PHYSICAL REVIEW VOLUME 134, NUMBER 2B 27 APRIL 1964

Decay of Nd^{149} to Pm^{149}

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(Received 26 September 1963)

The radiations from the decay of the 1.8-h Nd^{149} have been investigated using an intermediate-image beta-ray spectrometer and scintillation coincidence spectrometers in conjunction with a 512-channel analyzer. Various gamma-gamma and beta-gamma coincidence measurements, not reported earlier, have been made in order to establish the decay scheme with improved techniques. The beta spectrum showed four major components with end-point energies 1555 keV (6%), 1425 keV (38%), 1130 keV (26%), and 1025 keV (30%). The singles gamma-ray spectrum showed the following gamma rays: 62, 80, 114, 158, 190, 210, 240, 272, 330, 375, 425, 540, and 650 keV. 62, 80, 158, 272, and 330 keV gamma rays were not reported earlier. To explain the various gamma-gamma and beta-gamma coincidences a new decay scheme with levels in Pm^{149} at 114, 210, 272, 352, 510, 538, 650, and 750 keV is proposed. The K-conversion coefficient of the 114-keV transition, which is not determined earlier, has been measured and is found to be 0.83±0.1.

I. INTRODUCTION

It is known that nuclear structure undergoes a rapid change from spherical to deformed equilibrium shape in passing from neutron number 88 to 90. In odd-A promethium nuclei—Pm^{145}, Pm^{147}, Pm^{149}, and Pm^{151}—the neutron number changes from 84 to 90. Pm^{145} should exhibit the properties of a nearly spherical nucleus, while Pm^{151} should show those of a deformed nucleus. To investigate the effect on the odd-proton level structure upon addition of neutrons pairwise, a systematic study of odd-A promethium levels was undertaken. At present the nuclear data on these nuclei, particularly Pm^{149} and Pm^{151}, are very incomplete. The present work deals with the levels of Pm^{149} studied from the beta decay of Nd^{149}.

Nd^{149} was observed as a 2-h activity produced by fast and slow neutron irradiation of neodymium.[1,2] It was also observed in fission products[3,4] as a 1.8-h activity. Its mass assignment and genetic relationship were established[3,4] by ion-exchange separation of irradiated neodymium. This is further confirmed[5] by observing the 1.8±0.1 h Nd^{149} activity by $(n,2n)$ reaction on enriched Nd^{150}. By absorption method[3] the energy of beta rays was found to be 1.5 MeV and the total decay energy 1.6±0.1 MeV.[6] By neutron irradiation of enriched Nd^{148}, Rutledge, Cork, and Burson[7] produced Nd^{149} and studied its internal and some external-conversion electron spectra with a permanent-magnet spectrograph. From the observed conversion lines, at least fourteen gamma-ray transitions were deduced and they were fitted into a decay scheme. An alternate level scheme was recently proposed[8] on the basis of the internal-conversion electron intensities of Rutledge *et al.*[7] and theoretical conversion coefficients, in order to account for the different beta-ray branches. Since there is no other detailed work reported on this decay, it was thought necessary to make a systematic study on gamma-gamma and beta-gamma coincidences to establish the decay scheme more correctly. In the present work extensive investigations on beta- and gamma-ray spectra, gamma-gamma and beta-gamma coincidences, and summing gamma-ray spectrum have been carried out. Based on the results of these measurements the decay scheme as shown in Fig. 1 is proposed.

II. MEASUREMENTS AND RESULTS

A. Preparation of Source

In the present study Nd^{149} was prepared by irradiating an enriched sample of neodymium with 88% Nd^{148} in the Trombay Reactor "Apsara." The sample contained 3.2% of Nd^{146} and 3.4% of Nd^{150}. The length of irradiation was chosen to be one hour so as to minimize the contribution of the 10-day Nd^{147} produced from the Nd^{146}. The source was allowed to cool down for a period of one hour so that the 12-min Nd^{151} produced from the Nd^{150} died out. The contribution of Nd^{147} and the Pm^{149} and Pm^{151} were taken into account in singles spectra by following the half-life.

B. Beta Spectrum

An intermediate-image Siegbahn-Slätis beta-ray spectrometer with a resolution of 2.2% was used for the study of the beta spectrum. The source was deposited on a 500 $\mu g/cm^2$ Mylar film, over a diameter ~2 mm and an estimated thickness of 1.5 mg/cm^2. The observations on the beta spectrum were started two hours after the end of irradiation. The beta spectrum was scanned above 700 keV. The decay of the spectrum was followed

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[7] W. C. Rutledge, J. M. Cork, and S. B. Burson, Phys. Rev. **86**, 775 (1952).
[8] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences–National Research Council, Washington, D. C., 1958 to 1962), 5–2–16 and 5–2–18, (Dec. 1962).

