PHYSICAL REVIEW C VOLUME 13, NUMBER 1 JANUARY 1976

$N = 85$ nuclei. I. Decay of ^{145}Pr to levels of ^{145}Nd†

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(Received 21 July 1975)

A γ-ray spectroscopy study of the decay of ^{145}Pr has led to the identification of 61 γ rays. These and γ-γ coincidence studies have been used to identify 20 levels in ^{145}Nd at (J^π value in parentheses): ground state ($\frac{7}{2}^-$), 67.1 ($\frac{3}{2}^-$), 72.50 ($\frac{5}{2}^-$), 657.67 ($\frac{11}{2}^-$), 748.28 ($\frac{9}{2}^-$), 780.45 ($\frac{3}{2}^-$), 919.9 ($\frac{1}{2}^-$), 920.72 ($\frac{9}{2}^-$), 937.05 ($\frac{5}{2}^-$), 1011.22 ($\frac{11}{2}^-$), 1051.41 ($\frac{7}{2}^-$), 1085.2 ($\frac{3}{2}^+$), 1150.26 ($\frac{9}{2}^\pm$), 1101.05 ($\frac{5}{2}^-$), 1161.05 ($\frac{5}{2}^-$), 1162.32 (–), 1249.7 ($\frac{5}{2}^-$), 1285.6 (–), 1338.6 (–), 1403.92 ($\frac{5}{2}^-$), and 1527.05 ($\frac{9}{2}^-$) keV. These levels and these properties are discussed in terms of the clustering and the dressed n-quasiparticle model.

[RADIOACTIVITY Isolated from fission products and produced from ^{146}Nd(n,p) reaction, enriched targets; measured E_γ, I_γ, $\gamma\gamma$ coin; deduced levels, J, π, log*ft* Ge(Li).]

INTRODUCTION

Only two reports have been published since 1966 concerning γ rays from the decay of ^{145}Pr.[1] Both Bullock and Large[2] and Gritchenko *et al.*[3] report only nine γ rays in the decay of ^{145}Pr. However, neutron capture γ-ray data[1,4] and reaction spectroscopy studies[1,5-7] have identified a number of levels in ^{145}Nd that occur below the ^{145}Pr decay energy. The main difficulty in observing the possible population of these levels arises from the fact that 96% of all decays populate the ground state.[1] We have produced intense sources of ^{145}Pr in order to identify and study the levels of ^{145}Nd with three neutrons beyond the $N = 82$ neutron shell closure. This is part of a program to study the low energy nuclear structure of odd mass nuclei[8-10] and the applicability of the dressed n-quasiparticle model[11-17] and clustering model[18-28] to odd mass nuclei.

EXPERIMENTAL

We used two methods to produce ^{145}Pr sources. In the first method, ^{145}Pr sources were produced via the ^{145}Nd(n,p) reaction on a 0.5-g target of Nd enriched to 85% ^{145}Nd at the Lawrence Livermore Laboratory Intense Neutron Facility, a 14-MeV neutron generator with a flux of 6×10^{12} n/s. This source had equal γ-ray abundances of ^{145}Pr, ^{147}Nd, and ^{149}Nd. In the second method, nearly pure ^{145}Pr sources were prepared by isolation of Pr from the thermal neutron fission products of ^{235}U. A 1-mg sample of enriched ^{235}U was irradiated in the thermal column of the Lawrence Livermore Laboratory pool-type reactor. After a cooling period of 4 h the rare earth elements were isolated from the gross fission products. Praseodymium carrier was added to the rare earth fraction, which was then adsorbed onto an anion exchange column and eluted under 400 lb pressure. The Pr fraction was precipitated as the quinolate then redissolved. A second pass through the high pressure column ensured separation of the Pr from any remaining Nd fission products. Use of the high-pressure ion-exchange column, developed by Sission and Mode,[29] allowed the attainment of the Pr sample 6 h after the beginning of chemical separation.

The γ rays from the ^{145}Pr sources were measured on a variety of Ge(Li) detectors. In all cases several spectra were taken over a period of 48 h in order to identify the ^{145}Pr lines with the 6-h half-life of Pr. The low-energy γ rays were measured with a Ge(Li) low energy photon spectrometer (LEPS). The higher-energy γ rays were measured with and without graded lead absorbers. In most measurements, an aluminum absorber was used to reduce the bremsstrahlung background. The γ-ray energies were calibrated by several experiments in which the ^{145}Pr was counted at different gains. Standards used were ^{182}Ta, ^{110}Ag^m, ^{137}Cs, ^{113}Sn, ^{60}Co, ^{56}Co, ^{57}Co, and ^{133}Ba.[30] The known lines[29] of ^{147}Nd and ^{149}Nd in the (n,p) sources were also used as internal calibration points.

