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Short note

(EC+β^+) decay of ^{130}Nd and ^{140}Tb

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Abstract. ^{130}Nd and ^{140}Tb were produced by irradiation of ^{96}Ru and ^{106}Cd with ^{36}Ar. The two nuclides were identified and studied by using a He-jet fast tape transport system in combination with X-γ and γ-γ coincidence measurements. The half-life of ^{130}Nd was determined to be 13 ± 3 s. The (EC+β^+) decay scheme of ^{130}Nd was proposed for the first time, and the spins and parities of the ground state and observed low-lying states in the daughter nucleus ^{130}Pr were tentatively assigned. The previous (EC+β^+) decay scheme of ^{140}Tb was revised, and the spin and parity of its ground state were assigned to be 7^+.

PACS. 23.40.-s β decay; double β decay; electron and muon capture – 23.20.Lv Gamma transitions and level energies – 21.60.Cs Shell model

The half-life of the EC/β^+decay of ^{130}Nd was reported as 28 ± 3 s by Bogdanov *et al.* [1] in 1977, which is the only information about the decay of ^{130}Nd known so far. According to the mass predictions made by Audi *et al.* [2], ^{140}Tb is the lightest bound isotope of terbium and very close to the proton-drip line in nuclear chart. The EC/β^+ decay of ^{140}Tb was previously studied by Firestone *et al.* [3] in 1991, including the half-life of 2.4 s and two decay γ lines. In addition, the ground-state spin and parity of ^{140}Tb were tentatively assigned as 5^+ [3]. The in-beam γ study of ^{140}Gd was published by Paul *et al.* in 1989 [4].

The experiment described here was carried out at the SFC accelerator of IMP, Lanzhou, China. A 220 MeV ^{36}Ar^{11+} beam from the cyclotron entered a target chamber filled with 1 atm. helium, passing through a 1.94 mg/cm^2 thick Havar window and a degrader, and finally bombarded a 2.8 mg/cm^2 thick ^{96}Ru target (94% enriched) with a 0.3 mg/cm^2 aluminum backing to produce ^{130}Nd, or bombarded a self-supported 2.5 mg/cm^2 thick ^{106}Cd target (75% enriched) to produce ^{140}Tb. The beam intensity was about 0.5 eμA. We used a He-jet in combination with a tape-transport system to move the radioactivity into a shielded counting room. $PbCl_2$ was used as aerosol at 430 °C. The 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 tapes.

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^{130}Nd: Besides the intense γ lines in the decay of ^{129}Nd [5], four other intense γ lines of 92.2, 120.3, 121.5, and 140.5 keV were found in the γ spectrum gated on Pr-K_α X-rays in the ^{36}Ar + ^{96}Ru reaction. Comparing the excitation functions of the four γ lines with that of the 91.1 keV γ line, an intense γ line in the decay of ^{129}Nd (fig. 1), we assigned the four γ lines to the decay of ^{130}Nd. From the time spectra of the four intense γ lines (fig. 2), the weighted average half-live of ^{130}Nd was determined to be 13 ± 3 s which, however, is different from the result

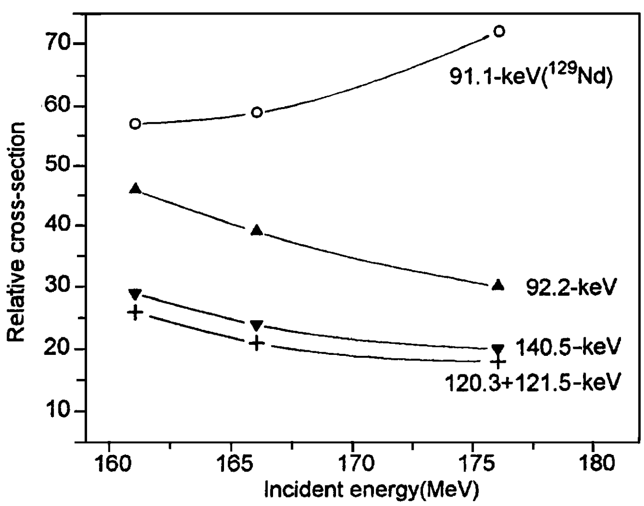

Fig. 1. Excitation functions of the intense γ-rays in the decay of ^{130}Nd.

