Nuclear Properties of Some Isotopes of Californium, Elements 99 and 100†

G. R. Choppin, S. G. Thompson, A. Ghiorso, and B. G. Harvey
Radiation Laboratory and Department of Chemistry, University of California Berkeley, California
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In recent publications[1,2] we reported the formation of the nuclides 99^{253}, 99^{254}, and 100^{254} by intense neutron bombardment of plutonium and higher-mass nuclides. Further observations of the nuclear properties of these nuclides have now been made, using, in some cases, samples of higher activity prepared in new neutron bombardments. In addition, a 15-hour alpha-emitting isotope of element 100 has been observed in the products of the neutron bombardment of plutonium.

Cf^{253} and 99^{253}.—The nuclide Cf^{253} decays by β^- emission to 99^{253}. From the rate of growth of the 99^{253} alpha activity in a purified Cf^{253} sample and the rate of decay of separated 99^{253}, the half-life of both these nuclides was found to be approximately 20 days.

Because of the high spontaneous fission rate in californium (due mainly to Cf^{252}), the β^- emitting fission fragments prevented any simple measurement of the β-particle energy of Cf^{253}.

By comparison with Bi^{211} and Po^{214} alpha-energy standards, the energy of the 99^{253} alpha particles was found to be 6.63 ± 0.02 Mev.

99^{254}, 100^{254}, and 100^{255}.—Pure samples of element 100 were separated from 99 and californium by elution through columns of Dowex-50 ion-exchange resin. A typical elution curve is shown in Fig. 1. For this run the bulk of the californium had been removed in a previous ion-exchange column.

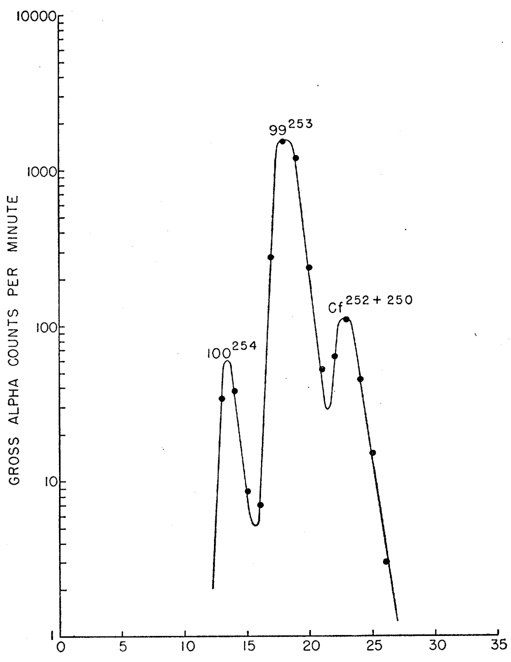

Fig. 1. Elution of elements 98, 99, and 100 from Dowex-50 column with 0.04 *M* ammonium lactate, *p*H 4.50.

Two alpha activities assigned to element 100 have been observed. The more abundant, probably due to 100^{254}, decays with a half-life of 3.2 hours (Fig. 2) by emission of 7.22 ± 0.03-Mev alpha-particles, as previously reported.[2] The other, probably due to 100^{255}, decays with a half-life of about 15 hours by emission of 7.1-Mev alpha particles.

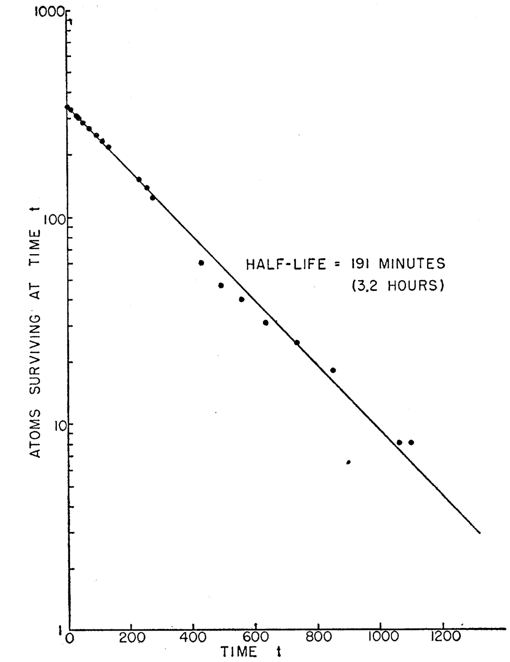

Fig. 2. Decay curve of 100^{254}.

