TRANSFER CROSS SECTIONS AT NEAR-BARRIER ENERGY FOR THE ^{24}Mg + ^{90,92}Zr SYSTEMS*

D. Wójcik[a], A. Trzcińska[b], E. Piasecki[b], M. Kisieliński[b]
M. Kowalczyk[b], M. Wolińska-Cichocka[b], C. Bordeanu[c]
B. Gnoffo[d,e], H. Jia[f], C. Lin[f], N.S. Martorana[g,e], M. Mutterer[h,i]
E.V. Pagano[g], K. Piasecki[a], P. Russotto[g], L. Quatrocchi[d,e]
W.H. Trzaska[j], G. Tiurin[j], R. Wolski[k,l], H. Zhang[f]

[a]Institute of Experimental Physics, Faculty of Physics, University of Warsaw
Warszawa, Poland
[b]Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
[c]Horia Hulubei National Institute for Physics and Nuclear Engineering
Bucharest-Măgurele, Romania
[d]INFN — Sezione di Catania, Catania, Italy
[e]Dipartimento di Fisica e Astronomia Università di Catania, Italy
[f]China Institute of Atomic Energy, Beijing, China
[g]INFN-LNS, Catania, Italy
[h]Institut für Kernphysik, Technische Universität Darmstadt
Darmstadt, Germany
[i]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
[j]Department of Physics, University of Jyväskylä, Jyväskylä, Finland
[k]Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia
[l]H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland

(Received December 6, 2017)

We have tested the hypothesis that for systems ^{24}Mg + ^{90,92}Zr, the shape of the barrier height distribution is not influenced by transfers processes. The experiment was performed using the ICARE detector system at the Warsaw Cyclotron. Having measured the transfer cross sections of the near-barrier collisions of ^{24}Mg + ^{90,92}Zr, we have found them to be roughly half of the value obtained for the ^{20}Ne + ^{90,92}Zr systems. From that observation, we conclude that in the ^{24}Mg + ^{90,92}Zr case, the leading cause of washing out the barrier distribution structure is the partial dissipation of relative kinetic energy into the non-collective excitation of the system.

DOI:10.5506/APhysPolB.49.387

* Presented at the XXXV Mazurian Lakes Conference on Physics, Piaski, Poland, September 3–9, 2017.

1. Introduction

Investigation of the nucleus–nucleus barrier has been intensively pursued throughout the last decades [1–5]. It is known that interplay between the relative motion of two colliding nuclei and their internal degrees of freedom results in a splitting of the single value of the barrier into many barriers. The distribution of their heights is given by [6, 7]

$$D_{\rm qe} = -\frac{{\rm d}(\sigma_{\rm qe}/\sigma_{\rm Ruth})}{{\rm d}E} \quad , \tag{1}$$

where $\sigma_{\rm qe}$ is the cross section for the quasi-elastic processes, the latter defined as the sum of elastic, inelastic scattering and transfer processes, $\sigma_{\rm Ruth}$ is the Rutherford cross section, and E is the center-of-mass energy, often parameterized in terms of $E_{\rm eff}$, the center-of-mass energy corrected for the centrifugal energy [8].

The experimentally observed shape of the barrier distribution can either exhibit structures, or appear smeared out [9]. Within the current understanding, the shape is the result of coupling of various reaction channels involved in the reaction dynamics. The standard theoretical description within the Coupled Channels (CC) approach takes into account only the strong collective (rotational and/or vibrational) excitations, while the treatment of the non-collective excitations and transfer channels is either absent or not implemented appropriately [10]. It has been suggested [9, 11–13] that these, presumably weak, reaction channels, omitted from the standard CC calculations, could, in fact, be responsible for washing out of the structure in barrier distribution.

Recently, the studies of the near-barrier collisions of the ^{20}Ne+^{90,92}Zr systems have shown that while the structure is observed in barrier distribution for ^{90}Zr case, it vanishes for ^{92}Zr, still the total transfer cross sections for both targets are very similar. This observation has led to the suggestion that weak but numerous couplings to non-collective levels (by order of magnitude more abundant in ^{92}Zr than in ^{90}Zr nuclei) [9, 14] are responsible for the smoothing of the structure.

In the recent experiment performed at the LNS, Catania, we have investigated the barrier height distribution of ^{24}Mg+^{90,92}Zr systems [15]. The very strong deformation of projectile ^{24}Mg should give rise to similarly structured shapes for these systems. However, according to the preliminary finding, described elsewhere in this proceedings volume [15], the $D_{\rm qe}$ pattern appears to be structured for ^{90}Zr, and smooth for ^{92}Zr. They are also found to disagree with the predictions of the standard CC calculations, taking into account only collective excitations of the system. The aim of our study is to verify whether these discrepancies were caused by the transfer reactions, or other non-collective excitations.

