QUASIELASTIC BARRIER DISTRIBUTIONS FOR THE ^{20}Ne $+^{92,94,95}$ Mo SYSTEMS: INFLUENCE OF DISSIPATION*

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A comparative study of the quasielastic barrier distributions of the ^{20}Ne+^{92,94,95}Mo systems was performed at the Heavy Ion Laboratory (HIL) of the University of Warsaw. The experiment aimed to study the influence of dissipation due to single-particle excitations on the barrier distribution structure. The preliminary results indicate that the larger number of single-particle excitations for the heaviest Mo isotopes leads to the smoothing of the barrier distribution, which loses the structure foreseen by the coupling to only collective excitations. Theoretical calculations performed including the coupling to the non-collective excitation are in good agreement with the experimental barrier distributions for the ^{20}Ne + ^{92,94,95}Mo systems.

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1. Introduction

During the fusion reaction, the excited states of the projectile and target nuclei are populated and their relative motion couples with them. The extraction of barrier distributions from careful and detailed measurements proved to be particularly useful in the identification of the nature of these

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couplings [1]. In the frame of the Coupled Channels (CC) model [2, 3], the couplings of the relative motion to intrinsic degrees of freedom, such as collective inelastic excitations of the colliding nuclei and/or transfer processes, lead to the split of the barrier into several distributed barriers. As a result, the barrier distributions show significant differences among different systems, giving a fingerprint of the structure of the interacting nuclei and the dynamics of the reaction.

The CC model successfully explained the strong enhancement of sub-barrier fusion cross sections as well as the observed structures in the barrier distributions for many systems. However, there are several mechanisms whose influence on the fusion is still not clear: for example, the influence of weak (non-collective) reaction channels on barrier height distributions and, consequently, on fusion dynamics.

The experimental quasielastic barrier distributions (D_{qe}) of some systems turned out to be smooth (without any structure), in contradiction to theoretical CC predictions. This was observed for the ^{20}Ne + ^{92}Zr [4], ^{20}Ne + ^{61}Ni [5], and ^{24}Mg + ^{92}Zr [6] systems. The cause of the difference in respect of the CC expectations was found in a dissipative mechanism, where part of the kinetic energy is dissipated into the excitation of a multitude of internal non-collective levels of the system. Despite the coupling of these levels is generally much weaker than that of the collective ones, the non-collective excitations are so numerous that they can influence the barrier penetrability, therefore the shape of barrier distribution. Such experimental evidence triggered the development of a new theoretical technique able to include the coupling to non-collective excitations in the fusion reactions through the model [7], where a statistical approach is merged with quantum mechanics by extending the CC method using the random matrix theory (RMT). The method was successfully applied to some studied systems [8].

In this framework, at the Heavy Ion Laboratory (HIL) of the University of Warsaw, a detailed comparative study of the quasielastic barrier distributions of the three systems ^{20}Ne + ^{92,94,95}Mo was performed. The aim of the experiment was the study of the influence of dissipation on fusion via measurements of quasielastic barrier distributions under well-controlled conditions by choosing isotopes of the same element which differ by single particle level densities. In this perspective, the target nuclei were chosen to minimize the influence of transfers and maximize the difference between the single-particle (s.p.) level densities. As in the previous studied cases, according to the standard CC method, the shapes of the barrier distributions for all three systems should be similar, determined mainly by the ^{20}Ne projectile structure. However, the influence of the larger number of s.p. excitations for heavier Mo isotopes should manifest in the smoothing of the barrier distributions.

2. Experiment

The U200-P Cyclotron of HIL provided the ^{20}Ne beam at an average current of 25 enA and energies of 65, 70, and 73 MeV. Changes in beam energy in small steps (~ 0.5 MeV) were obtained using degraders consisting of thin $^{\text{nat}}$Ni and $^{\text{nat}}$Au foils. Thin ^{92}Mo (enriched to 98.27%), ^{94}Mo (92.03%), and ^{95}Mo (96.47%) targets of 181, 156, and 162 μg/cm^2 thickness, respectively, were used. The targets were prepared from MoO_3 on a C backing of 40 μg/cm^2 thickness.

The experiment was performed by employing the compact CUDAC3 chamber. The scattering chamber is equipped with an array of 30 silicon detectors (PIN diodes) placed at the backward angles of 145, 135, and 125 degrees and four PIN diodes at the forward angle of 35 degrees. The setup allows us to measure the quasielastic barrier distribution with the backscattering method, where the backward detectors provide the energy and number of the backscattered projectiles, while the forward detectors are used for beam energy determination and normalization by the Rutherford scattering. The detectors also constantly monitor the energy resolution which was equal to $\sim$ 1.5 MeV, 2.2 MeV, and 1.3 MeV for ^{92,94,95}Mo, respectively, in the center-of-mass system and was determined mainly by beam properties.

3. Results

Following the conversion of the energy spectra of the detected ions into Q-value spectra [4, 9], the number of quasielastic backscattered and Rutherford scattered events was estimated by integrating the Q-value spectra in

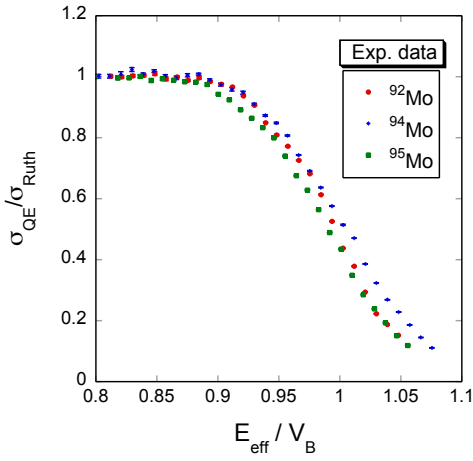

Fig. 1. Comparison of the excitation functions for the three ^{20}Ne + ^{92,94,95}Mo systems. The energy scale is normalized to the height of the Coulomb barriers V_{B} estimated according to the Akyüz–Winther parametrization.

