α-Ternary decay of Cf isotopes, Statistical Model

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Introduction

The process of splitting a heavier nucleus to three simultaneous fragments is termed as ternary fission and compared to usual binary fission, it is a rare process. Depending on the nature of third particle either it is called light charged particle (LCP) accompanying fission if it is light or true ternary fission if all three fragments have nearly same mass distributions. After experimental observations in early seventies [1], initially with a slow pace, now theoretical studies in ternary fission has turned to a hot topic in nuclear decay studies especially in past one decade [2]. Mean while various models have been developed, existing being modified and seeking for new with a hope that it can beam a little more light to the profound nature of nuclear interaction. In this study a statistical method, level density formulation, has been employed.

Formulation

The Nuclear Level density for a particular nucleus is obtained by [3]

$$\rho(E) = \frac{1}{12}\left(\frac{\pi^2}{a}\right)^{\frac{1}{4}} E^{-5/4} exp\left(2\sqrt{aE}\right) \quad (1)$$

Here a is level density parameter and E is excitation energy at a particular temperature T. The corresponding quantities are

$$a = \frac{E}{T^2} \quad \text{and} \quad E = E_T - E_0 \quad (2)$$

Here E_0 is the ground energy and E_T the system energy at the temperature T. E_T is obtained from Fermi probability distribution functions. Parameters in distribution function can be obtained by normalising function to neutron and proton numbers with the following equations.

For neutrons

$$n_k^N = [exp(-\alpha^N + \beta\varepsilon_k^N) + 1]^{-1} \quad (3\text{-a})$$

and for protons

$$n_k^Z = [exp(-\alpha^Z + \beta\varepsilon_k^Z) + 1]^{-1} \quad (3\text{-b})$$

Normalization can be done by

$$Z = \sum_{k=1}^{Z} n_k^Z \quad \text{and} \quad N = \sum_{k=1}^{N} n_k^N \quad (4)$$

Energy at temperature T is

$$E_T = \sum_{k=1}^{Z} n_k^Z \varepsilon_k^Z + \sum_{k=1}^{N} n_k^N \varepsilon_k^N \quad (5)$$

Fission probability is assumed proportional to the level density of resulting fragments, in ternary fission

$$P(A_i) \propto \prod_{i=1}^{3} \rho_i(E) \quad (6)$$

The yield for ternary fragmentation is obtained by taking the fraction of a single probability over the total probability.

$$Y(A_i) = \frac{P(A_i)}{\sum P(A_i)} \quad (7)$$

Results and Discussion

The possible fragmentations in ternary decay are determined initially by taking all decay combinations that are energetically possible, and following the conditions $\sum_i A_i = A$ and $\sum_i Z_i = Z$. Here A and Z are mass and charge of parent, with suffix the same of fragments. Then minimised the driving potential (V-Q) at touching configuration (in collinear) by varying masses of outer two fragments. Here nuclear potential V at touching configuration is determined using Coulomb and proximity potential [2] and Q value is from the ground state mass differences. Level density calculations have been done by the formulation given above by taking single particle energies from SPL-FRDM in NuDat. The yield related to the different fragmentations are then determined by using Eq.(7).

In this paper ternary yield is determined for alpha accompanied fission. For checking the validity of this formulation initially calculations have done over ^{252}Cf and it has available experimentally observed values. Calculations are done on different energies and comparison of data by normalising to experimentally observed values and are given in Table.1. The last two columns respectively correspond to the calculated value at 1MeV and 2MeV. From the table it can be seen that there exists a considerable agreement between the two sets of values. Here calculations have done with same value of energy for outer two fragments. The calculated and experimental yield will come to an agreement when excitation energy changes from 1MeV to 2MeV. Here we assume that there may be a fluctuation in energy among the fragments during the process of ternary fission to bring an agreement in yield of calculated and experimental values or may happen a coincidence with an unequal distribution of energy among the fragments by keeping the total value as a constant.

The result of entire calculations done over ^{252}Cf is depicted in Fig.1. Here pictured only the region with

Table 1. Comparison of ternary yield with experimentally observed combinations.

