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Six New Nuclides Near the Proton-drip Line in the Rare-earth Region*

Xu Shuwei[1] Li Zhankui[1] Xie Yuanxiang[1] Pan Qiangyan[1] Yu Yong[1] J.Adam[2] Wang Chunfang[1] Xing Jianping[1] Hu Qingyuan[1] Li Shihong[1] Chen Hongyan[1] Zhang Tianmei[1] Jin Genming[1] Luo Yixiao[1] Yu. Penionzhkevich[2] Yu.Gangrsky[2]

1 (*Institute of Modern Physics, The Chinese Academy of Science, Lanzhou* 730000)

2 (*Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia*)

Abstract Unknown isotopes ^{125}Nd, ^{128}Pm, ^{129}Sm, ^{137}Gd[1)], ^{139}Dy and ^{139}Tb were produced using enriched targets ^{92}Mo, ^{96}Ru and ^{106}Cd, respectively, bombarded by ^{36}Ar ion beam with the energies of 165—180MeV from the SFC cyclotron of HIRFL. The six new nuclides were separated and identified by a He-jet combined with a fast-tape transport system as well as "p-γ" and "X-γ" coincidence measurements. Their half-lives were determined to be (0.60 ± 0.15)s, (1.0 ± 0.3)s, (0.55 ± 0.10)s, (2.2 ± 0.2)s, (0.6 ± 0.2)s and (1.6 ± 0.2)s, respectively. Energy spectra of β-delayed protons from ^{125}Nd, ^{128}Pm, ^{129}Sm, ^{137}Gd and ^{139}Dy decay were measured. Two γ-rays with the energies of 109.0 keV and 119.7 keV were assigned to EC/β^+ decay of ^{139}Tb.

Key words new nuclide, proton-drip line, β-delayed proton precursor

A straight line $Z=0.743N+11.6$ in the chart of nuclides was suggested by Hofmann[2] to speculate the most neutron-rich candidates of proton radioactivity between ^{109}I and ^{142}Re. The synthesis of the new nuclides along the Hofmann line, in particular ^{128}Pm, ^{132}Eu, ^{138}Tb and ^{142}Ho, etc., the study of their exotic decay, mainly proton radioactivity, and then the experimental determination of the exact location of the proton-drip line in this region, were deeply concerned by many nuclear physicists[3—5]

In the decay of an even (Z)-odd (N) β-delayed proton precursor most of the excited-state decays of the even $(Z-2)$-even $(N+1)$ daughters of each odd $(Z-1)$-even $(N+1)$ proton emitter have finally resulted in the transition between the lowest-energy 2^+ state and the 0^+ ground state. Therefore, the $2^+\rightarrow0^+$ γ-ray transition specific for a particular daughter nucleus in coincidence with β-delayed protons, as we called "p-γ" coincidence, can be used to identify its mother, the β-delayed proton precursor, instead of using an ISOL. Similar method can also be used to identify some of the odd (Z)-odd(N) precursors. We proposed and employed the "p-γ" coincidence method in combination with a He-jet tape transport system (HJTTS), and successfully increased the sensitivity of

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1) A Doubtful Experimental Result of ^{137}Gd Decay Was Reported in 1983[1]

measuring β-delayed protons by a factor of about 50[6] in comparison with that of the ISOL + "X-p" coincidence method. Two new β-delayed proton precursors ^{135}Gd and ^{121}Ce were then synthesized and identified with a ^{32}S beam in our previous experiments[6—8]. In this work, six new isotopes along the Hofmann line, including ^{128}Pm, were produced by ^{36}Ar ion induced reactions and identified using the HJTTS + "p-γ" (or "X-γ") coincidence method.

The experiments were carried out at the HIRFL of National Laboratory of Heavy-ion Accelerator in Lanzhou (NLHIAL). A 220MeV ^{36}Ar beam from the SFC cyclotron of HIRFL entered a target chamber filled with 0.1MPa helium, passing through a 1.94mg/cm^2 Havar window and a degrader before bombarding different targets with the thickness of 2—3 mg/cm^2: ^{92}Mo (enriched 97%), ^{96}Ru (enriched 94%) and ^{106}Cd (enriched 75%). The beam intensity was about 0.5 eμA. $PbCl_2$ was used as aerosol, with working temperature about 430℃. The reaction products stopped in the helium gas were transported through a 6m, ϕ2mm capillary to the movable tape in a collection chamber. The radioactivity attached on the tape was transported periodically to a shielded location for p-γ(X)-t or X(γ)-γ(X)-t coincidence measurements. Two 350μm thick totally depleted silicon surface barrier detectors were used for proton measurements, two coaxial HpGe (GMX) detectors for γ (X) measurements and a planar HpGe(GLP) detector for X(γ) measurements. The experimental details have been reported in our previous papers[6—8].

