Index

SPIN OF EXCITED LEVELS IN ^{149}Pm

[1]I.M.M.A. Medeiros, [1]C.B.Zamboni, [1,2]J. A.G. de Medeiros, [1]F.A. Genezini, [3]M.T.F. da Cruz , [3]J.Y. Zevallos-Chávez
[1]Instituto de Pesquisas Energéticas e Nucleares - IPEN-CNEN/SP
Av. Lineu Prestes 2.242
05508-900 Butantã, São Paulo, SP, Brasil
[2]Universidade Santo Amaro, UNISA – SP – Brasil
Rua Professor Enéas de Siqueira Neto, 340
04829-900 Jardim da Imbuias, São Paulo, SP, Brasil
[3]Universidade de São Paulo – Brasil
Rua do Matão, Travessa R, 187
05508-970 Butantã, São Paulo, SP, Brasil

ABSTRACT

The level structure of ^{149}Pm has been investigated by studying the gamma rays emitted following the beta decay of ^{149}Nd ($T_{1/2}$ =1.7 h). The single and the gamma-gamma coincidence spectra were taken using several HPGe detectors with high energy resolution. The energy and relative intensities of 181 gamma rays have been determined with a better overall precision than previously. A decay scheme with 51 levels have been proposed . This include 6 new levels at: 1407keV, 1368keV, 1364keV, 1329keV, 1293keV and 1181keV . The present results, together the results of earlier studies, permitted assignments of spin and parity for a number of these levels.

Keywords: gamma rays, coincidence, decay scheme.

I. INTRODUCTION

The nuclear structure investigation of N=88 isotopes with Z=64 suggest the coexistence of both deformed and non-deformed states which reflect the effect of the Z=64 closed proton core as well as a tendency to deformation. To study this important phenomenon, excited levels in ^{149}Pm and γ-transitions linking them were obtained from the investigation of γ-rays following the decay of ^{149}Nd ($T_{1/2}$ =1.7 h) by means of γ-ray spectroscopy and γγ coincidence measurements. These measurements were performed at IPEN (Instituto de Pesquisas Energéticas e Nucleares, São Paulo) and IFUSP (Instituto de Física , Universidade de São Paulo) facilities.

II. EXPERIMENTAL PROCEDURE

The ^{149}Nd isotope was generated by thermal neutron irradiation of Nd_2O_3 (enriched to 94% by the ^{148}Nd isotope). About 10 mg of ^{148}Nd were irradiated for 5 minutes in the IEA - R1 reactor with a neutron flux of 10^{12} neutrons/cm^{2}s. The ^{149}Nd gamma ray spectra were recorded through five successive half-lifes. Singles and Gamma-gamma coincidence spectra were measured using four HPGe detectors (FWHM<1.9 keV at 1.32 MeV of ^{60}Co). The energy calibration and the relative efficiencies of these detectors were done using standard gamma rays of ^{60}Co, ^{109}Cd, ^{133}Ba, ^{60}Cs and ^{152}Eu.

The direct γ-ray spectrum from about 20 keV to 1.6 MeV, recorded during 200 hours of live counting, was analyzed using the IDF program [1].

Coincidence measurements were performed using a multidetector acquisition system [2], at IFUSP facilities, with two 90 cm^3 HPGe detectors and the coincidence data have been analyzed using the BIDIM program [3].

III. EXPERIMENTAL RESULTS

From single gamma ray spectrum analysis a number of new transitions were proposed. Table 1 shows the energy, relative intensity and the placement of these gamma rays.

Table 1. Energy, relative intensity and placement of γ-ray in the beta decay of ^{149}Nd, observed for the first time.

Energy (keV) **Intensity * (%)**	**E_i ® E_f** **(keV)**
90.12 (5) 1.99 (11)	515.796 (4) → 425.2798 (22)
211.4403 1000*	211.3624 (15) → 0
224.49 (6) 0.92 (9)	1181.18 (6) → 956.83 (7)

