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Total Spontaneous Fission Half-Life, Mass and Charge Distribution of ^{252}Cf

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Abstract. We have examined the total spontaneous fission half-life, mass and charge distribution in the decay of ^{252}Cf within the context of the recently proposed coupled channel decay theory of fission and find substantial agreement with observed data.

Recently the fission phenomenon has been treated within the context of a reaction theory [1, 2]. Furthermore, it has been shown that the interaction potential between the daughter pair contains an external barrier which plays the central role in determining life-times. This barrier results from the facts that i) the nuclear density varies as a function of the distance from the centre and ii) a density reorganization occurs as a daughter pair is formed out of a parent nucleus. Both of these points are evident from our experimental knowledge of the nuclear density as a function of the distance from its centre and from the obvious fact that the daughter pair and its parent have a Fermi or a similar type of density distribution having a surface of about 3 Fermi thickness to be compared to a half density radius of about 6 to 7 F.

Within the context of such a coupled channel approach and a barrier, it has been possible to reproduce [3] i) the total spontaneous and isomer fission half-lives of ^{234}U, ^{236}U and ^{240}Pu, ii) the mass yield curve for both the spontaneous and the isomer fissions of these nuclei, and iii) associate kinetic energy spectra and observed mean kinetic energies. In addition, the observed spontaneous and isomer fission half-lives of ^{244}Cm and ^{246}Cf are accounted for.

Here we extend this investigation of treating fission as a multichannel decay process [2, 3] to the decay of ^{252}Cf. Apart from the kinetic energy spectrum, the half-lives and the mass yield curve, recently the charge yield curve in the decay of spontaneous fission of ^{252}Cf has been measured. All these data together provide a very stringent test to the theory because a simultaneous explanation of the mass and charge yield curves reflects that the theory can account for partial half-lives in enormous number of decay modes.

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To this end we use *exactly the parameters of Ref.* [3]. The characteristic feature of this fission barrier is an external thin barrier around 15 Fermi. This is a direct consequence of the many-body density dependent mass formula [1, 4, 5].

We note that i) the maximum of the barrier height used is about 200 MeV which is in accord with the customary belief and ii) the mass dependence of the coupling constant λ can be simply reproduced by (A is the mass of the parent)

$$\lambda = 4.56 + (36.1)\exp(-|(175 - A)/75.3|^{9.5}). \tag{1}$$

For the final computation, the kinetic energy spectrum is to be specified. To obtain the kinetic energy spectrum, we use the theory of Terrell [6]. The kinetic energy E_{kin} associated with fission to a particular daughter pair is given by

$$E_{\mathrm{kin}} = Q - E(\mathrm{exc}). \tag{2}$$

Q is the Q-value for the decay to a daughter pair in its ground state and $E(\mathrm{exc})$ is average excitation energy and is equal to

$$E(\mathrm{exc}) = \sum_{n(i),\, i=1,2} B(i, n(i)) - \sum_{i=1,2} (\nu(i)\,\eta(i) + \gamma(i))$$

where, $B(i,n(i))$ is the binding energy of the $n(i)$th neutron emitted from the ith fragment i ($i = 1, 2$) and can be obtained from a mass formula of Myers and Swiatecki [7]. $\gamma(i)$ is the energy of prompt gamma rays emitted from the ith fragment and is estimated [6] to be approximately equal to $(\frac{1}{2})(B(i,\eta(i))$. $\nu(i)$ and $\eta(i)$ are, respectively, the number of neutrons emitted and the average centre of mass kinetic energy of emitted neutrons from the ith fragment. $\eta(i)$ is about 1.4 MeV (Ref. [6]) and from the analysis of Terrell $\nu(i)$ is given by

$$\begin{aligned} \nu(i) &\simeq 0.08(A(i) - 82)\,; \quad \text{if } 82 < A < 126 \\ &\simeq 0.1(A(i) - 126)\,; \quad \text{if } 126 < A. \end{aligned} \tag{3}$$

Clearly, the Figure 11 of Terrell's first paper indicates that to a first approximation $\nu(i)$ does not depend on the parent nucleus but on the individual daughter fragments and equation (3) reflects that the shell structure of the daughter pair plays an important role in determining $\nu(i)$. This conclusion is further confirmed by the recent work of Facchini and Saetta-Menichella [8]. Using (3) and (2), the kinetic energy associated with the decay of ^{252}Cf to a daughter pair can be calculated and are shown in Figure 1 by dotted curve. Actually, this dotted curve represents a simple average of the calculated kinetic energy of a daughter pair having the same mass number but different charges, or atomic numbers, i.e., in actuality an average of the decay of ^{252}Cf to a pair of the same isotones. Dashed curves are the actual values used in our calculation and is associated with the decay of ^{252}Cf to a well-defined daughter pair having atomic number Z_1 and Z_2. The larger of these two atomic numbers is marked next to a dot. The experimental result [9] is plotted by a solid line.