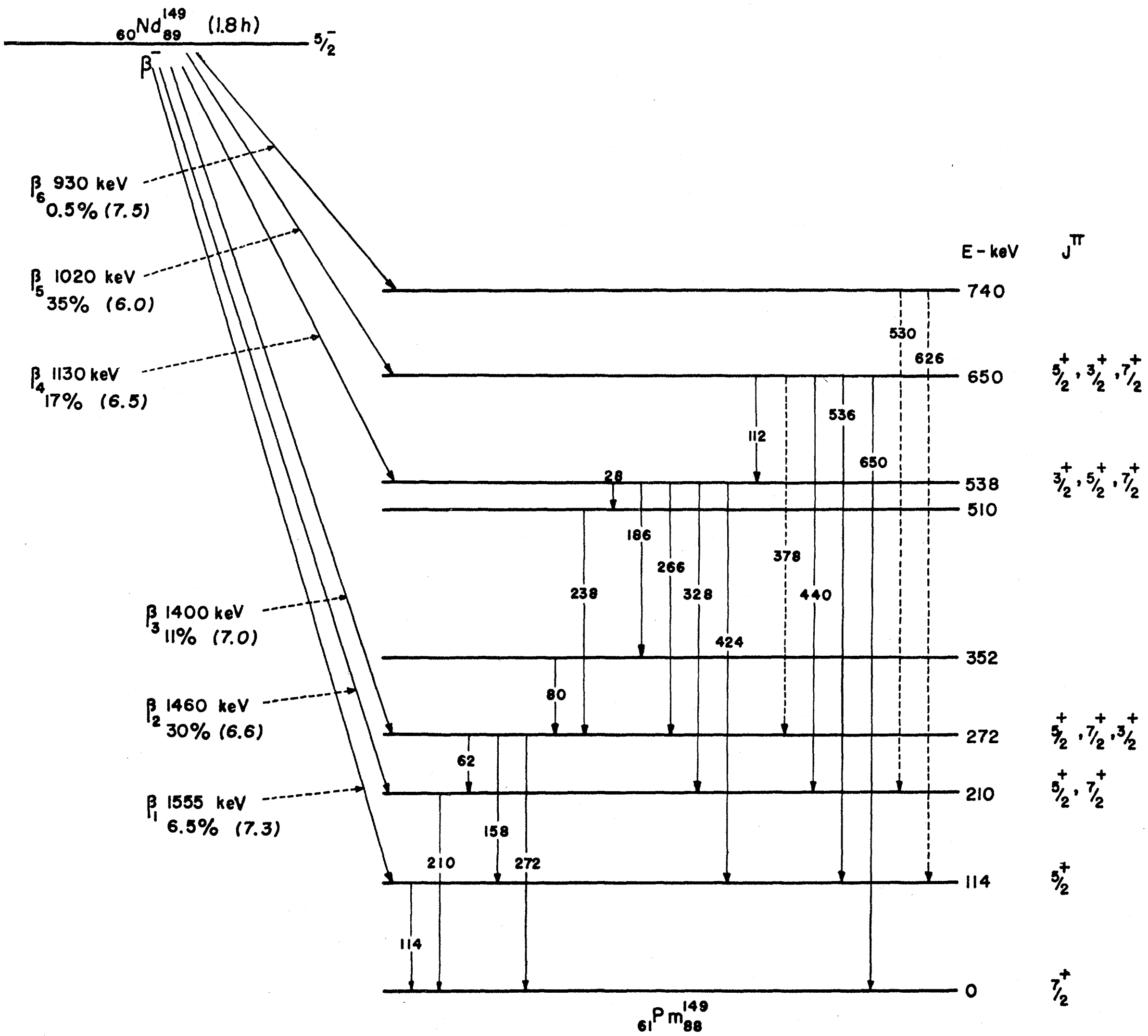


FIG. 1. Decay scheme of Nd^{149} from the present investigations.

over a period of three half-lives. The spectrum above 1.0 MeV was found to decay with the 1.8-h half-life of Nd^{149} indicating the presence of impurities negligible in this energy region. Below 800 keV, contributions of Nd^{147} and $Pm^{149,151}$ were observed. These contributions were taken into account in the analysis of the spectrum. The Fermi-Kurie plot of the beta spectrum above 750 keV (Fig. 2) showed four beta components of end-point energies 1555 ± 10 keV (6%), 1425 ± 20 keV (38%), 1130 ± 20 keV (26%), 1025 ± 20 keV (30%).

C. Study of Gamma-Ray Spectrum

The gamma spectrum was studied by means of a scintillation spectrometer consisting of a 3-in.-diam $\times$3-in.-thick NaI(Tl) crystal coupled to a Dumont 6363 photomultiplier and a 512-channel pulse-height analyzer. The spectrometer had a resolution of 7.6% for the 662-keV line of Cs^{137}. It was calibrated using standard lines from Cs^{137}, Na^{22}, Au^{198}, Cr^{51}, Hg^{203}, In^{114}, Ce^{141}, and Gd^{153}. The source was deposited on a Mylar film and covered with Scotch tape. In order to avoid coincidence summing, the source was kept at 20 cm from the top of the detector. A beta absorber of 1.2 cm Perspex was placed halfway between the source and the crystal. This reduced the effective geometry for detection of bremsstrahlung. The correction for bremsstrahlung was estimated by using a P^{32} pure-beta emitter source of approximately the same strength as the Nd^{149}, in the same geometry.

The decay of the spectrum was observed over a period of four half-lives. The correction for the contribution of Nd^{147} and $Pm^{149,151}$ was taken into account. The gamma spectrum (Fig. 3) showed peaks at 39, 62, 80, 114, 158, 210, 272, 330, 425, 540, and 650 keV. The gamma rays of 62, 80, 158, 272, and 330 keV were not observed

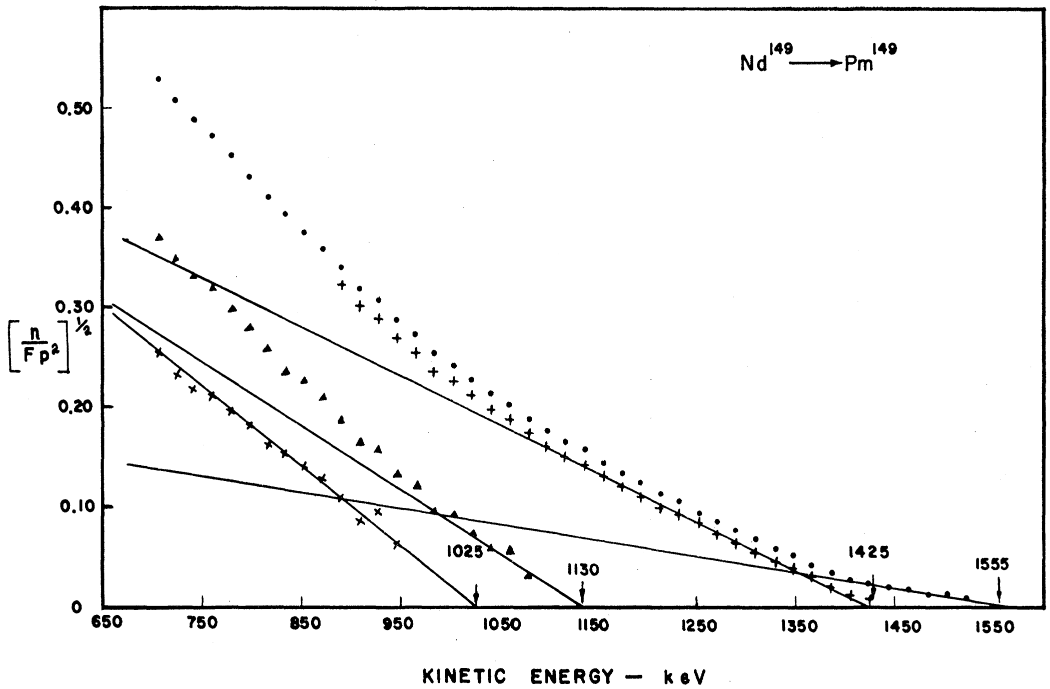


FIG. 2. Fermi-Kurie plot of the beta spectrum of Nd^{149} in a Siegbahn-Slätis beta-ray spectrometer.

previously. Gamma rays of similar energies have been observed[9] in the decay of Pm^{151}, but the intensities of these gamma rays follow the half-life of 1.8 h, which indicate that the contribution of Pm^{151} is negligible. The spectrum was analyzed using standard line shapes from the sources mentioned above. In addition to the peaks mentioned earlier, weaker gamma rays of 190, 240, and 370 keV were also observed in the analysis, their existence being confirmed by coincidence measurements. The intensities of the various gamma rays from the analysis of the singles spectrum are given in Table I.

D. Gamma-Gamma Coincidences

For the study of gamma-gamma coincidences, a 3-in.-diam×3-in.-thick NaI(Tl) crystal coupled to a Dumont 6363 photomultiplier was used as the gate detector and the coincidence spectrum was scanned using a 1.5-in.-diam×1-in.-thick NaI(Tl) crystal coupled to a Dumont 6292 photomultiplier. The latter had a resolution of 8.5% for the 662-keV line. The two detectors were placed at right angles with a graded anti-Compton wedge shielding them from each other. The fast-slow coincidence unit had a resolving time $2\tau = 0.15\ \mu$sec. The coincidence spectra were recorded in a 512-channel analyzer. The coincidence efficiency was checked using a Na^{22} source and was found to be 100% above 20 keV.

TABLE I. Relative intensities of gamma rays in the decay of Nd^{149}.

E_γ (keV)	Relative intensity	E_γ (keV)	Relative intensity
62	4[a]	272	70
80	5[a]	266	24[a]
114	67	330	20
158	16	370	7
190	9	425	36
210	100	540	37
240	20	650	32

[a] Intensities calculated from coincidences.

