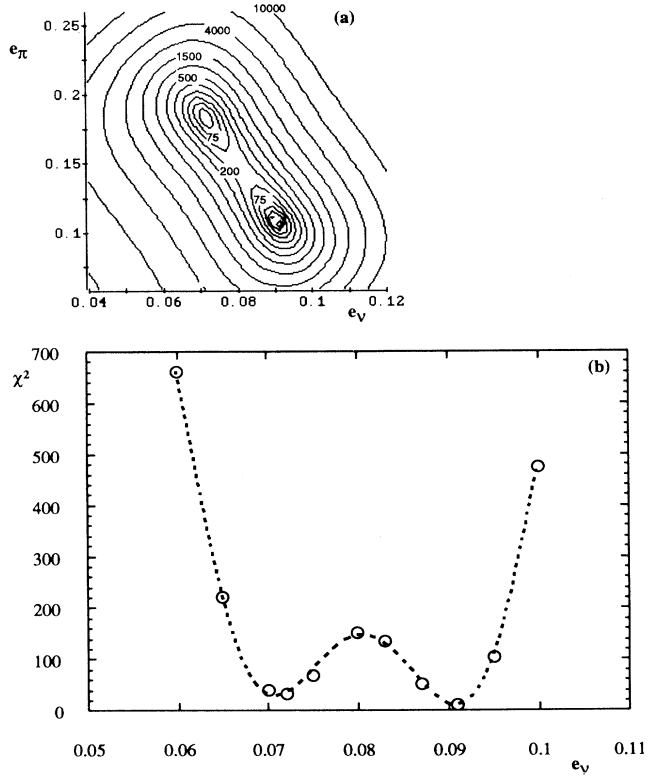

FIG. 2. (a) Contour plot for the variable χ^2 derived from a comparison of theoretical and experimental values of selected $B(E2)$ transition strengths (see text) as a function of the boson effective charges e_π,e_ν (in units of e b). (b) Section of the $\chi^2(e_\pi,e_\nu)$ surface along the straight line connecting the two local minima.

Steps (b)–(d) below were executed separately for sets (I) and (II).

(b) For any given value of χ_π (in the range $[-0.9,+0.4]$), the parameters ϵ, $c_{i\nu}$ and ξ_2 have been adjusted to reproduce, within 2–3 keV, the energies of the low-lying levels except for the 0_3^+ level. The parameters ξ_1 and ξ_3 have been chosen to force the excitation energies of the 1^+ and 3^+ mixed-symmetry states above some MeV.

(c) In order to choose the value of χ_π (and thereby the best set of parameters ϵ, $c_{i\nu}$ and ξ_2), $E2$ moments, transitions, and mixing ratios have been considered. First, boson charges e_π, e_ν and g factors g_π, g_ν were determined from a fit to $E2$ and $M1$ moments and transitions for which matrix elements of $\hat{Q}_\rho$ and $\hat{L}_\rho$ are not sensitive to the values of χ_π and χ_ν. Second, the value of χ_π was determined by comparing experimental and theoretical values of $E2$ and $M1$ moments and transitions which are sensitive to this parameter.

(d) The final choice between sets (I) and (II) was performed via a comparison of the calculated and experimental $B(E2)$ values.

Concerning step (b), we remark that the location of the 2^+ states is very sensitive to the value of ξ_2, which is clearly selected by a comparison with the experimental excitation energies. This is shown for ^{110}Cd, as an example, in Fig. 1. It is also noteworthy that the presence of the Majorana term naturally accounts for the low excitation energy of the 2_3^+ state (which has been otherwise considered an intruder state [11]), thus suggesting that it could be identified as the first low-lying mixed-symmetry state.