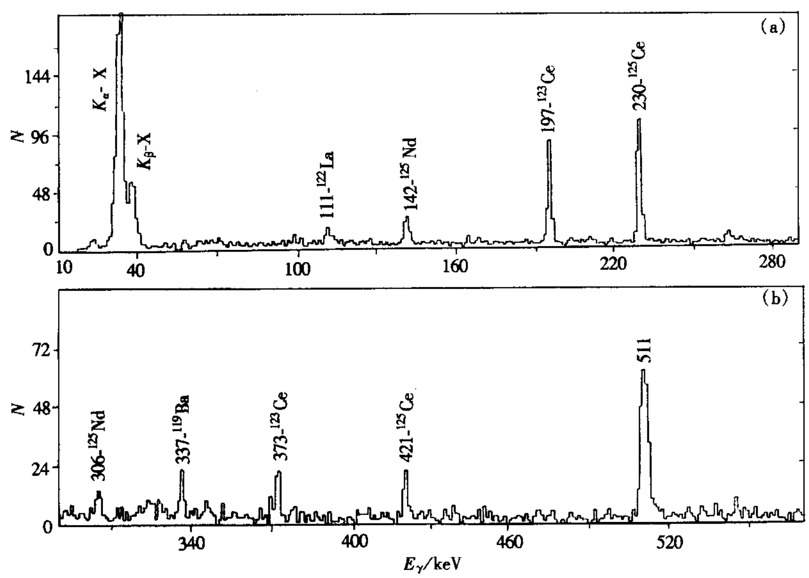

Fig.1. (a),(b) The γ(X)-ray spectrum measured with the GMX detector and gated on 2.5 to 5.5 MeV protons in the reaction ^{36}Ar+^{92}Mo.

The γ (X)-ray spectrum measured with the GMX detector and gated on 2.5 to 5.5 MeV protons in the reaction ^{36}Ar + ^{92}Mo is shown in Fig.1 (a, b). All strong γ lines in Fig.1 were assigned to their β-delayed proton precursors except X-ray and 511keV γ-ray. Among them, the 142 and 306keV γ lines were assigned to $2^+ \to 0^+$ and $4^+ \to 2^+$ γ-ray transitions in the daughter ^{124}Ce[9] of the new β-delayed proton precursor ^{125}Nd. The decay curve of 142keV γ line in the p-γ coincidence spectrum is shown in Fig.2, from which the half-life of the new nuclide ^{125}Nd was extracted to be (0.60 ± 0.15)s.

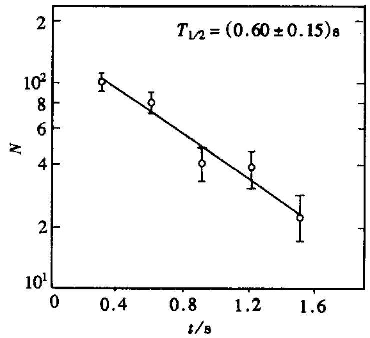

Fig.2. The decay curve of 142keV γ line in the p-γ coincidence spectrum.

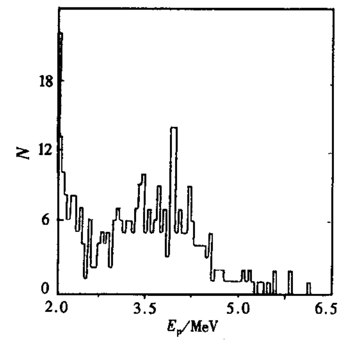

Fig.3. The proton energy spectrum gated on the 142keV γ line.

The proton energy spectrum gated on the 142keV γ line is shown in Fig.3, which is the spectrum of β-delayed protons from ^{125}Nd decay followed by the 142keV transition in ^{124}Ce. The component with the energies lower than 2 MeV in the spectrum is attributed to the pile-up of positrons in the silicon detector.

The other four β-delayed proton precursors ^{128}Pm, ^{129}Sm, ^{137}Gd and ^{139}Dy were synthesized and identified for the first time by means of the above method. Their half-lives and β-delayed protons were also measured. In 1983 the half-life and the energy spectrum of the β-delayed protons of ^{137}Gd were measured by Nitschke[10] et al., who, however, pointed out that the experimental half-life (7 ± 3)s had to be redetermined in a later experiment. The measured half-life of ^{137}Gd in our experiment is (2.2 ± 0.2)s, which is in good agreement with the theoretical prediction (see table 1) and the experimental-value systematics, but quite different from the Nitschke's result within the experimental errors. We guess that the energy spectrum of β-delayed protons observed by Nitschke is mixed with a long-life component from another proton emitter.

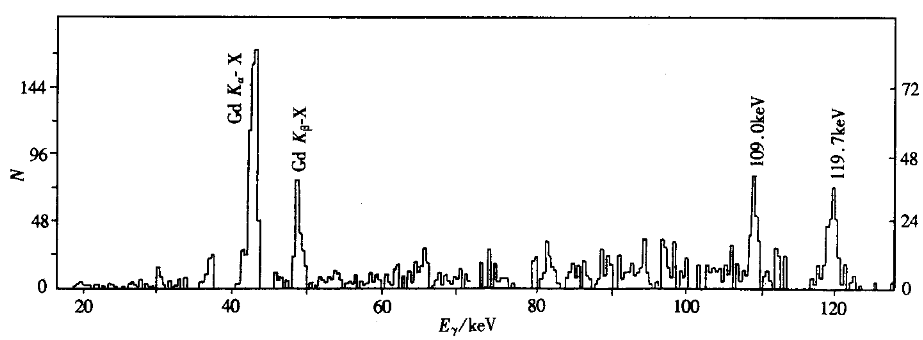

Fig.4. The low energy part of the γ(X)-spectrum gated on Gd-$K\alpha$-X ray in the reaction ^{36}Ar+^{106}Cd.

