Measurement of fusion excitation function for ^{7}Li+^{64}Ni near the barrier

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Abstract

Total fusion (TF) excitation function has been measured for the system ^{7}Li + ^{64}Ni at the energies near the Coulomb barrier of the system. The evaporation residue (ER) cross sections have been estimated through the online detection of characteristic γ-rays of the ERs. The summed ER cross sections yielding the experimental TF cross section have been compared with the theoretical one dimensional barrier penetration model (1DBPM) prediction. The measured and the model cross sections are very close to each other at above barrier energies. However, an enhancement of the experimental TF cross section with respect to the 1DBPM prediction is observed at below barrier energies. Coupled channels (CC) calculation with inelastic excitations alone could not explain the enhancement. The origin of the enhancement is identified as due to the enhanced population of the αxn channels.

A complete understanding of the effect of direct reaction channels like, breakup or transfer followed by breakup on fusion of weakly bound systems at near barrier energies is of primary importance [1, 2]. In case of fusion of weakly bound stable projectiles like, ^{6}Li (S_α = 1.47 MeV), ^{7}Li (S_α =

2.47 MeV) and ^{9}Be (S_n =1.67 MeV), two principal observations are: the suppression of complete fusion (CF) cross section with respect to one dimensional barrier penetration model (1DBPM) prediction at the above barrier energies and the enhancement of fusion cross section at below barrier energies [3–12]. While, the suppression at above barrier energies received maximum attention in the study of fusion of weakly bound systems, the sub-barrier enhancement of fusion cross section of these systems is also equally important to understand the interplay of reaction mechanisms in this energy regime.

Though the measurements of fusion cross sections for these projectiles show consistent behavior of suppression at above barrier energies for heavy mass targets, the evolution of the behavior as the target mass decreases needs to be clearly understood. The problem in the collision with lower medium target is to experimentally distinguish the CF cross sections from other reaction processes producing the same residues. Hence the observable cross section is known as total fusion (TF) cross section [10,13–15]. However, very recently our group has reported the extraction of CF excitation function from the measured TF excitation function for the system ^{6}Li+ ^{64}Ni where the target has six additional neutrons over the N = 28 closed sub-shell [12].

To further explore the method, we have measured the fusion excitation function of the other weakly bound Li-isotope, ^{7}Li (S_α= 2.47 MeV), with the target ^{64}Ni at near-barrier energies. We present here the experiment, analysis and interpretation of only the below barrier behavior of the fusion excitation function.

The experiment was performed at BARC-TIFR Pelletron Facility in Mumbai, India. An enriched metallic ($\sim$99%) and 507 μg/cm^2 thick ^{64}Ni target, procured from Oak Ridge National Laboratory, USA, was used for the present experiment. The target thickness was verified using α-energy loss method with 3-line α source (^{239}Pu, ^{241}Am and ^{244}Cm). The estimated uncertainty in the thickness was $\sim$2%. The target was bombarded with ^{7}Li beam with energies varying from 12 to 28 MeV. The online characteristic γ-ray detection method was used for the measurement of fusion cross section [16]. The γ-rays were detected by a HPGe detector placed at 135° and a clover detector placed at 45° with respect to the beam direction. The detector resolutions were 2.8 keV and 5.0 keV, respectively for HPGe and clover detectors for 1408 keV γ-line of ^{152}Eu. The data were recorded using the data acquisition system LAMPS [17]. Fig. 1 shows a representative γ-ray spectrum recorded at E_{lab} = 26 MeV with some of the observed γ-lines.

