Transcurium Isotopes Produced in the Neutron Irradiation of Plutonium

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We have succeeded in producing isotopes of three transcurium elements by the irradiation of the starting material Pu^{239} in the Materials Testing Reactor. The heaviest elements were separated completely from plutonium, fission products, americium, and curium by methods involving combinations of precipitation and ion exchange.[1-4] In the element 97 (berkelium) fraction, soft beta particles were observed. In the californium fraction, alpha particles of three different energies were observed, namely, about 6.15 Mev, 6.05 Mev, and 5.8 Mev. In the fraction just preceding the californium in elution from the hot Dowex-50 resin column, specifically the element 99 fraction,[5] alpha particles of 6.6-Mev energy were observed. The amount of activity observed in this fraction was extremely small; nevertheless, its assignment to element 99 is regarded as certain. All of these isotopes have half-lives longer than one week.

The berkelium isotope which decays by the emission of soft beta particles is probably Bk^{249}. Other work[6] has indicated that Bk^{247} is probably a relatively short-lived isotope which decays by electron capture to Cm^{247} which is beta stable. Therefore the lightest curium isotope which decays to berkelium would be Cm^{249}. The assignment to Bk^{249} is also reasonable since its radiations should be very soft whereas Bk^{248} or Bk^{250} (both odd-odd isotopes) would be expected to emit energetic radiation. On the basis of this assignment, it is interesting to note that there are no beta-stable berkelium isotopes.

The californium isotope or isotopes emitting the above-mentioned alpha particles must be heavier than 248. From alpha systematics, the alpha half-lives corresponding to the measured energies should range from a few years to several hundred years.[7]

The isotope of element 99 emitting 6.6-Mev alpha particles is logically assigned as 99^{253}. A reasonable half-life estimated from systematics, assuming a hindrance factor of ten, would be very roughly a month.

The isotopes mentioned here were all produced as a result of combinations of successive neutron captures and beta decays. A possible sequence leading to the production of 99^{253} might be the following:[8]

$$\begin{array}{lllll}
Pu^{239}(n,\gamma)Pu^{240}(n,\gamma) & Pu^{241}(n,\gamma) & Pu^{242}(n,\gamma) & Pu^{243} & \\
 & \downarrow & \uparrow & \downarrow & \\
 & Am^{241}(n,\gamma) & Am^{242}(n,\gamma) & Am^{243}(n,\gamma) & Am^{244} \\
 & & \downarrow & & \downarrow \\
 & & Cm^{242}(n,\gamma) & Cm^{243}(n,\gamma) & Cm^{244},
\end{array}$$

$$\begin{array}{r}
Cm^{244}(n,\gamma)Cm^{245}(n,\gamma)Cm^{246}(n,\gamma)Cm^{247}(n,\gamma)Cm^{248}(n,\gamma)Cm^{249} \\
\downarrow \\
Bk^{249},
\end{array}$$

$$\begin{array}{lllll}
Bk^{249}(n,\gamma) & Bk^{250} & & & \\
\downarrow & \downarrow & & & \\
Cf^{249}(n,\gamma) & Cf^{250}(n,\gamma) & Cf^{251}(n,\gamma) & Cf^{252}(n,\gamma) & Cf^{253} \\
 & & & & \downarrow \\
 & & & & 99^{253}.
\end{array}$$

There is unpublished information relevant to element 99 at the University of California, Argonne National Laboratory, and Los Alamos Scientific Laboratory. Until this information is published, the question of the first preparation should not be prejudged on the basis of this paper or the preceding one.[5]

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"V Dinucleons"*

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In a previous paper[1] (hereafter referred to as A) we have suggested the possibility of the existence of "V deuterons": particles involving a nuclearly stable structure of a proton bound to a neutral V.[2] These V deuterons are subject to nonmesonic and mesonic decay according to the schemes:

$$V\ \text{deuteron} \equiv [V^0+p] \rightarrow \begin{cases} p+n+\approx 175\text{-Mev K.E.} & (1) \\ p+p+\pi^-+\approx 35\text{-Mev K.E.} & (2) \\ p+n+\pi^0+\approx 35\text{-Mev K.E.} & (3) \\ d+\pi^0+\approx 35\text{-Mev K.E.} & (3') \\ n+n+\pi^++\approx 35\text{-Mev K.E.} & (4) \end{cases}$$

Schemes (3′) and (4) were not mentioned in A; on the basis of charge symmetry, scheme (4) should obviously occur if scheme (2) occurs, while scheme (3′) is an alternative to (3) since the n and p may on occasion be produced in a bound (deuteron) state. The relative probabilities of the nonmesonic decay scheme (1) and of the mesonic decay schemes (2), (3), (3′), (4) have been shown in A to be of the same order of magnitude; the mean life of the V deuteron has been shown in A to be of the same order as the mean life (for the mesonic decay) of a free V^0 ($\approx 3\times 10^{-10}$ sec).

