Neutron-rich In and Cd isotopes close to the doubly magic ^{132}Sn

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Microsecond isomers in the In and Cd isotopes, in the mass range $A=123$ to 130, were investigated at the ILL reactor, Grenoble, using the LOHENGRIN mass spectrometer, through thermal-neutron induced fission reactions of Pu targets. The level schemes of the odd-mass $^{123–129}$In and new measurements of the μs half-lives of the odd-odd $^{126–130}$In are reported. However, the expected 8^+ isomers in the even-mass Cd isotopes were not observed. The comparisons between the experimental $B(M2)$ strengths for In and Sn isotopes are discussed. A shell-model study of the heaviest In and Cd nuclei was performed using a realistic interaction derived from the CD-Bonn nucleon-nucleon potential. The calculation predicts values of the half-lives of the first 8^+ states in ^{126,128}Cd of $\sim$10 ns, which could explain the nonobservation of μs isomers. Comparison shows that the calculated levels of ^{130}In and ^{129}In are in good agreement with the experimental values while some discrepancies occur for the lighter In isotopes. The collectivity of ^{126,128}Cd is discussed in the framework of the shell model and in comparison with ^{204}Hg.

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I. INTRODUCTION

Experimental progress is currently being made in the region around doubly magic ^{132}Sn. However, nuclear structure information is more complete for nuclei above the $Z=50$ shell closure [1] (for instance, Sb and Te isotopes) than for the In and Cd isotopes, which are much more difficult to produce. Only recently, Kautzsch *et al.* [2] have obtained some spectroscopic information on ^{126,128}Cd, which have two proton and two and four neutron holes, respectively, inside the ^{132}Sn core. Although this information is still rather scarce, it seems to indicate that these nuclei possess some degree of collectivity. This is one of the reasons that spurred us to carry out a study of the neutron-rich nuclei of this region.

In the present work, we searched for and studied the decay of μs isomers in the neutron-rich mass $A=123$ to 130 nuclei with the LOHENGRIN spectrometer at the ILL reactor in Grenoble. The aim was to complete the previous data on the heavy Cd and In isotopes. Apart from the above-quoted study on the Cd isotopes, the low-spin levels up to $13/2$ in $^{123–127}$In were previously investigated from the β decay of Cd isotopes [3,4] and, very recently, high-spin ms isomers in $^{125–129}$In were discovered [5,6]. Preliminary reports were also presented by Hellström *et al.* [7,8] on the search for μs isomers in the heavy Cd and In isotopes at the FRS spectrometer at GSI, but no level schemes were proposed.

Motivated by the new data from the present experiment, we have performed calculations to test the ability of the shell model to describe the heavy Cd and In isotopes, with proton and neutron holes inside the ^{132}Sn core. In this work, a realistic effective interaction derived from the CD-Bonn nucleon-nucleon potential [9] is used. Similar calculations were performed in Ref. [10] for nuclei with proton particles and neutron holes around ^{132}Sn, and in Ref. [11] for ^{129}In. In both cases, good agreement with the experimental data was found.

The paper is organized as follows. In Sec. II, we describe the experimental procedure, while in Sec. III the results of our measurements are presented. In Sec. IV, the level schemes of odd In isotopes, as they result from different experimental studies, are reported and discussed. Section V is devoted to the comparison of the results of our shell-model calculations with the experimental data. In Sec. VI, all the available information on $M2$ and $E3$ transitions in heavy In and Sn isotopes is summarized. Section VII contains a summary of our conclusions.

II. EXPERIMENTAL PROCEDURE

Two different experiments have been performed to explore the In and Cd region in the vicinity of ^{132}Sn. In the first one, devoted to the odd masses, both the conversion electrons and γ rays were measured, while in the second, devoted to the even masses, only γ rays were measured.

The nuclei of mass $A=123,125,127$ were produced by thermal-neutron induced fission of ^{239}Pu and ^{241}Pu. The LOHENGRIN mass spectrometer has been used to separate the fission fragments (FFs) recoiling from a thin target of about 400 μg/cm^2, according to their mass to ionic charge ratios (A/q). The FFs were detected in a gas detector of 13 cm length, and subsequently stopped in a 12-μm-thick Mylar

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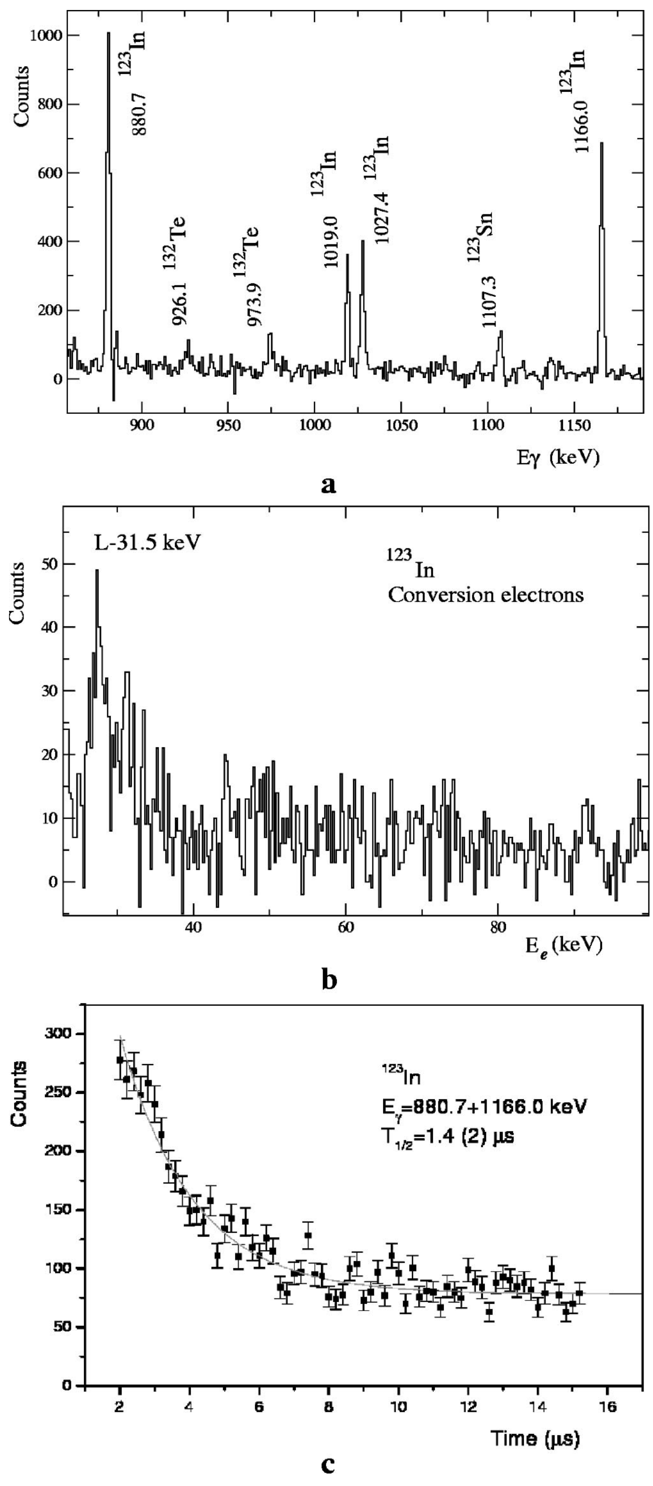

