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THE ALPHA AND GAMMA SPECTRA OF Cf^{246}

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November 29, 1954

Printed for the U. S. Atomic Energy Commission

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Radiation Laboratory and Department of Chemistry
University of California, Berkeley, California

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ABSTRACT

The alpha and gamma spectra of Cf^{246} have been studied with an alpha particle spectrograph and gamma ray scintillation spectrometer. Alpha groups of 6.753 Mev (78 percent) and 6.711 Mev (22 percent) were observed. L x-rays and gamma rays of ~ 100 kev (1.4×10^{-2} percent) and ~ 44 kev were assigned to Cf^{246} . These results are evaluated with respect to the developing theory and systematics of complex alpha spectra and excited states of even-even nuclei.

$\dagger$ This work was performed under the auspices of the U. S. Atomic Energy Commission.

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INTRODUCTION

The preparation of Cf^{246} in a state of high radioactive purity can be effected by irradiating a mixture of curium isotopes (Cm^{242-6}) with alpha particles of about 40 Mev energy.¹ (The mixture of curium isotopes is obtained by prolonged neutron irradiation of Pu^{239} .²) Of the californium isotopes produced, Cf^{246} has a half life of 35.7 hr,¹ while Cf^{247} , Cf^{244} , and presumably Cf^{245} have half lives sufficiently short^{1, 3} to allow their complete decay during a period in which the Cf^{246} is not greatly reduced. No appreciable contribution to the radioactivity comes from Cf^{248} because of its relatively long half life (250 d⁴) and low yield since there were only small amounts of Cm^{246} and Cm^{245} in the bombarded curium. Curium 242 would be present as the daughter product of Cf^{246} decay.

The interest in examining the alpha spectrum of Cf^{246} lies largely in extending the range of even-even alpha emitters for which accurate information can be obtained on the nature of the spectroscopic states and the degree of population of these states. The regularities observed in alpha spectra of heavy nuclei and their implications on nuclear structure and alpha decay theory have been reviewed recently.^{5, 6, 7}

The sample of Cf^{246} made available for the present study contained initially 2.9×10^5 alpha disintegrations per minute. Since the transmission of the alpha particle spectrograph is about 4×10^{-5} , it was

necessary to make as long an exposure as possible in order to obtain a reasonable number of alpha tracks. The ratio of peak height to background was about 50 for the main group which makes it impossible to measure alpha groups of abundance lower than several percent. From other spectra of even-even alpha emitters in the region, it was obvious that the transition to the ground state (0+) and first excited state (2+) should be discernible but no others. The sensitivity of gamma-ray detection, however, is such that some information could reasonably be expected from this source on the expected transition to the second excited state (4+). At the time of the first measurements the Cm²⁴² activity was small relative to the Cf²⁴⁶. There was some Cf²⁵⁰ and Cf²⁵² in the sample due to their incomplete removal from the target curium before bombardment. The Cf²⁵⁰ and Cf²⁵² contribute spontaneous fission-gamma ray coincidences. With our detection system the intensity of these coincidences is nearly constant over the energy range under consideration.

EXPERIMENTAL

The Cf²⁴⁶ source was prepared by vacuum sublimation and exposed in the alpha-particle spectrograph according to methods already described.⁸ The spectrum so obtained showed, as expected, only two alpha groups characteristic of transitions to the ground state and first excited state of an even-even alpha emitter (see the decay scheme, Fig. 1).

The abundance of the transition to the first excited state could be obtained directly from the alpha spectrum and indirectly by determining the coincidence rate between alpha particles and L x-rays.

This indirect determination comes about from the fact that the first excited state drops to the ground state by an E2 transition which is highly converted in the L shell. The method of making the coincidence measurement and the corrections necessary to transfer these data into the degree of population of the first excited state are discussed elsewhere.⁹

The gamma-ray spectrum was measured with a scintillation spectrometer and besides the L x-rays, peaks at ~100 kev, ~60 kev, and ~44 kev showed up. The 100-kev photon is interpreted as a gamma ray leading from the sparsely populated second excited state to the first excited state. The 44-kev photon is the gamma ray from the first excited state. The 60-kev peak is probably due to Am^{241} impurity. Because of the high intensity of the Am^{241} 60 kev gamma ray and the low intensities of the Cf^{246} photons, an extremely small amount of Am^{241} (80 disintegrations per minute) would give the observed intensity. The gamma-ray spectrum is measured most effectively by α - γ coincidence counting, the details of which are described elsewhere.⁹ The coincidence spectrum for Cf^{246} is shown in Fig. 2.

