Quaternary fission of ^{296,298}118 isotopes accompanied by two alpha particles

Amaya Pavithran[1], M. K. Preethi Rajan[2] and R. K. Biju[1,3,*]
[1]*Department of Physics, Govt. Brennan College, Thalassery -670106, INDIA*
[2]*Department of Physics, Payyanur College, Payyanur-67027, INDIA*
[3]*Department of Physics, Pazhassi Raja NSS College, Mattanur-670702, INDIA*

Introduction

Quaternary fission is a rare radioactive decay process in which a nucleus breaks into four fragments. Quaternary fission is considered as the generalisation of ternary fission, with emission of two light charge particles. Collinear and equatorial are the two modes in which light charge particles are emitted. In equatorial mode, the light charge particles are emitted at right angle to the direction of main fission fragments, while in collinear mode, they are emitted in the same direction of the main fission fragments. According to Poenaru et al. [1], as one goes from lighter to heavy nuclei, the possibility of two or more necks during fission increases. This makes the study of quaternary fission in the superheavy region particularly significant. In this work we have investigated the possibility of spontaneous quaternary fission of $^{296,\ 298}$118 with two alpha particles as light charge particle in equatorial configuration.

Theoretical Frame Work

The spontaneous quaternary fission is energetically possible for the reactions that have Q value positive. i.e;

$$Q = M - \sum_{i=1}^{4} m_i > 0 \qquad (1)$$

Where *M* is the mass excess of the parent and m_i is the mass excess of the fragments.

The interacting potential, V is calculated as;

$$V = \sum_{i=1}^{4}\sum_{i>j}^{4}\left(V'_{c_{ij}} + V'_{p_{ij}}\right) \qquad (2)$$

where V'c_{ij}, the Coulomb interaction including deformation and orientation [2, 3] between two nuclei is evaluated as;

$$V'_{c_{ij}} = \frac{Z_i Z_j e^2}{r_{ij}} + 3Z_i Z_j e^2 \sum_{\lambda,i=1,2} \frac{1}{2\lambda+1}\frac{R_{0i}^{\lambda}}{r_{ij}^{\lambda}+1} Y_{\lambda}^{(0)}(\alpha_i) \times \left[\beta_{\lambda i} + \frac{4}{7}\beta_{\lambda i}^{2} Y_{\lambda}^{(0)}\left(\alpha_i\right)\delta_{\lambda,2}\right] \qquad (3)$$

The nuclear proximity potential V'p_{ij} between two fragments is given by Blocki et al. [4],

$$V'_{p_{ij}} = 4\pi\gamma b\left[\frac{c_i c_j}{c_i + c_j}\right]\phi\left[\frac{z}{b}\right] \qquad (4)$$

Applying one-dimensional WKB approximation, the barrier penetrability, P is computed as,

$$P = \exp\left\{\frac{-2}{\hbar}\int_{z_1}^{z_2}\sqrt{2\mu(V-Q}dz\right\} \qquad (5)$$

Turning points, z_1=0 for touching position and z_2 is determined from the equation V(z_2)=Q.

Further relative yield of the particular fission channel is evaluated as;

$$Y\left(A_i, Z_i\right) = \frac{P\left(A_i, Z_i\right)}{\sum P\left(A_i, Z_i\right)} \qquad (6)$$

Result and Discussion

In this study, the most suitable fission path is determined by plotting and evaluating cold valley and relative yield graphs for each parent case. The cold valley is a plot of driving potential versus the mass number of one of the fragments, and the driving potential is calculated as the difference between interacting potential V and Q, the decay energy of the fission. The driving potential is calculated at touching configuration for the fixed light charge particles A_3 and A_4. Then, the set of charges that result in

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Electronic address: bijurkn@gmail.com*

minima in driving potential corresponding to each fixed pair of masses (A_1, A_2) is singled out. Further, the cold valley is plotted with this driving potential against mass number of one of the fragments, A_1.

