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A. Ghiorso, W. W. Meinke and G. T. Seaborg

Berkeley, California

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ARTIFICIAL COLLATERAL CHAINS TO THE THORIUM AND ACTINIUM FAMILIES

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ABSTRACT

We have produced and identified two new series of alpha-particle emitting radioactive elements; one is a "collateral" branch of the actinium (4n + 3) radioactive family and the other is collateral to the thorium (4n) family. The series are of considerable interest in that they are the first whose early members lie on the neutron deficient side of beta stability. They have been produced in high yield by irradiation of thorium with deuterons of energy about 80 Mev in the Berkeley 184-inch cyclotron. So far as the present observations are concerned both of these series begin with isotopes of protactinium (atomic number 91), although progenitors with higher atomic numbers are to be expected and will possibly be produced and identified. These protactinium isotopes are Pa^{227} and Pa^{228} formed by d,7n and d,6n reactions respectively.

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We have produced and identified two new series of alpha-particle emitting radioactive elements; one is a "collateral" branch of the actinium (4n + 3) radioactive family and the other is collateral to the thorium (4n) family. The series are of considerable interest in that they are the first whose early members lie on the neutron deficient side of beta stability. They have been produced in high yield by irradiation of thorium with deuterons of energy about 80 Mev in the Berkeley 184-inch cyclotron. So far as the present observations are concerned both of these series begin with isotopes of protactinium (atomic number 91), although progenitors with higher atomic numbers are to be expected and will possibly be produced and identified. These protactinium isotopes are Pa^{227} and Pa^{228} formed by d,7n and d,6n reactions respectively.

After bombardments of the order of one-half to four hours duration, the metallic thorium was dissolved and the element protactinium was isolated in essentially weightless fractions.

The decay of the alpha-particles from these was measured both through the use of standard alpha-particle counting devices and also with the help of an alpha-particle pulse analyzer[1] equipped

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1. See, e.g., A. Ghiorso, A. H. Jaffey, H. P. Robinson and B. Weissbourd, "An Alpha-Pulse Analyzer Apparatus", Plutonium Project Record 14B, 17.3 (1948) (to be issued).

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with a fast sample-changing mechanism. Through the use of the latter, a number of alpha-particle groups were observed and their energies determined.

Prominent soon after bombardment are a number of alpha-particle groups, which decay with the 38-minute half-life of the protactinium parent. These are due to the following collateral branch of the 4n + 3 radioactive family:

$$_{91}Pa^{227} \xrightarrow{\alpha} {}_{89}Ac^{223} \xrightarrow{\alpha} {}_{87}Fr^{219} \xrightarrow{\alpha} {}_{85}At^{215} \xrightarrow{\alpha}$$

$$_{83}Bi^{211}(AcC) \xrightarrow{\alpha} {}_{81}Tl^{207}(AcC'') \xrightarrow{\beta^-} {}_{82}Pb^{207}(stable).$$

The branch which arises from orbital electron capture by Pa^{227} is not shown. The mass type was identified by observation of the characteristic energy and half-life of the Bi^{211}(AcC) alpha-particles, the half-life of the beta-particle-emitting Tl^{207}(AcC") and the growth of 18.9-day Th^{227}(RdAc) as an orbital-electron-capture branching decay product of the Pa^{227} (ratio $K/\alpha = \sim 0.2$). The energy obtained for these At^{215} alpha-particles is several hundred kilovolts less than that reported[2] for At^{215}

2. B. Karlik and T. Bernert, Naturwissenschaften 32, 44 (1944).

as formed by the beta-particle branching decay of Po^{215}(AcA).

Identification of members of the series was aided by a simple method of recoil collection. Recoil atoms were collected from a plate which contained the entire series in equilibrium and measurements using the plate upon which these were collected established the half-life and the energy of the Ac^{223} alpha-particles. In a "second order" recoil experiment recoils were collected from the plate containing Ac^{223}(and daughters) in order to check the half-life of the alpha-particles attributed to Bi^{211}(AcC) and similarly a third order recoil experiment was effected in order to isolate the beta-particle emitter and prove that it decayed with the known half-life of Tl^{207}(AcC"). The very short half-lives of the Fr^{219} and At^{215} were estimated and their energies identified through crude coincidence experiments using the pulse analyzer apparatus to operate the driven sweep of a cathode ray oscillograph. The measured half-lives and energies for the members of this series are summarized in Table I below.