The compound nucleus (CN) ^{71}Ga, produced in the collision of the system ^{7}Li+^{64}Ni, predominantly decays through the $2n$ and $3n$ evaporation
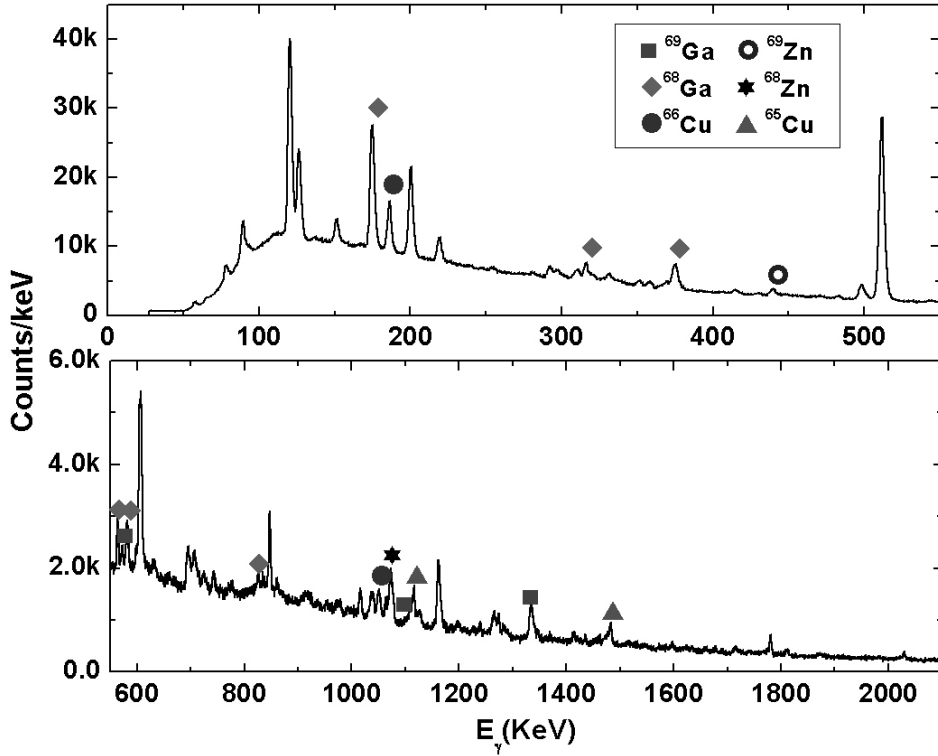
Figure 1: Representative characteristic γ-ray spectrum obtained at $E_{lab}= 26 \; MeV$ from the collision of the projectile ^{7}Li with the target ^{64}Ni.

channels. The evaporation residues from decay channels pn, $p2n$ or t, αn and $\alpha 2n$ were also observed. The residues produced through $2n$, $3n$ and pn evaporation channels are associated only with CF process. The other channels are produced from CF as well as from the other reaction processes like breakup or transfer-breakup reactions. As an example the residue produced from CF process through αn channel, can also be produced from t-ICF process with subsequent evaporation of a neutron. The direct cluster transfer (DCT) to unbound state of ^{67}Cu can also populate the channel.

Each evaporation residue channel cross section (σ_{chn}^{exp}) was obtained by summing over the measured cross sections of the observed γ-transitions directly to the ground state of the residue. The experimental fusion cross section (σ_{fus}^{exp}) at each energy was obtained from,
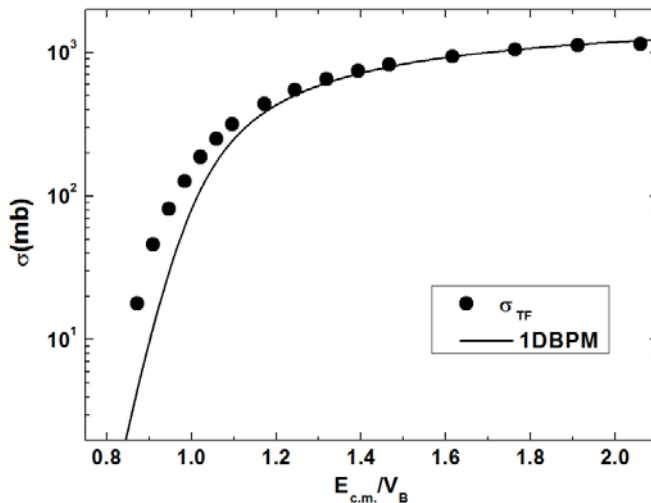
$$\sigma_{fus}^{exp} = \sum_{chn} \sigma_{chn}^{exp}. \tag{1}$$

Figure 2: Experimental and theoretical fusion excitation functions for the system ^{7}Li+^{64}Ni at near barrier energies. The data points are represented by solid bullets and the 1DBPM predictions is denoted by solid line.

