Study of decay of ^{260}Sg* formed in ^{51}V + ^{209}Bi and ^{52}Cr + ^{208}Pb fusion reactions using KDE0(v1) Skyrme Force

Aman Deep[1],* Niyti[2], Nirupama Kumari[1], Rajesh Kharab[1], and Sahila Chopra[3]
[1]*Department of Physics, Kurukshetra University, Kurukshetra - 136119, INDIA*
[2]*Gandhi Memorial National College, Ambala Cantt., Haryana-133001, INDIA and*
[3]*Department of Physics, Panjab University, Chandigarh - 160014, INDIA*

Introduction

The study of superheavy nuclei (SHN) (Z>100) is exciting area of research in nuclear physics. There are many unanswered questions such as, how many elements can exists in nature?, how to increase the stability of SHN?, how to produce stable targets of SHN? and many more. The existence of superheavy nuclei is possible only by compensating the colombian repulsive force by shell stabilization. The superheavy nucleus can be synthesized by cold fusion(E*=10-20 MeV) and hot (E*=30-40 MeV) fusion reactions. Theoretically, both of these "cold and "hot fusion reactions refer to cold fusion which corresponds to the lowest interaction barrier and largest interaction radius, i.e., to a noncompact, elongated nuclear shape [1]. In the present work, we have studied the excitation functions (EFs) of ^{260}Sg*, formed in fusion reactions ^{51}V+^{209}Bi [2] and ^{52}Cr+^{208}Pb [3], based on Dynamical Cluster-decay Model (DCM) [1]. For the nuclear interaction potentials, we use the Skyrme energy density functional (SEDF) based on semi-classical extended Thomas Fermi (ETF) approach under frozen density approximation. The Skyrme force used is the new KDE0(v1) [4–6] force for our calculation for cross section and comparison with the experimental data taken from [2, 3]. Here, only the EFs for the production of ^{260}Sg* isotope via 2n decay channel from the ^{260}Sg* compound nucleus are studied at $E^* = 20$ to 26 MeV for two incoming channel, including quadrupole deformations β_{2i} and "cold-optimum" orientations θ_i. The calculations are made within 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) which assimilates the neck formation effects.

*Electronic address: aman.46582@gmail.com

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, both old and new, and here we have chosen new KDE0(v1) Skyrme[6] force for our calculation. 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 $R_{0i}(T) = R_{0i}(T = 0)(1 + 0.0007T^2)$ [7] for the nuclear proximity pocket formula, and $R_{0i}(T) = R_{0i}(T = 0)(1 + 0.0005T^2)$ 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

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

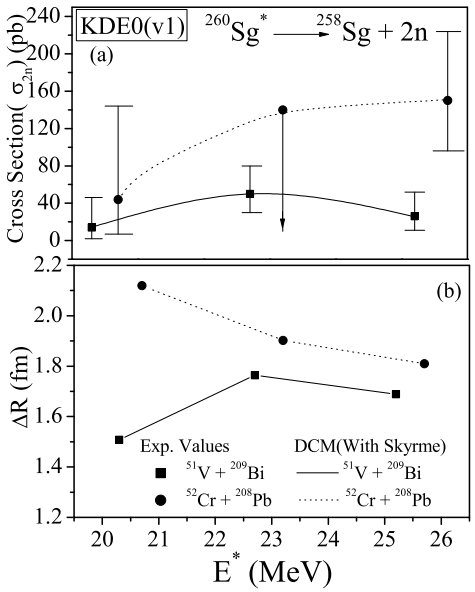

FIG. 1: (a) A comparison of experimental 2n evaporation channel cross section (σ_{2n}) for the fusion reactions ^{209}Bi(^{51}V,2n)^{260}Sg [2] and ^{208}Pb(^{52}Cr,2n)^{260}Sg [3], with the Skyrme included DCM. Fig1(b) The best fitted ΔR values obtained for 2n evaporation cross section from compound nucleus ^{260}Sg* as a function of excitation energy for KDE0(v1) Skyrme force.

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

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

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 [1].

Calculations and Results

Fig.1 (a) shows the comparison of experimental 2n evaporation channel cross section with the calculations made by using the KDE0(v1) Skyrme Force. Fig.1 (b) shows the best fitted neck-length parameter ΔR as a function of E^* for 2n evaporation channel cross section of ^{260}Sg*. An interesting result from Fig.1(b) is that ΔR for a given decay channel for 2n, is independent of the entrance-channel (t,p) combination. Specifically, we notice that, though cross sections for the 2n decay channel in two reactions^{51}V+^{209}Bi [2] and ^{52}Cr+^{208}Pb [3] and are quite different (i.e. cross section ^{208}Pb(^{52}Cr,2n)^{260}Sg 3-5 times larger than ^{209}Bi(^{51}V,2n)^{260}Sg as shown in fig1(a)); ΔR is nearly the same, the small change of ($\pm$ 0.26fm) being due to the spread in E* from 20 to 26 MeV. In other words, the decay process at a fixed E* occurs at the same relative separation, independent of incoming channel, irrespective of their producing strongly varying cross sections. This result strongly agrees with experiment and supports our previous findings [4].

References

[1] R. K. Gupta, in Lecture Notes in Physics, 818, Vol. **1**, *Clusters in Nuclei*, edited by C. Beck (Springer-Verlag, Berlin, Heidelberg, 2010), pp. 223-264.

[2] J. B. Patin Thesis(University of California, Berkeley),(2002).

[3] C. M. Folden et. el., Phys. Rev. C. **79**, 027602 (2009).

[4] Aman Deep, Niyti, Rajesh Kharab, Rajpal Singh, and Sahila Chopra, Phys. Rev. C **102**, 034607 (2020).

[5] Aman Deep, Niyti, Rajesh Kharab, Rajpal Singh and Sahila Chopra, IJMPE, Vol.28, No.10, 1950079 (2019)

[6] Niyti, Aman Deep, Rajesh Kharab, Sahila Chopra and Raj. K. Gupta, Phys. Rev. C. **95**, 034602 (2017).

[7] G. Royer and J. Mignen, J. Phys. G: Nucl. Part. Phys. **18** 1781 (1992).