Energy (keV) Intensity * (%)	E_i ® E_f (keV)
290.374 (20) 2.43 (6)	651.132 (6) → 360.139 (5)
332.167 (18) 0.68 (4)	1363.85 (4) → 1031.75 (4)
371.92 (6) 0.86 (10)	1328.79 (9) → 956.83 (7)
413.693 (15) 0.67 (5)	1049.653 (24) → 635.983 (25)
434.90 (7) 0.14 (4)	1156.971 (8) → 721.929 (26)
441.47 (13) 1.22 (10)	956.83 (7) → 515.796 (5)
590.74 (17) 0.16 (4)	1312.590 (20) → 721.929 (26)
652.744 (7) 26.46 (15)	1190.728 (7) → 537.9789 (20)
665.22 (7) 0.59 (4)	1181.18 (6) → 515.796 (4)
726.822 (12) 1.54 (10)	1264.28 (5) → 537.9789 (20)
736.18 (11) 0.71 (16)	924.05 (21) → 188.6796 (17)
771.91 (4) 1.0 (5)	1234.242 (6) → 462.349 (3)
794.58 (3) 3.28 (18)	1156.971 (8) → 360.139 (5)
806.10 (8) 0.97 (9)	1363.83 (4) → 556.233 (4)
835.18 (6) 1.24 (8)	1391.691 (6) → 556.233 (4)
839.24 (5) 1.06 (8)	1049.653 (24) → 211.3624 (15)
858.74 (11) 0.76 (7)	1406.88 (6) → 547.076 (6)
976.2 (3) 0.25 (10)	1363.85 (4) → 387.609 (4)
1016.1 (3) 0.14 (5)	1411.89 (3) → 396.8556 (23)
1040.7 (4) 0.21 (7)	1156.971 (8) → 114.3534 (15)
1119.79 (5) 3.1 (18)	1234.242 (6) → 114.3534 (15)
1170.88 (19) 0.68 (9)	1568.63 (6) → 396.8556 (23)
1180.54 (26) 1.53 (11)	1181.18 (6) → 0
1206.7 (3) 0.15 (6)	1495.19 (11) → 288.2274 (21)
1237.61 (3) 1.49 (9)	1449.250 (23) → 211.3624 (15)
1293.4 (4) 0.07 (3)	1293.4 (4) → 0
1367.96 (13) 0.6 (5)	1367.91 (13) → 0
1407.26 (6)	1406.88 (6) → 0
0.58 (5)	

*Intensities were normalized to 1000% .

In the gamma-gamma coincidence experiments the research was made in the energy region between 30 keV and 1.6 MeV.

A summary of the observed coincidences is shown in table 2.

Table 2. Gamma-gamma coincidence relations.

Energy (keV)	g-rays in coincidence (keV)
39	80, 156, 199, 214
44	39, 156
60	39, 44, 192, 211, 270
67	156, 288, 541
69	97
75	44, 114, 156, 189, 199, 270
96	60, 77, 114, 214, 268, 556
108	270, 276
114	60, 97, 123, 141, 156, 178, 189, 192, 199, 208, 214, 230, 245, 258, 276, 283, 301, 311, 327, 349, 426, 541, 556, 579, 583, 630, 634, 687, 696, 809, 830, 843, 979, 1023, 1042, 1125
123	39, 114, 227, 301
127	156, 258, 270
137	230
139	245
141	97, 114, 126, 185, 270
156	77, 114, 127, 258, 268, 276, 381, 385, 652, 687, 696
171	327
178	114, 245
186	258
189	75, 123, 214, 227, 258, 448, 598, 696, 992, 1124
192	60, 77, 97, 114, 270
197 + 199	75, 114, 676, 806, 976

Energy (keV)	g-rays in coincidence (keV)
208	255, 259, 348, 583
211	60, 75, 114, 230, 241, 255, 270, 327, 444, 533, 541, 549, 557 653, 696, 713,

Index

Energy (keV)	g-rays in coincidence (keV)
	979, 1023, 1079, 1101, 1238
214	67, 96, 114, 809
227	80, 123
230	76, 96, 114, 245, 268, 270, 288, 311, 426
241	318
245	211, 241, 270
245	295
251	211
255	114, 189, 208, 283, 583
258	208, 283
268	211, 241, 270
270	245, 276, 384, 480, 498, 595, 687, 696, 865, 875
276	211, 241, 270, 595, 687
283	255, 258
286	270, 681
288	951
288	270
295	246, 270
301	331, 741, 981
311	230, 343, 499
327	211, 494, 653
343	211, 214
349 + 347	74, 114, 208, 653
357	199
362	156, 178, 361
377	156, 208, 653
381	114, 211, 584
385	156
391	480, 750
397	141, 214, 230, 843, 893, 1016
424	494, 541, 653, 696
426	114, 156, 214, 230, 809, 865
442	224, 372, 515
444	211
449	188, 413
480	270, 480