Two separate γ-γ coincidence experiments were performed. A Tennecomp system was used on the (n,p) source while a Nova-based buffer system was used with the fission sources. These systems have been discussed elsewhere.[10,31,32]

RESULTS AND DECAY SCHEME

We present the spectra of ^{145}Pr isolated from fission products in Fig. 1. The results of the anal-

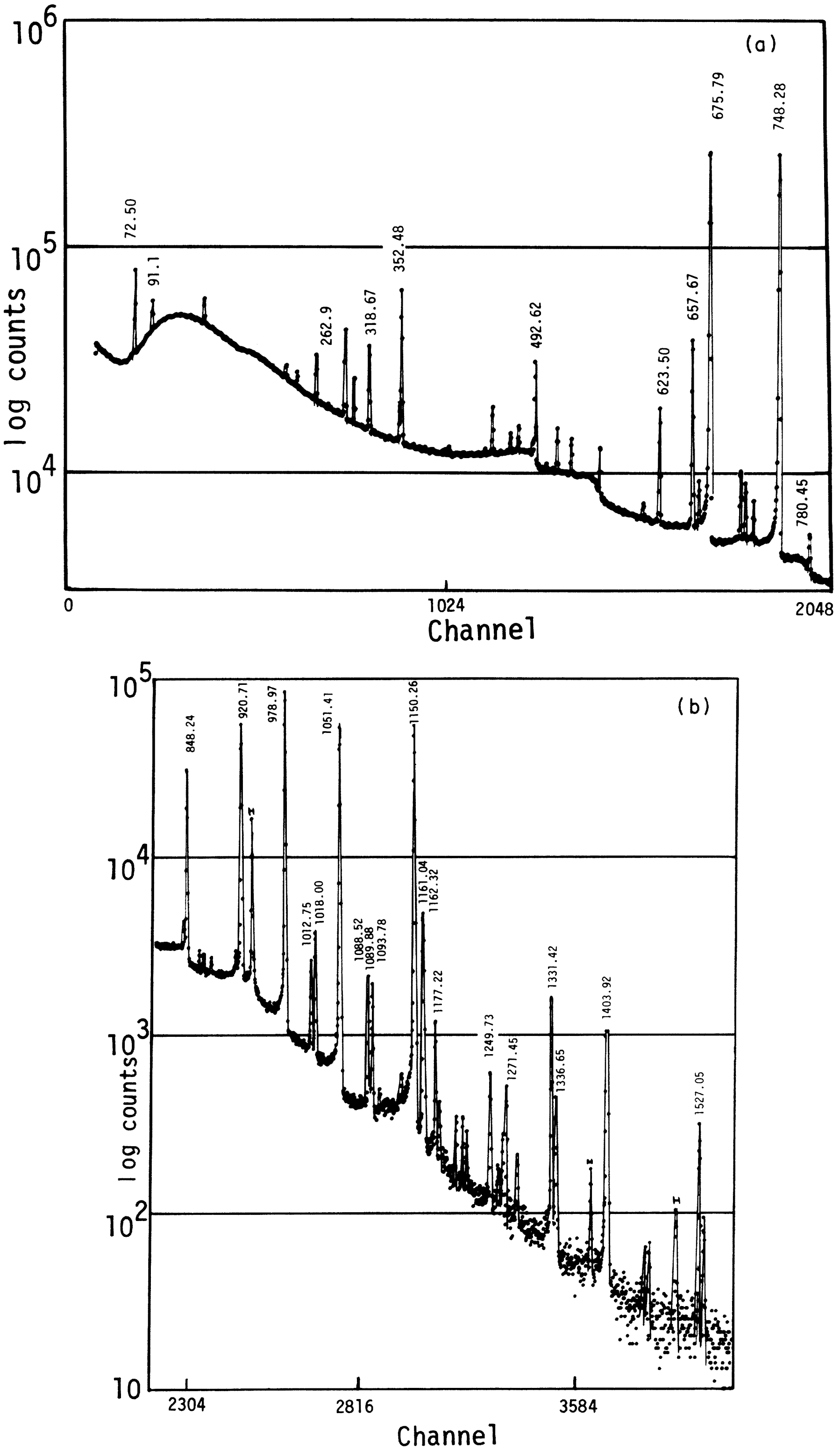

FIG. 1. The γ-ray spectrum of ^{145}Pr separated from fission products: (a) γ rays from 0 to 800 keV; (b) γ rays from 800 to 1500 keV. (N.B. an "*I*" signifies a γ ray that did not follow a 6-h half-life.)

TABLE I. γ-ray energies and intensities in the decay of ^{145}Pr to ^{145}Nd.

