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Evidence for a positive parity decoupled band in neutron-deficient ^{103}Cd

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Excited levels of ^{103}Cd have been investigated in the ^{94}Mo(^{12}C,$3n\gamma$)^{103}Cd reaction and observed up to 4027 keV excitation energy. A decoupled band, based on the 188.1 keV $7/2^+$ intrinsic state has been observed up to spin $19/2^+$. An interpretation of the experimental results is proposed in the framework of the axial symmetric rotor plus particle model using deformed self-consistent quasiparticle states.

[NUCLEAR REACTIONS ^{94}Mo(^{12}C, $3n\gamma$), E=44–65 MeV; measured E_γ, I_γ, $\gamma(\theta)$, P_γ, ^{12}C-γ delay, γ-γ coin, ^{103}Cd deduced levels and J^π, Ge(Li) detectors, enriched target.]

I. INTRODUCTION

A considerable amount of experimental data has been recently collected on light cadmium isotopes. The main purpose of these studies was to search for a decoupling mechanism in a transitional region.[1] In ^{105,107,109,111}Cd isotopes a decoupled $\Delta I = 2$ band based on the unique parity $\nu h_{11/2}$ neutron orbital has been observed (Refs. 2–6). Positive parity perturbed bands built on the $\nu g_{7/2}$ and $\nu d_{5/2}$ orbitals were also identified.

From the 1 min ^{103}In → Cd decay, the first excited state of ^{103}Cd has been located at 188.1 keV excitation energy and assigned $\frac{7}{2}^+$ by Lhersonneau *et al.*[7]

The aim of the present work is, using HI reactions, to search for the high spin states in ^{103}Cd where only two low-lying levels are known so far from on-line radioactivity studies. It is also worth checking whether the rotor-plus-particle model successfully applied to heavier isotopes[8] is able to give a satisfactory account for experimental results on the neutron deficient ^{103}Cd.

II. EXPERIMENTS AND RESULTS

The ^{103}Cd nucleus has been studied using the ^{94}Mo (^{12}C, $3n$) reaction at the GRENOBLE Cyclotron. A 4 mg/cm^2 metallic target of isotopically enriched ^{94}Mo (94, 6%) has been used in these experiments. Excitation functions were measured at bombarding energies ranging from 44 to 65 MeV. The 188 keV γ-ray yield was maximum at 54 MeV and this bombarding energy was adopted in subsequent experiments. A typical γ single spectrum measured with a 15% efficiency ($L_{1/2}$=2.1 keV at 1332 keV) Ge(Li) coaxial detector is shown in Fig. 1.

γ-γ coincidence experiments, using two Ge(Li) detectors, were performed to establish a level scheme. The γ-γ data were stored on magtapes via a PDP 9 computer and the 2048 × 2048 channels matrix was constructed and analyzed offline. Typical coincidence spectra are shown in Fig. 2.

The ground state ($\frac{5}{2}^+$) and first excited level (188.1 keV, $\frac{7}{2}^+$) have been used as starting points of the level scheme presented in Fig. 3. γ rays have been assigned to ^{103}Cd on the basis of a coincidence relationship with the 188.1 keV γ line. The γ intensities are reported in Table I where the contribution of parasitic reactions has been subtracted. The strong contamination in the spectrum by γ rays assigned to ^{103}Ag produced via the ^{94}Mo (^{12}C, $p2n$) reaction was not a severe difficulty because of our recent investigation on this nucleus.[9] γ rays belonging to ^{103}Pd (from ^{103}Ag decay), $^{101-100}$Pd, and ^{104}Ag produced by ^{94}Mo (^{12}C, αn), ^{94}Mo(^{12}C, $\alpha 2n$), and ^{94}Mo(^{12}C,pn) respectively were unambiguously identified. To search for long-lived isomers (10–100 ns), γ singles were measured between the beam bursts and compared to direct spectra in coincidence with the high-frequency signal of the cyclotron. There was no evidence for such lifetimes in the ^{103}Cd nucleus.

