Near and sub-barrier fusion for a proton-rich system ^{7}Be+^{58}Ni using Skyrme energy density formalism

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Introduction

In a very recent paper [1], fusion cross-section of the $^7Be +^{58} Ni$ system is measured at six near barrier energies and the calculations based on one dimensional barrier-penetration model as well as optical model potential shows fusion enhancement. In this paper we attempted the same with Skyrme energy density formalism (SEDF) in semiclassical extended Thomas-Fermi approach. Since the nucleus-nucleus interaction potential is an important ingredient for the fusion study and SEDF give opportunity to have different potentials for different Skyrme forces and for different nuclear densities. The nuclear density used here is the two parameter Thomas-Fermi density, the detail is given below.

Method

The nuclear interaction potential in the Skyrme energy density formalism (SEDF) is defined as

$$V_N = E(R) - E(\infty) \tag{1}$$

where E $= \int H(\vec{r})d^3\vec{r}$, is the energy expectation value. The nuclear interaction potential in the slab approximation is (for detail see [2, 3]),

$$V_N(R) = 2\pi\bar{R}\int_{s_0}^{\infty} e(s)ds, \tag{2}$$

where $\bar{R} = R_{01}R_{02}/(R_{01} + R_{02})$ is the mean curvature radius and $e(s)$ is the interaction energy per unit area between two flat slabs of semi-infinite nuclear matter with surfaces parallel to the $x - y$ plane and moving in the z-direction and separated by distance s, is

$$\int_{s_0}^{\infty} e(s)ds = \int [H(\rho,\tau,\vec{J}) - \{H_1(\rho_1,\tau_1,\vec{J}_1) + H_2(\rho_2,\tau_2,\vec{J}_2)\}]dz, \tag{3}$$

where H is the Skyrme Hamiltonian density of the compound system, and $\rho(=\rho_1+\rho_2)$, $\tau(=\tau_1+\tau_2)$ and $\vec{J}(=\vec{J}_1+\vec{J}_2)$, are nuclear density, kinetic energy density and spin-orbit density respectively, for composite system and 1, 2 for the two interacting nuclei. The two parameter Thomas Fermi (TF) density in slab approximation with temperature dependence included, is

$$\rho_i(z_i,T) = \frac{\rho_{0i}(T)}{\left[1 + \exp\left(\frac{z_i - R_{0i}(T)}{a_{0i}(T)}\right)\right]} \tag{4}$$

with $z_2 = R - z_1$ and central density is

$$\rho_{0i}(T) = \frac{3A_i}{4\pi R_{0i}^3(T)}\left[1 + \frac{\pi^2 a_{0i}^2(T)}{R_{0i}^2(T)}\right]^{-1} \tag{5}$$

The central radii R_{0i}, surface thicknesses a_{i0} and temperature dependence of these parameters are taken from [2]. The nuclear density $\rho_i = \rho_{n_i} + \rho_{p_i}$, with neutron densities $\rho_{n_i} = (N_i/A_i)\rho_i$, and protons densities $\rho_{p_i} = (Z_i/A_i)\rho_i$, i=1, 2 for two nuclei. Then Coulomb potential, $V_C = k\frac{Z_1Z_2}{R}$ is added directly to SEDF potential to give total interaction potential as,

$$V_T(R) = V_N(R) + V_C(R) \tag{6}$$

The properties of the interaction potential, given by Eq.(6), like the barrier height V_B,

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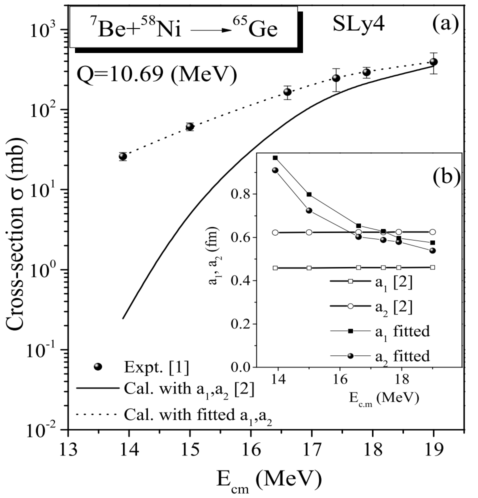

FIG. 1: (a) The calculated fusion cross-section with surface thickness of [2] (solid lie) & dotted line for fitted, is compared with the data of [1]. (b) The Modified surface thickness parameters are compared with the parameters of [2].

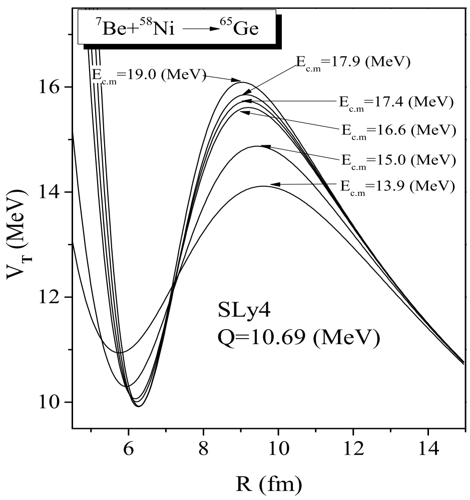

FIG. 2: The variation of total interaction potential V$_T$, at different E$_{cm}$ as a function of inter nuclear distance R, for the Skyrme force SLy4 with fitted a$_1$ and a$_2$.

barrier position R_B and curvature $\hbar\omega_0$ are used in Wong's Formula [4] given below to calculate fusion cross-section as a function of center of mass energy (E_{cm}).

$$\sigma(E_{cm}) = \frac{\hbar\omega_0 R_B^2}{2E_{cm}} \ln\left[1 + e^{\left(\frac{2\pi}{\hbar\omega_0}(E_{cm}-V_B)\right)}\right] \quad (7)$$

Calculations and results

First of all, the fusion cross-section is calculated using the properties of the interaction potential of Eq. (6) for Skyrme force SLy4, with the surface thickness parameters of [2] as shown by solid line in Fig.1(a) and clearly shows the fusion enhancement with respect to our calculations. In ref [5], it is shown that larger diffuseness leads to a better agreement with the data, using this idea we attempted to explore the diffuseness parameters/surface thickness parameters required to reproduce the fusion data [1]. The obtained surface thickness parameters are compared with the parameter of [2] as shown in Fig. 1(b), at different center of mass energies.

In Fig. 2, the total interaction potential required to reproduce the data/obtained with the fitted surface thickness parameters as a function of inter nuclear distance is shown. In conclusion, for the energies well below the barrier, the required surface thickness and $\hbar\omega_0$ is large while the barrier height required to reproduce the fusion data is low.

References

[1] E. Martinez-Quiroz, et al., Phys. Rev. C **90**, 014616 (2014).
[2] R.K. Gupta, Dalip Singh, R. Kumar and W. Greiner, J. Phy. G: Nucl. Part. Phys **36**, 075104 (2009).
[3] R.K. Gupta, Dalip Singh and W.Greiner, Phys. Rev.C **75**, 02460 (2007).
[4] C.Y. Wong, Rev. Lett **31**, 766 (1973).
[5] S. Misicu and H. Esbensen, Phys. Rev. C **75**, 034606 (2007).