[9] R. Chery, Nucl. Phys. **32**, 319 (1962).

The gamma spectrum in coincidence with 540-keV gamma rays (Fig. 4) showed, in addition to strong coincidence with 39-keV x rays and 114-keV gamma rays, a weak coincidence with 210 keV. With 424 keV in the gate, 39 and 114 keV are again strongly in coincidence and there is a weak coincidence with 210 keV (Fig. 5A). From the observed intensities of the coincidences, it was found that only 3% of 540-keV and 10% of 424-keV gamma rays are in coincidence with the 210-keV transition. To explain this weak 540–210-keV cascade a level is proposed at 740 keV (Fig. 1). A 440-keV transition from the 650-keV level is proposed to explain the weak coincidence between 424-keV region and 210 keV (Fig. 1). The 330-keV gamma ray is in strong coincidence with x ray, 114 and 210 keV gamma rays (Fig. 5B). When 210 keV was taken in the gate, coincidences were observed with x ray, 62-, 80-, 114-, 190+210-, 270-keV region and 330-keV gamma rays and also feeble coincidences with 440 and 540 keV (Fig. 6A). In order to see if these coincidences were really due to Nd^{149} itself, the decay of the coincidence spectrum was observed over two half-lives and they

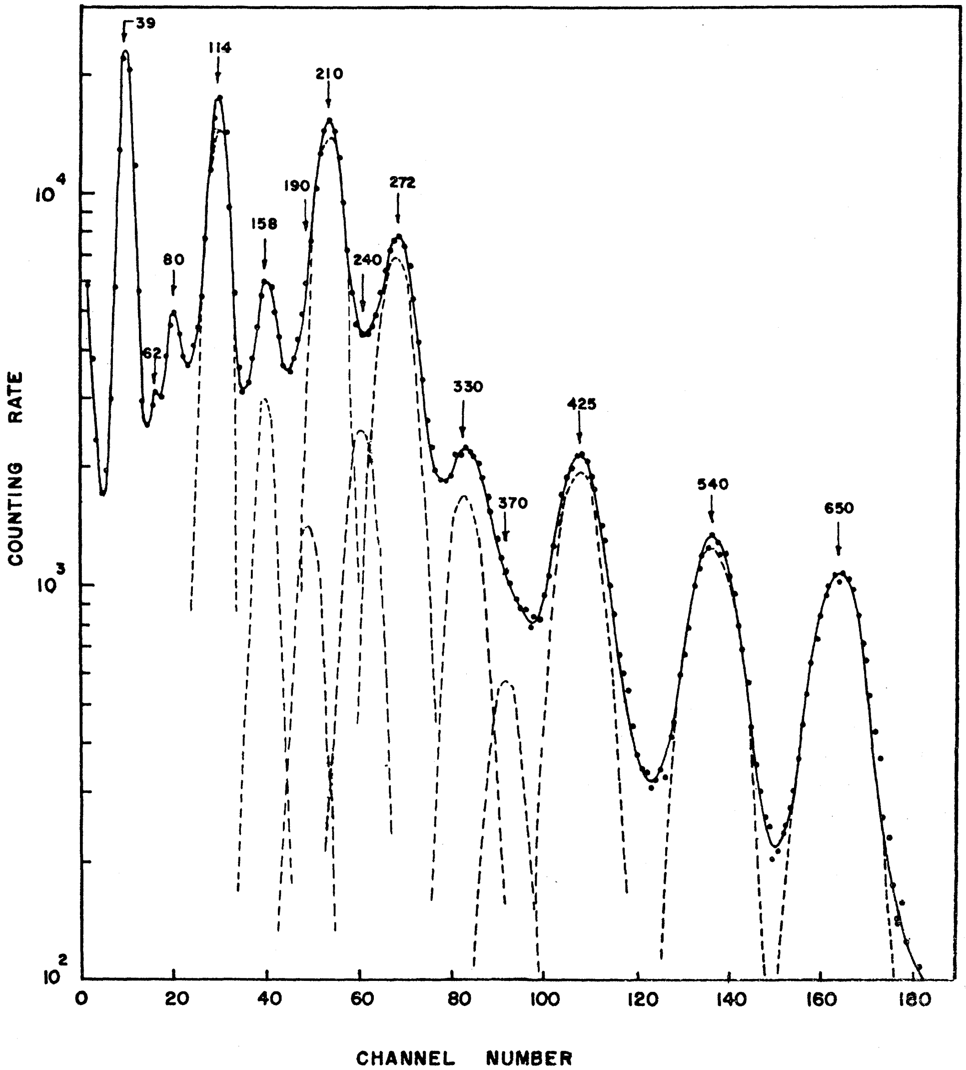


FIG. 3. Singles gamma-ray spectrum of Nd^{149} in a 3-in.-diam×3-in.-thick NaI(Tl) crystal. Source-to-detector distance was 20 cm. The energies are given in keV.

were found to belong to the 1.8-h Nd^{149}. With 272-keV region in the gate 39, 62, 80, 114, 158, 210+240, and 270 keV were in coincidence and a weak 370 keV was also found in coincidence (Fig. 6B). The decay of this coincidence spectrum was also followed and all the observed coincidences were found to belong to Nd^{149}. The weak 370-keV gamma ray is shown as a transition between 650- and 272-keV levels. It was estimated that 16% of the 270-keV gamma ray is in coincidence with a gamma ray of similar energy. In the decay scheme (Fig. 1) this is shown as the 266-keV transition from the 538- to the 272-keV level. It is to be noticed that a 62-keV gamma ray is observed in coincidence with 210- and 272-keV gamma rays. This is shown as a transition between the 272- and 210-keV levels. This also explains a peak in the 270-keV region observed in coincidence with the 210-keV region and vice versa. With 158-keV gamma rays, 39, 80, and 114 keV were found in coincidence and a peak in the 240-keV region and 270 keV were also weakly in coincidence. To explain these coincidences, the 158 keV is shown as a transition between the 272- and 114-keV levels. The 80-keV transition is shown between the 352- and 272-keV levels and a 238-keV transition between 510- and 272-keV levels are shown (Fig. 1). When the 80-keV region was taken in the gate, 39, 114, 158, 210, and 272-keV gamma rays were in coincidence. All the observed gamma rays, except 650 keV were found in coincidence with 39-keV x rays and 114-keV gamma rays. Table II shows the various gamma-gamma coincidences.

When the 650-keV region was taken in the gate, a weak coincidence was observed with 39 and 114 keV. Even though the coincidence counts were low, they were several times the chance coincidence counts. From the observed intensity of the 114-keV peak, about 4% of the 650-keV gamma ray could be in coincidence with 114 keV. This weak coincidence is explained by a 626-keV transition between 740- and 114-keV levels (Fig. 1). This coincidence was confirmed by the total-absorption gamma-ray spectrum.

TABLE II. Gamma-gamma coincidences in the decay of Nd^{149}.

Gamma ray in gate (keV)	Gamma rays observed in coincidence (keV)
540	39, 114, (210)[a]
425	39, 114, (210)
330	39, 114, 210
270	39, 62, 80, 114, 158, 210, 270, (370)
210	39, 62, 80, 114, 210, 270, 330, (440), (540)
158	39, 80, 114, 210, 266
114	39, 80, 114, 158, 210, 270, 330, 425, 540
80	114, 158, 210, 272
39 (x ray)	80, 114, 158, 210, 272, 330, 423, 540

[a] Those given in parenthesis are weak coincidences.

