Probing reaction mechanisms in ^{14}N fusion with ^{93}Nb

Himanshu Sharma[1], Moumita Maiti[1,*] T. N. Nag[2], and S. Sodaye[2]
[1] *Department of Physics, Indian Institute of Technology Roorkee, Roorkee-247667, Uttarakhand, INDIA and*
[2] *Radiochemistry Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*

Introduction

Numerous aspects of nuclear reactions have been uncovered with the development of accelerators and spectroscopic equipment. In the low energy region, the strength of reaction mechanisms, such as complete fusion (CF), incomplete fusion (ICF) or breakup fusion, deep inelastic collision (DIC), quasielastic collision (QEC), direct reaction (DR), transfer reaction (TR), pre-equilibrium emission (PEQ), etc., [1] is still not completely understood. In the PEQ emission process, light particles (neutrons, protons, etc.) are emitted with relatively higher energy than expected from the compound process. Pre-equilibrium particle emission and ICF are expected at higher incident projectile energies, however, both processes occur at energies lower than 10 MeV/nucleon [2, 3, 4]. Therefore, heavy ion-induced reactions have attracted much interest in recent years at energies below 10 MeV/nucleon, particularly just above the Coulomb barrier, where complete fusion is expected to be the only contributor to the reaction cross section. However, more research is required to comprehend the relationship between PEQ emissions and energy of the projectile and its type, the threshold for the PEQ emission for various target-projectile combinations, the cross-section distribution between PEQ and CF-ICF processes, etc., from slightly above to well above the Coulomb barrier.

We have made an attempt to analyze the nuclear reaction processes in the fusion of ^{14}N with ^{93}Nb, as there have only been a few experiments employing non-α-cluster projectiles like ^{14}N and ^{19}F.

*Electronic address: moumita.maiti@ph.iitr.ac.in

Experiment

The experiment for the system ^{14}N+^{93}Nb was performed at the BARC-TIFR Pelletron facility, Mumbai, India. The ^{14}N^{5+}-ion beam was allowed to incident on Nb targets backed by Al foils of thickness $\approx$ 1.5 mg/cm^2 arranged in a stack. Self-supporting Nb foils of thickness $\approx$ 1.4 mg/cm^2 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 bombardment (EOB), target ^{93}Nb and catcher ^{27}Al foils were assayed using offline γ-spectroscopy for a sufficient time to measure the activity of the residues with the help of the 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.

Results and Discussion

In this experiment, five radionuclides were identified namely, ^{104}Cd, ^{104}Ag, ^{103}Ag, ^{101}Pd, and ^{101m}Rh. However, ^{104}Ag produced via *p2n* emission channel will be the main focus of this abstract. A comparison of theory and experiment is important to understand the dynamics of nuclear reaction processes, such as pre-equilibrium (PEQ) and equilibrium (EQ) emission of particles. It is also an indirect way to check the reliability and improve the parametrization of the theoretical model codes. The measured excitation function of residue ^{104}Ag has been compared with the theoretical predictions from PACE4 and EMPIRE3.2.2. The main distinction in these model codes is that PACE4 only considers EQ emissions while EMPIRE considers all three major nuclear reactions - direct, PEQ, and EQ during calculations. PACE4 is based on Hauser-Feshbach (HF) formalism for EQ emission of particles. EMPIRE is also based on HF formalism but incorporates the phenomenological exciton model for PEQ emission of particles. In EMPIRE computations, the fusion cross section is determined using coupled channel code (CCFUS), whereas PACE uses a one-dimensional tunneling fusion barrier utilizing Bass potential. PACE4 uses Fermi gas formalism for level densities. The level density parameter a is calculated from $a = A/k$, where A is the atomic number of the nucleus and k is the free parameter. Figure 1 illustrates the impact of free parameter k on the excitation function of ^{104}Ag in PACE4. The figure shows that $k = 9$ is the best option for the free parameter.

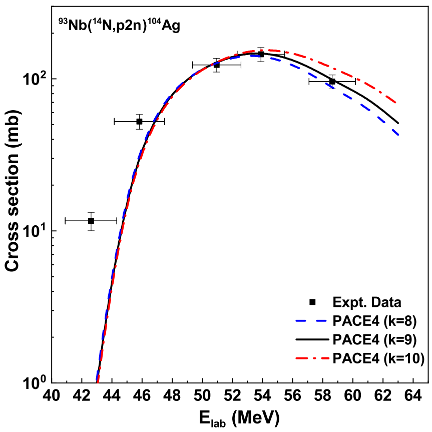

FIG. 1: Comparison of measured excitation function of ^{104}Ag with theoretical predictions from PACE4 at different k values.

The Enhanced Generalized Superfluid Model (EGSM) has been used for level density in EMPIRE calculations, shown in Figure 2. It is evident from this figure that the mean free path parameter in the PCROSS code controls the PEQ contribution. The calculations with a mean free path parameter of 1.6 are closer to the experimental

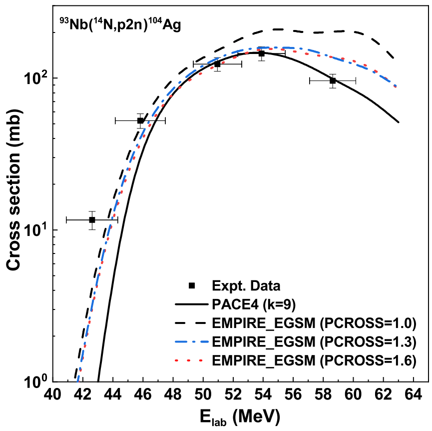

FIG. 2: Comparison of measured excitation function of ^{104}Ag with theoretical predictions from PACE4 and EMPIRE3.2.2.

data. The measured excitation function is satisfied by EMPIRE in the lower energy region (Figure 2). However, deviations are observed above 50.9 MeV incident energy. In the higher incident energy region (E_{lab} > 45.8 MeV), PACE4 predicts the experimental measurements accurately. Thus, the production of ^{104}Ag can only be thought of through an equilibrium mechanism as PACE4 calculations are based on the EQ formalism and do not consider the PEQ emission.

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