Mass Assignment of the 44-Minute Californium-245 and the New Isotope Californium-244†

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(Received January 16, 1956)

The 44-minute californium alpha emitter previously thought to be Cf^{244} has been reassigned to mass number 245 on the basis of milking experiments, excitation functions, cross bombardments, and decay-scheme studies. Californium-245 decays by the emission of (7.11±0.02)-Mev alpha particles (~30%) and by orbital electron capture (~70%). The new isotope Cf^{244} was also identified and found to decay by the emission of (7.17±0.02)-Mev alpha particles with a half-life of 25±3 minutes. The mass assignment of this isotope was established by its genetic relationship to Cm^{240} and by the excitation function for its formation by the $(\alpha,4n)$ reaction on Cm^{244}.

RECENT studies on the 44-minute isotope of californium previously assigned to mass number 244 have indicated that this assignment is in error and that the isotope is most probably of mass number 245. No other isotope of californium has hitherto been associated with mass number 245.

This isotope was first produced by Thompson *et al.*[1] in 1950. It was chemically identified as an isotope of californium and shown to decay by the emission of 7.1-Mev alpha particles. Further work has confirmed the 44-minute half-life and established the energy of the alpha particles as 7.11±0.02 Mev. The original mass assignment was chosen from the three possible mass numbers of the isotopes of californium that would have been produced in the alpha-particle bombardments of Cm^{242}, namely $Cf^{243,244,245}$. Mass 244 was chosen with reference to the systematics of alpha radioactivity and in view of the short half-lives toward electron capture that were predicted for Cf^{243} and Cf^{245} at that time. Because of the small amounts of the isotope that could be produced with the limited amounts of target material available in 1950, attempts to establish its genetic relationship to Cm^{240} were unsuccessful.

The recent development of recoil collection techniques in the bombardment of transuranium isotopes[2] and improvements in the speed of chemical separations have made possible the further production of this isotope in much larger amounts. These bombardment techniques have also made possible several experiments that were excluded previously by the necessity of separating the product from the entire target.

Samples of curium consisting mostly of Cm^{244} (95%) and containing smaller quantities of heavier curium isotopes were bombarded with intense alpha beams in the 60-inch cyclotron of the Crocker Laboratory, by use of the specially designed deflector channel probe. The product nuclei recoiling from the target were collected on thin gold foils. These foils were dissolved and the bulk of the fission-product and induced activity was removed by a combination of solvent-extraction and ion-exchange techniques. The actinide fraction could then be examined immediately in the alpha pulse-height analyzer. In some experiments, the actinide fraction was separated into its components by rapid elution from Dowex-50 cation-exchange resin, with α-hydroxy isobutyric acid as the eluant.[3]

The following evidence for the assignment of the 44-minute alpha emitter to Cf^{245} rather than Cf^{244} was obtained.

(a) In four separate experiments the californium fraction was separated chemically from the small amount of curium knocked out of the target by elastic and inelastic scattering, and the decay of the 7.1-Mev alpha emitter was followed by counting in a grid ionization chamber connected to a 48-channel pulse-height analyzer. After the 44-minute activity had decayed for a number of half-lives, a careful search was made for the 6.26-Mev alpha particles of the 27-day Cm^{240}. In every case less than 5% of the amount of Cm^{240} that would result from the alpha decay of the 44-minute californium was found.

(b) A sample of californium containing approximately 1200 alpha disintegrations per minute (dis/min) of the 44-minute isotope and approximately 750 dis/min of Cf^{246} (6.76 Mev, 35.7 hour) was examined by means of alpha-gamma coincidence techniques for the presence of L x-rays in coincidence with alpha particles. No L x-rays in coincidence with alpha particles attributable to the 44-minute activity were found. By direct comparison with the Cf^{246} present in the sample, an upper limit to their abundance was set at 2% of the alpha decays. Since every even-even alpha emitter that has been examined in the region above uranium decays ~20% to an excited state with attendant L x-rays in 10% to 15% abundance, this is additional strong evidence that the 44-minute activity is not an even-mass californium. No other photons were seen in appreciable intensity in this experiment.

(c) An excitation function for the production of the

† This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] Thompson, Street, Ghiorso, and Seaborg, Phys. Rev. **80**, 790 (1950).

[2] Ghiorso, Harvey, Choppin, Thompson, and Seaborg, Phys. Rev. **98**, 1518 (1955).

[3] Choppin, Harvey, and Thompson, J. Inorg. Nuclear Chem. **2**, 66 (1956).

