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Short note

New nuclide ^{139}Tb and (EC+ β^+) decay of ^{138,139}Gd

Xie Yuanxiang, Xu Shuwei, Li Zhankui, Yu Yong, Pan Qiangyan, Wang Chunfang, Zhang Tianmei

Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, P.R. China

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Abstract. The unknown isotope ^{139}Tb and the known isotopes ^{138,139}Gd were produced in the ^{36}Ar+^{106}Cd reaction and studied by using a He-jet tape transport system in combination with X-γ and γ-γ coincidence measurements. The half-lives of ^{139}Tb, ^{139g}Gd, ^{139m}Gd and ^{138}Gd were determined to be 1.6(2), 5.8(9), 4.8(9) and 4.7(9) s, respectively. Partial (EC+β^+) decay schemes of ^{139g}Gd, ^{139m}Gd and ^{138}Gd were proposed for the first time.

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

The unknown isotope ^{139}Tb is located very close to the proton-drip line, its one-proton separation energy being predicted to be negative [1, 2].Search for ^{139}Tb will be helpful for further investigation of the proton radioactivity in the rare-earth region. A detailed in-beam γ study of ^{138}Gd was published in 1994 [3], but the decay properties of ^{138}Gd have not been studied so far. The β-delayed proton decay of ^{139}Gd with a half-life of 4.9(10) s was investigated by Nitschke et al. in 1983 [4]. However, the (EC+β^+) decay scheme of ^{139} Gd has not been reported yet. Study of (EC+β^+) decay of ^{138,139}Gd will provide the nuclear-structure information of the low-lying states in their daughter nuclei near the proton-drip line.

The experiment was carried out at the SFC cyclotron of HIRFL (Heavy Ion Research Facility in Lanzhou), Lanzhou, China. A 220-MeV ^{36}Ar^{11+} beam from the cyclotron entered a helium-filled target chamber through a 1.94mg/cm^2 thick Havar window and an energy degrader,and finally bombarded a 2.5 mg/cm^2 thick enriched ^{106}Cd (enrichment 75%) foil surrounded by a water-cooling device. The beam intensity was about 0.3 eμA. We used a helium-jet in combination with a tape transport system to move the radioactivities into a shielded counting room. PbCl$_2$ as aerosol at 430^{o}C was added to the helium gas. Beta-delayed γ rays from the reaction products were measured up to 2.0 MeV by using two coaxial HpGe(GMX) detectors. A HpGe planar detector was used for X-ray measurements. The γ-γ-t or X-γ-t coincidence events were collected event-by-event on magnetic tape.

^{139}**Tb**: In the γ spectrum gated by Gd-K$_\alpha$ X rays (Fig. 1) two new γ rays with the energies of 109.0- and 119.7-keV were observed. Comparing the excitation functions of the two γ rays with that of the 328.4-keV γ ray (Fig. 2), the most intense γ ray of ^{140}Tb [5], we assigned the 109.0- and 119.7-keV γ rays to the decay of ^{139}Tb. These two γ rays are not among the γ transitions between the high-spin states in ^{139}Gd reported from in-beam measurements [6]. This fact is not surprising since the ground-state spin-parity of ^{139}Tb was predicted to be $3/2^+$ by Möller et al. [1] and β decay populates only low-spin state in ^{139}Gd. However, the fact seems to be not consistent with the $11/2^-$ assignment of the ground-state spin-parity of ^{139}Tb estimated from systematic trends by Audi et al. [2]. From the time spectra of these two γrays (Fig. 3), the half-life of ^{139}Tb was determined to be 1.6(2) s, which is consistent with the predictions by the gross theory [7] (1.6 s) or microscopic theory [8] (1.5 s (Hilf), 1.7 s (Groote) and 1.2 s (Möller)), where Hilf, Groote, and Möller stand for different mass formula used in the theoretical predictions.

