The Decay of ^{139m}Nd

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A revised level scheme is proposed for ^{139}Pr with the following excited levels: 113.9, 821.9, 828.0, 851.9, 1024.0, 1369.9, 1447.8, 1523.0, 1624.4, 1834.0, 1926.8, 2048.6, 2174.4, 2196.4 and 2292.2 keV. Both γ-ray energies and intensities are given and $\log(ft)$-values for the β decay of ^{139m}Nd are estimated.

The γ ray and conversion electron spectra following the β decay of the 5.5 h isomeric level in ^{139}Nd have previously been measured both with NaI crystals and magnetic spectrometers [1], and with Ge(Li) and Si(Li) detectors [2]. In view of the uncertainties in the level scheme of ^{139}Pr as a result of the large number of γ rays observed, it was thought worthwhile to re-examine this decay with a high-resolution Ge(Li) detector.

The isomeric state in ^{139}Nd was produced through the reaction ^{142}Nd$(\gamma,3n)^{139m}$Nd by irradiating a 10 mg Nd_2O_3 sample enriched to 95% in ^{142}Nd with the Bremsstrahlung of 55 MeV electrons. Following irradiation, the γ rays were detected with a Ge(Li) detector of about 3 cm^3 active volume and recorded in a 4096-channel analyzer. A series of five four-hour singles spectra, each covering the region to 2.8 MeV, was taken, thus permitting discrimination against γ rays of other radioactive nuclei on the basis of half-lives. A portion of the first of these spectra is shown in Fig. 1. The energies were determined with respect to several well-known standard γ rays counted simultaneously in the second spectrum. The relative photo peak efficiency of the detector over the range of γ rays investigated was established using the relative γ-ray intensities of ^{133}Ba, ^{60}Co, ^{22}Na, ^{24}Na, ^{75}Se, ^{228}Th, and ^{168}Tm.

The analysis of these five singles spectra has been made by applying a least squares fitting procedure to the γ-lines. The resultant energies and intensities of the

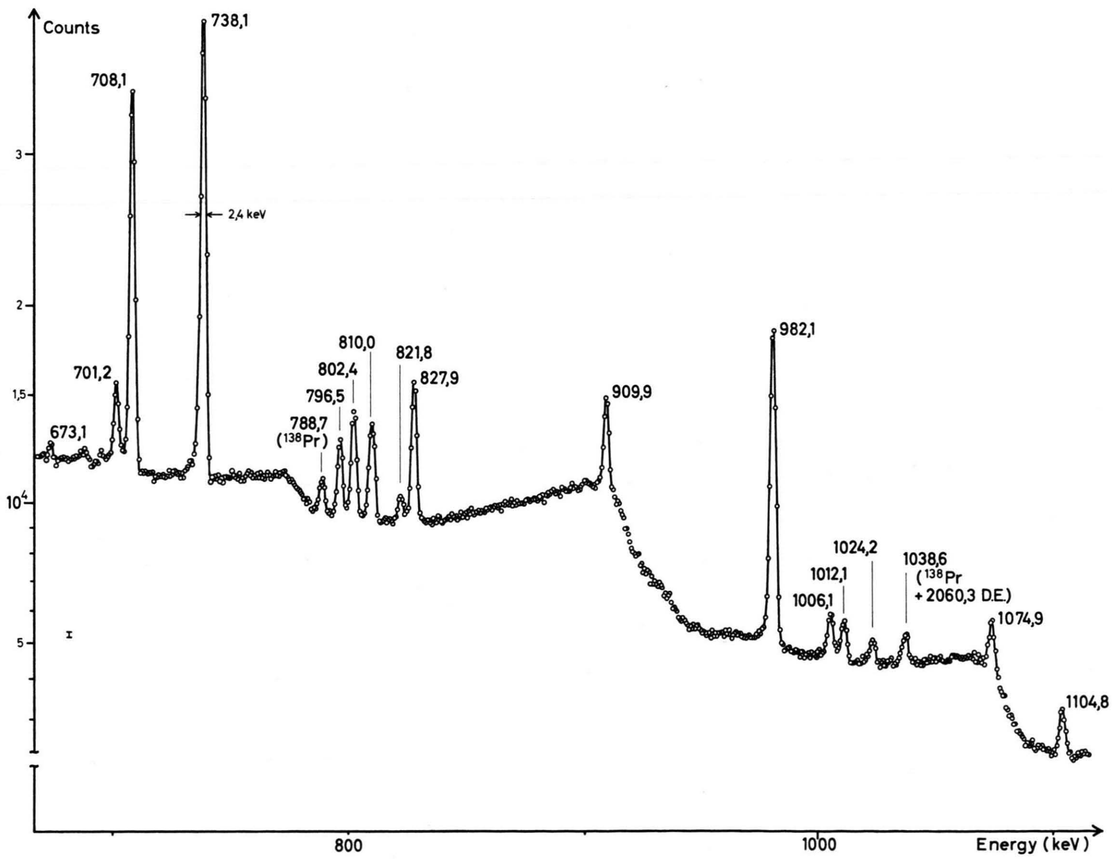

Fig. 1. A portion of the first singles spectrum. The ordinate scale is the square root of the counts/channel, thus the errors appear to be constant (D. E. = double escape peak).

