Near and sub-barrier fusion cross-sections for neutron-rich system $^{20}O +^{12} C$; using Skyrme energy density formalism

Dalip Singh Verma*
Department of Physics and Astronomical Science,
Central University of Himachal Pradesh, Dharamshala,
District Kangra, (H.P.) - 176215, INDIA

Introduction

In a very recent experiment [1], the fusion cross-sections resulting from the bombardment of radioactive ^{20}O ions on natural ^{12}C target has been measured at three center of mass energies 7.35, 9.29 and 15.24 MeV, at GANIL-SPIRAL facility in Cean, France for the first time. In this paper, the calculated fusion cross-sections are compared with the fusion data of [1]. The fusion cross-sections are calculated using Wong's formula and the nuclear interaction potentials used are obtained in semiclassical extended Thomas-Fermi approach of Skyrme energy density formalism (SEDF) for an arbitrarily chosen Skyrme force SIV, although different interaction potentials can be obtained for different Skyrme forces. Also, the SEDF interaction potential is modified by adjusting the surface thickness parameters of the interacting nuclei to reproduce the observed data.

Calculation methods

The SEDF defines the nuclear interaction potential as

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

where $E =< \Psi \mid H \mid \Psi >= \int H(\vec{r})d\vec{r}$ is the energy expectation value. In the slab approximation (for detail see our earlier work [2] and references there in) the nuclear proximity potential is

$$\begin{aligned} V_N(R) &= 2\pi\bar{R}\int \{H - [H_1 + H_2]\} dz \\ &= 2\pi\bar{R}\int_{s_0}^{\infty} e(s)ds \end{aligned} \tag{2}$$

where $H = H(\rho, \tau, \vec{J})$ is the Skyrme Hamiltonian density of composite system and $H_i = H_i(\rho_i, \tau_i, \vec{J_i})$ (i = 1, 2; for first and second colliding nuclei), $\rho(= \rho_1 + \rho_2)$, $\tau(= \tau_1 + \tau_2)$ and $\vec{J}(= \vec{J_1} + \vec{J_2})$ are respectively, the nuclear, kinetic energy, and spin-orbit densities for the composite system, $\bar{R}(= R_{01}R_{02}/(R_{01} + R_{02}))$ is the mean curvature radius defining the geometry of the system, R_{0i} are the half density radii of colliding nuclei 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.

Since, both τ and $\vec{J}$ depends on the nuclear density ρ, which is taken here as the two parameters Fermi distribution, and in the slab approximation it becomes, $\rho_i(z) = \rho_{0i}\left[1 + \exp{(z - R_{0i})/a_i}\right]^{-1}$ with $\rho_{0i} = \frac{3A_i}{4\pi R_{0i}^3}\left[1 + (\pi^2 a_i^2/R_{0i}^2)\right]^{-1}$ as the central density of the nuclei. The temperature (T) dependence in ρ and hence in $V_N(R)$ is introduced by using T-dependent parameters R_{oi} and a_i of [2]. The E_{cm} and T relates as: $E_{cm}+Q_{in} = (A/9)T^2-T$, where $A = A_1+A_2$ is the mass number of the compound system. The Coulomb potential, $V_C(R) = k\frac{Z_1Z_2e^2}{R}$, between two nuclei of charges Z_1 and Z_2, is added directly to the SEDF nuclear proximity potential to give the total interaction potential, $V_T(R) = V_N(R)+V_C(R)$. The total interaction potential gives its curvature ($\hbar\omega_0$), the corresponding barrier position (R_B) and barrier height (V_B) and Wong's formula [3] gives

*Electronic address: `dalipverma2003@yahoo.co.in`

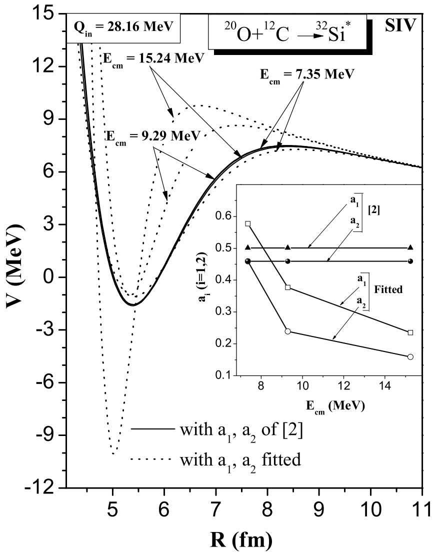

FIG. 1: The total interaction potentials for the system $^{20}O + ^{12}C$, at $E_{cm} = 7.35$, 9.29 and 15.24 MeV, (i) for a_i of our earlier work [2] (solid lines) and (ii) for the fitted a_i (dotted lines). The inset shows a_i of [2] and those required to fit the data.

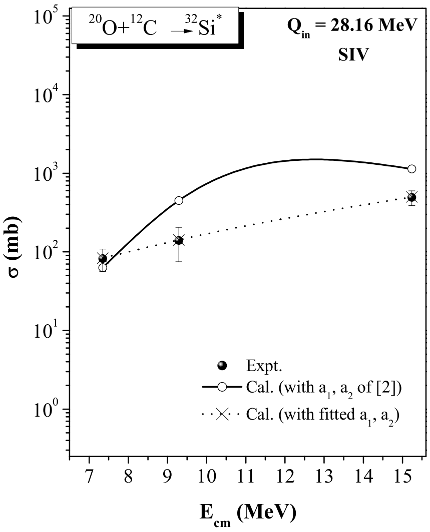

FIG. 2: The fusion cross-sections as a function of E_{cm} (i) the solid black spheres for data of [1] (ii) the solid line with empty circles for the calculations with a_i of our earlier work [2] and (iii) the dotted line with $\times$ symbols for the fitted a_i.

the fusion cross-sections as a function of center of mass energy, as given below:

$$\sigma = \frac{\hbar\omega_0 R_B^2}{2E_{cm}} \ln\left(1 + \exp\left[\frac{2\pi}{\hbar\omega_0}(E_{cm} - V_B)\right]\right) \quad (3)$$

Results and discussions

The solid lines, in Fig. 1, shows the total SEDF interaction potentials at $E_{cm} = 7.35$, 9.29 and 15.24 MeV, calculated for Skyrme force SIV with surface thickness parameters of [2] and dotted lines shows the modified total SEDF interaction potentials. The inset of Fig. 1, shows the surface thickness parameters of [2] and those required for fitting the measured cross-sections. In Fig. 2, the solid line with empty circles shows the calculated fusion cross-sections with total SEDF interaction potential and is compared with the measured fusion cross-sections (solid spheres). The calculated fusion cross-section is found to be less at $E_{cm} = 7.35$ MeV and more at $E_{cm} = 9.29$ and 15.24 MeV with respect to the experimental data. But, it is exactly the same as is predicted by the evapOR model (see Fig. 8 of ref. [1]). The dotted line with $\times$ symbols shows the fusion cross-sections calculated with the modified interaction potentials. At $E_{cm} = 7.35$ MeV, the interaction potential is modified to fit the data by raising surface thickness parameters to have lower barrier height and lower curvature at higher barrier position (see Fig. 1). Similarly, at $E_{cm} = 9.29$ and 15.24 MeV, for reproduction of fusion data, smaller surface thickness parameters are required to have higher potential barrier and higher curvature at smaller barrier positions (see Fig. 1). Thus, for neutron rich system, smaller values of surface thickness parameters are expected at center of mass energies 9.29 and 15.24 MeV and larger values at center of mass energy 7.35 MeV with respect to parameters of [2].

References

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