RESULTS AND DISCUSSION

Alpha spectrum. --Two exposures (22.6-hr and 33-hr, respectively) were made on the alpha particle spectrograph before the sample became too weak. In the first, 5137 tracks were registered: 78 percent in the main group and 22 percent in the group leading to the first excited state. Also by the α -L x-ray coincidence method, the abundance of population of the 2+ (first excited) state was found to be 22 percent.

The energy difference between the two groups was found to be 42.0 kev. When correction is made for the differences in recoil energy, the corresponding gamma-ray transition becomes 42.7 kev. The appearance of the first excited state of Cm^{242} is also prominent in the β -decay of $\text{Am}^{242\text{m}}$. The transition energy has been measured as 42.3 ± 0.2 kev with a bent crystal photon spectrometer (Jaffe¹⁰), and from the conversion electron spectrum, the value 42.2 ± 0.3 kev was obtained (Church¹¹). This photon is also seen in the α - γ coincidence spectrum of Cf^{246} (see Fig. 2), but the energy determination is not as accurate as the three values cited here.

In the second alpha spectrum taken, the photographic plate was also exposed to a source containing the U^{230} series. The Em^{218} line at 7.127 Mev¹² was taken as the energy standard and from this the main group of Cf^{246} was found to be 6.753 Mev. When the recoil energy correction is made, the decay energy for Cf^{246} becomes 6.865 Mev.

Alpha-gamma coincidence spectrum. -- The photon spectrum in coincidence with Cf^{246} alpha particles is shown in Fig. 2.

42-kev transition. -- The conversion coefficient for this transition was determined by the ratio of the abundance of the 42-kev gamma ray to the previously discussed population of the 42-kev state (22 percent). Two determinations gave the L-shell conversion coefficient as 800 and 1200. These values are in the expected range for an E2 transition on the basis of extrapolations from the data of Gellman, Griffith and Stanley.¹³

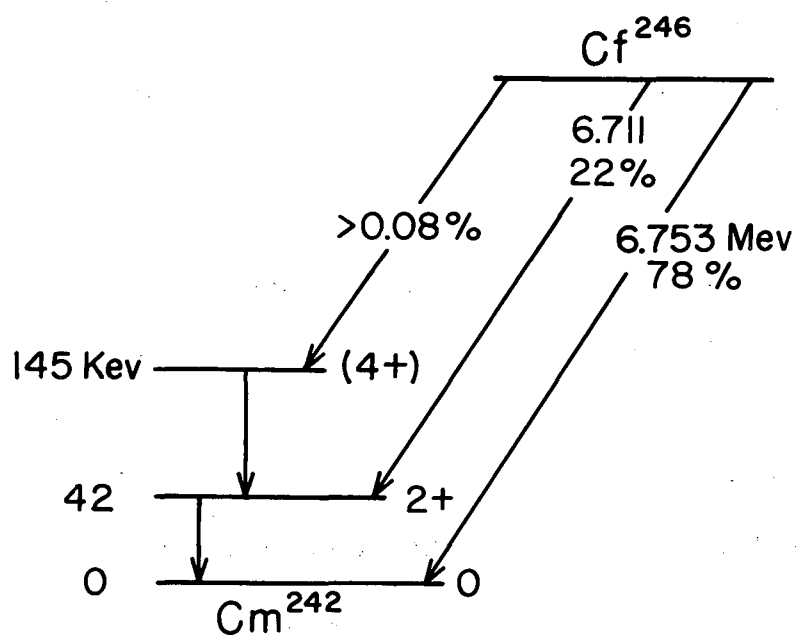
100-kev transition. -- Four determinations gave an average intensity of 1.4×10^{-4} photons per alpha disintegration. Since the

energy of this photon corresponds well with the expected transition from the 4+ state to the 2+ state, we can assume that it is an E2 transition. Then if we assume that the conversion coefficient is the same as that measured for the corresponding transition in the decay of Cm^{242} ,¹⁴ the minimum intensity of population of the 4+ state becomes approximately 8×10^{-4} as indicated in Fig. 1.

