Study of reactions with the weakly bound projectile: ^{9}Be

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Introduction

Reactions with weakly bound unstable nuclei have been rigorously studied in the last two decades or more due to availability of new generation of accelerators and development in experimental techniques. This has led to a renewed interest in studying reactions with weakly bound stable nuclei because of similarities in their structural properties. It is expected that reaction studies with latter would be helpful in understanding the dynamics of reactions with the weakly bound unstable nuclei. Due to the low breakup threshold energies of these nuclei, the breakup channel is expected to influence other reaction channels significantly. This has been the prime investigation topic in all reaction studies with the weakly bound stable nuclei in order to understand the dynamics of such reactions [1]. Two methods of investigation have been widely used for this purpose, namely elastic scattering and fusion.

Elastic scattering studies with the tightly bound nuclei from heavy targets exhibit the threshold anomaly (TA) in the energy dependence of the optical potential. In contrast, scattering of the weakly bound nuclei have been found to exhibit the breakup threshold anomaly (BTA). Results from scattering of the weakly bound stable ^{6}Li nuclei from heavy mass targets shows the presence of the BTA, while the TA has been observed for ^{7}Li scattering. For similar measurements carried out using ^{9}Be projectile, contradictory results have been reported. TA has not been observed for $^{9}Be+^{27}Al$ and $^{9}Be+^{144}Sm$, inconclusive results for $^{9}Be+^{12}C$, $^{9}Be+^{64}Zn$ and $^{9}Be+^{209}Bi$, while the TA has been observed for the $^{9}Be+^{208}Pb$ system.

A complimentary method of investigating the effect of the breakup channel on other reaction channels is to study the fusion of the weakly bound nuclei. A suppression of ~30 % of the complete fusion (CF) cross-sections has been observed for fusion induced by $^{6,7}Li$ on heavy targets. For similar studies carried out for ^{9}Be induced fusion in heavy mass targets, a suppression factor of ~32 %, similar to $^{6,7}Li$ results, has been observed as compared to coupled-channels (CC) calculations that exclude the effect of breakup coupling. This suppression has been suggested to be due to the breakup of ^{9}Be leading to loss of flux from the CF channel. In the case of fusion studies with light mass targets, namely for the $^{9}Be+^{27}Al$ and $^{9}Be+^{64}Zn$ systems, charge particle evaporation dominates. Thus, only the total fusion (TF) cross-sections has been measured for these systems, as differentiation between the observed ERs due to compound nucleus (CN) formation via CF and its decay or CN formation via incomplete fusion (ICF) and its decay could not be done. Their comparison with CC calculations shows no suppression, with the conclusion that for light systems TF is not affected by the breakup channel. Thus with the aim of understanding the effect of breakup channel on the elastic and the fusion channels for ^{9}Be induced reactions with a medium mass target, we have carried out the scattering and fusion measurements for the $^{9}Be+^{89}Y$ system.

Experimental details

The elastic scattering measurement [2] was carried inside a 1 m diameter scattering chamber having two rotatable arms. Silicon surface barrier (SSB) detectors were mounted in the ΔE-E telescopic configuration on one arm with an angular separation of 10^{o} to detect the elastically scattered ^{9}Be particles. Another SSB detector was placed at an angle of 25^{o} on the other arm to serve as a monitor. Elastic scattering angular distributions were obtained, between angles 15^{o} to 175^{o}, at near barrier beam energies from 19 to 33.5 MeV in steps of ~2 MeV.

The offline γ-counting technique was used in the $^{9}Be+^{89}Y$ fusion measurement [3]. Irradiations of the ^{89}Y targets (~0.93 mg/cm^{2}

thick) were carried out for beam energies between 20 to 33 MeV in steps of 1 MeV. A HPGe detector was employed for detecting γ emitted from the ERs. A CAMAC scaler was utilized to record the integrated current in intervals of 1 minute.

Analysis and Results

Optical model analysis (OMA) of the elastic scattering data has been carried out to get the best fit parameters for the real and imaginary parts of the optical potential. A dispersion relation has been applied to study the energy dependence of the potential parameters. Analysis shows the presence of BTA for the ^{9}Be+^{89}Y system.

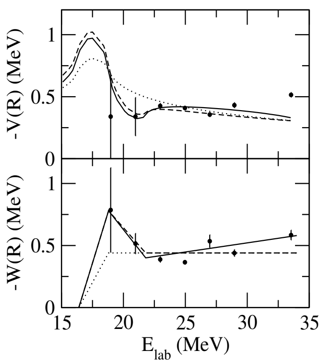

Fig. 1 Real (top) and imaginary (bottom) parts of the optical potential as a function of projectile laboratory energy plotted at the strong absorption radius R_{sa}=10.6 fm. The lines are fits from application of a dispersion relation.

Continuum discretized coupled-channels (CDCC) calculations have been carried out using the code FRESCO in which the breakup continuum is coupled to the elastic channel. Cross-sections for the elastic scattering thus obtained, which also reproduce the experimental values, have been found to be enhanced at backward angles as compared to uncoupled calculations. This implies that the DPP produced due to breakup coupling is repulsive in nature. Thus the magnitude of the effective real potential is reduced leading to the observed BTA.

Inclusive breakup α cross-sections for the system have been extracted from the elastic data and their comparison made with the reaction cross-sections obtained from the OMA and experimental fusion cross-sections. Comparison shows that the inclusive breakup α cross-sections form a large fraction of the reaction in the energy range investigated. Especially at below barrier energies, the breakup cross-section is equal to the reaction cross-sections. This suggests that it is indeed the breakup channel which is present at below barrier energies which reflects in the persistence of the imaginary part at these energies. This confirms the BTA for the ^{9}Be+^{89}Y system.

From the fusion measurement, CF cross-sections have been obtained from addition of individual ER cross-sections. In addition, a lower limit of the ICF cross-sections has been obtained. Barrier distribution has been obtained from the experimental data to fix the potential V_b and understand the effect of coupling of the projectile and/or target excited states on the cross-sections. CC calculations have been carried out in which the projectile ground state deformation and target excited state couplings have been included. Comparison of the experimental CF cross-sections with the corresponding values from CC calculations show a suppression of the experimental CF cross-sections by (20$\pm$5)%

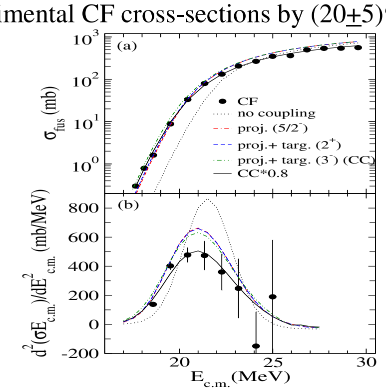

Fig. 2 (a) Experimental CF cross-sections (filled dots) for the ^{9}Be+^{89}Y system. The lines are corresponding calculation values as mentioned in the legends in figure. (b) Experimental barrier distribution extracted from the fusion cross-sections.

References

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