On the contrary, no reasonable choice of Majorana parameters can reproduce in cadmium isotopes the energy of the 0_3^+ level, which is close to the 0^+ member of the two-phonon triplet. It is probably to be interpreted as the head of an intruder rotational-like band originating from proton-boson excitation across the $Z=50$ shell closure. It is expected that, in the IBA-2-plus configuration mixing approach, its properties will be explained in terms of a mixing with the 0_2^+ level. On the other hand, the 2_2^+ and 2_3^+ states should not be affected too much by the intruder configuration, since the 2_4^+ level, which presumably belongs to the $N_\pi=3$ configuration, lies at higher excitation energy. Our possible identification of the 2_3^+ level with the one of mixed symmetry would then be preserved.

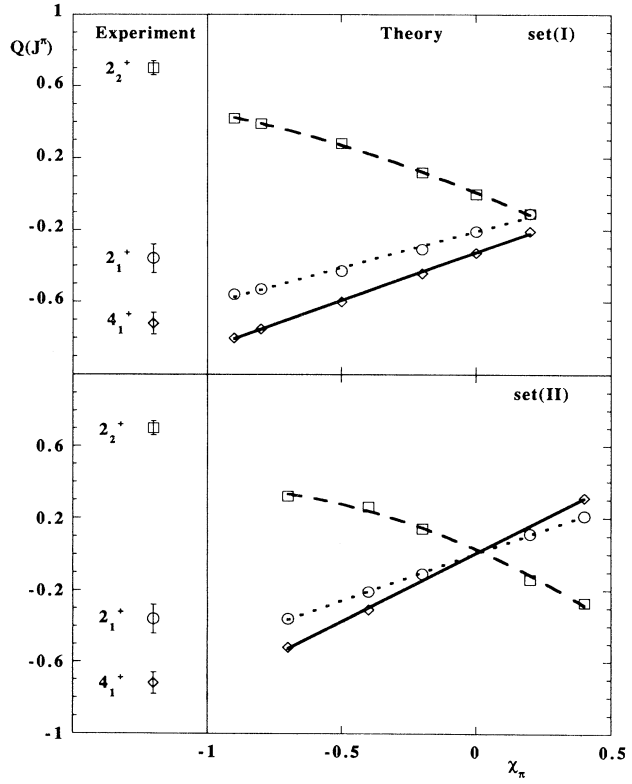

FIG. 3. Calculated values of the quadrupole moments (in e b) of the indicated levels in ^{114}Cd as a function of the parameter χ_π for parameter sets (I) and (II) (see text). Effective boson charges $e_\pi=0.18$ e b, $e_\nu=0.072$ e b have been used. Very similar results are obtained with the set $e_\pi=0.105$ e b, $e_\nu=0.087$ e b. On the left-hand side the experimental data are reported.