We now wish to point out that an alternative structure of the V deuteron is also possible, namely $[V^+ + n]$, i.e., a nuclearly stable structure of a neutron bound to positively charged V; this alternative V deuteron will also be capable of decay according to schemes (1) through (4) but with a considerably larger kinetic energy release, since the rest energy of the $V^\pm$ is some 85 ± 40 Mev larger than the rest energy of the $V^0[M(V^0)\approx(2185\pm 10)m_e$; $M(V^\pm)\approx(2350\pm 80)m_e]$.[3]

In addition, particles which might be called "negative V deuterons," "V diprotons," and "V dineutrons" can be nuclearly stable even if the "specifically nuclear" attractive forces between nucleons and V's in various angular momentum states are no stronger than the corresponding forces between nucleons and other nucleons. For unlike ordinary dinucleons, all of these "V dinucleons" can exist in $^3S_1$ states (Pauli exclusion inoperative between a V and a nucleon); moreover the relatively greater mass of the V will tend to increase the binding energy of a V dinucleon relative to that of a deuteron. Having postulated the existence of these particles, one must envisage the following possible mesonic and nonmesonic decay schemes:

$$\text{negative } V \text{ deuteron} \equiv [V^- + n] \to n + n + \pi^- \quad (5)$$

$$V \text{ diproton} \equiv [V^+ + p] \to \begin{cases} p+p & (6) \\ p+n+\pi^+ & (7) \\ d+\pi^+ & (7') \\ p+p+\pi^0 & (8) \end{cases}$$

$$V \text{ dineutron} \to \begin{cases} \equiv [V^0+n] \to \begin{cases} n+n & (9) \\ n+p+\pi^- & (10) \\ d+\pi^- & (10') \\ n+n+\pi^0 & (11) \end{cases} \\ \equiv [V^- + p] \to \begin{cases} n+n & (12) \\ n+p+\pi^- & (13) \\ d+\pi^- & (13') \\ n+n+\pi^0 & (14) \end{cases} \end{cases}$$

The mean lives of these particles will again be $\approx 10^{-10}$ sec [assuming comparable mean lives (for the mesonic decay) of the free V^0, the free V^+ and the free V^-] while the branching ratios for the mesonic and nonmesonic decays will, as before, be of the order of unity.[1]

It is very interesting to note that the mesonic decay of a V dineutron according to scheme (13′) will appear in an emulsion or a cloud chamber as the two-body decay into a deuteron and a π^- meson of a neutral particle with mass: $[\{2350\pm 80\}+\{1836\} - [V^- + p] \text{ binding energy}] m_e \approx \{4180\pm 80\} m_e$.[4] A decay of just this type has recently been reported by Lal, Pal, and Peters[5] who estimate the mass of the neutral particle as $\{4120\pm 20\} m_e$.

It should also be mentioned, as pointed out to us by Bolsterli, that neutral particle→visible $\{p+\pi^-\}$ decays, with a Q (calculated on a two-body basis) considerably different from (e.g., very much larger than), 35–40 Mev,[6] might actually be V-dineutron decays according to schemes (13) or (10). On such an assumption, these anomalous Q values would form a distribution with an upper limit given by the Q of the V^- decay (≈ 125 Mev).

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1 W. Cheston and H. Primakoff, Phys. Rev. **92**, 1537 (1953).

2 According to a notation now coming into use: V^0, V^+, $V^- \equiv \Lambda^0$, Λ^+, Λ^- ≡neutral, positive, negative hyperon.

