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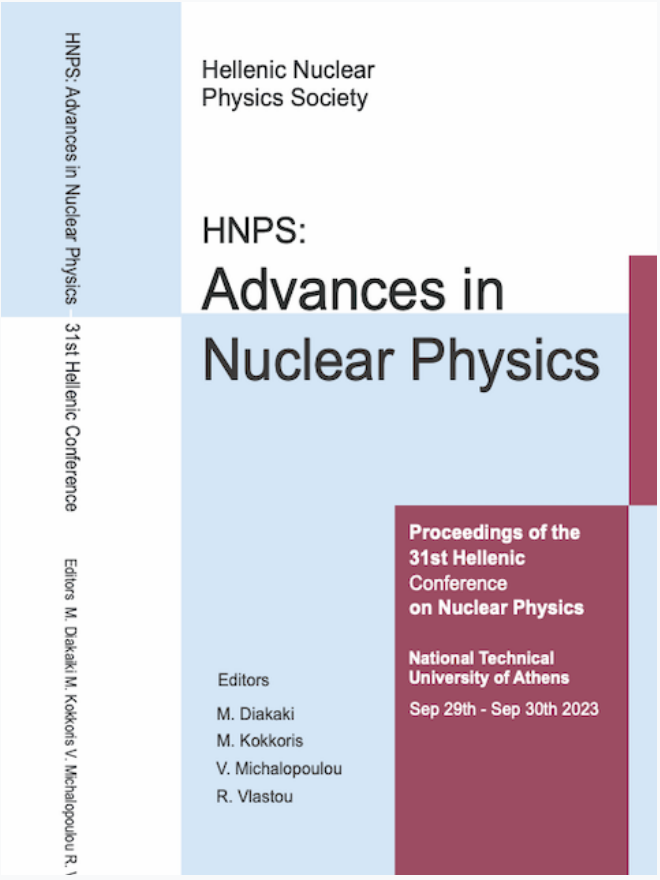

Multinucleon Transfer in 40Ar (15 MeV/nucleon) + 64Ni via High-Resolution Studies of Momentum Distributions

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Multinucleon Transfer in ^{40}Ar (15 MeV/nucleon) + ^{64}Ni via High-Resolution Studies of Momentum Distributions

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Abstract Multinucleon transfer (MNT) reactions have been extensively used in recent years as an effective tool to move further toward the neutron-rich side of the chart of nuclides. The efficient production of these exotic nuclides is currently at the epicenter of the research interest in facilities around the world. The current contribution focuses on our efforts to systematically study the reaction mechanism of the reaction of a ^{40}Ar beam at 15 MeV/nucleon with a ^{64}Ni target through a detailed analysis of momentum distributions of various reaction channels. The experimental data presented in this work were obtained with the MARS spectrometer at the Cyclotron Institute of Texas A&M University. The experimental distributions are compared with two dynamical models, the Deep-Inelastic Transfer (DIT) model and the Constrained Molecular Dynamics (CoMD) model, followed by the de-excitation code GEMINI. In this contribution we study mass and momentum distributions for various reaction channels that result in neutron rich products. The comparison of the data with our calculations indicates agreement of the model calculation with the data in the dissipative part of the p/A spectra. The quasielastic part cannot be described by the models hinting to reaction mechanisms beyond successive nucleon exchange.

Keywords Neutron Rich Isotopes, Multinucleon Transfer, Momentum Distributions, Mass Distributions, Fermi Energy

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INTRODUCTION

The production of neutron-rich nuclides in peripheral collisions of heavy ions in the Fermi energy regime (15–25 MeV/nucleon) is of great interest to the nuclear community. The investigation of very neutron rich nuclides may offer a good understanding of the nuclear structure with increasing *N/Z* ratio. Besides, it can elucidate aspects of the astrophysical rapid neutron capture process, also known as r-process, which plays a significant role in the production of nuclides heavier than iron [1].