FIG. 1. (a) γ-decay spectrum of the mass $A=123$ in delayed coincidence with the fission fragments. (b) Si(Li) spectrum of the mass $A=123$ in delayed coincidence with the fission fragments. (c) Time spectrum of 880.7 and 1166.0 keV.

foil. Behind the foil, two cooled adjacent Si(Li) detectors covering an area of 2×6 cm^2 were placed to detect the conversion electrons and x rays deexciting the isomers, while the γ rays were detected by two large-volume Ge detectors placed perpendicular to the beam. Details on the experimental setup can be found in [1,12].

To produce the nuclei of mass $A=126,128,130$, a thin target of ^{241}Pu of about 400 μg/cm^2 was used. The FFs were detected in a $\Delta E-E$ gas detector to achieve very good mass resolution, and the γ rays in two germanium detectors: one Clover detector (efficiency ~150%) and one triple cryostat of the Miniball array [13]. The efficiency for γ-ray detection of the second setup was higher than the first one, making the study of nuclei with low production rates possible.

TABLE I. Relative intensities of the transitions observed in ^{123}In.

Transition	Transition's energy	Intensity
$(13/2^-)\rightarrow 13/2^+$	880.7(2)	107
$(13/2^-)\rightarrow 11/2^+$	1019.0(3)	40
$11/2^+\rightarrow 9/2^+$	1027.4(3)	42
$13/2^+\rightarrow 9/2^+$	1166.0(3)	100

III. EXPERIMENTAL RESULTS

A. ^{123}In

A new μs isomer has been found in ^{123}In. In the γ-decay spectrum of the mass $A=123$ in delayed coincidence with the FFs (see Fig. 1), four new γ lines (880.7, 1019.0, 1027.4, and 1166.0 keV), not belonging to the already known 6 μs isomer of ^{123}Sn [14], are present. Two γ rays of 1027.5 and 1165.9 keV, respectively, were previously observed in β-decay studies of ^{123}Cd to ^{123}In [4]. They deexcite two levels of ^{123}In with possible spin and parity assignments of $11/2^+$ and $13/2^+$, respectively. The fact that we observe two transitions with almost the same energy as those in ^{123}In, and the absence of any common γ rays belonging to ^{123}Sn, allow this isomer to be attributed to ^{123}In, the only element along with ^{123}Sn which has sufficient production yield. The γ ray of ~138 keV connecting the $13/2^+$ level to the $11/2^+$ level was not observed, due to the low expected relative intensity (~6) deduced from the intensities of the observed transitions reported in Table I.

The half-life of the isomer is 1.4(2) μs, as shown in Fig. 1. Due to the poor statistics, it was not possible to observe the conversion electrons in coincidence with the γ rays of the

TABLE II. Half-lives measured in the present work along with the previous data.

Nucleus	Transition	Half-life (μs) this work	Half-life (μs)[a] previous value
^{123}In	$17/2^-\rightarrow 13/2^-$	1.4(2)	
^{127}In	$29/2^+\rightarrow 25/2^+$	9(2)	<0.5 and 13(2)
^{126}In	$1^-\rightarrow 3^+$	22(2)	29(2)
^{128}In	$1^-\rightarrow 3^+$	23(2)	175(90)
^{130}In	$3^+\rightarrow 1^-$	3.1(3)	1–10

[a]See [7].