The computed mass yield curve (dots) and the experimental data (solid curve) are shown in the lower half of the figure. Clearly, the theoretical mass yield curve is in agreement with the observation. Theoretical computation is performed in the JWKB approximation [13, 2 and 3].

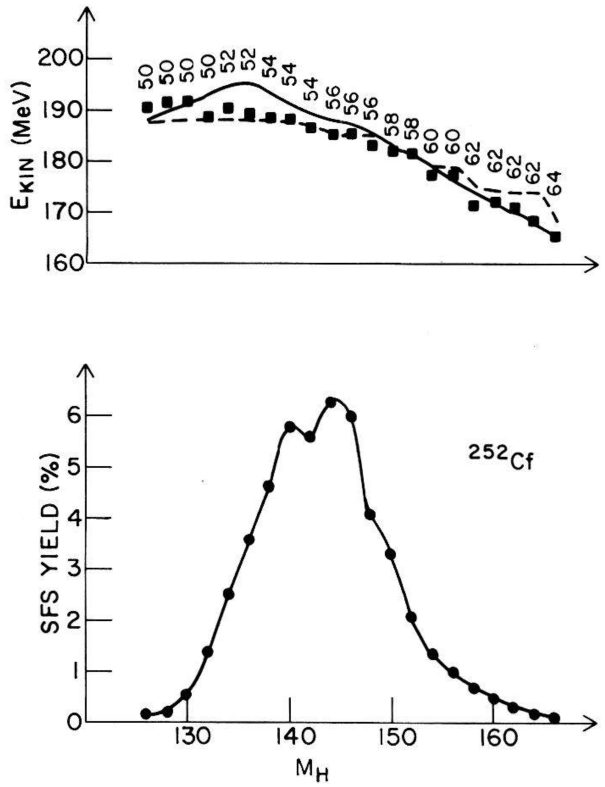

Figure 1
Upper half: Comparison between the theoretical (dashed curve and dots) and experimental (solid line) kinetic energy spectrum. Lower half: Comparison between the theoretical (dots) and experimental (solid like) mass yield spectrum.

The computed total half-life of the spontaneous decay and mean kinetic energy are respectively 86 years and 185.4 MeV. These are in agreement with observed value of (85.5 ± 0.5) years [10] and (186.5 ± 1.2) MeV [9].

Table I
Comparison between the theoretical and experimental percentage charge yields and average masses $A(p)$

Charge	Theory		Exp. (Ref. [11])		Exp. (Ref. [12])	
Z	$A(p)$	% yield	$A(p)$	% yield	$A(p)$	% yield
34	86	0.1	—	—	—	—
36	93.5	1.7	—	—	—	—
38	97.5	2.3	94.6	1.97 ± 0.27	95.5	2.9 ± 0.1
40	101.9	9.5	100.8	7.38 ± 0.52	100.6	7.9 ± 0.3
42	107.5	17.9	105.0	15.36 ± 1.13	105.2	15.4 ± 0.3
44	112.7	10.4	109.8	11.86 ± 0.85	109.6	13.6 ± 0.2
46	116.5	6.1	114.1	6.83 ± 0.73	113.8	7.8 ± 0.3
48	119.5	2.2	118.9	1.66 ± 0.21	—	—
50	131	2.2	—	—	—	—
52	135	6.1	134.5	4.96 ± 0.32	133.9	7.8 ± 0.3
54	139.4	10.4	138.5	9.63 ± 0.70	138.5	13.6 ± 0.2
56	144.5	17.9	143.3	16.23 ± 1.08	143.3	15.4 ± 0.3
58	150.2	9.5	148.0	9.2 ± 0.68	147.9	7.9 ± 0.3
60	154.5	2.3	152.6	2.40 ± 0.26	152.5	2.9 ± 0.1
62	159.5	1.7	158.6	1.08 ± 0.99	156.9	1.13 ± 0.06
64	166	0.1	—	—	—	—

Table I represents a comparison of theoretical percentage charge yield and average mass with experimental results of Ref. [11] and Ref. [12]. The theoretical average mass represents an average of two or three masses associated with the fastest decay modes for a given set of (Z_1 and Z_2). In general, the theoretical results are in substantial agreement with experimental data.

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