Systematic study of decay of ^{292}Fl* formed in ^{48}Ca + ^{244}Pu fusion reaction using SLy4 Skyrme Force

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Introduction

The identification of the centre of an island of stability in the region of superheavy nuclei has been a long-standing problem in nuclear structure research, specifically in identifying the next doubly magic nucleus (magic proton and neutron numbers) heavier than ^{208}Pb. The stability of superheavy nuclei depends heavily on shell effects, increasing significantly at closed proton and neutron shells. For elements beyond uranium, the stability of these nuclei decreases rapidly with increasing the atomic number Z but rises sharply when the neutron number approaches the spherical shell closure. According to various theoretical models, the next spherical shell closure for the neutrons beyond neutron no. N=126 is predicted to occur at N=184 [1]. Therefore, to synthesize the superheavy nuclei, it is preferable to select reaction partners with N as close as possible to N=184 in order to approach the shell closure.

In the present work, we have studied the excitation functions (EFs) for the production of ^{292}Fl*(Z=114) compound nucleus formed in the hot fusion reaction ^{48}Ca + ^{244}Pu [2, 3] and evaporation residue cross-sections σ_{3n-4n} of the decay of ^{292}Fl*, at an excitation energy of compound nucleus $E^* = 35$ to 52.6 MeV, based on the dynamical cluster-decay model (DCM) [4], including quadrupole deformations β_{2i} and hot-optimum orientations θ_i. We have used Skyrme nuclear interaction potential derived from Skyrme Energy Density Functional (SEDF) based on semiclassical extended Thomas Fermi (SETF) approach under the frozen density approximation. We have calculated the evaporation residue cross-sections using the Skyrme SLy4 [5] force within the framework of DCM where the neck-length ΔR is the only parameter representing the relative separation distance between two fragments and/or clusters A_i(i=1,2) which assimilates the neck formation effects. The calculated results have been compared with the experimental data taken from Ref. [2, 3]. The DCM reproduced the measured data on fusion evaporation residue (ER) nicely within a single parameter fitting of ΔR.

Methodology

The nucleus-nucleus interaction potential in SEDF, based on ETF method, is defined as

$$\begin{aligned} V_N(R) &= E(R) - E(\infty) \\ &= \int H(\vec{r})d\vec{r} - \Big[\int H_1(\vec{r})d\vec{r} + \int H_2(\vec{r})d\vec{r}\Big] \end{aligned} \quad (1)$$

where H is the Skyrme Hamiltonian density, a function of nuclear, kinetic-energy, and spin-orbit densities, the latter two themselves being the functions of the nucleon/ nuclear density, written in terms of, so-called, the Skyrme force parameters, obtained by fitting to ground-state properties of various nuclei. There are many such forces and here we have chosen SLy4 Skyrme[5] force. The radius vectors for axially symmetric deformed nuclei are

$$R_i(\alpha_i, T) = R_{0i}(T)\big[1 + \sum_{\lambda} \beta_{\lambda i} Y_{\lambda}^{(0)}(\alpha_i)\big], \quad (2)$$

with T-dependent equivalent spherical nuclear radii $R_{0i}(T) = R_{0i}(T = 0)(1 + 0.0007T^2)$ for the nuclear proximity pocket formula, and $R_{0i}(T) = R_{0i}(T = 0)(1+0.0005T^2)$ for SEDF,

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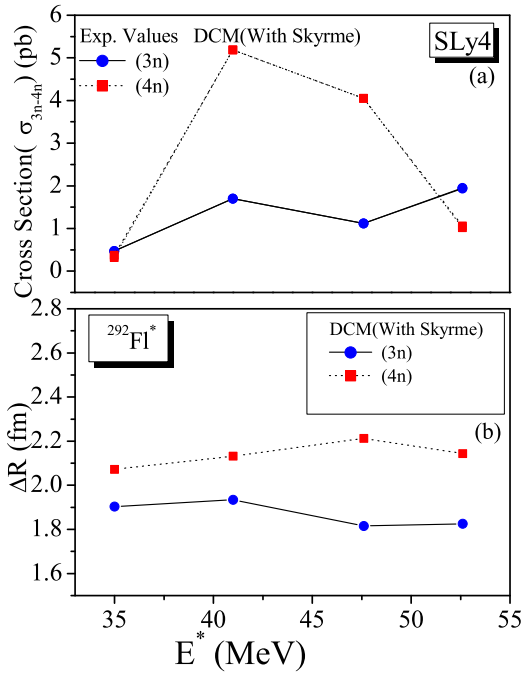

FIG. 1: (a) represents the excitation functions for the individual 3n and 4n evaporation channels for the fusion reactions ^{244}Pu(^{48}Ca,3n-4n)^{288,289}Fl using the Skyrme force SLy4. The solid and dotted lines represent our calculations on DCM for the best fitted ΔR values is shown in Fig1(b).

where $R_{0i}(T = 0) = [1.28A_i^{1/3} - 0.76 + 0.8A_i^{-1/3}]$.

Finally, the compound nucleus temperature T (in MeV) is given by

$$E^* = E_{c.m.} + Q_{in} = (A/10)\,T^2 - T. \qquad (3)$$

Adding to V_N, the Coulomb and angular momentum ℓ-dependent potentials V_C and V_ℓ, we get the total interaction potential $V(R,\ell)$, characterized by barrier height V_B^ℓ, position R_B^ℓ and curvature $\hbar\omega_\ell$, each being ℓ-dependent.

The compound nucleus decay/ fragment formation cross sections are calculated within the DCM, given as

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P; \qquad k = \sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \qquad (4)$$

where P_0 is preformation probability referring to mass asymmetry η [$= (A_1 - A_2)/(A_1 + A_2)$] motion and P, the penetrability, to R motion. For further details, refer to [4].

Calculations and Results

The DCM, with effects of deformations of the incoming nuclei or outgoing fragments and their compact-orientation degrees of freedom included, is used to calculate the evaporation residue excitation functions of equatorial compact ($\theta_c = 90^0$ for ^{292}Fl*) hot fusion reaction ^{48}Ca + ^{244}Pu. We have compared our calculated results with the experimental 3n and 4n evaporation channel cross-sections using the SLy4 Skyrme force as shown in Fig.1(a) and we observed that the ΔR is larger for 4n emission than 3n emission implied that 4n emission took place earlier than 3n emission from the CN ^{292}Fl*. The best fitted neck-length parameter ΔR as a function of E^* for 3n and 4n evaporation channel cross section of ^{292}Fl* represented in Fig.1(b). Our calculated results coincided with the experimental data indicating that the DCM successfully addresses the experimental results.

References

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