Measurement of fusion excitation functions around the Coulomb barrier for ^{28}Si + ^{90,94}Zr systems

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Introduction

Among the various degrees of freedom that influence the sub barrier fusion cross-section enhancement, the role of static deformation and quantal zero point motion is well established but there are still ambiguities in the quantitative effects of transfer channels [1, 2]. The multi nucleon transfer can take place either sequentially or simultaneously making it difficult to incorporate transfer channels in theoretical fusion cross section calculations.

In order to probe the role of transfer on the sub barrier fusion cross section enhancement, in the present experiment, we measured fusion excitation functions for ^{28}Si + ^{90,94}Zr systems using Heavy Ion Reaction Analyzer (HIRA) at IUAC [3]. The motivation behind choosing these systems was the fact that ^{90}Zr and ^{94}Zr have similar values of quadrupole and octupole deformations but the Q values are positive for up to four neutron pick - up in the case of ^{28}Si + ^{94}Zr. Hence, one can see the role of multi neutron transfer in sub barrier fusion cross section enhancement.

Experimental Setup

Pulsed beam of ^{28}Si (with 2μs repetition rate) was bombarded on ^{90,94}Zr targets (97.65% and 96.07% enriched respectively) of 280 μg/cm^2 thickness each prepared on 45 μg/cm^2 carbon backings in the target lab at IUAC. In the target chamber of HIRA, two silicon surface barrier detectors were mounted at ±25^o to monitor the beam and for normalization in the extraction of cross section. A carbon charge reset foil of 30 μg/cm^2 thickness was used for charge re-equilibration of evaporation residues (ERs), after possible internal conversion processes, coming out of the target. At the focal plane of HIRA, a Multi Wire Proportional Counter (MWPC) of 150 X 50 mm^2 active area was used for the detection of ERs. Time of flight was defined for particles reaching the focal plane with respect to RF of beam to separate multiply scattered beam-like particles and ERs at the focal plane. The fusion excitation function measurements were performed from 82 MeV to 120 MeV in steps of 2 MeV near the barrier and 3 to 5 MeV above the barrier (at 15 energies). This energy range covers ~15% below to ~25% above the Coulomb barrier. The solid angle of acceptance for HIRA was kept 5 mSr for fusion excitation function measurements and 1mSr for angular distribution measurements from 0^o to 10^o in steps of 2^o. A raw spectrum of data taken is shown in Fig.1. From the spectrum, it is clearly visible that beam like particles are very well separated from the ERs.

HIRA transmission efficiency was measured by coincident γ ray method for ^{28}Si + ^{94}Zr at 103 MeV. The efficiency was determined to be 3.2 % which was found to be in good agreement (within 15%) with Monte Carlo simulated value using code TERS [4]. As the ERs were not very far in mass for ^{28}Si + ^{90}Zr similar values were used after checking with simulation program.

Results and Discussion

The measured fusion excitation functions for ^{28}Si + $^{90,94}Zr$ systems are plotted in Fig. 2 and Fig. 3, respectively. Corrections for loss of beam energy in carbon backing and half target thickness were appropriately taken into account.

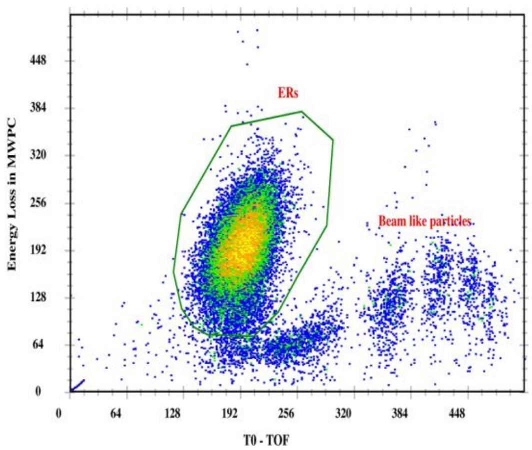

Fig.1 A 2-dimensional spectrum showing energy loss of ERs in MWPC vs. TOF.

Coupled channels code CCFULL [5] was used for the theoretical analysis of the data. The ion - ion potential used in calculation was Woods – Saxon parameterization of Akyuz-Winther potential. Measured cross-sections for ^{28}Si + ^{90}Zr are shown in Fig.2 along with the theoretical calculations obtained using CCFULL. The cross-sections estimated by One Dimensional Barrier Penetration Model (1D-BPM) are an order of magnitude less than the experimentally measured cross-sections in the sub barrier region. Coupled channels calculations were performed for this system including 2^+, 3^- states of target one after the other and it was found that 3^- state enhances cross-section more as compared to 2^+ state of the target implying that coupling to 3^- state is stronger in this case. Inclusion of 0^+, 2^+ states of ^{28}Si fit the data reasonably well near as well as below the barrier. Using the same coupling scheme, we analyzed ^{28}Si + ^{94}Zr data. In this system, coupling to 2^+, 3^- states of ^{94}Zr and 0^+, 2^+ states of ^{28}Si under predicted the measured cross sections in the sub barrier region. In this case, up to four neutron pick up channels have positive Q values. Therefore, the likely reason is the role of transfer channels in enhancing the experimental cross sections in this case.

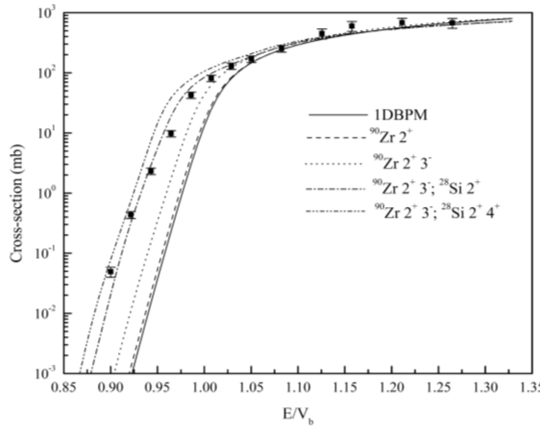

Fig. 2 Fusion excitation function for ^{28}Si + ^{90}Zr along with CCFULL calculations.

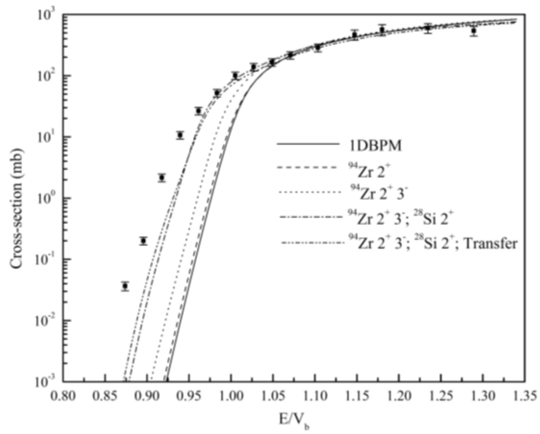

Fig. 3 Fusion excitation function for ^{28}Si + ^{94}Zr along with CCFULL calculations.

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References

[1] M. Dasgupta et al., Ann. Rev. Nucl. Part. Sci. **48** (1998) 401.

[2] M. Beckerman, Rep. Prog. Phys. **51** (1988) 1047.

[3] A. K. Sinha et al, Nucl. Instr. and Meth. A **339** (1994) 543.

[4] S. Nath Comp. Phys. Comm. **179** (2008) 492.

[5] K. Hagino, N. Rowley, A. T. Kruppa Comp. Phys. Comm. **123** (1999) 143.