Promethium Isotopes*†

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The half-lives and radiation characteristics of some promethium isotopes have been measured. Bombardments of isotopically enriched neodymium oxide samples by 8.9–32-Mev protons and of praseodymium oxide samples by 15–36-Mev helium ions were used to produce these nuclides. They were identified chemically and on the basis of relative yields. Nuclides studied: Pm^{141}, Pm^{142}, Pm^{143}, Pm^{144}, Pm^{146}, Pm^{149}, and Pm^{150}.

PROMETHIUM is one of the two medium-weight elements not found in nature, an absence that has been explained as arising from the fact that its most stable nuclides are 2–4 neutrons above the closed 82 neutron shell.[1,2] This work was undertaken to add to the knowledge concerning the radioactive characteristics of the promethium isotopes and thus to further substantiate the nuclear shell structure theory in this region.

PROCEDURE

The nuclides studied were produced by bombardment of isotopically enriched[3] neodymium oxides with 8.9-Mev protons from the 60-inch cyclotron, with 10-, 20- and 32-Mev protons from the linear accelerator, and by bombardment of praseodymium oxide with 15- to 36-Mev helium ions from the 60-inch cyclotron.

Since the number of radionuclides produced by the relatively low energy bombarding particles was limited, in general, chemical procedures were designed to isolate the rare earth elements as a group but not separate them from each other. The bombarded oxides were dissolved in nitric acid from which the rare earth fluoride was precipitated. This was dissolved; the hydroxide was precipitated and dissolved in concentrated hydrochloric acid, which was sucked through a column of anion exchange resin (Dowex A-1). The rare earth hydroxide was then prepared for counting samples. In those cases where complete chemical identification was desirable, rare earth separations were made using a cation exchange resin column (Dowex-50, citrate eluting solution of *p*H 3.5) at elevated temperatures as described by Thompson *et al.*[4]

The particle and electromagnetic radiation energies and the ratios of the various components of the decays were determined from aluminum, beryllium, and lead absorption data. When possible, positrons and negatrons were differentiated, and their approximate energies were determined using a 180° low resolution beta-ray spectrometer. The electromagnetic radiation of several samples was studied on a scintillation spectrometer, and the negatron spectra of Pm^{149} and Pm^{150} were examined on the double focusing beta-ray spectrometer described by O'Kelley.[5]

RESULTS

The bombardment of $(Nd^{142})_2O_3$ with 8.9–10.9-Mev protons and of $(Pr^{141})_6O_{11}$ with 15–36-Mev helium ions did not produce an observable Pm^{142} activity. If this nuclide undergoes a highly forbidden positron decay analogous to that[6] of La^{138}, which might be the case since both Pm^{142} and La^{138} have 81 neutrons, an activity with a very long half-life would be expected. The experiments limit the half-life to less than 2 minutes or more than 100 years.

The $(Nd^{142})_2O_3$ yielded a 20-minute half-life activity when bombarded with 20- and 32-Mev protons. This was assigned to Pm^{141} from the $Nd^{142}(p, 2n)$ reaction.

Wilkinson and Hicks[7] reported an isotope decaying by electron capture with 285-day half-life and another decaying by positron emission with 4-hour half-life produced by bombardment of $(Pr^{141})_6O_{11}$ with 18–35 Mev helium ions. These were assigned to Pm^{143} and Pm^{144}, respectively, on the basis of the variation of their formation cross sections with energy. The nuclide with 285-day half-life was identified chemically as an isotope of promethium. In the present work, the bombardments were repeated with similar results. It was shown chemically, however, that the 4-hour half-life probably does not belong to an isotope of praseodymium, neodymium, promethium, samarium, or europium. It does not arise from deuteron contamination of the beam, but may be due to an impurity in the sample. This seems unlikely since spectroscopic analysis could detect none.[8] Bombardments of $(Nd^{143})_2O_3$ and $(Nd^{144})_2O_3$

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[1] L. Kowarski, Phys. Rev. **78**, 477 (1950).

[2] H. E. Suess, Phys. Rev. **81**, 1071 (1951).

[3] The percentage of the main constituent in each of the enriched fractions was as follows: $(Nd^{142})_2O_3$ (93.00), $(Nd^{143})_2O_3$ (83.93), $(Nd^{144})_2O_3$ (93.45), $(Nd^{145})_2O_3$ (78.60), $(Nd^{146})_2O_3$ (95.60), $(Nd^{148})_2O_3$ (89.85), and $(Nd^{150})_2O_3$ (94.76). Chemical purity >99 percent.

[4] Thompson, Ghiorso, and Seaborg, Phys. Rev. **80**, 781 (1950).

[5] G. D. O'Kelley, University of California Radiation Laboratory Declassified Report No. 1243 (1951).

