Fusion in $^{9}Be+^{89}Y$ system

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Introduction

There has been an interest recently in studying the influence of the breakup of weakly bound nuclei on fusion at near barrier energies. These studies are important in understanding astrophysical reactions and have also gained importance due to the availability of radioactive ion beams. The unstable weakly bound nuclei often have larger radii and low breakup threshold energies and it is proposed that this may affect fusion and other reaction channels [1]. In particular the breakup of the projectile might lead to fusion suppression due to loss of flux to the breakup channel. On the other hand one can expect the fusion cross sections to be enhanced due to their larger radii and the coupling to internal degrees of freedom of colliding nuclei especially at sub-barrier energies. Thus enhancement or suppression of fusion will depend on the system and the energy range. In case of the stable weakly bound projectile ^{9}Be, complete fusion suppression of ~32% and ~10% at near barrier energies have been reported for the ^{9}Be+^{208}Pb [1] and ^{9}Be+^{144}Sm [2] systems respectively. With an aim to investigate this phenomenon for targets in the mass region A= 80 to 100 we have carried out a study of fusion reaction for the ^{9}Be+^{89}Y system.

Experiment

The experiment was performed using the 14 UD BARC-TIFR Pelletron Accelerator. $^{9}Be^{3+}$ projectile beam and ^{89}Y targets of thicknesses 0.90 mg/cm^2 and 0.96 mg/cm^2 were used. An aluminum catcher foil of thickness 1.27 mg/cm^2 was placed along with the target to stop the recoiling residues. Targets were irradiated with a beam current ~40 nA at different energies starting from 20 to 33 MeV in 1 MeV steps. A scaler was utilized during each of the irradiations to correct the data later for any current fluctuations. Irradiation times were typically 4 hrs per energy at all energies above the barrier (V_b~ 24MeV in lab) and 6-12 hrs for below barrier energies. Offline counting of all the irradiated samples was done employing an HPGe detector. Efficiency of the detector in the range of the γ-lines of interest was obtained using standard ^{152}Eu and ^{133}Ba sources.

Analysis

The following evaporation residues (ERs) were identified from the offline counting: ^{96}Tc (2n), ^{95}Tc (3n), ^{94}Tc (4n), ^{92}Nb (α2n-CF or 1n-ICF).

Statistical model calculations using the code PACE [3] have been performed to estimate the experimental cross sections as follows: *l*-distributions from the code CCFULL [4] at each energy were given as input to PACE. Cross sections for 2n and 3n ERs for complete fusion were found to be dominant (nearly 80-90% of σ_{fus}) from PACE. The value of the level density parameter was decided as A/10.9 MeV^{-1} by reproducing the measured σ_{3n}/σ_{2n} ratio. Cross sections not measured were then accounted by the PACE calculations. The fraction, *f* of the fusion cross section accounted by PACE is small and does not exceed 23% even at the highest energy as shown in Table 1.

Fusion excitation function is plotted as solid circles in Fig. 1(a). The experimental barrier distribution was also obtained from the fusion data using the expression $d^2(\sigma E_{cm})/d^2E_{cm}$ as in Ref. [5]. An average barrier height V_b= 22.2 MeV has been obtained by taking weighted average of the barriers, the weights being given by $d^2(\sigma E_{cm})/d^2E_{cm}$ at each energy.

Simplified coupled channel calculations have been performed using a modified version of CCFULL which allows coupling of deformed projectile excited states including its ground state spin. Couplings to the ^{9}Be ground state spin of

3/2$^-$ with deformation parameter β= 1.3 [6], and the 5/2$^-$ excited state in its K= 3/2$^-$ ground state rotational band with E_x=2.429 MeV, β= 0.72 [7] were included. Target coupling included the 3$^-$ vibrational excited state in ^{89}Y with E_x= 2.742 MeV, β= 0.208 [8]. Initial couplings were done using the Woods-Saxon parameterization of the Akyuz-Winther potential (V_0= 43.46 MeV, r_o= 1.128 fm, a_o= 0.622 fm). These were then varied so as to reproduce the experimental V_b as obtained above. The final potential parameters were V_o= 55 MeV, r_o= 1.03 fm, a_o= 0.78 fm. Results of the calculated cross sections using the 1D-BPM and the coupled calculations (CC) are shown in Fig. 1(a). The experimental fusion cross sections are given by filled circles, 1D-BPM calculations (dotted line) and coupled channels calculations (dashed line). Solid line shows the cross sections obtained by multiplying the CC cross sections by 0.78. Fig. 1(b) shows the corresponding barrier distributions. A lower limit of incomplete fusion (ICF) cross section is also deduced as represented by hollow circles in Fig.1(a).

Table 1: Experimental fusion cross sections

E_{lab} (MeV)	*f*	σ_{fus} (mb)
20	0.0	0.23 ± 0.014
20.5	0.111	0.66 ± 0.02
21	0.125	1.36 ± 0.02
22	0.116	6.28 ± 0.08
23	0.124	26.99 ± 0.88
24	0.128	65.79 ± 1.41
25	0.135	108.19 ± 1.62
26	0.140	171.31 ± 5.90
27	0.146	221.32 ± 3.35
28	0.153	293.48 ± 2.63
29	0.162	302.10 ± 3.93
30	0.172	415.03 ± 3.08
31	0.184	445.76 ± 2.68
32	0.201	445.97 ± 2.71
33	0.230	454.92 ± 3.28

Conclusions

From Fig.1 it can be seen that the experimental σ_{fus} is systematically lower than the corresponding cross sections obtained from coupled channels calculations in the entire energy region. Multiplication of calculated σ_{fus} by a factor of (0.78 ± .04) reproduces the experimental cross sections. This implies that the complete fusion for ^{9}Be+^{89}Y is suppressed by (22 ± 4) % due to the effect of breakup which is not included in the CC calculation. Furthermore, the large ICF cross section obtained is a manifestation of loss of incident flux due to the breakup of ^{9}Be, which supports this conclusion.

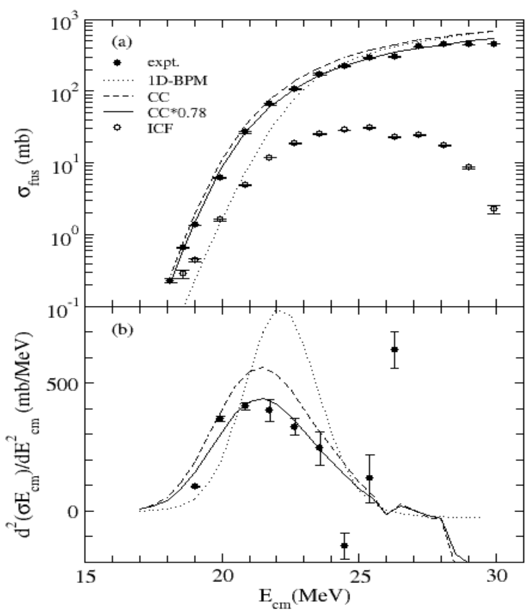

Fig. 1 (a) Experimental fusion cross sections along with the calculated ones and (b) corresponding barrier distributions.

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