Investigation of fusion reactions induced by ^{7}Li on ^{16}O and ^{27}Al targets

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Introduction

Revealing the effect of breakup of weakly bound nuclei on fusion processes and scattering is one of the most intriguing and hot topics of research in the past few years. From literature, it has been learnt that CF cross sections are suppressed at above barrier energies as compared to 1D-BPM or coupled channel calculations which do not account the breakup and transfer channels [1, 2]. In the last few years, major focus of studies was to establish a systematic behaviour for suppression of CF with target charge. A clear picture of behaviour of CF suppression is not yet obtained since the effect of breakup of weakly bound nuclei on light targets is not fully explored due to lack of availability of CF data for these targets. Therefore, in the present contribution, theoretical calculation of TF and CF cross sections have been carried out for reactions induced by weakly bound projectile ^{7}Li on low mass targets ^{16}O and ^{27}Al.

Calculational details

Continuum Discretized Coupled Channels (CDCC) calculations have been performed for fusion reactions ^{7}Li + ^{16}O and ^{7}Li + ^{27}Al in near and above barrier energy domain by employing the computer code FRESCO [3, 4]. The CDCC calculations have been performed assuming a two-body α + t cluster structure for the ^{7}Li nucleus. The ground state of ^{7}Li ($j = 3/2^{-}$, l = 1) and its excited state with energy $\epsilon = 0.48 MeV (j = 1/2^{-}$, l = 1)and the l = 0, 1, 2, 3 α-t continuum couplings along with the $5/2^{-}$ and $7/2^{-}$ resonances are taken into account during the calculations. The continuum above the ^{7}Li $\rightarrow \alpha$ + t breakup threshold (2.47 MeV) has been discretized into a series of bins in energy space with varying $\Delta\epsilon$ (narrow bins are used to cover the resonances). TF cross sections has been calculated corresponding to different values of a maximum energy of the continuum states (ε_{max}) and continuum partial waves (l_{max}) for system ^{7}Li+^{16}O. Converged cross sections have been obtained at ε_{max} = 8 MeV and l_{max} =3 $\hbar$.To calculate individual CF and TF cross sections CDCC calculations have been performed using the procedure used by V.V Parkar et al. [5] in which two short-range Wood-saxon potential ($W_{\alpha-T}$ and W_{t-T})with parameters W_{sr} = 50 MeV, r_w = 0.8 fm, and a_w = 0.1 fm are used to account the absorption between projectile fragments and target. The required (fragment potentials): real nuclear potentials $V_{\alpha-T}$ and V_{t-T} have been obtained using Akyuj-Winther parameterization scheme [6] and tabulated in table I. Besides, an additional imaginary volume-type potential W_{P-T} with W = 25 MeV, r_w = 1.0 fm, and a_w = 0.4 fm, without any real part is used to stimulate complete fusion between ^{7}Li (g.s) and the target.

TABLE I: Optical model potential parameters for fragment-target interaction used in the CDCC calculations.

Systems	V_0(MeV)	a_0(fm)	r_0(fm)
$\alpha + {}^{16}O$	29.635	0.553	1.156
t + ^{16}O	27.219	0.542	1.155
$\alpha + {}^{27}Al$	32.324	0.567	1.161
t + ^{27}Al	29.155	0.554	1.159

Results and Discussion

The results of calculations carried out for ^{7}Li + ^{16}O system are shown in figure 1. The calculated TF cross sections without any continuum couplings (bare) are denoted by solid line, while TF and CF cross sections after including continuum couplings are shown by dash-dot line. Experimental TF data results are denoted by solid squares. It is clearly noticed from figure that inclusion of continuum couplings is essentially required for this system since bare TF cross sections underpredict the data while the TF predictions with continuum couplings match quite well with the data. Also it is observed from figure that there is negligible difference between TF and CF predictions in the above barrier region thus it is inferred that there is no suppression of CF for this system. The CF cross sections for this system have been taken from ref [7] and also shown in figure by solid stars. The dashed green line is obtained by multiplying TF results by 0.965, that is needed to fit the estimated experimental CF data and it shows that extracted CF cross sections are suppressed by 4% with respect to our theoretical predictions (TF cross sections). However, the large error bars for TF and CF data shows that the CF suppression

