Shell closure effects in the decay of Fr isotopes

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Introduction

The decay of a compound nucleus (CN) in the mass region A_{CN} >200 has been of much interest for several decades. In addition to the fusion-fission (ff) component, the de-excitation of these systems possess considerable contribution from light-particle evaporation residues (ER) as well. For an equilibrated CN, the dynamical cluster-decay model (DCM) [1–3] treat all these decay processes on equal footing as barrier penetration of preformed fragments or clusters. On the other hand, in the other available statistical formalisms, the fission and ER are treated on two different models, the fission models and the statistical evaporation codes.

Very recently, the DCM has been applied [2, 3] to study the odd-mass heavy nuclear systems ^{213,215,217}Fr* over a wide range of center-of-mass energies 48 to 94 MeV. The decay of ^{215}Fr*, studied on the DCM [2], formed via two different reactions ^{11}B+^{204}Pb and ^{18}O+^{197}Au, confirms the entrance channel independence, in agreement with experimental data and statistical model (PACE2) calculations [4]. The decay paths of compound systems ^{213}Fr* (with neutron number N=126) and ^{217}Fr* (with N=130), formed in ^{19}F+^{194,198}Pt reactions, are also analyzed in the framework of DCM [3] in reference to the data of Ref. [5]. As the DCM is based on collective clusterization picture, which allows us to study the role of magic proton/ neutron number of decay products only, an attempt was made [3] to explore the relevant information regarding the shell closure aspect of the decay fragments for ^{213,217}Fr* systems. A small hump/ shoulder was observed [3] in mass fragments, which arises due to deformed shell closure of light fragment Z_2=36 and spherical shell closure of heavy fragment Z_1=50, being somewhat more pronounced in case of ^{213}Fr* (N=126) as compared to ^{217}Fr* (N=130).

In the present work, the above study is extended further to the decay of ^{215}Fr*, for use of another isotope of Pt in ^{19}F+^{196}Pt reaction [6], and to understand the dynamics of two other neighboring isotopes ^{211,219}Fr* formed in the proposed reactions ^{19}F+^{192}Pt and ^{19}F+^{200}Pt. The main emphasis here is to carry out a comprehensive analysis of the possible role of shell effects in decay fragments or else the isospin (N/Z ratio) effect in context of various mass distributions of $^{211-219}$Fr* isotopes.

Methodology

In terms of collective coordinates of mass (and charge) asymmetry and relative separation R, the CN decay cross-section in DCM is calculated by using the preformation probability P_0 and the penetrability P. The preformation probability

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

is obtained as the solution of Schrödinger equation in η coordinate, given as

$$\{-\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}\frac{1}{\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}+V_R(\eta,T)\}\psi^\nu = E^\nu\psi^\nu \quad (2)$$

where ν=0,1,2,3.... refers to ground ($\nu = 0$) and excited-states solutions. Also, the penetrability P is obtained via the WKB approximation. Both the quantities, i.e., P_0 and P carry the effects of T and angular momentum ℓ at a given $E_{c.m.}$.

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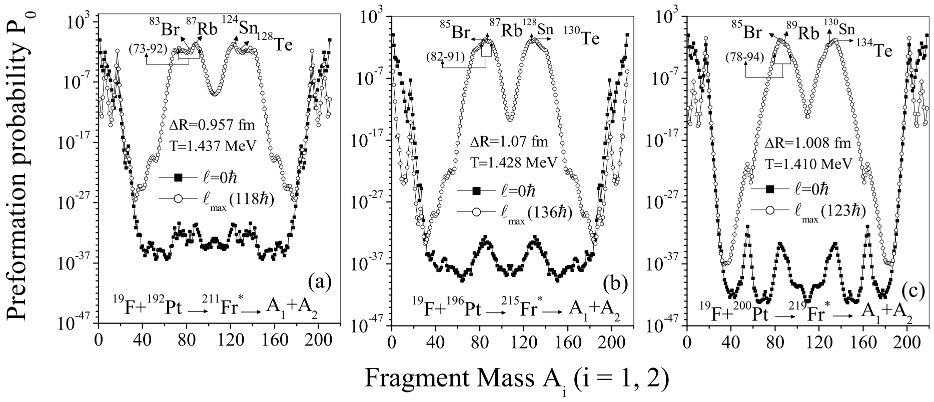

FIG. 1: Fragment preformation probability P_0 as a function of fragment mass number A_i (i = 1, 2) for different compound systems (a) ^{211}Fr*, (b) ^{215}Fr*, and (c) ^{219}Fr*, at $E^*_{CN} \sim 47$ MeV, showing the presence of same shell effects in all cases.

Calculations and discussion

Fig. 1 shows a comparative analysis of the preformation probability P_0, plotted at two extreme ℓ=0 and $\ell=\ell_{max}$ values, for the decay of ^{211,215,219}Fr* formed in ^{19}F+^{192,196,200}Pt reaction channels at a comparable excitation energy $E^*_{CN}\sim$ 47 MeV with deformations taken upto β_2 and 'optimum' orientations. The preformation probability P_0 of the fragments (before tunnelling through the barrier) accounts for the structure effects in the decay process of a nuclear system. One may see in Fig. 1 that the fission pattern remains asymmetric and the fragments in mass range A_2=73-94 (plus complementary heavy fragments) seem to be the prominent contributors toward fission cross-sections for the considered Fr isotopes. It has been shown explicitly in this figure that the shell effects arise due to the deformed closed shell around light-fragment charge Z_2=36 (actually at Z_2=35 and 37), and spherical shell closure around heavy-fragment charge Z_1=50 (actually at Z_1= 52 and 50) in all the odd-mass ^{211,215,219}Fr* isotopes. This is explicitly marked in Fig. 1 in terms of two strong maxima and as a hump/ shoulder for both the light and heavy-mass fragments. Comparing ^{211}Fr* with ^{215,219}Fr* for the $\ell=\ell_{max}$ case, we find that the hump in mass fragmentation of ^{211}Fr* (with N=124) is slightly more dominant and goes on decreasing with the increase in N/Z ratio. Thus, the above observation clearly signifies the importance of shell effects of decay fragments in the above studied odd-mass ^{211,215,219}Fr* isotopes, supporting the result of our earlier work [3] on ^{213,217}Fr* isotopes.

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