Fusion dynamics of ^{6}Li + ^{96}Zr reaction

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The heavy ion fusion reactions involving halo and/or weakly bound nuclei present attractive features and in the recent years were extensively investigated. The weakly bound nuclei possess low binding energy and when such nuclei interact with target, then due to force field of target, weakly bound system splits into two or more breakup fragments. In incomplete fusion events, a part of the projectile is absorbed by target and the complete fusion cross-sections data at above barrier energies get suppressed. Generally, the separation of complete fusion event from incomplete fusion events is also not an easy task on experimental ground and in such situation, total fusion cross-sections data are measured [1-3]. For heavier target system, the separation between complete fusion events and incomplete fusion events can be possible but in case of light and medium mass target such measurements are limited to few projectile-target combinations.

In this paper, the fusion mechanism of ^{6}Li + ^{96}Zr reaction [4] is analyzed by opting energy dependent Woods-Saxon potential (EDWSP) model [5-11] and coupled channel code CCFULL [12]. For the present reaction, EDWSP calculations are carried by considering energy dependent Woods-Saxon potential in conjunction with simple Wong formula [13]. The EDWSP model based output brings barrier alteration mechanism and empirically consider the effects of relevant channel couplings into theoretical predictions and hence predicts significantly larger fusion cross-sections relative to the output of the one dimensional barrier penetration model (BPM). The authors of Ref. [4] experimentally measured the fusion data and theoretical predictions of complete fusion cross-sections at above barrier energies were found to be suppressed by an amount of 25% with respect to the coupled channel outputs. This suppression effect was correlated with the low breakup threshold of the weakly bound system. However, the EDWSP based calculations predicted that the above barrier fusion cross-sections are suppressed by 10% and suppression factor can be minimized up to 15% relative to the reported value. The so extracted suppression effects can be linked with the low breakup threshold of the weakly bound projectile that breaks up into two fragments in the presence of the Coulomb or nuclear force field of the target isotope. In EDWSP model, the Woods-Saxon form of the nuclear potential is utilized for theoretical predictions and the conventional form of Woods-Saxon potential is defined below.

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

Here, V_0 is depth; R_0 is sum of radii of fusing participants and 'a' is diffuseness parameter of nuclear potential. The total interaction potential contains three terms as nuclear potential, Coulomb potential and centrifugal potential. For ℓ=0, the contributions of centrifugal potential term is zero and sum of nuclear potential and Coulomb potential term at barrier position is termed as Coulomb barrier. In EDWSP model; the depth of Woods-Saxon potential is given by standard parameterization that depends upon mass numbers and isospin asymmetry terms of the interacting partners and is defined below.

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

with $I_P = \left(\frac{N_P - Z_P}{A_P}\right)$ & $I_T = \left(\frac{N_T - Z_T}{A_T}\right)$ are the isospin asymmetry of the collision partners. In EDWSP model [5-11], the energy dependence in the Woods-Saxon is taken via its diffuseness parameter $a(E_{c.m.})$ and hence is given below

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

with, $E_{c.m.}$ and V_{B0} respectively are incident energy in center of mass frame and height of the Coulomb barrier. The range parameter (r_0) which is related to the geometrical shape of the fusing nuclei through relation $R_0 = r_0\left(A_P^{1/3}+A_T^{1/3}\right)$ is taken as *1.060 fm* for given reaction. The potential depth $V_0 = 30.95$ *MeV* and values of diffuseness parameter changes from *0.93 fm to 0.85 fm* as incident energy varies from 10MeV to 30MeV. The barrier characteristics of interaction barrier like barrier height $V_{B0} = 17.10\ MeV$, barrier position $R_B = 9.37\ fm$ and barrier curvature of the top of the Coulomb barrier = *4.19 MeV* are used for the theoretical calculations. The above set of potential parameters brings required order of barrier modifications that empirically considers the effects of dominant channel couplings and EDWSP based calculations are able to describe the sub-barrier fusion data of the studied system as evident from Fig.1.

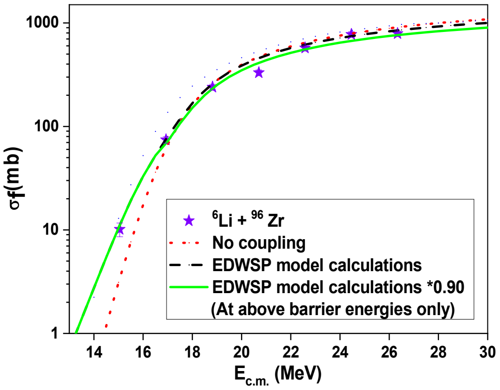

Fig. 1 The complete fusion cross-sections for ^{6}Li + ^{96}Zr reaction obtained using the EDWSP model and results are compared with the experimental data taken from the Ref. [4].

However, the same calculation overestimates the complete fusion cross-sections data by 10% at above barrier energies. This clearly suggested that the above barrier cross-sections data for complete fusion process are suppressed by 10%. This suppression factor is considerably smaller than the reported value. In literature, a suppression factor of 25% at above barrier energies was reported for complete fusion process given reaction. For sake of completeness, the no coupling calculation, which is obtained by using the coupled channel code CCFULL has been compared with the EDWSP based calculations and experimental data and is shown in Fig.1. The no coupling calculation does not include the effect of intrinsic degrees of freedom of the collision partner. The EDWSP suppression factor is 15% smaller than that of the reported value. This fusion suppression effect can be correlated with low binding energy of weakly bound system (Binding Energy = 1.475MeV). The weakly bound system breaks up into alpha particle and deuteron and the probability of absorption of alpha particle by target is prominent and leads to the suppression effects at above barrier energies. The flux lost from the complete fusion at above barrier energies appeared as incomplete fusion yields.

In EDWSP model, the energy dependent nature of the Woods-Saxon potential causes barrier alternation and barrier lowering phenomenon and encompass empirically the effects of dominant channel couplings linked with the fusing pairs. As a result, EDWSP model predicts larger fusion cross-sections in comparison to the outputs of the one dimensional BPM. In this sense, the EDWSP based predictions reasonably describe the sub-barrier fusion data for complete fusion process of given reaction. For given range parameter *1.060 fm* for the studied system, the EDWSP predictions explain the sub-barrier fusion enhancement of ^{6}Li + ^{96}Zr system but same calculation overestimates the complete fusion data by 10% at above barrier energy regions. The EDWSP based suppression factor is sufficiently smaller than reported value (suppression factor =25% at above barrier energies). Such suppression effects can be correlated with the low binding energy of the weakly bound projectile.

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