One of the current points of interest in alpha-decay theory is to explain the variation in population of 4+ states by different even-even alpha emitters. A convenient reference for comparisons is the "hindrance factor", which expresses the ratio of the observed partial half life for the alpha transition to that calculated on the basis of the theory which gives good agreement with the observed half lives for the ground state transitions. For the Cf^{246} transition to the 4+ state the minimum experimental intensity, as mentioned above, is 8×10^{-4} , and this can be shown to correspond with a hindrance factor of 220. This factor is probably somewhat too large because the approximations used in estimating the population of the 4+ state are expected to produce a value which is too low. The relation between this hindrance factor and those of corresponding alpha groups of other alpha emitters is shown in Fig. 3 of another publication.⁹ A brief statement on the possible implications of these trends will also be found there.

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Fig. 1. Decay scheme for Cf^{246} .

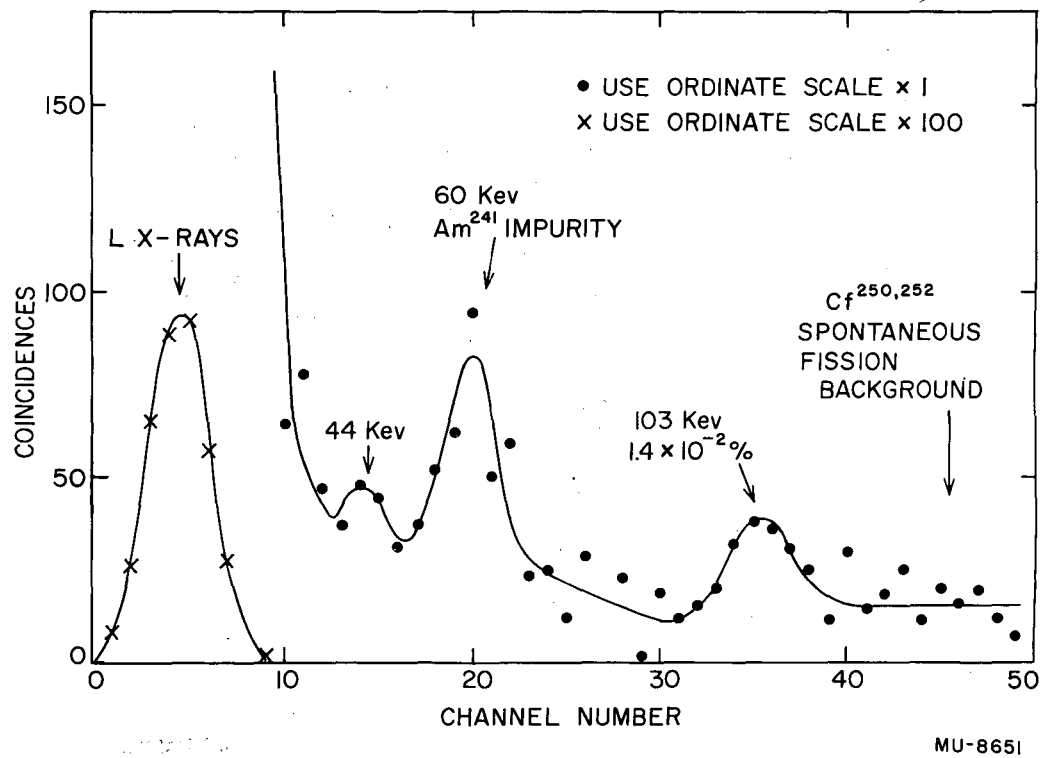


Fig. 2. Alpha-gamma coincidence spectrum of Cf^{246} .