A possible sign of incomplete fusion in ^{9}Be induced reaction on ^{93}Nb

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Introduction

Significant theoretical and experimental investigations in the reactions and scattering caused by weakly bound nuclei, with an emphasis on fusion, breakup, and elastic scattering, have been carried out in recent years [1, 2]. The study of how the breakup channel affects nuclear fusion reactions involving radioactive projectile, like ^{6}He, ^{8}He, ^{11}Li, ^{11}Be, and ^{8}B, is also a topic of great interest. The low intensity of radioactive beams, however, significantly reduces the accuracy of the measurements. Thus, fusion reactions with stable projectiles can help us better understand those processes. Because of weak binding, some stable nuclei such as ^{6}Li ($\alpha + d$, E_{BU} = 1.47 MeV), ^{7}Li ($\alpha + t$, E_{BU} = 2.47 MeV), and ^{9}Be ($\alpha + \alpha + n$, E_{BU} = 1.57 MeV) breakup even at low energies. If all the projectile fragments (after breakup) fuse with the target, the process is called sequential complete fusion. If only one fragment fuses with the target while the remaining act as spectators, the process is called incomplete fusion (ICF). It is crucial to note that experimentally distinguishing between ICF and direct transfer reactions is highly complex. It is also observed that the dependence of ICF on different entrance channel parameters, such as projectile energy, structures of the colliding nuclei, mass asymmetry μ, $Z_p Z_t$ factor, α-separation energy, and role of input angular momentum (ℓ), is not well understood. Gomes *et al.* [3] reported that in contrast to the study carried out by Jha *et al.* [4], the probability of ICF decreases with decreasing target charge (Z_t) for ^{9}Be-induced reactions. The breakup of the projectile results in the reduced incoming flux, and therefore, the complete fusion cross section is suppressed at energies above the barrier. It has been observed that the suppression does not follow a systematic trend for ^{9}Be-induced reactions, in contrast to other weakly bound projectiles. This article discusses the cross section measurement of ^{96}Tc residue from the ^{9}Be+^{93}Nb reaction within the 20–46 MeV energy range.

Experiment

The experiment was performed at the BARC-TIFR Pelletron facility in Mumbai, India. The ^{9}Be-ion beam was allowed to incident on Nb targets (1.4–2.1 mg/cm^2 thick) backed by Al foils of thickness $\approx$ 1.5–1.9 mg/cm^2 arranged in a stack. Self-supporting Nb foils were made by proper rolling in a machine. The use of Al foil served the purpose of an energy degrader as well as a catcher for recoils. Energy degradation in each foil was estimated by the Stopping and Range of Ions in Matter (SRIM) code. After the end of the bombardment, target ^{93}Nb and catcher ^{27}Al foils were assayed using γ-spectroscopy for a sufficient duration to measure the activity of the residues with the help of an HPGe detector, coupled with a PC operating with GENIE-2K software (Canberra). Based on characteristic γ–rays and decay profile, residues were identified, including the factors responsible for the uncertainty in the measurement.

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Results and discussion

In this experiment, seven radionuclides were identified namely, ^{100}Rh, ^{99m}Rh, ^{98}Rh, ^{97}Ru, ^{99m}Tc, ^{96}Tc, and ^{95}Tc. When the measured excitation functions of these radionuclides were compared to the theoretical predictions from PACE4, it was found that both the measured and calculated excitation functions exhibited a similar trend. However, the production of ^{96}Tc via $\alpha 2n$ channel will be the main focus of this abstract (refer to Fig. 1). PACE4 is based on Hauser-Fashbach formalism and deals with the equilibrium emission process. The bass model is used to compute the fusion cross section. The Fermi gas level density with level density parameter $a = A/k$, where A is the mass number of compound nuclei, and k is the free parameter, has been used. The comparison of experimental cross sections of ^{96}Tc with the PACE calculations at $k = 8$, 9, and 10 shows no meaningful disparity in the cross sections among the different k values. Compared to the theoretical calculations, a significant enhancement is observed in the measured cross sections, and PACE4 fails to reproduce the experimental data within the measured energy range. One plausible explanation for the notable production cross sections observed in ^{96}Tc residues could be due to ICF or nucleon transfer processes occurring in ^{9}Be+^{93}Nb reaction. Due to the cluster structure of ^{9}Be, this reaction demonstrates two possible mechanisms: (i) the disintegration of ^{8}Be (lifetime $\approx 10^{-16}$ s), formed after neutron transfer, and (ii) prompt breakup involving $\alpha+\alpha+n$ (Q value = -1.57 MeV) or ^{5}He+α (Q value = -2.46 MeV). In one scenario, an α particle, one of the fragments resulting from the breakup, fuses with ^{93}Nb, leading to the production of ^{97}Tc, which subsequently releases a neutron to form ^{96}Tc. Meanwhile, the other fragment continues along its trajectory as an observer. Alternatively, another possibility is the fusion of ^{5}He with ^{93}Nb yields ^{98}Tc, which subsequently emits two neutrons to form ^{96}Tc. Another scenario involves transferring a single neutron followed by an α transfer from ^{8}Be, which could produce ^{98}Tc. ^{98}Tc then emits two neutrons to form ^{96}Tc. Importantly, it is worth noting that the yield of Tc isotopes results from ICF and a potential contribution arising from direct transfer reactions. It is challenging to distinguish between ICF and transfer reactions. The detailed analysis is in progress.

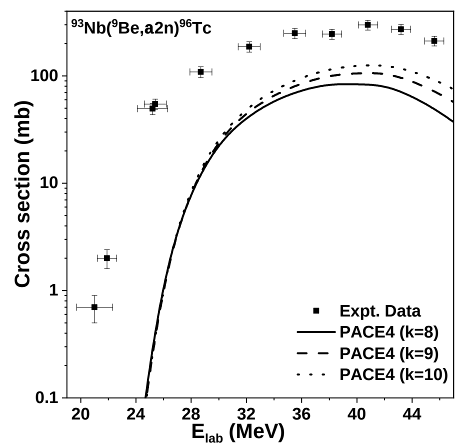

FIG. 1: Comparison of measured excitation function of ^{96}Tc with theoretical predictions from PACE4 at different k values.

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