Extending the $^{40}\text{Ca} + \text{Zr}$ systematics to low energy

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INTRODUCTION

The sub-barrier fusion in $^{40}\text{Ca} + \text{Zr}$ was recently measured down to very low cross sections [1], looking for fusion hindrance. No evidence of hindrance was found even though the measurements extended well below the fusion barrier, actually below the potential pocket minimum, as constrained by the available experimental information [2]. Such a result is incompatible with the “sudden approximation” model so successfully employed with medium-heavy systems, including other isotopic combinations of the same elements.

In contrast, the fusion of $^{40}\text{Ca} + ^{90}\text{Zr}$ drops quickly below barrier suggesting the rapid onset of hindrance: thus, at low energy, the “isotopic effect” in these systems appears to span all the way from prompt to no hindrance, and from the sudden to the adiabatic regime.

However, the fusion hindrance of $^{40}\text{Ca} + ^{90}\text{Zr}$ was never experimentally observed due to the contamination of the zirconium target with heavier isotopes having a substantially larger fusion cross section, namely $^{94,96}\text{Zr}$, $^{92}\text{Zr}$ and to a minor extent $^{91}\text{Zr}$. Fusion evaporation residues (ER) resulting from such contaminants cannot be experimentally discriminated and despite an isotopic enrichment at 99.36% their combined contribution is comparable, or even superior, to the production from $^{90}\text{Zr}$ at the expected onset of hindrance.

In this study, we exploited the precise knowledge of fusion cross-sections with the heavier zirconium isotopes ($^{94,96}\text{Zr}$), at the same time measuring the next critical contaminant ($^{92}\text{Zr}$), in order to correct for target-impurity contributions in $^{90}\text{Zr}$, as long as they are not too large.

EXPERIMENT AND PRELIMINARY RESULTS

The $^{40}\text{Ca}$ beam, from 128 to 155 MeV, was accelerated by the XTU-Tandem of the LNL onto thin $^{90,92}\text{Zr}$ targets, 50µg/cm² thick, evaporated onto 15 and 20 µg/cm² carbon foils, respectively. The beam was monitored by four collimated Si-detectors at 23.2° and the evaporation residues were separated from the beam-like particles by an electrostatic deflector, placed at 2° with respect to the beam, and further discriminated thanks to a detector telescope providing Energy, Time-of-Flight and Energy-loss signals. Thus, the events were amply over-determined, allowing effective background rejection by use of multiple gates with a negligible loss in efficiency.

Even so, correcting for the heavier contaminants in the $^{90}\text{Zr}$ target only proved effective down to the level of 70 µb, below which we can only provide an upper limit.

Angular distributions were measured at 152 MeV, but the absolute cross sections were obtained by normalizing to the previous $^{40}\text{Ca} + ^{90}\text{Zr}$ data.

Fig. 1. Old and new fusion excitation functions of different $^{40}\text{Ca} + \text{Zr}$ combinations. For the sake of clarity, the lowest energy point in $^{40}\text{Ca} + ^{90}\text{Zr}$ is not shown.

The excitation function of $^{40}\text{Ca} + ^{92}\text{Zr}$ was measured for the first time; the structure of $^{92}\text{Zr}$ is very similar to $^{94}\text{Zr}$ and positive neutron-transfer Q-values are also available, but not so much as with $^{94}\text{Zr}$ and $^{96}\text{Zr}$. It should provide a valuable contribution to the understanding of such systems within the coupled-channels formalism.