2. The experiment

The measurement was performed at the Heavy Ion Laboratory, University of Warsaw, with help of the multidetector system ICARE [16]. Figure 1 shows the scheme of the experimental set-up. The Time-of-Flight (ToF) technique was used to identify the masses of backscattered ions. The "start" signal was given by the Microchannel Plate (MCP) detector. The "stop" signal was triggered by one of the four 20 mm $\times$ 20 mm Si detectors placed at a laboratory polar angle $\theta_{\mathrm{lab}} = 142^{\circ}$. The Si detectors measured also the energy of the reaction products. The base length of the ToF system was 78 cm. Three Si detectors mounted at the forward angle of $\theta_{\mathrm{lab}} = 30^{\circ}$ were used to monitor the beam energy.

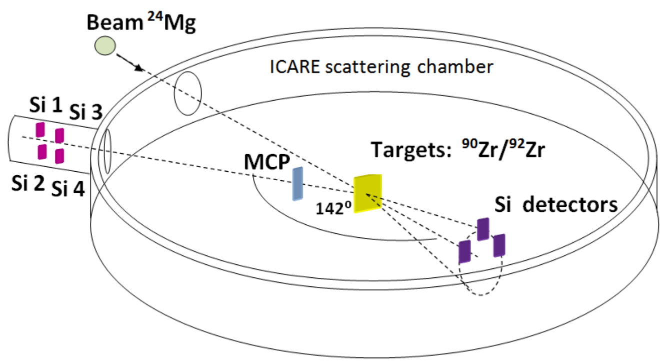

Fig. 1. Schematic view of the experimental setup (see the text for details).

The targets were bombarded with the ^{24}Mg ions accelerated in the Warsaw U200-P Cyclotron. The laboratory beam energy $E_{\mathrm{lab}} = 76$ MeV (corresponding to $E_{\mathrm{eff}} \sim 56$ MeV at 142°) was chosen in order to investigate the region of the "structure" in the barrier height distribution [15]. The ^{90}Zr and ^{92}Zr targets were of $\sim$100 μm/cm^2 thickness, evaporated on the 20 μm/cm^2-thick carbon support.

3. Analysis

The raw E–ToF spectra of backscattered ions are shown in Fig. 2. Groups of events corresponding to different transfer reactions are marked by the appropriate atomic mass values of detected ions. Within the available statistics and resolution, the stripping reactions involving up to 4 nucleons, and the reaction channels with up to 2 nucleons picked up were identified.

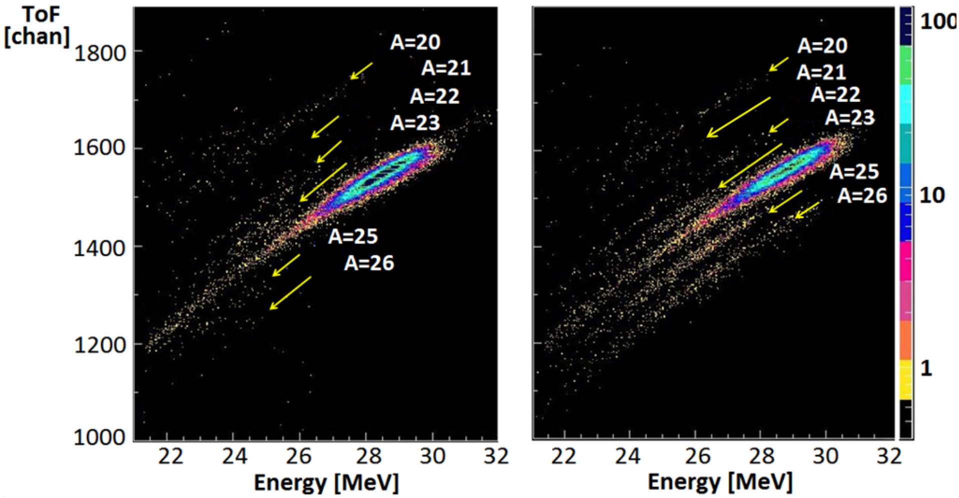

Fig. 2. The raw E–ToF spectra of backscattered ions, measured at $\theta_{\rm lab} = 142^{\circ}$ for the ^{24}Mg + ^{90}Zr (left panel) and ^{24}Mg + ^{92}Zr (right panel) systems.