E. The Summing Spectrum

The gamma spectrum was studied by keeping a weak source in the well of 0.25-in. diam×1.5-in.-deep in a 3-in.-diam×3-in.-thick NaI(Tl) crystal, whereby the cascade gamma rays give sum peaks. The beta rays were absorbed by 0.5 mm copper. The spectrum (Fig. 7) showed indication of the strong 650- and 540-keV levels by the enhancement of these peaks as compared to the spectrum with the source outside. The enhancement of the 425-keV peak can be explained as due to summing of 330+112-, 266+158-, and 210+240-keV gamma rays (Fig. 1) which are observed in gamma-gamma coincidences. A weak level was also found at 740 keV by the presence of the sum-peak at that energy. The shift in the peak of summing spectra towards the higher energy side due to the nonlinear response of NaI(Tl) crystal[10] was taken into account while assigning the energy for the 740-keV level. This sum-peak was found to belong to Nd^{149} by following its decay over four half-lives (Fig. 7). The presence of this level is also in confirmation of the weak 530–210- and 626–114-keV cascades as observed in gamma-gamma coincidences. A small peak observed at 890 keV was of doubtful origin as it had no other supporting evidence.

F. Beta-Gamma Coincidences

The end points of beta spectra in coincidence with gamma rays of various energies were found out by scintillation method. The gamma rays were detected in a 3-in.-diam×3-in.-thick NaI(Tl) gate detector and the beta rays in coincidence with them scanned by means of a 2.5-cm-diam×1-cm-thick anthracene crystal coupled to a Dumont 6292 photomultiplier and a 512-channel analyzer. The coincidence resolving time was $2\tau=0.2$ μsec. The anthracene spectrometer was calibrated using the 976- and 432-keV K-conversion lines of Bi^{207}, the 624- and 329-keV K-conversion lines of Cs^{137} and Au^{198}, respectively. Its performance was checked by the end point of the beta spectrum of P^{32} at 1700 keV and that of the Au^{198} beta spectrum in coincidence with 412-keV gamma rays at 960 keV.

[10] H. G. Devare and P. N. Tandon, Nucl. Instr. **22**, 253 (1963).

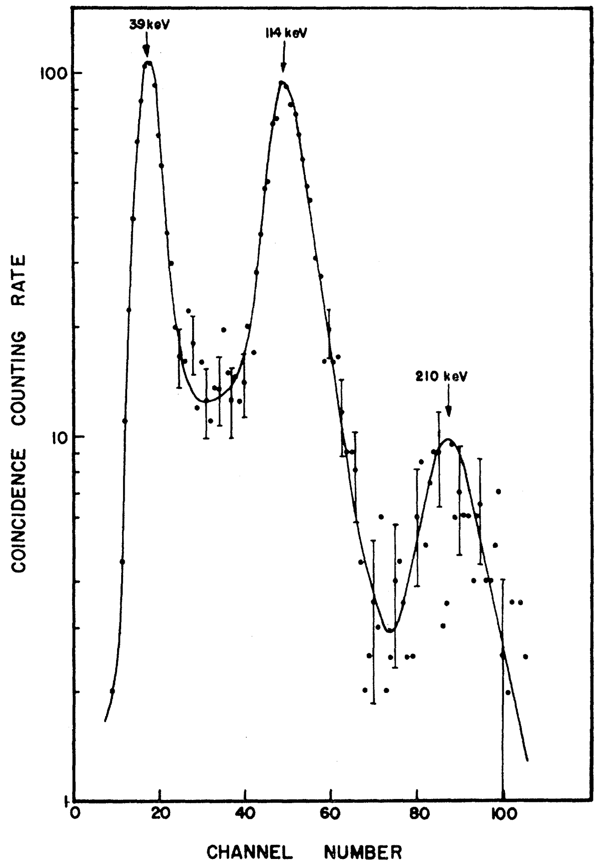


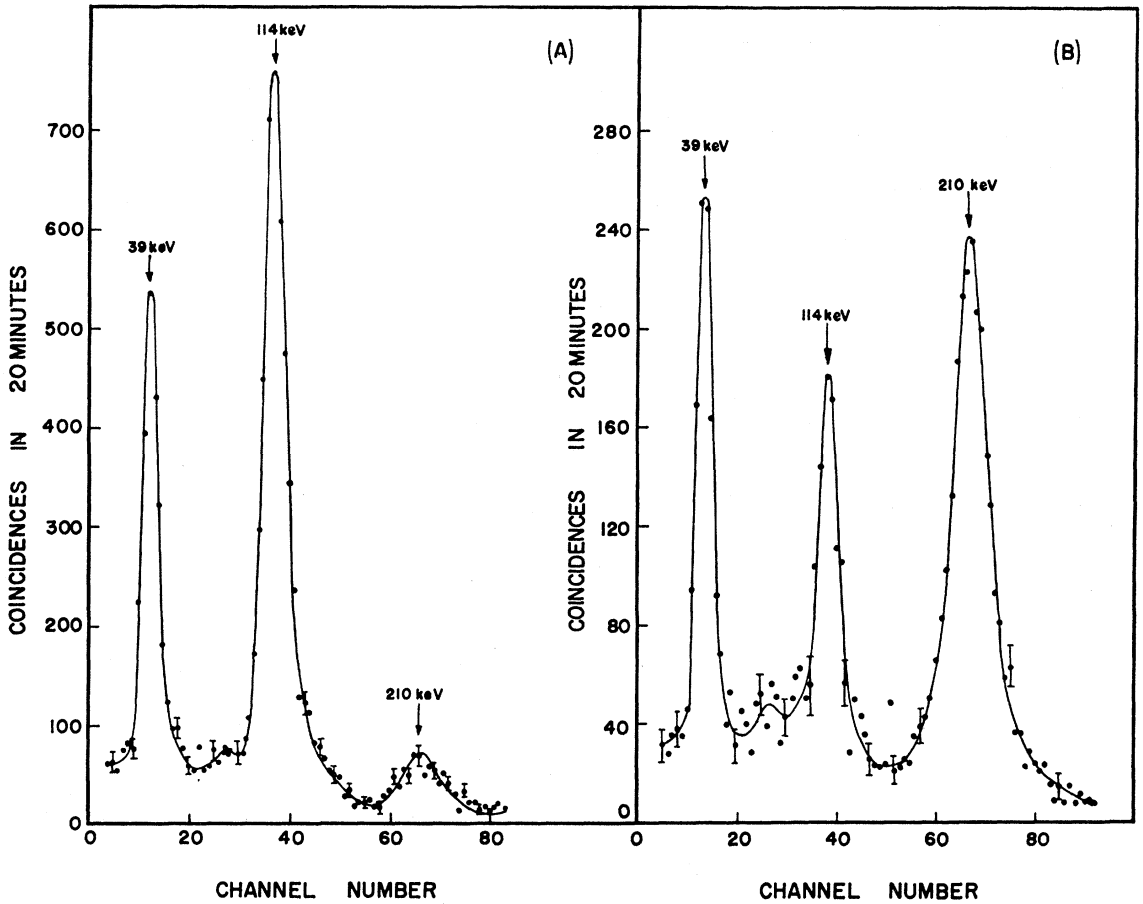
FIG. 4. Gamma spectrum in coincidence with 540-keV gamma rays using a 1.5-in.-diam×0.5-in.-thick NaI(Tl) crystal with an aluminum window of 10 mg/cm² thickness.