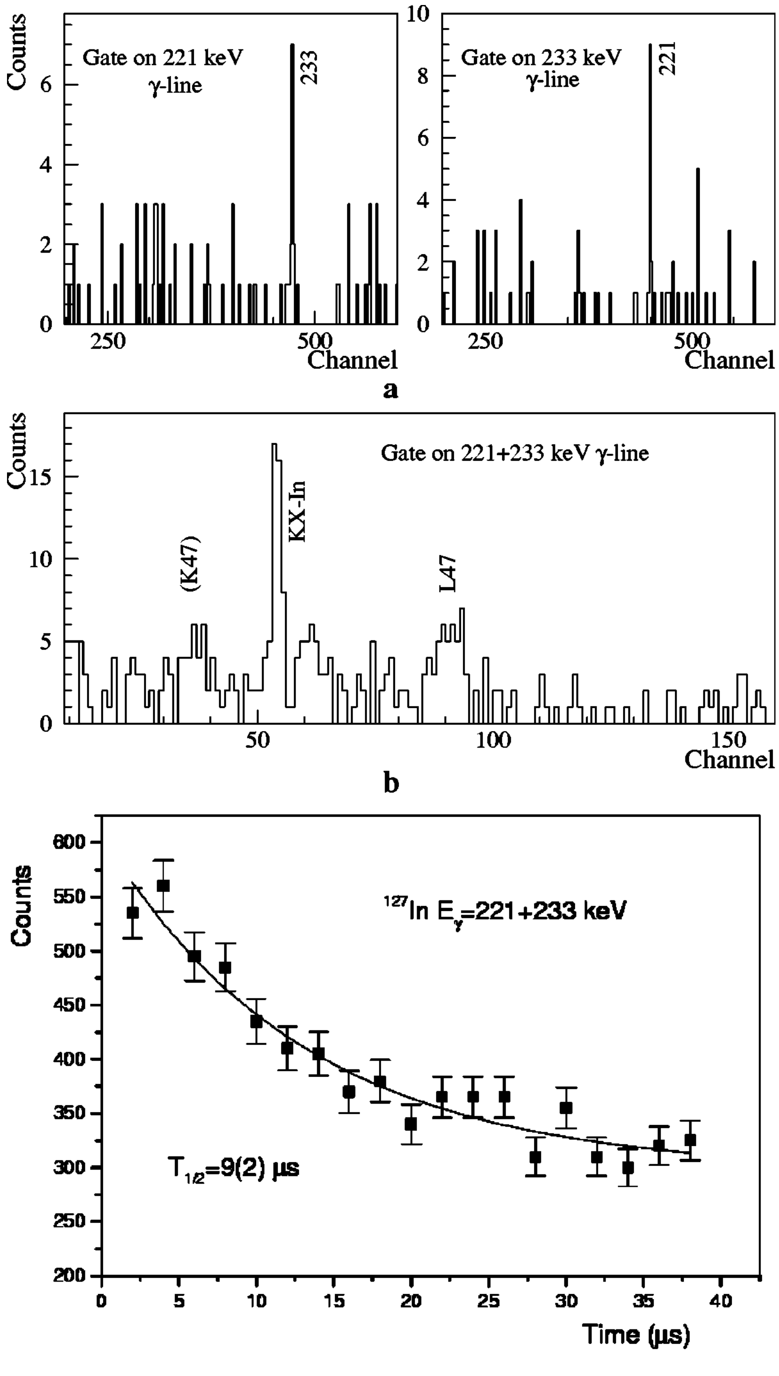

FIG. 2. (a) Coincidence spectra gated on the γ ray of 233 or 221 keV. (b) Si(Li) spectrum obtained in coincidence with the γ rays of 221 and 233 keV. (c) Time spectrum of 221 and 233 keV.

isomeric decay. However, in the Si(Li) spectrum in delayed coincidence with the FFs of mass $A=123$, an electron line of 27.5(5) keV decaying with a half-life comparable to the γ cascaded was observed (see Fig. 1). The nonobservation of another electron group suggests that this line corresponds to L conversion electrons of a transition of 31.5(5) keV. A value so close to the binding energy of the K electrons explains the nonobservation of the K-X rays. Assuming that this low-energy transition has an $E2$ multipolarity, as suggested by the absence of crossover transition between the 2078.5 keV level and the 1165.8 keV level, a value of $B(E2)=3.3(5)$ W.u. can be deduced.

B. ^{127}In

We have observed in the present work a 9(2) μs isomer which decays by a cascade consisting of a strongly converted $E2$ transtion of 47.0(5) keV, and two γ rays of 221.3(5) and 233.4(5) keV in coincidence one with the other (Fig. 2). The two γ rays are the same as those first observed by Hellström *et al.* [7], and the reported value of the half-life 13(2) μs is in rough agreement with that found in this work (see Table II). Moreover, these authors also observed an abnormally high number of counts in the first 500 ns interval of the time spectrum and suggested the possible presence of two isomeric states in ^{127}In. We have not observed the short component in our data and we feel that, if it exists, its half-life is shorter than ~ 0.5 μs. The Si(Li) spectrum obtained in coincidence with any of these two lines (Fig. 2) shows the characteristic indium x rays, and the *K* and *L* conversion electrons of the isomeric transition. The large broadening of the *K*-electron line, due to absorption in the Mylar foil of this low-energy transition (19 keV), does not allow a precise evaluation of the peak's area. Consequently, the *X* over *L* ratio was used to deduce the multipolarity of the isomeric transition. The comparison of the experimental value 1.2(3), with the theoretical ones, 6.1 for an *E*1, 6.5 for an *M*1, and 0.9 for an *E*2, suggests an *E*2 multipolarity, and a $B(E2) = 0.30(7)$ W.u. value was deduced.

C. Odd-odd indium isotopes

In this work, the half-lives of the previously known isomeric transitions in ^{130}In [7], ^{128}In [15], and ^{126}In [7] were measured (Fig. 3). The result of this work is reported in Table II, where the values obtained in previous works [7,8] are also shown. In the case of ^{126}In, our value is shorter than the previous measurement, whereas in the case of ^{130}In and ^{128}In our values are much more precise.

D. Cadmium isotopes

Two μs isomer were reported by Hellström *et al.* [8] in the odd-mass Cd isotopes, one in ^{127}Cd and the other in ^{125}Cd. We have also seen the two γ lines of 720 and 743 keV belonging to ^{125}Cd, but not the γ ray of 830 keV in ^{127}Cd.

Furthermore, as the GSI group, we have not observed the μs isomers in the even-mass Cd isotopes. If ^{130}Cd, with the predicted fission yield lower than 10^{-6}, is not experimentally observable, ^{126,128}Cd, with fission yields $\sim 10^{-4}$, comparable to the yield of the observed ^{125}Cd, should be observed. We found no evidence of the presence of μs isomers with half-lives longer than 0.5 μs in the heavy Cd isotopes, which most likely means they can be excluded.

IV. LEVEL SCHEMES OF ODD-In NUCLEI

The heavy In and Cd nuclei, with neutron and proton holes inside the ^{132}Sn core, are characterized by the presence of two high-spin states, $\pi g_{9/2}^{-1}$ and $\nu h_{11/2}^{-1}$, at low excitation energy. The *p*-*n* interaction in the $(\pi g_{9/2}^{-1} \nu h_{11/2}^{-1})_{10^-}$ state is very strong and is expected to produce very perturbed yrast lines. These features greatly complicate the construction of the level schemes and therefore different experimental techniques are needed to study these nuclei. The level schemes of $^{123-129}$In shown in Fig. 4 are the result of the synthesis of different works: the ms isomer experiments performed at the OSIRIS mass separator [5,6], and the μs isomer experiments performed with the FRS at GSI [7,8] and the LOHENGRIN spectrometer [1,11]. All the reported levels are in the vicinity of the yrast line, therefore the low-spin levels fed in previous works by β-decay experiments are not shown in Fig. 4.

