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Total Spontaneous Fission Half-Lives, Kinetic Energy and Mass Yield Spectra of ^{250}Cm, ^{254}Cf and ^{258}Fm

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Abstract. i) The absolute spontaneous fission half-lives of ^{250}Cm, ^{254}Cf and ^{258}Fm, ii) the preference of ^{258}Fm to decay in symmetric modes, and iii) trends of half-lives of even Curium and Californium isotopes are accounted for within the context of the recent theory.

Among isotopes of Curium, Californium and Fermium, ^{250}Cm, ^{254}Cf and ^{258}Fm have the shortest half-lives against spontaneous fission. It has not yet been possible, theoretically, to account for this fact as well as their absolute total spontaneous fission half-lives. In addition, recent measurements indicate that dominant decay modes of ^{258}Fm are near the symmetric mass splitting [1] and ^{258}Fm has an extremely short spontaneous fission half-life [2] of $(3.8 \pm 0.6)\ 10^{-4}$ sec. Thus ^{258}Fm is one of the first detected isotopes decaying mostly to symmetric decay modes. Since this is also the heaviest isotope whose spontaneous fission half-life is now known reasonably well, the understanding of its half-life and its mass yield curve in terms of a theoretical model is necessary for predicting half-lives and mass yield curves of superheavy nuclei.

We examine in this article the decay of these isotopes within the context of the recently developed theory of fission [3, 4] using an interaction characterized by a thin external barrier. Such a barrier follows directly from the computation of the interaction potential using a density dependent mass formula [3, 5, 6], i.e., a mass formula which explicitly incorporates in the energy expression the appropriate variation of the nuclear density as a function of the distance from the centre of the nucleus. Such a mass formula [7–9] accounts for known masses of nuclei as good as any standard mass formula obtained from a liquid droplet of a constant density. Using a simple parametrized version of such a barrier, we have already examined various observed properties associated with the spontaneous fission of ^{234}U, ^{236}U, ^{240}Pu and ^{252}Cf (Refs. [10] and [11]) and found substantial agreement between the theoretical calculations and observed data. We apply this theory and use *the same set of parameters* as those in Refs. [10] and [11]

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to calculate various observables associated with the spontaneous decay of ^{250}Cm, ^{254}Cf and ^{258}Fm. We also compute their kinetic energy versus mass spectra using the theory of Terrell [12].

Yield curves are then computed in the JWKB approximation discussed in Refs. [22], [11] and [4]. These theoretical kinetic energy spectra associated with the decay of ^{250}Cm, ^{254}Cf and ^{258}Fm by fission are drawn in the upper half of Figures 1, 2 and 3, respectively, by solid points. Dashed curves in these figures represent actual values used in computing the mass yield curve. Numerals next to solid points refer to the atomic number of the heavy fragment of a particular daughter pair used in calculating the kinetic energy. The lower half of these figures plots the theoretical percentage yield curves as a function of the mass of the heavy fragment.

We clearly see that while the dominant decay modes of ^{250}Cm and ^{254}Cf are non-symmetric, ^{258}Fm prefers to decay primarily in the symmetric daughter pairs. This is consistent with observations.

Table I

Experimental and theoretical values of spontaneous fission half-lives (referred, respectively, as E_{kin}(exp) and E_{kin}(th)) for the fission of a number of transuranic elements. Half-lives and kinetic energies of elements marked with an (*) refer only to the decay to their respective fastest decay modes. Energies and half-lives are given in MeV and years, respectively

Element	E_{kin}(exp)	E_{kin}(th)	$T_{1/2}$ SFS (exp)	$T_{1/2}$ SFS(th)
^{244}Cm*	185.5 ± 5.0 [19]	185	$1.34 \cdot 10^{7}$ [17]	$6.80 \cdot 10^{7}$
^{250}Cm (set 1)		180.5	$2.00 \cdot 10^{4}$ [16]	$2.20 \cdot 10^{6}$
(set 2)		182.3		$3.10 \cdot 10^{4}$
^{246}Cf*	195.6 ± 2.0 [20]	196	$2.00 \cdot 10^{3}$ [21]	$3.80 \cdot 10^{3}$
^{252}Cf	186.5 ± 1.2 [13]	186.7	85.5 [17]	86
^{254}Cf	185.0 ± 2.0 [14]	188.6	$1.78 \cdot 10^{-1}$ [18]	$2.40 \cdot 10^{-1}$
^{258}Fm (set 1)	190 ~ 200 [15]	200.7	$3.8 \cdot 10^{-11}$ [2]	$3.90 \cdot 10^{-9}$
(set 2)		203.3		$5.10 \cdot 10^{-11}$

In Table I we have compared theoretically calculated total spontaneous decay half-lives and average kinetic energy with experimental data. The theoretical computations for the decay of ^{250}Cm and ^{258}Fm are given for two sets of kinetic energy spectrum. Set 1 corresponds to the dashed curve plotted in the upper halves of Figures 1, 2 and 3 and set 2 corresponds to adding 2 MeV extra to our computed kinetic energy for all decay modes. The mass yield curves corresponding to set 2 look essentially the same as those plotted in Figures 1, 2 and 3 using set 1.

In the table we have also reproduced our results of the decay of ^{252}Cf from Ref. [11] and the theoretically computed partial decay half-lives associated with the decay of ^{244}Cm and ^{246}Cf to one of their fastest decay modes (i.e., $^{244}\text{Cm} \rightarrow {}^{144}\text{Ba} + {}^{100}\text{Zr}$ and $^{246}\text{Cf} \rightarrow {}^{144}\text{Ce} + {}^{102}\text{Zr}$) using the same set of parameters.

