Fusion studies of weakly bound ^{6}Li nucleus with ^{90}Zr near coulomb barrier

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Introduction

The effect of the breakup of loosely bound stable nuclei on fusion process is subject of current theoretical and experimental investigation due to recent increasing interest in the study of nuclei far from β–stability line with scarcely available rare ion beams. It has been a subject of contradiction about the suppression and enhancement of the fusion process compared to the predictions of single barrier penetration model where weakly bound nuclei are involved. Recently, coupled channel calculations were performed by Hagino et al. [1] which predicts suppression above barrier and enhancement below barrier. Due to low breakup threshold (1.47MeV) of ^{6}Li, other channels open up, which may be the cause of this kind of phenomena? More experimental data are required to better understand this anomaly. In this paper, we present different channel cross-sections for the ^{6}Li+^{90}Zr system.

Experimental details

The experiment was performed using the ^{6}Li(3+) beam delivered by 14UD Pelletron accelerator of TIFR/BARC Facility in Mumbai, India at bombarding energies 11, 13, 14, 15, 16, 17, 18, 19, 21, 13, 25 and 30 MeV. The beam energies were corrected for the half target thickness in the analysis process that amounts to minimum 71.2 keV for 30 MeV and maximum 132.6 keV for 11 MeV. Beam currents were typically in the range of 5-30 nA. The beam impinged on a 500μg/cm^{2}, self-supported enriched ^{90}Zr (99%) target. The experiment was carried out with in-beam and off-beam spectroscopy method using clover setup consisting of 4 Ge-detectors at angle of 65 degree. Some of the evaporation channels producing stable residues were identified with characteristic gamma-lines. The offline gamma ray measurements were done after a short beam stop during the run. ^{152}Eu and ^{133}Ba were used in the same geometry as of target for the energy calibration as well as efficiency measurement. ^{94}Tc, ^{93}Tc (unstable), ^{94}Mo, ^{93}Mo, ^{91}Nb, and ^{91}Zr (stable/long lived) are the major evaporation residues (ER) populated in ^{6}Li+^{90}Zr reaction. The silicon surface barrier detectors in ΔE+E telescopic arrangement were put for particle gamma coincidence. One Monitor detector was put at 30 degree along with current integrating Faraday cup for beam current measurement. The telescope was constituted with thickness of ΔE=32.9μm and E=1mm, and the monitor was of 1mm thickness.

Experimental results

The preliminary analysis was carried out for some of the channels identified. Offline analysis was done for the 2n and 3n channels populating ^{94}Tc and ^{93}Tc. Both of these nuclei could either be populated in ground or meta-stable states. Details of the half lifes $T_{1/2}$, γ-ray energies Eγ, and branching ratio Iγ are given in Table 1. The ERs were identified with half life and Eγ. The same target was irradiated at all the energies due to this reason the contribution of the previously formed residues were subtracted in the subsequent irradiation. The statistical model calculation, which gives good description for the spherical nuclei, were performed with PACE2 [2] using default potential parameters. The results are compared with the experimental data in Fig.1-2. The experimental data are lower and higher compared to the PACE2 calculated values for both 2n and 3n channels at above and below coulomb barrier, respectively.

The online analysis is presented for the ^{94}Mo and ^{91}Zr nuclei in Fig. 3. Here all ground state contributions were added to obtain the ER cross-sections. Direct feeding to g.s. is very small in this mass region [3]. The γ-line of online measurement was also mixed with offline decay in some cases like decay lines from ^{94}Tc were same as characteristic lines of ^{94}Mo. In this case, the offline yield was subtracted. The results are presented in Fig. 4. Similar trend like 2n, 3n channels is observed in Fig. 3 in case of ^{94}Mo. The ^{91}Zr production is significantly higher due to similar ER formation from neutron transfer channel.

Table 1: Decay data of observed ERs corresponding to 2n and 3n channels populating ^{94}Tc and ^{93}Tc in ground and meta-stable states.

ER	Eγ (keV)	Iγ (%)	$T_{1/2}$
$^{94}Tc^{g}$	871	100	4.88h
	702.6	99.6	
	849.7	95.7	
$^{94}Tc^{m}$	871	94	52m
	1868.7	5.7	
$^{93}Tc^{g}$	1363	66	2.75h
$^{93}Tc^{m}$	391.8	58	43.5m
	2644.5	14.2	

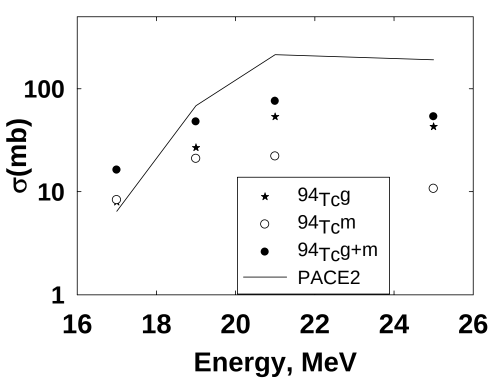

Fig. 1 Measured ER cross-section for the ground state (star), meta-stable state (open circle), and total (g.s.+m.s., filled circle). PACE2 calculations are presented by lines.

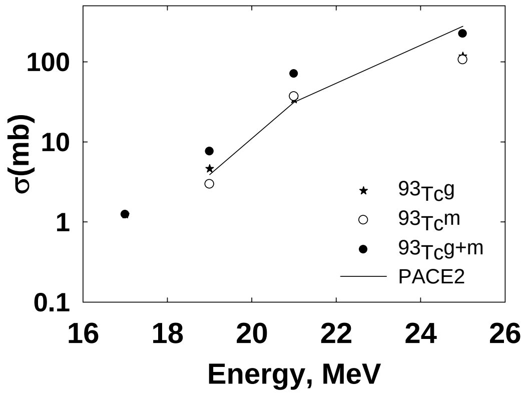

Fig. 2 3n channel cross-section. Symbols are same as in Fig. 1..

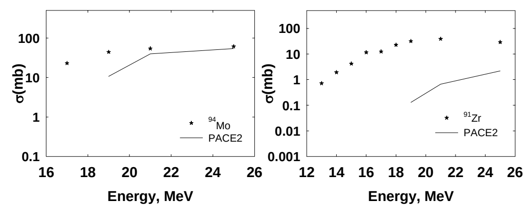

Fig. 3 Measured ER cross-section for the ^{94}Mo and ^{91}Zr nuclei using in-beam spectroscopy method.

Discussion

The cross-sections for different ERs have been measured and presented in the present work. All observed channels show suppression of Complete Fusion above coulomb barrier and enhancement below coulomb barrier as compared with statistical model calculations.

References

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