Ternary fission in ^{242}Cm isotope using Coulomb and proximity potential

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Introduction

A true ternary fission is defined as the break-up of a radioactive nucleus into three fragments of approximately equal size but occur in about one in million fission events. Most common ternary fission processes occur with the light charged particle accompanied fission, in which one of the fragments is very light compared to the main fission fragments. The light charged particle is often emitted in a direction perpendicular to the direction of motion of main fission fragments and is termed as equatorial or orthogonal emission whereas in the case of polar emission, the light charged particle emitted in the direction of the other two fission fragments. The ternary fission with α particle as light charged particle was first discovered by Green and Liversy [1] in 1946.

The Model

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

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

Here M is the mass excess of the parent and m_i is the mass excess of the fragments. The interacting potential barrier for a parent nucleus exhibiting cold ternary fission consists of Coulomb potential and nuclear proximity potential of Blocki *et al.*, [2] and is given by

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

where V_{Cij} is the Coulomb interaction and V_{Pij} is the nuclear proximity potential between the fragments.

Using one-dimensional WKB approximation, the three-body barrier penetrability P is given as,

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

The turning points z_1 represent the touching configuration and z_2 is determined from the equation $V(z_2) = Q$. Here the mass parameter is replaced by reduced mass μ and is defined as

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

where m is the nucleon mass and A_1, A_2, 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 ^{4}He accompanied cold ternary fission of ^{242}Cm has been studied using the Three Centre Shell Model (TCSM) with triangular configuration, taking interaction barrier as the sum of Coulomb and proximity potential. The favourable fragment combination is obtained from the plot of cold valley (plot connecting driving potential and mass number of fragment) and by calculating the yield for charge minimized fragments.

The concept of cold valley was introduced in relation to the structure of minima in the so-called driving potential. The driving potential (V-Q) for a particular parent nuclei is calculated (with keeping third fragment A_3 as ^{4}He) for all possible fragments as a function of mass and charge asymmetries, at the touching configuration. For every fixed mass pair (A_1, A_2) a pair of charges is singled out for which driving potential is minimum.

In present work, the driving potential for the touching configuration of fragments is calculated for ^{242}Cm as the representative parent nucleus with ^{4}He as light charged particle (LCP) In Figure 1 we have plotted the driving potential for ^{242}Cm as a function of mass number A_1.

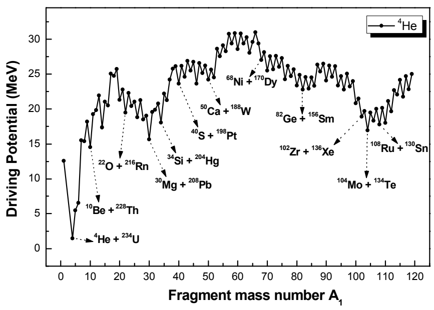

Fig. 1 The driving potential for ^{242}Cm isotope plotted as a function of mass number A_1.

In the Figure 1, fragments occuring in the cold valley will be the most probable ternary fission fragments. The minima in the cold valley keeping ^{4}He as light charged particle are at ^{4}He, ^{10}Be, ^{14}C, ^{16}C,^{18}O, ^{22}O, ^{24}Ne, ^{26}Ne, ^{28}Mg, ^{30}Mg, ^{34}Si, ^{36}Si, ^{40}S, ^{42}S, ^{44}Ar, ^{46}Ar, ^{48}Ca, ^{50}Ca, ^{52}Ca etc. Here the deepest minimum for the fragmentation ^{4}He+^{234}U+^{4}He occur due to the doubly magic nucleus ^{4}He which proves the occurrence of α-particle in ternary fission more fundamental. The minimum found for the splitting ^{14}C + ^{224}Ra + ^{4}He is due to the magic shell N = 8 of ^{14}C. The next deepest minimum for fragment configuration ^{30}Mg + ^{208}Pb + ^{4}He is due to the doubly magic nucleus ^{208}Pb.

The second minimum valley occur around ^{82}Ge for the fragment combinations ^{76}Zn + ^{162}Gd + ^{4}He, ^{78}Zn +^{160}Gd + ^{4}He, ^{80}Ge + ^{158}Sm + ^{4}He, ^{82}Ge + ^{156}Sm + ^{4}He, ^{84}Se + ^{154}Nd + ^{4}He, ^{86}Se + ^{152Nd} + ^{4}He and are likely to be the possible fission fragments, where the minimum for ^{82}Ge + ^{158}Sm + ^{4}He and ^{84}Se + ^{154}Nd + ^{4}He is due to the neutron magic shell N = 50 of Ge. Another deep valley occurs around ^{134}Te for the fragment combinations ^{102}Zr + ^{136}Xe + ^{4}He, ^{104}Mo + ^{134}Te + ^{4}He, ^{106}Mo + ^{132}Te + ^{4}He, ^{108}Ru + ^{130}Sn + ^{4}He, ^{110}Ru + ^{128}Sn + ^{4}He, ^{112}Ru + ^{126}Sn + ^{4}He. In this case, the first and the second minimum is due to the near doubly magic nucleus ^{134}Te (with N = 82 and Z = 52) and ^{130}Sn (with N = 80 and Z = 50) respectively. The third minimum found for splitting with ^{128}Sn is due to the presence of magic shell Z = 50.

The barrier penetrability is calculated for each charge minimized fragment combinations occuring in the cold ternary fission of ^{242}Cm using the formalism described above. Using eqn (5) relative yield is calculated and is plotted as a function of fragment mass number A_1 and A_2 in Figure 2.

From the Figure 2, it is clear that the combination with ^{104}Mo and ^{134}Te is the most favoured ternary fragments with ^{4}He as LCP. The next higher yield can be observed in the ^{108}Ru+^{130}Sn+^{4}He combination. The various other fragment combinations observed in this α-accompanied ternary fission of parent nuclei ^{242}Cm are ^{108}Ru + ^{130}Sn + ^{4}He, ^{110}Ru + ^{128}Sn + ^{4}He, ^{106}Mo + ^{132}Te + ^{4}He, ^{102}Zr + ^{136}Xe + ^{4}He, ^{100}Zr + ^{138}Xe + ^{4}He. Our study reveals the presence of near doubly magic nuclei in the ^{4}He accompanied cold ternary fission of ^{242}Cm.

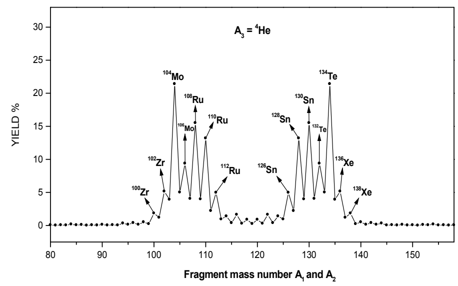

Fig. 2 The calculated yields plotted as a function of mass numbers A_1 and A_2.

Acknowledgments

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References

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