Breakup Effects in ^{6}He + ^{209}Bi Fusion Reaction

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The fusion of stable and radioactive weakly bound nuclei has been the subject of intense theoretical and experimental activities since past two decades [1]. Owing to very small binding energy of last one or two nucleons, some of the weakly bound radioactive nuclei lying in the close proximity of drip lines exhibit various unique features. For instance, the existence of a novel halo structure is now very well established. Also very large breakup cross section has been observed for reactions involving nuclei having halo structure. Both of these static (halo structure) and dynamic (breakup) effects strongly influence the near barrier fusion cross section of these nuclei on heavy targets. A complete understanding of the breakup effects on the fusion is directly relevant to the production of nuclei near the drip lines, and possibly super heavy nuclei. However, contradictory results have been proposed regarding the role of strong coupling to breakup channel in the fusion reaction. In some cases sub-barrier enhancement in fusion cross section is observed while in other cases suppression is found. Thus the study of the effects of breakup on the fusion needs further investigation. In the present work we have studied the effect of coupling to the breakup channel on the fusion cross section for ^{6}He + ^{209}Bi system at near barrier energies. To include the breakup channel coupling effect into the theoretical formulation, it is convenient to express the cross section in the following form

$$\sigma_f = \frac{\pi}{k^2}\sum_{l=0}^{\infty}(2l+1)\ T_l^f \tag{1}$$

with

$$T_l^f = \left(1+\exp\left(\frac{2\pi}{\hbar\omega}\left(V_B+\frac{\hbar^2 l(l+1)}{2\mu R_B^2}-E_{c.m.}\right)\right)\right)^{-1} \tag{2}$$

Above R_B , V_B and $\hbar\omega$ represent the Coulomb barrier radius, height and curvature and have values 11.6fm, 19.3MeV and 3.9MeV respectively for ^{6}He + ^{209}Bi system. When the breakup channel coupling is taken into account the above expression for the fusion cross section is modified as

$$\sigma_f^{bu} = \frac{\pi}{k^2}\sum_{l=0}^{\infty}(2l+1)\ (1-T_l^{bu})T_l^f \tag{3}$$

where T_l^{bu} is the breakup transmission factor. Finally using the two channel coupling model the fusion cross section is given by [2]

$$\sigma^{coup}{}_f = \frac{1}{2}\frac{\pi}{k^2}\left[\left(\sum_{l=0}^{\infty}(2l+1)\ (1-T_l^{bu})T_l^f(+F)\right) + \left(\sum_{l=0}^{\infty}(2l+1)\ (1-T_l^{bu})T_l^f(-F)\right)\right] \tag{4}$$

with F as the coupling potential . Neglecting the contribution of Coulomb breakup the breakup transmission factor T_l^{bu} can be evaluated via

$$T_l^{bu} = 1-\exp\left[-2\int_{\rho_0}^{\infty}\frac{\operatorname{Im}V_{pol}/E_{c.m.}}{\sqrt{1-2\eta/\rho-l(l+1)/\rho^2}}\,d\rho\right] \tag{5}$$

Here η is the Sommerfeld parameter and the ρ_0 represents the product of the distance of closest approach and the wave number k , and is obtained from

$$1-2\eta/\rho_0-l(l+1)/\rho_0{}^2 = 0 \tag{6}$$

Using the trivially equivalent local potential for the dynamic polarisation potential the T_l^{bu} can be expressed in the following closed form [3]

$$T_l^{bu} = 1-\exp\left[-\frac{4\mathrm{F}_0^2}{E^2}\left|S_l^{(1)}\right| I_l^2(\eta,s)\right] \tag{7}$$

where F_0 is a coupling strength factor, $\left|S_l^{(1)}\right|$ is the modulus of the elastic S matrix in the breakup channel and $I_l(\eta,s)$ is a Coulomb radial integral. The explicit expression for $I_l(\eta, s)$ is discussed in detail in Ref. [3]. In the present work we have treated F_0 as a free parameter and the variation of T_l^{bu} with the incident energy around the barrier is shown in Fig. 1 for three different values of F_0 .

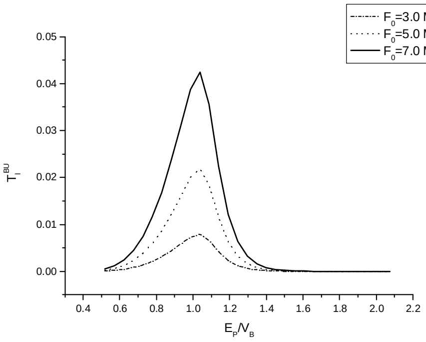

Fig. 1 Variation of T_l^{bu} with the E_P/V_B for different values of coupling strength factor.

It is clear in this figure that there is a large increase in the peak of breakup transmission factor with the increase in the coupling strength factor. Since the breakup effects are pronounced for larger values of F_0, we have taken F_0=7.0 MeV to calculate the fusion cross section. Further it can be seen from Fig.2 that T_l^{bu} is maximum around the barrier.

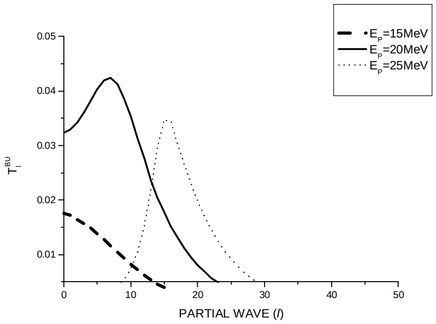

Fig.2Variation of T_l^{bu} with the number of partial waves at energies 15.0, 20.0 and 25.0 MeV.

At energies much smaller than the barrier, the T_l^{bu} is very small and hence fusion cross section as calculated by using Eq.(4) is enhanced in comparison to that obtained by using Hill-Wheeler (HW) formula to a larger extent but at energies near the barrier, where T_l^{bu} is maximum, the enhancement is smaller [see Fig.3]. On the other hand at energies above the barrier the fusion cross sections are somewhat suppressed with respect to the predictions of HW formula.

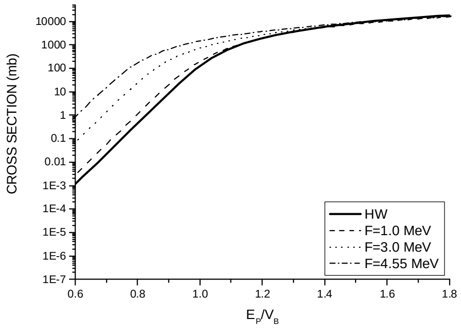

Fig. 3 Fusion cross sections for ^{6}He + ^{209}Bi system calculated by considering the breakup channel (dashed, dotted and dash-dotted lines) and without breakup channel (solid line).

In conclusion there is a large enhancement in the fusion cross section at sub barrier energies due to coupling to the breakup channel and this enhancement increases with increase in the strength of the coupling.

References

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