Fusion using proximity potentials and effect of projectile breakup

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Introduction

Recently we have measured the complete fusion (CF) cross sections for several reactions involving weakly bound stable projectiles (e.g., ^{6,7}Li,^{9}Be). The CF cross sections at energies above the Coulomb barrier have been found to be suppressed by ~20-30% compared to the results of coupled-channels calculations by CCFULL with or without couplings. Here, potential parameters were chosen to reproduce the fusion barrier distribution derived from the measured CF excitation functions. CF suppression has also been confirmed when the above experimental data were compared to the experimental fusion cross section involving tightly bound projectiles. A systematic study on CF suppression factor showed that the suppression increases with the decrease in projectile breakup threshold. Earlier we measured the CF cross sections for ^{6}Li+^{144,152}Sm reactions which were found to be suppressed by ~30% [1]. Motivated by the above systematics we measured the CF cross sections for reactions involving the above targets but ^{7}Li as a projectile which has a larger breakup threshold (~2.47 MeV) compared to that for ^{6}Li (~1.48 MeV) to see the suppression factor [2] and verify the systematics. Experimental data for ^{7}Li+^{144,152}Sm reactions are already reported in previous symposium [2]. Detailed coupled-channels calculations using CCFULL[3] have been made. It was found that the suppression factor is ~24% with respect to the CCFULL calculations. In this paper, we present the results on further calculations of fusion cross section by an independent method using the proximity potentials and their comparisons to the experimental data to find the suppression or enhancement if any. A systematics on CF suppression factors for the reactions with ^{6,7}Li, ^{9}Be and ^{10,11}B projectiles versus their breakup threshold is also presented.

Fusion using proximity potentials

CF cross sections data for the present reactions were compared to those predicted using the "Proximity potentials" [4,5]. These potentials are parameterized from the existing fusion data in the literature for many systems involving mostly the tightly bound projectiles. Fusion barrier parameters i.e., barrier height 'V_B', barrier radius 'R_B' and barrier curvature '$\hbar\omega$' are obtained by adding the Coulomb potential to the proximity potentials ($V_{Tot}=V_{nucl}+V_{coul}$) and then used in the Wong model to predict the fusion cross section. The original version of this potential (Proximity 1977) was described by J. Blocki et al. [4]. This was later modified and renamed as ``Proximity 1988'' by W. Reisdorf to incorporate more refined mass formula of M¨oller and Nix. Myers and Swiatecki, using their concept of droplet model, have updated the values of nuclear radii and nuclear surface tension coefficients in the latest version of the above potential and named as ``Proximity 2000'' [5]. In the present work, fusion cross sections are calculated using the versions '1977' and '2000' of proximity potentials. The fusion barrier parameters 'V_B', 'R_B' and '$\hbar\omega$' derived from these two potentials for ^{7}Li+^{144}Sm and ^{7}Li+^{152}Sm reactions are given in the following Table.

Table: Fusion barrier parameters

Reaction	Prox. potential	V_B (MeV)	R_B (fm)	$\hbar\omega$ (MeV)
^{7}Li+^{144}Sm	Prox.'77	24.83	10.01	4.01
	Prox.'00	24.96	9.95	4.52
^{7}Li+^{152}Sm	Prox.'77	24.55	10.11	4.35
	Prox.'00	24.73	10.06	4.46

The above parameters were used in the simplified Wong's formula (which assumes the potential barrier to be of parabolic shape) to calculate the fusion cross sections using the following expression:

$$\sigma_{fus}=(R_B^{\,2}\hbar\omega/2E_{c.m.})$$
$$\text{x} \quad ln\{1+exp[(2\pi/\hbar\omega(E_{cm.}-V_B)]\}$$

Fusion cross section thus obtained using two versions of proximity potentials are shown in Fig. 1(a) and (b) as solid and dashed lines respectively. It can be observed that they overestimate the experimental data at above barrier energies. To reproduce the experimental data, the calculated cross sections for both ^{7}Li+^{144}Sm as well as ^{7}Li+^{152}Sm reactions using 'Proximity 1977' ('Proximity 2000') potentials were required to be normalized by a factor of 0.76 (0.78) which is represented by a dash-dot (dash-dot-dot) line. This implies that the experimental CF for both the reactions at above barrier energies is suppressed by ~23% compared to the theoretical predictions using Proximity potentials of either version. This is consistent with our earlier conclusions on CF suppression factors which were obtained by comparing the data with the predictions from the coupled-channels calculations using CCFULL.

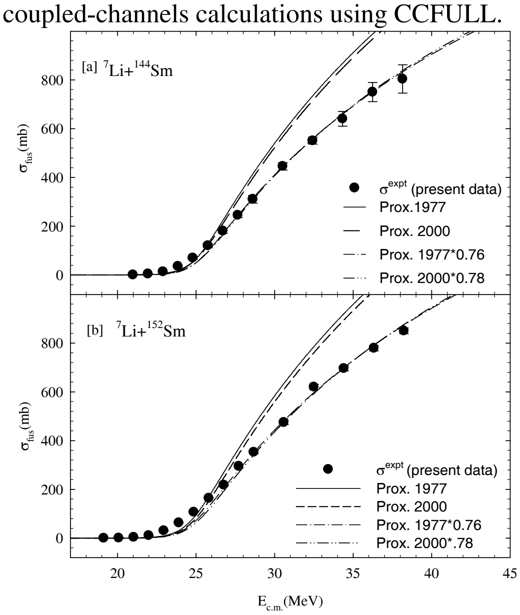

Fig.1 CF cross sections for (a) ^{7}Li+^{144}Sm and (b) ^{7}Li+^{152}Sm reactions. Solid (dashed) line is obtained by Prox77(Prox00) and corresponding normalized values that reproduce the measured data represented by dash-dot (das-dot-dot) line.

To find the dependence of CF suppression factors on projectile breakup threshold, a systematic comparison was made for several reactions, including the present data, involving weakly bound projectiles with α+x structures and different breakup threshold. Fig.2 shows the plot of suppression factor '1-F_{CF}' (where F_{CF} is complete fusion fraction) as a function of threshold energy for the breakup of the projectiles into α and x. It can be observed that there is a smooth fall in the suppression factor with the increase of the breakup threshold energy.

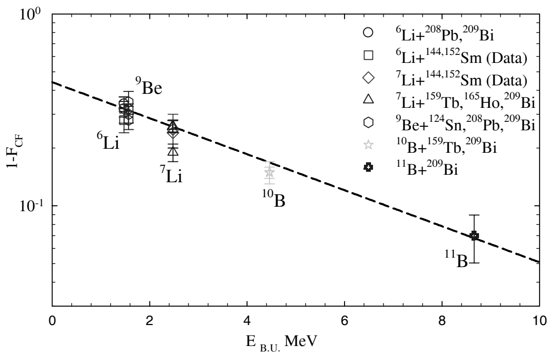

Fig.2 Suppression factor (1-F_{CF}) as a function of breakup threshold for several reactions involving ^{6,7}Li, ^{9}Be, ^{10,11}B projectiles. Dashed line is to guide the eye.

Acknowledgment

One of the authors (P.K.Rath) acknowledges the financial support of CSIR (09/114/0178/2011/EMR-I) in carrying out these investigations

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