A. ^{129}In

In ^{129}In, ms and μs isomers are present. Fogelberg *et al.* [5] have shown evidence of a high-spin $29/2^+$ yrast trap

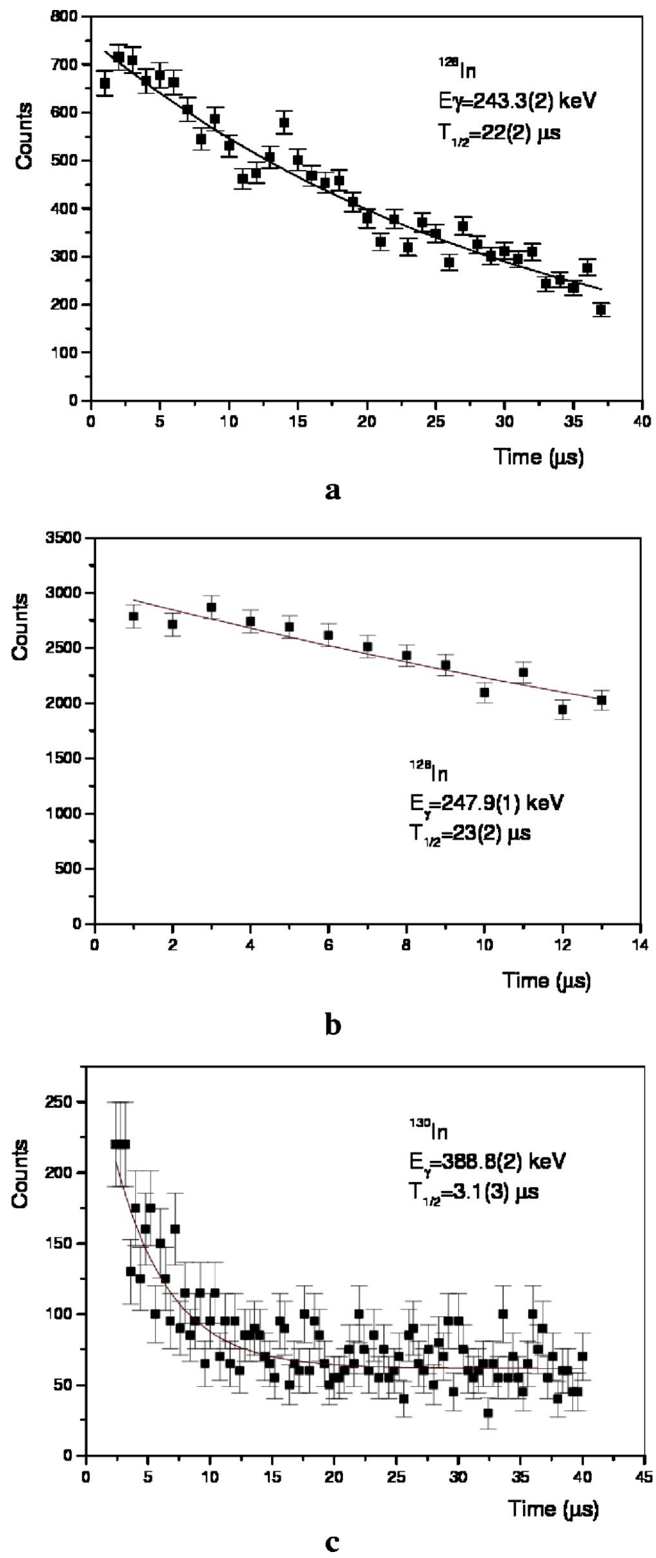

FIG. 3. Time spectrum of ^{126,128,130}In.

which decays by an *E*3 transition (110 ms half-life) to another yrast trap of spin $23/2^-$ (half-life 700 ms), which β decays to ^{129}Sn. More recently, a more precise value of the excitation energy, 1630(56) keV, was measured for the $23/2^-$ state from the β-decay spectra [6].

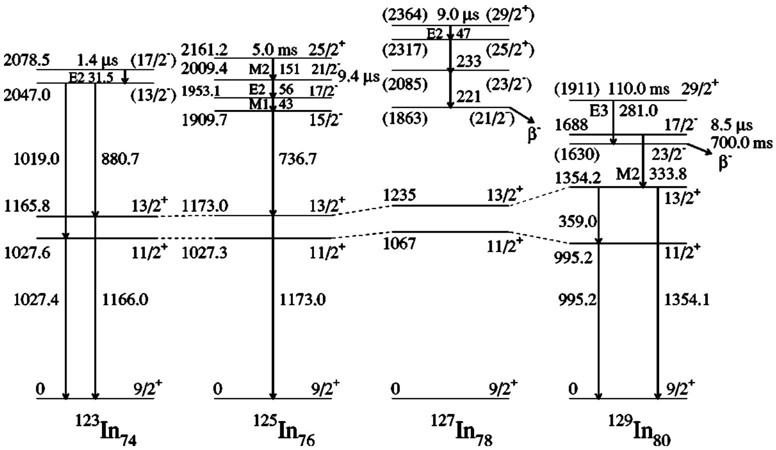

FIG. 4. Level schemes of ^{123,125,127,129}In. The level energies in parentheses are deduced from β spectra [6] and have large uncertainties.

Genevey *et al.* [11] have shown evidence of a $17/2^-$ isomer of 8.5 μs, which decays by a γ cascade to the $9/2^+$ ground state.

B. ^{127}In

The isomeric cascade observed in this isotope has no overlap with the previously known γ rays which feed directly or indirectly the $1/2^-$ isomer of 420(65) keV energy [3,6]. Moreover, the comparison with the neighboring ^{125}In and ^{129}In shows that the excited states above the $9/2^+$ ground state have energies higher than about 1 MeV, which excludes the possibility that the observed cascade ends at this level. Consequently, this cascade most likely deexcites a $29/2^+$ isomer to a $21/2^-$ state, decaying itself by β emission. This finding agrees with the measurement of Gausemel *et al.* [6], who have found a $21/2^-$ isomer in ^{127}In of 1.0 s half-life and have deduced its energy, 1863(58) keV, from β-decay spectra. In Fig. 4, the order of the transitions of 221 and 233 keV, respectively, is arbitrary and could be inverted.

Two other states at energies of 1067 keV and 1235 keV, feeding directly the $9/2^+$ ground state, are added to the level scheme. They were reported by Hoff *et al.* [3] but without spin and parity assignments. By analogy with ^{125}In and ^{129}In, spin and parity assignments of $11/2^+$ and $13/2^+$, respectively, are proposed for these two states.