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[2] J. GILAT and W. J. TREYTL, Nucl. Chem. Ann. Rep. **1966**, UCRL 17299, p. 20.

γ rays ascribed to the decay of ^{139m}Nd are presented in Table 1. The competing γ rays of ^{141}Nd and ^{140}Nd could be clearly identified on the basis of their half-lives of 2.5 h and 3.3 d respectively. The decay of ^{139}Pr is known [3]. Here only its two most intense γ rays, 1347 and 1630 keV, were detected, along with the 165.8 keV γ ray of the daughter-nuclide ^{139}Ce. The occurrence in our spectra of the cascade 303 – 1039 – 789 keV (which is fed by 2 h ^{138m}Pr) with a half-life of about 5 h indicates that 5.2 h ^{138}Nd was also produced by the reaction (γ,4n). Practically, the ^{138}Nd γ rays can be distinguished from those of ^{139m}Nd only by coincidence-measurements. (Because the above mentioned γ cascade is fed by a 6^--level [4], we suppose that the 5.2 h activity of even-even ^{138}Nd is emitted from an isomeric (7^- ?) state.)

In addition, γ-γ coincidence spectra were taken, using for the second detector either a 3″ × 3″ NaI crystal or another Ge(Li) detector. Spectra were recorded in coincidence with single γ rays which had in the latter case been selected after analog-to-digital conversion by a digital window. It was possible to measure and store four coincidence spectra at the same time, each within 1024 channels. The coincidence results are summarized in the third column of Table 1.

The revised level scheme for ^{139}Pr which we propose on the basis of these results is shown in Fig. 2. Levels at 113.9, 821.9, 851.9, 1024.0, 1834.0, 1926.8, and 2174.4 keV were previously established by other authors [1, 2]. New levels are proposed at 828.0, 1369.9, 1447.8, 1523.0, 1624.4, 2048.6, 2196.4, and 2292.2 keV, while several levels given in the literature could not be confirmed. Especially the introduction of a level at 828.0 keV, which seems to decay to the ground state only, permits the inclusion of the 796.5, 1006.1, 1220.6, and 1464.0 keV γ rays in the decay scheme without difficulty.

A balance of populating and depopulating γ intensities permits rough evaluation of the relative β feed-in to the levels. Using a singles electron spectrum given by GILAT [2], we estimate that the ratio of conversion electrons in the 113.9 keV transition in ^{139}Pr to those of the 232 keV isomeric transition in ^{139}Nd is about three. This implies that 13.7% of ^{139m}Nd decay to the ground state of ^{139}Nd (by conversion electrons only, since, as it is to be expected from the conversion coefficient [5], no γ rays were seen). The ^{139g}Nd β decay will predominantly feed the ^{139}Pr ground state.

Unfortunately no Q values are known for the β decay of ^{139}Nd. Estimates from β decay systematics, or the $\log(ft)$ systematics for the $3/2^+ \rightarrow 5/2^+$ β decay in neighbouring nuclei yield a Q value of about 2.8 MeV for the transition between the ground states. Using this value, one obtains the estimates for the $\log(ft)$ values given on the right of Fig. 2. Although no definite conclusions can be drawn concerning spins and parities of the levels, the spins problably cover the range 9/2 to 13/2.

E_γ (keV)	Intensities	Coincidences
93.2 ± 0.4	5.4 ± 1.5	A, (B), D, F, H, J
101.6 ± 0.4	1.4 ± 0.8	A, B
113.9 ± 0.2	92 ± 15	A*, B, C, D, E, F, G*, H, J
172.4 ± 0.6		D, F
209.5 ± 0.3	5.2 ± 1.0	A, [B], [C], [E], G, [H]
214.6 ± 0.3	1.6 ± 0.5	A, F, [H], (J)
254.4 ± 0.3	5.2 ± 1.0	A, C
362.2 ± 0.3	7.1 ± 1.5	A, D, J
403.7 ± 0.3	8.6 ± 1.5	A, B, C
423.8 ± 0.3	1.8 ± 0.8	(A), H
547.7 ± 0.4	7.1 ± 1.5	A, C
572.3 ± 0.5	2.0 ± 1.0	
673.1 ± 0.4	1.2 ± 0.5	A, (C), (D)
701.2 ± 0.3	11.6 ± 1.5	A, C
708.1 ± 0.2	72.4 ± 8.0	A, B, E, (H*), (J)
738.1 ± 0.2	100	A, B*, C*, D*, E*, F*, G*, H*, J
796.5 ± 0.3	13.0 ± 0.2	G
802.4 ± 0.3	20.5 ± 2.5	A, C
810.0 ± 0.3	18.6 ± 2.5	A, H
821.8 ± 0.4	4.3 ± 1.0	
827.9 ± 0.2	28.1 ± 3.0	E
909.9 ± 0.3	22.3 ± 3.0	A, (E), F
982.1 ± 0.2	79.7 ± 9.0	A, D
1006.1 ± 0.3	8.9 ± 1.5	G
1012.1 ± 0.3	8.2 ± 1.5	A, C
1024.2 ± 0.3	4.2 ± 1.0	(H)
1074.9 ± 0.3	8.9 ± 2.0	A, D
1104.8 ± 0.3	6.6 ± 1.5	A, C
1220.6 ± 0.3	4.0 ± 1.0	G
1226.7 ± 0.3	3.0 ± 0.8	A, C
1322.5 ± 0.3	6.2 ± 1.5	A, (D)
1344.7 ± 0.5	1.5 ± 1.0	(A)
1464.0 ± 0.4	1.1 ± 0.5	
1470.4 ± 0.4	2.1 ± 0.8	(A)
2060.3 ± 0.4	14.6 ± 2.0	A

