Measurement of transfer reaction cross sections for ^{28}Si + ^{90,94}Zr in sub-barrier and near barrier regions

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Introduction

The study of heavy ion collisions around the Coulomb barrier provides an excellent opportunity to explore several spectacular effects leading to a better understanding of reaction mechanisms as well as the involved nuclear structure effects [1-4]. For the nuclei in mass region ~ 100, there are many particles outside the closed shell so the formation of superfluid condensate takes place that leads to an enhanced transfer of pair of nucleons between the colliding nuclei.

Here we report the results of measurements of multi - nucleon transfer for ^{28}Si + ^{90,94}Zr systems at near barrier energies. The studies revolve around the quantitative effect of transfer channel coupling (mainly positive Q value multi neutron pick-up) on fusion cross sections around the Coulomb barrier. For these systems, we have already carried out fusion cross section measurements [5]. As ^{90}Zr has closed neutron shell, the effect of shell closure on neutron transfer can be studied. On the other hand, ^{94}Zr has four nucleons outside the closed shell, which allows us to investigate the effects of pairing correlation on multi-nucleon transfer mechanism.

Experimental Setup

The experiment was performed with pulsed ^{28}Si beam having a repetition rate of 1μs using Heavy Ion Reaction Analyzer (HIRA) at IUAC, New Delhi. The targets used were isotopically enriched ^{90,94}Zr (97.65% and 96.07% respectively) 280 μg/cm^2 foils prepared on 45 μg/cm^2 carbon backings in the target lab of IUAC. In the target chamber of HIRA, two silicon surface barrier detectors were mounted at ±25^o to monitor the beam. To improve beam rejection, HIRA was rotated to 6^o. A silicon surface barrier detector of 20 X 20 mm^2 active area was mounted at back angle to set-up kinematic coincidence between forward moving target - like recoiling particles and back scattered projectile - like nuclei. The angle of this back detector was optimized by maximizing the coincidence counts. At the target chamber of HIRA, 14 elements BGO array was also mounted for gamma detection in coincidence with recoils. A carbon charge reset foil of 30 μg/cm^2 thickness was used for charge equilibration of recoiling particles 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 followed by ionization chamber was used for the detection of recoiling particles. The timing information (TOF) was obtained with arrival of particles at focal plane MWPC as start and RF of the beam as stop to separate multiply scattered beam-like and recoiling target–like particles at the focal plane. Forward moving recoils were dispersed according to their mass/charge values at the focal plane of HIRA. The measurements were performed from 85 MeV to 97 MeV (in lab) in steps of 3 MeV. At 97 MeV, the BGO array set up was used to obtain ground state and total excited state transfer strengths. The solid angle of acceptance for HIRA was kept 5 mSr for carrying out all these measurements.

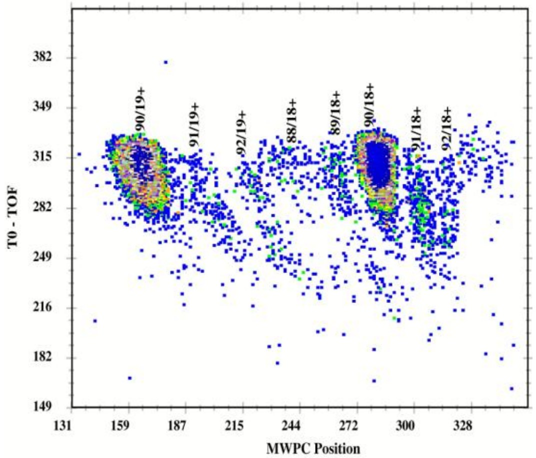

Fig.1 A 2-dimensional spectrum for ^{28}Si+ ^{90}Zr at 94MeV.

Results

Two dimensional spectra between the time of flight (TOF) vs. MWPC position for ^{28}Si + ^{90,94}Zr at 94 MeV are shown in Fig. 1 and Fig. 2, respectively. Fig. 3 shows the corresponding projected mass spectrum of recoiling target like particles for ^{28}Si + ^{94}Zr. The transfer of up to 4-nucleon pick-up and one nucleon stripping can be noted in the figure. We could clearly resolve m/q ambiguity by time of flight. From the Q-value considerations it was found that pick-up channels were neutron transfer whereas stripping channels were proton transfer.

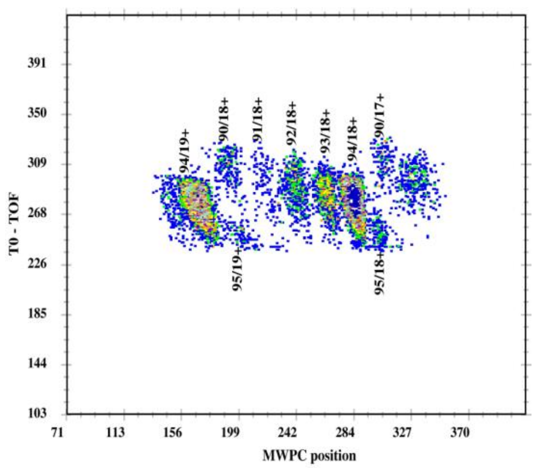

Fig.2. A 2-dimensional spectrum for ^{28}Si + ^{94}Zr at 94 MeV

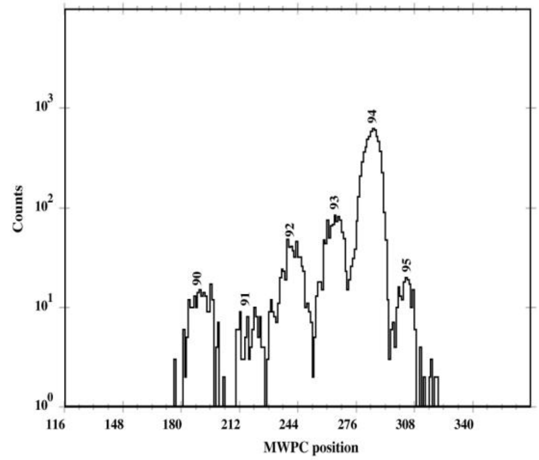

Fig. 3 Projected mass spectrum for ^{28}Si + ^{94}Zr.

An extreme low energy run was taken at 70MeV (much below the Coulomb barrier so that transfer does not take place significantly) to determine the isotopic contents of the targets experimentally. The values so obtained were found to be consistent with the values provided by supplier. Further analysis of the data is in progress to extract transfer form factors and transfer probabilities. The transfer form factors will be used for performing coupled channels calculations to explain an order of magnitude enhancement of the fusion cross section observed for ^{28}Si + ^{94}Si as compared to ^{28}Si + ^{90}Zr.

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References

[1] Steadman SG, Rhoades-Brown MJ. Annu. Rev. Nucl. Part. Sci. **36** (1986) 649.

[2] W. Reisdorf J. Phys. G **20** (1994) 1297.

[3] M. Dasgupta et al. Annu. Rev. Nucl. Part. Sci **48** (1998) 401.

[4] W von Oertzen, A Vitturi Rep. Prog. Phys. **64** (2001) 1247.

[5] Sunil Kalkal et al. IUAC Annual Report 2008-2009, 166.