$E_\gamma(\Delta E_\gamma)$ (keV)	$I_\gamma(\Delta I_\gamma)$ [a]	Assignment	$E_\gamma(\Delta E_\gamma)$ (keV)	$I_\gamma(\Delta I_\gamma)$ [a]	Assignment
67.100 (95)	17 (9)	67 g.s.	869.469 (83)	2.8 (5)	··· ··· [c]
72.500 (4)	470 (50)	72 g.s.	920.710 (5)	280 (2)	920 g.s.
91.100 (200)	14 (1)	748 657	937.049 (49)	5 (1)	937 g.s.
130.953 (150)	0.6 (3)	1050 920	978.969 (15)	445 (3)	1052 72
242.913 (26)	3.1 (3)	1404 1161	1011.0 (2)	1.6 (6)	1010 g.s.
262.886 (9)	13.2 (5)	··· ··· [b]	1012.745 (21)	10.5 (6)	1085 72
303.192 (9)	12.5 (5)	1051 748	1017.999 (11)	18.2 (7)	1085 67
318.666 (6)	26.2 (5)	1403 1085	1051.412 (5)	336 (2)	1051 g.s.
352.481 (5)	70 (1)	1403 1051	1088.517 (26)	10.8 (5)	1161 72
353.544 (64)	7 (1)	1010 657	1089.882 (97)	3.2 (4)	1162 76
364.808 (250)	0.5 (2)	1527 1162	1093.778 (16)	10.3 (3)	1161 67
402.101 (80)	1.3 (3)	1150 748	1150.258 (3)	383 (2)	1150 g.s.
424.921 (153)	1.3 (4)		1161.039 (39)	28.6 (9)	1161 g.s.
448.500 (500)	(≤0.4)	(1106 657)	1162.319 (67)	16.7 (9)	1162 g.s.
467.030 (32)	4.9 (5)	1404 937	1177.221 (26)	7.2 (4)	1249 72
475.606 (24)	8.1 (5)	1527 1051	1182.483 (70)	1.5 (3)	1249 67
492.624 (5)	53 (1)	1150 657	1213.080 (64)	1.4 (4)	1285 72
504.650 (155)	1.1 (4)	1162 657	1218.216 (85)	1.3 (4)	1285 67
516.071 (15)	14 (1)	1527 1010	1249.731 (28)	4.5 (6)	1249 g.s.
606.420 (58)	3.3 (6)	1527 920	(1259.000 (900))	(0.5 (4))	
623.502 (6)	40.7 (9)	1403 780	1266.126 (69)	1.2 (3)	1338 72
657.668 (5)	111 (2)	657 g.s.	1271.450 (85)	2.8 (4)	1338 67
675.795 (5)	878 (4)	748 72	1285.480 (84)	1.0 (3)	1285 g.s.
707.949 (12)	19.0 (8)	780 72	1331.416 (16)	12.6 (6)	1403 72
713.224 (17)	16.1 (8)	780 67	1336.653 (41)	3.2 (4)	1403 67
748.278 (5)	1000 (4)	748 g.s.	1338.600 (–)	≤0.3	1338 g.s.
778.770 (150)	1.1 (5)	1527 748	1403.920 (35)	9 (1)	1403 g.s.
780.453 (32)	7.8 (8)	780 g.s.	1527.050 (43)	3.0 (4)	1527 g.s.
848.237 (17)	129 (1)	920 72	1532.017 (90)	0.8 (3)	
864.454 (61)	2.3 (5)	937 72			

[a] Relative γ-ray intensities. For absolute intensities a 20% error must be added in quadrature because of the error in $I_\gamma(72)/100\beta$ (see Ref. 1). See text for the procedure used to convert to absolute decays.

[b] 262 is a doublet; from γ-γ coincidence experiments we obtain 262.94, 5.3 (5), 1010 748; and 262, 7.9 (5), 920 657.

[c] 848 is a doublet; from γ-γ coincidence experiments we obtain 869.38, 1.1 (6), 1527 657; and 869.89, 1.7 (6), 937 67.

TABLE II. γ rays observed in selected coincidence gates.

Gate	γ rays observed
72	302.4, 318.9, 352.7, 624.6, 675.9, 708.0, 848.3, 978.7, 1013, 1068, 1088, 1177, (1266), 1331
91	72.5, 657.8
262.3+262.9	516.6, (559.7), 657.7, 675.9, 748.3, (843)
303	352.7, 676.1, 748.8
318	1012.8, 1018.0
352+353	303.7, 516.3, 657.7, 978.8, 1051.7
492	561, 657, 912, 934, 1697
516	263.1, 353.2, 657.7, 675.3, 748.7
623	708.0, 713.0, 780.3
657	91.1, 263.7. 353.2, 448.5, 493.0, 504.6, 515.7, 562.1, (869?)
675	262.6, 303.9, 352.1, 448.8, 516.4
707+713	448.3, 492.5, 561.0, 623.7, 912.5
748	262.6, 303.5, 352.7, (402), 447.4, 516.3
978	352.9, 476.5
1013	72.3, 318.3, (320.2)
1018	319
1051	352.4, 476.5
1130	493.6, 561.0

ysis of the singles spectra from both experiments are given in Table I. In Table II we present the combined results of both coincidence studies.