The X-γ coincidence spectra of short-life products in the reaction ^{36}Ar + ^{106}Cd were observed by X(γ)-γ(X)-t coincidence measurements. Two unknown γ lines with the energies of 109.0 and 119.6keV were found in the low-energy region of the γ-spectrum gated on Gd-$K\alpha$-X ray (Fig.4). The two γ-ray transitions were assigned to the EC/β^+ decay of ^{139}Tb, based on the measured excitation function (Fig.5) in comparison with that of the known 328.4keV γ-line of ^{140}Tb decay. In addition, from the decay curves of the two γ lines (Fig.6), the half-life of ^{139}Tb decay was extracted to be (1.6 ± 0.2)s.

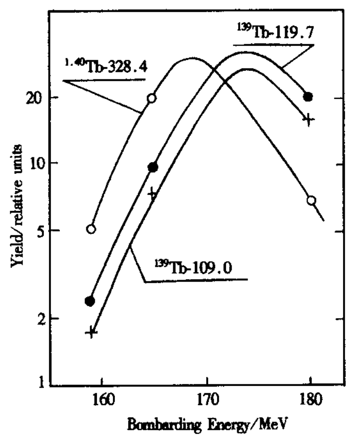

Fig.5. The measured excitation functions for the 109.0, 119.6 and 328.4keV γ lines.

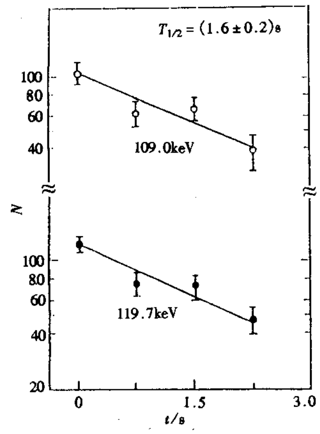

Fig.6. The decay curves of the 109.0 and 119.6keV γ lines.

The six new nuclides, their half-lives, including the experimental values and theoretical predictions, and the reaction channels used are summarized in Table 1.

Table 1. Summary of the experimental results.

New nuclide	Reaction channel	Bombarding energy (MeV)	Exp. half-life (s)	Theoretical prediction of half-life (s)			
				Gross theory[10]	Microscopic theory[11]		
					Hilf	Groote	Moeller
^{125}Nd	^{36}Ar+^{92}Mo	169	0.60±0.15	0.67	0.79	0.78	0.58
^{128}Pm	^{36}Ar+^{96}Ru	174	1.0±0.3	0.71	1.8	2.5	1.5
^{129}Sm	^{36}Ar+^{96}Ru	165	0.55±0.1	0.58	0.33	0.62	
^{137}Gd	^{36}Ar+^{106}Cd	176	2.2±0.2	2.0[1]			
^{139}Dy	^{36}Ar+^{106}Cd	176	0.6±0.2	0.61	0.57	0.65	0.47
^{139}Tb	^{36}Ar+^{106}Cd	180	1.6±0.2	1.6	1.5	1.7	1.2

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合成和研究稀土区质子滴线附近的 6 种新核素 *

徐树威[1]　李占奎[1]　谢元祥[1]　潘强岩[1]　于　涌[1]　J. Adam[2]
王春芳[1]　邢建萍[1]　胡青元[1]　李世洪[1]　陈红艳[1]　张天梅[1]
靳根明[1]　罗亦孝[1]　Yu. Penionzhkevich[2]　Yu. Gangrsky[2]

1(中国科学院近代物理研究所　兰州　730000)
2(Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia)

摘要　利用兰州重离子加速装置(HIRFL)的SFC加速器引出的能量为165—180MeV 的^{36}Ar重离子束,分别轰击^{92}Mo、^{96}Ru和^{106}Cd缺中子同位素靶,产生了稀土区质子滴线附近的新核素^{125}Nd、^{128}Pm、^{129}Sm、^{137}Gd[1)]、^{139}Dy和^{139}Tb. 借助高灵敏度的氦喷嘴快速带传输系统和"p-γ"或"X-γ"符合测量方法对它们进行了分离鉴别,确定它们的半衰期分别为(0.60 ± 0.15)s, (1.0 ± 0.3)s, (0.55 ± 0.10)s, (2.2 ± 0.2)s, (0.6 ± 0.2)s和(1.6 ± 0.2)s, 并测量了^{125}Nd、^{128}Pm、^{129}Sm、^{137}Gd和^{139}Dy的β延发质子能谱, 指认了能量为109.0 和 119.7keV 的两条γ射线属于^{139}Tb 的 EC/β$^+$衰变.

关键词　新核素　质子滴线　β延发质子先驱核

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1) 有关^{137}Gd的衰变,前人[1]曾报道过一次有待确认的实验结果