An ^{94}Mo target deposited on a 130 mg/cm^2 lead backing was used for the angular distribution and linear polarization measurements. The beam monitoring was performed using an extra Ge(Li) γ counter placed at a fixed angle. γ singles were measured at 5 position angles from 0° to 90°. A three detector Ge(Li) Compton polarimeter already described in Ref. 10 has been used to measure the linear polarization. The experimental results are reported in Table I, the angular dis-

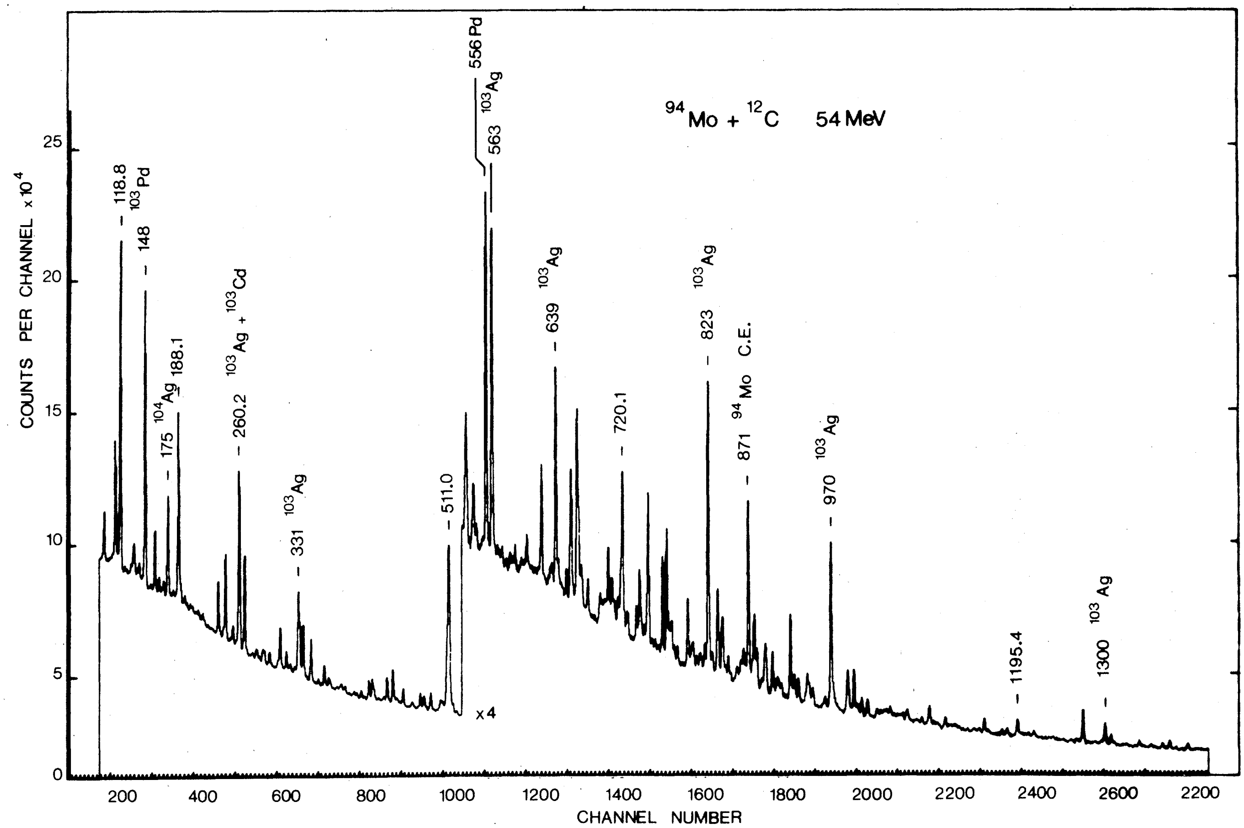

FIG. 1. Singles γ-ray spectrum measured in the ^{94}Mo(^{12}C,$3n\gamma$) ^{103}Cd reaction at 54 MeV bombarding energy. The strongest γ-ray lines due to other product nuclei are reported.

