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(EC + β^+) decay of ^{133}Sm and 1.1 s isomer of ^{133}Pr

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Abstract. The very neutron-deficient isotope ^{133}Sm was produced by irradiation of an enriched target of ^{96}Ru with ^{40}Ca and studied by using a helium-jet fast tape transport system in combination with X-γ and γ-γ coincidence measurements. A simple (EC + β^+) decay scheme of ^{133}Sm was proposed for the first time. As a by-product ^{133}Pr was produced simultaneously because of the $^{98\text{-}102}$Ru content of the ruthenium target. The half-life of a $11/2^-$ low-lying isomeric state in ^{133}Pr was measured to be 1.1 ± 0.2 s.

PACS. 23.40.-s Beta decay; double beta decay; electron and muon capture – 21.10.Tg Lifetimes – 27.60.+j $90 \leq A \leq 149$

^{134}Sm is the lightest neutron-deficient samarium isotope, the (EC + β^+) decay scheme of which has been reported so far. The β-delayed proton decay of ^{133}Sm has been observed, the ground-state spin and parity of ^{133}Sm have been suggested as $5/2^+$ preliminarily by Bogdanov *et al.* [1] and Wilmarth *et al.* [2], and its half-life has been evaluated to be 3.7 ± 0.7 s [3,4]. Two γ-lines of 156.8 keV and 369.6 keV were assigned to the (EC + β^+) decay of ^{133}Sm [4]. However, the (EC + β^+) decay scheme of ^{133}Sm has not been proposed yet. The systematics of $11/2^-$ isomeric states in the odd-A praseodymium isotopes has been summarized by Genevey *et al.* [5]. Supplement of the half-life of $11/2^-$ isomeric state in ^{133}Pr is necessary.

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 2.5 cm thick layer of helium gas, and a 0.3 mg/cm^2 thick aluminum foil used as a target support, and finally bombarded in turn two ^{96}Ru targets (94% enriched) with a thickness of about 1.4 mg/cm^2 each. The targets contained 5.4% of $^{98\text{-}102}$Ru. The two targets were uniformly mounted on a copper wheel surrounded by a cooling device. The target wheel rotated by 180° once every 10 minutes. The beam intensity was about 0.5 eμA. We used a helium-jet in combination with a tape transport system to periodically move the radioactivity into a shielded counting room. The collection time, tape moving time, waiting time, and accumulation time were 1.20, 0.18, 0.02, and 1.18 s, respectively. $PbCl_2$ was used as aerosol at 430°C. Two coaxial HpGe(GMX) detectors were used as γ-ray detectors, and a HpGe planar detector was used for X-ray measurements. In order to improve the energy resolution of low-energy γ-rays, sometimes another HpGe planar detector was used for γ-ray measurements instead of the coaxial HpGe(GMX) detector. Energy and time spectra of γ- and X-rays were taken in single and coincidence modes.

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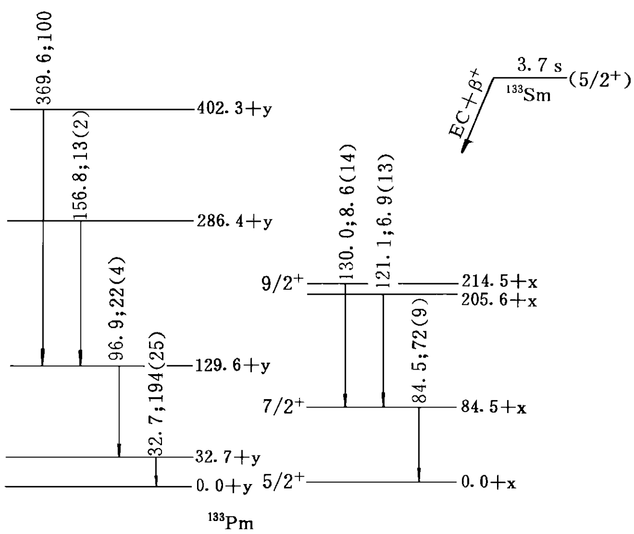

Fig. 1. Proposed decay scheme of ^{133}Sm.

