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Effects of nuclear breakupon $^{6}Li+^{64}Zn$ fusion reaction around barrier energies

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ABSTRACT

We have studied the effect of breakup of weakly bound projectile on fusion reactions involving intermediate mass target within the framework of dynamic polarization potential approach. The sub barrier enhancement and the above barrier suppression have been found which significantly improves the matching between the fusion excitation function data and calculations for $^{6}Li+^{64}Zn$ system.

Keywords :Halo Nucleus; Fusion; Breakup; Dynamic Polarisation Potential.

Introduction

The availability of the beams of loosely bound nuclei lying in the close proximity of drip lines, over a wide energy range, has created a renewed interest in nuclear reaction studies[1]. The fusion of loosely bound radioactive ions with the stable targets is of immense importance in conjugation with the production of super heavy elements and the reactions of astrophysical interest and has attracted considerable attention over past few decades. As a result many efforts have already been made, both theoretical and experimental, to study the static and dynamic effects on the fusion cross section and so far very conflicting results have been reported in the literature about whether the fusion of loosely bound nuclei is enhanced or hindered at above and below barrier energies[2].

In the present work, we have studied the effects of coupling to breakup channel for $^{6}Li+^{64}Zn$ system on fusion cross section in near barrier energy regime within the framework of DPP approach. We have taken into account the DPP induced by strong nuclear interaction.

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Theoretical Formalism

Using the Feshbach projection operator formalism, the polarization potential can be written as [3]

$$U^{Pol}(\mathbf{r},\mathbf{r}') \equiv G^{(+)}(\mathbf{r},\mathbf{r}')F(\mathbf{r},\mathbf{r}') \quad (1)$$

with

$$F(\mathbf{r},\mathbf{r}') = \int |\phi_0(\mathbf{x})|^2 v\ (\mathbf{r},\mathbf{x})\ v\ (\mathbf{r}',\mathbf{x}) d^3\mathbf{x} \quad (2)$$

and

$$G^{(+)}(\mathbf{r},\mathbf{r}') = \frac{1}{\mathrm{rr}'} \sum_{l'm'} Y_{l'm'}(\hat{\mathbf{r}}) G_{l'}^{(+)}(\mathrm{r},\mathrm{r}') Y^{*}{}_{l'm'}(\hat{\mathbf{r}}') \quad (3)$$

All the symbols used in these expressionsare same as defined in[3,4].

The nuclear induced DPP is obtained by considering[5]

$$\begin{aligned} v\ (\mathbf{r},\mathbf{x}) \equiv v^{N}(\mathbf{r},\mathbf{x}) &= 4\pi U_{PT}^{N}(\mathrm{r})\left\{\sum_{l,m}(i)^{l} Y_{lm}^{*}(\hat{\mathbf{r}}) Y_{lm}(\hat{\mathbf{x}})\right\}\left[exp\left(-\left[\frac{m_b \mathrm{x}}{m_P a}\right]^2\right)\right] j_l\left(i\frac{2m_b \mathrm{r\,x}}{m_P a^2}\right) \\ &+ (-1)^{l} 4\pi U_{PT}^{N}(\mathrm{r})\left\{\sum_{l,m}(i)^{l} Y_{lm}^{*}(\hat{\mathbf{r}}) Y_{lm}(\hat{\mathbf{x}})\right\}\left[exp\left(-\left[\frac{m_c \mathrm{x}}{m_P a}\right]^2\right)\right] j_l\left(i\frac{2m_c \mathrm{r\,x}}{m_P a^2}\right) \\ &- 4\pi U_{PT}^{N}(\mathrm{r}) \end{aligned} \quad (4)$$

and is expressed as

$$U_l^{Pol,N}(\mathrm{r},\mathrm{r}') = F_1(\mathrm{r},\mathrm{r}')\left\{\frac{l+1}{2l+1} G_{l+1}^{(+)}(\mathrm{r},\mathrm{r}') + \frac{l}{2l+1} G_{l-1}^{(+)}(\mathrm{r},\mathrm{r}')\right\} + F_2(\mathbf{r},\mathbf{r}') G_l(\mathrm{r},\mathrm{r}') \quad (5)$$

Now the corresponding breakup polarization potential is obtained by using the following expression

$$U_l^{bu}(\mathrm{r}) = \frac{1}{u_l(k\mathrm{r})} \int U_l^{Pol}(\mathrm{r},\mathrm{r}') u_l(k\mathrm{r}') d\mathrm{r}' \quad . (6)$$

