Effect of deformation on ternary fission of ^{248}Cm

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Introduction

The breakup of a radioactive nucleus into three fragments in which one of them is very light compared to the main fission fragments is termed as light charged particle accompanied ternary fission. In 1947, Alvarez et al. (see Ref. [1]) discovered the ternary fission with ^{4}He as light charged particle in the fission of ^{235}U, using photographic plate methods and various counter techniques. Most of the ternary fission process occurs with the emission of ^{4}He as light charged particle with fragments in equatorial configuration.

Unified Ternary Fission Model

The light charged particle accompanied ternary fission is energetically possible only if Q value of the reaction is positive. ie.

$$Q = M - \sum_{i=1}^{3} m_i > 0 \tag{1}$$

Here M is the mass excess of the parent and m_i is the mass excess of the fragments. The interacting potential barrier V is taken as the sum of Coulomb potential V_{Cij} and nuclear proximity potential V_{Pij} of Blocki et al. [2] and is given as,

$$V = \sum_{i}^{3} \sum_{j>i}^{3} (V_{Cij} + V_{Pij}) \tag{2}$$

Using one-dimensional WKB approximation, the barrier penetrability P the probability for which the ternary fragments to cross the three body potential barrier is given as,

$$\mathrm{P} = \exp\left\{ -\frac{2}{\hbar} \int_{z_1}^{z_2} \sqrt{2\mu(V-Q)}\, dz \right\} \tag{3}$$

The turning point $z_1 = 0$ represents touching configuration and z_2 is determined from the equation $V(z_2) = Q$, where Q is the decay energy. The reduced mass is given as,

$$\mu = m \frac{A_1 A_2 A_3}{A_1 A_2 + A_2 A_3 + A_3 A_1} \tag{4}$$

where m is the nucleon mass and A_1, A_2 and A_3 are the mass numbers of the three fragments.

The relative yield can be calculated as the ratio between the penetration probability of a given fragmentation over the sum of penetration probabilities of all possible fragmentation as follows,

$$Y(A_i, Z_i) = \frac{P(A_i, Z_i)}{\sum P(A_i, Z_i)} \tag{5}$$

Results and Discussions

The alpha accompanied ternary fission of ^{248}Cm for the equatorial configuration is studied using the concept of cold reaction valley which was introduced in relation to the structure of minima in the so called driving potential (V-Q), which is due to the shell effect.

The effect of deformation and orientation of fragments in ^{4}He accompanied ternary fission of ^{248}Cm isotopes have been analyzed by taking the interacting potential barrier as the sum of the deformed Coulomb and deformed proximity potential. The Coulomb interaction between the two deformed and oriented nuclei is given as,

$$V_C = \frac{Z_1 Z_2 e^2}{r} + 3 Z_1 Z_2 e^2 \sum_{\lambda, i=1,2} \frac{1}{2\lambda+1} \frac{R_{0i}^{\lambda}}{r^{\lambda+1}} Y_{\lambda}^{(0)}(\alpha_i) \left[\beta_{\lambda i} + \frac{4}{7} \beta_{\lambda i}^2 Y_{\lambda}^{(0)}(\alpha_i) \delta_{\lambda,2} \right]$$

with (6)

$$R_i(\alpha_i) = R_{0i} \left[1 + \sum_{\lambda} \beta_{\lambda i} Y_{\lambda}^{0}(\alpha_i) \right] \tag{7}$$

Here $R_{0i} = 1.28 A_i^{1/3} - 0.76 + 0.8 A_i^{-1/3}$ and α_i is the angle between the radius vector and symmetry axis of the i^{th} nuclei. In proximity potential, $V_P(z) = 4\pi\gamma b \bar{R} \Phi(\varepsilon)$, the deformation comes only in the mean curvature radius. The mean curvature radius, $\bar{R}$ for two deformed nuclei lying in the same plane can be obtained by the relation,

$$\frac{1}{\bar{R}^2} = \frac{1}{R_{11} R_{12}} + \frac{1}{R_{21} R_{22}} + \frac{1}{R_{11} R_{22}} + \frac{1}{R_{21} R_{12}} \tag{8}$$

The four principal radii of curvature R_{11}, R_{12}, R_{21} and R_{22} are given by Baltz and Bayman [3].