In the present work two dynamical models, that follow a Monte Carlo approach, are used to describe these reactions, the Deep-Inelastic Transfer (DIT) model [2] and the Constrained Molecular Dynamics (CoMD) model [3]. The de-excitation in both cases is carried out by the GEMINI code [4]. The DIT model is a phenomenological model used to describe peripheral collisions. This model considers a di-nuclear configuration of the system, initially approaching each other at Coulomb trajectories, followed by the representation of two Fermi gases that allow stochastic exchange of nucleons, through a "window" that opens in the potential. The CoMD model is a microscopic model that is based on Quantum Molecular Dynamics (QMD) and considers nucleons as Gaussian wave packets in the phase space. The comparison between the models and the experimental data through the study of the momentum distributions, as hinted by continued efforts of our group [5-7], is providing an insight toward understanding the mechanisms of the reactions near the Fermi energy.

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EXPERIMENTAL DETAILS

The experimental data were obtained at the Cyclotron Institute of Texas A&M University and are presented in detail in previous work [8,9]. A brief description of the experimental set-up is provided. A $^{40}Ar^{9+}$ (15 MeV/nucleon) beam, accelerated by the K500 Cyclotron, interacted with a ^{64}Ni target with thickness of 2 mg/cm^2. The MARS recoil separator was used to collect and identify the projectile fragments. The ^{40}Ar beam was sent to the primary target location of MARS with a 4^o angle with respect to the optical axis of the separator and the projectile fragments were collected in the polar angular range of 2.2^o–5.5^o covering a solid angle of $\Delta\Omega$=4 msr. The fragments, after the interaction with the target, traversed a parallel-plate avalanche counter (PPAC), which provided information for the position and the magnetic rigidity, as well as the START-time, and they were focused on the end of the separator passing through a second PPAC (for STOP-time information) and were collected in a ΔE−E Si detector telescope. To identify the fragments and obtain their atomic number Z, mass number A, velocity and ionic charge, standard techniques of magnetic rigidity, energy-loss, residual energy and time-of-flight were used on an event-by-event basis [10]. Data were obtained in a series of successive magnetic rigidity settings of the spectrometer in the range of 1.1–1.5 Tm [9].

RESULTS AND DISCUSSION

The aforementioned experimental results as well as their comparison with the theoretical calculations will be presented in this part of this work.

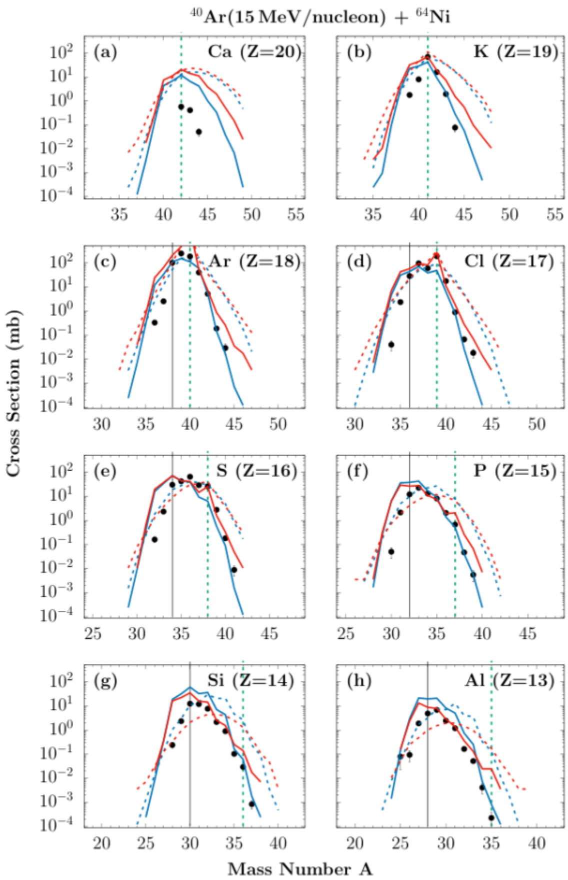

Figure 1. *Mass distributions of projectile-like fragments from the reaction of ^{40}Ar (15 MeV/nucleon) with ^{64}Ni. The black points represent the experimental data. The DIT calculation is represented by the blue lines and the CoMD calculation by the red lines. The data to the left of the vertical black lines are incomplete. The dashed vertical green lines show the beginning of neutron pick-up. The primary projectile-like fragments are represented by the blue dotted lines for the DIT calculation and by the red dotted lines for the CoMD calculation.*

