Fusion and quasifission studies for the ^{40}Ca + ^{186}W, ^{192}Os reactions

E. Prasad,* D. J. Hinde, E. Williams, M. Dasgupta, I. P. Carter, K. J. Cook, D. Y. Jeung, D. H. Luong, C. S. Palshetkar,† D. C. Rafferty, K. Ramachandran,† C. Simenel, and A. Wakhle‡
Department of Nuclear Physics, Research School of Physical Sciences and Engineering, Australian National University, Canberra, Australian Capital Territory 2601, Australia
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Background: All elements above atomic number 113 have been synthesized using hot fusion reactions with calcium beams on statically deformed actinide target nuclei. Quasifission and fusion-fission are the two major mechanisms responsible for the very low production cross sections of superheavy elements.
Purpose: To achieve a quantitative measurement of capture and quasifission characteristics as a function of beam energy in reactions forming heavy compound systems using calcium beams as projectiles.
Methods: Fission fragment mass-angle distributions were measured for the two reactions ^{40}Ca+^{186}W and ^{40}C+^{192}Os, populating ^{226}Pu and ^{232}Cm compound nuclei, respectively, using the Heavy Ion Accelerator Facility and CUBE spectrometer at the Australian National University. Mass ratio distributions, angular distributions, and total fission cross sections were obtained from the experimental data. Simulations to match the features of the experimental mass-angle distributions were performed using a classical phenomenological approach.
Results: Both ^{40}Ca+^{186}W and ^{40}C+^{192}Os reactions show strong mass-angle correlations at all energies measured. A maximum fusion probability of 60−70% is estimated for the two reactions in the energy range of the present study. Coupled-channels calculations assuming standard Woods-Saxon potential parameters overpredict the capture cross sections. Large nuclear potential diffuseness parameters ∼1.5 fm are required to fit the total capture cross sections. The presence of a weak mass-asymmetric quasifission component attributed to the higher angular momentum events can be reproduced with a shorter average sticking time but longer mass-equilibration time constant.
Conclusions: The deduced above-barrier capture cross sections suggest that the dissipative processes are already occurring outside the capture barrier. The mass-angle correlations indicate that a compact shape is not achieved for deformation aligned collisions with lower capture barriers. The average sticking time of fast quasifission events is 10^{-20} s.

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I. INTRODUCTION

Superheavy elements (SHEs) exist solely due to the microscopic stabilization resulting from nuclear shell effects; as a result, they offer an extreme test of our understanding of nuclear physics. The synthesis of SHEs and investigation of their properties are among the most challenging research topics in science, owing to the very low production cross sections of the SHEs, often of the order of a pico barn or less.

The production of a SHE is generally considered to follow a sequence of three processes: the capture of the projectile and target, formation of the completely equilibrated compound nucleus (CN), and the survival of the CN against fission decay resulting in an evaporation residue (ER). Hence, the ER formation cross section may be treated as the product of the capture cross section ($\sigma_{\rm cap}$), CN formation probability ($P_{\rm CN}$), and survival probability ($W_{\rm sur}$) of the CN against fission. The outcome of the first stage—capture—has two competing components: fusion and quasifission [1–4]. Quasifission is partly responsible for the very low production cross sections of SHEs because in quasifission, the system reseparates soon after capture, before reaching the CN configuration. It thus suppresses fusion and the ER cross sections.

Quasifission is a dynamical nonequilibrium process which is heavily influenced by entrance channel properties such as beam energy [5–7] and entrance channel mass asymmetry [8–10], and nuclear structure effects such as static deformation [7,11,12], shell closure [13,14], and isospin [13]. Even though quasifission has very high cross sections in reactions involving heavy nuclei, a complete understanding of this process is marred by both the significant overlap of quasifission and fusion-fission observables and the complex dependence of quasifission on various entrance channel variables. Knowing that quasifission and fusion-fission are the most significant processes determining $P_{\rm CN}$ and $W_{\rm sur}$, understanding the competition between these processes is essential for making reliable predictions of the best reactions to form new superheavy elements and isotopes.

Both cold [15,16] and hot [17–19] fusion reactions have been employed for the synthesis of SHEs. Elements between $Z = 107-113$ have been produced using cold fusion reactions where target nuclei of ^{208}Pb or ^{209}Bi were collided with massive projectiles [16]. Elements beyond $Z = 113$ were

*Permanent address: Department of Physics, School of Mathematical and Physical Sciences, Central University of Kerala, Kasaragod 671314, India; prasadcukerala@gmail.com
†Present address: Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai 400085, India.
‡Present Address: National Superconducting Cyclotron Laboratory, Michigan State University, Michigan 48824, USA.

