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First decay study of the new isotope ^{129}Pm near the proton drip line

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Abstract. The very neutron-deficient nuclide ^{129}Pm was produced via the ^{92}Mo(^{40}Ca, p2n) reaction and identified for the first time by using the X-γ coincidence in combination with a He jet tape transport system. According to the decay curve of a 99 keV γ-ray which corresponds to the known $5/2^- \to 1/2^-$ transition in the daughter nucleus ^{129}Nd of the ^{129}Pm decay, the half-life of ^{129}Pm was determined to be 2.4(9) s. Based on the nuclear potential energy surface (PES) calculations, the ground-state spin-parity of ^{129}Pm was predicted as $5/2^-$ which is favorable to feed a $5/2^-$ low-lying state in the daughter nucleus ^{129}Nd via the (EC $+\beta^+$) decay.

PACS. 23.40.Hc Relation with nuclear matrix elements and nuclear structure – 21.10.Hw Spin, parity, and isobaric spin – 24.10.Pa Thermal and statistical models – 27.60.+j $90 \leq A \leq 149$

The extreme neutron-deficient nuclide ^{128}Pm lies on the $Z = 0.743N + 11.6$ proton drip line introduced by Hofmann [1], and has been synthesized and identified to be a β-delayed proton precursor for the first time by our group [2] in 1999. It is also the lightest isotope of promethium which has already been studied. However, ^{129}Pm remains unknown so far. Recently, a detailed in-beam γ study for the daughter nucleus ^{129}Nd has been reported by Zeidan *et al.* [3], which is very helpful for the assignment of the (EC $+\beta^+$) delayed γ transitions of ^{129}Pm.

The experiment described here was carried out at the Sector-Focusing Cyclotron in the Institute of Modern Physics, Lanzhou, China. A 232 MeV ^{40}Ca^{12+} beam from the cyclotron entered a target chamber filled with 1 bar helium, passed through a 1.89 mg/cm^2 thick Havar window, a 6.0 cm thick layer of helium gas and an aluminum degrader, and finally bombarded a ^{92}Mo target (95% enriched) with thickness of 1.97 mg/cm^2. The beam energy at target center could be varied from 164 to 190 MeV. The beam intensity was about 40 particle/nA. The ^{129}Pm nuclei were produced via the p2n evaporation channel. We used a helium jet in combination with a tape transport system to periodically move the radioactivity into a shielded counting room, where the X-γ-t and γ-γ-t coincidence measurements were carried out. $PbCl_2$ was used as aerosol at 430 °C. Normally, the collection time, tape moving time, waiting time, and accumulation time were 4.00, 0.26, 0.04, and 3.96 s, respectively. We used two coaxial HpGe(GMX) detectors for γ-ray and a HpGe planar detector for X-ray spectroscopy. In order to improve the energy resolution for low-energy γ-rays, in some runs a second HpGe planar detector was used instead of one of the two coaxial HpGe(GMX) detectors. The energy and time spectra of γ- and X-rays were taken in single and coincidence modes.

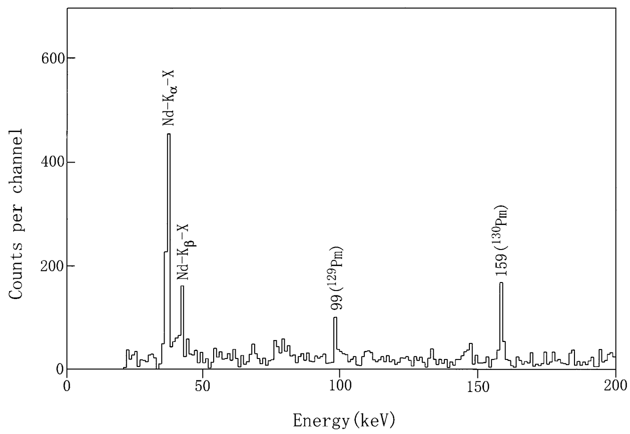

Fig. 1. The measured γ(X)-ray spectrum of the products gated on the Nd-K_α-X ray in the 183 MeV ^{40}Ca $+^{92}$ Mo reaction. The intense peaks are labeled with their energies in keV and their (EC $+\beta^+$) precursor nucleus.

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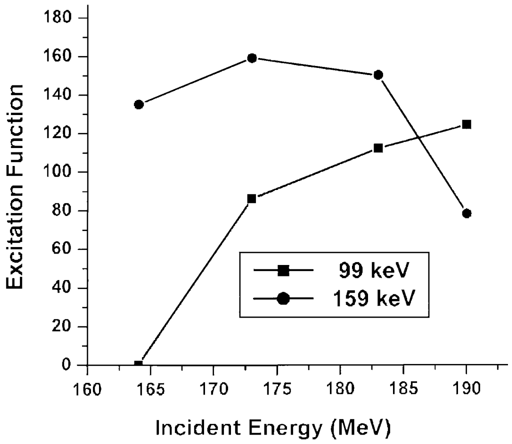

Fig. 2. Excitation functions of the 99 keV and 159 keV γ lines of fig. 1. The uncertainties of all data are about 20%. The data points represent relative intensities of the 99 and 159 keV γ lines. However, the data points of the 99 keV γ line have been multiplied by a factor of 2.5.

