Quantitative analysis of fusion reaction data induced by ^{6}Li projectile with ^{152}Sm target around Coulomb barrier

Neha Rani[1], Pardeep Singh[1*], Jaideep[1], Rajiv Kumar[2] and Rajesh Kharab[3]
[1]Department of Physics, Deenbandhu Chhotu Ram University of Science and Technology, Murthal 131039, Haryana, India
[2]Department of Physics, Govt. P.G. College for Women, Karnal, 132001, Haryana, India
[3]Department of Physics, Kurukshetra University, Kurukshetra, 136119, Haryana, India
∗ panghal005@gmail.com

Introduction

Fusion of weakly bound projectile has been the special concern during last few decades due their importance in nucleosynthesis and energy production [1]. The low breakup threshold of these nuclei increases the probability of breakup and that of transfer of its fragments to the target. Therefore during last decade much attention has been paid to investigate the breakup and transfer effects on fusion reactions initiated by these nuclei. Furthermore, the consideration of coupling of excited states of target and projectile also influences the fusion reaction cross section.

Hence in this conference contribution we present the results of our investigation on influence of coupling of excited states of projectile and target and those of deuteron transfer on the fusion reaction induced by ^{6}Li on ^{152}Sm target using coupled channel approach through code CCFULL [2].

Theoretical formalism

The reduced coupled channel equation after employing Iso- centrifugal or rotating frame approximation is written as

$$\left[-\frac{\hbar^2}{2\mu}\frac{d^2}{dr}+\frac{J(J+1)\hbar^2}{2\mu r^2}+V_N^0(r)+\frac{Z_pZ_Te^2}{r}+\varepsilon_n - E_{c.m.}\right]\psi_n(r) + \sum_m V_{nm}(r)\psi_m(r) = 0$$

The all variables appeared here are having their usual meaning and are discussed in ref. [3]. The nuclear potential ($V_N^0(r)$) in entrance channel is approximated by Woods-Saxon potential which is expressed as

$$V_N^0(r) = \frac{V_0(r)}{1+exp\left[\frac{r-R}{a}\right]}$$

Here $V_0(r)$, R and a gives the depth, range and diffuseness parameters of the potential. The depth and range are further parameterized as

$$V_0(r) = -40\frac{R_P R_T}{R_P + R_T}$$

with $R_{P(T)} = r_0(A_{P(T)})^{1/3} - 0.77(A_{P(T)})^{-1/3}$

and $R = r_0(A_P^{1/3} + A_T^{1/3})$,r_0=1.17fm

In present calculations the rotational and vibrational coupling of interacting nuclei has also been included. For detailed description see refs. [2, 3]. Now fusion reaction cross section may be calculated through expression [2,3]

$$\sigma_f(E) = \sum_J \sigma_J(E) = \frac{\Pi}{k_0^2}\sum_J (2J+1)P_J(E)$$

where $P_J(E)$ is the penetration probability corresponding to angular momentum J.

Results and discussion

The fusion reaction cross section for ^{6}Li + ^{152}Sm system has been calculated using Coupled channel code CCFULL and results obtained are presented in fig.1. The values for potential parameters, deformation parameters and energy of excited state of projectile and target are taken from ref. [3].

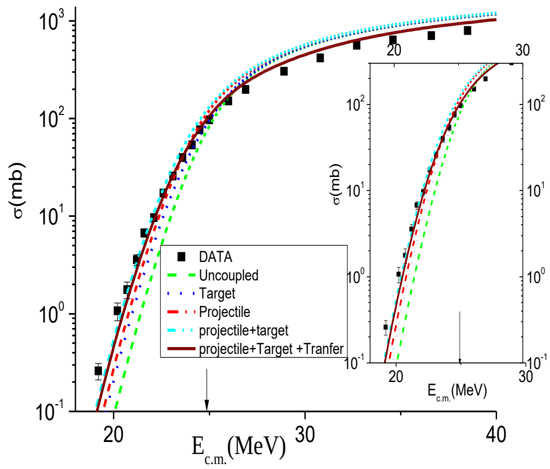

Fig. 1 (color online) Fusion reaction cross section for ^{6}Li+^{152}Sm system. Data points are taken from [4].

Fig. 1 depict the results corresponding to the cases (I) when only target excited states are considered (dotted line), (II) when only excited states of projectile are taken (dashed-dot line), (III) when excited states of both target and projectile are considered (dashed-dot-dot line) (IV) when deuteron transfer in addition to coupling of both projectile and target excited states are considered (solid line) (V) when no coupling is considered (dashed line). From these calculations it can be clearly observed that uncoupled calculations underestimate the data in below barrier (arrow(↓) represents the barrier height in figs.) region while data is overestimated in above barrier region. Inclusion of excited states of target alone produces an enhancement of 21% in fusion reaction cross section while due to projectile excited states produces an enhancement of 56% as compared to uncoupled calculations. An enhancement of 74% has been observed on inclusion of both the projectile and target excited states at energies below the Coulomb barrier. However, the inclusion of deuteron transfer decreases this enhancement by 15%.

Here for clear understanding of degree of suppression or enhancement in fusion cross section we have defined an enhancement factor (EF_i) as

$$EF_i = \frac{\sigma_i}{\sigma_{UC}}, \; i = 1,2;$$

$$\sigma_i = \{\sigma_{PC+TC}\; for\; i = 1;\; \sigma_{PC+TC+Tr}\; for\; i = 2\}$$

where PC, TC, Tr and UC correspond to the coupling of projectile excited states only, of target excited states only, deuteron transfer and uncoupled case.

The enhancement factor has been plotted as a function of center of mass energy, $E_{c.m.}$(MeV) in Fig. 2.

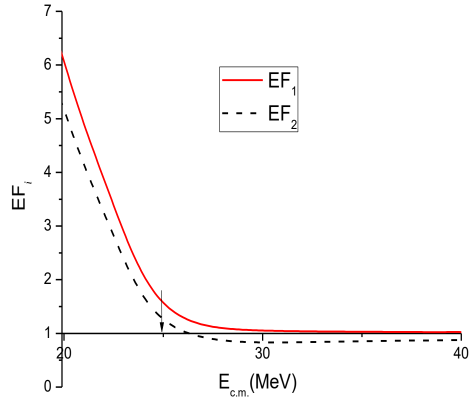

Fig. 2 (color online) Enhancement factor for ^{6}Li+^{152}Sm system.

It is clearly visible from fig. 2 that the coupling of excited states of both the projectile and target leads to an enhancement in fusion reaction cross section near Coulomb barrier energy region while in the above barrier energy region coupling effects remains negligible. However, the inclusion of deuteron transfer leads to the reduction of the enhancement factor in whole region of spectrum.

Conclusively, coupling to the excited states of reactants leads to an enhancement in fusion reaction cross section in below barrier region while no significant effects have been observed in above barrier region. Further the inclusion of deuteron transfer reduces this enhancement in whole energy region especially in above barrier region which eventually reproduces the data.

Acknowledgement

The first author would like to acknowledge the financial support from TEQIP Phase-III.

References

[1] L.F. Canto, P.R.S. Gomes et al., Phys. Rep. 596, 1 (2015) and refs. there in.
[2] K. Hagino, N. Rowley et al., Comput. Phys. Comm. 123,143 (1999).
[3] N. Rani, P. Singh et al., Nucl. Phys. A 990, 149 (2019).
[4] P. K.Rath, S. Santra et al., Nucl.Phys. A 874,14 (2012).