Study of the effect of projectile breakup on ^{17}F + ^{208}Pb fusion reaction at near barrier energies

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The nuclear reactions induced by loosely bound nuclei lying in close vicinity of drip lines, both stable and radioactive, have received a great attention during last three decades [1]. Because of their unusual structural properties and a very low breakup threshold the fusion involving these nuclei differs fundamentally from those involving tightly bound nuclei. So far lot of dedicated efforts, both experimental as well as theoretical, have been made to understand the peculiarities involved in fusion reactions induced by weakly bound nuclei. As far as the static effects arising because of the large spatial extension are concerned, it is now well established that these lead to the lowering of barrier and a corresponding enhancement in the fusion cross sections. However, regarding the dynamical effects of the breakup of projectile conflicting results have been found in various studies [1-2]. Further it is important to mention that most of the studies on fusion reactions are limited to those involving neutron rich projectiles [1-4]. Thus, it is quite tempting to investigate the breakup effects on the fusion of proton rich nuclei wherein additional complexity is added due to the present of Coulomb barrier between the valance proton and the core.

Thus in the present work we have studied the fusion induced by proton rich nucleus ^{17}F on ^{208}Pb target at energies around the barrier within the framework of quantum diffusion model of Sargsyan et al. [5] wherein various channel coupling effects are simulated through the dissipation and fluctuation effects. For nucleus-nucleus potential we have adopted the proximity model [6].

The partial wave capture cross-section, the cross-section for the formation of dinuclear system, is given by

$$\sigma_c(E_{c.m.}) = \pi\hbar\!\!\!\lambda^2 \sum_L (2L+1) P_{cap}(E_{c.m}, L) \qquad (1)$$

The partial capture probability, P_{cap}, is obtained by integrating an appropriate propagator from initial state at t = 0 to the final state at time t and is given by

$$P_{cap} = \lim_{t\to\infty} \frac{1}{2} erfc\left[\frac{-r_{in} + \overline{R(t)}}{\sqrt{\Sigma_{RR}(t)}}\right] \qquad (2)$$

The first moment, $\overline{R(t)}$, and the variance, $\Sigma_{RR}(t)$, are given by

$$\overline{R(t)} = A_t R_0 + B_t P_0$$

and

$$\sum\nolimits_{RR}(t) = \frac{2\hbar^2\lambda\gamma^2}{\pi} \int_0^t d\tau' B_{\tau'} \int_0^t d\tau'' B_{\tau''} \times \int_0^\infty d\Omega \frac{\Omega}{\Omega^2+\gamma^2} \times coth\left[\frac{\hbar\Omega}{2T}\right] cos[\Omega(\tau' - \tau'')]$$

with

$$B_t = \frac{1}{\mu}\sum_{i=1}^{3} \beta_i\,(s_i+\gamma) e^{s_i t}$$

$$A_t = \sum_{i=1}^{3} \beta_i [s_i(s_i+\gamma) + \hbar\lambda\gamma/\mu] e^{s_i t}$$

Using these expressions one finally obtains

$$P_{cap} = \frac{1}{2} erfc\left[\left(\frac{\pi s_1(\gamma - s_1)}{2\mu\hbar(\omega_0^2 - s_1^2)}\right)^{1/2} \frac{\mu\omega_0^2 R_0/s_1 + P_0}{[\gamma \ln(\gamma/s_1)]^{1/2}}\right]$$

In order to include breakup effects, Eq. (1) is multiplied by survival probability of projectile against breakup and is written as

$$\sigma_c(E_{c.m.}) = \pi\hbar\!\!\!\lambda^2 \sum_L (2L+1) P_{cap}(E_{c.m}, L) \times (1 - P_{bu}(R_{min}))$$

The breakup probability $P_{bu}(R_{min})$ for a fixed energy and impact parameter is given as an exponential function of distance of closest approach, R_{min} [7]

$$P_{bu} = A\exp(-\alpha R_{min})$$

The parameters A and α are determined to reproduce the measured breakup probabilities at two different energies [8] and for the system considered here we have obtained 1.02× 10^3 and 0.67 fm^{-1} as values of A and α respectively. The friction coefficient (ħλ) and the internal excitation width (ħγ) are kept fixed at 2 MeV and 15 MeV, respectively throughout the calculations. The proximity potential model is used to calculate the values of barrier height (V_b) and barrier position (R_b) which comes out to be 88.21 MeV and 11.77fm respectively. Besides these the values of R_0, which is very crucial and strongly depends on the separation of the region of pure Coulomb interaction and that of Coulomb nuclear interference, and P_0 are determined through the procedure described in the Ref. [9]. In Fig. 1, R_0 is plotted as a function of incident energy.

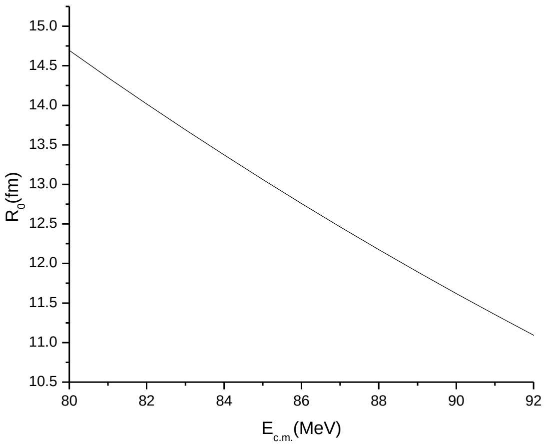

Fig.1. Variation of average separation at t = 0 (R_0) between the colliding nuclei ^{17}F and ^{208}Pb is shown as a function of incident beam energy $E_{c.m.}$ in centre of mass system.

In Fig 2, the fusion excitation functions of $^{17}F + ^{208}Pb$ system are compared with the corresponding data taken from Ref. [10]. It is clearly seen in Fig. 2 that the projectile breakup suppressed the fusion at sub barrier energies while it does not alter the fusion cross section at above barrier energies. At energies much higher than the barrier energy, the projectile is quickly captured by the target and the effects of other reaction channel becomes negligible hence no suppression or enhancement is found in this energy region. But at near and sub barrier energies the projectile has to tunnel through a barrier which is a comparatively slow process and the possibilities of occurring reactions other than fusion are opened up. In particular the breakup channel dominates in case of a weakly bound nucleus and because of a significant loss of flux in this channel the fusion cross section is substantially suppressed as shown in Fig. 2.

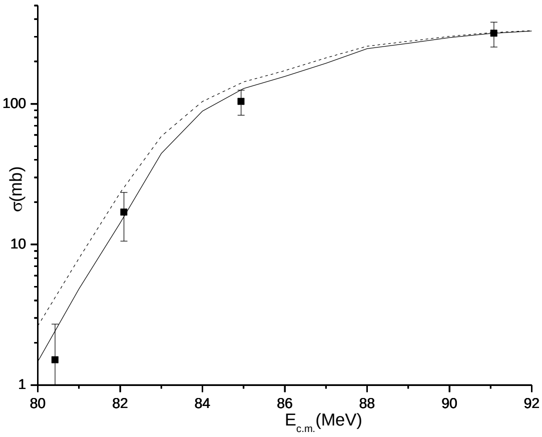

Fig.2. The fusion excitation functions of $^{17}F + ^{208}Pb$ system calculated by using quantum diffusion approach without breakup effect (dotted line) and with breakup effect (solid line) are compared with the experimental data (solid square) taken from Ref.[10].

In summary, the breakup of projectile leads to suppression in fusion cross section at below barrier energies while no effect is observed at above barrier energies which in turn results in a good agreement between data and predictions.

References

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