The 7.22-Mev alpha activity of 100^{254} was observed to grow into a separated 99 fraction, and then to decay with a 36-hour half-life, that of its 99^{254} β^- emitting parent (Fig. 3). (These curves are from the first experiments performed early in January and have since been repeated with substantially the same results using orders of magnitude more activity.) The β particles of 99^{254} were found to have a maximum energy of 1.1 ± 0.1 Mev as determined by an anthracene scintillation spectrometer.

The 7.1-Mev alpha activity was also observed in purified element-99 fractions, and thus it was deduced that it also has a β^- emitting parent. Rough decay measurements of this activity in the element-99 fraction indicate that the half-life of this parent, presumably 99^{255}, is approximately one month.

Spontaneous fissions, decaying with a half-life of about 3 hours, were observed in pure element-100 fractions. These are presumably due to 100^{254}. From the ratio of fission to alpha-emitting events ($\sim$0.001), the partial half-life of 100^{254} for spontaneous fission was found to be approximately 200 days. Spontaneous fissions were not observed in purified element-99 samples, but appeared as the 100^{254} grew from the 99^{254} β^- decay.

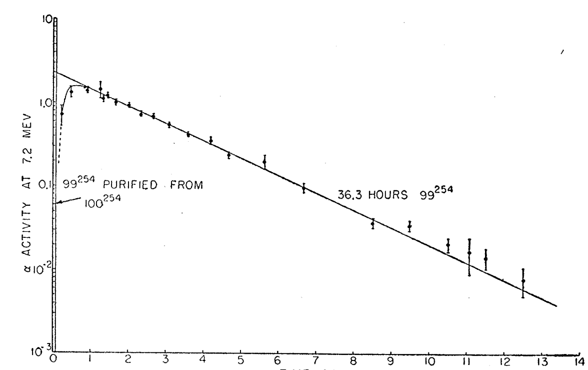

Fig. 3. Decay curve of 99^{254}.

We wish to acknowledge the continued interest of Professor G. T. Seaborg in this work. We are indebted to the staff of the Materials Testing Reactor, and particularly to Dr. W. B. Lewis and Dr. R. R. Smith, for arranging the neutron bombardments.†

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1 Thompson, Ghiorso, Harvey, and Choppin, Phys. Rev. **93**, 908 (1954)
2 Harvey, Thompson, Ghiorso, and Choppin, Phys. Rev. **93**, 1129 (1954)

New Isotopes of Americium, Berkelium and Californium*

A. Ghiorso, S. G. Thompson, G. R. Choppin, and B. G. Harvey
Radiation Laboratory and Department of Chemistry, University of California, Berkeley, California
(Received March 19, 1954)

In a recent publication,[1] the preparation of new heavy isotopes of berkelium (mass number probably 249) and californium (mass numbers greater than 248) by prolonged neutron irradiation of Pu^{239} with thermal neutrons was described. As the result of neutron irradiation of Am^{243} and Bk^{249}, it has been possible to make new observations on the radioactive decay of Am^{244}, and to prepare new berkelium and californium activities.

Am^{244}.—This nuclide was produced by short neutron bombardments of americium, whose principal constituent was Am^{243}. After bombardment the americium was rapidly purified by a combination of precipitation and ion-exchange procedures.[2] The Am^{244} was found to decay by emission of β^- particles; its half-life was 26 minutes, in good agreement with a previously published value.[3]

The beta and gamma radiations of Am^{244} were studied with anthracene and sodium iodide crystal spectrometers. Only one β^- end point, at 1.5 Mev, could be resolved. There were no prominent gamma rays.

Bk^{250}.—A sample of Bk^{249} was subjected to a short neutron bombardment, followed by chemical purification, and a new activity, presumably Bk^{250}, was produced. It decayed by β^- emission with a half-life of 3.13 hours.

The β spectrum showed the existence of two groups, with end points at 900 and 1900 kev. The lower-energy β group was in coincidence with a gamma ray of about 900 kev.

Cf^{250}.—Part of the neutron-irradiated berkelium, after chemical purification, was allowed to decay for five hours to produce the Cf^{250} daughter of the Bk^{250}. The californium was then separated. The Cf^{250} was found to emit 6.05-Mev alpha particles. From the alpha disintegration rate and the beta disintegration rate of the Bk^{250} parent, the alpha half-life of Cf^{250} was found to be about 12 years.

Spontaneous fissions were observed in the samples containing Cf^{250}. The ratio of alpha disintegrations to fissions was 400. The spontaneous fission half-life of Cf^{250} is therefore about 5000 years.

