Sensitivity of fusion cross-sections and barrier distribution towards the choice of potential parameters

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Introduction

It is well reported in the literature that the nuclear structure degrees of freedom (DOF) of fusing pairs have a considerable impact on the fusion cross-sections as well as on barrier distribution near the Coulomb barrier [1-3]. The coupling between the relative motion and their intrinsic DOF of fusing pairs, like inelastic surface excitations, vibrational states, rotational states, and nucleon transfer channel(s), gives rise to a significant increase in sub-barrier fusion cross-sections than one-dimensional barrier penetration model prediction. The couplings to intrinsic channels of the collision systems with their relative motion change the original barrier into barriers of varying heights and weights, and hence results in greater fusion cross-sections in the sub-barrier domain [4,5]. Barrier distribution serves as a blueprint for the kinds of coupling involved in the fusion enhancement at the sub-barrier domain, and because of that, it is an effective tool for investigating the impacts of internal DOF in the fusion process.

It is clear from the literature that the choice of nuclear potential is critical for the understanding of the kinematics of the fusion reactions [6,7]. The standard Woods-Saxon potential (WSP) has been widely employed to investigate the behavior of heavy-ion fusion events. The WSP is made up of three parameters: range, potential depth, and diffuseness. For theoretical estimations, the Woods-Saxon form of nuclear potential has been adopted in this work, and it has been found that both the fusion cross sections and barrier distributions of ^{18}O + ^{116}Sn reaction are quite sensitive to the choice of potential parameters in the entire range of bombarding energies.

SAGBD model

To explore the intrinsic DOF in theoretical approaches, one must be friendly with the multidimensional aspect of quantum tunneling. Authors of Refs. [8,9] proposed that the multidimensional nature of tunneling can be achieved by using a weighted type Gaussian function. Hence, in the SAGBD approach [10-13], the influences of intrinsic DOF are considered via weighted Gaussian function multiplied by the Wong formula and represents the total fusion cross-section as

$$\sigma_F = \int_0^\infty D_f(V_{CB})\,\sigma^{Wong}(E_{c.m.},V_{CB})\,dV_{CB} \qquad (1)$$

here, $\sigma^{Wong}(E_{c.m.},V_{CB})$ is the Wong formula [14] and given by

$$\sigma^{Wong}(E_{c.m.},V_{CB}) = \frac{\hbar\omega_B R_B^2}{2E_{c.m.}} \ln\left[1+\exp\left(\frac{2\pi}{\hbar\omega_B}\left(E_{c.m.}-V_{CB}\right)\right)\right] \qquad (2)$$

where, R_B, $\hbar\omega_B$ and V_{CB} respectively represents the barrier position, barrier curvature and barrier height. In Eq. (2), $D_f\left(V_B\right)$ is symmetric, normalized, continuous function and defined as

$$D_f(V_B) = \frac{1}{N}\exp\left[-\frac{(V_B-V_{B0})^2}{2\Delta^2}\right] \qquad (2)$$

with $N = \Delta\sqrt{2\pi}$

where, Δ and V_{B0} respectively indicates the standard deviation and mean barrier height.

Result and discussion

The sub-barrier cross-sections data are highly dependent on the nuclear structure DOF of the nuclei involved in the fusion process, whereas the fusion data at energies lying well above the barrier is somewhat insensitive to the nuclear structure of participants. Hence, the fusion data at above the barrier should be replicated by using one-dimensional barrier penetration model. In order to extract the potential parameters of Woods-Saxon potential, the potential depth (V_0) is kept fixed at $120\,MeV$ while the other parameters i.e. range (r_0) and diffuseness parameter (a_0) are varied so that the shape of the fusion cross-sections data and barrier distribution data can be retrieved for the chosen system. In this way, the sensitivity of fusion cross-sections as well as barrier distributions with respect to change in potential parameters is analyzed for ^{18}O + ^{116}Sn reaction. In this work, the dependency of fusion data towards the choice of potential parameters are shown in Fig. 1 and Fig. 2. In both figures, the fusion cross-sections as well as barrier distribution data of ^{18}O + ^{116}Sn system are found to be depend strongly on the choice of the parameters of the Woods-Saxon potential.

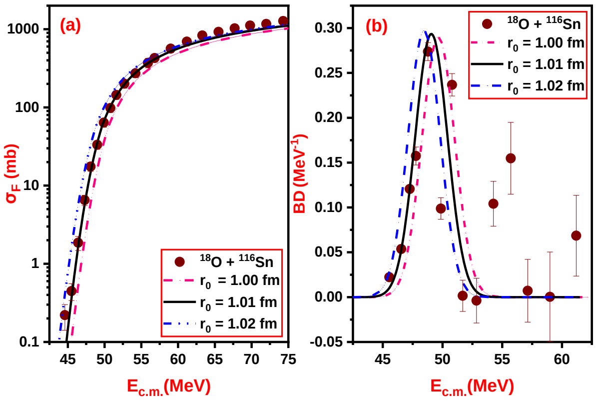

Fig. 1: (a) The fusion cross-sections and (b) barrier distributions for ^{18}O + ^{116}Sn system as a function of $E_{c.m.}$ for distinct values of r_0. The obtained results due to SAGBD method are also compared with fusion data [15].

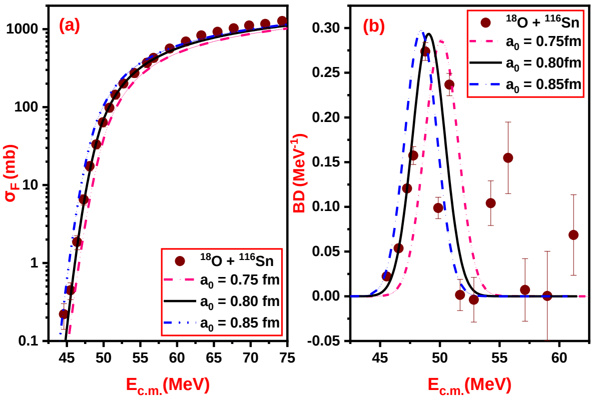

Fig. 2: Same as Fig. 1, but for different values of diffuseness parameter (a_0).

In Fig. 1, the sensitivity of range parameter (r_0) and in Fig. 2, the sensitivity of diffuseness parameter is analyzed, while potential depth in both figures is fixed at $120\,MeV$. From both figures, one can clearly noticed that for appropriate addressal of fusion dynamics of chosen system, potential parameters must be chosen carefully. The value of r_0 and a_0 are found to be $1.01\,fm$ and $0.80\,fm$, respectively for appropriate explanation of the fusion dynamics of chosen reaction. In other words, if one slightly changes the values of either one or both parameters then one is not able to address fusion dynamics of chosen system. The SAGBD model properly explain the fusion dynamics of studied system in the whole range of bombarding energies and the optimum values of depth, range and diffuseness of WSP are $120\,MeV$, $1.01\,fm$ and $0.80\,fm$, respectively.

Conclusion

In summary, the sensitivity of fusion cross sections and experimental barrier distributions is investigated for ^{18}O + ^{116}Sn reactions in the close vicinity of the nominal barrier. The theoretical predictions based on WSP parameterization in SAGBD model suggest that the fusion cross sections as well as barrier distributions are extremely sensitive to the potential parameters. The SAGBD model with optimum choice of WSP parameters as $V_0 = 120\,MeV$, $r_0 = 1.01\,fm$ and $a_0 = 0.80\,fm$ qualitatively describes the fusion data of ^{18}O + ^{116}Sn reactions in the entire range of bombarding energies.

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