In Fig. 1 we present mass distributions of projectile-like fragments from the reaction of ^{40}Ar (15 MeV/nucleon) with ^{64}Ni. We present the production cross sections for the observed isotopes of the elements with *Z*=13–20. Black points represent the experimental data. The DIT calculation is represented by blue lines and the CoMD calculation by red lines. The data to the left of the vertical black lines are incomplete. The dashed vertical green lines show the beginning of neutron pick-up. Both DIT and CoMD models describe the neutron-rich region with some success. Where the data is incomplete, an inconsistency between the observed data and theoretical calculations arises. Alongside the other calculations, yield distributions of the primary projectile-like fragments are represented by the dotted, blue lines for the DIT calculation and the dotted, red lines for CoMD calculation.

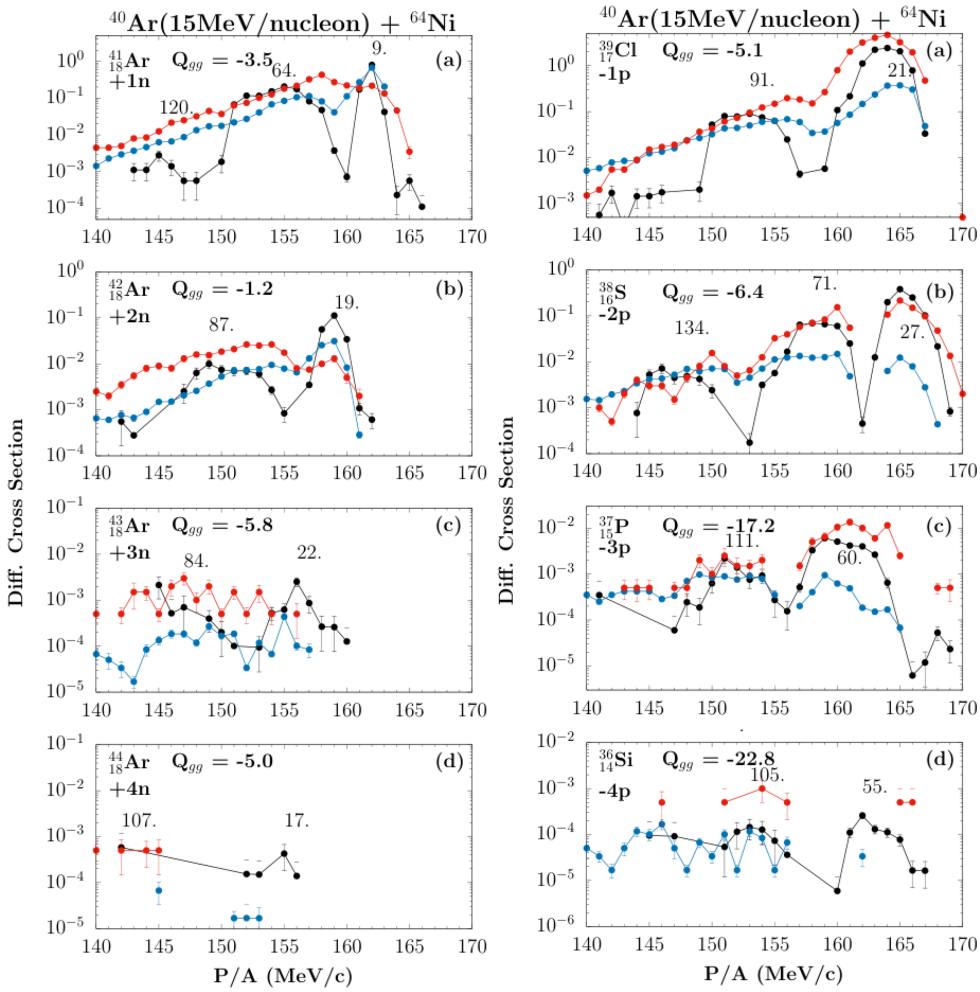

Figure 2. *Momentum distributions of projectile-like fragments from the reaction of ^{40}Ar (15 MeV/nucleon) with ^{64}Ni for 1 to 4 neutron pick-up channels (left panels) and for 1 to 4 proton removal channels (right Panels. Black points: experimental data. Blue points: DIT calculation. Red points: CoMD calculation.*