The driving potential is calculated for the ternary fragmentation of ^{248}Cm and plotted it as a function of mass number A_1 as shown in figure 1. In the figure 1, three cases are considered (1) three fragments taken as spherical (2) two fragments (A_1 and A_2) as deformed with $0^0 - 0^0$ orientation and (3) two fragments (A_1 and A_2) as deformed with $90^0 - 90^0$ orientation. It can be seen from the plot that, in most of the cases, $0^0 - 0^0$ orientation has a low value for driving potential compared with the $90^0 - 90^0$ orientation. In the former case, either both the fragments are prolate or one fragment is prolate and the other one is spherical; and in latter case both fragments are either oblate or one fragment is oblate and the other one is spherical. Also it should be noted that when deformation are included, the optimum fragment combination are found to be changed. For example, the fragment combination ^{116}Ru+^{4}He+^{128}Sn changed to ^{116}Pd+^{4}He+^{128}Cd and ^{108}Mo+^{4}He+^{136}Pu changed to ^{108}Ru+^{4}He+^{136}Sn with the inclusion of deformation.

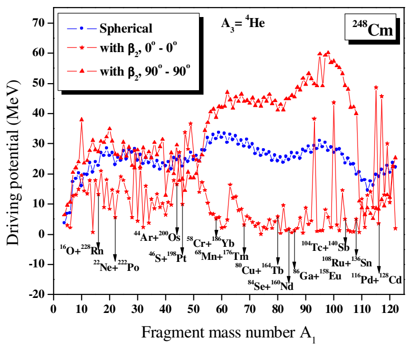

Fig. 1 The driving potential for ^{248}Cm isotope with ^{4}He as light charged particle with the inclusion of quadrupole deformation β_2 and for different orientation plotted as a function of mass number A_1.

The barrier penetrability is calculated for all possible fragment combinations in the cold valley plot, having the minimum $(V-Q)$ value. The relative yield is calculated and plotted as a function of mass numbers A_1 and A_2 and is shown in figure 2. Here figure 2(a) represents the case for deformed fragments and figure 2(b) for spherical case. With fragments treated as spherical, the highest yield is obtained for the fragment combination ^{112}Ru+^{4}He+^{132}Sn, here ^{132}Sn is a doubly magic nucleus. But with the inclusion of quadrupole deformation β_2, the highest yield is found for the fragment combination ^{114}Ru+^{4}He+^{130}Sn, which possess near doubly magic nuclei ^{130}Sn (N=80, Z=50) and the next highest yield is found for the fragment combination ^{116}Pd+^{4}He+^{128}Cd which possess near neutron magicity N=80 of ^{128}Cd.

Our studies on the influence of deformation in the alpha accompanied ternary fission of ^{248}Cm isotope reveal the fact that the ground state deformation has an important role in ternary fission as that of shell effect.

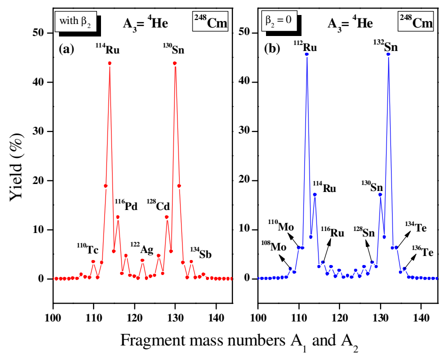

Fig. 2 The relative yields for the charge minimized third fragment ^{4}He with the inclusion of quadrupole deformation β_2 and for the fragments taken as spherical are plotted as a function of mass numbers A_1 and A_2 for ^{248}Cm isotope. The fragment combinations with higher yields are labeled.

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