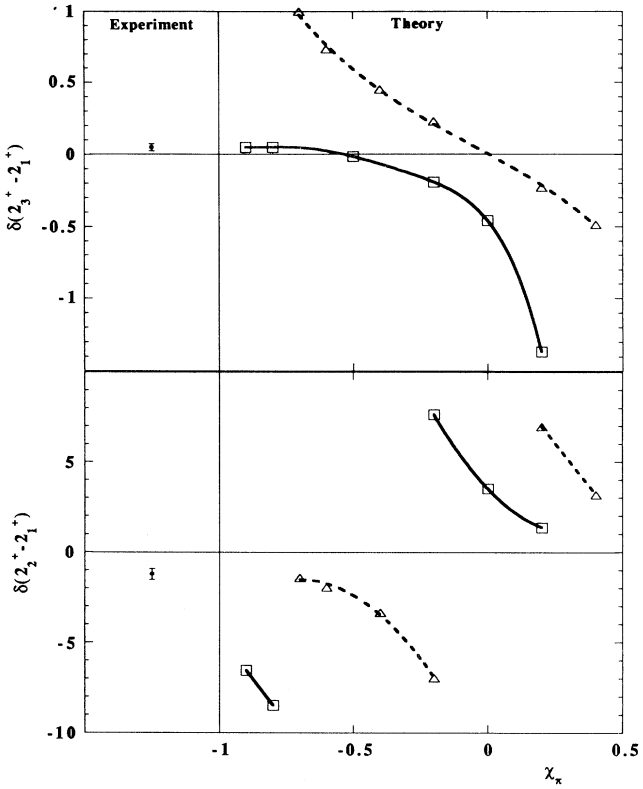

FIG. 4. Calculated $E2/M1$ mixing ratios in ^{114}Cd for the transitions $2_2^+ \rightarrow 2_1^+$ and $2_3^+ \rightarrow 2_1^+$ as a function of the parameter χ_π. Squares and triangles refer to parameter sets (I) and (II) (see text), respectively. Effective boson charges $e_\pi=0.18$ e b, $e_\nu=0.072$ e b and g factors $g_\pi=0.55\mu_N$, $g_\nu=0.21\mu_N$ have been used. Quite similar trends are obtained for the corresponding transitions in ^{110,112}Cd. On the left-hand side the experimental data are reported.

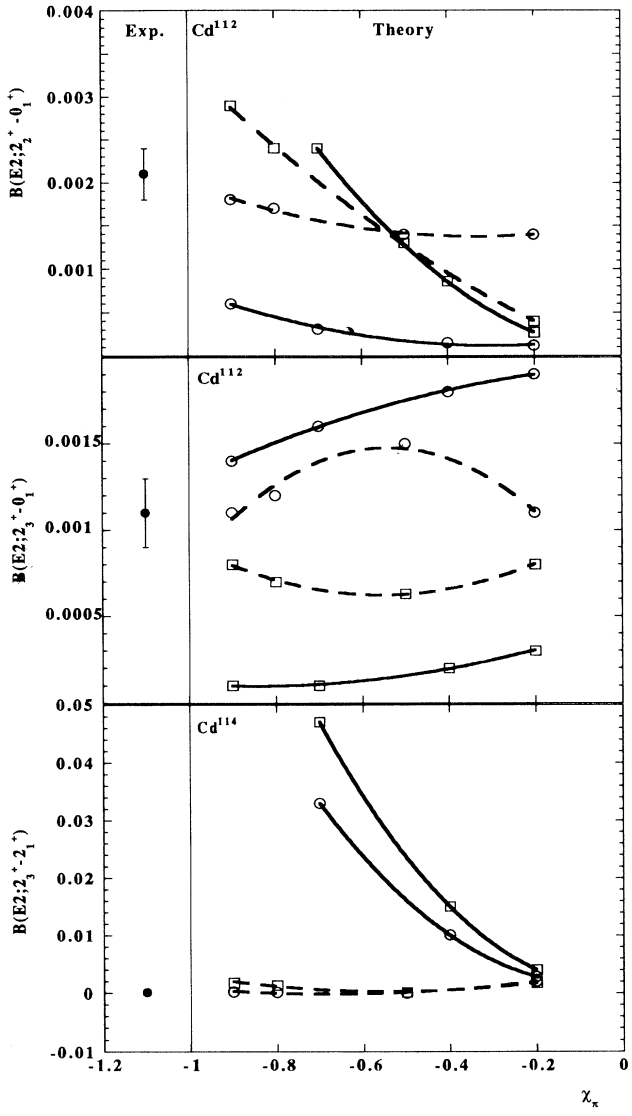

FIG. 5. Calculated $B(E2)$ values (in e^2b^2) of the indicated transitions as a function of the parameter χ_π. Dotted lines connect values calculated using parameter set (I), while continuous lines connect values obtained with set (II). Open circles refer to boson charges $e_\pi=0.072$ e b, $e_\nu=0.18$ e b, while the squares refer to boson charges $e_\pi=0.087$ e b, $e_\nu=0.105$ e b. On the left-hand side the experimental data are reported.