C. ^{125}In

Fogelberg *et al.* [5] have found a 5 ms isomer in ^{125}In which decays by an $M2$ transition to a 9.4 μs isomer which itself decays by a γ-ray cascade to the $9/2^+$ ^{125}In ground state. We have also observed the decay of the μs isomer and agree with the previous level scheme and the $E2$ and $M1$ mutipolarities measured for the 56 and 43 keV transitions, respectively. Fogelberg *et al.* have suggested a spin and parity assignment of $23/2^-$ for the ms isomer, and positive parities for the states below the isomer. However, this hypothesis seems inconsistent with the nonobservation of the crossover between the 1953.1 keV and 1173.0 keV levels and between the 1909.7 and 1027.3 keV levels, respectively. A $25/2^+$ spin and parity assignment for the ms isomer and a change of parity for the three successive levels seem necessary to explain the nonobservation of the crossover in the experimental data.

D. ^{123}In

The isomer in ^{123}In decays by a low-energy transition expected to be $E2$ and a γ-ray cascade to the $9/2^+$ ground state. The simultaneous feeding of the $11/2^+$ and $13/2^+$ levels at 1027.6 and 1165.8 keV, respectively, suggests a spin and parity assignment $13/2^-$ or $15/2^+$ for the 2047.0 keV level. The negative parity assignment is preferred by analogy with the heavier In isotopes and is reported in Fig. 4, but a positive parity cannot be completely ruled out.

V. SHELL-MODEL CALCULATIONS IN INDIUM AND CADMIUM ISOTOPES

Our shell-model study of the indium and cadmium isotopes has been performed using a realistic effective interaction derived from the CD-Bonn nucleon-nucleon potential. The ^{132}Sn nucleus was considered as a closed core, the proton and neutron holes occupying the levels in the 28–50 shell and the 50–82 shell, respectively. We have assumed an effective proton charge $e_\pi = 1.35\ e$, as a result of a study performed on the $N=50$ isotones [16], and an effective neutron charge $e_\nu = 0.78\ e$, which reproduces the $B(E2;10^+ \rightarrow 8^+)$ in ^{130}Sn. Details on the calculation can be found in [11] and references therein. The results presented in this section have all been obtained by using the OXBASH shell-model code [17].

A. Odd In nuclei

In Fig. 5(a), the experimental and calculated levels of ^{129}In and ^{130}Sn are compared. The results for ^{129}In have been previously reported in [11]. For ^{129}In, all the experimental levels, except the $1/2^-$ at 369 keV, are shown, while in the spectrum of ^{130}Sn only some selected yrast levels are included. The dominant configurations of all these states are also indicated. It should be mentioned, however, that a significant configuration mixing is present in some states. More precisely, only the 7^- and 10^+ states in ^{130}Sn and the $11/2^-$, $23/2^-$, $17/2^-$, and $29/2^+$ states in ^{129}In have a weight of the dominant configuration larger than about 85%. The excita-

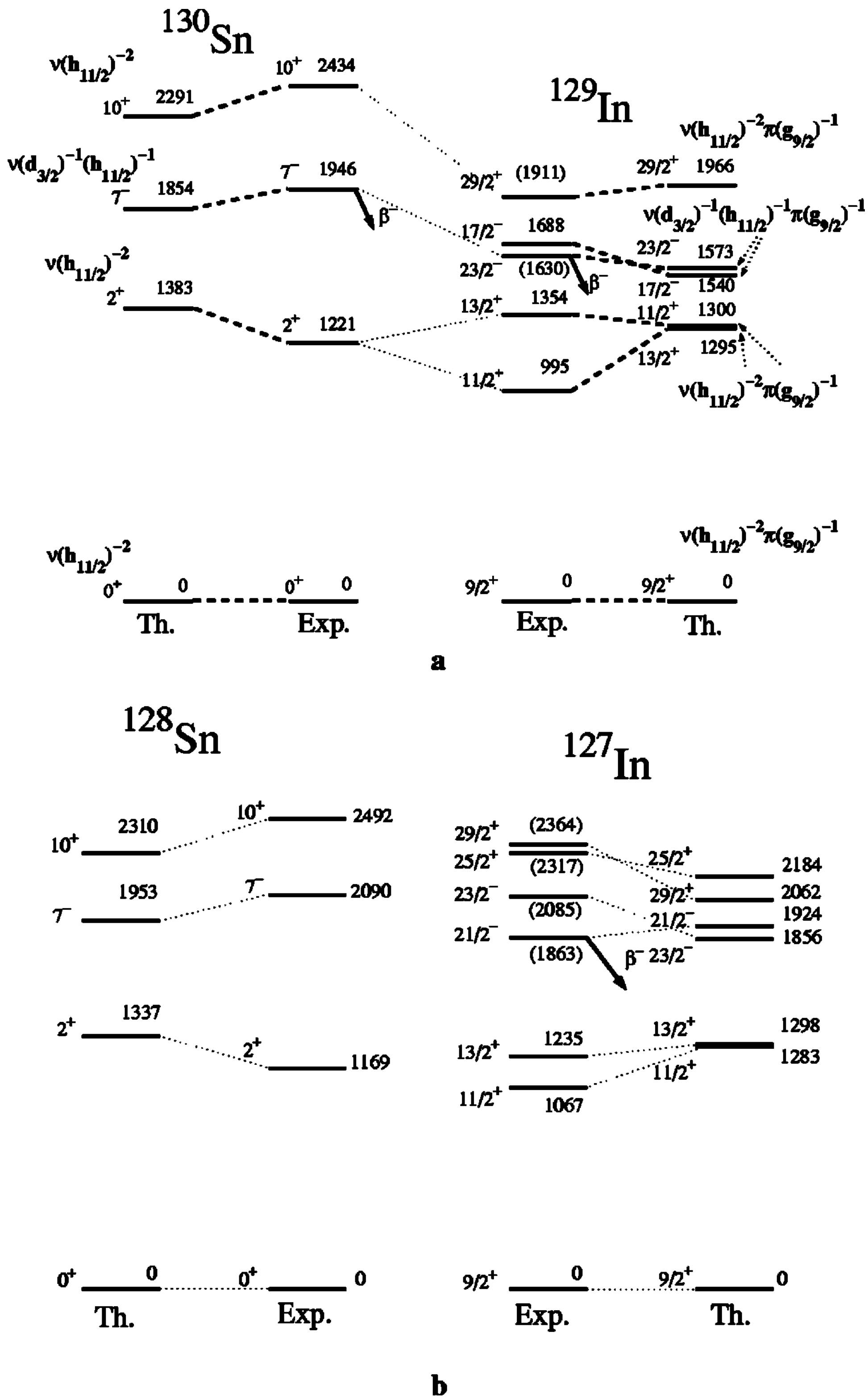

FIG. 5. Experimental and calculated energies for ^{129}In and ^{130}Sn (a), and for ^{127}In and ^{128}Sn (b).

tion energies in ^{130}Sn are rather well reproduced by the shell-model calculations. However, it is interesting to note that the first 2^+ state is overestimated by 162 keV. This is a common feature in this region, and it may be traced to the model-space truncation.

