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Observation of a γ-decaying millisecond isomeric state in $^{128}Cd_{80}$

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ABSTRACT

A new high-spin isomer in the neutron-rich nucleus ^{128}Cd was populated in the projectile fission of a ^{238}U beam at the Radioactive Isotope Beam Factory at RIKEN. A half-life of $T_{1/2} = 6.3(8)$ ms was measured for the new state which was tentatively assigned a spin/parity of (15^-). The experimental results are compared to shell model calculations performed using state-of-the-art realistic effective interactions and to the neighbouring nucleus ^{129}Cd. In the present experiment no evidence was found for the decay of a 18^+ $E6$ spin-trap isomer, based on the complete alignment of the two-neutron and two-proton holes in the $0h_{11/2}$ and the $0g_{9/2}$ orbit, respectively, which is predicted to exist by the shell model.

The regions in the nuclear chart around doubly-magic nuclei such as ^{100}Sn and ^{132}Sn offer a rich testing ground for the study of isomeric states of different types. Seniority isomers are observed due to the properties of the isovector pairing interaction which lead to a decreasing energy spacing between the excited states formed by the successive alignment of two identical nucleons occupying the same orbital. As a consequence the fully aligned state of such a two-nucleon configuration is often long-lived due to the small transition energy for the electromagnetic decay. Examples of such seniority isomers with half-lives in the μs range are the 8^+ states in the semi-magic two-proton hole nuclei ^{98}Cd$_{50}$ and ^{130}Cd$_{82}$ [1,2]. An analogous isomer based on the fully-aligned $\nu(0h^{-2}_{11/2})$, 10^+ neutron configuration is observed in the semi-magic two-neutron hole nucleus ^{130}Sn [3]. Another type of isomer frequently observed in the regions around ^{100}Sn and ^{132}Sn are spin-gap isomers. In these cases the decay to states at lower excitation energy requires a large change in nuclear spin and therefore the emission of γ rays with high multipolarity. In cases of large hindrances a decay mediated by the weak interaction, i.e. β decay, is favoured as compared to the electromagnetic decay. Examples are low-lying β-decaying states in odd nuclei around the doubly-magic Sn cores due to the closely lying $0g_{9/2}$–$1p_{1/2}$ proton and $1d_{3/2}$–$0h_{11/2}$ neutron single-particle orbitals which would require electromagnetic decays with a multipolarity of $M4$. Another example of a spin-gap isomer has recently been reported in the two-proton hole and two-neutron hole nucleus ^{96}Cd [4,5]. The observed β-decaying state with a half-life of $T_{1/2} = 0.45^{+0.05}_{-0.04}$ s was interpreted as being based on the configuration in which the two neutron holes and the two proton holes, all occupying the $0g_{9/2}$ orbit, couple to the maximum possible spin of $I = 16$. Shell-model (SM) calculations suggest that this 16^+ state lies below the 12^+ and 14^+ levels so that a γ decay would have to proceed via an $E6$ transition to the 10^+ state. Instead, β decay to the 15^+ isomeric state in ^{96}Ag as well as β-delayed proton emission populating high-spin states in ^{95}Pd have been observed [4,5].

In ^{128}Cd, containing two neutron holes and two proton holes with respect to ^{132}Sn, the observation of a 10^+ isomer ($T_{1/2} = 3.56(6)$ μs) at an excitation energy of 2.714 MeV was reported in Ref. [6] and assigned to have a predominant $0h^{-2}_{11/2}$ neutron character. SM calculations predict in addition the existence of a spin-gap isomer based on the fully aligned $\pi(0g^{-2}_{9/2})\nu(0h^{-2}_{11/2})$ configuration with a spin of 18^+, in analogy to the 16^+ isomer in ^{96}Cd. Furthermore, the recent identification of a $(21/2^+)$ γ-decaying ms isomer in the neighbouring nucleus ^{129}Cd with a dominant $\pi(0g^{-1}_{9/2}(1p,0f_{5/2})^{-1})\ \nu(0h^{-1}_{11/2})$ configuration [7] may suggest the existence of an analogous 15^- isomer in the even–even ^{128}Cd built on the $\pi(0g^{-1}_{9/2}(1p,0f_{5/2})^{-1})\ \nu(0h^{-2}_{11/2})$ configuration. It was therefore the aim of the present work to search for additional β- or γ-decaying isomers at higher angular momentum in ^{128}Cd.

The experiment was performed at the Radioactive Isotope Beam Factory (RIBF) of the RIKEN Nishina Center within the EURICA campaign. The neutron-rich ^{128}Cd nuclei were produced following the projectile fission of a 345 MeV/u ^{238}U beam with an average intensity of about 8 pnA, impinging on a 3 mm thick Be target. The ions of interest were separated from other reaction products and identified on an ion-by-ion basis by the BigRIPS in-flight separator [8]. The particle identification was performed using the ΔE-TOF-$B\rho$ method in which the energy loss (ΔE), time of flight (TOF) and magnetic rigidity ($B\rho$) are measured and used to determine the atomic number, Z, and the mass-to-charge ratio, A/q, of the fragments. Details about the identification procedure can be found in Ref. [9]. In total about 6×10^5 ^{128}Cd ions were identified, transported through the ZeroDegree spectrometer (ZDS) and finally implanted into the WAS3ABi (Wide-range Active Silicon Strip Stopper Array for β and ion detection) Si array positioned at the focal plane of the ZDS. The WAS3ABi detector [10,11] consists of eight closely packed DSSSD with an area of 60×40 mm^2, a thickness of 1 mm and a segmentation of 40 horizontal and 60 vertical strips each. All decay events detected in WAS3ABi during the first five seconds following a valid implantation signal were stored and correlated offline in space and time with the implanted ions. To detect γ radiation emitted in the decay of the implanted radioactive nuclei 12 large-volume Ge Cluster detectors [12] from the former EUROBALL spectrometer [13] were arranged in a close geometry around the WAS3ABi detector.

In a first step, spectra of γ rays observed in prompt coincidence with the first decay event after the implantation of a ^{128}Cd ion in WAS3ABi were studied applying different time windows between the implantation and the decay as well as different conditions with respect to the spatial correlation. No new γ transitions were observed besides the ones already known to occur following the decay of the ground state of ^{128}Cd [14]. Furthermore, during the analysis of the time distribution of the decay events with respect to the implantation, both with and without requiring a coincidence with one of the observed γ rays in the daughter nucleus, no indication for the existence of a second β-decaying state besides the ground state ($T_{1/2} = 245(5)$ respectively 246.2(21) ms [15,16]) was obtained. To search for a γ-decaying isomer with a half-life in the ms range we followed the procedure already successfully applied in the identification of a $(21/2^+)$, $T_{1/2} = 3.6(2)$ ms isomer in ^{129}Cd [7]. Fig. 1 shows the spectrum of γ rays detected in the Ge detectors in the time interval of -4 μs $< (t_\gamma - t_{decay}) < 20$ μs with respect to the first decay event after the implantation of a ^{128}Cd ion. Only decay events registered during the first 20 ms after the implantation were considered and furthermore they had to fulfil the condition that energy was deposited exclusively in the Si detector in which the ion was implanted. This condition was shown in Ref. [7] to significantly suppress the β-decay events and enhance those in which the emission of conversion electrons occurs.

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