Fusion systematics for ^{12}C and weakly bound ^{9}Be projectiles using neutron flow and collective degrees of freedom

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Introduction

Sub-barrier fusion is a topic of great interest due to the observation of enhanced cross sections around the Coulomb barrier energies. It is well established that the fusion cross-sections are significantly enhanced at sub-barrier energies compared to the one dimensional barrier potential model [1]. The enhancement of the fusion cross-sections is explained due to the various relative degrees of freedom of the interacting nuclei. In addition to this, the role of neutron rearrangement in the fusion cross-sections has been explored in order to explain the enhancement of fusion cross-sections [2]. There are several theoretical prescriptions proposed to describe the enhancement in the fusion cross-sections at near barrier energies and it is observed that two different models are very much successful in explaining the enhancement in the cross-sections [3, 4]. The first model (Coupled Channel model) is based on the effect of couplings of the incident projectile and the target where the barrier height of the interacting system is lowered and leads to an enhancement of the fusion cross-section [3]. The second model (Stelson model) based on the neutron flow due to the exchange of neutrons between the interacting projectile and target nuclei [4]. It is observed that both these models predict different barrier distributions for the reactions studied. In the past, there have been few studies in order to understand the enhancement of the sub barrier fusion cross-sections by using both the models [5, 6]. There were only a few attempts in literature to explain the experimental data around the coulomb barrier energies for various projectile target combinations, in order to identify which mechanisms more appropriate to explain the experimental data on sub barrier fusion [5]. Further, there are several reports in literature showing that the reaction cross-sections involving weakly bound projectiles (WBPs) very high around the barrier energies. In this context, we have investigated the systematics of WBP ^{9}Be along with stable projectile ^{12}C on various targets by using both the Stelson model and coupled channel formalisms.

1. Methodology

The well known expression for the fusion cross-section for projectile energies greater than the barrier (B) can be written as

$$\sigma_{fus} = \pi R_b^2 (1 - \frac{B}{E}) \tag{1}$$

where B, R_b are the Coulomb barrier and Coulomb radius respectively. According to the Stelson model, at near barrier energies the fusion barriers can be explained by a flat distribution of barriers with a threshold energy cutoff (T) [4]. This barrier corresponds to the energy at which the interacting nuclei come sufficiently close to each other for neutrons to flow freely between target and projectile. So, the above expression transforms at near barrier energies to

$$\sigma_{fus} = \pi R_b^2 \frac{(E-T)^2}{4E(B-T)} \tag{2}$$

We can calculate maximum value of the merged neutron potential V_{max} by assuming neutron shell potential centered on each of the interacting nuclei. In this configuration, the distance between the interacting nuclei is given by R_t, the distance at which the threshold barrier (T) is reached. According to this model, if the merged neutron potential (V_{max}) is lower than the binding energy of the valence neutron of the two interacting nuclei then only the neutron flow is possible. Further the extent of the barriers discussed above (B - T) are correlated by the difference between the maximum merged neutron potential and valance neutron binding energy (V_{sn}). On the other hand in the coupled channel formalism, it is well established that the coupling between the incident projectile and target channels (vibration, rotational, transfer) can modify the barrier heights [3]. By including the transmission probabilities and strength of the couplings (F) through the modified barriers the fusion cross-section can be calculated. If we consider only inelastic couplings, the channel couplings (F) may lead to the decrease or increase in the barrier height and it is expected that the B - T values will be related to F [5]. Depending on the values of $S_{2n}/2$ for stable and S_n for weakly bound projectiles the neutron flow process may takes place from projectile to target or from target to projectile.

2. Results

We have analyzed the fusion data for WBP ^{9}Be and strongly bound projectile ^{12}C around the coulomb barrier energies for various targets by using Stelson model and coupled channels formalism. In Fig.1, we have plotted the B - T values as a function of V_{max} and F. One can observe that there is a good correlation between B - T vs V_{max} and F and the results from both models are well reproduced by linear fits. From this analysis, it is observed that for reactions with ^{12}C on various targets, the extracted B - T values are better correlated with the variable F deduced from the coupled channel analysis when compared to the values extracted from the Stelson model V_{max}. A similar kind of of result was also observed for the case of reactions involving ^{9}Be on various targets. The present results show that both the prescriptions provide a good description of near barrier fusion data.

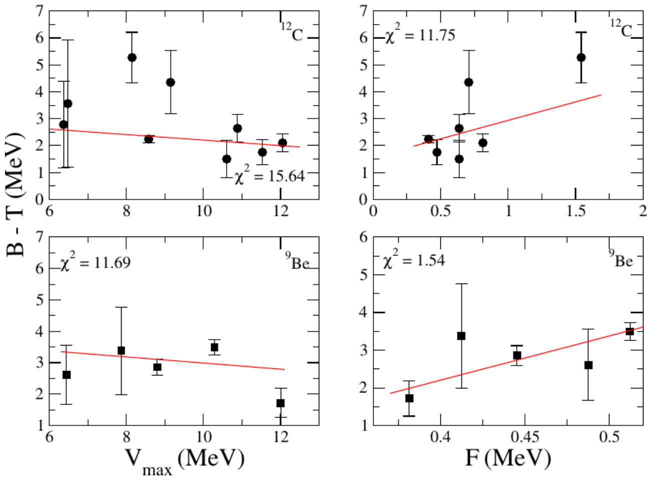

FIG. 1: The extracted values of B-T as a function of V_{max} (left) and F (right) for the ^{12}C and ^{9}Be on various targets along with their best linear fits to the data.

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