A comparative study of breakup effects in the fusion dynamics of $^{6,7}Li+^{152}Sm$ reactions around the Coulomb barrier

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Fusion reactions at sub-barrier energies have received considerable attention during last thirty years as the fusion cross-section data is strongly affected by intrinsic degrees of freedom such as collective excitations, permanent shape deformation and particle transfer channels etc. associated with fusing nuclei. In fusion of weakly bound/halo nuclei, due to low breakup threshold weakly bound/halo system may break up into two or more fragments and subsequently one breakup fragment or more than one or all may get absorbed by the target nucleus. In such case, the absorption of projectile as a whole by the target leads to complete fusion (CF) process while the partial absorption of projectile by the target results in incomplete fusion (ICF) events [1]. Rath *et al*. [2] have measured the fusion data of $^{6,7}Li+^{152}Sm$ reactions by using 14MV BARC-TIFR pelletron facility at Mumbai, India. In the contemporary work, the fusion excitation data of $^{6,7}Li+^{152}Sm$ systems is theoretically investigated within the context of the energy dependent Woods-Saxon potential (EDWSP) model [3-5] and coupled channel formulation [6]. In EDWSP model, the depth of 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 fusing nuclei. In EDWSP model, the diffuseness parameter $a(E)$ is treated as energy dependent and is defined as

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

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 describes the radii of participating nuclei.

In the present work, the coupled channel calculations are carried out by using the code CCFULL [6]. The no-coupling calculations, wherein fusing nuclei are taken as inert, are significantly smaller than the experimental fusion data at sub-barrier energies (see Fig.1). Since target is a well deformed nucleus and one must include the target degrees of freedom in the coupled channel calculations for reproduction of fusion data. Therefore, the coupling to rotational states up to 10^+ ground state rotational band having $\beta_2 = 0.280$ and $\beta_4 = 0.005$ for the ^{152}Sm-nucleus significantly enhances the magnitude of fusion cross-sections and brings theoretical calculations closer to the fusion data. However, couplings to some additional intrinsic channels are needed in order to recover the fusion enhancements at below barrier energies. In fusion of $^{6,7}Li+^{152}Sm$ reactions, the projectiles are weakly bound nuclei and with the inclusion of the projectile excitations along with the rotational states of target bring close agreement between coupled channel calculations and sub-barrier fusion data. However, the coupled channel calculations over predict the CF data at above barrier energies for both reactions. At above barrier energies, the CF data of $^{6}Li+^{152}Sm$ ($^{7}Li+^{152}Sm$) reaction is suppressed with respect to the outcomes of the coupled channel approach by 28% (25%)

and such suppression effects can be correlated with the low breakup threshold of alpha breakup channel of the projectile.

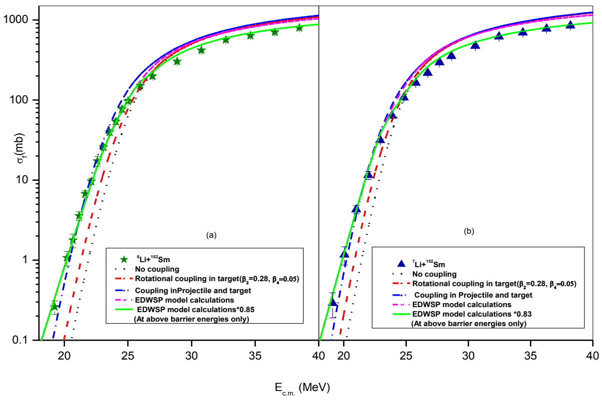

Fig.1. Fusion excitation functions of $^{6,7}Li+^{152}Sm$ reactions obtained by using the EDWSP model and coupled channel model. The theoretical outcomes are compared with the available experimental data taken from Ref. [2].

For more concrete conclusion, the fusion dynamics of the chosen reactions is also analyzed within the context of the EDWSP model along with the one dimensional Wong formula [7]. In this approach, due to the energy dependence in nucleus-nucleus potential, the barrier profile of the interaction barrier is modified and consequently lowers the effective fusion barrier between colliding nuclei. As a result, the EDWSP model based calculations reasonably recover CF data at below barrier energies but so obtained calculations overestimate the CF data at above barrier energies. Although, the EDWSP model calculations over predict the CF data at above barrier energies, the extracted suppression factor is smaller by 13% (8%) with respect to the reported value [2]. Therefore, at above barrier energies, the CF fusion data is inhibited by 15% (17%) with reference to the estimations of the EDWSP model as evident from Fig.1. At above barrier energies, the channel coupling effects due to target isotope impart negligible contribution to the fusion cross-sections. Therefore, the role of the projectile breakup effects is clearly visible in above barrier energy region. From present work, one can easily point out that the complete fusion cross-section data of the analyzed reactions are suppressed with respect to outcomes of the EDWSP/coupled channel model. Such suppression effects are directly linked with the low binding energy of the alpha breakup channel associated with the projectile.

In summary, the fusion dynamics of $^{6,7}Li+^{152}Sm$ reactions is analyzed via the EDWSP and the coupled channel model. The calculations based on coupled channel approach predict fusion enhancements over the no-coupling calculations. With the inclusion of appropriate intrinsic channels, the coupled channel calculations adequately reproduced the below barrier fusion data but such predictions overestimates the complete fusion data at above barrier energies by 28% (25%) for $^{6}Li+^{152}Sm\,(^{7}Li+^{152}Sm)$ reaction. In contrast, the energy dependent interaction potential (EDWSP model) modifies barrier characteristics and subsequently modeled the quantum tunneling in such a way that it reasonably recover the observed fusion enhancements at below barrier energies for the studied reactions. Although, the EDWSP based calculations overestimate the CF data at above barrier energies, the extracted suppression effects are smaller by 13% (8%) than the reported value for $^{6}Li+^{152}Sm\,(^{7}Li+^{152}Sm)$ reaction. Such suppression effects can be accredited to the low breakup threshold of alpha breakup channel of the projectile. Furthermore, it is worth mentioning here that the suppression effects are more pronounced in lighter projectile as compare to heavier projectile which in turn linked with the smaller value of breakup threshold of lighter projectile.

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