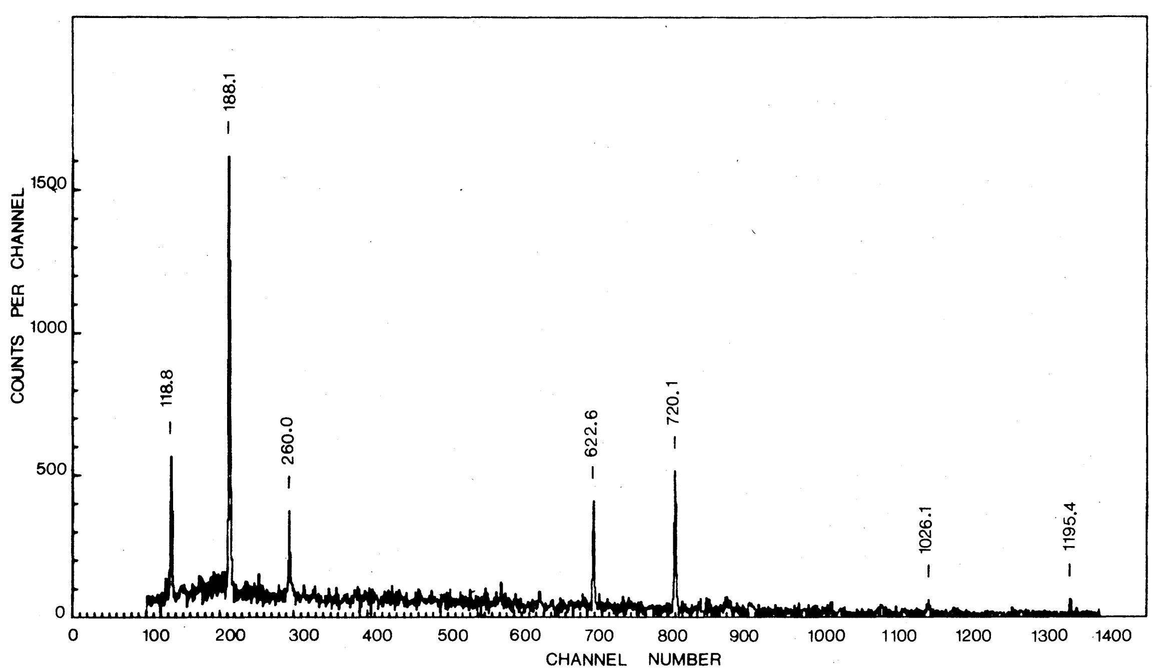

FIG. 2. Coincident γ-ray spectrum in ^{103}Cd. This spectrum is background subtracted and corresponds to a gate set on the 921.7 keV γ ray.

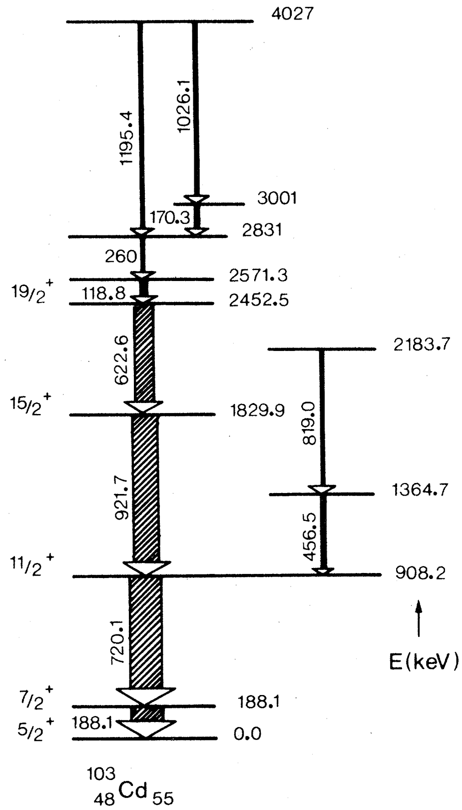

FIG. 3. Level scheme of ^{103}Cd as determined from the ^{94}Mo(^{12}C, $3n\gamma$) reaction at 54 MeV incident energy.

