Role of static and energy dependent interaction potential in sub-barrier fusion dynamics of $^{6}Li + ^{152}Sm$ reaction

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In past few decades, the extensive investigations on theoretical as well as on experimental grounds clearly pointed out the effects of nuclear structure degrees of freedom such as inelastic surface excitations, permanent shape deformation and/or particle transfer channel on fusion process. For well bound nuclei, the coupling of relative motion of participant nuclei to their internal degrees of freedom leads to the substantially large fusion enhancements at below barrier energies over the expectations of the one dimensional barrier penetration model. However in case of weakly bound/halo nuclei, the breakup channel strongly influences the fusion process around the Coulomb barrier and subsequently leads to the suppression of the fusion cross-sections at above barrier energies with reference to the coupled channel calculations. This suppression effect is directly related with the low binding energy of the breakup channel associated with loosely bound system [1].

Recently, Rath *et al.*[2] performed the experimental measurement of $^{6}Li + ^{152}Sm$ reaction at near and above barrier energies. The interesting aspect of the this reaction is that the projectile is weakly bound nucleus while the target isotope is a well deformed nucleus and role of projectile breakup channel is directly inferred from the fusion mechanism of this reaction. In this regard, we have analyzed the fusion dynamics of $^{6}Li + ^{152}Sm$ reaction within the framework of the static nuclear potential and the energy dependent interaction potential [3-5]. In this work, we have tested standard Woods-Saxon potential, which is static in nature and the energy dependent Woods-Saxon potential (EDWSP) model [3-5] along with one dimensional Wong formula [6] for exploring the fusion dynamics of the chosen reaction. In the EDWSP model [3-5], the depth (V_0) of the real part of the Woods-Saxon potential is defined as

$$V_0 = \left[A_P^{\frac{2}{3}} + A_T^{\frac{2}{3}} - (A_P + A_T)^{\frac{2}{3}}\right]\left[2.38 + 6.8(1 + I_P + I_T)\frac{A_P^{\frac{1}{3}} A_T^{\frac{1}{3}}}{\left(A_P^{\frac{1}{3}} + A_T^{\frac{1}{3}}\right)}\right] MeV$$

where, $I_P = \left(\frac{N_P - Z_P}{A_P}\right)$ and $I_T = \left(\frac{N_T - Z_T}{A_T}\right)$ are the isospin asymmetry of the colliding systems. The energy dependent diffuseness parameter is defined as

$$a(E) = 0.85\left[1 + \frac{r_0}{13.75\left(A_P^{-\frac{1}{3}} + A_T^{-\frac{1}{3}}\right)\left(1 + \exp\left(\frac{\frac{E}{V_{B0}} - 0.96}{0.03}\right)\right)}\right] fm$$

with, $a(E)$ is the energy dependent diffuseness parameter, E is the incident energy in center of mass frame, V_{B0} is the Coulomb barrier and r_0 is the range parameter, which geometrically defines the radii of colliding pairs.

The static Woods-Saxon potential produces a single Coulomb barrier between the collision partners and one has to include the channel coupling effects in order to recover sub-barrier fusion data of chosen reaction. However in EDWSP model, due to energy dependence in the nucleus-nucleus potential instead of single fusion barrier a spectrum of the energy dependent fusion barriers of variable height is produced. The distribution of energy dependent fusion barriers of different heights is shown in Fig.1. In this spectrum, some of the energy dependent fusion barriers are lower than that of the Coulomb barrier (25.10 *MeV*), which in turn, shift the flux from incoming channel to fusion channel. Such kinds of barrier modification result in the barrier lowering effects and lower the effective fusion barrier between the colliding systems. As a result, the EDWSP model predicts larger fusion cross-sections at sub-barrier energies over the expectations of the one dimensional barrier penetration model which will be discussed in detail in Fig.2.

