Two center shell model approach to light and heavy particle accompanied fission of ^{252}Cf

R. Monisha,* C. Karthikraj, and M. Balasubramaniam
Department of Physics, Bharathiar University, Coimbatore - 641 046, Tamilnadu

Introduction

In 1970's, Maruhn and Greiner [1] have developed the two-center shell model (TCSM) for symmetric and asymmetric fission process based on Merzbacher's double oscillator potential which is capable of explaining the nuclear fusion, fission and cluster decay processes.

Recently in Ref. [2] the complete mass distribution for ternary fission of ^{252}Cf with ^{48}Ca as a fixed third fragment has been studied within statistical theory. The main ingredient is the single particle energies, which are based on finite range droplet model taken from RIPL-3. Further, the three fission fragments are considered in touching configuration.

In this work, we apply single particle energies of TCSM obtained from Ref. [3].

Methodology

The first quantitative model of the spectrum of single-particle states of deformed nuclei was suggested by Nilsson. This model was based on axially-symmetric harmonic oscillator mean-field potential and nuclear shape was assumed to be ellipsoid. The model fails for large nuclear deformations. The generalization of the Nilsson model is referred to as the two-center shell model, which correctly describes the transition from small elliptic deformations of the nuclear ground state, for which the model is identical to the Nilsson model, to strongly deformed nuclei and then to two separated nuclei, reducing to the Nilsson model for each of the fragments.

In particular, the TCSM was generalized to the case of mass-asymmetric nuclei and the nuclear mean-field potential was modified to be a smooth function at the contact point of two fragments. The Hamiltonian of the two-center shell model is,

$$H = \frac{-\hbar^2}{2m_0}\nabla^2 + V(r) + V_{LS}(r,p,s) + V_{L^2}(r,p)$$

Here, V(r) is the double oscillator potential described by the shape parameter as,

$$z^{'} = \begin{cases} z - z_1, & \text{if } z < 0, \\ z - z_2, & \text{if } z > 0. \end{cases} \quad (1)$$

From Eq. 1 the nuclear shape in the regions $z < z_1$ and $z > z_2$ is a half ellipsoid with the centers at z_i $(i = 1, 2)$. The fragment deformations δ_1 and δ_2 defined as the deformations of two harmonic oscillator potentials as,

$$\delta_i = \frac{a_i}{b_i} - 1 = \frac{\omega_{\rho i}}{\omega_{zi}} - 1 \quad (2)$$

where a_i and b_i are the ellipsoid semi-axes related to the corresponding frequencies as $a_i\omega_{zi} = R_0\omega^0 = b_i\omega_{\rho i}$. Here, we have considered $\delta_i = 0$. In TCSM, the nuclear shape parameterization explain the three fission stages namely, compound nucleus (elliptic shape), strongly deformed nucleus, and two nuclear fragments.

The neck parameter ε appears because of the smoothing of the potential $V(\rho, z)$ in the region between the oscillator centers z_1 and z_2 and is defined as the ratio of the smoothed and original potentials at the crossing point of the harmonic oscillator potentials. Therefore, smaller values of ε correspond to a thicker neck at fixed values of other parameters.

*Electronic address: monisharathinam@gmail.com

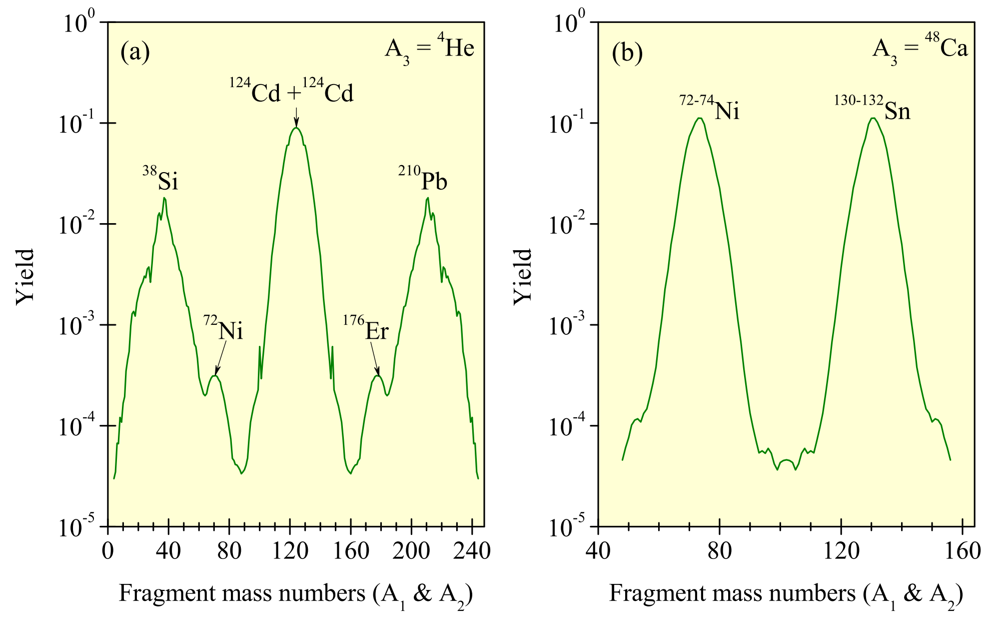

FIG. 1: Ternary fission of ^{252}Cf with A_3 = ^{4}He and ^{48}Ca at T = 2 MeV.

Results and discussion

In the present work, we have considered that the three fragments are in overlapping configuration. For these arrangements of fragments, one can get the necessary single particle energies from TCSM. For the two main fission fragments, the single particle energies are obtained from [3] but for the third fragment, the single particle energies are generated with the use of Nilsson model.

Within the level density picture, we have studied the ternary fission of ^{252}Cf with A_3 = ^{4}He and ^{48}Ca at T = 2 MeV and the results are presented in Fig. 1 (a) and (b) respectively. From the ^{4}He accompanied fission, the symmetric fission configuration, i.e. ^{124}Cd+^{124}Cd, pronouncing the largest yield values. In addition to this, ^{38}Si+^{210}Pb and ^{72}Ni+^{176}Er are also showing the largest yield values. Here, ^{210}Pb and ^{72}Ni are the magic nuclei having Z = 82 and 28 respectively.

From the ^{48}Ca accompanied fission, the ^{72}Ni+^{132}Sn, ^{73}Ni+^{131}Sn, and ^{74}Ni+^{130}Sn configurations having the largest yield values. Here, Ni and Sn are the magic nuclei with Z = 28 and 50 respectively. Our results also shows that the largest yield configurations having the closed shell nature in either one or both the fission fragments.

Conclusion

It is a preliminary work, which can be improved by varying the various parameters associated with the nuclear shapes such as δ_i, η, etc. In this work, the necessary single particle energies are retrieved from the Ref. [3], however, the actual TCSM codes can be used. This may be our future work.

References

[1] J. Maruhn and W. Greiner, Z. Phys. **251**, 431 (1972).
[2] M. Balasubramaniam, C. Karthikraj, S. Selvaraj and N. Arunachalam, Phys. Rev. C **90**, 054611 (2015).
[3] `https://www-nrv.jinr.ru/nrv/webnrv/two_center_shell_model/`