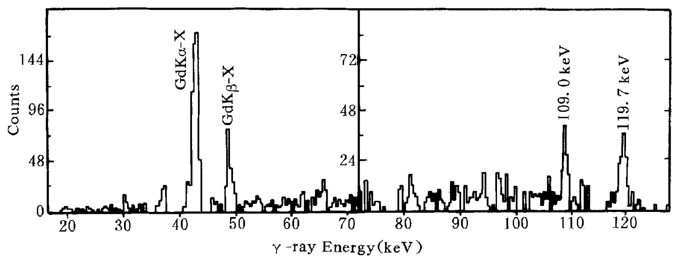

Fig. 1. Low-energy part of the γ spectrum gated by Gd-K$_\alpha$ X rays in the ^{36}Ar + ^{106}Cd reaction

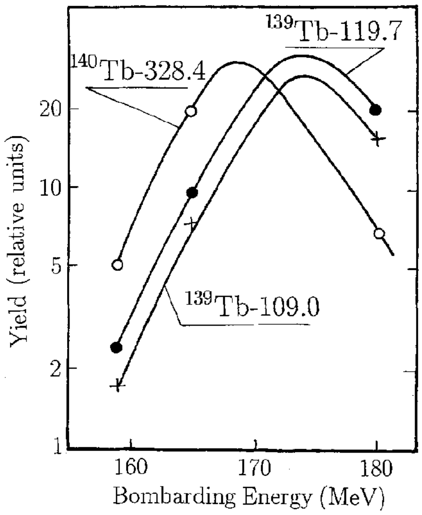

Fig. 2. Excitation functions of the 109.0- and 119.7-keV rays in the ^{36}Ar + ^{106}Cd reaction

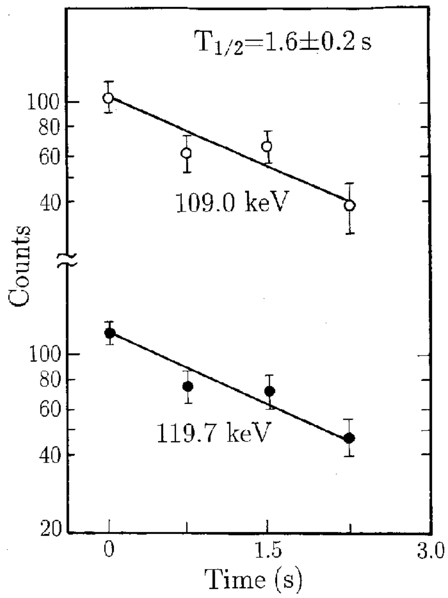

Fig. 3. Time spectra of the 109.0- and 119.7-keV rays in the ^{36}Ar + ^{106}Cd reaction

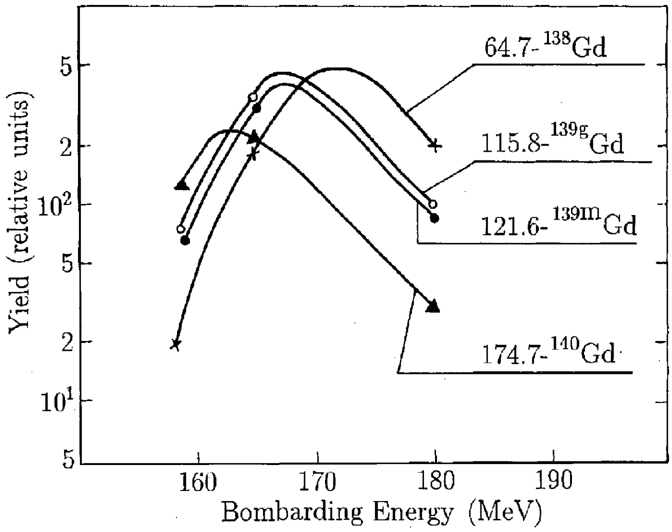

Fig. 4. Excitation functions of the four intense γ rays in the γ spectrum gated by Eu-K$_\alpha$ X rays in the ^{36}Ar + ^{106}Cd reaction