In Figures 2, 3 and 4, we present the momentum distributions of several projectile-like fragments from the reaction ^{40}Ar with ^{64} Ni target at 15 MeV/nucleon. Black points represent the experimental data. The DIT calculation is represented by blue points and the CoMD calculation by red points. The reaction channels studied are the ones for 1 to 4 neutron pick-ups in Figure 2, for 1 to 4 proton removals in Figure 3 and for Single Charge Exchange (SCE) and Double Charge Exchange (DCE) in Figure 4. The horizontal axis of the momentum distributions shows momentum per nucleon, which essentially represents velocity. The vertical axis gives the measured differential cross sections with respect to p/A, obtained in the solid angle window of ΔΩ = 4 msr at a reaction angle of 4°.

The general feature of the momentum distributions is the presence of two main regions, the narrow quasi-elastic peak that corresponds to direct processes on the right side and a broader region (located in lower values of p/A) that corresponds to more dissipative mechanisms. The total excitation energy of the quasi-projectile and quasi-target system was obtained by binary kinematics calculations. These calculations assume no nucleon evaporation. These excitation energies are reported on some of the peaks of the momentum distributions and indicate the degree of dissipation that is involved.

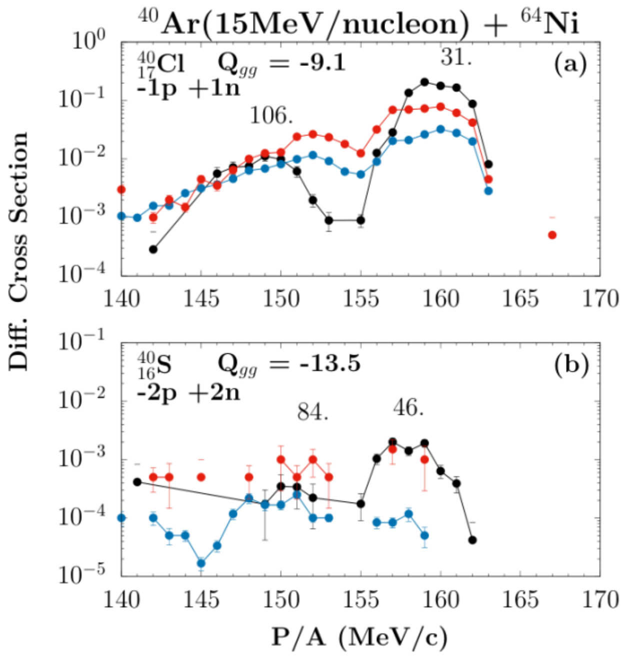

Figure 3. *Momentum distributions of projectile-like fragments from the reaction of ^{40}Ar (15 MeV/nucleon) with ^{64}Ni for single and double charge exchange. Black points: experimental data. Blue points: DIT calculation. Red points: CoMD calculation.*

CONCLUSIONS

In this contribution we study the reaction a ^{40}Ar beam at 15 MeV/nucleon and a ^{64}Ni target. We compare the experimental data with the DIT and CoMD theoretical models. Both of them describe the experimental data effectively, particularly the mass distributions. Concerning the momentum distributions both models are challenged at describing the quasi-elastic peak but appear to describe the region of the more dissipative mechanisms sufficiently. These challenges in the description of the quasielastic part imply that the mechanisms involved may include direct processes that we are actively investigating more thoroughly. In the future, conducting more studies of peripheral reactions of medium-mass nuclei in the Fermi energy regime, along with the study of additional reaction channels will enhance our understanding of this energy region.

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