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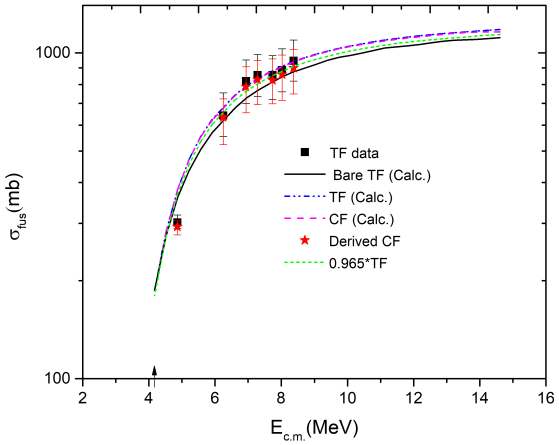

FIG. 1: Calculated fusion cross-sections for ^{7}Li+^{16}O reaction. The solid square (black) represents the TF data and stars(red) represents derived CF data[7]. The dash-dot and solid lines denotes the calculations with and without including the breakup couplings respectively.

is in the range 0-4%. Figure 2 represents the results obtained for system ^{7}Li + ^{27}Al. It is clearly noticed from figure that the inclusion of breakup couplings enhances the TF cross sections in the above-barrier region however, the calculations at higher energies seems less sensitive toward inclusion of these couplings. The experimental TF data (shown by solid squares) is reproduced quite well by the calculations including the continuum couplings. Further, we have also estimated the CF cross sections and it is observed that for this system CF cross sections are suppressed (approx. by 2-3%) with respect to theoretical TF cross sections.

Conclusion

With an aim to establish a systematic behaviour of CF suppression (due to breakup of projectile) with target charge or mass, the fusion reactions induced by weakly bound projectile ^{7}Li on light mass targets ^{16}O and ^{27}Al have been analysed by employing continuum discretized coupled channel (CDCC) approach using code FRESCO. The breakup absorption model introduced by Parkar et al. have been used for simultaneous measurements of total fusion (TF) and complete fusion (CF) cross sections. It is found that calculated TF is in agreement with the data and CF cross sections are suppressed with respect to TF cross sections by 2-3% for ^{7}Li + ^{27}Al in above barrier region whereas no suppression has been observed for ^{7}Li + ^{16}O reaction. The suppression appeared in CF cross sections for low mass targets is very less than that observed for heavy targets (around 30%)[5]. So it is concluded that CF suppression may vary with the target charge or mass. More work with low and medium mass targets is required to establish a systematic behaviour of CF suppression with target charge.

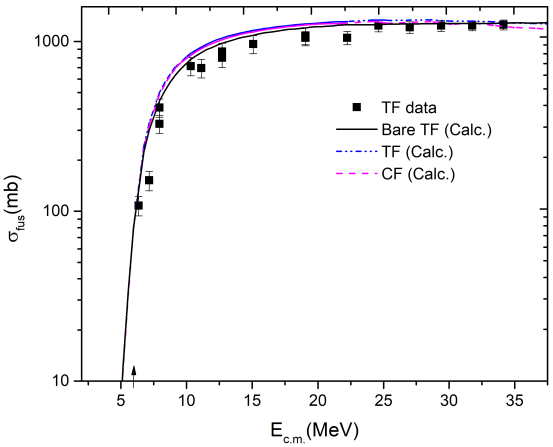

FIG. 2: Calculated fusion cross-sections for ^{7}Li+^{27}Al reaction. The solid square (black) represents the data taken from ref [8]. The dash-dot and solid lines denotes the calculations with and without contribution of the continuum couplings respectively.

References

[1] H.Kumawat,V.Jha et al., Phys. Rev. C 86 (2012) 024607.

[2] V.V. Parkar,S.K.Sharma et al., Phys. Rev.C 97 (2018) 014607.

[3] Y. Sakuragi, Y. Masanobu, and M. Kamimura, Prog. Theor. Phys. 70 (1983) 4.

[4] I. J. Thompson, Comput. Phys. Reports 7 (1988) 4.

[5] V. V. Parkar, V. Jha, and S. Kailas, Phys. Rev. C 94 (2016) 024609.

[6] R. A. Broglia and A. Winther, I (1981 Benjamin/Cummings Publ. Company), 1981.

[7] M. F. Guo, G. L. Zhang et al., Phys. Rev. C 94 (2016) 044605.

[8] D. Patel, S. Santra et al., Journal of Phys 81 (2013) 4.