Thus, the theory is in a position to explain

i) the decay of ^{258}Fm predominantly to symmetric decay modes,
ii) the variation of spontaneous fission half-lives among the even–even isotopes of Curium and Californium and
iii) absolute total half-lives of spontaneous fission.

The reasons for the success of this simple theory in correlating so many data is evident from the discussion in Ref. [22], elucidating the relation between decay constant, kinetic energy and fission barrier.

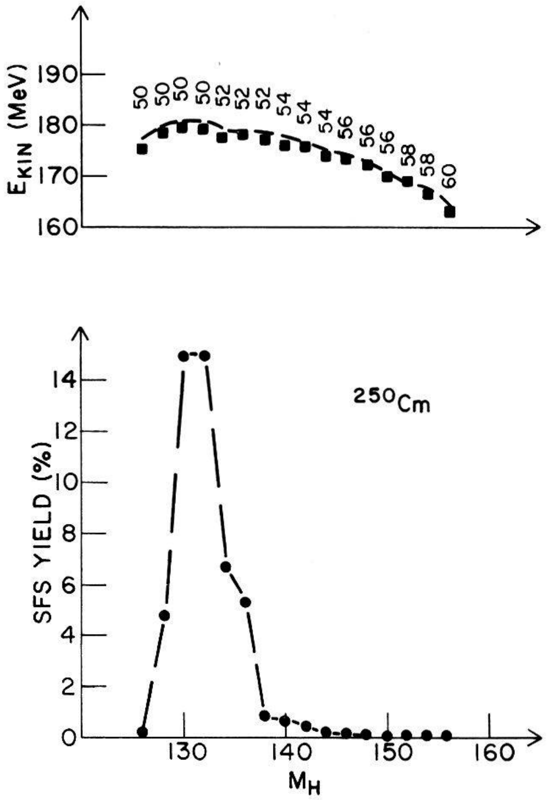

Figure 1
The kinetic energy spectrum associated with the binary spontaneous fission of ^{250}Cm. M_H refers to the heavier of the two fragments in the decay product and 'SFS yield %' means the percentage mass yield curve in the spontaneous fission.

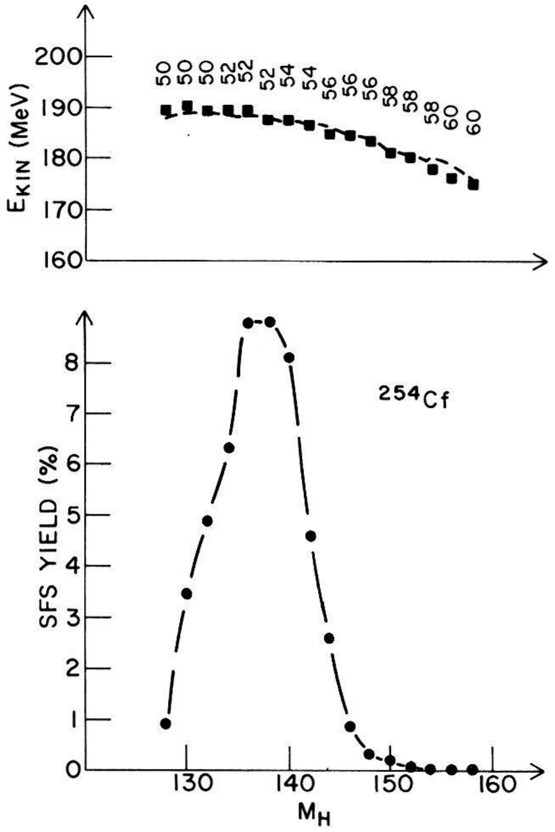

Figure 2
The same as in Figure 1 for the binary spontaneous fission of ^{254}Cf.

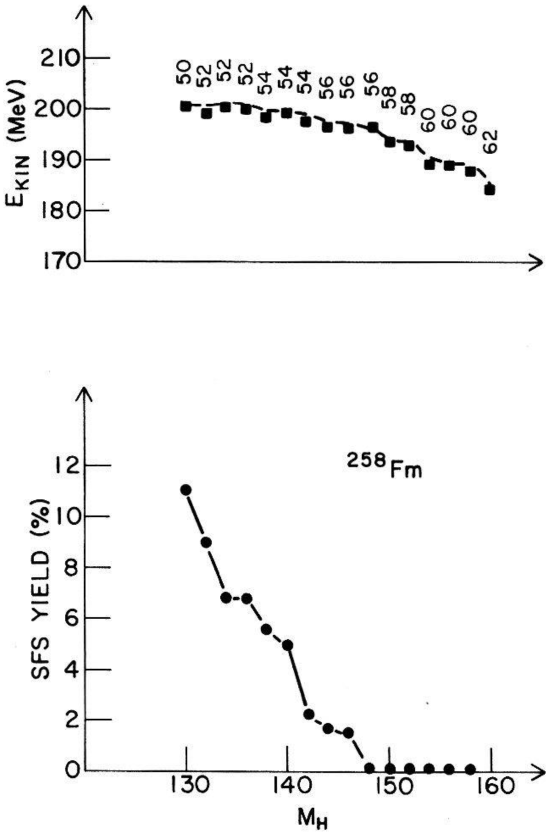

Figure 3
The same as in Figure 1 for the binary spontaneous fission of ^{258}Fm. Note that the yield curve is symmetric with respect to the mass splitting.

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