The decay scheme shown in Fig. 2 was constructed using our γ-ray energies and intensities in conjunction with the reaction spectroscopy data of Gales, Lessard, and Foster[5] and Bingham, Hills, and Ball.[6] Because we observe direct β decay to levels with known J^π values of $\frac{9}{2}^-$, we suggest an assignment of $\frac{7}{2}^+$ for the ground-state

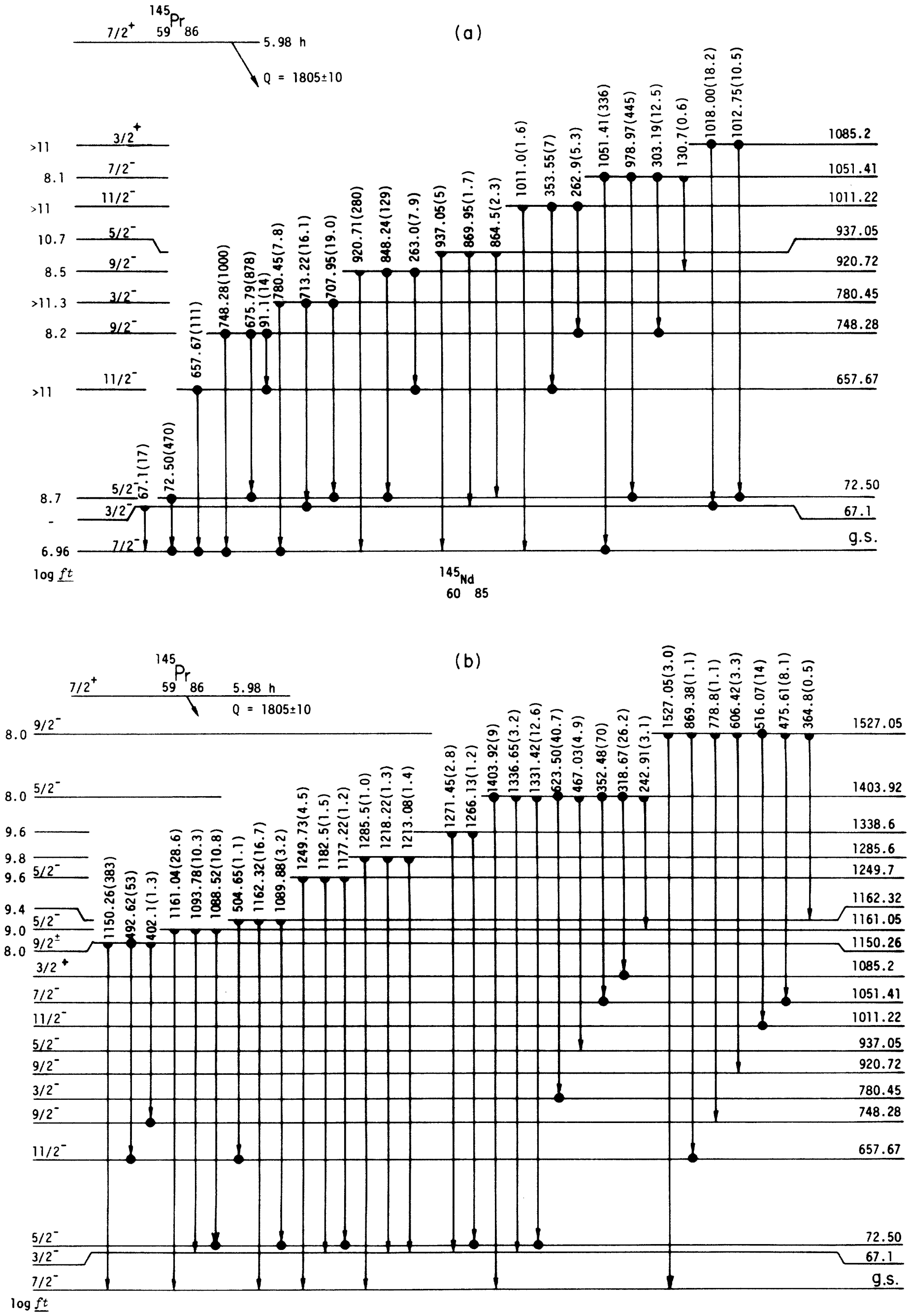

FIG. 2. (a) Decay scheme of ^{145}Pr up to 1100 keV. (b) Decay scheme of ^{145}Pr from 1100 to 1600 keV. Key: A dot at the bottom of an arrow represents the fact that the γ ray was placed by observation in at least one appropriate γ ray gate in the γ-γ coincidence study. A dot at the top of the arrow indicates that a gate was set at this γ-ray energy. An arrow with only a semicircle was placed by Reitz combination principle only.

TABLE III. Percent β decay and log*ft* values.

