Mass and charge dispersion of ^{224,230}Th nuclei using Skyrme Energy Density Formalism within the collective clusterisation approach

Shivani Jain,* Raj Kumar, and Manoj K. Sharma
School of Physics and Materials Science,
Thapar Institute of Engineering and Technology, Patiala - 147004, Punjab, INDIA

Introduction

In the recent experimental study of nuclear fission of the Thorium isotopic chain, a transition of symmetric to asymmetric fission has been observed, as one moves from ^{222}Th to ^{230}Th nuclei [1]. For lighter-mass isotopes of Thorium, i.e. ^{222,224}Th, it has been observed (at E^*_{CN} >11 MeV) that, the asymmetric fission mode starts appearing with a small effect, in comparison to the symmetric fission [2].
In view of above observation, the present work is aimed to explore the symmetric and asymmetric fission modes via the mass and charge distributions of ^{224,230}Th nuclei, at $E^*_{CN} \approx$ 20 MeV. For above analysis, the preformation probability (P_0) and fragmentation potential ($V(\eta)$) have been calculated within the framework of Dynamical Cluster-decay Model (DCM), based on the Quantum Mechanical Fragmentation Theory (QMFT) [3]. Additionally, we have employed the semiclassical extended-Thomas Fermi approach of Skyrme Energy Density Formalism (SEDF) [4] to obtain the nuclear potential, which is an input term of $V(\eta)$.
Out of number of available Skyrme forces available in literature [4, 5], we have considered SIII (an earlier version) and GSkI (a modified version which considers the iso-spin dependence) Skyrme forces [4], which give different barrier characteristics, to analyze the corresponding effects on the mass and charge distributions of ^{224,230}Th isotopes.

Methodology

Based on the QMFT [3], the preformation probability P_0, which contains the structural information of the compound nuclear system, has been calculated by solving the stationary Schrodinger equation in η-coordinates. Subsequently, for the mass-dispersion case, the preformation factor P_0 is obtained as a function of mass-asymmetry parameter η_A as [6],

$$P_0(\eta_A) = |\psi(\eta(A_i))|^2 \sqrt{B_{\eta_A\eta_A}} \frac{2}{A_{CN}}. \quad (1)$$

On the other hand, for charge-dispersion case, P_0 is obtained as a function of charge-asymmetry parameter η_Z reads as [6]

$$P_0(\eta_Z) = |\psi(\eta(Z_i))|^2 \sqrt{B_{\eta_Z\eta_Z}} \frac{2}{Z_{CN}}. \quad (2)$$

Further, the fragmentation potential, $V(\eta)$ an input term of P_0 involves the binding energy (obtained from the macro-microscopic method of Strutinsky) and the total interaction potential (summation of repulsive and attractive potentials). In the present work, the attractive nuclear potential is obtained using the SEDF. Within this approach, different sets of Skyrme force parameters (SIII and GSkI [4]) are employed to analyze corresponding effect in the mass- and charge-distributions of considered Thorium isotopes.

Result and discussion

For the mass and charge dispersion analysis of ^{224,230}Th compound nuclei, the term $V(\eta)$ is minimized respectively in reference to the mass and charge number of the decay fragments formed in the exit channel of *Th* isotopes. The present work is focused to study the fission modes of ^{224,230}Th nuclei, at a common value of $E^*_{CN} \approx$ 20 MeV. So, the mass and charge numbers of fission fragments belong to $A_2 \approx \frac{A_{CN}}{2} \pm 30$ and $Z_2 \approx \frac{Z_{CN}}{2} \pm 15$ regions, respectively. The contour plots of Fig.1