tribution coefficients are corrected for finite solid angle attenuation, and the polarization p is defined as indicated in Ref. 10. Simultaneous fits of the angular distribution coefficients and of the linear polarization data versus the nuclear spin alignment and the mixing ratio values led to unique spin and parity assignments in the case of four levels. In the χ^2 analysis, the alignment attenuation factors α_2 were allowed to vary freely between 0 and 1 with α_4 bound to the α_2 value assuming a Gaussian distribution of the m substates. The deduced spin and parities are reported in Fig. 3 and a more detailed discussion of the level scheme will be given in the next section.

III. LEVEL SCHEME

From the 65 s ^{103}In → Cd β decay, Lhersonneau *et al.*[7] assigned $\frac{5}{2}^+$ and $\frac{7}{2}^+$ for the g. s. and first excited levels respectively. In our experiment the angular distribution and linear polarization of the 188.1 keV γ ray leads to an $M1$ ($\frac{7}{2}^+ \to \frac{5}{2}^+$) transition with $\delta^2(E2/M1) \leq 0.01$ in agreement with the internal conversion coefficient measurement of Ref. 7.

The angular distribution and linear polarization of the three strong 622.6, 921.7, and 720.1 keV coincident γ rays allow us to connect the spin sequence $\frac{19}{2}^+ \to \frac{15}{2}^+ \to \frac{11}{2}^+$ with corresponding excited levels. Above the 2452.5 keV excited level and for both 1364.7 and 2183.7 keV levels, no spin and parity could be assigned due to either low statistics or the complex nature of the lines involved as mentioned in Table I.

IV. DISCUSSION

The present results are consistent with the existence of a cascade of strong stretched $E2$ transitions based on the $\frac{7}{2}^+$ first excited level. A se-

TABLE I. Properties of γ rays assigned to ^{103}Cd from the ^{94}Mo (^{12}C, $3n$) reaction. The accuracy on the energy determination is about 0.2 keV except for complex lines where it is ~0.5 keV. (a) Line contaminated by ^{103}Ag → Pd decay. Intensities of lines marked (b) have been deduced from coincidence measurements.

E_γ (keV)	I_γ ($E_{^{12}C}$ = 54 MeV)	A_2	A_4	p	Assigned multipolarity or spin change
118.1 [a]	27 (3)				
170.3	6 (2)	−0.18 (8)	−0.05 (8)		±1
188.1	100	−0.14 (3)	−0.05 (4)	−0.26 (7)	$M1$
260 [b]	22 (5)				
456.5 [b]	6 (2)				
622.6	53 (5)	+0.28 (2)	−0.06 (3)	+0.49 (8)	$E2$
720.1	91 (5)	+0.27 (2)	−0.07 (2)	+0.49 (7)	$E2$
819.0 [b]	4 (2)				
921.7	67 (5)	+0.28 (2)	−0.09 (2)	+0.40 (8)	$E2$
1026.1	8 (3)	−0.27 (8)	+0.01 (10)	−0.15 (30)	($M1$)
1195.4	17 (3)	+0.34 (4)	−0.21 (6)	+0.2 (2)	0, −2

quence consisting of $\frac{19}{2}^+$-$\frac{15}{2}^+$-$\frac{11}{2}^+$-$\frac{7}{2}^+$ states has been unambiguously established and is the main path of deexcitation. The level spacings of this $\Delta I = 2$ cascade is quite similar to that of the even-even ^{104}Cd core. Such an analogy was already observed in heavier Cd isotopes ($A = 105, 107, 109, 111$) studied via (α, xn) reactions as shown in Fig. 4.