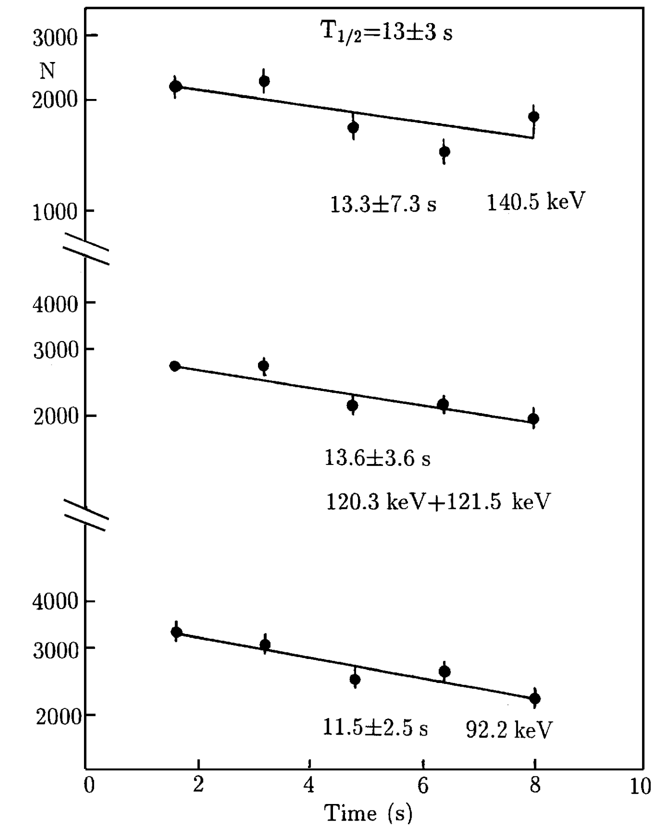

Fig. 2. Half-lives of four intense γ-rays in the decay of ^{130}Nd.

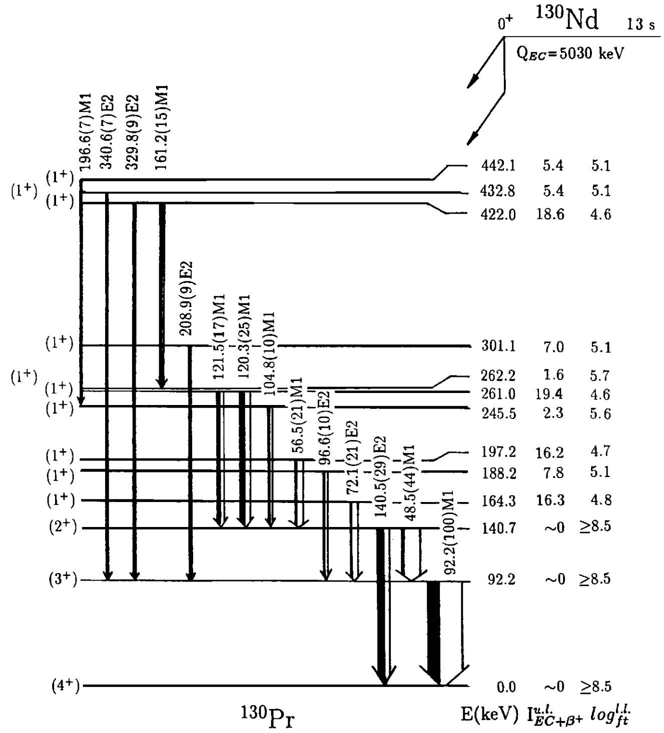

Fig. 3. Proposed decay scheme of ^{130}Nd: the intensity of each transition includes the correction of internal conversion electron.

