Role of projectile breakup channel on fusion of $^{7}Li+^{152}Sm$ reaction

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Heavy ion fusion reactions at near and above barrier energies have received considerable interest as the fusion cross-section data is strongly influenced by collective excitations, permanent shape deformation and particle transfer channels etc. In fusion of weakly bound nuclei, due to the low binding of the weakly bound systems, it may break up into two or more fragments and consequently either of them or more than one or all may get absorbed by the target nucleus. The absorption of projectile as 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 [1-3]. Rath *et al.* [4] have measured the fusion data of $^{7}Li+^{152}Sm$ reaction by using 14MV BARC-TIFR pelletron facility at Mumbai. In this work, the fusion of $^{7}Li+^{152}Sm$ system is theoretically examined within the context of the energy dependent Woods-Saxon potential (EDWSP) model [5-7] and coupled channel formulation [8]. In EDWSP model, the parameters of the Woods-Saxonare defined below

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

where $I_P = \left(\dfrac{N_P - Z_P}{A_P}\right)$ and $I_T = \left(\dfrac{N_T - Z_T}{A_T}\right)$

are the isospin asymmetry of the colliding pairs. The energy dependent diffuseness parameter is defined as

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

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.

In this work, the coupled channel calculations are performed by using the code CCFULL [8].The no-coupling calculations, wherein fusing systems 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 torotational states up to 10^+ ground state rotational band having $\beta_2 = 0.280$ and $\beta_4 = 0.005$ for the $^{152}_{62}Sm$-nucleus significantly enhances the magnitude of fusion cross-sections and brings theoretical calculations closer to the fusion data. But couplings to some additional intrinsic channels are essentially required in order to recover the sub-barrier fusion enhancements.

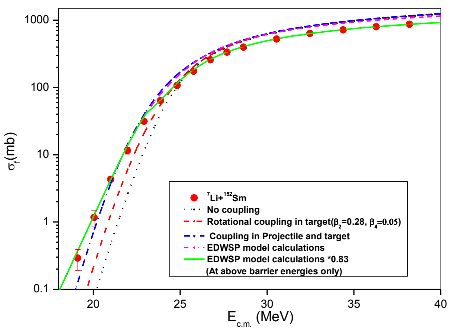

Fig.1. Fusion excitation functions of $^{7}Li+^{152}Sm$ reaction obtained by using the EDWSP model and coupled channel model. The theoretical predictions are compared with the available experimental data taken from Ref. [4].

Here, the projectile is a weakly bound nucleus and with the inclusion of the projectile excitations along with the rotational states of target brings the close agreement between coupled channel calculations and below barrier fusion data. However, the coupled channel calculations over predict the experimental fusion data at above barrier energies by 25%. In other words, the above barrier fusion data of studied reaction is suppressed significantly with respect to the outcomes of the coupled channel model and such suppression effects can be correlated with the small binding energy of alpha breakup channel of the projectile.

For more concrete conclusion, the fusion dynamics of the chosen reaction is also analyzed within the context of the energy dependent interaction potential (EDWSP model) along with the one dimensional Wong formula [9]. In the EDWSP model, 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 reproduce the sub-barrier fusion data but such calculations overestimate the fusion data at above barrier energies. Although, the EDWSP model calculations over predict the above barrier fusion data, the extracted suppression factor is smaller by 8% with respect to the reported value [8]. Therefore, the above barrier fusion data is inhibited by 17% with reference to the estimations of the EDWSP model as evident from Fig.1.

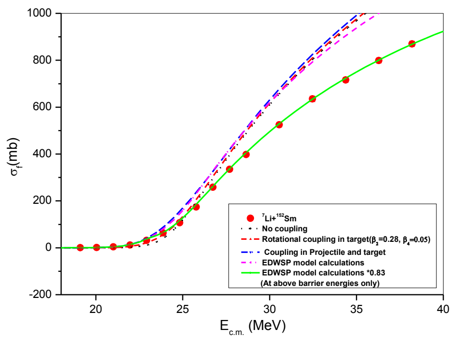

Fig.2. Same as Fig.1 but in linear scale.

In Fig.2, the theoretical results obtained by using the adopted models are shown in linear scale. 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 Fig.2, one can easily point out that fusion cross-section data of the studied reaction is suppressed with respect to the EDWSP/coupled channel model. Such suppression effects are directly linked with the low binding energy of the projectile and consequently originate due to breakup of the projectile in the entrance channel prior to the Coulomb barrier.

In summary, the fusion of ${}^{7}Li + {}^{152}Sm$ reaction is analyzed via the EDWSP and the coupled channel model. The calculations based on coupled channel model 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 overestimate the fusion data at above barrier energies by 25%. In contrast, the energy dependent interaction potential (EDWSP model) modifies barrier characteristics and consequently modeled the quantum tunneling in such a way that it reasonably recover the observed sub-barrier fusion data. Although, the EDWSP model based calculations overestimate the fusion data at above barrier energies, the suppression effects are smaller by 8% than the reported value. Such suppression effects are attributed to the breakup of projectile in the entrance channel before reaching the Coulomb barrier due to its low threshold associated with the alpha breakup channel.

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