the range of −5 MeV and 11 MeV. The preliminary quasielastic excitation functions obtained are shown in Fig. 1. The overall data were binned over 0.5 MeV intervals and normalized to the $\sigma_{\rm qe}/\sigma_{\rm Ruth}$ at the lowest measured energy. The last procedure allows for neglecting precise information on detectors' solid angles, target thickness, and absolute beam current, as well as associated systematic errors. The comparison of the excitation functions indicates small differences among the systems. In particular, a steeper trend of the ^{92}Mo is observable with respect to the neighbour isotopes at energies above the Coulomb barrier.

To highlight differences between the three systems, the barrier distributions were extracted. Preliminary results are shown in Fig. 2, where the experimental barrier distributions are compared with the theoretical pre-

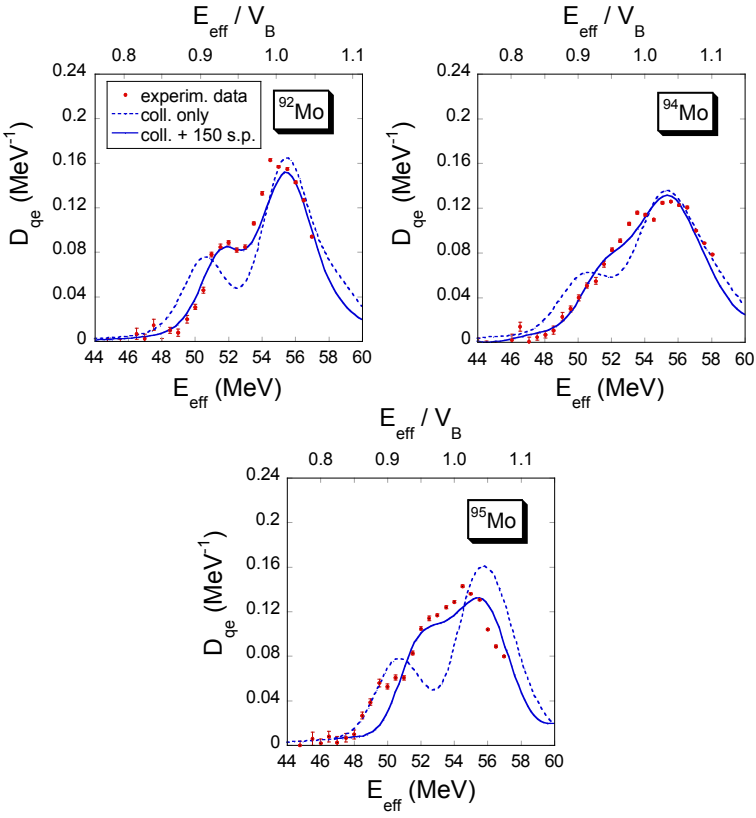

Fig. 2. Quasielastic barrier distributions of the ^{20}Ne + ^{92,94,95}Mo systems. The experimental data are compared with predicted barrier distributions, with (solid lines) and without including dissipation due to non-collective excitations (dashed lines). The energy resolution for the three systems was taken into account by folding the calculated distributions with a Gaussian function with a correspondent FWHM.

dictions. The theoretical calculations performed within the CC method (dashed lines) included the rotational coupling to the first three excited states of ^{20}Ne and vibrational couplings up to the two-phonons excitations of the first quadrupole and octupole excited states of ^{92,94}Mo isotopes. In the case of the odd ^{95}Mo isotope, the couplings to the one phonon excitation of the $3/2^+$ and to the one and two phonons excitations of the $5/2^+$ excited states were included by treating them as quadrupole and octupole excitations, respectively.

As expected, for the ^{92}Mo target, where the level density is low, the barrier distribution is still structured, as foreseen by the CC model. For the ^{94}Mo and ^{95}Mo targets, the structures of the experimental barrier distribution are almost structureless and significantly smoothed out.

Couplings to 150 s.p. levels were included by employing the CC+RMT model (solid lines). By taking into account the couplings to non-collective excitations, the predicted barrier distributions nicely reproduce the experimental barrier distributions of the $^{20}\mathrm{Ne} + {}^{92,94,95}\mathrm{Mo}$ systems. For the intermediate case of the ^{94}Mo isotope, the structure of the experimental barrier distribution is smoother and wider with respect to the one of ^{95}Mo, despite the higher level density of the latter.

4. Summary and conclusions

The comparative study of the $^{20}\mathrm{Ne} + {}^{92,94,95}\mathrm{Mo}$ systems indicates the influence of the dissipation due to the coupling to non-collective excited states on the shape of the barrier distributions. This manifests in the smoothing out of the barrier distribution with respect to the CC prediction, more evident for the heavier Mo isotopes, where the level density is higher. The theoretical calculations performed within the CC+RMT model are in good agreement with the experimental data, supporting the hypothesis that non-collective excitations can alter the structure of the barrier distributions. Surprising is the case of the ^{94}Mo, whose structure is smoother and wider with respect to the ^{95}Mo, for which a smoother structure was expected due to its highest level density. This could be caused by still another mechanism of dissipation, being the projectile–target transfers of light particles. In this perspective, the measurement of the transfer cross sections for different transfer channels and the following comparison between the neighbour isotopes can determine whether for these systems the transfer couplings might play a significant role in the dynamic of the reaction [4, 10, 11]. As a next step, it is therefore mandatory to study the influence of transfer channels on the considered systems.

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