28 ± 3 s given by Bogdanov *et al.* [1] within the experimental errors. The observed weak γ lines of ^{130}Nd were assigned by the coincidence measurements with the Pr-K_α X-rays and with already assigned intense γ-rays of ^{130}Nd. The observed γ-ray intensities mainly from γ-singles measurements as well as the γ-γ coincidence relations in ^{130}Nd decay are listed in table 1, which leads us to suggest the decay scheme shown in fig. 3. The Q_{EC} value in fig. 3 is a systematic prediction made by Audi *et al.* [2]. From the decay scheme of ^{130}Nd, we try to deduce some nuclear-structure information related to the low-spin states in the daughter nucleus ^{130}Pr, which is unable to be provided with in-beam measurements. The ground-state spins and parities of ^{131}Pr and ^{129}Ce were reported as $3/2^+$ [6] and $5/2^+$ [7], respectively. In addition, two lowest-energy excited states with the spins and parities of $1/2^+$ and $3/2^+$ in ^{129}Ce were also found [7]. Therefore, we assumed the ground-state spin and parity of ^{130}Pr to be 4^+, and the spins and parities of its two low-lying, 92.2 and 140.7 keV states to be 3^+ and 2^+, respectively. Based on the selection rule of β-allowed transition, all allowed β-transitions from the 0^+ ground state of the even-even ^{130}Nd must feed 1^+ states in ^{130}Pr. The rest of low-lying states of ^{130}Pr in fig. 3 were then assumed to be 1^+states. Finally, the multipolarities of all γ transitions were proposed and the contribution from internal conversion electron for each transition between the low-lying states in ^{130}Pr was corrected [8]. According to the upper limits of side feeding to each level ($\mathrm{I}^{\mathrm{ul}}_{\mathrm{EC}+\beta^+}$) via (EC+$\beta^+$) decay in fig. 3 the lower limits of the $\log ft$ values ($\log ft^{\mathrm{ll}}$) shown in the right part of fig. 3 were calculated with the table of Gove and Martin [9]. On the one hand, the upper limits of side feeding to the 92.2 and 140.7 keV levels are close to zero. Therefore, the β-transitions feeding to the two levels should be forbidden. On the other hand, the lower limits of the $\log ft$

Table 1. The γ-transitions and their coincidence relationships in the decay of ^{130}Nd.

E^*_γ (keV)	I_γ	Coincident relations
48.5	10(2)	56.5, 92.2, 104.8, 120.3, 121.5, 161.2
56.5	7(2)	48.5, 92.2, 140.5
72.1	7(2)	92.2
92.2	100	48.5, 56.5, 72.1, 96.6, 104.8, 120.3, 121.5, 161.2, 196.6, 208.9, 329.8, 340.6
96.6	9(2)	92.2
104.8	12(2)	48.5, 92.2, 140.5, 196.6
120.3	39(4)	48.5, 92.2, 140.5
121.5	27(3)	48.5, 92.2, 140.5, 161.2
140.5	47(5)	56.5, 104.8, 120.3, 121.5, 161.2
161.2	31(3)	48.5, 92.2, 121.5, 140.5
196.6	16(2)	48.5, 92.2, 104.8, 140.5
208.9	21(2)	92.2
329.8	23(2)	92.2
340.6	19(2)	92.2

(*) Energy uncertainty is ± 0.2 keV.