In order to account for these experimental data we used the results of the self-consistent quasi-particle + rotor model, described in detail in Ref. 8. In spite of the absence of any free adjustable parameter, the available experimental data concerning ^{105,107,109,111}Cd isotopes have been reproduced correctly and predictions have been given for ^{103,101}Cd, both for negative parity band ($h_{11/2}$) and positive parity ones ($g_{7/2}$ and $d_{5/2}$).

From constrained Hartree-Fock calculations including pairing correlations and using the Skyrme SIII effective force, the deformation energy of $^{102-106-110}$Cd, the equilibrium deformation, and the corresponding single quasi-particle states have been obtained. A variable moment of inertia $J(R)$ is taken into account by projecting the standard wave functions $|IMK>$ onto $|IMJR>$ eigenfunctions of the core angular momentum. This allowed us to introduce exactly in the core Hamiltonian the experimental level sequence of the neighboring even adjacent isotopes.

We present in Fig. 5 the theoretical level schemes of ^{103}Cd for the two equilibrium deformations (oblate and prolate) of the ^{102}Cd core, and we report for each state the weight of the main component in the wave function: The theoretical spectrum consists of three different bands, arising mainly from the $g_{7/2}$, $d_{5/2}$, and $h_{11/2}$ neutron states coupled to the R core states.

From the comparison between experimental and calculated schemes it is clear that the ^{103}Cd nucleus is prolate, the $g_{7/2}$ band being decoupled only in this case. The yrast favored $\frac{11}{2}^+$, $\frac{15}{2}^+$, $\frac{19}{2}^+$ levels which we have observed mainly arise from the coupling of the $\nu(g_{7/2})$ quasi-particle to the 2^+, 4^+, 6^+ core states.

The negative parity $\frac{11}{2}^-$ band has not been observed experimentally in ^{103}Cd, in contrast with heavier odd Cd isotopes. This could be explained by the fact that the $\nu h_{11/2}$ state is predicted at ~2 MeV excitation energy in ^{103}Cd: It is well known that the $\nu h_{11/2}$ state rises in energy as N decreases (0.396 MeV in ^{111}Cd, 0.463 MeV in ^{109}Cd, 0.845 MeV in ^{107}Cd, 1.162 MeV in ^{105}Cd and thus is less and less fed.

The excited members of the $d_{5/2}$ band seem to be absent in our experimental spectrum. A possible explanation for their non-observation could be that, for instance, the $\frac{7}{2}^+_2$ state lies above the $\frac{11}{2}^+_1$, in contrast with what has been observed in $^{105-107}$Cd.

We should note that even in this neutron deficient cadmium isotope, the decoupling mechanism involving the $\nu g_{7/2}$ orbital plays an important role, regarding the high spin structure of the nucleus.