Since, the evaporation residues produced from the ICF processes were experimentally indistinguishable from the residues produced in the CF process, the measured fusion cross section provides only the total fusion cross section.

The measured TF excitation function has been plotted in Fig. 2. The data have been compared with the theoretical 1DBPM prediction calculated with the code CCFULL [18]. The potential parameters used in the calculation are: strength $V_0 = 48.0$ MeV, radius parameter $r_0 = 1.12$ fm and diffuseness $a_0 = 0.66$ fm and the corresponding barrier parameters are: 12.20 MeV, 9.19 fm and 3.41 MeV, respectively. It can be observed from Fig. 2 that the 1DBPM reproduced the above barrier fusion excitation function quite well. However, as the energy is decreased towards the barrier the experimental TF cross sections start to increase and at the sub-barrier energies they are significantly larger compared to the theoretical values.

To probe the possible admixture from ICF and/or transfer channels with CF processes at below barrier region, we have constructed the summed cross sections of the measured xn and αxn channels. The experimental $\sum xn$ and $\sum \alpha xn$ cross sections are shown in Fig. 3. In the figure, the experimental cross sections are compared with the statistical model predictions of $\sum xn$ and $\sum \alpha xn$ channel cross sections by PACE4 [19]. Remarkably good reproduction of the experimental $\sum xn$ cross section is obtained with the statisti-
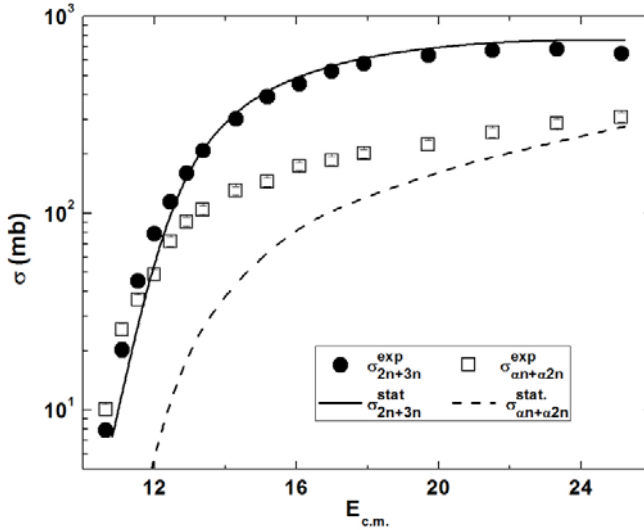
Figure 3: Experimental excitation functions for the sum of pure CF evaporation channels and the sum of mixed channels in comparison with their corresponding statistical model predictions.

cal model indicating the purity of their CF origin. The small enhancement at the subbarrier energies clearly shows the effect of channel coupling in CF cross sections. On the other hand, large underprediction of experimental $\sum \alpha x n$ cross sections by the statistical model highlights the strong presence of non-compound processes in $\sum \alpha x n$ cross sections. It can also be noticed from Fig. 3 that at energies below the barrier $\sum \alpha x n$ cross sections are higher than $\sum x n$ cross sections coming only from CF evaporation. Thus at these energies the non-compound process has comparable cross section relative to the CF process.

The possible non-compound processes that can contribute are the incomplete fusion of triton, or t-ICF, followed by neutron evaporation; the transfer of clusters like 't' or 'd' to unbound state of the residues. Clear estimation of the contributions of these reaction mechanisms is however limited by the setup used in the present experiment.

To summarize, in the present work we have measured the TF excitation function for the weakly bound projectile ^{7}Li with medium mass target ^{64}Ni at near barrier energies. The TF cross sections have been obtained from the measured residue cross sections identified from the characteristic γ rays. There is no suppression in TF cross sections in above barrier region with

respect to the theoretical predictions. This observation agrees with the earlier observations from all the weakly bound stable projectiles, that the TF cross sections are unaffected by the breakup of projectile irrespective of target mass [4–7,10,12–15]. But the observed subbarrier enhancement of TF cross sections is not understood clearly. The admixture of cluster transfer cross section may be the reason behind this large enhancement. To settle the issue, exclusive measurements with particle- γ coincident is required.

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