Energy (keV)	g-rays in coincidence (keV)
214	67, 96, 114, 809
227	80, 123
230	76, 96, 114, 245, 268, 270, 288, 311, 426
241	318
245	211, 241, 270
245	295
251	211
255	114, 189, 208, 283, 583
258	208, 283
268	211, 241, 270
270	245, 276, 384, 480, 498, 595, 687, 696, 865, 875
276	211, 241, 270, 595, 687
283	255, 258
286	270, 681
288	951
288	270
295	246, 270
301	331, 741, 981
311	230, 343, 499
327	211, 494, 653
343	211, 214
349 + 347	74, 114, 208, 653
357	199
362	156, 178, 361
377	156, 208, 653
381	114, 211, 584
385	156
391	480, 750
397	141, 214, 230, 843, 893, 1016
424	494, 541, 653, 696
426	114, 156, 214, 230, 809, 865
442	224, 372, 515
444	211
449	188, 413
480	270, 480

Index

Energy (keV)	g-rays in coincidence (keV)
484	44, 270, 480
494	114, 211, 270
498 + 499	114, 270, 311
515	442, 665, 813
541	75, 114, 579, 653
546 + 548	211, 858
557	211
579	114, 653
583	60, 75, 114, 444, 541
598	114
630	114
634	114
653	579
676	114, 198, 245
687	114, 270, 276
696	114, 270, 327, 349, 424
713	75, 114, 211
718	276
741	301
762	270
809	245, 288, 311, 424
859	547
865	211, 270, 311
871	270
893	397
946	288
951	245
994	270
964	114, 270
1023	114
1079	211
1101	114
1125	114

Using the multidetector apparatus in the coincidence experiments many multiplets could be resolved. These results are shown in table 3.

Table 3. Energy from the multiplets identified in the β decay of ^{149}Nd

Energy of transitions (keV)	
Present study	**Schneider *et al.* [4]**
58.526(11)	58.85(3)
59.652 (8)	
224.49 (6)	226.85 (4)
227.072 (9)	
238.611 (3)	240.23 (2)
240.4660 (18)	
288.2516 (25)	288.20 (2)
288.374 (20)	
432.76 (7)	432.81 (7)
434.90 (7)	
652.744 (7)	654.83 (3)
654.838 (3)	
726.822 (12)	727.87 (8)
727.23 (3)	
793.19 (3)	793.48 (8)
794.58 (3)	
806.10 (8)	808.89 (5)
808.892 (12)	
976.09 (23)	978.8 (5)
978.43 (21)	978.99 (7)
979.52 (22)	
1040.7 (4)	1041.89 (9)
1042.36 (17)	
1170.88 (19)	1171.74 (18)
1172.76 (7)	

The level energies were obtained through a least-squares fit of all transitions placed in the decay scheme. The intensities that beta feeds these levels were obtained from intensity balance of transitions feeding and dexcintig the levels. These results are presented in table 4.

Table 4. The beta -decay branching ratios and the spin and parity for the excited level in ^{149} Pm.

Energy Level (keV)	I^{p}	Branching ratio
0		—
114.3534 (15)	$5/2^{+}$	2.709
188.6796 (17)	$3/2^{+}$	—
211.3624 (15)	$5/2^{+}$	20.44
240.3946 (19)	$11/2^{-}$	0.519
270.2069 (15)	$7/2^{-}$	12.195
288.2274 (21)	$9/2^{+}$	0.025
360.139 (5)	$7/2^{+}$	0.629
387.609 (4)	$1/2^{+}$	0.037
396.8556 (23)	$5/2^{+}$	2.189
415.559 (5)	$3/2^{+}$	0.262
425.2798 (22)	$7/2^{+}$	1.204
462.3498 (35)	$3/2^{-}$	1.125
515.796 (5)	$9/2^{-}$	0.454
537.9789 (20)	$5/2^{-}$	23.81
547.076 (6)	$5/2, 7/2^{+}$	0.249