Level	% β decay[a]	Log*ft*
g.s.	96.7	6.96
67.1	...[b]	...[b]
72.50	1.7	8.7
657.67	$\leq 1\times 10^{-3}$	(≥ 11.7)[c]
748.28	0.80	8.2
780.45	$\leq 5\times 10^{-4}$	(≥ 11.3)[c]
920.72	0.18	8.5
937.05	$<1\times 10^{-3}$	>11
1011.22	$<8\times 10^{-4}$	>11
1051.41	0.30	8.1
1085.2	$<6\times 10^{-4}$	>11
1150.26	0.19	8.0
1161.05	0.02	9.0
1162.32	8×10^{-3}	9.4
1249.7	3×10^{-3}	9.5
1338.6	1.7×10^{-3}	9.6
1403.92	0.072	7.7
1527.05	0.031	8.0

[a] For all except the g.s. transition the error in the % β decay is 20% due to the error in $I_\gamma(72)/100\beta$ (see Ref. 1).

[b] We note that the 67.1-keV level could possibly be fed by β decay or an unobserved 6-keV γ ray from the 72.5-keV level. If there is no 6-keV γ ray and we use the theoretical value for $\alpha_k = 3.4$ and $K/L = 0.68$ (hence $\alpha_T \approx 10$)[1] we can estimate a $\log f_1 t \approx 12$; however, our large error on the γ-ray intensity value for the 67.1-keV γ ray precludes setting any firm value.

[c] This is the limit for a $\log f_1 t$ value (Ref. 37).

J^π value of ^{145}Pr. It should be noted that *Nuclear Data Sheets*[1] have limited the J^π assignment to either $\frac{7}{2}^+$ or $\frac{5}{2}^+$ on the basis of the shell model and systematics.

The β intensities and log*ft* values are presented in Table III. The β intensities were calculated by the detailed balance technique using our γ-ray data; the measurement of 0.20 parts per 100 decays for the 72-keV transition and the α_T value corresponded to a δ^2 value of 0.10 for the 72-keV transition.[1]

All the levels that have been observed in this and other studies are presented in Table IV. For these levels we suggest the following assignments:

Ground state 67.1-, and 72.50-keV levels. These levels have been assigned J^π values in previous studies[1-6] of $\frac{7}{2}^-$, $\frac{3}{2}^-$, and $\frac{5}{2}^-$, for the ground state (g.s.), 67.1-, and 72.50-keV levels, respectively.

657.67-keV level. We find no β feeding of this level or any γ-ray branching to the 67- or 72-keV levels. This and the 91.1-keV γ ray observed to be in coincidence with the 657-keV γ ray suggest a J^π value of $\frac{11}{2}^-$ for this level. This level may have been observed in the work of Alkhazov, Erokhina, and Lemberg.[7]

748.28-keV level. This level exhibits an $l=5$ angular distribution in (d,p) studies.[5,6] This, the γ-ray branching ratios, and the direct β-decay feeding of this level limits the J^π value to $\frac{9}{2}^-$.

780.30-keV level. This level is populated by γ rays cascading into it and not fed directly in β decay. The level has been observed in stripping reaction studies and given a J^π value of $\frac{3}{2}^-$ or $\frac{1}{2}^-$. Our observation of a ground-state transition limits its J^π value to $\frac{3}{2}^-$.

919.9- and 920.7-keV doublet. A doublet of 920 keV has been suggested from the results of (d,p), $(\alpha,{}^3\mathrm{He})$, (n,γ), and decay-scheme studies. We observe the population of a level at 920.73 keV. This, its decay properties, the suggested $l=5$ component of the stripping-reaction studies, and its observation in Coulomb excitation,[7] limits the J^π value to $\frac{9}{2}^-$. The second member of this doublet can be identified at 919.9 keV from the neutron-capture γ-ray studies of McClure, Raman, and Harey,[4] who suggest a J^π value of $\frac{1}{2}^-$ for this level.

Levels between 930 and 1100 keV. Four levels are observed between 930 and 1100 keV at 937.05, 1011.22, 1051.41, and 1085.2 keV. Except for the 937- and 1051-keV levels, none of these have been observed before. Only the 1051.43-keV level is populated directly in the ^{145}Pr β decay. This, as well as the γ-ray decay branching ratios, leads us to suggest a J^π assignment of $\frac{7}{2}^-$ for this level. The 937.05-keV level has decay properties consistent with the $J^\pi = \frac{5}{2}^-$ assignment by Gales *et al.*[8] The decay of the 1011.22-keV level is consistent with a J^π value of $\frac{11}{2}^-$, while the 1085-keV level has decay properties indicative of a J value of $\frac{1}{2}$ or $\frac{3}{2}$; we take both these assignments as tentative.

1106.2-keV level. Bingham *et al.* suggest a $\frac{13}{2}^+$ level at 1104 keV based on an $l=6$ distribution in their (d,p) and $(\alpha,{}^3\mathrm{He})$ data, while Gales finds an $l=5$ assignment and suggest a $\frac{9}{2}^-$ value for J^π. We do not observe a level that is populated directly in β decay, as would be consistent with the $\frac{13}{2}^+$ assignment of Bingham *et al.* However, we do note that such a level could be populated at 1106.2 keV, as we observe a low-intensity 448.5-keV γ ray in coincidence with the 657-keV γ ray.