The Nd^{149} source was deposited on a Mylar film. The source had a thickness ~10 mg/cm². The end points of the beta spectra in coincidence with photopeaks of various gamma rays were determined by Fermi-Kurie analysis of the coincidence spectra and are shown in Table III.

The beta spectra in coincidence with 650 keV (Fig. 8A) and 114 keV had end points of 1020±20 and 1560±20 keV, respectively, indicating that the total decay energy of $Nd^{149}\rightarrow Pm^{149}$ is 1670±20 keV. The

TABLE III. End points of beta spectra in coincidence with gamma rays.

Gamma ray in gate (keV)	End point of the highest energy beta group (keV)
650	1020±20
540	1020±20
424	1130±20 (complex)
330	1140±20 (complex)
270	1400±20, 1140±20 (complex)
210	1450±20 (complex)
158	1390±20
114	1560±20



(A) (B)

FIG. 5. Gamma spectrum in coincidence with (A) 424-keV; (B) 330-keV gamma rays.

end point of the beta spectrum in coincidence with 540-keV gamma rays (Fig. 8B) was 1020±20 keV. This indicated that the 540- and 650-keV gamma rays originate from the same level (Fig. 1), in contradiction to the decay scheme suggested earlier.[7] The spectrum in coincidence with the 270-keV gamma rays showed distinctly two beta groups with end points at 1400±20 and 1140±20 keV, respectively (Fig. 8C). The end point of the beta spectrum in coincidence with 158 keV was 1390±20 keV (Fig. 8D). These observations suggest that there is a beta branching with end-point energy of 1390±20 keV going to the 272-keV level (Fig. 1) and that the 158-keV gamma ray originates from the 272-keV level. The beta spectrum in coincidence with the 210-keV gamma rays was complex, but the highest energy beta group was found to be 1450±30 keV.

In further confirmation of the position of the 540-keV transition, the gamma spectra in coincidence with beta rays of various energy intervals were scanned in a 3-in.-diam×3-in.-thick NaI(Tl) spectrometer. The anthracene scintillation spectrometer was used to fix the energy gate of beta rays. When the beta energy was fixed above 1020 keV, all the lower energy gamma rays up to 424 keV were found in coincidence and no 540 keV was observed in coincidence, and when the beta energy was below 1020 keV, 540- and 650-keV gamma rays appeared in coincidence (Fig. 9). This again confirms that the 540-keV gamma ray originates from the 650-keV level.

G. *K*-Conversion Coefficient of the 114-keV Transition

Since it is established that the 540-keV gamma ray goes to the 114-keV level (Fig. 1), the *K*-conversion coefficient of the 114-keV transition could be determined by coincidence with the 540-keV gamma rays. To reduce the absorption of the 39-keV *K*-x ray of promethium in the cover of the detector, a 1.5-in.-diam ×0.5-in.-thick NaI(Tl) crystal with an aluminium window of thickness 10 mg/cm^2 was used as the scanner detector. Otherwise, the coincidence set up was identical to that used for gamma-gamma coincidence. From the

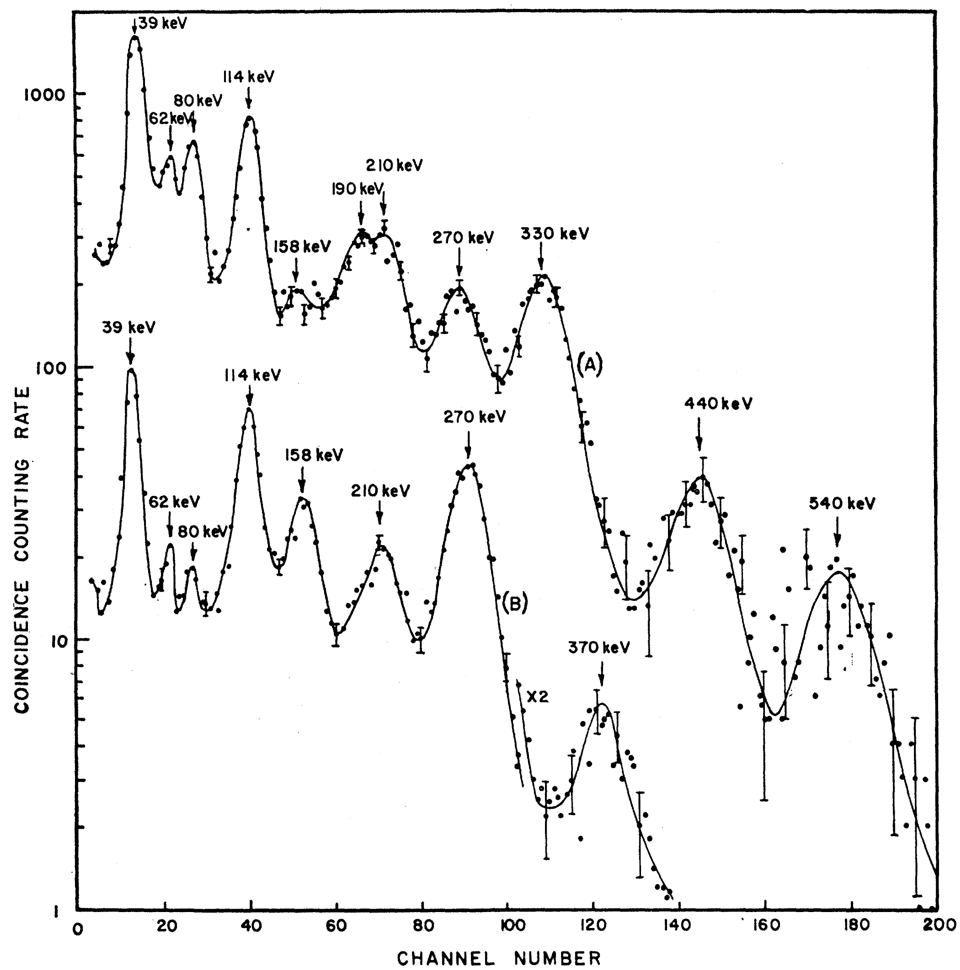


FIG. 6. Gamma spectrum in coincidence with (A) 210-keV (B) 270-keV gamma rays.

observed coincidence spectrum (Fig. 4) the contributions of 39-keV x rays and 114-keV gamma rays were calculated. Various corrections[11] such as that for escape peak, absorption of x rays and 114-keV gamma rays in the cover of the crystal and the 6-mm Perspex beta absorber used, and the contribution of the 210-keV Compton continuum under the 114- and 39-keV peaks and the K-fluorescence yield of promethium[12] were applied. The details of the various corrections in the measurement are described elsewhere.[11] The total detection efficiency for the 1.5-in.-diam$\times$0.5-in.-thick detector was taken as the one extrapolated from the calculated[13] values. The value of α_K was found to be 0.83 ± 0.1. The K/L ratio as determined by Rutledge *et al.*[7] for this transition is 4.8 ± 1.6. By comparing these with the theoretical values[14,15] the 114-keV transition is assigned to be of $M1(90\%)+E2(10\%)$ character.

