Nuclear structure dependence of fusion hindrance in heavy element synthesis

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(Received 4 February 2018; revised manuscript received 2 March 2018; published 28 June 2018)

The production of the heaviest elements in fusion-evaporation reactions is substantially limited by very low cross sections, as fusion cross sections (including fusion-fission) are greatly reduced by the competing quasifission mechanism. Using the Australian National University Heavy Ion Accelerator Facility and CUBE detector array, fission fragments from the ^{48}Ti + ^{204,208}Pb and ^{50}Ti + ^{206,208}Pb reactions have been measured, with the aim to investigate how the competition between quasifission and fusion-fission evolves with small changes in entrance-channel properties associated mainly with the nuclear structure. Analysis of mass-distribution widths of strongly mass-angle-correlated fission fragments within the framework of the compound-nucleus fission theory demonstrates significant differences in quasifission (and therefore fusion) probabilities among the four reactions. The impact of nuclear structure on fusion highlights the importance of future radioactive beams.

DOI: 10.1103/PhysRevC.97.064618

I. INTRODUCTION

The fusion of two nuclei is a process relevant for the production of many chemical elements. Moreover, the fusion of heavy ($Z \geqslant 16$) projectiles and massive ($Z = 82$–98) target nuclei followed by the evaporation of neutrons has been used to synthesize the superheavy elements (SHEs) up to $Z =$ 118 [1–3]. The probability of the fusion-evaporation process proceeding through the formation of a compound nucleus (CN) with full equilibration in all degrees of freedom at an excitation energy E^* can be expressed as $P_{fu}W_{\rm CN}$, where P_{fu} is the fusion probability and $W_{\rm CN}$ is the survival probability of the CN through particle evaporation against fission. The fusion can be strongly hindered by the competing quasifission (QF) process, where the two touching nuclei re-separate before reaching equilibrium [4–6]. Generally, QF occurs with shorter sticking times of the two reactant nuclei when compared with reaction timescales for fusion [4–8]. Thus, the properties of fragments from QF are more influenced by dynamical effects associated with the entrance channel (e.g., mass-angle correlation and broad mass distribution) compared with those from fusion-fission (FF), which are well describable by statistical theories, e.g., through the rotating liquid drop model (RLDM [9]). However, separation, or even quantitative estimates of the contributions from QF and FF are usually limited due to overlap of the experimental observables [4–8,10–18].

Reliable predictions of P_{fu}, which are essential for the successful execution of SHE experiments involving new projectile-target combinations, remain problematic because the QF process is still poorly understood. Consequently, the selection of an appropriate projectile-target combination is one of the important challenges for SHE synthesis.

Fusion hindrance by QF can be studied in reactions leading to formation of the same CN, whose influence can be neglected based on Bohr's independence hypothesis of CN decay [19]. However, reactions with significantly different entrance channels are often used to contrast the fission properties from FF and QF [5,12,14,20,21]. Therefore, the effect of a particular variable on fusion hindrance can often not be isolated. To date, the presence of QF is mainly ascribed to two variables: the product of the projectile and target charge numbers, Z_pZ_t, and the deformation of the target nuclei.

For a long time, $Z_pZ_t = 1600$ was accepted as a lower limit for reactions that have predominantly QF outcomes [22]. Recently, however, evidence for the presence of QF in reactions with a much smaller Z_pZ_t has been uncovered [20,21,23,24]. In this regard, recent experiments on the ^{34}S + ^{208}Pb and ^{36}S + ^{206}Pb reactions (which form the same CN ^{242}Cf*, share the same Z_pZ_t, have no static deformation, and are thus expected to have similar $P_{fu}W_{\rm CN}$) have highlighted the effect of nuclear structure on fusion. Fusion-evaporation cross sections of the ^{36}S + ^{206}Pb reaction have been found to

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