The experimental levels of ^{129}In are expected to result from the coupling of a $\pi g_{9/2}$ hole to the two-neutron hole states in ^{130}Sn. The observed decrease in energy of the $29/2^+$ aligned state with respect to the 10^+ in ^{130}Sn is explained by the strong *p-n* interaction in the $(\nu h_{11/2}^{-1} \pi g_{9/2}^{-1})_{10^-}$ state. An

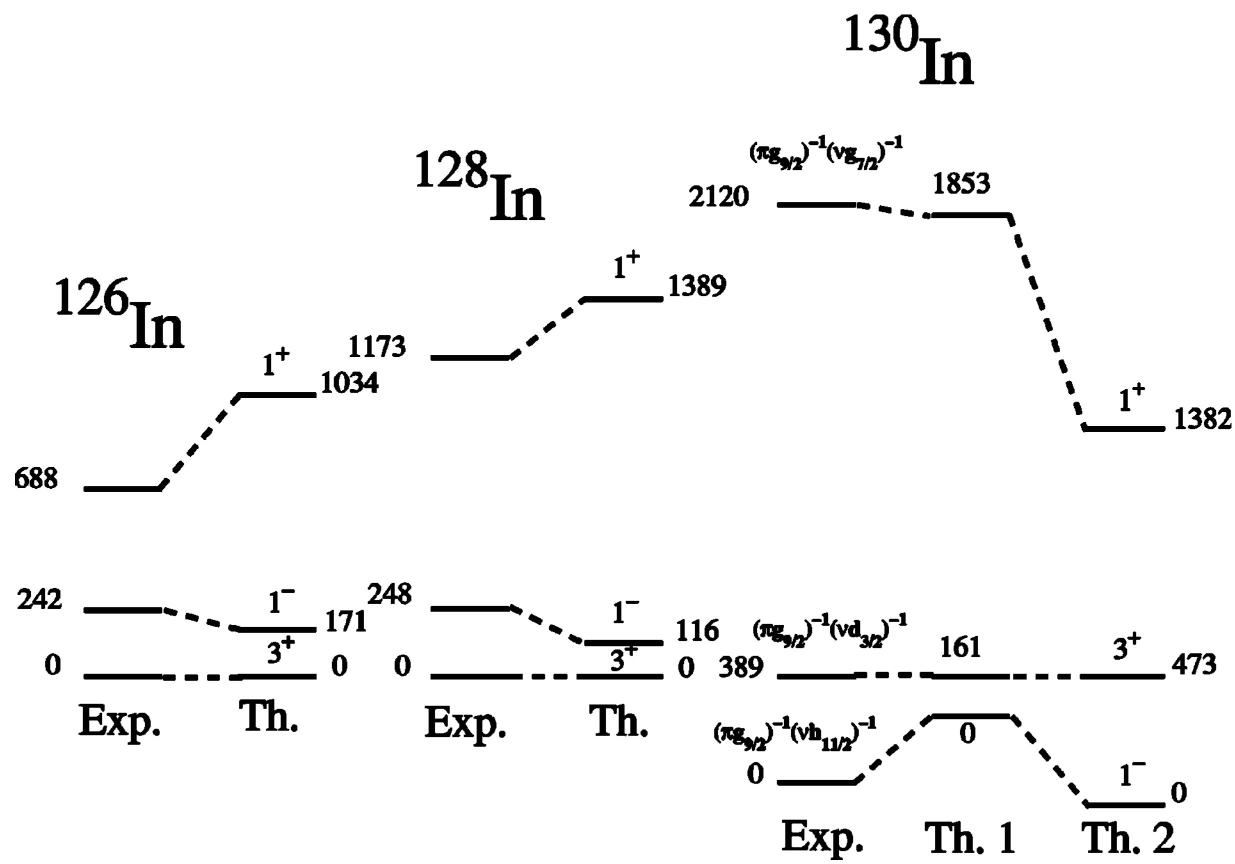

FIG. 6. Experimental and calculated energies for the odd-odd In.

analogous effect is observed for the other aligned state, $J^{\pi}=23/2^{-}$, of dominant configuration $\pi g_{9/2}^{-1}\nu h_{11/2}^{-1}\nu d_{3/2}^{-1}$. However, this effect is weaker because the *p-n* interaction in the $(\pi g_{9/2}^{-1}\nu d_{3/2}^{-1})_{6^+}$ state is less attractive than in the $(\pi g_{9/2}^{-1}\nu h_{11/2}^{-1})_{10^-}$ state. This strong decrease in energy of the $23/2^{-}$ and $29/2^{+}$ is responsible for these two states to be long-lived isomers. This is very well reproduced by the shell-model calculation which also predicts μs isomerism for the $17/2^{-}$ state, which decays by an $E2$ transition. The main discrepancy between experiment and theory occurs for the $11/2^{+}$ level, which is overestimated by 300 keV. This is not surprising since it originates essentially from the coupling of the 2^{+} state in ^{130}Sn to the $g_{9/2}$ proton hole, the energy of the former, as we have already seen, being overestimated by the theory.

From Fig. 5(b), it appears that the observed $29/2^{+}$ and $23/2^{-}$ states in ^{127}In are closer to the 10^{+} and 7^{-} in ^{128}Sn, respectively, as compared to what is shown in Fig. 5(a). This effect could be explained by a decrease in the effects of the *p-n* interaction from ^{129}In to ^{127}In. This is underestimated by the theory, indicating that the distribution of the two extra neutron holes may not be properly described. Another feature, possibly related to the effects of the *p-n* interaction, is the inversion of the $29/2^{+}$ and $25/2^{+}$ and $23/2^{-}$ and $21/2^{-}$ levels, respectively, in the calculated spectrum of ^{127}In. As a consequence, a $29/2^{+}$ ms isomer decaying by an $E3$ transition is predicted, while a μs one decaying by an $E2$ transition is measured. Moreover, the theory predicts a $23/2^{-}$ β-decaying isomer, while a $21/2^{-}$ one is measured [6]. While it would be very interesting to compare experiment and theory for ^{125}In and ^{123}In, the number of configurations is too large to allow calculations with the OXBASH code.

