Time scales in fission processes in reactions involving ^{197}Au as target

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I. INTRODUCTION

Superheavy elements (SHEs) are produced in the laboratory by fusing the heavy nuclei. Elements up to Z = 118 have already been synthesized in the laboratory till date. These elements are existing solely due to the microscopic stabilization provided by shell effects.

Quasifission is a major hurdle in SHE synthesis. In quasifission the system after capture re-separates before achieving complete equilibration in all degrees of freedom. Hence formation of compound nucleus is suppressed by the quasifission phenomenon. This process has a strong entrance channel dependence, and it is very important to understand the time scales involved in fusion-fission and quasifission. It has been demonstrated [1, 3] that mass-angle distributions can be used as an effective probe to understand time scales involved in these processes. Quasifission occurs on short time scales (around 10^{-20} seconds), while fusion-fission takes longer duration, typically 10^{-18} - 10^{-19} seconds [1–3]. Understanding the time scale involved in this processes would help us to improve the SHEs synthesis.

II. EXPERIMENTAL METHOD

The measurements were performed at the Australian National University using the 14UD pelletron accelerator facility and the LINAC facility. Pulsed beams of ^{32,36}S, ^{48}Ca, ^{50,58}Ti, ^{54}Cr, ^{58}Fe and ^{64}Ni with a pulse width (FWHM) of 1.5 ns were used in the measurement to bombard ^{197}Au target of thickness 180 $\mu g/cm^2$. The measurements were carried out in the energy range of 225-382 MeV. The binary fragments produced in the reaction were detected using CUBE [4] detector setup. Kinematic reconstruction [5] method was used for obtaining the fragment masses and mass ratio distributions.

III. DISCUSSION

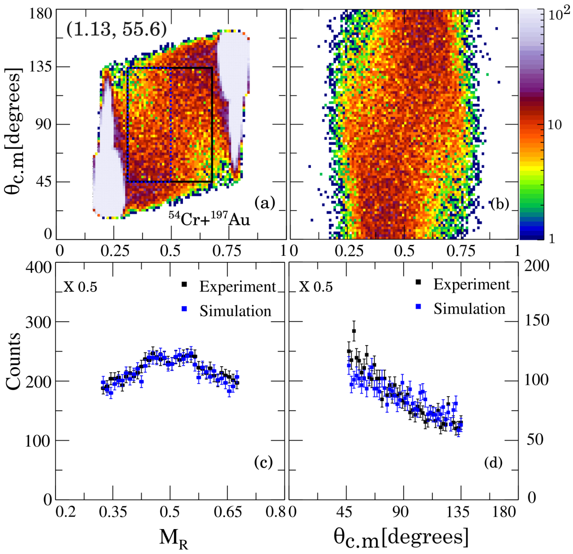

FIG. 1: Upper panels show the mass-angle distribution (MAD) for ^{54}Cr + ^{197}Au: (a) experimental, (b) simulated. Lower panels present projections: (c) onto M_R axis ($0.3 \leq M_R \leq 0.7$, $45° \leq \theta_{\text{c.m.}} \leq 135°$), and (d) onto $\theta_{\text{c.m.}}$ axis M_R ($0.3 \leq M_R \leq 0.5$, $45° \leq \theta_{\text{c.m.}} \leq 135°$), with regions highlighted by black solid and blue dashed boxes in panel (a).

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In this work, we have reproduced the MADs previously reported in ref. [6] by a Monte Carlo simulation method. The experimental MAD, simualted MAD, the experimental and simulated M$_R$ distributions (X-projections of experimental and simulated MAD within the selected window) and the experimental and simulated angular distributions (Y-projections of the experimental and simulated MAD within the selected window) are shown in Fig 1, for ^{54}Cr + ^{197}Au reaction, as an example. Simulations have been performed for all the systems reported in ref. [6].

The key ingredients of the model used in this simulation are the angular distribution, and the distribution of sticking times of the di-nuclear system [1, 3]. The classical rigid body moment of inertia is used in these calculations, accounting for the deformation of the reaction partners. The sticking time distribution was parametrized using a half-Gaussian rise followed by an exponential fall. The mean and width of the half-Gaussian (rise time) and the fall time were the variables adjusted to reproduce experimental MADs in the simulation. Simulations were separately carried out for the side and tip collisions. The prescription of Toke *et. al.,* [5] with mass equilibration constant 5.2 × 10^{-21}s was used for the mass evolution, after contact. Separate angular momentum distributions were generated using CCMOD for collisions ranging from 0°-25° for tip collisions and from 26°-90° for side collisions. The distribution for tip collisions was used to generate fast quasifission, while the distribution for side collisions was used to generate slow quasifission and fusion fission.

$$\theta_s(t_s) = \frac{\sqrt{J(J+1)}\hbar}{I} t_s \tag{1}$$

The contact time scale of various reactions studied in this work is plotted against the charge product Z$_P$Z$_T$ in Fig. 2, where Z$_P$ and Z$_T$ are the atomic numbers of the projectile and target, respectively. A strong dependence of quasifission on the charge product may be noticed here. As anticipated, the reaction ^{32}S + ^{197}Au exhibits a longer timescale, evidenced by its high mean sticking time. The corresponding MAD is dominated by fusion-fission and slow quasifission [6]. On the other hand, for the ^{64}Ni + ^{197}Au reaction, we observe the shortest timescale, suggesting fast quasifission dominating the reaction mechanism. Details will be discussed in the symposium.

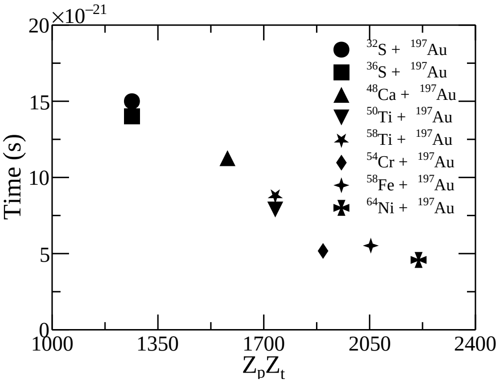

FIG. 2: Mean sticking time as a function of the charge product (Z$_p$Z$_t$) for all the reactions.

Acknowledgments

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