After the decay of the above described series, a second group of alpha-particle emitters can be resolved. This second series, which decays with the 22-hour half-life of its protactinium parent, is a collateral branch of the 4n radioactive family as follows:

$$ {}_{91}Pa^{228} \xrightarrow{\alpha} {}_{89}Ac^{224} \xrightarrow{\alpha} {}_{87}Fr^{220} \xrightarrow{\alpha} {}_{85}At^{216} \xrightarrow{\alpha} $$

$$ {}_{83}Bi^{212}(ThC) \xrightarrow[34\%]{\alpha} {}_{81}Tl^{208}(ThC'') \xrightarrow{\beta^-} {}_{82}Pb^{208}(stable) $$

$$ {}_{83}Bi^{212}(ThC) \xrightarrow[66\%]{\beta^-} {}_{84}Po^{212}(ThC') \xrightarrow{\alpha} {}_{82}Pb^{208}(stable) $$

The branch which arises from orbital electron capture of Pa^{228} and Ac^{224} is not shown. The mass type was identified through observation of the characteristic radioactive properties of the Bi^{212}(ThC) and its daughters, chemical identification of Bi^{212}(ThC), the growth of Th^{228}(RdTh) as an orbital-electron-capture branching decay product of the Pa^{228} (ratio $K/\alpha = \sim 50$) and the growth of Ra^{224}(ThX) as a similar product of the Ac^{224}(ratio $K/\alpha = \sim 10$). Of interest is the check, within about 0.15 Mev, of the energy of these At^{216} alpha-particles with the energy reported[3] for At^{216} as formed by the beta-particle

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3. B. Karlik and T. Bernert, Naturwissenschaften **31**, 492 (1943).

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branching decay of Po^{216}(ThA). The half-life of the Ac^{224} could be measured and the energy of its alpha-particles identified as the result of its collection in recoil experiments. Similarly, the half-life and alpha-particle energy of the Fr^{220} could be determined by second order recoil experiments from plates containing only Ac^{224}(and daughters). The very short half-life of At^{216} was estimated as described above and its energy could be determined by measurements on samples containing its progenitors. The half-lives and energies are summarized in Table I. The radioactive properties of ThC (and AcC) and daughters are the accepted values taken from the literature[4].

4. See, e.g., G. T. Seaborg, Rev. Mod. Phys. 16, 1 (1944).

Table I

Isotope	Type of Radiation	Half-life	Energy of Radiation (Mev)
$_{91}Pa^{227}$	α	38 min.	6.46
$_{89}Ac^{223}$	α	$\sim$ 2 min.	6.64
$_{87}Fr^{219}$	α	$\sim 10^{-4}$ sec.	7.30
$_{35}At^{215}$	α	$\sim 10^{-4}$ sec.	8.00
$_{83}Bi^{211}$ (AcC)	α(99.7%)	2.16 min.	6.62
$_{81}Tl^{207}$ (AcC'')	β^-	4.76 min.	1.47
$_{82}Pb^{207}$	stable		
$_{91}Pa^{228}$	α	22 hr.	6.09
$_{89}Ac^{224}$	α	$\sim$2.5 hr.	6.17
$_{87}Fr^{220}$	α	$\sim$30 sec.	6.69
$_{85}At^{216}$	α	$\sim 10^{-3}$ sec.	7.79
$_{83}Bi^{212}$ (ThC)	α (34%)	60.5 min.	6.05
	β^-(66%)		2.20

Table I (cont'd)

Isotope	Type of Radiation	Half-life	Energy of Radiation (Mev)
$_{81}Tl^{208}$ (ThC")	β^-	3.1 min.	1.82
$_{84}Po^{212}$ (ThC')	α	3×10^{-7} sec.	8.78
$_{82}Pb^{208}$	stable		

These data extend the information on the isotopes of protactinium, actinium, francium and astatine so that more interesting correlations[5] of mass and atomic numbers, etc., with alpha-particle decay energies and half-lives are possible.

5 See e.g., J. Schintlmeister, Oesterr. Chem. Zt. 41, 315 (1938); A. Berthelot, Jour. de Phys. et Rad. (VIII) 3, 17 (1942).

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