Fission partition a reflection of the structure of fission fragments; The decay of ^{229}Am* excited at 43 MeV

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Introduction

The outcome of the heavy-ion collisions depends not only on the properties of the incoming channels like incident energy, angular momentum, mass asymmetry, iso-spin asymmetry, shell structure, etc. but also on the shell closures of the outgoing fragments [1]. Depending on the incident energy and angular momentum, a hot and rotating compound nucleus (CN) can undergo either evaporation or fission plus evaporation. The fission of CN often produces mass asymmetric fragments which is usually attributed to the shell closures of the outgoing fragments. For example, the two peaks visible in the mass distribution of the binary fission-fragments formed in the decay of compound nucleus ^{229}Am* excited at 43 MeV has been found to coincide with A_L = 98±8 and M_H = 130±8 amu and has been claimed to be due to the structure of fission fragments [2]. The experiments have shown that the main driver to asymmetric fission in the actinide region is the number of protons of the heavy fragment of $Z \approx 54$ [3]. Thus, it will be interesting to investigate the dominant shell effects in the pre-fragments at the scission point in the fission partition and positions of the asymmetric fission channels.

In this paper, the effects of shell closures of the fission fragments of the compound nucleus ^{229}Am* at the scission point have been analysed using dynamical cluster-decay model. The emission of binary fragments in the model is considered as the dynamical mass motion of the preformed fragments/clusters through the interaction barrier and the fragmentation potential energy is defined as the sum of the liquid drop energy, shell corrections, the nuclear, Coulomb and centrifugal potential energies at the scission point.

Methodology

The dynamical cluster-decay model defines CN-decay or fusion cross section [4], in terms of the partial waves as

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

where the preformation probability P_0 is the solution of the stationary Schrödinger wave equation in η-coordinate with potential energy calculated at the scission point

$$P_0(A_i) = |\psi(\eta(A_i))|^2\sqrt{B_{\eta\eta}}(2/A) \qquad (2)$$

and the penetration probability P in WKB approximation is

$$P = \exp\left[-\frac{2}{\hbar}\int_{R_a}^{R_b}\sqrt{2\mu(V(R)-Q_{eff})}dR\right] \qquad (3)$$

where, R_a and R_b are the first and second turning points of the penetration path, $\mu = \frac{1}{4}Am(1-\eta^2)$ is the reduced mass, ℓ_{max} is either the critical angular momentum ℓ_c which is the property of the incoming channel or ℓ_{fus} the angular momentum at which the cross-section for the emission of the light particles tends to zero, m is the nucleon mass and E_{cm} is the incident energy. The compound nucleus excitation energy is related to its temperature T (MeV) as

$$E_{CN} = (A/9)\,T^2 - T, \qquad (4)$$

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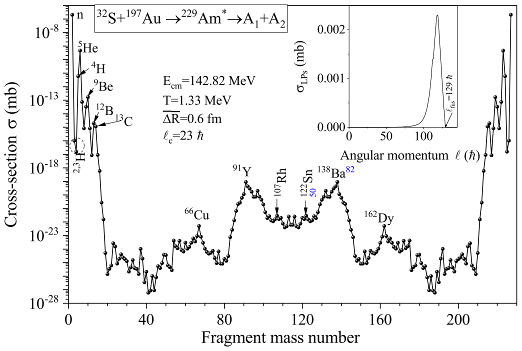

FIG. 1: Fragment cross-section as a function of the fragment mass number for the decay of hot and rotating compound nucleus ^{229}Am*. Inset is for σ_{LPs} as a function of ℓ.

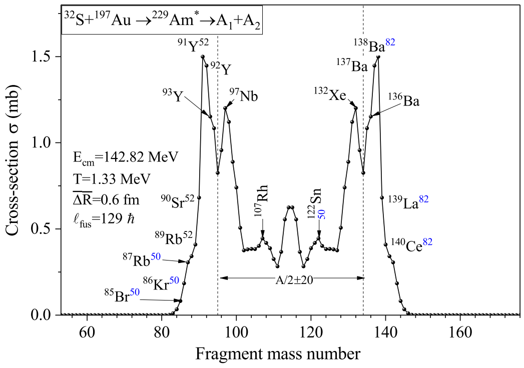

FIG. 2: Mass distribution of the fission fragment cross-section for the symmetric and nearly symmetric mass region of ^{229}Am*.

where A is the mass of the compound nucleus. The deformations of the interacting nuclei and random position of rupturing CN has been taken care by taking an average inter-nuclear surface separation $\overline{\Delta R}$.

Calculations and results

Fig. 1 shows the mass distribution of the cross-section for the decay of hot and rotating compound nucleus ^{229}Am* formed in ^{32}S+^{197}Au reaction at an incident energy of 142.82 MeV and $\ell_{max} = \ell_c$ on log scale. Here, the emission of LPs (Z≤2) and IMFs (Z≤12) dominate over the fission. In the mass region of the LPs and IMFs, the cross-section is maximum, respectively for neutron and ^{9}Be while for fission fragments it is for the fragment combination ^{91}Y + ^{138}Ba, which is near to the symmetric mass region (A/2±20). The variation of the cross-section summed up for LPs with angular momentum, see inset Fig. 1, shows that $\sigma_{LP} \rightarrow 0$ at 129 ħ (say ℓ_{fus} [4]). This angular momentum can be an alternate to the critical angular momentum for the compound nucleus decay/fission. Next, the cross-section has been calculated by considering $\ell_{max} = \ell_{fus}$, see Fig. 2.

Fig. 2 shows the mass distribution of the cross-section for the symmetric and nearly symmetric mass regions for the decay of hot and rotating the compound nucleus ^{229}Am* with cross-section summed up over angular momentum range 0 - ℓ_{fus}. Due to the additional number of partial waves a tremendous increase in the cross-section of the fission fragments of the symmetric and nearly symmetric mass regions have been found. In this case, the cross-section for the fission fragments dominates over the LPs and IMFs (not shown in Fig. 2). The mass distribution peak on the lighter mass region contains fragments with N=50 or ≈50 while the heavier mass side has N=82 fragments. Thus signifying the importance of shell closure/structure of the outgoing fragments in the decay of compound nucleus ^{229}Am*. The peaks found in the mass distribution of the fission fragments coincide with A$_L$ = 98±8 and M$_H$ = 130±8 amu and Z$_H$ ≈ 54 (here ^{132}Xe) are in accordance with the respective experimental work of ref. [2] and [3].

References

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