Neutrons Emitted in Spontaneous Fission of ^{246}Cm†

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The value of $\bar{\nu}$ for ^{246}Cm was found to be 3.20 ± 0.22 in a BF_3 proportional counter calibrated with a ^{252}Cf standard.

The average number of prompt neutrons $\bar{\nu}$ emitted per fission has been measured for the actinides in several different ways.[1-3] Most measurements have been on induced fission of the isotopes ^{233}U, ^{235}U, and ^{239}Pu, which are important to reactors. Although the spontaneous fissioning of some even isotopes has been studied, and values have been obtained for isotopes through mass 254, there is little reported on the isotopes between mass 244 and mass 252.[1]

Measurements were made with a ^{246}Cm sample enriched in an electromagnetic separator at Oak Ridge National Laboratory. Composition of the sample determined by mass spectrometry is shown in Table I.

Two 5-ml aliquots from a solution of 9.948×10^8 dis/(min ml) with 93.05 α% ^{244}Cm (measured by absolute α counting and α-pulse analysis) were counted in a BF_3 proportional counter. The α half-life of ^{244}Cm was taken as 18.099 ± 0.015 yr,[4] and the α-energy distributions given by Lederer, Hollander, and Perlman[5] were applied. The ^{246}Cm samples were counted at two different times, and the counting efficiency was determined by two methods.

In the first method, counting efficiency was determined with a ^{252}Cf solution obtained from a sample whose neutron emission rate had been determined to ±3% in a manganese sulfate counter calibrated with a National Bureau of Standards neutron standard.[6] A 10-μl aliquot of the original ^{252}Cf solution was diluted to 5 ml, and a 500-μl aliquot of the dilution was counted. Neutron emission rate of the ^{252}Cf standard was $3.705 \pm 0.190 \times 10^5$ n/min, including original uncertainty in emission rate and errors in pipetting and dilution. The averages of 15 five-minute counts of two ^{246}Cm samples were $31\,972 \pm 57$ and $32\,041 \pm 74$ counts/min; the average of 15 five-minute counts of the ^{252}Cf standard was $38\,624 \pm 74$ counts/min; and background counts of 30 and 60 min gave 10 ± 0.6 and 10 ± 0.4 counts/min, respectively. The ^{252}Cf was counted the day after its neutron emission was determined, so that decay calculations were unnecessary.

The total emission rate for ^{246}Cm was found to be $3.071 \pm 0.172 \times 10^5$ n/min, with the counting efficiency of 0.1042 ± 0.0056 and the average count rate of the ^{246}Cm samples. The $\bar{\nu}$ for ^{246}Cm was then calculated from this emission rate and from the half-life, and the $\bar{\nu}$ values are shown in Table II.

In the second method, two 100-μl aliquots from a californium solution of 1.753×10^7 dis/(min ml) with 78.1 α% ^{252}Cf (measured by absolute α counting and α-pulse analysis and corrected for fissions) were diluted to 5 ml and counted in the BF_3 proportional counter. From the α half-life of 2.731 yr,[8] from the α particle to fission ratio of 31.3 ± 0.2,[8] and from the $\bar{\nu}$ shown in Table II, a neutron emission rate of 1.658×10^6 n/min was calculated for these samples. The averages of 10 five-minute counts of two ^{246}Cm samples were 31371 ± 44 and $31\,378 \pm 90$ counts/min; averages of two ^{252}Cf samples were $17\,471 \pm 61$ and $17\,471 \pm 80$ counts/min (a 30-min background count showed 18 ± 0.8 counts/min). The ^{246}Cm and ^{252}Cf results are corrected for coincidence.[11]

TABLE I. Compositon of ^{246}Cm sample.

Mass No.	Atom %
244	4.98
245	0.161
246	94.74
247	0.064
248	0.061

TABLE II. Spontaneous-fission half-lives and $\bar{\nu}$ for curium isotopes.

Isotope	Half-life (yr)	Prompt neutrons, $\bar{\nu}$
^{244}Cm	1.346×10^7[a]	2.810 ± 0.059[b]
^{246}Cm	1.80×10^7[c]	3.20 ± 0.22[d]
^{248}Cm	4.22×10^7[c]	3.3[e]
^{252}Cf	85.5[a]	3.79[f]

[a] See Ref. 8.
[b] See Ref. 1.
[c] See Ref. 9.
[d] This work.
[e] Estimated from graph in Ref. 1.
[f] See Ref. 10.

The total emission rate for ^{246}Cm was found to be $2.98 \pm 0.16 \times 10^5$ n/min, with the counting efficiency of 0.1054 ± 0.0064 and the average count rate of the ^{246}Cm samples. The $\bar{\nu}$ for ^{246}Cm was then calculated from this measurement and from the half-life and $\bar{\nu}$ values shown in Table II. The values obtained were $\bar{\nu} = 3.26 \pm 0.22$ and 3.15 ± 0.25, which agree with the value estimated by assuming that $\bar{\nu}$ varies linearly with A, as shown by Hyde.[1] Although it is known that $\bar{\nu}$ varies with Z as well as A, more elaborate calculations such as those of Gordeeva and Smirenkin[7] have not been completely successful in predicting $\bar{\nu}$ for spontaneous fission. No further theoretical interpretation of our result has been attempted.

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[1] E. K. Hyde, *The Nuclear Properties of the Heavy Elements* (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1964), Vol. 3, pp. 217–219.

[2] I. Asplund-Nilsson, H. Conde, and N. Starfelt, Nucl. Sci. Eng. 16, 124 (1963).

[3] D. A. Hicks, J. Isle, Jr., and R. V. Pyle, Phys. Rev. 101, 1016 (1956).

[4] W. C. Bentley, J. Inorg. Nucl. Chem. 30, 2007 (1968).

[5] C. M. Lederer, J. M. Hollander, and I. Perlman, *Table of Isotopes* (John Wiley & Sons, Inc., New York, 1967), 6th ed., p. 436.

[6] Sample supplied by A. R. Boulogne (Savannah River Laboratory) who determined the neutron emission rate of the original sample.

[7] L. D. Gordeeva and G. N. Smirenkin, At. Energ. (USSR) 14, 530 (1963) [transl.: Soviet J. At. Energy 14, 562 (1964)].

[8] D. Metta, H. Diamond, R. F. Barnes, J. Milsted, J. Gray, Jr., D. J. Henderson, and C. M. Stevens, J. Inorg. Nucl. Chem. 27, 33 (1965).

[9] D. N. Metta, H. Diamond, and F. R. Kelly, J. Inorg. Nucl. Chem. 31, 1245 (1969).

[10] P. H. White and E. J. Axton, J. Nucl. Energy 22, 73 (1968).

[11] Coincidence curve determined by R. F. Overman (Savannah River Laboratory).