The β-delayed γ-lines related with the (EC + β^+) decays of samarium isotopes were selected by the X-γ coincidence measurements. Among them an intense 369.6 keV γ-line with the half-life of 3.4 ± 0.5 s and another intense 84.5 keV γ-line with the half-life of 2.8 ± 0.5 s were assigned to ^{133}Sm decay. According to the γ-γ coincidence relationships, including the two γ-lines of 156.8 keV and

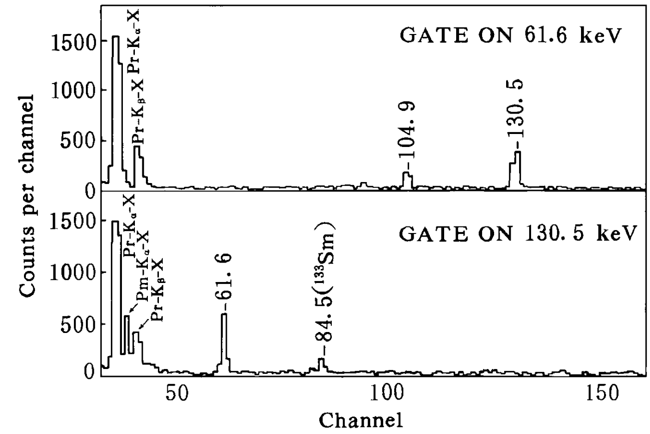

Fig. 2. Observed γ(X)-γ(X) coincidence spectrum from the decay of $11/2^-$ isomeric state in ^{133}Pr.

369.6 keV suggested by Breitenbach in ^{133}Sm decay [4], a simple (EC + β^+) decay scheme of ^{133}Sm was proposed in fig. 1. The uncertainties of the energies of the γ-transitions in fig. 1 are ± 0.5 keV. The relative intensities of the γ-lines in fig. 1 are mainly based on the γ-single measurements, and the corrections of conversion electron for the γ-transitions were not taken into account. The assignments of the spins and parities for the low-lying states in ^{133}Pm on the right side of fig. 1 were taken from an in-beam γ study of ^{133}Pm [6]. Based on the systematics shown in fig. 3 of ref. [4], the low-lying states in ^{133}Pm on the left side of fig. 1 are possibly related to the decoupled $h_{11/2}$ band structure with negative parity.

The low-lying $11/2^-$ isomeric state in ^{133}Pr was reported to de-excite through a cascade of 130.5 and 61.7 keV transitions to the ground state [7]. In the Pr-K_α X coincident γ-spectrum, we observed the two γ-lines of 61.6 keV and 130.5 keV which were in coincidence with each other (fig. 2). This coincidence relationships is consistent with the level scheme of ^{133}Pr, shown in fig. 3, and the decay scheme of ^{133}Sm, displayed in fig. 1. From the time spectra of the 130.5 keV γ-ray gated on the Pr-K_α X-ray and the 61.6 keV γ-ray gated on the 130.5 keV γ-ray (see inset of fig. 3), the half-life of the $11/2^-$ isomeric state with the excitation energy of 192.1 keV in ^{133}Pr was extracted to be 1.1 ± 0.2 s. The systematics of $11/2^-$ isomeric states and related $3/2^+$, $5/2^+$, and $7/2^+$ states in the odd-A praseodymium isotopes are shown in fig. 3. With the energy of the γ-ray between the $11/2^-$ isomeric state and the lowest-lying $5/2^+$ state increasing, the half-life of the $11/2^-$ isomeric state decreases regularly with increasing mass number of these isotopes.

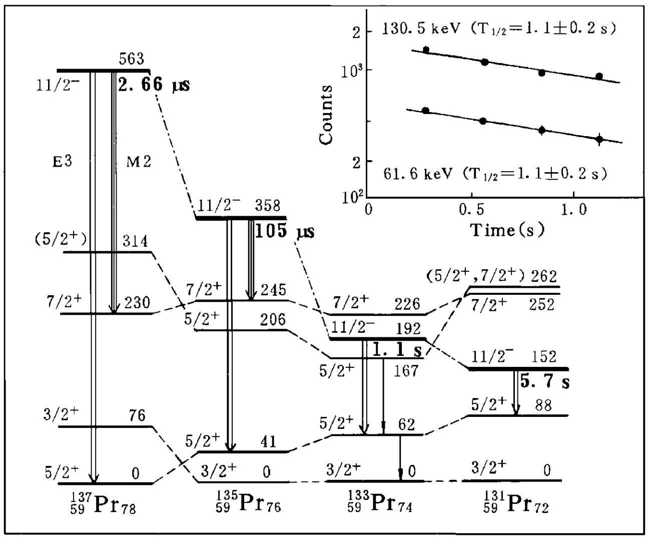

Fig. 3. Systematics of $11/2^-$ isomeric states and related $3/2^+$, $5/2^+$, and $7/2^+$ states in the odd-A praseodymium isotopes. The half-life of the $11/2^-$ isomeric state in ^{133}Pr is from the present work. Other informations except the inset are from ref. [5] and references therein. The observed time spectra of the 130.5 keV γ-ray gated on the Pr-K_α X-ray and of the 61.6 keV γ-ray gated on the 130.5 keV γ-ray are shown in the inset.

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