Multi-nucleon transfer in the reaction ^{28}Si+^{94}Zr

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Multi-nucleon transfer (MNT) reactions play a key role in understanding the structural features of atomic nuclei. Single particle transfer gives the information about the shell structure. Two particle transfer is a direct probe for extracting the pairing information in atomic nuclei. Three and four neutron transfer reactions provide the evidence of super-fluidity.

The first experiment for measurement of MNT channels by detecting the forward-moving target-like recoils (TRs) using a Recoil Mass Spectrometer (RMS) was performed by Betts *et al.* [1]. Further, Napoli *et al.* [2], Roberts *et al.* [3], Katariya *et al.* [4] and Kalkal *et al.* [5] measured the transfer channels by using RMS. In all these measurements, transfer probability was extracted by assuming that all the channels have the same transmission efficiency (ϵ) through the RMS. To calculate differential transfer cross sections, Betts *et al.* additionally assumed that the sum of differential elastic, inelastic and transfer cross sections was equal to the differential Rutherford scattering cross sections at energies near and below the barrier. However, Biswas *et al.* [6] recently demonstrated that all the transfer channels did not have the same ϵ. The authors developed a Monte Carlo code to simulate study of transfer reactions in an RMS and a methodology for extraction of differential transfer cross sections from the yields measured at the focal plane of an RMS.

In this work we extracted differential cross sections for $1n$ and $2n$ pick-up channels in the reaction ^{28}Si+^{94}Zr [5], following the methodology proposed in Ref. [6]. MNT transfer probabilities for this reaction had already been reported. To understand the mechanism of $1n$ and $2n$ transfer, we have performed Coupled Reaction Channel (CRC) calculations using the code FRESCO [7].

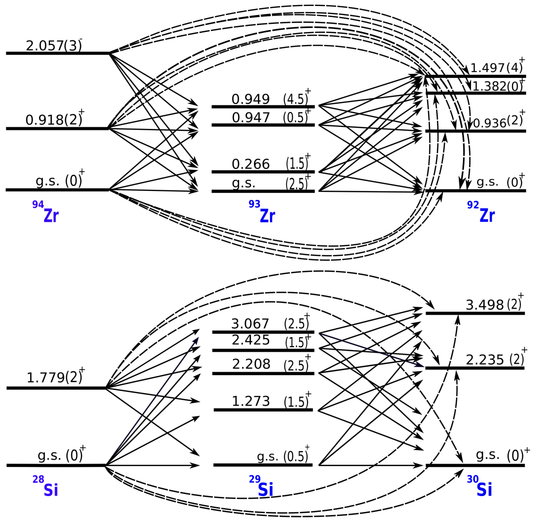

FIG. 1: Schematic of the couplings between states of the projectile and the target nuclei for $2n$ pick-up channel. Solid and dashed lines represent sequential and simultaneous mechanism, respectively.

The calculations for transfer excitation functions have been performed at $\theta_{\text{c.m.}}=168^o$, the same angle at which measurements had been carried out. In CRC calculations, we used Woods-Saxon form for the Optical Model Potential (OMP) for entrance as well as exit channels. The OMP parameters for entrance channels were taken from Ref. [6]. The depth (V_0), the radius (r_0) and the diffuseness (a_0) parameters of the real part of Woods-Saxon potential were -67.6 MeV, 1.17 fm and 0.66 fm, respectively. Parameters for the imaginary part of the inter-nuclear potential were

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W_0 = -50.0 MeV, r_w = 1.0 fm and a_w = 0.4 fm. The Coulomb and nuclear deformation parameters of ^{28}Si and ^{94}Zr were taken form Ref [8]. We analyzed one and two step mechanism in case of 2n pick-up channel. Coupling scheme for various intermediate states involved in the calculations is shown in Fig 1. Important ingredients of bound state wave functions were generated by Wood-Saxon Potential form for all the channels, where the depth of the potential was varied to match with the experimental binding energies for 1n and 2n pick-up channels. Binding radius and diffuseness parameter for ^{28}Si were taken as 1.20 fm and 0.66 fm, respectively whereas the Coulomb radius for 1n and 2n pickup channels were taken as 1.26 fm. For the heavier nucleus, ^{94}Zr, radius and diffuseness parameter for 1n and 2n transfer were taken as 1.20 fm and 0.66 fm, respectively, The Coulomb radius was 1.25 fm. In the calculations, we took the prior form of transition potential for 1n and 2n mechanism (direct process). Along with that, full complex remnant term and non-orthogonality correction were also included. The spectroscopic factors for 1n and 2n channels for projectile-like nuclei were taken from Ref. [9]. The spectroscopic factors for some of the channels were not available in the literature. In such cases, the same were taken as unity.

Fig 2 shows experimental data along with CRC results for the reactions ^{94}Zr(^{28}Si,^{29}Si)^{93}Zr and ^{94}Zr(^{28}Si,^{30}Si)^{92}Zr. The experimental data follow the bell-shaped trend for both channels. The CRC results reproduce the experimental data quite well. CRC result also follows the bell-shaped pattern for 1n channel. We performed calculations for all the configurations for 2n channel. The cluster transfer configuration reproduced the data quite satisfactorily. However, it did not follow the bell-shaped pattern of the excitation function. The sequential transfer reproduced the shape of the excitation function well, but under-predicted the data by an order. The simultaneous transfer under-predicted the measured cross-section by nearly three orders. No arbitrary normalization was included in the CRC calculations.

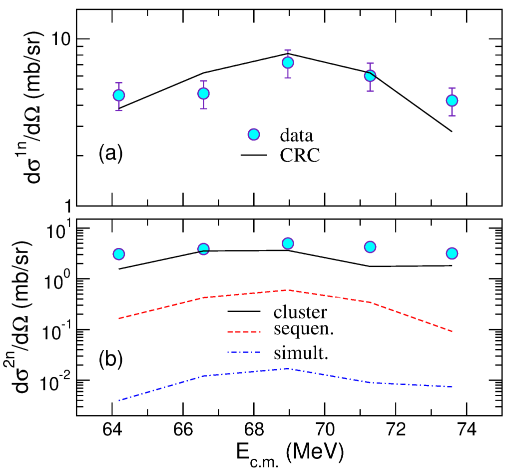

FIG. 2: a) Differential transfer cross sections for (a) ^{94}Zr(^{28}Si,^{29}Si)^{93}Zr and b) ^{94}Zr(^{28}Si,^{30}Si)^{92}Zr along with results from CRC calculations.

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References

[1] R. R. Betts *et al.*, Phys. Rev. Lett. **59**, 978 (1987).
[2] D. R. Napoli *et al.*, Nucl. Phys. A **559**, 443 (1993).
[3] R. B. Roberts *et al.*, Phys. Rev. C **47**, R1831 (1993).
[4] D. O. Kataria *et al.*, Phys. Rev. C **56**, 1902 (1997).
[5] S. Kalkal *et al.*, Phys. Rev. C **83**, 054607 (2011).
[6] R. Biswas *et al.*, Eur. Phys. J. A **57**, 1 (2021).
[7] I. J. Thompson, Comput. Phys. Rep. **7**, 167 (1988).
[8] S. Kalkal *et al.*, Phys. Rev. C **85**, 034606 (2012).
[9] E. N. Cardozo *et al.*, Phys. Rev. C **97**, 064611, (2018).