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Nuclear structure effects in quasifission – understanding the formation of the heaviest elements

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Abstract. Quasifission is an important process suppressing the fusion of two heavy nuclei in reactions used to create superheavy elements. Quasifission results in rapid separation of the dinuclear system initially formed at contact. Achieving reliable a priori prediction of quasifission probabilities is a very difficult problem. Through measurements with projectiles from C to Ni, the Australian National University's Heavy Ion Accelerator Facility and CUBE spectrometer have been used to map out mass-angle distributions (MAD) - the fission mass-ratio as a function of centre-of-mass angle. These provide information on quasifission dynamics in the least model-dependent way. Average quasifission time-scales have been extracted, and compared with TDHF calculations of the collisions, with good agreement being found. With the baseline information from the survey of experimental MAD, strong influences of the nuclear structure of the projectile and target nuclei can be clearly determined.

1 Introduction

Fusion of two heavy nuclei has been a successful pathway to produce new very heavy and superheavy elements (SHE). However, the production yield of SHE is very significantly suppressed [1] by quasifission [2]. This dynamical non-equilibrium process results when the combined system formed after capture separates before a compact compound nucleus is formed, resulting in two (fission-like) fragments. The probability of quasifission (P_{QF}) can be very large, with the complementary probability of compound nucleus formation ($P_{CN} = 1 - P_{QF}$) being possibly lower than 10^{-6} in unfavourable reactions. Understanding the competition between quasifission and fusion is thus crucial to predict the best fusion reactions to use to form new isotopes of heavy and super-heavy elements. The months of beamtime needed to determine if a given reaction is likely to be successful or not gives additional motivation to obtain a reliable predictive model based on an full understanding of this competition.

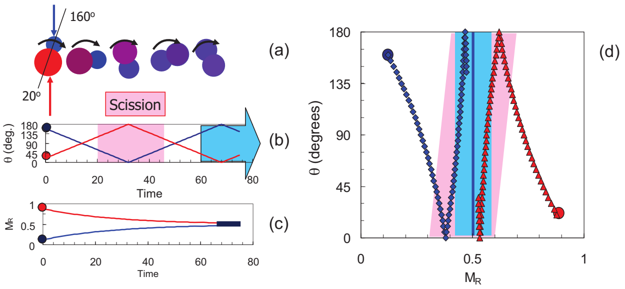

Figure 1. The relationship between sticking time and the mass-angle distribution. For the reaction sequence sketched in (a), the time dependence (arbitrary units) of angle (b) and mass-ratio (c) are shown. Such short times cannot be measured directly, but angle and mass-ratio can. The individual mass and angle dependencies combine to give a trajectory (d) on the MAD for a single impact parameter. Including a range of impact parameters, scission after half a turn (pink) or a full turn (blue) will give strong or weak mass-angle correlations respectively.

2 Mass-Angle Distributions

The measurement of all binary mass-splits (characterised by the mass ratio $M_R = M_1/(M_1 + M_2)$ between the initial projectile mass M_1 and the target mass M_2, when determined over a wide range of scattering angles, results in a two-dimensional matrix, referred to as a mass-angle distribution (MAD). The relationship of the MAD to the "sticking time" between capture and scission is illustrated schematically in Fig. 1. The projectile nucleus (blue) is incident from the top of the page, and sticks to the larger target nucleus (red). The system then rotates, Fig. 1(b) illustrating schematically angle against time (in arbitrary units) for a single angular momentum value; in reality a distribution will be present. For a parabolic potential, mass-symmetry is approached with an expected time dependence $1-\exp(\frac{t}{\tau_{eq}})$, where τ_{eq} is the mass-equilibration time

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