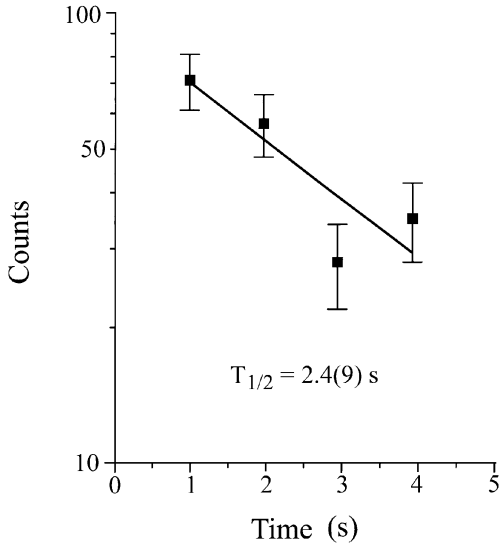

Fig. 3. Decay curve of the 99 keV γ line in coincidence with the Nd-K_α-X ray.

The low-energy γ(X) spectrum of the products gated on the Nd-K_α-X ray in the 183 MeV ^{40}Ca + ^{92}Mo reaction is shown in fig. 1. It is a spectrum measured in one planar detector with a coincidence gate set by another planar detector. The 159 keV γ line with half-life of 2.6 s in fig. 1 is the most intense γ transition in the (EC $+\beta^+$) decay of ^{130}Pm [4]. According to the in-beam γ study for the daughter nucleus ^{129}Nd [3], another intense γ line of 99 keV in fig. 1 was assigned to the $5/2^- \to 1/2^-$ transition in ^{129}Nd via the (EC $+\beta^+$) of ^{129}Pm for the first time. The Nd-K_α-X and Nd-K_β-X rays in fig. 1 stem either from EC decay of Pm or from the internal conversion in the daughter element Nd. The Q_{EC} value of ^{129}Pm was predicted to be 10.2 MeV [5], and then the EC/β^+ ratio of ^{129}Pm was expected to be 2.5%. The internal conversion coefficients of the 99 keV transition in ^{129}Nd and the 159 keV transition in ^{130}Nd were estimated to be 2.0 and 0.5, respectively. In addition, the excitation functions of the 99 keV and 159 keV lines (fig. 2) also support the assignment of the 99 keV transition to the ^{129}Pm decay. The decay curve of the 99 keV γ line gated on Nd-K_α-X is shown in fig. 3, from which the half-life of the ^{129}Pm decay was extracted to be 2.4(9) s.

The following predicted half-lives of ^{129}Pm have been reported in different articles over the last decade, including 1) 1.0 s given by Audi *et al.* [6] based on systematic trends, 2) 0.79 s by Möller *et al.* [5] using the macroscopic-microscopic mass model, 3) 1.57 s by Horiguchi *et al.* [7] using the gross theory, and 4) 3.45 s (Hilf), 3.35 s (Groote), and 2.00 s (Möller) given by Hirsch *et al.* [8] using a microscopic theory. Hilf, Groote and Möller in parentheses are the authors of different mass formulae used in ref. [8]. Our experimental result is near the average value of those predicted half-lives.

Nuclear potential energy surface (PES) calculations were performed using the Woods-Saxon Strutinsky method [9]. A minimum with $\beta_2 = 0.316$ and $\gamma = -0.1°$ was found in the PES for the negative-parity configurations (see fig. 4), which corresponds to the $\pi 5/2^-[532]$ assignment. The calculated result suggests the ground-state spin-parity of ^{129}Pm as $5/2^-$. This is consistent with the prediction given by Möller *et al.* [5]. The predicted $5/2^-$ of the ground-state spin-parity of ^{129}Pm is favorable to feed a $5/2^-$ low-lying state in the daughter nucleus ^{129}Nd via the (EC $+\beta^+$) decay followed by the observed $5/2^- \to 1/2^-$ γ transition of 99 keV.

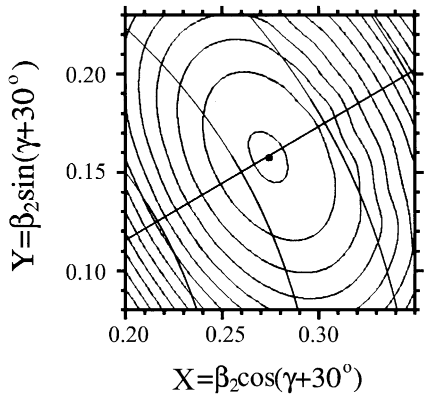

Fig. 4. Calculated potential energy surface of ^{129}Pm for the negative-parity configurations.

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