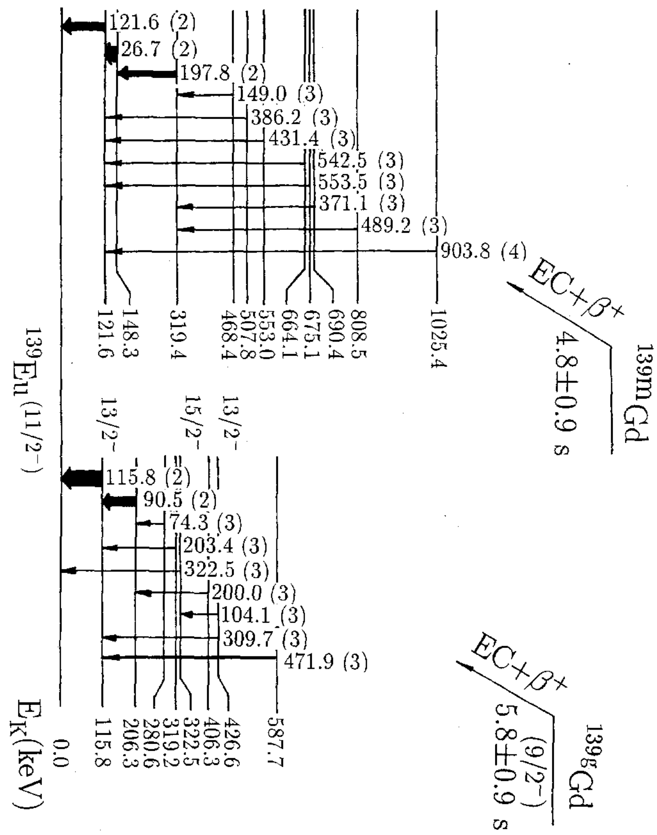

Fig. 5. Proposed (EC+β^+) decay schemes of ^{139g}Gd and ^{139m}Gd

^{139,138}**Gd**: In the γ spectrum gated by Eu-K$_\alpha$ X rays at least four groups of γ rays were observed. One group with an intense 174.7-keV γ ray was assigned to the decay of ^{140}Gd, which is already known [9]. Another group with an intense 115.8-keV γ ray as well as 104.1-, 309.7- and 322.5-keV γ transitions was assigned to the decay of the ground state of ^{139}Gd (^{139g}Gd), based on the in-beam γ study of ^{139}Eu [10]. According to the excitation functions shown in Fig. 4, the remaining two groups with intense 121.6- and 64.7-keV γ rays were assigned to the decays of a low-spin isomeric state of ^{139}Gd (^{139m}Gd) and ^{138}Gd, respectively. The partial (EC+β^+) decay schemes of ^{139g}Gd and ^{139m}Gd, including 16 new low-lying states in the daughter nucleus ^{139}Eu, are shown in Fig. 5. The half-lives of ^{139g}Gd (5.8(9) s) and ^{139m}Gd (4.8(9) s) agree with the previous result of 4.9(10) s extracted from the β-delayed proton decay of ^{139}Gd by Nitschke et al. [4]. Furthermore, the measured half-life of ^{139g}Gd is in good agreement with the value of 5.9 s calculated by using the macroscopic-microscopic mass model of Möller et al. [1]. A partial (EC+β^+) decay scheme of ^{138}Gd, including 7 new

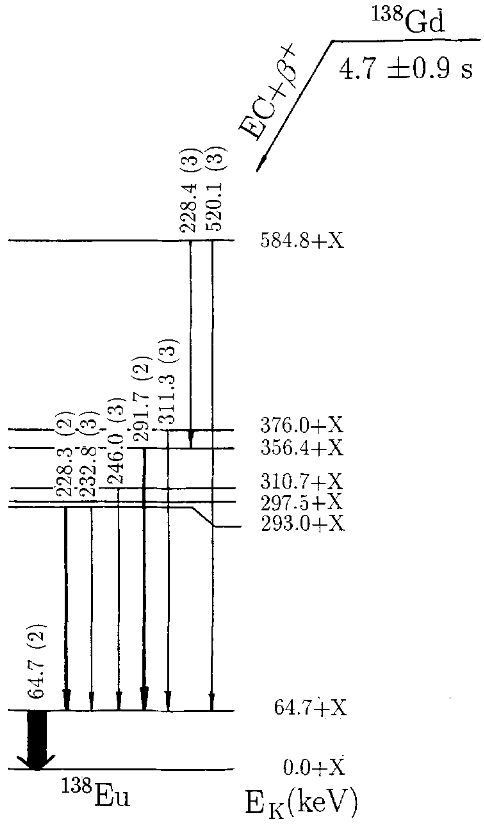

Fig. 6. Proposed (EC+β^+) decay scheme of ^{138}Gd

low-lying states in the daughter nucleus ^{138}Eu, is shown in Fig. 6. The measured half-life of ^{138}Gd decay (4.7(9) s) is in good agreement with the predictions by the gross theory [6] (4.9 s) or the macroscopic-microscopic model of Möller et al. [1] (4.2 s). The half-lives for ^{139}Tb, ^{139g}Gd, ^{139m}Gd, and ^{138}Gd are important results in the experiment, and compared with different theoretical predictions or previous result. Since the Beta-decay half-life is a gross property, the agreement between theory and experiment does not necessarily mean that the theoretical calculations of Q_{EC} value and beta-strength distribution are correct.

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