The fusion cross section is related to the fusion transmission coefficient through the following relation

$$\sigma_f = \frac{\pi}{k^2} \sum_{l=0}^{\infty} (2l+1) \; T_l^f \qquad (7)$$

The effect of breakup channel coupling on the fusion cross section is incorporated by multiplying the partial fusion probability T_l^f with the breakup survival probability $\sqrt{1-T_l^{bu}}$. Thus the fusion cross section becomes

$$\sigma_f^{coup} = \frac{1}{2} \frac{\pi}{k^2} \left[\left(\sum_{l=0}^{\infty} (2l+1) \sqrt{1-T_l^{bu}} \, T_l^f \, (+F) \right) + \left(\sum_{l=0}^{\infty} (2l+1) \sqrt{1-T_l^{bu}} \, T_l^f \, (-F) \right) \right] \qquad (8)$$

Here F is the channel coupling strength parameter.

The breakup transmission co-efficient T_l^{bu}, is related to breakup polarization potential and is given by

$$T_l^{bu} = 1 - exp\left[-2 \int_{\rho_0}^{\infty} \frac{Im\, U_l^{bu} / E_{c.m.}}{\sqrt{1 - 2\eta/\rho - l(l+1)/\rho^2}} d\rho \right] \qquad (9)$$

Here ρ_0 represents the product of the distance of closest approach and the wave number k_l, and is obtained from

$$1 - 2\eta/\rho_0 - l(l+1)/\rho_0^2 = 0 . \qquad (10)$$

Results and Discussions

In case of ^{6}Li+^{64}Zn system, the projectile ^{6}Li will breakup into ^{4}He and deuteron fragments. As the two fragments have same charge to mass ratio the reduced transition strength corresponding to dipole term B(E1) become identically zero within the cluster model. Since we are here considering only the dipole Coulomb polarizability, there will be no contribution from Coulomb breakup in this reaction and only nuclear induced breakup takes place. So in Fig. 1 the fusion excitation function for ^{6}Li+^{64}Zn system is calculated by considering coupling to the nuclear induced breakup and compared with the results of the standard one dimensional barrier penetration model (BPM) and the corresponding data. In the sub-barrier energy regime it has been found that there is significant enhancement in the fusion cross section obtained by coupling to the breakup channel as compared with the predictions of simple one dimensional barrier penetration model. It may be ascribed to the fact that coupling to other reaction channels at sub-barrier energies would lead to an enhancement of the transmitted flux and thus of the fusion cross-section. It is equivalent, at the nuclear level, to the enhancement of the tunneling probability due to the presence of additional degrees of freedom, as observed in coupled channel analysis, for a given system. On the other hand, at energies greater than the barrier height there is a strong suppression of the fusion cross section with respect to one dimensional barrier penetration model. This suppression may be attributed to the flux lost to the breakup channel resulting in the decrease of nuclei available for fusion. In addition, by considering the coupling to nuclear induced breakup the agreement between the data and the theoretical predictions has improved considerably.

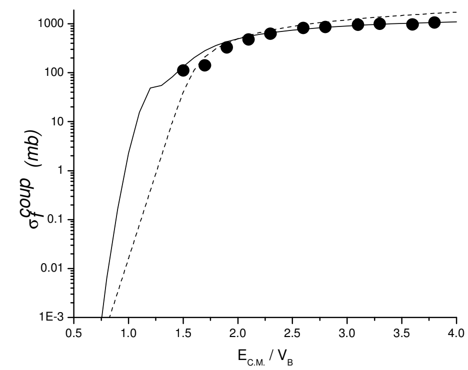

Figure 1. The fusion excitation function for ^{6}Li+^{64}Zn system corresponding to the calculation performed by simple BPM (dashed line) and by including nuclear induced breakup channel (solid line). Data is taken from [6].

In conclusion, we have investigated the effects of breakup of weakly bound nuclei on the fusion reaction using the dynamic polarization potential approach for ^{6}Li+^{64}Zn system. It has been found that in the sub-barrier energy regime there is an enhancement in the fusion cross section while in above barrier energy regime a strong suppression of the fusion cross section with respect to one dimensional barrier penetration model is there. The agreement between the data and predictions for the system under consideration improves significantly due to the inclusion of nuclear induced breakup effects in the analysis.

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