III. DECAY SCHEME AND DISCUSSION

The decay scheme given in Fig. 1 is consistent with the observed gamma-gamma coincidences and the end points of beta spectra in coincidence with the various gamma rays. In addition to the four major beta groups observed in the singles beta spectrum, weaker beta transitions to the 272- and the 740-keV levels are also present. The actual intensities of the various beta transitions were calculated from the gamma intensities obtained from singles and coincidence spectra. These intensities and the log ft values are shown in Table IV.

The levels at 114, 210, 538, and 650 keV were reported earlier.[7] The levels at 272 and 538 keV explain the end

[11] B. V. Thosar, M. C. Joshi, R. P. Sharma, and K. G. Prasad, Nucl. Phys. **50**, 305 (1964).

[12] A. H. Wapstra, G. J. Nijgh, and R. Van Lieshout, *Nuclear Spectroscopy Tables* (North-Holland Publishing Company, Amsterdam, 1959).

[13] E. A. Wolicki, R. Jastrow, and F. Brooks, U. S. Naval Research Laboratory Report No. 4833, 1956, (unpublished); quoted in *Handbuch der Physik*, edited by S. Flügge (Springer-Verlag, Berlin, 1958), Vol. XLV, p. 122.

[14] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

[15] L. A. Sliv and I. M. Band, *Tables of Internal Conversion Coefficients of Gamma Rays* (Academy of Sciences, U.S.S.R., 1956 and 1958), Parts 1 and 2.

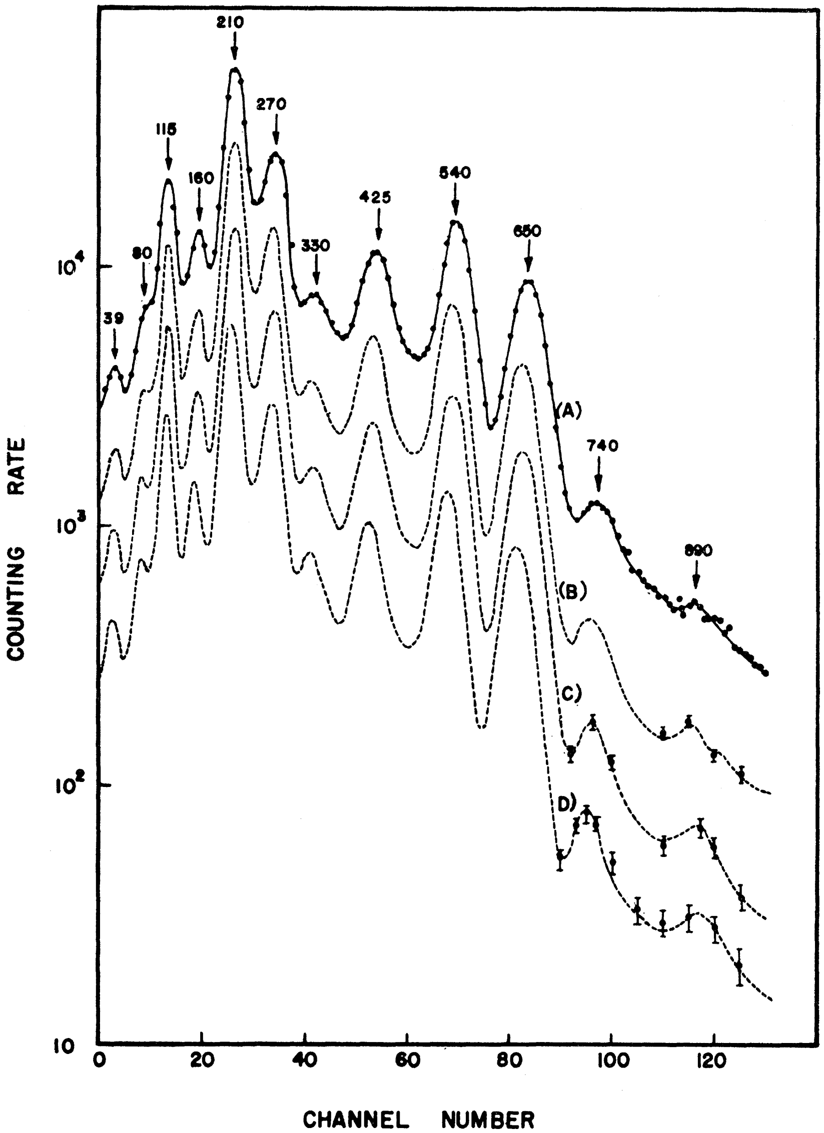


FIG. 7. The total-absorption gamma-ray spectrum with the source inside the well of a 3-in.-diam ×3-in.-thick NaI(Tl) crystal. (A) at 10.14 h, (B) at 12.15 h, (C) at 14.17 h, and (D) at 16.35 h.

points of the beta spectra in coincidence with 272-keV gamma rays and the 112–266–272-keV cascade. There is no evidence for a direct transition to the ground from the 538-keV level beyond the limits of the experimental error. The levels at 352 and 510 keV are proposed to explain the presence of the 80- and 62-keV transitions observed in coincidence with 210- and 272+266-keV gamma rays. The 238- and 186-keV gamma rays observed in the analysis of the singles spectrum and in gamma-gamma coincidences could be explained with these levels. Within the limits of the experimental accuracy no beta transitions to the 510- and 352-keV levels are observed. Rutledge *et al.*[7] have proposed levels at 124 and 312 keV to explain the 124-, 226-, and 188-keV transitions observed in the conversion electron spectrograph work. In our work the presence of a possible 226–188–124-keV cascade cannot be completely ruled out in presence of the strong cascades of similar energies.

TABLE IV. Intensities of beta transitions calculated from gamma intensities and their log *ft* values.

β_{group}	E_β (keV)	Intensity	log *ft*
β_1	1555	6.5%	7.3
β_2	1460	30%	6.6
β_3	1400	11%	7.0
β_4	1130	17%	6.5
β_5	1020	35%	6.0
β_6	930	0.5%	7.5

For the odd-*A* promethium nuclei with 61 protons, the ground-state spin and parity could be expected to be $5/2^+$ for the proton configuration $(g_{7/2})^6(d_{5/2})^5$ from