Energy Level (keV)	I^{p}	Branching ratio
556.233 (4)	$9/2^{+}$	0.704
635.983 (25)	$3/2^{+}$, $5/2^{+}$	0.031
651.132 (6)	$5/2^{+}$	0.120
654.9478 (23)	$7/2^{-}$	23.89
721.929 (26)	$7/2^{+}$	0.167
744.575 (6)	3/2, $5/2^{+}$	1.984
750.491 (15)	$7/2^{-}$	0.343
758.076 (19)	$5/2^{+}$, 7/2, $9/2^{+}$	0.236
767.482 (12)	5/2, $7/2^{+}$	1.083
785.860 (26)	$3/2^{+}$, $5/2^{+}$	0.049
885.82 (14)	$5/2^{+}$	0.015
924.049 (21)	$5/2^{+}$, $7/2^{+}$	0.236
942.50 (20)	$3/2^{+}$, 5/2, $7/2^{+}$	0.566
956.836 (7)	$7/2^{+}$	0.014
1031.75 (4)	$7/2^{+}$	0.090
1043.69 (20)	$3/2^{+}$, 5/2, 7/2	0.019
1049.653 (24)	$1/2^{+}$, 3/2, $5/2^{+}$	0.159
1141.66 (4)	$5/2^{+}$	0.052
1156.971 (8)	$3/2^{+}$, 5/2, $7/2^{+}$	0.441
1181.18 (6)	$3/2^{+}$, $5/2^{+}$	0.111
1190.728 (7)	5/2	1.063
1234.242 (6)	$7/2^{-}$	1.578
1239.76 (3)	$5/2^{+}$, 7/2	0.159
1264.28 (5)	5/2, 7/2	0.058
1290.085 (22)	$3/2^{+}$, 5/2, 7/2	0.107
1312.506 (20)	5/2	0.273
1328.79 (9)	$(3/2^{+})$	0.039
1363.85 (4)	$5/2^{+}$	0.068
1367.91 (13)	$5/2^{+}$, 7/2, 9/2	0.022
1391.69 (6)	$5/2^{+}$, $7/2^{+}$	0.101
1406.88 (6)	$9/2^{-}$	0.049
1411.9 (3)	$7/2^{-}$	0.110
1449.250 (23)	$3/2^{+}$, 5/2, $7/2^{+}$	0.067
1495.19 (11)	$5/2^{+}$, $7/2^{+}$	0.014
1568.63 (6)	$5/2^{+}$, 7/2	0.063

* calculated using Q_{β^-} = 1691 (3) keV [5].

IV. CONCLUSIONS

On the basis of the present results a detailed beta decay scheme of ^{149}Nd has been built, where the energy and intensity of the γ transitions have been measured with better overall precision than previously [4,6,7]. Also, using a multidetetor apparatus [2] in the coincidence experiments many multiplets could be resolved.

In the scheme proposed 181 gamma transitions observed have been placed in 51 levels; this include 6 new excited levels at: 1407keV, 1368keV, 1364keV, 1329keV, 1293keV and 1181keV.

The present results together with the results of earlier studies also permitted definite assignments of spins to the majority of the excited levels in ^{149}Pm.

REFERENCES

[1] GOUFFON, P. **Manual do program IDF.** Instituto de Física da Universidade de São Paulo, Laboratório do Acelerador Linear, São Paulo, 1982.

[2] BARG Fº.D.; NEVES R.C.; VANIN, V.R. **Isa-to-CAMAC Interface. Proceedings of the XX Brazilian Worshop on Nuclear Physics**, Guaratingueta S.P., 424-426, 1997.

[3] GUIMARÃES FILHO, Z. O**. Medidas Precisas de Energias de Transições Gama em Coincidência : Espectroscopia das Séries do ^{232}U e ^{233}U. 1998.** Dissertação (Mestrado) - Universidade de São Paulo, São Paulo.

[4] SCHNEIDER, E. W.; GLASCOCK, M. D.; WALTERS W. B. **Radioactive Decay of 1.7-h ^{149}Nd to Levels of Transitional ^{149}Pm**. Z. Physik A, v.291, p.77-86, 1979.

[5] SZUECS, J.A.; JOHNS, M.W.; SINGH, B. **Nucl. Data Sheets for A=149**. v.46(1), p.1-185, 1985.

[6] HIDEKI, I.; TAKESHI, S.; SHIGERU,Y. **Energy Levels and Gamma-ray Transitions in ^{149}Pm.** J. Phys. Soc. Jap., v.55(4), p1108-1121, 1986.

[7] CHEN, C. H.; ARNS R, G. **Energy Levels of ^{149}Pm**. Nucl. Phys., v.63, p.233-240, 1965.