Study of the role of breakup following neutron transfer in fusion induced by ^{9}Be at near barrier energies

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The studies on the breakup effects of weakly bound nuclei, both stable and radioactive, on fusion cross section is a subject of contemporary interest[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 very interesting because it has low break up threshold of 1.67 MeV and has a possible three body $n+\alpha+\alpha$ Borromean structure. So far, numbers of experiments have been carried out to study the fusion reactions induced by ^{9}Be on various targets at near barrier energies. But in these studies conflicting results have been found regarding breakup effects [2-3]. On the theoretical front also controversial results have been reported. Thus, further investigations, both experimental and theoretical, are needed for unambiguous understanding of the breakup effects on fusion reactions involving weakly bound ^{9}Be as projectile. Hence we have studied here the fusion induced by ^{9}Be on ^{208}Pb and ^{209}Bi targets by taking into account breakup following neutron transfer effects which strongly affects the fusion cross section. In the present work, we use the quantum diffusion model of Sargsyan et al. [4] wherein various channel coupling effects are simulated through the dissipation and fluctuation effects. For nucleus–nucleus potential, we have adopted the proximity model [5].

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

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

Within the framework of quantum diffusion model, 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 [6].

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

The first moment, $\overline{R(t)}$, and the variance, $\Sigma_{RR}(t)$, are obtained by constructing a suitable Hamiltonian for quantum nuclear system which results in integro-differential equations for Heisenberg operator R and P and are written as

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

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

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

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

This expression is used to calculate the capture probability and hence the total capture cross section. In order to include breakup effects, eq. (1) is multiplied by survival probability of projectile against breakup and is written as

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

The breakup probability $P_{bu}(R_{\min})$ for a fixed energy and impact parameter is given as 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 probability. By using the values of breakup probability quoted in ref. [8], we obtain A and α as 1.37× 10^{3} and 0.841fm^{-1} for ^{9}Be+^{208}Pb system and 1.39 × 10^{3} and 0.763fm^{-1} for ^{9}Be+^{209}Bi system respectively. The friction coefficient (ħλ) and the internal excitation width (ħγ) are kept fixed at 2 MeV and 15 MeV, respectively throughout the calculations. As a result of neutron transfer process, the values of barrier height (V_b), barrier position (R_b), mass asymmetry (η), parameter (ħs_1) and renormalized frequency (ħω_0) change from 41.62MeV, 11.22fm, 0.917, 2.56MeV and 2.97MeV to 41.20MeV, 11.09fm, 0.926, 2.64MeV and 3.09MeV respectively for ^{9}Be+^{208}Pb system. Similarly for ^{9}Be+^{209}Bi system these barrier parameters change from 42.37MeV, 11.43fm, 0.917, 2.42MeV and 2.81MeV to 41.89MeV, 11.51fm, 0.92, 2.54MeV and 2.96MeV. The parameters R_0 and P_0 are determined through the procedure described in Ref.[9].

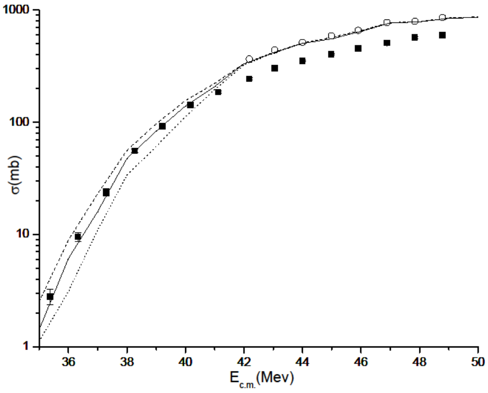

Fig.1. The fusion excitation functions of ^{9}Be + ^{208}Pb system calculated by using quantum diffusion approach without neutron transfer and breakup effect (dotted line), with neutron transfer effect (dashed line) and with breakup following neutron transfer (solid line) are compared with the experimental total fusion cross section data (open circle) and complete fusion cross section data (solid square) taken from Ref.[10].

In Figs 1 and 2, the fusion excitation functions of ^{9}Be+^{208}Pb and ^{9}Be+^{209}Bi systems are compared with the corresponding data taken from Refs. [10] and [2,11] respectively. After one neutron transfer from projectile to the target, the barrier height reduces for both the systems and hence there is an enhancement in fusion cross section. On the other hand, the breakup reduces this enhancement. Consequently the improvement between the data and predictions improve significantly as can be seen in Figs. 1 and 2. Further, at higher energies the complete fusion data are significantly over predicted by the calculation but total fusion data are very well explained. It may be ascribed to the fact that within the framework of the model used here it is not possible to evaluate complete and incomplete fusion separately only total fusion cross section is evaluated

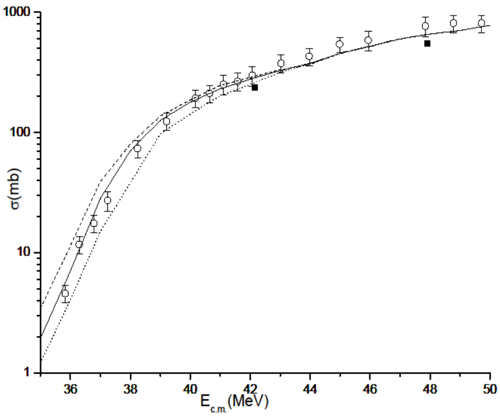

Fig.2. Same as Fig. 1 but for ^{9}Be + ^{209}Bi system.

In summary, neutron transfer effect leads to an enhancement in fusion cross section for both the system considered here while the inclusion of breakup reduces this enhancement. The overall cumulative effects of both these processes for ^{9}Be+^{208}Pb and ^{9}Be+^{209}Bi system results in good matching between data and predictions.

Acknowledgment: A.K. is thankful to U.G.C., New Delhi for providing financial assistance in the form of B.S.R. fellowship.

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