3 We take 38 Mev for the Q value of $V^0 \to p+\pi^-$, and suppose that $M(V^+) \cong M(V^-)$, Q values for the decay: $V^\pm \to$neutron$+\pi^\pm$ may be obtained from Lal, Pal, and Peters, Phys. Rev. **92**, 438 (1953). ($Q=135 \pm 35$ Mev); King, Seeman, and Shapiro, Phys. Rev. **92**, 838 (1953). ($Q=103\pm 20$ Mev); M. Ceccarelli and M. Merlin, Nuovo cimento **10**, 1207 (1953) ($Q=131\pm 24$ Mev). We also suppose that the V^+ possesses the alternative decay scheme: $V^+ \to$proton$+\pi^0$ [with a Q, according to Bonetti, Setti, Panetti, and Tomasini, Nuovo cimento **10**, 1736 (1953), of 115.3 Mev].

4 We take the $[V^- + p]$ binding energy as ≈ 3 Mev; assumption of the scheme (10′) would predict a mass of $\{4015\pm 10\} m_e$ for the neutral particle, provided that the $[V^0+n]$ binding energy is also taken as ≈ 3 Mev. We also suppose that the rates of the energetically possible processes: $[V^- + p] \to V^0 + n$ and $[V^+ + n] \to V^0 + p$ are not appreciably greater than $\approx 10^{10}$ sec^{-1}.

5 Lal, Pal, and Peters (reference 3).

6 Leighton, Wanlass, and Anderson [Phys. Rev. **89**, 148 (1953)] find, in decays of neutral particles into $p+\pi^-$, Q values ranging from 10 ± 3 Mev to 87 ± 15 Mev; it is likely that at least several of these anomalous Q's are not consequences of experimental error.

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Minutes of the 1953 Thanksgiving Meeting Held at Chicago, November 27–28, 1953

IN 1953 the Thanksgiving meeting of the American Physical Society returned to its traditional home at the University of Chicago after two years of wandering: the dates were Friday and Saturday, November 27 and 28. The programme was of excellent quality; it is all the more surprising to have to record that both the number of contributed papers (142) and the number of registrants (516) dropped below the peaks of past years. This may have been because some of our members overlooked the announcement printed in the Rochester Bulletin in lieu of being made by summons-card, or it may have been because the deadline (September 25) came so soon after the academic year began: the Secretary has no facts to support either theory. Perhaps the November meeting has definitely yielded to the March meeting its former rank of the third largest of the year. The meeting was very efficiently administered by Mrs. Dorothy C. Johnson.

The banquet of the Society was held on the Friday evening in Hutchinson Commons, with a regrettably small attendance (170). The after-dinner speakers were S. K. Allison, D. H. Loughridge, and R. S. Mulliken.

The Council met on the Friday afternoon. It elected to Fellowship four candidates, and to Membership 285 whose names are appended.

Elected to Fellowship: W. R. Fredrickson, A. W. Friend, J. A. Sanderson, and L. Seren.

Elected to Membership: Walter Abramowitz, Rutherford H. Adkins, Victor S. Aiello, Richard Ballantine Allen, Saul Altshuler, Sa'adia Amiel, Brita Aminoff, Cecil Earl Angell, George Ludwig Appleton, Tetsuo Arase, Bernell Edwin Argyle, George Edward Austin, Milton Ash, Bjorn Astrom, Leon S. August, Glen Gordon Bach, Winslow Furber Baker, Nandor L. Balazs, William Chalmers Barr, Asim O. Barut, Robert H. Bassel, Philip Baumel, Allan Frank Beck, Leon Edward Beghian, Edgar D. Berners, Edward Joseph Bernier, William Bertozzi, Bruce Joseph Biavati, Rudolf Hermann Bieri, Charles Huffman Blakewood, Herbert Howard Bolotin, Howard Colson Borough, Gene Braught, Francis Christopher Brosnan, Arthur Austin Brown, Edward Byerly Brucker, Paul James Bryant, Joseph Ignatius Budnick, Charles Andrew Burrus, Jr., Anthony John Calio, Chieh Chien Chang, Lloyd Fremont Chase, Jr., Ivan Gabriel Chasalow, Morris Samuel Chester, Donald Ray Childs, William Gilbert Clark, Darwin Wayne Clutter, Carolus Melville Cobb, Malcolm Young Colby, Robert Vincent Coleman, Joseph Lawrence Collins, Charles Philippe Courtoy, Walter Leslie Crider, William Edwin Cummins, Robert Hanson Cunningham, John Spillers Dahler, Bascom S. Deaver, Jr., John Hans Dessauer, Peter Joseph Drevinsky, Richard Henry Duncan, Lucille Anne DuSault, Alexander J. Elwyn, Frank Durrell Enck, Karl Lembit Erdman, Robert Arthur Farrall, Fabio Maria Ferrari,