The transfer cross sections $\sigma_{\rm trans}$ were determined using Eq. (2)

$$\sigma_{\rm trans} = \frac{\sigma_{\rm trans}}{\sigma_{\rm qe}} \frac{\sigma_{\rm qe}}{\sigma_{\rm Ruth}} \sigma_{\rm Ruth} \,. \tag{2}$$

The $\sigma_{\rm trans}/\sigma_{\rm qe}$ ratio was obtained from the above mentioned plot. The $\sigma_{\rm Ruth}$ is the Rutherford cross section calculated at $\theta_{\rm lab} = 142^{\circ}$ and has the value 57.9 mb/sr and 58.2 mb/sr for ^{90}Zr and ^{92}Zr targets, respectively. The $\sigma_{\rm qe}/\sigma_{\rm Ruth}$ ratios were obtained in another experiment for the same colliding system and beam energy, described in the accompanying paper [15] in these proceedings. They were found to be 0.74 and 0.67, respectively [17].

4. Results and discussion

A compilation of the obtained transfer cross sections is presented in Fig. 3. One can see that, whereas the cross sections for the systems with neon beam are very similar, the values for the systems with magnesium one are clearly different from each other. Moreover, the alpha transfer channel, which was dominating in the cases of ^{20}Ne + ^{90,92}Zr [13], and ^{20}Ne + ^{58,60,61}Ni [10] is found to be very weak for the ^{24}Mg beam. Most importantly, the cross sections for the sum of transfer processes in ^{24}Mg + ^{90,92}Zr cases were found to be: 0.48 ± 0.02 mb/sr, and 1.74 ± 0.04 mb/sr, respectively, less than half of that for the ^{20}Ne + ^{90,92}Zr systems [9], also shown for comparison in Fig. 3.

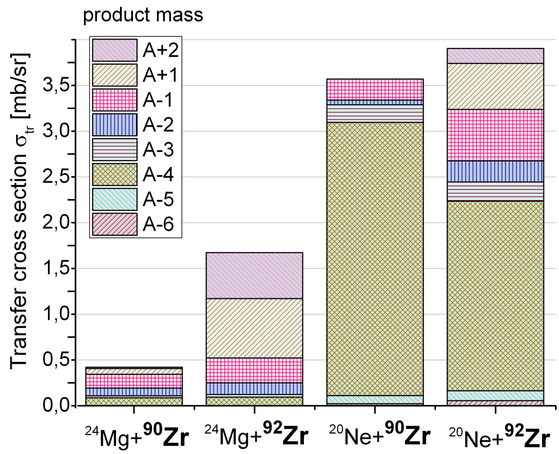

Fig. 3. Preliminary values of transfer cross sections measured for backscattering of ^{24}Mg ions on ^{90,92}Zr targets (at $E_{\mathrm{eff}} = 56$ MeV and $\theta_{\mathrm{lab}} = 142°$). A is the projectile mass number. The transfer cross sections for ^{20}Ne+^{90,92}Zr at near-barrier energy [9] are also shown.

It is important to note that in the ^{20}Ne+^{90}Zr system, a structure in D_{qe} was observed [9], although the transfer in this case is clearly stronger than for ^{24}Mg+^{92}Zr. Moreover, since in the ^{20}Ne+^{92}Zr the structure smoothing was most probably not due to transfer [9], that is the strong indication that the transfer channels do not play a significant role in the shape of barrier height distribution also in the system under study. The conclusion of Ref. [10] was the same.

Thus, an explanation of the lack of structure in D_{qe} for ^{92}Zr target would be that this is caused by the influence of weak but numerous non-collective excitations. In this context, it is worthwhile to realize that the ^{92}Zr nucleus has two extra neutrons in comparison with the magic ^{90}Zr nucleus, what enhances by order of magnitude the level density of single-particle states [18].

5. Summary

The transfer reactions cross sections for the collisions of ^{24}Mg + ^{90,92}Zr systems at the near-barrier energy and $\theta_{\mathrm{lab}} = 142°$ have been measured. The extracted cross sections of 0.48 ± 0.02 mb/sr and 1.74 ± 0.04 mb/sr, respectively, are considerably smaller than those for the ^{20}Ne + ^{90,92}Zr systems, where for ^{90}Zr we observed a clear structure in D_{qe}.

These findings suggest that in the ^{24}Mg + ^{92}Zr case, the leading cause of washing out the barrier distribution structure is the partial dissipation of relative kinetic energy into the non-collective excitation of the system, like in the case of ^{20}Ne projectiles.

This project has received funding from the European Union's Horizon 2010 research and innovation programme under the grant agreement No. 654002. This research was supported in part by the PL-Grid Infrastructure. The authors are grateful to LNS technical staff for the ^{90,92}Zr targets of high quality.

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