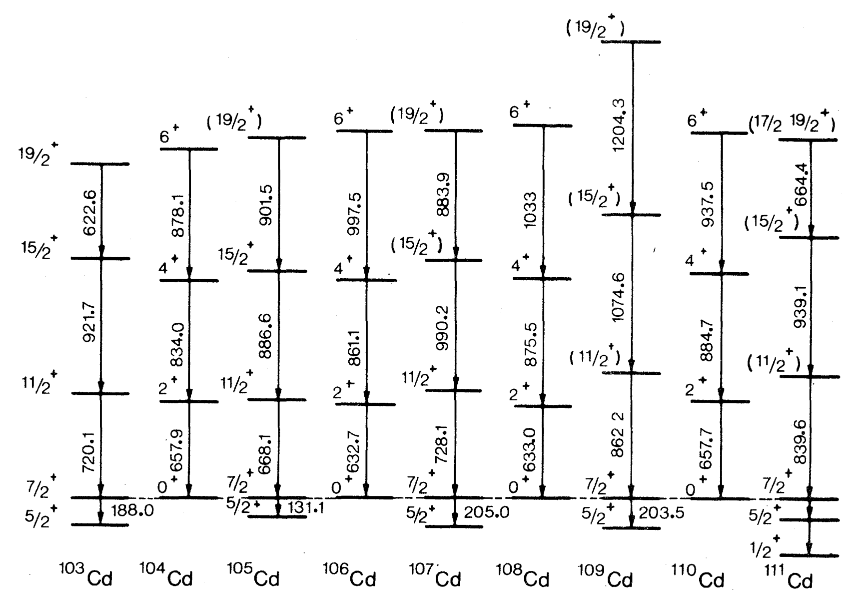

FIG. 4. Positive parity $\frac{7}{2}^+$ band in odd Cd isotopes compared with ground state band in adjacent even cores. The energy of the $\frac{7}{2}^+$ level has been normalized to that of the 0^+ g.s. of the even isotopes.

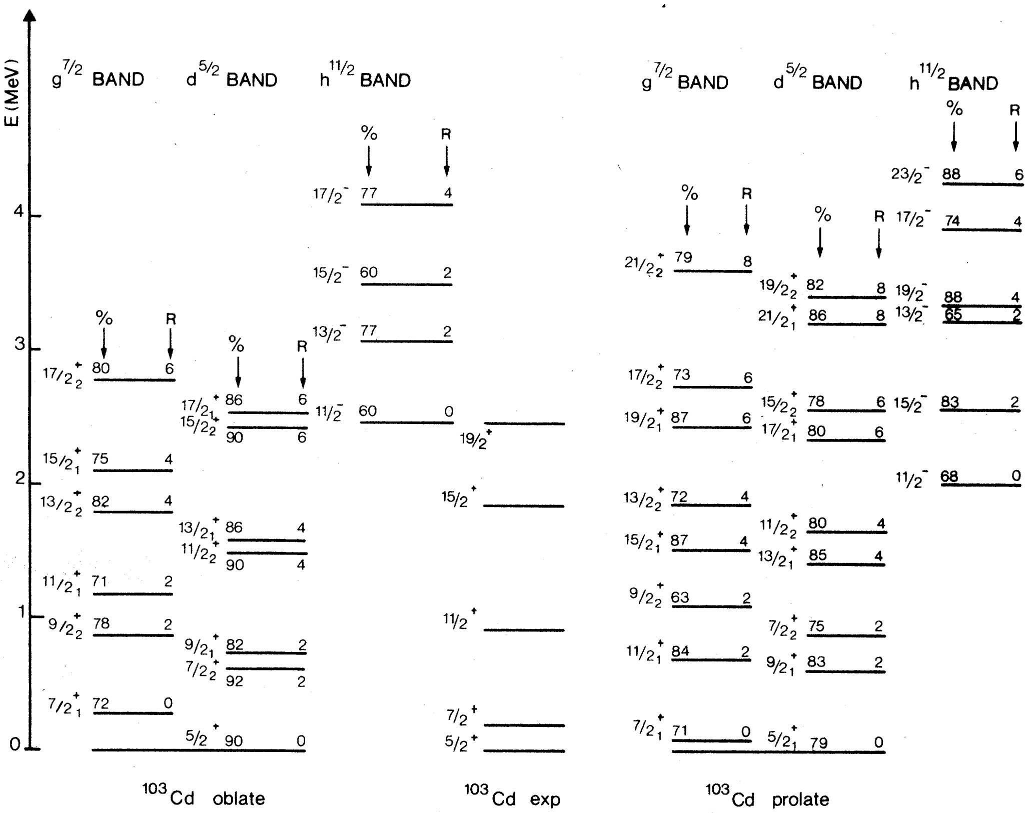

FIG. 5. Comparison between the ^{103}Cd experimental scheme and those calculated in the framework of the rotor-plus-particle model described in Ref. 8. On each calculated level we have reported the percentage (%) of the main component of the wave function. Only experimental levels with unambiguously assigned spin and parity have been reported here.

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