Revisiting 1*p*- and 2*p*-stripping angular distributions in ^{28}Si+^{90}Zr

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Study of multi-nucleon transfer (MNT) reactions has played an important role in exploring interesting phenomena related to single-particle configurations, pairing correlations and cluster degrees of freedom in nuclei [1, 2]. At energies above the Coulomb barrier, transfer reactions have been proven to be useful tools for extracting accurate spectroscopic information. Synthesis of neutron-rich transactinides and nuclides along the $N = 126$ shell closure via heavy ion-induced MNT reactions has been a topic of significant current interest [3–5]. Transfer of nucleons are also known to strongly influence fusion dynamics below the Coulomb barrier [6].

Impressive advancement of computational resources has made the application of nuclear reaction theories for analysis of experimental data, obtained from complex experiments, possible. In this context, new opportunities for using MNT reactions as tools for studying nuclear structure and reaction mechanism have opened up [7, 8].

MNT reactions are quite well described by the coupled reaction channel (CRC) formalism as it allows the coupling of all possible channels in a heavy ion–induced reaction. Hence the role of channel coupling and relative importance of single-step and multi-step processes in MNT can be understood. In various recent studies [7–9], experimental cross-sections of 1*n*- and 2*n*-transfer reactions *viz.*, ^{12,13}C(^{18}O, ^{17}O)^{13,14}C, ^{12}C(^{18}O, ^{16}O)^{14}C and ^{28}Si(^{18}O, ^{16}O)^{30}Si have been reproduced by CRC calculations without any arbitrary normalization factor. The relative importance of simultaneous and sequential two nucleon transfer has thus been understood in these systems.

Kalkal *et al.* [10], had reported measurement of angular distributions for 1*p*- and 2*p*-stripping channels of ^{28}Si+^{90,94}Zr at $E_{\mathrm{lab}} = 120$ MeV. In the present work, we have re-analyzed the angular distribution data for ^{28}Si+^{90}Zr within the framework of CRC model using the code FRESCO [11].

We used Woods-Saxon form of the optical potential for entrance as well as exit channels for both 1*p*- and 2*p*-stripping. Optical potential parameters, real as well as imaginary, for entrance channel were taken from Ref. [10]. Depth, radius and diffuseness parameters for the real part of the potential were taken as $V_0 = -66.01$ MeV, $r_0 = 1.176$ fm and $a_0 = 0.659$ fm. Parameters for the imaginary part of the potential were $W_0 = -50.0$ MeV, $r_w = 1.0$ fm and $a_w = 0.4$ fm. For the exit channel, global optical potential parameters were used. Relative strength of inelastic couplings incorporated in the present calculations for Coulomb and nuclear transitions was also taken from Ref. [10]. Spin-orbit potential, with its standard form, was incorporated in our calculations. To define the bound state parameters for 1*p*- and 2*p*-stripping channels, Woods-Saxon shape of the real potential with radius parameter 1.20 fm (1.16 fm) was used for 1*p*- (2*p*-) channel. The diffuseness parameter was kept as 0.65 fm for both channels. Depth of the real part of bound state potential was varied to reproduce 1*p* and 2*p* binding energies. Coulomb radius was taken to be 1.25 fm for both 1*p* and 2*p*-stripping channels.

Spectroscopic amplitudes for the projectile and the target overlaps were extracted from large scale shell model calculations using the code NuShellX [12]. We used the prior form of the transition potential along with the full

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complex remnant terms. We carried out the simultaneous (one step) transfer calculations for $2p$-stripping channel using two approaches: (1) the extreme cluster model [13] and (2) the microscopic cluster model [7]. In both of these approaches, interaction potential was assumed to act on the centre of mass (c.m.) of the proton cluster and not on its internal variables. In the extreme cluster model, we considered only the $S = 0$ anti-parallel configuration and the cluster was assumed to be in the $1s$ internal state. Spectroscopic amplitudes were taken to be 1 in this approach. In the microscopic approach, the pair of protons was not restricted to be in a state of zero total spin. The spectroscopic amplitudes in the c.m. frame of reference were calculated from shell model results using Moshinsky transformation brackets [14]. Coupling schemes for the states of projectile-like and target-like nuclei, included in the calculations, are shown in Fig. 1.

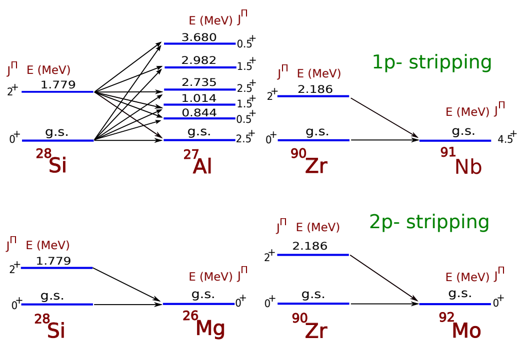

FIG. 1: Coupling scheme followed in CRC calculations for $1p$- and $2p$-stripping channels of the reaction ^{28}Si+^{90}Zr.

Fig. 2 shows the results of CRC calculations along with experimental data [10] for (a) ^{90}Zr(^{28}Si, ^{27}Al)^{91}Nb and (b) ^{90}Zr(^{28}Si, ^{26}Mg)^{92}Mo. It can be observed that our calculations reproduce the shape and magnitude of angular distribution for both $1p$- and $2p$-stripping channels quite well. Inclusion of projectile excitation up to the second 0.5^+ (E = 3.680 MeV) was necessary to reproduce the angular distribution for $1p$-stripping channel. Inclusion of more excited states of the projectile resulted in no significant enhancement of the cross sections. For $2p$-stripping channel, result of the extreme cluster model could explain the data quite satisfactorily. Cross sections for $2p$-stripping, calculated using the microscopic approach, underpredicted the experimental data by nearly two orders of magnitude, though the shape of the distribution was rather well reproduced. In our calculations, no arbitrary normalization (the so-called "unhappiness factor") was incorporated.

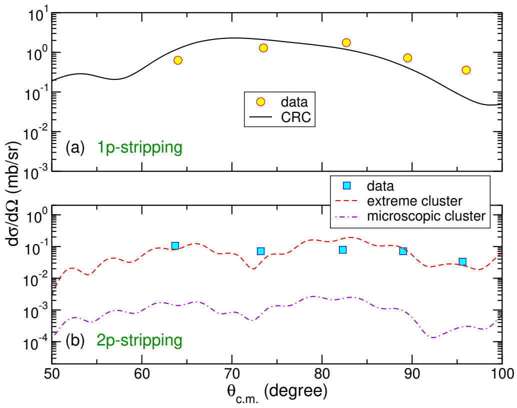

FIG. 2: Results of CRC calculations for the angular distribution of the reactions (a) ^{90}Zr(^{28}Si, ^{27}Al)^{91}Nb and (b) ^{90}Zr(^{28}Si, ^{26}Mg)^{92}Mo along with experimental data.

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