B. Even In nuclei

Nuclear structure information is very scarce for the heavy odd-odd In nuclei. However, the 1^{-}, 3^{+}, and 1^{+} states, resulting from the coupling of a proton hole $g_{9/2}$ with the neutron holes $h_{11/2}$, $d_{3/2}$, or $g_{7/2}$, respectively, are experimentally known [18,19] in $^{126-130}$In. In these three states, the neutron and proton are in coplanar orbits and the *p-n* interaction is expected to become strongly attractive, in particular for the 1^{+} state. A weaker interaction is expected for the 3^{+} state where a $d_{3/2}$ neutron is involved, and this level is used to normalize the level schemes of Fig. 6. The shell-model calculations reproduce rather well the relative energies of the three levels in ^{130}In as well as their evolution when going from ^{130}In to ^{126}In. It is interesting to note the strong variation of the position of the 1^{-} state from ^{130}In to ^{128}In. This variation could be explained by a decrease in the effects of *p-n* interaction when increasing the number of neutron holes. However, as for the aligned $29/2^{+}$ state in ^{127}In, the decrease is underestimated by the calculation.

The very recent results of a shell-model calculation for ^{130}In by Dillmann *et al.* [18] are also reported in Fig. 6 (Th.2). Although in this work the two-body matrix elements

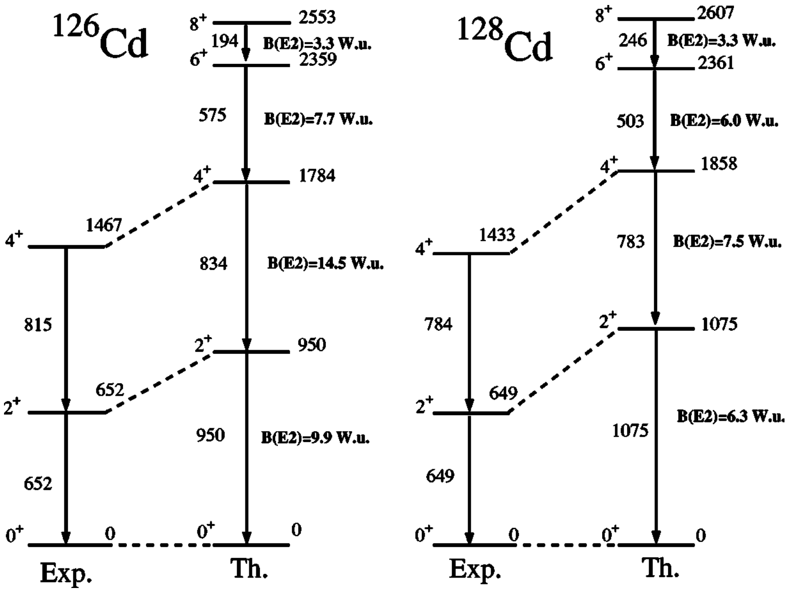

FIG. 7. Experimental and calculated energies for ^{126,128}Cd.

are also derived from the CD-Bonn potential, the energy of the 1^+ state is underestimated by 738 keV, which is in strong variance with the outcome of our calculation.

In conclusion, the shell model reproduces rather well the levels of ^{129}In and ^{130}In. However, it underestimates the decrease in the effects of the *p-n* interaction when two neutrons are removed from ^{130}In or ^{129}In. These results show the limits of the predictive power of the present shell-model calculations in the vicinity of ^{132}Sn for $N<82$.

C. Even Cd isotopes

In the vicinity of the two closed shells of ^{132}Sn, the μs isomers are very abundant and disappear rapidly far from them [1]. However, below $Z=50$ they disappear suddenly for the Cd isotopes, no isomers having been identified up to now in the even-mass ones.

Neutron-rich ^{126}Cd and ^{128}Cd isotopes were recently produced [2] at ISOLDE from the β decay of Ag isotopes. However, only the first 2^+ and 4^+ states were identified and are shown in Fig. 7. The value of $E(4^+)/E(2^+)\sim 2.2$ suggests that some degree of collectivity is present in these two nuclei. However, the authors of Ref. [2] have taken this as possible evidence for a weakening of the spherical $N=82$ neutron shell below ^{132}Sn.

Our shell-model predictions for these two nuclei are reported in Fig. 7. The comparison between experiment and theory shows that while the energies of both the 2^+ and 4^+ states are overestimated, the $4^+\rightarrow 2^+$ energy difference is correctly reproduced. The $E2$ transition rates are also reported. Unfortunately, it is not possible to compare them with the experimental data, but the $B(E2)$ values and the energy of the $8^+\rightarrow 6^+$ transitions allow us to predict a half-life of about 10 ns for the 8^+ state in both Cd isotopes. This value is much shorter than the time of flight of 2 μs of the FFs through the LOHENGRIN spectrometer and could explain the nonobservation of these isomers in our work.

It is now interesting to compare ^{128}Cd with ^{204}Hg (Fig. 8), since the latter has two neutron and two proton holes inside doubly magic ^{208}Pb (Fig. 8) and possesses some degree of collectivity. For ^{204}Hg, which is easier to study because it is on the line of stability, the energy levels and $E2$ transition rates have been reported in the literature. This nucleus presents a nice collective band based on the ground state and is characterized by an $E(4^+)/E(2^+)\sim 2.6$ ratio, which is larger than the one measured in ^{128}Cd. Rydström *et al.* [20] have shown that for ^{204}Hg, the energy levels and the $E2$ transition rates up to the 6^+ state are well reproduced by the shell model. These authors have also predicted that the collective band ends at the 8^+ state and that the states up to the 6^+ one are mostly built from the low-spin single-hole $s_{1/2}$ and $d_{3/2}$ orbits for the protons, and $p_{1/2}$, $f_{5/2}$, and $p_{3/2}$ orbits for the neutrons. Both of these sets of single-parity states are close to the Fermi level, while the unique parity states have about 1.5 MeV of excitation energy. The situation is different in ^{128}Cd, because the unique-parity states are very close to the Fermi level. This feature may play an important role in the structure of this nucleus, and could perhaps explain its weaker collectivity. However, the present information on this nucleus is too scarce to conclude that the collectivity is a consequence of the shell structure, and more experimental data are needed to clarify the situation.

VI. *M*2 and *E*3 TRANSITION PROBABILITIES IN Sn AND In ISOTOPES

In Table III, all the available $M2$ and $E3$ transitions in heavy In and Sn isotopes are reported. Among these transitions, only the first one corresponds to a spin change $\Delta I=3$, while all the others have $\Delta I=2$, and $M2/E3$ admixtures are possible.