Table 1. Gamma ray energies and intensities. In the third column, the coincidence spectra to specific γ rays [113.9 keV (A), 701.2 keV (B), 708.1 keV (C), 738.1 keV (D), 796.5 + 802.4 keV (E), 810.0 keV (F), 827.9 keV (G), 909.9 keV (H) and 982.1 keV (J)] in which the γ rays of the first column have been observed are listed; ( ) = observation uncertain; [ ] = observation impossible because of backscatter peak; * = coincidence probably with the underground below the selected line. The 172.4 keV γ ray was seen only in the coincidence spectra and may be a backscatter effect.

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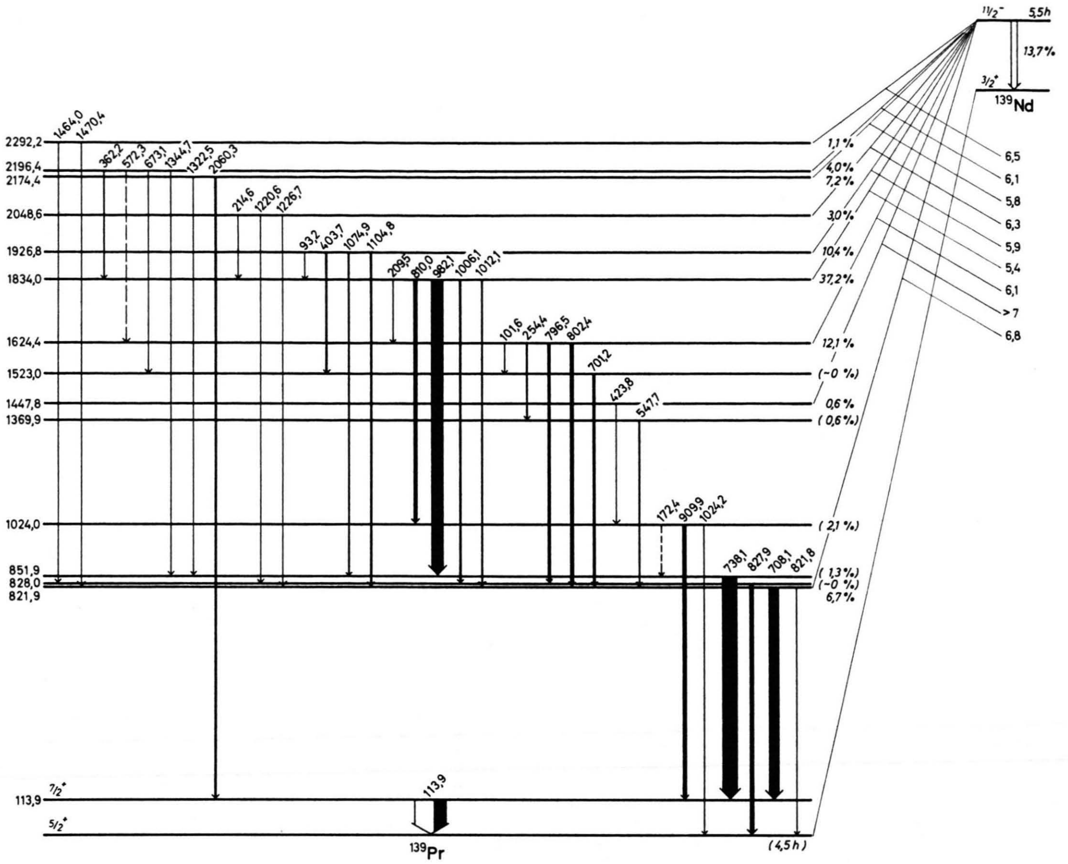

Fig. 2. The proposed partial decay scheme for ^{139}Nd. Where the percentage populations to the levels are bracketed, the errors exceed the quoted values.