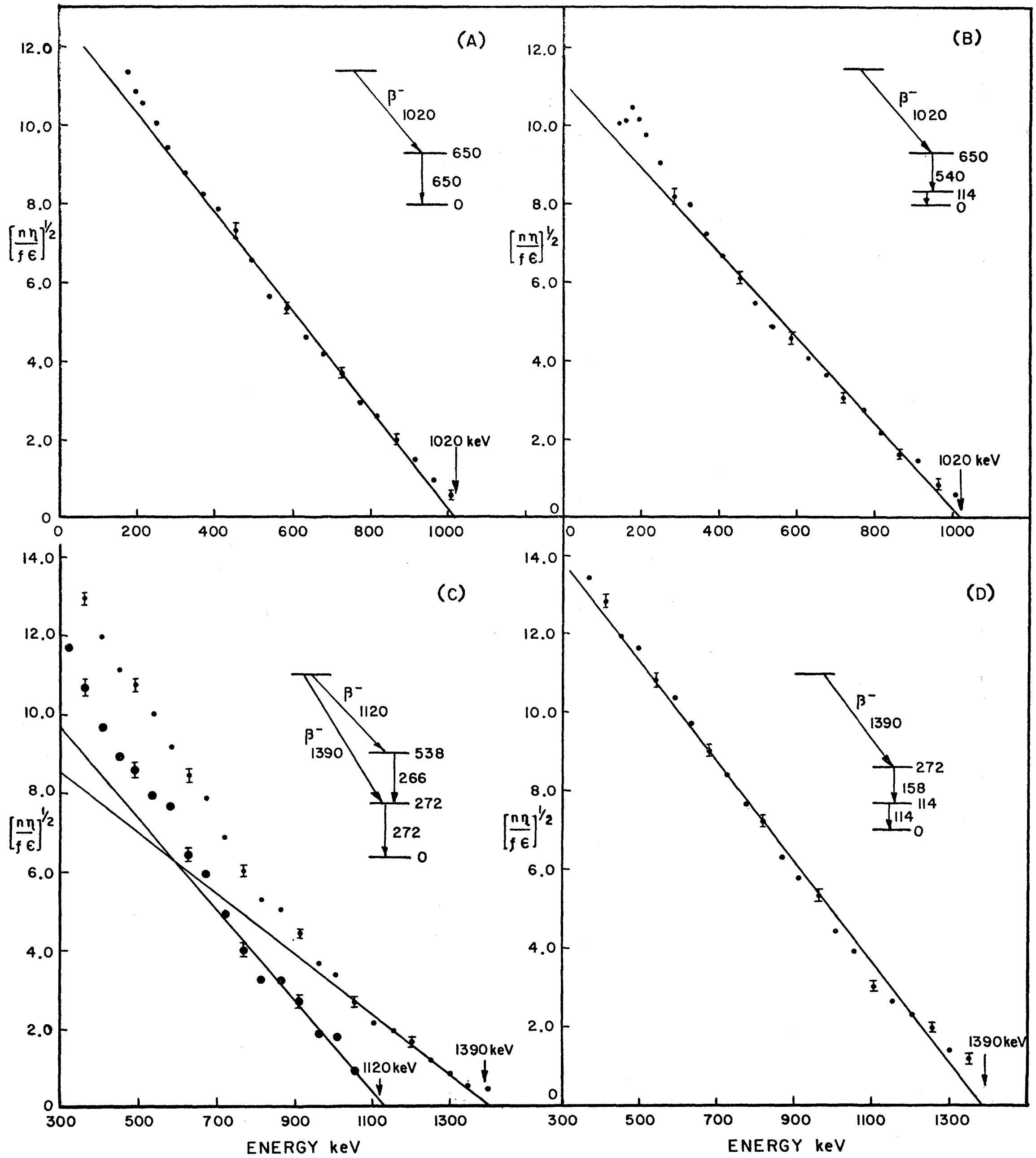


FIG. 8. Fermi-Kurie plot of beta spectrum in coincidence with (A), 650-keV, (B) 540-keV, (C) 270-keV, and (D) 158-keV gamma rays.

the shell model. The spins and parities of the ground state and the first excited state of Pm^{145}, which has nearly spherical-equilibrium shape, are probably $5/2^+$ and $7/2^+$ as assigned[16] from the decay schemes of Sm^{145} and Pm^{145}. Addition of more neutrons pairwise appears to change the effective spacing between $g_{7/2}$ and $d_{5/2}$ orbitals causing $g_{7/2}$ as the ground state for the heavier promethium nuclei—Pm^{147} and Pm^{149}. This is now confirmed by the direct measurement[17,18] of the ground-state spins of Pm^{147} and Pm^{149}. The first excited states

[16] A. R. Brosi, B. H. Ketelle, H. C. Thomas, and R. J. Kerr, Phys. Rev. **113**, 239 (1958).

[17] A. Y. Cabezas, I. Lindgren, and R. Marrus, Phys. Rev. **122**, 1796 (1961); Burton Budick and Richard Marrus, *ibid.* **132**, 723 (1963).

[18] A. Cabezas, I. Lindgren, E. Lipworth, R. Marrus, and M. Rubinstein, Nucl. Phys. **20**, 509 (1960).

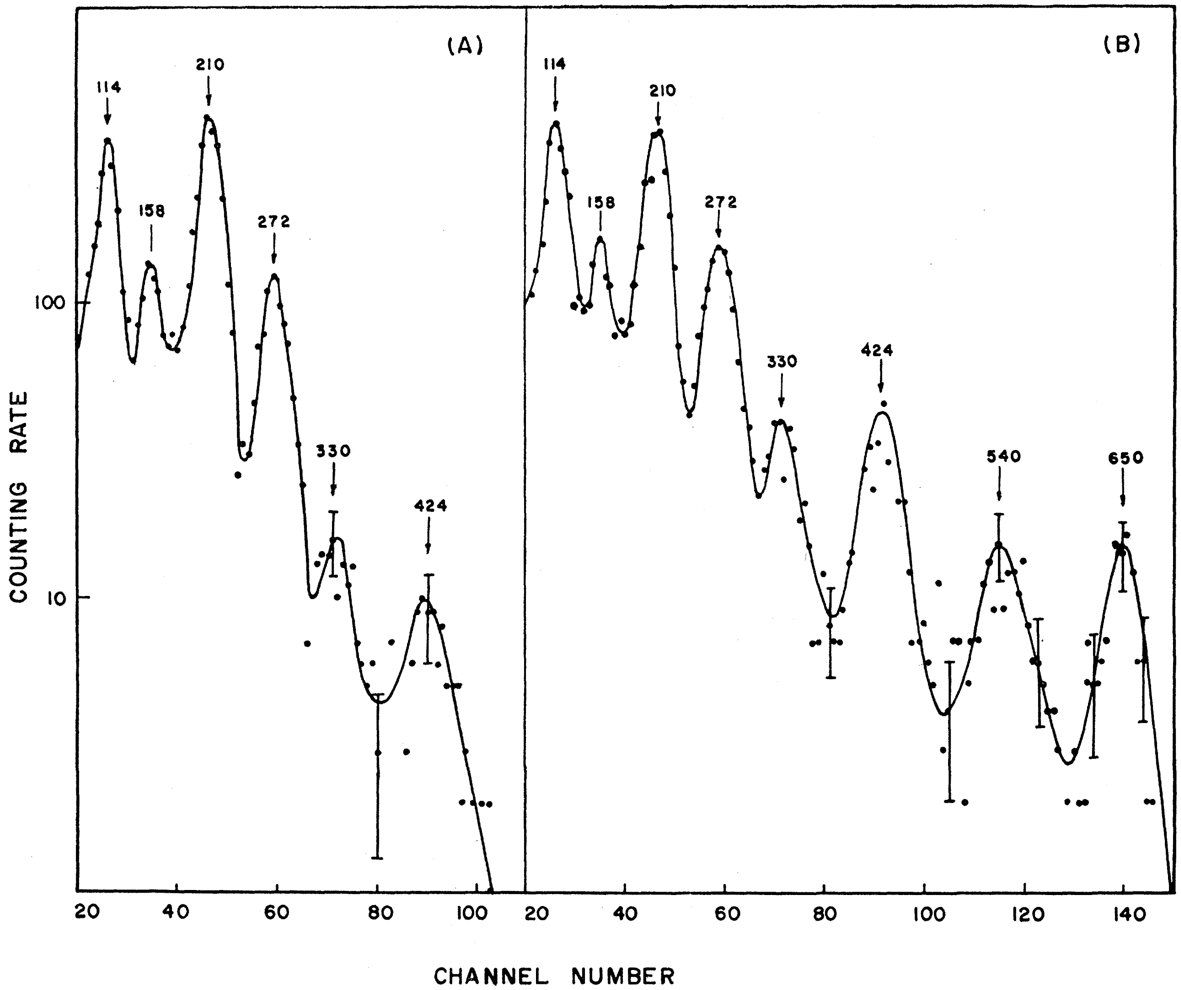


FIG. 9. Gamma spectrum in coincidences with beta rays in the energy intervals (A) 1010–1100 keV, (B) 740–830 keV. The energies of gamma rays are given in keV.