Sl.No	A_L/Z_L	A_H/Z_H	Y_{exp}	$Y_{cal(1)}$	$Y_{cal(2)}$
1	92/36	156/60	0.002	0.071	0.014
2	96/38	152/58	0.008	0.007	0.005
3	98/38	150/58	0.014	0.066	0.046
4	99/38	149/58	0.018	0.011	0.010
5	100/38	148/58	0.021	0.014	0.007
6	102/40	146/56	0.009	0.003	0.004
7	103/40	145/56	0.084	0.008	0.012
8	104/40	144/56	0.017	0.045	0.035
9	107/42	141/54	0.030	0.000	0.000
10	108/42	140/54	0.007	0.000	0.000
11	112/44	136/52	0.011	0.000	0.000
12	116/46	132/50	0.006	0.002	0.095

a considerable intensity for fragments and normalisation has done over the fragments in the corresponding region. From the graph we can see that

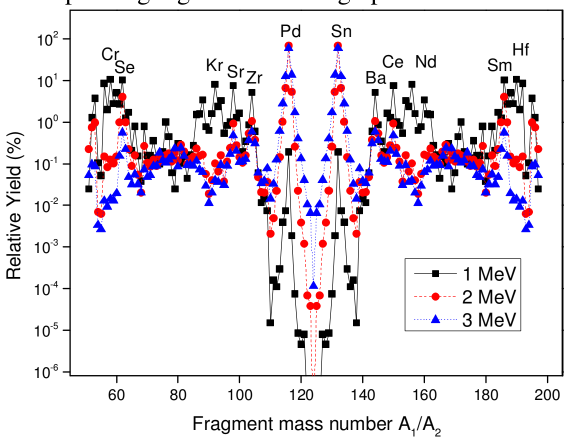

Fig.1. Relative logarithmic yield of alpha-ternary decay for ^{252}Cf at different temperature.

at low excitation energy, yield for a particular fragment or their corresponding combination is competing to others. And this is at the region of unequal distributions. But in the region of equal fragmentations, yield is very feeble. That means at low energy, in alpha ternary decay, most probable fragmentations are found to be distributed away from the centre of distribution graph. That is an asymmetric fission or a process like cluster decay is more probable. By increasing temperature the probability of more-asymmetric fragmentations start to decrease and splitting by near symmetric fragmentations start to increase. That means near-symmetric fission process starts to over dominate asymmetric fission. And this is consistent with the fact that at low energy excitation light particle emission is more probable than fission but at high excitation the latter dominates the former. By increasing temperature further fluctuation in distribution occurs slightly over a wide range. At the same time there are some combinations which keep its probability nearly invariant. From the values of yield at 2MeV and 3MeV, as an overall, we can say that there is no considerable change which can be seen except at far ends and here in these regions no experimentally observed values. For spontaneous decay there is a little chance to have high excitation energy for the resulting fragments. So for the convenient study of α-turnery fission it is desirable to limit the calculation up to 2 MeV.

As a remarkable observation we can say that there are some fragment combinations they keep the value high for some range of temperatures, such

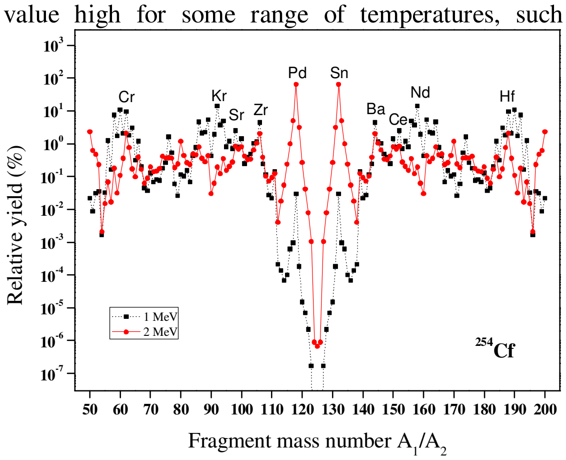

Fig.2. Mass distribution for α-accompanied ternary fission of ^{254}Cf.

as $_{40}Zr+_{56}Ba$ and $_{38}Sr+_{58}Ce$, show large experimental yield and fragment combinations having high fluctuation in yield leads to a less probable (at end points). As a prediction we have done calculation with the same methodology for ^{254}Cf and the distribution graph looks the same as that of ^{252}Cf. Hence in the case of ^{254}Cf also a same fragment combination may probable in α-accompanied ternary fission.

References

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