Ternary decay of ^{252}Cf using Statistical Method

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Introduction

Ternary fission (TF) is a process of splitting a heavier unstable nucleus simultaneously or very short interval of time as three fragments. Initially it has been observed that a long range alpha particle is associated with binary fission and later with more precise experimental observations it is found that it is not an accidental emission of a light charged particle (LCP). This process is very less probable comparing to the usual binary fission of splitting a heavier unstable nucleus into two stable nuclei. The momentum in theoretical studies has occurred especially in past one decade on the basis of more accurate theoretical observations [1]. The process of TF occurs both in induced and spontaneous way. The fragments resulting from TF are generally in excited state as like in binary, but the cold ternary fission is also observed. In cold fission the fragments are nearly in ground state and so no neutron emission. From existing models in binary fission by adapting the third particle involved in the process, different ternary fission models have been developed [2,3]. In this study a statistical method, level density formulation, has been used. TF either belongs in light charged particle (LCP) accompanied fission or true ternary fission. In LCP the third fragment is small like He or Be but in true ternary all fragments have nearly same mass distribution. The importance of TF study in nuclear physics is to extract more information regarding the profound nature of nuclear force.

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 state 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

In this work the ^{10}Be accompanied ternary fission of ^{252}Cf has been studied. The possible fragment combinations associated in ternary fission are determined by the following procedure. Initially we are taking all possible combinations which follows 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 for fragments. Then the driving potential (V-Q) at touching configuration (in collinear) has been determined for all fragment combinations. Here the potential V at touching configuration is determined using Coulomb and proximity potential [2] and Q value is from the ground state mass differences. Then the most probable fragments combination in a specified mass distribution is obtained by taking the fragments with least driving potential. Then the above procedure has repeated over entire mass range. 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).

The level density calculation have done on different energies and compared to the experimental data. The experimental data along with normalized calculated values are tabulated 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 experimental and theoretical value. Here calculations have done with same value of energy for outer two fragments A_1 and A_3. The two values of experimental data are corresponding to yield obtained from the channel for light fragment and heavier fragment respectively.

The entire calculation done over ^{252}Cf is depicted in Fig.1. Here the fragment combinations are pictured only having a considerable yield. Form the figure

Table 1. Comparison of ternary yield with experimentally observed combinations for ^{10}Be ternary fission.

A_1	A_3	Y_{exp}	$Y_{cal(1)}$	$Y_{cal(2)}$
$^{96}_{38}Sr$	$^{146}_{56}Ba$	0.0008/0.007	0.0015	0.0011
$^{98}_{38}Sr$	$^{144}_{56}Ba$	0.005/ 0.021	0.0177	0.0081
$^{100}_{38}Sr$	$^{142}_{56}Ba$	0.0002/0.002	0.0018	0.0015
$^{100}_{40}Zr$	$^{142}_{54}Xe$	0.027 / 0.011	0.0034	0.0025
$^{102}_{40}Zr$	$^{140}_{54}Xe$	0.03 / 0.0070	0.0008	0.0013
$^{104}_{40}Zr$	$^{138}_{54}Xe$	0.009/0.0046	0.0001	0.0004
$^{106}_{42}Mo$	$^{136}_{52}Te$	0.054 /0.005	0.0001	0.0007
$^{108}_{42}Mo$	$^{134}_{52}Te$	0.0032 /---	0.0035	0.0094
$^{110}_{44}Ru$	$^{132}_{50}Sn$	0.004 /0.003	0.1148	0.1065
$^{112}_{44}Ru$	$^{130}_{50}Sn$	0.015/ 0.020	0.0036	0.0158

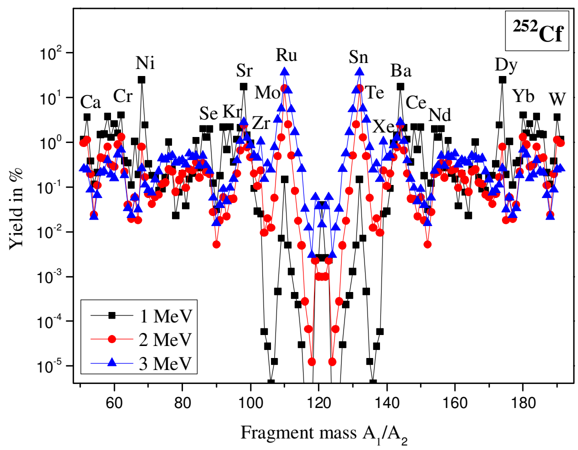

Fig.1. Relative logarithmic yield of alpha-ternary decay for ^{252}Cf at different temperature.

it is clear that at low excitation energy the most probable fragment combinations are at the region of unequal distributions. But in the region of nearly equal fragmentations, yield is very feeble. That is an asymmetric fission or a process like cluster decay is more probable. With the increase in temperature the probability for more-asymmetric fragmentations start to decrease and splitting by near symmetric fragmentations start to increase. This is consistent with the fact that at low energy excitations light particle emission is more probable than fission but at high excitation the latter dominates the former. The effect of further temperature increase is such that the most of the combinations 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. So for the convenient study of ^{10}Be turnery fission it is desirable to limit the calculation up to 2 MeV.

The calculations have repeated for the ^{14}C accompanied ternary fission of ^{252}Cf isotope and the comparison between experimental and theoretical values are tabulated in table 2. Here also the calculations have done with the same procedure by initially taking the possible fragment combinations and the determined the most probable distributions. Then the level density calculations has performed and finally determined the yield normalized to the experimentally observed data. The cal(1) and cal(2) are calculated values at the excitation energy of 1MeV and 2 MeV respectively.

Table 2. Comparison of ternary yield with experimentally observed combinations for ^{14}C accompanied ternary fission.

A_1	A_3	Y_{exp}	$Y_{cal(1)}$	$Y_{cal(2)}$
$^{98}_{38}Sr$	$^{140}_{54}Xe$	0.004/ 0.011	0.056	0.001
$^{100}_{38}Sr$	$^{138}_{54}Xe$	0.00044 / ---	0.000	0.000
$^{102}_{40}Zr$	$^{136}_{52}Te$	0.007 / 0.003	0.000	0.0001
$^{104}_{40}Zr$	$^{134}_{52}Te$	0.004 / 0.003	0.001	0.007
$^{106}_{42}Mo$	$^{132}_{50}Sn$	0.040/ 0.005	0.001	0.049
$^{108}_{42}Mo$	$^{130}_{50}Sn$	0.0027/0.002	0.000	0.001

References

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