Influence of Deformation and Neutrons Transfer on $^{11}Li+^{208}Pb$ Fusion Reaction around Barrier Energies

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Introduction

The worldwide availability of radioactive ion beams facilities has made it possible to study the fusion reactions induced by weakly bound nuclei at near barrier energies. Owing to their exceptionally largesize and very small binding energy of last nucleon(s) the fusion involving halo nuclei differs fundamentally from those involving tightly bound nuclei. The nucleus ^{11}Li being a representative of well-established two neutrons halo system is one of the most studied halo nuclei.The fusion excitation function of $^{11}Li+^{208}Pb$ system has been predicted by employing various theoretical approaches[1]. Very recently experimental measurement of fusion excitation function of this system has been carried out by A. M. Vinodkumaret. al. [2] and have found that almost all theoretical predictions substantially overestimate the data. In fact, the fusion of two nuclei is a very complex process which involves the effects arising because of coupling to inelastic channels. Besides the channel coupling effects, the nuclear deformation and neutron transfer processes have also been identified as playing a key role in the analysis of fusion reactions data.

In the present work, we use the quantum diffusion model of Sargsyan et al. [3] wherein various channel coupling effects are simulated through the dissipation and fluctuation effects to analyze the fusion excitation function data of $^{11}Li+^{208}Pb$ reaction in energy region around barrier witha special emphasis on the effects of deformation and neutron transfer process.

For the nuclear part of nucleus–nucleus potential, which is one of the most crucial factor for nuclear reactions, we have adopted the proximity model. According to this model, the strong nuclear interaction between the nuclei is given by

$$V_p = 4\pi\gamma b \frac{C_1 C_2}{C_1 + C_2} \Phi(s_0)$$

For further details of the proximity model see Ref. [4]. A typical graph showing the shape of the proximity potential (V_P)as well as total interaction potential($V_T = V_P+V_{coulomb}+V_{centrifugal}$) is presented in Fig.1 for $^{11}Li+^{208}Pb$ system.

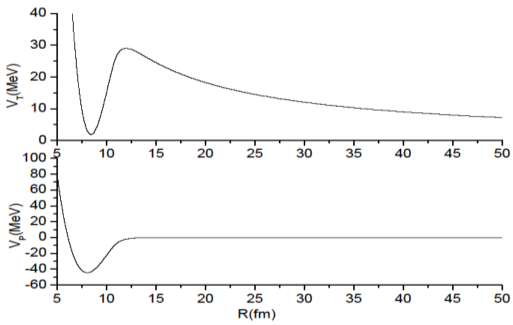

Fig.1. Calculated nucleus-nucleus (upper panel) total interaction potential and (lower panel) proximity potential for $^{11}Li+^{208}Pb$ system.

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

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

where $\lambda\!\!\!^{-2} = \hbar^2 / 2\mu E_{c.m}$ is the reduced de Broglie wavelength.

Within the framework of quantum diffusion model, the partial capture probability, P_{cap} ,which is defined as the passing probability of the potential barrier in the relative distance R between the colliding nuclei at a given L, is obtained by integrating an appropriate propagator from initial state at t = 0 to the final state at time t and is given by [5].

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

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

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

For further details of the model see Ref. [3]. In the present work we have used this expression for calculating P_{cap} and hence the fusion excitation function for the system considered.

The friction coefficient ($\hbar\lambda$) and the internal excitation width ($\hbar\gamma$) are kept fixed at 2 MeV and 15 MeV, respectively throughout the calculations**.**As a result of neutrons transfer process, the values of barrier height (V_b), barrier position (R_b), mass asymmetry (η), parameter ($\hbar s_1$) and renormalized frequency ($\hbar\omega_0$) change from 27.59MeV, 12.07fm, 0.89954, 3.48MeV and 3.301MeV to 27.01MeV,12.29fm, 0.91781, 3.50MeV and 3.49MeVrespectively. The parameter 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 is determined through a very recently proposed prescription which takes into account the spatial extension of the nucleus through R_{int}[6].Regarding P_0, if the value of r_{ex}, the position of external turning point, is larger than the interaction radius R_{int} then it is taken as $P_0 = 0$ while for $r_{ex}<R_{int}$,P_0 is equal to the kinetic energy at that point.

In Fig. 2, the fusion excitation function of ^{11}Li+^{208}Pb system is compared with the corresponding data taken from Ref. [2]. The nucleus ^{208}Pb, being a doubly magic nucleus, is spherical in shape with β_2=0.0 and here ^{210}Pb is also considered to be a spherical nucleus. After two neutrons transfer the mass numbers and deformations of the projectile change from 11 to 9 and β_2=0.58 to β_2=0.805respectively which in turn affect the height and shape of Coulomb barrier and hence the fusion cross section.

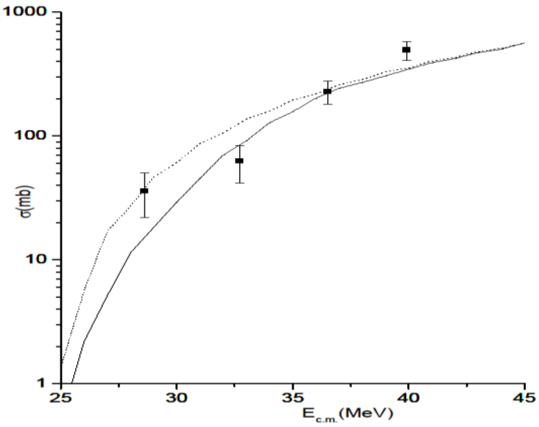

Fig.2. The fusion excitation function of ^{11}Li+^{208}Pb system calculated by using quantum diffusion approach without neutron transfer (solid line) and with neutron transfer (dotted line) are compared with the experimental data (solid square) taken from Ref. [2].

As the deformation increases the projectile becomes more prolate, barrier height decreases and hence the fusion cross section increases after neutron transfer. It may be noticed quite clearly from Fig.2 that there is enhancement in fusion cross section in the vicinity of Coulomb barrier when the neutrons transfer is taken into account. There is a reasonably good agreement between the data and predictions in the deep sub barrier energy region as well as at energies above the barrier.The agreement at sub barrier region shows that neutron transfer process plays a major role in sub barrier energy region. However, the calculations at energy around 32MeV considerably over predict the data which needs further investigations.

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