*Electronic address: `jain.shivani04@gmail.com`

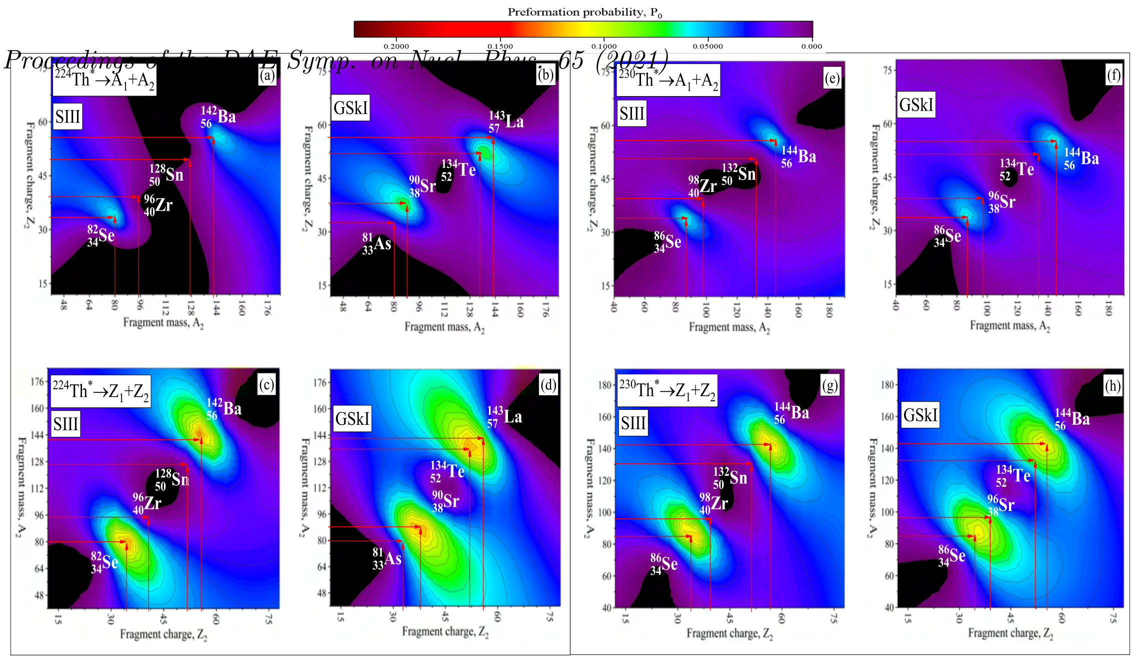

FIG. 1: (Color online) The contour representing the mass and charge distributions of (a)-(d) ^{224}Th and (e)-(h) ^{230}Th nuclei in terms of preformation probability, P_0, using two different Skyrme forces, i.e. SIII and GSkI.

represent the mass and charge distributions in terms of P_0 for ^{224,230}Th isotopes. The color indicates the scale of preformation probability of the fission fragments in the near-symmetric and asymmetric regions.

For ^{224}Th case, using SIII force, the decay fragments (^{96}Zr, ^{128}Sn) in the near-symmetric region have relatively lower preformation probability than the fragments of asymmetric region (^{82}Se, ^{142}Ba), see panels (a) and (c) of Fig.1. However, with the use of modified version of Skyrme force i.e. GSkI, the near-symmetric fission fragments (^{90}Sr, ^{134}Te) have larger possibility of emission from ^{224}Th compound nucleus, as compared to asymmetric fragments (^{81}As, ^{143}La), as shown in panels (b) and (d) of Fig.1. The above results hold true for both the mass as well as charge dispersion cases. As per earlier study [2] for E^*_{CN} around 20 MeV, the disintegration of ^{224}Th shows symmetric fission with larger effect from that of asymmetric fission, which seems justified for the use of GSkI force. Further, as we look on to the mass and charge distributions of heavier isotope of Thorium (^{230}Th), both the forces show higher peak of P_0 for asymmetric fission fragments. This result is in agreement with the experimental analysis [1]. In conclusion, it can be said that, the modified version of Skyrme force (i.e. GSkI) is able to explain the symmetric and asymmetric fission modes not only for heavy-mass isotope of Th, ^{230}Th, but also for lighter-mass nucleus ^{224}Th.

References

[1] A. Chatillo *et al*, Phys. Rev. C **99**, 054628 (2019).

[2] H. Pasca *et al*, Phys. Rev. C **94**, 064614 (2016).

[3] R. K. Gupta and W. Greiner, in *Heavy Elements and Related New Phenomena*, edited by W. Greiner and R. K. Gupta (World Scientific, SIngapore, 1999), Vol. **I**, p. 397; *ibid* Vol. **I**, p. 536.

[4] M. Brack *et al*, Phys. Rep. **123**, 275 (1985); B. K. Agrawal *et al*, Phys. Rev. C **73**, 034319 (2006).

[5] M. Dutra *et al*, Phys. Rev. C **85**, 035201 (2012).

[6] J. Maruhn and W. Greiner, Phys. Rev. L **32**, 10 (1974); R. K. Gupta, W. Scheid and W. Greiner, Phys. Rev. L **35**, 6 (1975).