Concerning step (c), it has been found that the $B(E2)$ strengths of the $2_1^+\rightarrow 0_1^+$, $0_2^+\rightarrow 2_1^+$, $4_1^+\rightarrow 2_1^+$, and $2_3^+\rightarrow 0_1^+$ transitions in ^{110,112,114}Cd are almost independent of χ_π and χ_ν. It is interesting to observe that, by restricting the fit to the first three transitions which connect almost pure $F=F_{\max}$ states (see Table II), one finds a single minimum for χ^2 in the $e_\nu-e_\pi$ plane corresponding to $e_\pi\simeq 2e_\nu\simeq 0.2$ e b. On the other hand, by including in the fit also the $2_3^+\rightarrow 0_1^+$ transitions, one finds two, about equally deep, minima, as shown in Fig. 2. This comes about because the matrix elements of $\hat{Q}_\pi$ and $\hat{Q}_\nu$ for the $2_3^+\rightarrow 0_1^+$ transition have opposite signs, contrary to what happens for the other transitions. Therefore, one has to consider both signs in the relation between theoretical and experimental data:

$$e_\nu\langle J_f\|\hat{Q}_\nu\|J_i\rangle+e_\pi\langle J_f\|\hat{Q}_\pi\|J_i\rangle = \pm[(2J_i+1)B^{\text{expt}}(E2;J_i\rightarrow J_f)]^{1/2}\ . \quad (9)$$

One of the minima corresponds essentially to the same charge determined by the restricted fit, while the other one corresponds to $e_\pi\simeq e_\nu=0.1$ e b. The two sets of boson charges thereby determined give similar agreement between theoretical and experimental transitions or moments (as seen in Table III below). We note also that, while the first minimum is close to that found by Hamilton [4] for this nuclear region in his systematic analysis of $B(E2)$ transition strengths in the SU(5) limit, the second one is close to the assumption of equal charges of about 0.1 e b often found in the literature [11].

The g factors have been deduced from a fit to the dipole moments of the 2_1^+ states and to the $M1$ components of the $2_3^+\rightarrow 2_1^+$ transitions in ^{110,112,114}Cd which are quantities not sensitive to the values of χ_ν and χ_π. We obtained the values (in nuclear magnetons) $g_\nu=0.21$ and $g_\pi=0.55$, which are also close to the values found in Ref. [4] ($g_\nu=0.25$ and $g_\pi=0.68$).

The procedure used to select the value of the parameter χ_π via a comparison of experimental and calculated data for quadrupole moments and mixing ratios is illustrated in Figs. 3 and 4. It is seen that large negative values of χ_π are required, in particular, to reproduce the signs of the mixing ratios. The best fit to the experimental data is obtained for $\chi_\pi=-0.8$.

Finally, for what concerns step (d), 14 theoretical data for $B(E2)$ strengths sensitive to the relevant parameters were compared to experimental data. Typical results are shown in Fig. 5. The "microscopic" χ_ν values are clearly

TABLE I. Adopted values for the Hamiltonian parameters used for IBA-2 calculations. All parameters are in MeV, except for χ_ν and χ_π (dimensionless).

	ε	κ	χ_ν	χ_π	$c_{0\nu}$	$c_{2\nu}$	$c_{4\nu}$	ξ_2	$\xi_1=\xi_3$
^{110}Cd	0.924	−0.15	−1.1	−0.8	0.074	−0.170	0.159	0.109	1.1
^{112}Cd	0.912	−0.15	−0.9	−0.8	−0.155	−0.306	0.053	0.002	1.1
^{114}Cd	0.857	−0.15	−0.7	−0.8	−0.136	−0.284	0.030	−0.023	1.1

TABLE II. Experimental and theoretical values for the excitation energies (in MeV) of low-lying states in ^{110,112,114}Cd. The columns labeled by $I(F_{max})$ specify the square of the amplitude of the $F=F_{max}$ component in the relevant wave function.

	^{110}Cd			^{112}Cd			^{114}Cd		
J^π	E_{expt}	E_{theor}	$I(F_{max})$	E_{expt}	E_{theor}	$I(F_{max})$	E_{expt}	E_{theor}	$I(F_{max})$
2_1^+	0.658	0.657	0.93	0.618	0.617	0.90	0.558	0.559	0.87
0_2^+	1.473	1.473	0.98	1.224	1.225	0.96	1.135	1.136	0.95
2_2^+	1.476	1.477	0.97	1.312	1.313	0.95	1.210	1.208	0.94
4_1^+	1.542	1.543	0.96	1.415	1.413	0.95	1.284	1.284	0.93
2_3^+	1.783	1.783	0.13	1.469	1.468	0.21	1.364	1.363	0.26

ruled out, while negative χ_ν of large absolute value are definitely suggested.

