Study of decay of ^{292}Fl* formed in ^{48}Ca + ^{244}Pu fusion reaction using KDE0(v1) Skyrme Force

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Introduction

The study of the synthesis and decay of superheavy nuclei(SHN) is one of the most important topics in both experimental and theoretical nuclear physics. All the presently known SHEs are short-lived and are artificially made through heavy ion induced nuclear rections. Due to their small lifetimes, their production probabilities are extremely low. Nevertheless, one can make trustworthy predictions about the probabilities for the synthesis of superheavy nuclei (SHN) through the Dynamical Cluster-Decay Model(DCM).
Thus, 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 [1, 2] and evaporation residue(ER) cross-sections σ_{3n-4n} in the decay of ^{292}Fl*, at excitation energy of compound nucleus E^* = 40.2 to 43 MeV, based on the (DCM) [3], 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. Specifically, the conventional Skyrme KDE0(v1) [4–6] force in conjugation with the 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) assimilating the neck formation effects, has been employed.

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Methodology

The DCM is worked out in terms of collective coordinates of mass [and charge] asymmetry $\eta = (A_1 - A_2)/(A_1 + A_2)$ [and $\eta_Z = (Z_1 - Z_2)/(Z_1 + Z_2)$], and relative separation R, the multipole deformations $\beta_{\lambda i}$ and orientations θ_i (i = 1,2) of two nuclei in the same plane. Here A_1 and A_2 [Z_1 and Z_1] are the mass [charge] numbers of fragments and A_1+A_2) [=A] is the mass number of the compound nucleus. In the DCM, using decoupled approximation to R- and η-motion, the compound nucleus decay cross-section in terms of partial wave is written as production cross-section is

$$\sigma = \sum_{\ell=0}^{\ell_{max}} \sigma_\ell = \frac{\pi}{k^2} \sum_{\ell=0}^{\ell_{max}} (2\ell+1) P_0^\ell P_\ell ; k = \sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \quad (1)$$

where the preformation probability P_0^ℓ refers to η-motion and the penetrability P_ℓ to R-motion. ℓ_{max} is the maximum angular momentum, fixed here for the light particle cross-section approaching zero, i.e., $\sigma_{ER}(\ell) \rightarrow 0$ at $\ell = \ell_{max}$ and $\mu = [A_1A_2/(A_1 + A_2)]m = \frac{1}{4}Am(1 - \eta^2)$ is the reduced mass with m the nucleon mass, $E_{c.m.}$, the entrance channel center of mass (c.m.) energy.

For the interaction potential we use nucleus-nucleus interaction potential in SEDF, based on ETF method, is defined as

$$\begin{aligned} V_N(R) &= E(R) - E(\infty) \\ &= \int H(\vec{r})d\vec{r} - \left[\int H_1(\vec{r})d\vec{r} + \int H_2(\vec{r})d\vec{r}\right] \quad (2) \end{aligned}$$

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

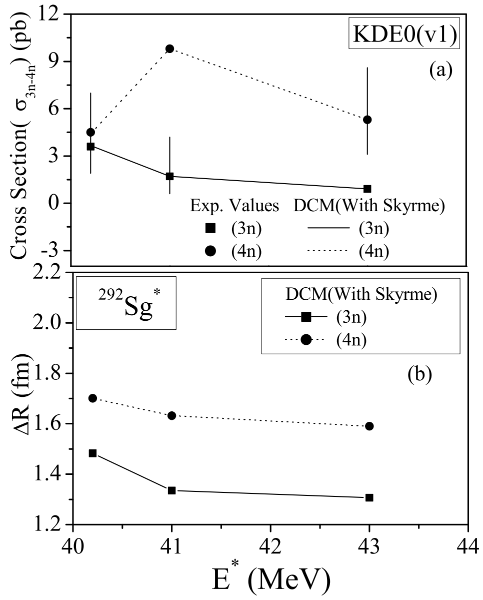

FIG. 1: (a) Excitation functions for the individual 3n and 4n evaporation channels for the fusion reactions ^{244}Pu(^{48}Ca,3n-4n)^{288,289}Fl using the Skyrme force KDE0(v1).The experimental data are taken from Ref.[1, 2], and the solid and dotted lines represent our calculations on DCM for the best fitted ΔR values as shown in Fig1(b).

parameters, obtained by fitting to ground-state properties of various nuclei.

The radius vectors for axially symmetric deformed nuclei are

$$R_i(\alpha_i, T) = R_{0i}(T)\big[1 + \sum_{\lambda} \beta_{\lambda i} Y_{\lambda}^{(0)}(\alpha_i)\big], \quad (3)$$

with T-dependent equivalent spherical nuclear radii $R_{0i}(T) = R_{0i}(T = 0)(1 + 0.0007T^2)$ [7] for the nuclear proximity pocket formula, and $R_{0i}(T) = R_{0i}(T = 0)(1 + 0.0005T^2)$ [8] for SEDF, 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

$$E^* = E_{c.m.} + Q_{in} = (A/10)\, T^2 - T. \quad (4)$$

Results and Discussion

We have compared our calculated results with the experimental 3n and 4n ER cross-sections using the KDE0(v1) Skyrme force as shown in Fig.1(a) and observed that the ΔR is larger for 4n emission than 3n emission implies that 4n emission took place earlier than 3n from the CN ^{292}Fl*. We have made the best fit of ER cross-sections at different time scales (equivalently, different neck-length parameter ΔR) for 3n and 4n evaporation channels at excitation energy E^*=40.2 to 43 MeV). The best fitted neck-length parameter ΔR as a function of E^* for 3n and 4n ER cross-sections of ^{292}Fl* are presented in Fig.1(b). Here, we have concluded that within one parameter(ΔR) fitting, the DCM provided a very good description of the excitation functions for light-particle (here xn, x = 3 and 4) decay channels of ^{48}Ca + ^{244}Pu reaction forming the compound nucleus ^{292}Fl* of super-heavy element Z = 114.

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