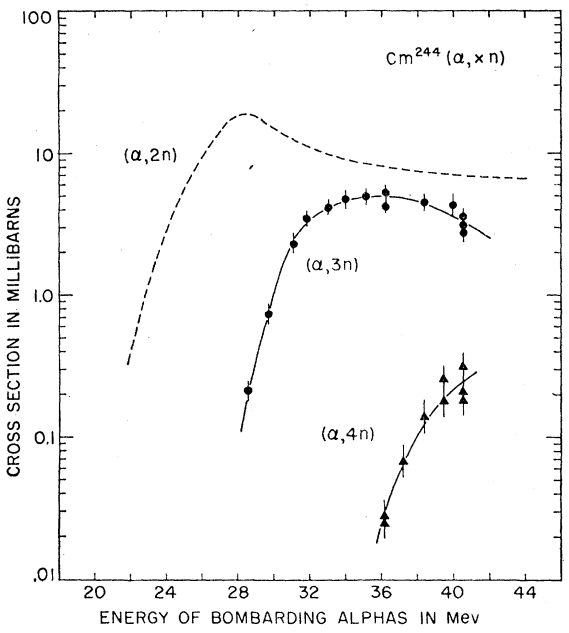

FIG. 1. Some excitation functions for the reactions $Cm^{244}(\alpha,xn)$. Dashed line: $(\alpha,2n)$ as determined from Cf^{246} alpha activity. Circles: $(\alpha,3n)$ as determined from Cf^{245} alpha activity. Triangles: $(\alpha,4n)$ as determined from alpha activity of Cm^{240} daughter.

44-minute isotope by the (α,xn) reaction on Cm^{244} was determined by alpha pulse analysis of the californium fractions from a number of bombardments. The cross sections reported for this reaction were calculated from these data and the branching ratio determined in separate experiments.

Since Cf^{244} should also be formed in small yield in bombardments at energies above the $(\alpha,4n)$ threshold, a search was made for its alpha-decay daughter, Cm^{240}. This latter activity was found in small but measurable amounts, and although the isotope Cf^{244} was not observed directly in these experiments, an excitation function for its production was obtained in this manner. No reasonable reaction other than $(\alpha,4n)$ followed by alpha decay would produce Cm^{240} in the observed yield.

The excitation functions obtained are shown in Fig. 1 together with the excitation function for the reaction $Cm^{244}(\alpha,2n)Cf^{246}$.[4] The magnitudes of the cross sections are such that the contribution of Cf^{244} to the alpha activity ascribed to Cf^{245} was negligible under the conditions of the experiments. These excitation functions for the production of the 44-minute activity and for the parent of Cm^{240} exhibit qualitatively and quantitatively the behavior expected of $(\alpha,3n)$ and $(\alpha,4n)$ reactions respectively.

(d) Cross bombardments of Cm^{244} at energies well below the $(\alpha,4n)$ threshold and of Cm^{242} have been shown to produce the 44-minute californium activity in high yield. Only Cf^{245} could have been made in both types of experiment.

[4] Chetham-Strode, Ghiorso, Harvey, Choppin, and Thompson (unpublished data).

Since californium-245 was expected to exhibit appreciable decay by electron capture, an experiment to measure the alpha-to-electron-capture ratio was carried out. The californium fraction resulting from the bombardment of Cm^{244} below the $(\alpha,4n)$ threshold was isolated soon after the end of bombardment and the amount of Bk^{245} (e.c., 5.0 day)[5] that grew from the electron capture decay of Cf^{245} was determined. From the results of this experiment, Cf^{245} was found to decay $\sim 70\%$ by electron capture. The partial half-life for alpha decay is, then, ~ 90 minutes. These half-lives are in good agreement with those predicted by alpha-decay systematics and the recent electron-capture systematics of Hoff.[6]

In order to study the properties of Cf^{244}, a series of bombardments of Cm^{242} with helium ions of various energies was made. In bombardments at energies close to the expected peak of the $(\alpha,2n)$ reaction on Cm^{242}, a new alpha group of 7.17 ± 0.02 Mev was seen in addition to the 7.11-Mev alpha group due to Cf^{245}. The new alpha emitter was found to decay with a (25 ± 3)-minute half life. The relative yields of the two alpha activities and their dependency on the energy of the bombarding helium ions were consistent with the identification of the 25-minute activity with the $(\alpha,2n)$ product Cf^{244}. Closed-cycle calculations indicate an electron-capture decay energy for this isotope of ~ 0.7 Mev and hence the partial half-life for electron capture is expected to be several times the observed half-life. No corrections for electron-capture branching of Cf^{244} were made in this work. The mass assignment was confirmed by separate experiments in which the growth of Cm^{240} in a separated californium fraction was followed and found to agree closely with that expected from the observed alpha decay of Cf^{244}.

It is interesting to note that the alpha-decay energies of Cf^{244} and Cf^{245} differ by only 55 kev. This small difference probably implies an extra stability of 150 to 200 kev in the Cf^{244} nucleus, since the alpha-decay energy of Cm^{240} does not seem to be anomalously large.[7] Energy differences of this magnitude are of the order of those expected from pairing effects in this region; however, other explanations are not precluded.

We wish to acknowledge the large contributions made to this work by Albert Ghiorso, Thomas C. Parsons, Robert J. Silva, and Hugo G. Simens, who helped with most of the bombardments. Thanks are due to Dr. Frank S. Stephens, Jr., for his coincidence measurements. The continued cooperation and assistance of G. Bernard Rossi, William B. Jones, and the crew of the 60-inch cyclotron is gratefully acknowledged. We wish to thank Dr. Glenn T. Seaborg for his continued interest in this work.

[5] Hulet, Thompson, Ghiorso, and Street, Phys. Rev. **84**, 366 (1951).

[6] R. W. Hoff and S. G. Thompson, Phys. Rev. **96**, 1350 (1954).

[7] R. A. Glass, thesis, University of California Radiation Laboratory Report No. UCRL-2560, April, 1954 (unpublished).