All these transitions take place between states dominated by configurations which differ by the replacement of an $h_{11/2}$ neutron with a $d_{3/2}$ one, or vice versa. As $M2$ or $E3$ transitions are not possible between these configurations, admixtures with configurations involving the $g_{7/2}$ or $d_{5/2}$ orbits are necessary. These two orbits are far from the Fermi level in

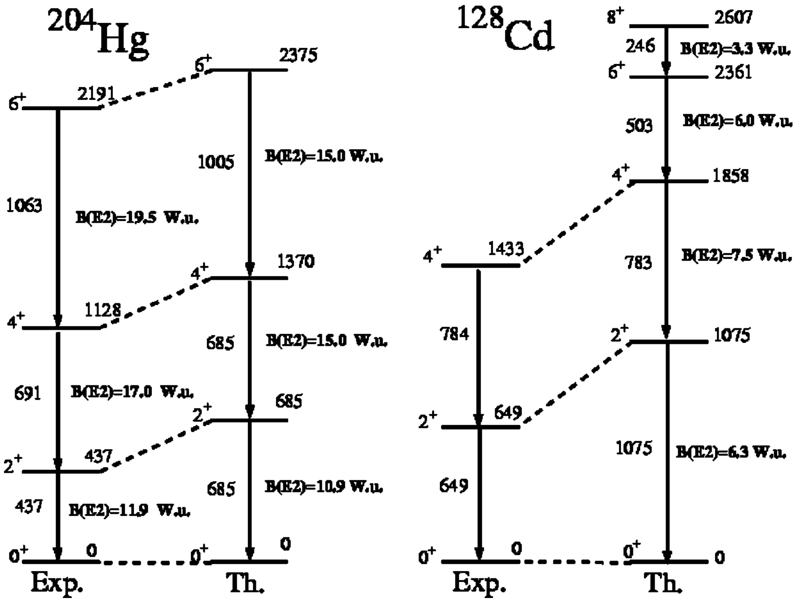

FIG. 8. Experimental and calculated energies for ^{204}Hg [20] and ^{128}Cd.

the Sn and In isotopes, and the admixtures are expected to be small. The experimental $B(M2)$ and $B(E3)$ values reported in Table III are obtained assuming no admixture of the multipolarities. The very small value $B(E3)=0.06$ W.u. for the $29/2^+ \rightarrow 23/2^-$ transition in ^{129}In gives the order of magnitude of the $E3$ strength in this region. Consequently, the very large values given in Table III for the other $B(E3)$ transition probabilities in the In isotopes are not realistic, and one may conclude that the transitions have mainly an $M2$ character. By contrast, in the Sn isotopes it is not possible to exclude an $E3$ component in the transitions, and the $M2$ strengths may be smaller than the reported values. It is interesting to note that the $B(M2)$ values are between 10 and 100 times smaller in the Sn isotopes than in the In ones. This effect is likely to be related to the magic character of the Sn isotopes. The results of our shell-model calculations in ^{129}In reported in Ref. [11] predict a $B(M2;17/2^- \rightarrow 13/2^+)=0.045$ and a $B(E3;29/2^+ \rightarrow 23/2^-)=0.052$; they are in good agreement with the experimental values 0.032(2) and 0.066(10), respectively. As regards the other $B(E3)$ transitions, our calculations predict very small values, typically 10^{-2} W.u. for the In isotopes and 10^{-1} W.u. for the Sn isotopes.

TABLE III. Experimental $B(M2)$ and $B(E3)$ values of $M2/E3$ transitions in ^{125,126,128,129,130}In and ^{123,125,127,129}Sn. The values reported for ^{129}In are taken from [11]; the values reported for ^{123,125,127,129}Sn are taken from [6,21]. The $B(M2)$ and $B(E3)$ values reported are obtained assuming pure $M2$ and $E3$ multipolarities. In the indium isotopes, the transitions have predominantly an $M2$ character, whereas in the tin isotopes it is not possible to exclude an $E3$ component, as discussed in the text.

Nucleus	Energy (keV)	Transition	$B(M2)$ W.u.	$B(E3)$ W.u.
^{129}In	281	$29/2^+ \rightarrow 23/2^-$		0.06
^{129}In	333.8	$17/2^- \rightarrow 13/2^+$	0.033	283
^{130}In	388.8	$3^+ \rightarrow 1^-$	0.047	27.6
^{128}In	247.9	$1^- \rightarrow 3^+$	0.047	73
^{126}In	243.3	$1^- \rightarrow 3^+$	0.053	89
^{125}In	151	$25/2^+ \rightarrow 21/2^-$	0.0015	43
^{129}Sn	590	$19/2^+ \rightarrow 15/2^-$	$<1.7\times10^{-4}$	0.49
^{127}Sn	723	$19/2^+ \rightarrow 15/2^-$	1.6×10^{-4}	0.30
^{125}Sn	806	$19/2^+ \rightarrow 15/2^-$	2.9×10^{-4}	0.47
^{123}Sn	838	$19/2^+ \rightarrow 15/2^-$	1.8×10^{-4}	0.29

VII. CONCLUSIONS

The present delayed γ rays and conversion electron measurements of fission products have allowed us to enrich the level schemes of the In isotopes in the mass range $A=123$ to 130. A new half-life was measured for ^{123}In, and several half-lives known with large uncertainties were remeasured. We have found out that, most likely, no μs isomers exist in ^{126,128}Cd with half-lives longer than 0.5 μs. It was also shown that the $M2$ transitions are much faster in the In isotopes than in the proton-magic Sn isotopes.

Along with the experimental work, we have performed realistic shell-model calculations for the odd-mass ^{127}In, the even-mass ^{126,128,130}In, and ^{126,128}Cd. These calculations provide a satisfactory interpretation of ^{129,130}In, but some discrepancies occur for the lighter isotopes. The calculations for ^{126,128}Cd predict short half-lives ($\sim$10 ns) for the 8^+ states, which could explain why they have not been observed in the present work. We have also shown that these nuclei present some similarities with ^{204}Hg. Both ^{128}Cd and ^{204}Hg have only two proton and two neutron holes inside doubly magic cores and present a collective behavior. However, more experimental data, in particular $B(E2)$ transition probabilities, are necessary to test this hypothesis.

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