1150.26-, 1161.05-, and 1162.32-keV triplet. Stripping reaction data suggest a level at approximately 1150 keV with $l=1$ or 3. However, we observe three. The level at 1161.05 keV has decay properties consistent with a $J^\pi = \frac{5}{2}^-$ assignment and the 1150.26-keV level, with $J = \frac{9}{2}$. The 1162.32-keV level has γ-ray decay properties suggesting a J^π of $\frac{7}{2}$ or $\frac{9}{2}$.

Levels between 1200 and 1400 keV. The three levels at 1249.7, 1285, and 1338.6 keV have all been observed in stripping reaction studies. The 1249.7-keV level decay properties are in agree-

TABLE IV. Levels observed in ^{145}Nd and their assignments.

This work (J^π)	^{144}Nd(d,p) [a]	^{144}Nd(d,p) [b]	^{144}Nd$(\alpha,{}^3$He$)$ [c]	(n,γ) [c]	(n,γ) [d]	Ref. 33 [e]
0 $(\frac{7}{2}^-)$	0 $(\frac{7}{2}^-)$	0 $(\frac{7}{2}^-)$	0 $(\frac{7}{2}^-)$			0 $(\frac{7}{2}^-)$
67.1 $(\frac{3}{2}^-)$	67 ± 72	67 ± 72	···			69 ± 72
72.50 $(\frac{5}{2}^-)$						
						(507)?
	657 $(l=1)$	652 $(\frac{3}{2}^-)$				
657.80 $(\frac{11}{2}^-)$						657 $(l=5)$
748.28 $(\frac{9}{2}^-)$	749 $(\frac{9}{2}^-)$	741 $(\frac{9}{2}^-)$	741 $(\frac{9}{2}^-)$		749.1	747 $(\frac{9}{2}^-)$
780.30 $(\frac{3}{2}^-)$	779 $(\frac{3}{2}^-)$	773 $(\frac{3}{2}^-)$				780 $(\frac{3}{2}^-)$
	918 $(\frac{1}{2}^-)$			919.9 $\frac{1}{2}^-$		919 $(\frac{1}{2}^-)$
920.73 $(\frac{9}{2}^-)$		923 $(l=5$ & $3)$			920.7	
937.05 $(\frac{5}{2}^-)$	934 $(\frac{5}{2}^-)$				937.0	930 $l=3+(1+5)$
1011.22 $(\frac{11}{2}^-)$						
1051.43 $(\frac{7}{2}^-)$					1050.9	
1085.2 $(\frac{3}{2}^+)$						1086 $(l=2)$
	1109 $(l=5)$	1104 $(\frac{13}{2}^+)$	1104 $(\frac{13}{2}^+)$			1112 $(\frac{13}{2}^+)$
1150.26 $(\frac{9}{2})$						1150 $(\frac{5}{2}^-)$
1161.05 $(\frac{5}{2}^-)$	1147 $(l=1)$	1142 $(\frac{5}{2}^-)$			1161.1	
1162.32 $(-)$						
				1213 $(\frac{1}{2}^+ ?)$		
1249.7 $(\frac{5}{2}^-)$	1248 $(l=3)$	1243 $(\frac{5}{2}^-)$	1243 $(\frac{5}{2}^-)$		1249.7	1252 $(\frac{5}{2}^-)$
1285.6 $(-)$	1284 $(l=1?)$				1285.5	
						1328 $(\frac{1}{2}^+)$
1338.6 $(-)$	1331 $(l=3)$	1324 $(\frac{5}{2}^-)$	1324 $(\frac{5}{2}^-)$		1338.5	1334 $(\frac{5}{2}^-)$
1403.92 $(\frac{5}{2}^-)$	1400 $(l=1?)$				1404.0	
						1529 $(\frac{3}{2}^+)$
1527.05 $(\frac{9}{2}^-)$	1527 $(l=3)$	1519 $(\frac{9}{2}^-)$	1519 $(\frac{1}{2}^-)$			1530 $(\frac{9}{2}^-)$
	1578 $(l=3)$	1579 $(\frac{5}{2}^-)$				
(1599.12 $(-)$)?	1592 $(l=1)$			1593.5		1590 $(l=3)$
		1639 $(\frac{5}{2}^-)$				
	1681 $(-)$	1673 $(\frac{5}{2}^-)$				1687 $(l=3)$
	1713 $(-)$					1712 $(\frac{1}{2}^+)$
	1745 $(l=1)$					
		1748 $(\frac{9}{2}^-)$	1748 $(=5$ & $3)$			1760 $(l=3+5)$
	1846 $(\frac{13}{2}^+)$	1833 $(\frac{13}{2}^+)$	1833 $(\frac{13}{2}^+)$			1849 $(\frac{13}{2}^+)$

[a] Taken from Ref. 5.

[b] Taken from Refs. 1 and 6.

[c] Taken from Refs. 1 and 4.

[d] We suggest these levels are populated in the (n,γ) work reported in Ref. 33. We assign them on the basis of our γ-ray energies and relative intensities and those unassigned γ rays in Ref. 33.

