Analysis of Breakup Effects on Fusion of ^{9}Be+^{64}Zn And ^{9}Be+$^{8\,9}$Y Systems in Near Barrier Energy Region

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The studies on the effects of breakup of weakly bound nuclei, both stable and radioactive, on fusion cross section have received a great attention during past three decades [1]. These weakly bound nuclei have low breakup threshold (binding energy) that makes the fusion induced by these nuclei fundamentally different from that induced by tightly bound nuclei. Among these nuclei, the nucleus ^{9}Be is quite interesting because it breaks up via two different two body channels viz. n+2α, [or n + ^{8}Be*], with neutron separation energy S_n = 1.67 MeV and α + ^{5}He, with alpha separation energy S_α = 2.47 MeV. In present work, we have studied the fusion induced by ^{9}Be on ^{64}Zn and ^{89}Y targets by using quantum diffusion approach. In particular, we have investigated the role of most likely breakup channel *via* excited ^{8}Be* state, produced following the transfer of single neutron to target, which is the fusion reaction.

Within the framework of the quantum diffusion model of Sargsyan et al. [2], for a given center of mass incident energy, $E_{c.m}$, the capture cross-section for the formation of compound nuclear system is written as

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

with P_{cap} is given by

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

Further, if the coupling between the collective and internal subsystem is linear in momentum then the quantities first moment, $\overline{R(t)}$, and the variance, $\Sigma_{RR}(t)$ in the co-ordinate acquire the following expressions

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

$$\sum_{RR}(t) = \frac{2\hbar^2\lambda\gamma^2}{\pi} \int_0^t d\tau' B_{\tau'} \int_0^t d\tau'' B_{\tau''} \times \int_0^\infty d\Omega \frac{\Omega}{\Omega^2+\gamma^2} \times coth\left[\frac{\hbar\Omega}{2T}\right] cos[\Omega(\tau' - \tau'')] \qquad (3)$$

with

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

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

Above $\beta_i = [(s_i - s_j)(s_i - s_k)]^{-1}$, $i, j, k = 1,2,3$ and $i \neq j \neq k$ and s_i are the real roots of

$$(s+\gamma)(s^2 - \omega_0^2) + \frac{\hbar\tilde{\lambda}\,\gamma s}{\mu} = 0 \qquad (4)$$

where γ, ω_0 and $\tilde{\lambda}$ are the internal excitation width, renormalized frequency and parameter related to the strength of linear coupling. Combining Eqs. (2) and (3) and for sub barrier fusion, in the limit of small temperature T→0, it is straightforward to obtain

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

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

$$\sigma(E_{c.m.}) = \frac{\pi}{k^2} \sum_L (2L+1) P_{cap} (1 - P_{bu})$$

where the breakup probability $P_{bu}(R_{\min})$ for a fixed energy and impact parameter is given as $P_{bu} = A \exp(-\alpha R_{\min})$ [3].

The parameters A and α are determined to reproduce the measured breakup probability at two different energies in near barrier energy. For ^{9}Be+^{89}Y system, we obtained A and α as 1.6487 and 0.08149 fm^{-1} respectively by extracting values of breakup probabilities from ref. [4]. Because of the unavailability of experimental P_{bu} values for ^{9}Be+^{64}Zn system we have adopted the A and α as for ^{9}Be+^{89}Y system as a first approximation. In addition, the values of R_0 and P_0 are taken by same procedure as given in Ref. [5]. The barrier parameters *viz* barrier height and barrier position are determined by plotting proximity potential [6] as a function of projectile-target relative separation. For ^{9}Be+^{64}Zn, calculated barrier height and barrier position are 18.63 MeV and 10.45 fm while for ^{9}Be+^{89}Y, these parameters are 22.21 MeV and 10.49 fm respectively. Following the prescription of Sargsyan et al. [2] the friction coefficient ($\hbar\lambda$) and the internal excitation width ($\hbar\gamma$) are kept fixed 2MeV and 15MeV throughout the calculations.

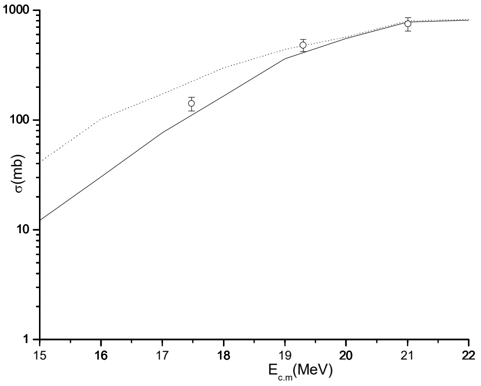

Fig.1. The fusion excitation functions of ^{9}Be+^{64}Zn system calculated by using quantum diffusion approach without breakup effect (dotted line) and with breakup effect (solid line) are compared with the experimental total fusion cross section data (open circle) taken from Ref. [7].

In Fig. 1 the fusion excitation function of ^{9}Be + ^{64}Zn fusion reaction is compared with the corresponding experimental fusion cross section data taken from Ref.[7]. The dotted line represents the result of calculation when breakup of ^{8}Be* into $\alpha + \alpha$ is not taken into account, while the solid curve represents the results obtained by considering breakup of ^{8}Be* into two alphas. As a consequence of the dependence of deformation parameter of colliding nuclei on neutron number, there occurs change in deformations after neutron transfer. The change in deformation parameters, mass numbers and the isotopic composition leads to change in Coulomb barrier position and height which in turn affect the fusion cross section. For ^{9}Be+^{64}Zn system, after one neutron transfer deformation parameter of target nucleus changes from $\beta_2 = 0.219$ to $\beta_2 = -0.264$ while that of projectile remains unchanged. The shape of target nucleus changes from prolate to oblate and hence the barrier height increases which results in suppression of fusion cross section. The increase in barrier height leading to decrease in fusion cross section is ascribed to the fact that the Coulomb field is lower on the tips of a deformed nucleus in comparison to its side. The suppression of fusion cross section in near barrier energy is amplified when the breakup is taken into account. It may be attributed to the flux lost in breakup channel. When the breakup effects are taken into account the sub barrier fusion cross section data are found to be in excellent agreement with the prediction. The similar behavior is obtained for ^{9}Be+^{89}Y system as shown in Fig.2.

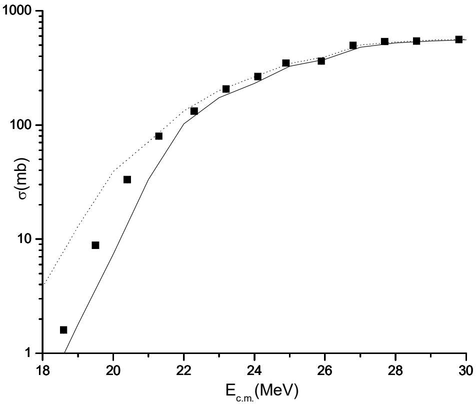

Fig.2. Same as Fig. 1 but for ^{9}Be+^{89}Y system. The experimental complete fusion cross section data (solid square) are taken from Ref. [8].

The observed overall suppression in fusion cross section for ^{9}Be+^{64}Zn, ^{89}Y systems arises because of the nature of shape change occurring in the target and the breakup of the projectile. In both cases the inclusion of breakup improves matching between data and predictions significantly.

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