The theoretical results obtained by using the static Woods-Saxon potential along with the one dimensional Wong formula substantially underestimate the experimental data particularly at below barrier energies while at above barrier energies, calculated results overestimate the fusion data as shown in Fig.2. Since the projectile is weakly bound nucleus and target isotope is a well deformed nucleus, therefore, the coupling to breakup channel and target degrees of freedom must entertained in the theoretical description. In order to explain the sub-barrier fusion enhancement of $^{6}Li+^{152}Sm$ system, Rath et al.[2] performed the coupled channel calculations by including both projectile and target couplings and such calculations adequately explored the below barrier fusion data but over predict the experimental complete fusion (CF) cross-sections at above barrier energies by 28%. This suppression of CF cross-section data in above barrier energy regions was correlated with the low breakup threshold of the alpha breakup channel associated with the projectile.

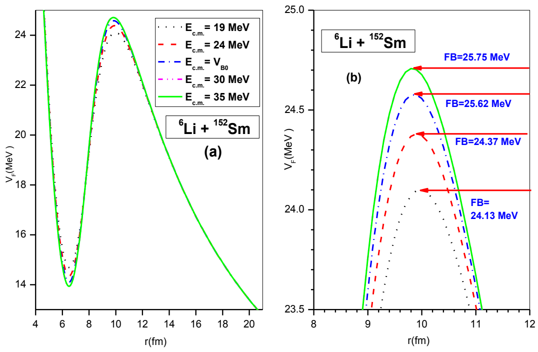

Fig.1. The fusion barrier (FB) for $^{6}Li+^{152}Sm$ system obtained by using the EDWSP model [3-5].

In the EDWSP model, the calculations reasonably described the sub-barrier fusion data but overestimate the fusion data at above barrier energies. Due to the energy dependence in the nucleus-nucleus potential, the fusion barrier between the fusion pairs gets modified and leads to barrier lowering effects. As a result, the present model calculations reasonably reproduced the observed fusion enhancements at below barrier energies (see Fig.2). Although, the EDWSP model calculations overestimate the fusion cross-section data at above barrier energies, the extracted suppression effects are much smaller than the reported value [2]. In other words, the suppression factor extracted by using the EDWSP model calculations is considerably smaller than the corresponding value obtained by using the coupled channel calculations. Thus in the present model, the suppression factor can be minimized up to 13% with respect to the reported value and subsequently the above barrier fusion data of $^{6}Li+^{152}Sm$ reaction is inhibited by 15% with reference to the outcomes of the EDWSP model (see Fig.2). Such suppression effects have intrinsic link with the small binding energy of alpha breakup channel associated with loosely bound projectile.

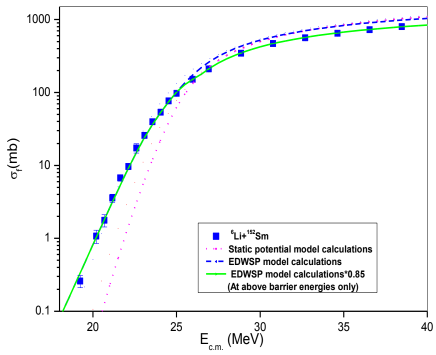

Fig.2. Fusion excitation functions of $^{6}Li+^{152}Sm$ reaction obtained by using the static Woods-Saxon potential and the EDWSP model [3-5]. The calculational results are compared with the experimental fusion data taken from Ref. [2].

In summary, the present work theoretically analyzed the fusion dynamics of $^{6}Li+^{152}Sm$ reaction by using the static Woods-Saxon potential and the EDWSP model along with one dimensional Wong formula. For the studied reaction, the theoretical calculations based on the static Woods-Saxon potential are substantially smaller than that of experimental data at below barrier energies and overestimate the fusion data at above barrier energies by 28%. In contrast, the EDWSP model based calculations provide adequate description to the below barrier fusion data. At above barrier energies, the present model calculations overestimate the fusion data but the extracted suppression factor is smaller by 13% with respect to the reported value. Therefore, the above barrier fusion data of the chosen reaction is inhibited by 15% with reference to outcomes of the EDWSP model.

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