Cf^{252}.—Direct alpha-decay measurements performed over a period of several months on a sample consisting largely of Cf^{252} indicate a half-life for this nuclide of roughly two years. It was found that 26 percent of the alpha particles in the original californium fraction produced from the highly irradiated plutonium were due to Cf^{250}. Thus from the previously mentioned alpha-to-fission ratio of 400 found for pure Cf^{250}, its contribution (approximately 3 percent) to the observed high spontaneous fission rate in the californium fraction (alpha-to-fission ratio = 42) can be calculated. The great bulk of the fission rate must therefore be due to Cf^{252}, and a calculation on this basis shows its spontaneous fission half-life to be about 100 years. For the purpose of this calculation it was assumed that in this case the correction for spontaneous fission from Cf^{254} would be small.

Cf^{249}.—The Bk^{249} grows a californium daughter Cf^{249} which decays by emission of 6.0-Mev (10 percent) and 5.82-Mev (90 percent) alpha particles. From the amount of Cf^{249} alpha activity which grew from a known amount of Bk^{249}, the alpha half-life of the Cf^{249} was found to be about 400 years.

It is a pleasure to acknowledge the continued interest of Professor G. T. Seaborg in this work. We are indebted to the entire staff of the Materials Testing Reactor, and particularly to Dr. W. B. Lewis and Dr. R. R. Smith. We wish to thank Almon E. Larsh for assistance with some of the experiments.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

1 Thompson, Ghiorso, Harvey, and Choppin, Phys. Rev. **93**, 908 (1954).
2 See, e.g., G. T. Seaborg in *The Actinide Elements* (McGraw-Hill Book Company, Inc., New York, 1954), National Nuclear Energy Series, Plutonium Project Record, Vol. 14A, Div. IV, Chap. 17.
3 Street, Ghiorso, and Seaborg, Phys. Rev. **79**, 530 (1950).

Interaction of High-Energy Pions with Nuclei*

E. D. Courant
Brookhaven National Laboratory, Upton, New York
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Recent experiments[1-3] have shown that the interaction cross sections of negative π mesons in the energy range of 0.6 to 1.0 Bev on protons are more than twice those of positive π mesons of the same energy range; the (π^-,n) cross section appears to be about equal to the (π^+,p) cross section, as expected from charge symmetry considerations.

This makes it attractive to employ π mesons as tools for the investigation of nuclear structure, in particular of the proton and neutron distributions in nuclei.[4] Johnson and Teller[5] have suggested that the neutrons in a heavy nucleus extend out to a larger radius than the protons. If this is the case, the apparent nuclear radius as measured with two different probe particles will be greater for that probe particle which interacts more strongly with neutrons.

The interaction cross sections of lead for positive and negative π mesons of 700 Mev have been computed using the "optical model"[6] and assuming (a) that the protons and neutrons are uniformly distributed in a sphere of radius R (uniform nucleus model), and (b) that the nucleus is composed of an inner zone of radius R_1 containing Z protons and Z neutrons, and an outer zone of radius R containing $N-Z$ neutrons (Johnson-Teller model). In model (b) the radii R_1 and R are chosen so that the neutron density is the same in both zones, i.e., $R_1/R=(Z/N)^{\frac{1}{3}}$.

In the optical model the nucleus is treated as a region with a complex refractive index. The total cross section may be divided into the diffraction (elastic scattering) portion σ_d and the interaction (absorption) portion σ_a, where

$$\sigma_d=2\pi\int_0^R|1-e^{i\delta(\rho)}|^2\rho d\rho, \tag{1}$$

$$\sigma_a=2\pi\int_0^R(1-|e^{i\delta(\rho)}|^2)\rho d\rho. \tag{2}$$

Here $\delta(\rho)$ is the (complex) phase shift of that part of an incident plane wave which passes through the nucleus along a line which is at a distance ρ from the center. Let $k=p/\hbar$ be the wave propagation number of the incident particle outside the nucleus, and let its propagation number inside the nucleus at a distance r from the center be $k+k_1(r)+\frac{1}{2}iK(r)$. Then

$$\delta(\rho)=2\int_0^{s(\rho)}[k_1(r)+\tfrac{1}{2}iK(r)]dx, \tag{3}$$

where $s(\rho)=(R^2-\rho^2)^{\frac{1}{2}}$, and $r=(\rho^2+x^2)^{\frac{1}{2}}$.

Table I. Interaction cross sections of 700-Mev pions on Pb.

Model	R (10^{-13} cm)	R_1 (10^{-13} cm)	σ_+ (mb)	$\sigma_- - \sigma_+$ (mb)
a	8.295		1862	41
b	8.295	7.188	1827	−114
a	7.110		1430	74
b	7.110	6.161	1405	−51