of Pm^{147} and Pm^{149} are assigned spin and parity $5/2^+$ which can be understood as the proton configuration $(g_{7/2})^6(d_{5/2})^5$. This assignment implies that the transition from the first excited state to the ground state is of l-forbidden $M1$ character. This is supported by experimental evidence[19] for Pm^{145} and Pm^{147}. In the case of Pm^{149} similar property is expected.

Recently Kisslinger and Sorensen[20] have calculated the low-energy level structure for spherical nuclei with residual forces taken into account. It is found that for odd-proton nuclei below the deformed region—$A \leq 150$, $82 \leq N \leq 90$—the theoretical predictions are not in agreement with the experimental results because of the approaching deformed region. However, it is still assumed that by adjusting the coupling strength, the single-particle level spacing, etc., the level structure of Pm^{149} can be described as due to the single-particle orbitals $g_{7/2}$, and $d_{5/2}$ of the odd proton, coupled to the vibrations of the even-even core of Nd^{148} which exhibits the character of vibrational spectrum at least up to the two-phonon state. When the coupling is introduced, one-phonon states will split into states corresponding to the addition of a j particle to the 2^+ level as 11/2, 9/2, 7/2, 5/2, and 3/2 due to the $g_{7/2}$ particle and 1/2, 3/2, 5/2, 7/2, and 9/2 due to the $d_{5/2}$ particle. The order of the level scheme can only be obtained by detailed calculations, which can then be used for comparing the experimental level scheme. With this in mind, tentative spin and parity assignments have been made to some of the Pm^{149} levels based on the observed relative beta- and gamma-ray transitions. The K/L conversion ratio for 210-keV transition[7] indicates that it is of $M1+E2$ character. The beta transition with log $ft=6.6$, to the 210-keV level is of first-forbidden ($\Delta J = \pm 1$, yes) type.

[19] E. Ye. Berlovich II, G. M. Bukat, Yu. K. Gusev, V. V. Il'in, V. V. Nikitin, and M. K. Nikitin, Phys. Letters **2**, 344 (1962).
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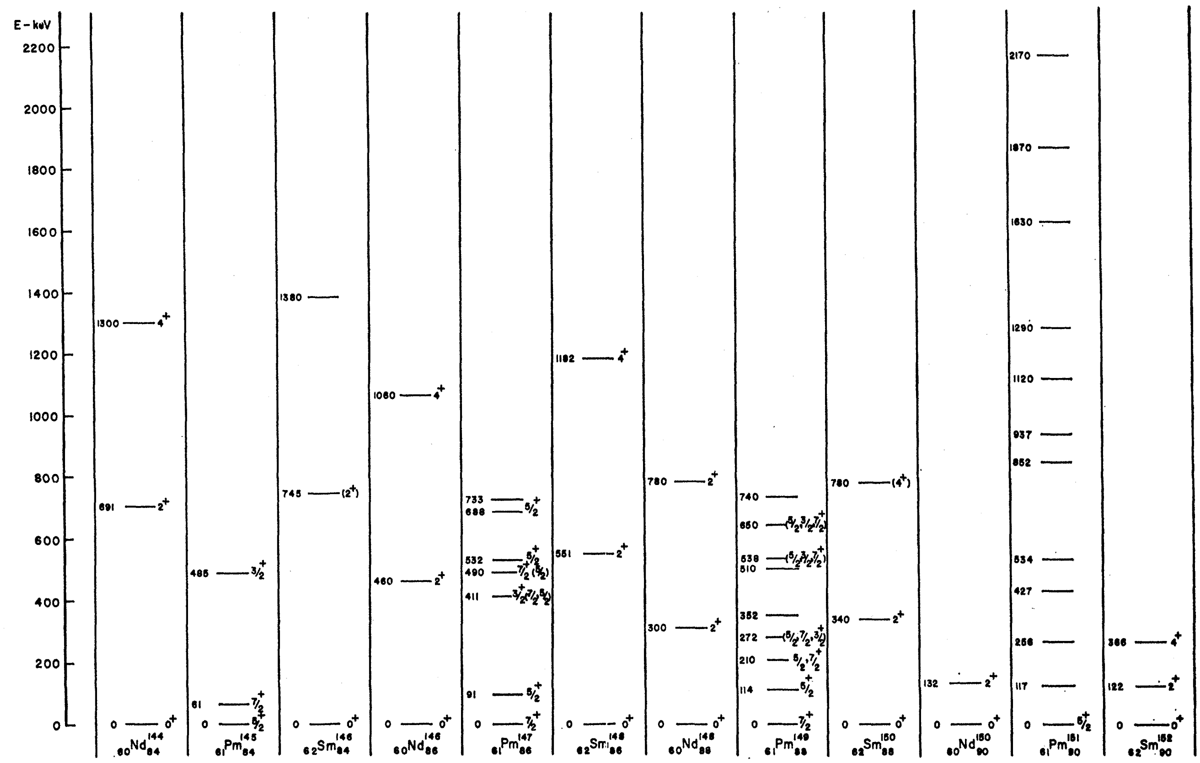

FIG. 10. Level systematics of odd-A Pm nuclei and the neighboring even-even nuclei.

The measured spin[21] of the ground state of Nd^{149} is $5/2^-$ which is assumed to be due to the neutrons in the $f_{7/2}$ orbital. From this information it is inferred that the spin of the 210-keV level is either $5/2^+$ or $7/2^+$. Similarly the log ft values of beta transitions to 650-, 538-, and 272-keV levels indicate the possible assignments $3/2^+$, $5/2^+$, or $7/2^+$, to these levels. Although levels with spin and parity $1/2^+$ and $9/2^+$ are also expected in the low-energy level structure of this nucleus, such assignments cannot be made unambiguously at present. More data are needed.

In Fig. 10, the levels of odd-A promethium nuclei are shown along with those of the neighboring even-even nuclei in order to show the change in the level pattern when passing from the spherical (Pm^{145}) to the deformed (Pm^{151}) region. The data on Pm^{147} are taken from the results of recent measurements on nuclear orientation[22] and gamma-gamma angular correlation[23] and those of Pm^{145} and Pm^{151} from *Nuclear Data Sheets*.[24] The data on Pm^{151} are still insufficient to make any definite conclusion.

ACKNOWLEDGMENTS

The authors are grateful to Professor B. V. Thosar for his keen interest in this work. Thanks are due to R. P. Sharma, R. R. Hosangdi, and M. Radha Menon for their cooperation during the work. We thank G. V. Nadkarny and his Reactor Operation Group at "Apsara" for neutron irradiation of the samples.

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