[e] Note that some of these data are identical with Refs. 4 and 6.

ment with the $\frac{5}{2}^-$ assignment of Bingham *et al.*

1403.92-keV level. The stripping reaction studies of Gales *et al.* report observing a level at approximately 1400 keV; however, they assign an $l=1$ distribution to this level, which is inconsistent with its being populated in β decay. A J^π value of $\frac{5}{2}^-$ is suggested on the basis of its γ-ray branching ratios. We note that a level was observed at approximately 1390 keV in the Coulomb excitation studies of Alkhazov *et al.*[7]

Note added. Work by D. L. Hillis *et al.* has been brought to our attention.[33] This article incorporates the work of Bingham,[6] McClure *et al.*,[4] and others.[1] The only previously unavailable data in Ref. 33 is the ^{145}Pr decay and the detailed neutron capture γ-ray data. In the work of Hillis *et al.*[23] the ^{145}Pr sources used for the decay scheme study were less pure and at least a factor of 10 less intense[33] than those used in this work. In addition, only one method of preparation was used to produce the activity. The decay scheme work also suffered from having only one coincident gate set with a NaI(Tl)-Ge(Li) arrangement, while we were able to perform two separate Ge(Li)-Ge(Li) coincidence experiments. The γ-ray singles data presented in Ref. 33 are in general agreement with ours except that we observe a number of transitions that were too low in intensity to be observed by Hillis *et al.* In addition we can place an intensity limit of less than 0.5 units to the following transitions (I_γ per 1000 units of intensity for the 748.278-keV γ ray as reported in Ref. 33): 339.7(2.5) and 743.7(30); also their study does not resolve doublets at 352.48 and 353.55 keV, 1088.52 and 1089.88 keV, and 1161.04 and 1162.32 keV. In addition, inspection of our data and known systematics suggests the following (note that the results of Ref. 33 has been incorporated in Table IV of this paper):

506.8-keV level. Confirmation of this level would be useful by some other technique. Our data give no evidence in support of this level being populated by levels of higher energy, although several other low spin levels in this region are fed by cascade.

840-keV level. Similar to the 506-keV level proposed in Ref. 33 we observe no γ-ray cascade into or out of this level. We note that neither the 506- nor 840-keV proposed levels are populated directly from the capture state as reported in Ref. 33; however, other known low spin levels are populated.

1578- and 1742-keV levels. We suggest these proposed levels do not exist. Our γ-γ coincidence data provide evidence for different placement of the γ rays used to construct these levels. No reaction studies observe these levels.

1599-keV level. We observed a 1532.02-keV γ ray in our spectra that we do not assign. We cannot exclude the existence of a 1526.62-keV component in the 1527.050± 0.043-keV γ ray that we assign as the ground-state transition of the 1527.05-keV level.

Assignment of levels populated in (n,γ) studies. Our identification and assignment of the γ rays in the decay of ^{145}Pr can be used to identify a number of unassigned γ rays reported in the neutron capture γ-ray data presented in Ref. 33. The levels we suggest as being populated either directly or by cascade are the (energies are those of Ref. 33): 749.1-, 920.7-, 937.0-, 1050.9-, 1161.1-, 1249.7-, 1285.5-, 1338.5-, and 1404.0-keV levels. These are compared to other results in the sixth column of Table IV.

DISCUSSION

As shown in Fig. 3 there is a dramatic change in the low-energy-level structure of the $Z = 60$ neodymium nuclei as pairs of neutrons are added beyond ^{143}Nd, the $N = 83$ nucleus with one neutron beyond shell closure to ^{147}Nd (Refs. 34 and 35) which has two neutrons less than the inception of permanent deformation at $N = 89$. Such a change is observed in several regions of the nuclear chart where three particles or three holes become available beyond a shell closure. This and the properties of the low-lying $J - 1$ and $J - 2$ levels have led to two nuclear models: the clustering model of Alaga, Paar, and Sips[18-28] and the dressed n-quasiparticle model of Marumori, Kuriyama, and co-workers.[11-17] Recently we have compared these models with the systematics of some odd proton nuclei[8,9] and with each other.[10] Here, we wish to point to the general

