Evidence for deformation in $^{113-116}$Cd isotopes

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Abstract. High-spin states in $^{113-116}$Cd have been investigated with the fusion-fission reaction $^{28}$Si + $^{176}$Yb at 145 MeV. The experiment has been performed with the Eurogam2 array. New rotational bands based on two quasi-particle states have been observed for even-even cadmium isotopes. A new level scheme based on the $11/2^-$ isomeric state is proposed for $^{113}$Cd and the one of $^{115}$Cd has been extended to spin (31/2$^+$). The decoupled bands identified in both odd-A nuclei are interpreted as being built upon a low-$Ω$ $h_{11/2}$ quasi-neutron configuration. Microscopic Hartree-Fock + BCS calculations confirm the prolate deformation in this mass region especially for the odd cadmium isotopes.


1 Introduction

For long time cadmium isotopes lying close to stability (111 ≤ A ≤ 114), studied by radioactive decay, have been considered as good examples of quadrupole vibrator with spherical shape, the even-even ones, namely $^{112,114}$Cd, exhibiting the typical two-phonon triplet states and the odd-A ones, $^{111,115}$Cd, the corresponding weak-coupling states [1]. Consequently several phenomenological calculations have described the even-even nuclei in the framework of the anharmonic vibrator model coupling two holes of protons ($\pi_{g9/2}$)$^2$ to an even-even Sn core [2] or of the generalized spdf IBA-1 model with configuration mixing of the normal and intruder states [3]. At high spin, lighter nuclei have been investigated using heavy-ion fusion-evaporation reactions [3–8]. The observation of decoupled bands in odd $^{113-111}$Cd isotopes [4–7,9] has pointed out that these nuclei are weakly prolate deformed. The existence of this axial deformation ($β$ ~ 0.1) has been shown by Hartree-Fock + BCS microscopic calculations in even-even cadmium isotopes [10].

The heavier even-even cadmium isotopes, $^{114-122}$Cd, have been produced at intermediate spins by fission [11] or transfer reactions [12]. For nuclei closer to the stability in this mass region, heavy-ion induced fission has recently allowed the population of high spin states which can not be populated otherwise. The new generation of large arrays of high-efficiency Compton-suppressed Ge detectors permits the study of these high spin states [13]. In the present work, high-spin states in $^{113-116}$Cd have been investigated. New rotational bands have been observed in even-even cadmium and new level schemes built above the $11/2^-$ isomeric state are proposed for $^{113}$Cd and, for the first time, for $^{115}$Cd. Preliminary results of this work have been reported in [14].

2 Experiment

The experiment was performed at the Vivitron accelerator, which delivered a $^{28}$Si beam at 145 MeV. The target consisted of a foil of 1.5mg/cm$^2$ of $^{176}$Yb deposited on a 15 mg/cm$^2$ gold backing. Prompt γ-rays emitted by the de-excitation of the fission fragments were detected using the Eurogam2 spectrometer [15] which consisted of 15 large escape suppressed Ge detectors at backward and forward angles respectively, and 24 escape suppressed “clover” Ge detectors near 90° relative to the beam direction. The data were recorded in an event-by-event mode with the
requirement that a minimum of five unsuppressed Ge fired in prompt coincidence. A total of 540 million coincidence events were collected. The off-line analysis consisted of both $\gamma-\gamma-\gamma$ sorts and multiple-gated spectra [16]. More than 130 nuclei have been obtained as fission fragments [17]. The relative production yield of the even-even Cd isotopes is about half of those of the most-produced even-even fission-fragments (Mo and Ru isotopes) [18] and the cadmium mass region reached extends from $A = 110$ to $A = 118$ with a maximum yield at mass 114.

For the assignment of new structures to odd cadmium isotopes we have used the identification method based on prompt coincidences between complementary nuclei. In our case, cadmium and krypton isotopes are complementary fragments. This method was applied initially for the study of spontaneous fission [19] and has recently been extended to that of heavy-ion induced fission reactions [13]. Because of the lack of statistics, no directional correlation information has been obtained and spin and parity assignments of the new states can not be extracted. However, in the new structures, spin and parity values have been tentatively assigned from comparisons with neighbouring isotopes.

3 Results

Yrast bands in the even-even isotopes $^{114,116}$Cd have been previously identified [11] and have been extended in this work up to spin (14h). The identification in this case is based on unambiguous coincidence relationships with low-lying transitions $4^+ \rightarrow 2^+ \rightarrow 0^+$. A new rotational band built on the $5^-$ state [20] has been established in both nuclei $^{114}$Cd and $^{116}$Cd respectively up to spin (13h) and spin (11h). A second connection to the yrast band is proposed via a $(7^-)\rightarrow 6^+$ transition. Additional side band has also been observed above the $8^+$ state in $^{114}$Cd. The partial level schemes of $^{114,116}$Cd are presented in Fig. 1. The relative intensities have been measured from spectra gated on the lowest transitions.

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The neutron-rich odd cadmium isotopes exhibit long-lived isomeric state based on a $\nu h_{11/2}$ configuration. The $^{113,115}$Cd nuclei have never been populated at very high spin. Only two states above the $11/2^-$ isomer have been previously identified in $^{113}$Cd by $^{110}$Pd($\alpha,n\gamma$) reaction [21] and by gating on the transitions (551 and 842 keV) deexciting these states, we obtain the spectrum shown in Fig. 2. We can see the new transitions labelled by their energies and the two first ones of the complementary fragment $^{85}$Kr, 269 and 1544 keV [22]. We have extended the level scheme based on the long-lived isomeric state $11/2^-$ [20] up to spin (31/2h), and assigned two rotational bands built on the $(21/2^+)$ and $(19/2^+)$ states as shown in Fig. 3.

Concerning the $^{115}$Cd isotope, no transition was known above the $11/2^-$ isomer before our studies. Gating on the two first transitions of the complementary $^{83}$Kr fragment (1122 and 1144 keV) [23], we obtained the spectrum presented in Fig. 4. Besides $\gamma$-rays belonging to $^{83}$Kr (204 and 897 keV), the other transitions can be associated with the complementary cadmium isotopes. We observe the main transitions of the fission fragments with respectively 7 and 5 neutrons evaporated : $^{114}$Cd (558 and 725 keV) and $^{116}$Cd (513 and 706 keV), and above all, candidate transitions for $^{115}$Cd appear clearly at 519 and 777 keV energies. Furthermore a coincidence relationship between these two transitions has been established. The coincidence spectrum double-gated on these 519 and 777 keV transitions is displayed on Fig. 5. Six new transitions clearly appear, namely 446, 645, 661, 677, 791 and 919 keV. The new level