Projectile breakup effects in the fusion dynamics of $^{6,7}Li + ^{159}Tb$ reactions at near and above barrier energies

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The understanding of the fusion mechanism wherein one of the collision partners is loosely bound system is one of the most studied problem in last few decades. Besides accumulations of large set of experimental data in this field, the quantum tunneling with many internal structure degrees of freedom is challenging phenomenon and further requires more intensive investigations on experimental as well on theoretical ground. In case of weakly bound systems, due to low breakup energy loosely bound nucleus offers large breakup probabilities and subsequently governs complete fusion (CF) events and incomplete fusion (ICF) events. In CF process, there is complete amalgamation of original projectile with target nucleus while in case of ICF process, one of the breakup fragment fuses with target nucleus [1]. In this paper, the fusion dynamics of $^{6,7}Li + ^{159}Tb$ reactions [2-4] have been analyzed by using the energy dependent Woods-Saxon potential (EDWSP) model [5-6]. In this approach, we have adopted the Woods-Saxon form of the nuclear potential. The standard form of Woods-Saxon potential is defined as

$$V_N(r) = \frac{-V_0}{\left[1+\exp\left(\frac{r-R_0}{a}\right)\right]}$$

where, V_0 is depth of nuclear potential, r is the range and a is the diffuseness parameter of the nuclear potential. In general, the three parameters of the standard Woods-Saxon potential are specified by fitting the experimental data for particular reaction under examination. However, the parameters of the above potential in EDWSP model [5-6] are specified 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 participating nuclei. In EDWSP model, the diffuseness parameter $a(E)$ has been considered as energy dependent and is defined as

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

$E_{c.m.}$ is the incident energy in center of mass frame, V_{B0} is height of the Coulomb barrier and r_0 is the range parameter that describes the radii of participating nuclei.

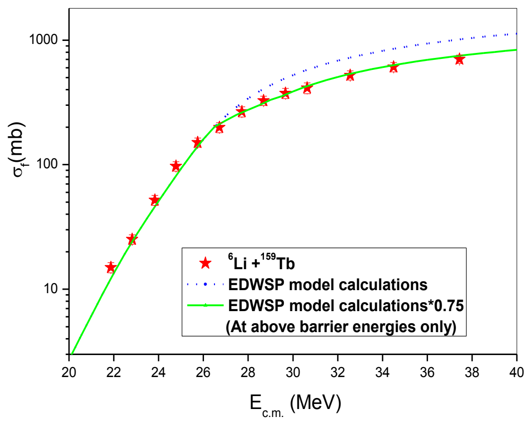

Fig.1. Fusion excitation functions of $^{6}Li + ^{159}Tb$ reaction obtained by using the EDWSP model [5-6] along with one dimensional Wong formula [7]. The theoretical calculations are compared with the available experimental data taken from Ref. [2].

In literature, the coupled channel analysis of $^{6}Li + ^{159}Tb$ ($^{6}Li + ^{159}Tb$) reaction have been done by using the continuum discretized coupled channel (CDCC) approach [2-4]. In this approach, the projectile ^{6}Li (^{7}Li) is taken as two body $\alpha + d$ ($\alpha + t$) cluster structure with a breakup threshold of 1.475 *MeV* (2.45 *MeV*). The CDCC calculations for both reactions suggested that due to loosely bound nature of projectiles, the projectile shows breakup effects and breakup into two fragments before reaching the Coulomb barrier. The lighter projectile ^{6}Li breaks up into α and d particles while the heavier projectile ^{7}Li splits into α and t particles and subsequently absorbed partially by the target nucleus. The partial absorption of projectile by the target results in the suppression of the fusion cross-section data at above barrier energies when compared with the no breakup case as evident from the Fig.1 and Fig.2. For $^{6}Li+^{159}Tb$ ($^{6}Li+^{159}Tb$) reaction, the fusion suppression up to 34% (26%) with reference to the estimations of the coupled channel approach have been pointed for the studied reaction.

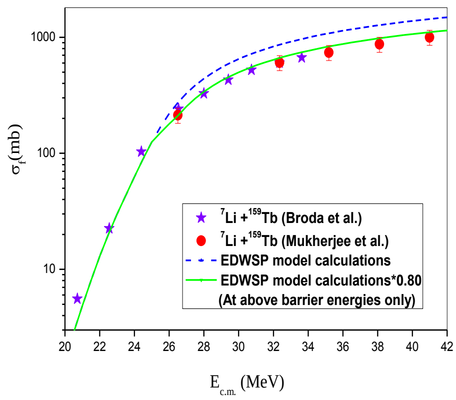

Fig.2. Fusion excitation functions of $^{7}Li+^{159}Tb$ reaction obtained by using the EDWSP model [5-6] along with one dimensional Wong formula [7]. The calculated results are compared with the experimental data taken from Ref. [3-4].

In order to identify the suppression effects, the fusion dynamics of the chosen reactions have been examined by using the energy dependent interaction potential. In case of EDWSP model, the energy dependence in the nucleus-nucleus potential has been governed by taking energy dependent diffuseness parameter. Due to introduction of the energy dependence in the nucleus-nucleus potential, the EDWSP model becomes much more attractive in the barrier regions as compare to the static Woods-Saxon potential. As a result, the EDWSP model produces gross potential modulation, henceforth, modifies the barrier profile and barrier characteristics of the interaction barrier between the colliding nuclei. For the chosen reactions, although, the experimental data at above barrier energies are suppressed with respect to the outcomes of the EDWSP model, the extracted suppression factor has been minimized considerably. In above barrier energy regimes, the fusion data is suppressed with respect to the expectations of the EDWSP model and the magnitude of the suppression factor is reduced by 9% (6%) with reference to the reported value. In other words, the above barrier fusion cross-section data of $^{6}Li+^{159}Tb$ ($^{6}Li+^{159}Tb$) reaction is inhibited by 25% (20%) in respect to predictions of the EDWSP method. The observed deficit complete fusion cross-sections appear in the form of incomplete fusion cross-sections. The presence of the incomplete fusion cross-section data clearly mirror the weakly bound nature of the projectiles and thus ensures the breakup of loosely bound projectile prior to the Coulomb barrier. .

In summary, the role of projectile breakup channel has been investigated for $^{6,7}Li+^{159}Tb$ reactions. The theoretical calculations have been performed by using the EDWSP model. As mentioned in the literature, the complete fusion cross-sections of $^{6}Li+^{159}Tb$ ($^{6}Li+^{159}Tb$) reaction are found to be suppressed by 34% (26%) when compared with the no breakup case. Such suppression effects can be correlated with the loosely bound nature of the projectile. The projectile ^{6}Li (^{7}Li) being as weakly bound structure splits into $\alpha+d$ ($\alpha+t$) cluster structure and subsequently either of the breakup fragment is captured by the target leading to the inhabitation of the complete fusion cross-sections at above barrier energies. However in case of the EDWSP model, due to the energy dependent interaction potential, the barrier profile of the interaction barrier gets modified and thus reasonably explored the sub-barrier fusion enhancement of the studied reactions. Although, there is suppression of complete fusion cross-section in above barrier regimes with reference to the EDWSP model calculations, the extracted suppression effects for $^{6}Li+^{159}Tb$ ($^{6}Li+^{159}Tb$) reaction are smaller by 9% (6%) with respect to the reported value. Hence, complete fusion yields of $^{6}Li+^{159}Tb$ ($^{6}Li+^{159}Tb$) reaction is inhibited by 25% (20%) when compared with the outcomes of the EDWSP method.

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