[6] Pringle, Standil, and Roulston, Phys. Rev. **78**, 303 (1950).

[7] H. Hicks, University of California Radiation Laboratory Declassified Report No. 298 (1949); G. Wilkinson and H. Hicks, University of California Radiation Laboratory Declassified Report No. 751 (1950).

[8] Analysis by W. N. Tuttle, University of California Radiation Laboratory, Berkeley, California: As, Bi, Ce, Co, Cr, Dy, Er, Eu, Ho, La, Lu, Mn, Mo, Ni, Pb, Sb, Sn, Tb, Ti, V, Yb, Yt, and Zn not detected. Al, Ca, Fe, Mg, Nd, Sm, and Sc <0.1 percent.

TABLE I. Observed radioactive characteristics of promethium isotopes.

A	Type of radiation	Half-life	Energy of radiation (Mev) Particles	Electromagnetic	Produced by
141	β^+, γ	20±2 min	2.4–2.8 (spect.)		Nd^{142} $(p, 2n)$
142		<2 min >200 yr			
143 and 144	e^-, γ K, L x-rays	200–400 days	0.6 (abs.)	0.9 (abs.) 0.17±0.02, 0.44±0.03 0.65±0.04 (spect.) K, L x-rays	Nd^{143} (p, n) Nd^{144} (p, n) Pr^{141} (α, n) Pr^{141} $(\alpha, 2n)$
146	β^- or e^-, γ (?) K, L x-rays (?)	~1 yr	0.7 (abs.)	?	Nd^{146} (p, n)
148	β^-, γ K x-rays (?)	42±1 days	0.7 (92.6%) 2.7 (7.4%) (abs.)	~1.0 (abs.) K x-rays (?)	Nd^{148} $(p, 2n)$ or Nd^{148} (p, n)
149	β^-, γ K x-rays	54.4±1.1 hr	1.0 (abs.) 1.05±0.10 (spect.)	0.3–0.35 (spect.) (low intensity) K x-rays	Nd^{150} $(p, 2n)$
150	β^-, γ K x-rays (?)	161±1 min	2.01±0.03 (70±8%), 3.00±0.01 (30±8%) (spect.)	0.3, 1.4 (abs.) K x-rays	Nd^{150} (p, n)

separately with 8.9-Mev protons both yielded activities with half-lives of 200-400 days, consisting principally of electromagnetic radiation. These activities from the $(Pr^{141})_6O_{11}$, $(Nd^{143})_2O_3$, and $(Nd^{144})_2O_3$ bombardments were examined on a scintillation spectrometer. The conclusions drawn from these measurements were that Pm^{143} and Pm^{144} are probably very similar in their decay characteristics and that the activity observed from $(Pr^{141})_6O_{11}$ bombardments is probably a mixture due to both these nuclides. The possibility has not been ruled out that these two activities are independent isomers.

A particle emitting nuclide with a half-life of approximately one year was observed in high yield from $(Nd^{146})_2O_3$ and lower yields from $(Nd^{144})_2O_3$ and $(Nd^{143})_2O_3$ after 8.9-Mev proton bombardments; on the basis of yield considerations it was assigned to Pm^{146}.

Bombardment of $(Nd^{148})_2O_3$ with 8.9-Mev protons yielded the 42-day negatron emitter shown by Folger[9] to be an isotope of promethium, a long-lived nuclide emitting a 0.2-Mev negatron (probably the 3.7-year[10] Pm^{147}), and the 5.3-day[10] activity characteristic of Pm^{148}. Recently Long and Pool[11] reported a 48-day activity produced by 6-Mev protons on neodymium enriched in Nd^{148}. This is probably identical with the 42-day activity observed here, which thus belongs to an isomer of Pm^{148}.

Radionuclides with 161-minute and 54-hour half-lives were produced by the bombardment of $(Nd^{150})_2O_3$ with 8.9–9.9-Mev protons. On the basis of cross section considerations, they were assigned to Pm^{150} and Pm^{149}, respectively. The nuclide Pm^{149} has been reported[10] to have a half-life of 47–55 hours and to emit a 0.95–1.1-Mev negatron and a 0.2–0.25-Mev gamma-ray. The 161-minute activity assigned to Pm^{150} can probably be identified with a previously reported [10,11] 2.7-hour half-life activity. In the present experiments it was shown chemically to belong to an isotope of promethium.

The conclusions drawn are summarized in Table I.

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[9] R. Folger and P. C. Stevenson, private communication (April, 1951).
[10] G. T. Seaborg and I. Perlman, Revs. Modern Phys. **20**, 585 (1948).
[11] J. K. Long and M. L. Pool, Phys. Rev. **85**, 137 (1952).