To summarize, the adopted Hamiltonian parameters are listed in Table I. It must be stressed that the Hamiltonian parameters considered in this work show a remarkable regularity once plotted versus the product $N_\pi N_\nu$ according to Casten's scheme [1]. This allows us to deduce with some confidence a set of IBA parameters also for the $N_\pi=3$ configuration, which can be checked against the parameters for neighboring nuclei available in the literature.

The experimental and calculated excitation energies together with the intensity (amplitude square) of the $F=F_{max}$ component of each state are reported in Table II. It is seen that the intensity of the $F=F_{max}$ component in the 2_3^+ state is rather small, thus implying that its mixed-symmetry character is weakly shared with the neighboring 2_2^+ state.

In a very recent systematic investigation limited to excitation energies of low-spin states in $^{106-120}$Cd, the 0_2^+ and 2_3^+ states are interepreted as the two lowest members of the two-particle–four-hole intruder band, as the difference in their excitation energy closely matches the excitation energy of the 2_1^+ state in even ruthenium and barium isotones [21]. These findings are at variance with present results.

A comparison between experimental and theoretical data concerning the electromagnetic properties of low-lying states is given in Table III for both sets of boson effective charges which minimize χ^2. The results do not allow a choice between the two sets. The theoretical data obtained by other authors [11,14,22] in the framework of the IBA-2-plus configuration mixing model are also reported. It is seen that, where the comparison is possible, the agreement between experimental and calculated values is about as good for the normal IBA-2 model as

TABLE III. Experimental and theoretical values for electromagnetic data of low-lying levels in ^{110,112,114}Cd. $B(E2)$ transition strengths are reported in $e^2b^2\times10^3$, quadrupole moments in e b, and magnetic moments in μ_N. For $E2$ transitions and moments, both values obtained by the two sets of boson effective charges are given in columns 3, 6, and 9 (the upper ones refer to the values $e_\pi=0.105$ e b, $e_\nu=0.087$ e b, while the lower ones refer to the values $e_\pi=0.18$ e b, $e_\nu=0.072$ e b). For the magnetic moments and mixing ratios, the g factors $g_\pi=0.55\mu_N$, $g_\nu=0.21\mu_N$ have been used. The values obtained by other authors in the frame of the IBA-2-plus configuration mixing are reported for comparison.

	^{110}Cd			^{112}Cd				^{114}Cd		
	Expt.	Present work	Ref. [14]	Expt.	Present work	Ref. [11]	Expt	Present work	Ref. [11]	Ref. [22]
$Q(2_1)$	$-0.40(4)^a$	-0.44 -0.46		$-0.37(3)^b$	-0.49 -0.50	-0.34	$-0.36(8)^c$	-0.51 -0.53	-0.36	-0.20
$Q(2_2^+)$							$0.70(^{+0.03}_{-0.04})^d$	0.39 0.39		0.65
$Q(2_3^+)$							$0.22(^{+0.08}_{-0.20})^d$	-0.38 -0.40		0.65
$Q(4_1^+)$							$-0.72(^{+0.03}_{-0.08})^d$	-0.76 -0.75		0.0
$B(E2;2_1^+\rightarrow0_1^+)$	$86(1)^a$	78 84	86	$97(1)^b$	91 97	103	$102(6)^c$	104 109	119	102
$B(E2;0_2^+\rightarrow2_1^+)$		98 88		$163(42)^b$	114 98	118	$90(5)^c$	123 102	139	102
$B(E2;2_2^+\rightarrow0_1^+)$	$3.4(4)^e$	1.3 0.8	0.3	$2.1(3)^b$	2.5 1.7	0.2	$1.7(1)^c$	3.6 2.2	0.02	0.8
$B(E2;2_2^+\rightarrow2_1^+)$	$94(15)^a$	70 65	112	$54(13)^b$	77 68	123	$93(6)^c$	90 77	140	104

TABLE III. (*Continued*).