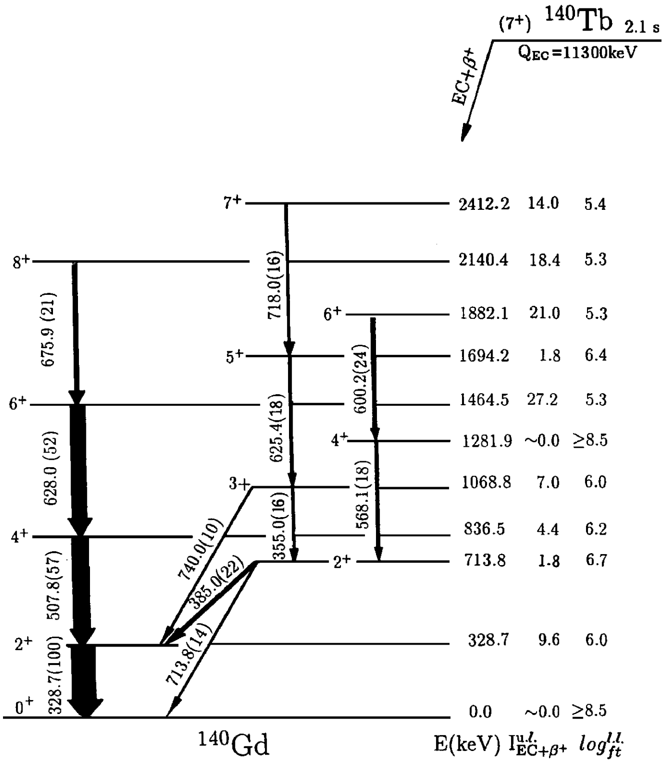

Fig. 4. Proposed decay scheme of ^{140}Tb.

values for the rest of low-lying states of ^{130}Pr in fig. 3 are less than 5.9, most probably the β-transitions populating those states are allowed. It should be noted that these two conclusions are self-consistent with the above spin-parity assumptions of the low-lying states of ^{130}Pr in fig. 3. In other words, the spin-parity speculations are reasonable. However, the apparent β intensities and $\log ft$ values in fig. 3 almost certainly change once complete spectroscopy data will become available, the spin-parity speculations should be further tested in a later experiment.

^{140}**Tb**: The observed γ lines of ^{140}Tb were assigned by the coincidence measurements with Gd-K_α X-rays in the $^{36}\mathrm{Ar} + {}^{106}\mathrm{Cd}$ reaction as well as based on the in-beam study of ^{140}Gd [4]. The weighted average half-life of intense γ lines in the decay of ^{140}Tb was determined to be 2.1(4) s, which is consistent with the previous result 2.4 s [3] within the experimental errors. The observed γ-ray intensities and the γ-γ coincidence relations in ^{140}Tb decay are listed in table 2. The proposed (EC+β^+) decay scheme of ^{140}Tb is shown in fig. 4, including the yrast band and a γ-vibrational band with $k = 2^+$ in the low-lying states of ^{140}Gd [10]. The Q_{EC} value in fig. 4 is a systematic prediction made by Audi *et al.* [11]. The lower limits of the $\log ft$ values for the 6^+, 7^+, and 8^+ states of ^{140}Gd in fig. 4 are less than 5.9. According to the empirical rules for spin and parity assignments based on $\log ft$ values [12], the ground-state spin and parity of ^{140}Tb were then assigned to 7^+ rather than the 5^+ assignment by Firestone *et al.* [3]. Our assignment as predicted by Möller and Firestone [13] is composed of a $\nu 9/2^-$ and a $\pi 5/2^-$ quasi-particle with quadrupole deformation $\varepsilon_2 = 0.208$.

Table 2. The γ-transitions and their coincidence relationships in the decay of ^{140}Tb.

E^*_γ (keV)	I_γ	Coincident relations
328.7	100	355.0, 385.0, 507.8, 568.1, 600.2, 625.4, 628.0, 675.9, 718.0, 740.0
355.0	16(6)	328.7, 385.0, 625.4, 713.8,
385.0	22(5)	328.7, 355.0, 568.1, 600.2 625.4, 718.0
507.8	57(13)	328.7, 628.0, 675.9
568.1	18(7)	328.7, 385.0, 600.2, 713.8
600.2	24(10)	328.7, 385.0, 568.1, 713.8
625.4	18(7)	328.7, 355.0, 385.0, 718.0 740.0
628.0	52(9)	328.7, 507.8, 675.9
675.9	21(6)	328.7, 507.8, 628.0
713.8	14(4)	355.0, 568.1, 600.2
718.0	16(6)	328.7, 355.0, 385.0, 625.4
740.0	10(3)	328.7, 625.4

(*) Energy uncertainty is ± 0.2 keV.

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