Transition from asymmetric to symmetric fission in the proton-rich nucleus ^{180}Hg* formed in ^{36}Ar+^{144}Sm reaction

Pooja Chauhan[1,2],[*] Vivek[1], Dalip Singh Verma[1], and S. Sihotra[2]
[1]Department of Physics and Astronomical Science,
Central University of Himachal Pradesh, Dharamshala - 176215 India
[2]Department of Physics, Panjab University, Chandigarh 160014, India

Introduction

Asymmetric fission of a proton-rich ^{180}Hg*, formed at 10.44 MeV excitation energy through the electron capture by ^{180}Tl, was discovered in the experiment conducted at ISOLDE (CERN) [1]. This is in contradiction to the general expectation of symmetric fission due to the shell closures of the symmetric masses. The latter experiments [2, 3], where ^{180}Hg* compound nucleus (CN) is formed in heavy-ion reactions at the excitation energy of range 34-53 MeV, also confirmed the asymmetric fission. The yield of the symmetric fission channel in these experiments increases with the CN excitation energy which agrees with the calculations of [3] and references therein. However, these calculations lack the dynamical study required to give a theoretical prediction for the energy where the transition from asymmetric to symmetric fission occurs. So, an investigation of the fission of ^{180}Hg* within the dynamical cluster decay model could be of interest.

In this work, the dynamical cluster-decay model has been used to investigate the fission of ^{180}Hg* formed in the reaction ^{36}Ar+^{144}Sm at the excitation energy of range 10-63 MeV and the angular momentum range of 0-200 $\hbar$. It is found that the transition from asymmetric to symmetric fission occurs at an excitation energy of around 40 MeV for both optimum hot-compact (HC) and cold-elongated (CE) configurations. The transition with angular momentum occurs but only in optimum HC configuration.

*Electronic address: poojachauhanphy@gmail.com

Methodology

The dynamical cluster-decay model [4, 5] is worked out in terms of mass or charge asymmetry coordinates, relative separation R between the fragments along with the orientation and deformation degrees of freedom. The CN decay/formation cross-section in terms of the partial waves for the fragmentation combination (A_1, A_2), is

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P;\ k=\sqrt{\frac{2\mu E_{cm}}{\hbar^2}} \quad (1)$$

where ℓ_{max} is the maximum value of angular momentum of the compound nucleus, μ is the reduced mass and E_{cm} is the incident centre of mass-energy. The preformation probability P_0 is obtained from the solution of the stationary Schrödinger equation in mass asymmetry coordinate η with the fragmentation potential, which is the sum of the mass energies, proximity, Coulomb, and centrifugal potentials of the interacting fragments. The calculations for both spherical and deformed fragments in their optimum HC and CE configurations have been done at internuclear surface separation $\overline{\Delta R}$ (=0.5 fm). The penetration probability P refers to the R-motion and is WKB integral.

Calculation and results

Fig. 1 (a) shows that when the fragments are considered spherical (β_2=0), the mass distribution of fission fragments is symmetric with the most probable channel consisting of masses (90, 90) and having shell closures at Z=40 (semi-magic) and N=50. This means symmetric fission is driven by spherical shell closures. When the fragments are deformed ($\beta_2(T)$) and oriented to their optimum HC

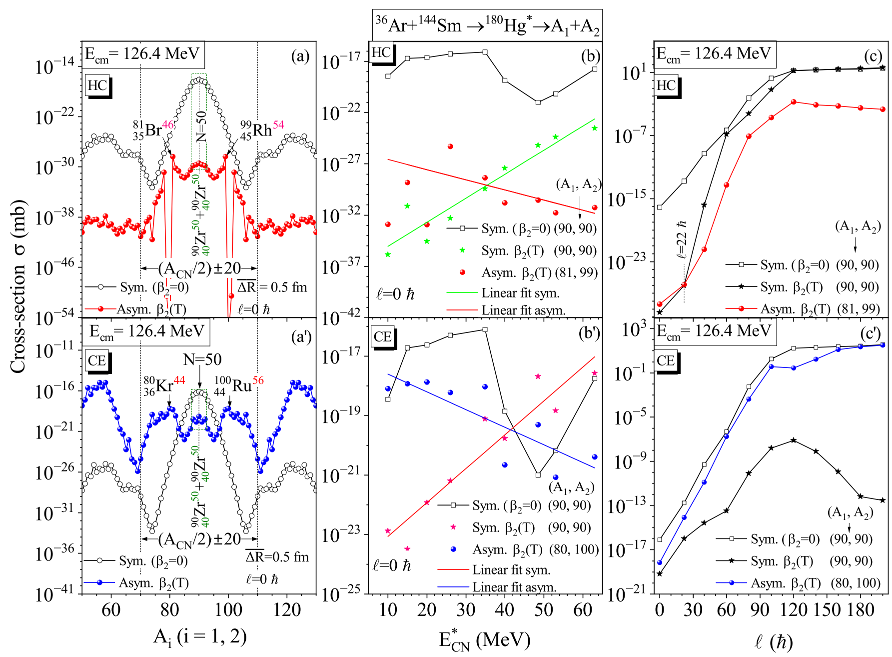

FIG. 1: Left panel: Mass distribution of fission fragments for spherical and deformed fragments in their optimum HC and CE configuration. Middle panel: cross-section as a function of E^*_{CN} for the fission channels of the symmetric and asymmetric masses along with their linear fit. Right panel: Same as middle one, but for the angular momentum ℓ.

and CE configurations, the mass distribution becomes asymmetric with the most probable fragment combination of masses (81, 99) with deformed neutron shell closures at (46, 54) and masses (80, 100) with deformed shell closures at (44, 56), respectively. This means that the deformed shell closures are responsible for the asymmetric fission of ^{180}Hg*. Figs. 1 (b) & (b′) shows that the fission channel of asymmetric masses is the most probable channel up to 40 MeV of excitation energy for both HC and CE configurations and beyond, it gets reversed. This transition energy is consistent with the experimental/theoretical results presented in ref. [3] and references therein. For the spherical case, a sharp fall in the cross-section around the transition energy occurs. Fig. 1 (c) shows that the transition of the asymmetric fission channel to the symmetric one with angular momentum takes place at 22 $\hbar$ for optimum HC configuration. No such transition is seen in the case of optimum CE configuration, see Fig. 1 (c′). When the fragments are considered spherical, the most probable channel is the combination of symmetric masses and its cross-section is higher than the deformed cases for all angular momentum.

Conclusion

The transition from asymmetric to symmetric fission for the CN formed the reaction ^{36}Ar+^{144}Sm→^{180}Hg* takes place at an excitation energy of 40 MeV for both optimum orientations. It appears to be due to the change in magnitude of deformation and hence the shell gaps with excitation energy. The transition energy (40 MeV) matches well with the experimental and theoretical findings. Such transition is seen with angular momentum but only for optimum HC configuration.

References

[1] A. N. Andreyev, J. Elseviers, M. Huyse *et al.*, Phys. Rev. Lett. **105**, 252502 (2010).

[2] K. Nishio, A. Andreyev, R. Chapman *et al.*, Phys. Lett. B **748**, 89 (2015).

[3] E. M. Kozulin, G. N. Knyazheva *et al.*, Phys. Rev. C **105**, 014607 (2022).

[4] R. K. Gupta, M. Balasubramaniam *et al.*, Phys. Rev. C **71**, 014601 (2005).

[5] D. S. Verma, P. Chauhan, Vivek, and A. S. Pawar, Nucl. Phys. A **1050** 122926 (2024).