	^{110}Cd			^{112}Cd				^{114}Cd		
	Expt.	Present work	Ref. [14]	Expt.	Present work	Ref. [11]	Expt.	Present work	Ref. [11]	Ref. [22]
$B(E2;2_2^+\rightarrow 0_2^+)$		21 19			26 24		$6(^{+3}_{-1})^c$	23 21	203	65
$B(E2;2_3^+\rightarrow 0_1^+)$	0.9(5)[f]	0.2 2.8		1.1(2)[b]	0.7 1.2	0.3	1.1(1)[c]	1.0 0.7	0.4	0.8
$B(E2;2_3^+\rightarrow 2_1^+)$		0.9 0.02		1.3(6)[b]	0.8 0.01	18	0.13(6)[c]	1.3 0.14	26	104
$B(E2;2_3^+\rightarrow 0_2^+)$		15 22		176(55)[b]	29 36	241	52(7)[c]	44 50	272	79
$B(E2;2_3^+\rightarrow 2_2^+)$		7 11			19 24		101(23)[c]	22 25	313	70
$B(E2;2_3^+\rightarrow 4_1^+)$		14 22			31 40		42(11)[c]	44 52	54	3
$B(E2;4_1^+\rightarrow 2_1^+)$	144(19)[a]	129 129	143	196(22)[b]	152 147	174	202(12)[c]	175 165	204	212
$B(E2;4_1^+\rightarrow 2_2^+)$		3 3			5 4		14(6)[c]	4 3	38	2
$\mu(2_1^+)$	−0.56(8)[a]	0.57		−0.64(8)[b]	0.60		0.58(14)[c]	0.60		
$\delta(2_2^+\rightarrow 2_1^+)$	−1.36(7)[a]	−12 −11		−0.77(6)[b]	−14 −13		−1.2(3)[c]	−9 −8.5		
$\delta(2_3^+\rightarrow 2_1^+)$	0.12(10)[g]	0.17 0.025		0.16(4)[g]	0.12 0.01		0.050(25)[h]	0.16 0.05		
$\delta(2_3^+\rightarrow 2_2^+)$							$\pm 1.95(^{+0.65}_{-0.37})^c$	−6.5 −7		

[a]Reference [25].
[b]Reference [26].
[c]Reference [27].
[d]Reference [22].
[e]Weighted average from Refs. [25] and [23].
[f]Reference [23].
[g]Reference [29].
[h]Reference [28].

for the extended one. As to the data involving the $M1$ operator, we note that the magnetic moments are fairly well reproduced, while only about a half of the absolute values of the mixing ratios are correctly predicted. We remark, however, that the sign of the mixing ratios is reproduced in each case. Altogether, we can say that the observed electromagnetic properties of low-lying levels in ^{110,112,114}Cd are consistent with those expected, assuming F-spin mixing to be small, for full-symmetry (2_1^+,2_2^+) and mixed-symmetry (2_3^+) states, respectively (see Fig. 11 in Ref. [2]).

It is worth mentioning that in a recent work on ^{110}Cd based on inelastic electron scattering [23], preference is given to the interpretation of the 2_3^+ level in terms of configuration mixing. Finally, in a very recent study [24] of ^{112}Cd, only the 2_6^+ state at 2.23 MeV excitation energy is proposed as a possible candidate for a mixed-symmetry state on the basis of its weak population in single-neutron-transfer reactions.

In conclusion, we can summarize the results of the present work as follows: (a) The relevant parameters for IBA-2 calculations have to be determined from a global analysis of the available experimental information, including $E2/M1$ mixing ratios; (b) standard IBA-2 calculations are able to reproduce many of the observed features of low-lying levels in ^{110,112,114}Cd; (c) the 2_3^+ level in ^{110,112,114}Cd is probably to be identified as the lowest mixed-symmetry state which is only weakly mixed with the nearby 2_2^+ level.

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