Probing the role of surface diffuseness and central radius on density distribution and barrier characteristics

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Introduction

In view of heavy-ion collision dynamics, nuclear potential is known to be governed by surface effects of projectile and target nuclei. Such effects are explicitly included in the nuclear interaction potential in the form of nuclear radius 'R_0', surface diffuseness 'a' and deformation/orientation of the colliding partners. Interestingly, a small variation in these parameters results in the significant change in the barrier profile of the colliding nuclei. Consequently, they show significant effect on the cross-sectional yields which may help to eradicate the anomalies related to the sub barrier region. In past, the role of diffuseness parameter and the effective sharp radius has been explored for various analytical potentials such as Wood-Saxon potential, Proximity 77 potential and it's modified versions. However, it is of interest to study their impact on the density profile and barrier characteristics calculated using non-relativistic Skyrme interactions, where the local density is evaluated using the two-parameter Fermi density approach [1].

In view of this, the standardized SIII Skyrme interaction is used to study the impact of 'R_0' and 'a' on the density and barrier characteristics of ^{37}Cl+^{169}Tm reaction [2], which emphasize that diffuseness parameter 'a' has dominant effect on the density distribution and barrier characteristics, in comparison to the nuclear radius.

Theoretical Framework

The nuclear interaction potential derived in view of effective Skyrme force [1] is expressed as

$$\begin{aligned} V_N(R) &= 2\pi\bar{R}\int_{s_0}^{\infty} e(s)ds \\ &= 2\pi\bar{R}\int H(\rho,\tau,\vec{J}) - [H(\rho_1,\tau_1,\vec{J}_1) + H(\rho_2,\tau_2,\vec{J}_2)] \\ &= V_P(R) + V_J(R) \end{aligned} \quad (1)$$

where, H($\rho, \tau, \vec{J}$) is the Skyrme Hamiltonian density with ρ, τ and $\vec{J}$ are nuclear density, kinetic energy density and spin-orbit density respectively. Here, the nuclear density ρ_i is determined using the two-parameter Fermi density (FD) approach

$$\rho_i(r) = \rho_{0i}\Big[1 + exp(\frac{r - R_{0i}}{a_i})\Big]^{-1} \quad (2)$$

having central density

$$\rho_{0i} = \frac{3A_i}{4\pi R_{0i}^3}\Big[1 + \frac{\pi^2 a_i^2}{R_{0i}^2}\Big]^{-1} \quad (3)$$

where, R_{0i} is obtained by fitting the experimental data to respective polynomial in the nuclear mass region A = 4 - 238 [1],

$$\begin{aligned} R_{0i} &= 0.9543 + 0.0994A_i - 9.8815\times10^{-4}A_i^2 \\ &+4.8399\times10^{-6}{A_i}^3 - 8.4366\times10^{-9}A_i^4 \end{aligned} \quad (4)$$

or by using the semi-empirical expression supported by assuming the finite compressibility of the nucleus, that describes the effective sharp radius [3], as

$$R_{0i} = 1.28A_i^{1/3} - 0.76 + 0.8A_i^{-1/3} \quad (5)$$

for the use of surface diffuseness parameter calculated using the polynomial fit [1]

$$\begin{aligned} a_i &= 0.3719 + 0.0086A_i - 1.1898\times10^{-4}A_i^2 \\ &+6.1678\times10^{-7}{A_i}^3 - 1.0721\times10^{-9}(A_i)^4 \end{aligned} \quad (6)$$

which gives standard value of 'a'$\sim$ 0.55, or by varying its value from 'a'=0.65 to 0.95.

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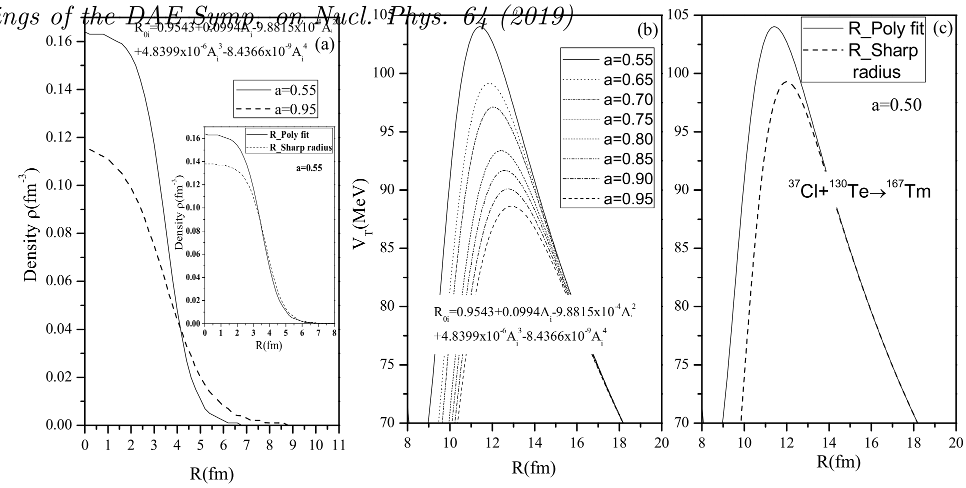

FIG. 1: (Color online)Variation in (a) nuclear density ρ (fm^{-3}) observed for different values of 'a' and R_0, (b) variation in total potential V_T evaluated for different values of 'a' at fixed R_0(using R_{Poly}) and (c) same as (b) but for different values of R_0 at fixed 'a'=0.55.

Results and Discussion

In the present calculations, the effect of diffuseness parameter 'a' and the nuclear radius R_0 is analyzed on two-parameter Fermi density distribution ρ(R) used in the standardized SIII Skyrme force. From Fig. 1(a), it is observed that diffuseness parameter plays an effective role in deciding the density distribution of the nucleus, as variation in the value of 'a' leads to a significant change in the central as well as peripheral region of the density profile. The increasing value of 'a' lowers the central part of the density and enhances the surface thickness region (or tail region), while changing the radius R_0 leads to the lowering of the central density part only, as shown in the inset of Fig. 1(a). This means that 'a' has strong influence on the density profile in comparison to radius parameter R_0 and thus appropriate choice of 'a' be made to analyze the heavy ion reaction dynamics. Further, the impact of these parameters is analyzed on the barrier profile of ^{37}Cl+^{130}Te $\rightarrow$ ^{167}Tm reaction. The variation in total interaction potential V_T(=V_C+V_N+V_ℓ) with respect to 'a' and R_0 is examined and shown in Figs. 1(b) and (c) respectively. Here, in Fig. 1(b) the total potential is calculated by varying the diffuseness parameter 'a' from 0.55 to 0.95 at fixed value of R_0. The observation shows that the barrier height reduces significantly on moving from low surface thickness to high surface thickness. In Fig. 1(c), the variation in V_T at fixed value of 'a'=0.55 is analyzed for two different choices of nuclear radius. It is observed that the barrier is lowered when the radius from polynomial fit is replaced with that of semi-empirical effective sharp radius.

From the above observations, it is concluded that (i)'a' reflects dominant effect on the density as well as barrier profile of the colliding nuclei in comparison to radius parameter R_0,(ii) the nuclear radius evaluated using the semi-empirical formula imparts lower barrier height and enhances barrier position as compared to that for R_{poly} case. Apart from the surface effects, it is of further interest to investigate the impact of bulk properties such as incompressibility and the effective mass in view of different set of Skyrme forces employed to govern nuclear reaction dynamics.

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