Mass Angle Distribution analysis of ^{40}Ca+^{178}Hf and ^{40}Ca+^{176}Yb reactions

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Introduction

The quest for superheavy elements (SHE) that populate the island of stability has culminated in experimentation with numerous projectile and target nuclei. A reduced production cross section of SHE is being observed due to the various non-equilibrium processes. Among these quasifission plays a crucial role. Being a dynamical process, many features of this process and the underlying reasons are not completely known yet and warrants a systematic study of quasifission. Here, we report the mass angle distribution measurements of ^{40}Ca+^{178}Hf and ^{40}Ca+^{176}Yb reactions and a comparison of the experimental results with theoretical models and other reactions.

Experimental details and analysis

The experiment was performed at the Heavy Ion Accelerator Facility of the ANU. Pulsed beams of ^{40}Ca with a pulse separation of 107 ns and FWHM of 0.7 to 1.5 ns from 14 UD Pelletron accelerator were further boosted in energy by the superconducting linear accelerator. The measurements were performed at 4 beam energies in the range 200 – 226 MeV. Isotopically enriched ^{178}Hf (35 μg/cm^2 on 30 μg/cm^2 Al backing) and ^{176}Yb (80 μg/cm^2 on 40 μg/cm^2 C backing) were used for the measurements. Fission fragments were detected using CUBE setup [1] consisting of two large area MWPCs mounted at 45^0 and 90^0 with respect to the beam direction.

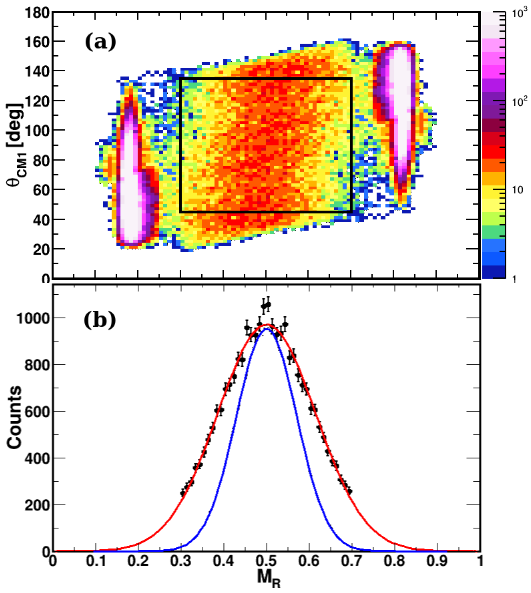

FIG. 1: (a) MAD scatter plot and (b) M_R distributions for the ^{40}Ca+^{178}Hf reaction at E_{lab}=226 MeV. Gaussian fit to the data and GEF M_R distribution are also shown.

The position and timing signals obtained from the fission detectors were used to generate the mass angle distribution (MAD) for the binary fragments [1]. Fragment velocity is determined by kinematic coincidence method and is used to estimate mass ratio (M_R) of the fragments [2],

$$M_R = \frac{m_2}{m_1 + m_2} = \frac{v_1}{v_1 + v_2}, \qquad (1)$$

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where m_1, m_2, v_1 and v_2 are the masses of the fragments at scission and their velocities in the center-of-mass frame respectively. The M_R distribution is obtained by projecting the MADs on to the M_R axis and are fitted using a Gaussian function. MAD and M_R distribution for the ^{40}Ca+^{178}Hf reaction at 226 MeV beam energy is given in FIG. 1 (a) and FIG. 1 (b), respectively. M_R distribution generated using GEF [3] calculation is also shown in FIG. 1(b). The width (σ_{MR}) of both experimental and GEF distributions are obtained from the Gaussian fit.

Results

Strong mass-angle correlation is observed in both reactions at all four measured energies. The mass angle correlation observed in M_R distribution highlights the dominance of quasifission in both reactions. The experimental values of mass width are compared with the theoretical values from GEF [3] and scission point model [4], and are shown in FIG. 2. Significantly higher M_R width is observed in both reactions compared with the theoretical calculations. An increasing trend in the σ_{MR} values with decreasing beam energy at near Coulomb barrier is noticed for both reactions, hinting the deformation alignment of the targets used in the present study. Such alignments are observed to favour quasifission process in heavy ion collisions.

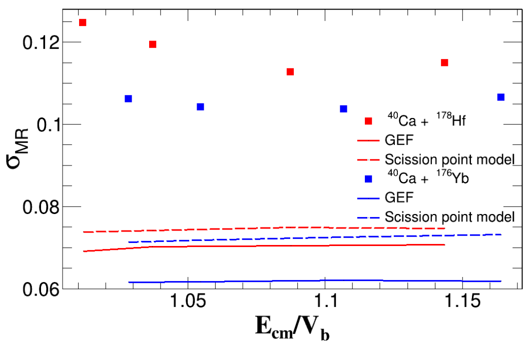

FIG. 2: Experimental σ_{MR} values compared with theoretical values.

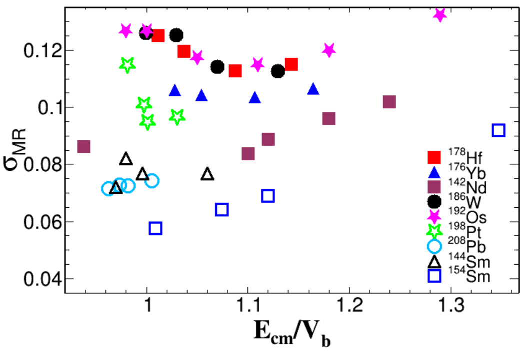

FIG. 3: σ_{MR} values for of various Ca induced reactions [2, 5–7]. Filled and open symbols are used for reactions using ^{40}Ca and ^{48}Ca beams, respectively.

In FIG. 3, σ_{MR} values for various Ca induced reactions are shown as a function of E_{cm}/V_b. Significant quasifission is observed in reactions using deformed targets such as Hf, Os, W, and Yb. Strikingly low σ_{MR} is noticed for the reaction with ^{208}Pb, though the charge product is higher for this reaction, compared to other pre-actinide targets. Despite of being highly deformed, reaction with ^{154}Sm also shows a narrow mass ratio distribution. Comparison of these Ca induced reactions displays the role of static deformation of the target, N/Z asymmetry in entrance channel, entrance channel magicity etc influencing the reaction mechanism in these reactions.

References

[1] D. J. Hinde et al. Phys. Rev. C 53, (1996)
[2] E. Prasad et al. Phys. Rev. C 96 (2017)
[3] Karl-Heinz Schmidt et al. Nucl. Data Sheets 131 (2016)
[4] A. Shamlath et al. Nucl. Phys. A 945 (2016)
[5] B. M. A. Swinton-Bland et al. EPJ Web of Conferences 232 (2020)
[6] E. Prasad et al. Phys. Rev. C 91 (2015)
[7] G. N. Knyazheva et al. Phys. Rev. C 75 (2007)