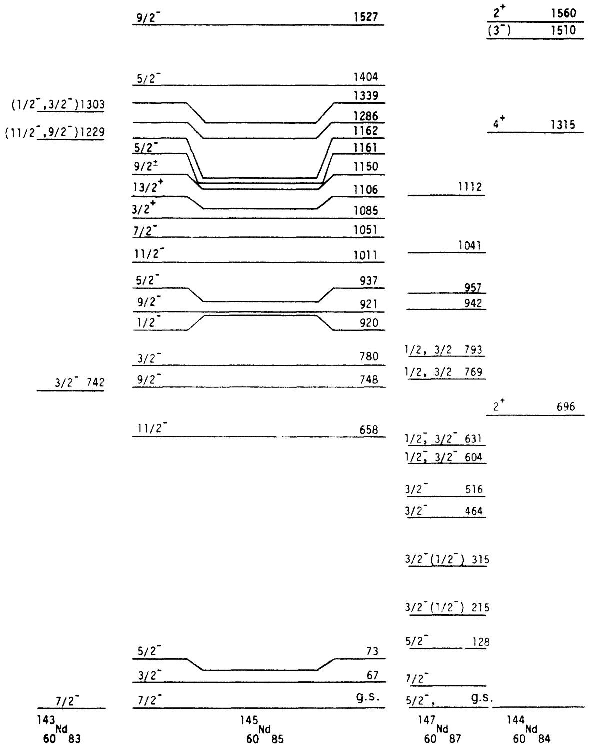

FIG. 3. Experimentally observed levels of selected nuclei with 60 protons. From left to right: the $N = 83$ nucleus ^{143}Nd (Ref. 38), the $N = 85$ nucleus ^{145}Nd, the $N = 87$ nucleus ^{147}Nd (Ref. 32), and the even-even core nucleus ^{144}Nd (Ref. 39).

features of the ^{145}Nd levels up to 1600 keV. In a subsequent paper on ^{147}Sm levels[32] we compare the properties of the $N = 85$ nuclei with the two models.

The first three levels of ^{145}Nd at ground state, 67, and 73 keV with J^π values of $\frac{7}{2}^-$, $\frac{3}{2}^-$, and $\frac{5}{2}^-$, respectively, arise from the $(\nu g_{7/2})^3$ configuration and its coupling with the available protons. Similar triplets have been observed for the $(\pi g_{9/2})^3$ configuration in nuclei such as ^{101}Tc where the $\frac{9}{2}^+$, $\frac{7}{2}^+$, and $\frac{5}{2}^+$ members lie at ground state, 9, and 15 keV, respectively. The dressed n-quasiparticle calculation requires the inclusion of a dressed five-quasiparticle configuration to bring the $J-2$ ($\frac{5}{2}^+$) level to low energy,[8] although the inclusion of the $J-2$ shell-model state across the shell ($d_{5/2}$) in the model space also has the effect of lowering the $J-2$ level.[13] This latter effect may be more pronounced in ^{145}Nd because of the presence of the $J-2$ $3p_{3/2}$ shell-model state in the valence shell. The dressed n-quasiparticle model does succeed in calculating most of the fast $B(E2)$ values measured in the decay of these two levels. The clustering model only predicts the J and $J-1$ levels at low energies but does yield a correct value for the $B(E2)$ between the J and $J-1$ level.[9]

The decay properties of the three observed $\frac{9}{2}^-$ levels at 748, 920, and 1527 keV illustrate the influence of the even-even ^{144}Nd core configurations, as well as the admixture of the $h_{9/2}$ shell-model state. The first two $\frac{9}{2}^-$ levels appear to be mixed $f_{7/2}$-plus-phonon and $h_{9/2}$ in character. Indeed the 748-keV level is strongly populated in the ^{144}Nd(d,p) reaction.[5,6] The single-particle character of the 920-keV level is less well established however, due to the observed multiplet in the (d,p) reaction.[1] Both levels exhibit decay branches indicative of photon character, and the strong 91-keV transition from the 748-keV level to the 658-keV level is perhaps indicative of some second phonon character or cross-phonon transition.[36]

The $\frac{11}{2}^-$ level at 658 keV may be considered to arise from the coupling of the ground state $f_{7/2}$ configuration with the even-even core phonon. This $J+2$ state is expected to be lowered somewhat in energy with respect to the full even-even core phonon energy as is observed (see Fig. 3). This is the case particularly when the particle-vibration coupling strength is large and is expected for the second phonon $J+2$ level as well. If the 1011-keV level does in fact have J^π of $\frac{11}{2}^-$, its γ-ray decay branchings are consistent with such a description. Note, however, that some admixture of $h_{9/2}$-plus-one-phonon configuration undoubtedly is also present. Such a mechanism presumably accounts for the strong branching of the 1527-keV $\frac{9}{2}^-$ level to the one-phonon multiplet over decay to the ground state.

On a phenomenological basis the two models show promise in explaining the level structure of ^{145}Nd. A detailed calculation will be complicated by the mixing between $(f_{7/2})^3$ and $(h_{9/2})^3$ configurations, although it does appear the $(f_{7/2})^3$ configurations are dominant.

ACKNOWLEDGMENTS

We wish to thank J. H. Landrum who performed the separation of Pr in the fission product experiment and Dr. L. G. Multhauf, W. Ruhter, and C. Jensen for the use of their respective γ-γ coincidence spectrometers. We are indebted to Dr. J. T. Larsen for the use of his recently developed data-reduction computer codes.

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†This work was performed under the auspices of the U. S. Energy Research and Development Administration.

*Associated Western Universities Graduate Student Fellowship to Lawrence Livermore Laboratory, 1975; Home Institution: Chemistry Department, University of Maryland, College Park, Maryland 20742.

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