Figure 1 depicts the cold valley plot without deformation and with β_2 and β_4 deformation at 0°-0° orientation for the isotopes ^{296}118 and ^{298}118. For the parent isotope ^{296}118 without deformation effects, a prominent first dip in the valley occurs for the combination ^{50}Ca+^{4}He+^{4}He+^{238}Pu with ^{50}Ca exhibiting a proton shell closure at Z=20. The next minima are observed for ^{79}Ga+^{4}He+^{4}He+^{209}Bi, ^{82}Se+^{4}He+^{4}He+^{206}Hg and ^{83}Se+^{4}He+^{4}He+^{205}Hg, which contain respective near doubly magic nuclei ^{209}Bi, ^{206}Hg and ^{205}Hg. In the case of parent ^{298}118, a deep minimum in the valley is observed for the combinations, ^{81}Ga+^{4}He+^{4}He+^{209}Bi, ^{84}As+^{4}He+^{4}He+^{206}TI and ^{85}As+^{4}He+^{4}He+^{205}TI containing respective proton magic nucleus ^{81}Ga and near proton magic ^{84,85}As.

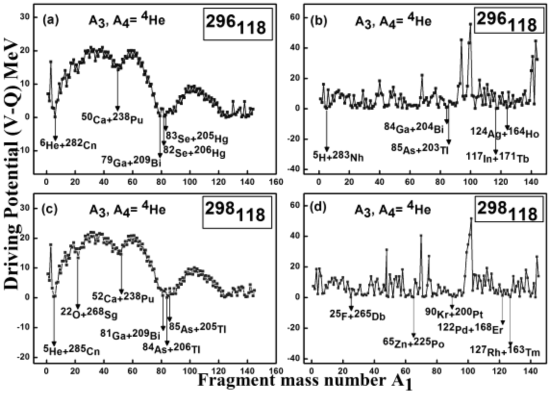

Fig.1. Driving potential of ^{296,298}118 isotopes without deformation (a and c) and with β_2 and β_4 deformation (b and d) plotted as a function of the fragment mass number A_1.

The cold valley plot, after including deformation effects, shows a decrease in the driving potential with sharp minima. These minima differ from those observed in the non-deformed case for the same isotope. For parent isotope ^{296}118, the graph shows a significant minimum in driving potential for combinations containing nuclei such as ^{84}Ga, ^{90}Kr, ^{117}In, ^{118}I, ^{122}Pd and ^{124}Ag which are either near proton or neutron magic. In the case of ^{298}118, a deep minimum is observed for combinations including near proton magic nuclei ^{25}F and ^{225}Po and the neutron magic ^{127}Rh.

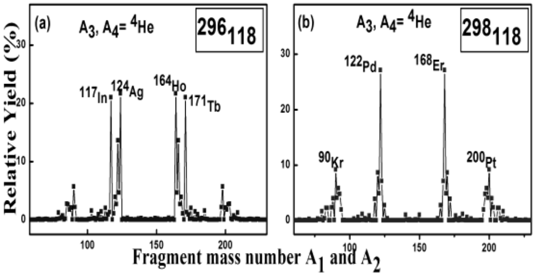

Fig.2. Relative Yield of ^{296,298}118 isotopes (a and b) plotted as a function of the fragment mass number A_1 and A_2 considering both deformation and orientation of fragments.

For parent isotope ^{296}118 parent isotope, a peak relative yield of 21.69% is observed for the combination ^{124}Ag+^{4}He+^{4}He+^{164}Ho, which contains the near proton magic nucleus ^{122}Ag. The next maximum relative yield, approximately 21.06% is exhibited by the ^{117}In+^{4}He+^{4}He+^{171}Tb combination, with a near proton shell closure at Z=49 of ^{117}In. In the case of ^{298}118 parent isotope, a maximum relative yield of approximately 27.13% is exhibited by the combination ^{122}Pd+^{4}He+^{4}He+^{168}Er. The next maximum yield, around 9.17% is shown by the configuration ^{90}Kr+^{4}He+^{4}He+^{200}Pt. The presence of a magic nucleus in the fission channel, along with the effects of deformation, plays a crucial role in determining the most favourable fission channel.

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