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Quasifission Dynamics in the Formation of Superheavy Elements

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Abstract. Superheavy elements are created through the fusion of two heavy nuclei. The large Coulomb energy that makes superheavy elements unstable also makes fusion forming a compact compound nucleus very unlikely. Instead, after sticking together for a short time, the two nuclei usually come apart, in a process called quasifission. Mass-angle distributions give the most direct information on the characteristics and time scales of quasifission. A systematic study of carefully chosen mass-angle distributions has provided information on the global trends of quasifission. Large deviations from these systematics at beam energies near the capture barrier reveal the major role played by the nuclear structure of the two colliding nuclei in determining the reaction outcome, and thus implicitly in hindering or favouring superheavy element synthesis.

1 Introduction

Superheavy elements (SHE) are formed by heavy-ion fusion reactions. Fusion cross sections can be considerably suppressed [1] by quasifission [2]. This non-equilibrium process results when the combined di-nuclear system, formed as the two nuclear surfaces stick together, subsequently separates into two (fission-like) fragments, with the initial kinetic energy largely or completely damped. Quasifission can occur very rapidly, typically in less than 10^{-20}s, before a compact compound nucleus can be reached [2–5]. The probability of quasifission (P_{QF}) can be very large, thus the complementary probability of compound nucleus formation (P_{CN} = 1 - P_{QF}) can be small, quite likely lower than 10^{-3} in reactions forming superheavy elements. Understanding the competition between quasifission and fusion is thus very important in predicting the optimal fusion reactions to use to form new elements and isotopes in the superheavy mass region.

A key characteristic, important for superheavy element formation, is the “sticking time” following contact of the two nuclear surfaces [6]. It is expected that the sticking time is correlated with P_{CN}: where the sticking time is longer, then P_{CN} would be expected to be larger (more favourable for SHE synthesis). The average sticking time can be extracted from measurements of quasifission angular distributions. The two colliding nuclei always approach each other along the beam axis, and after contact rotate with angular velocities that can be calculated. Measurement of the rotation angle thus allows estimation of the sticking time. As the system rotates, mass flow also occurs between the two nuclei. Measurement of the velocity vectors of both fragments gives direct information on the centre-of-mass angle and mass-ratio of the fragments at scission, defined as $M_R = M_1/(M_1 + M_2)$, as well as providing excellent discrimination against fission events resulting from peripheral (transfer-induced) processes [4, 7]. The mass-ratio (or mass) plotted as a function of the centre-of-mass angle is referred to as a mass-angle distribution, or MAD. This gives direct information on the dynamical time scales, as long as the system undergoes less than a full rotation (taking $\sim 10^{-20}$s). This is usually the case for collisions of heavy nuclei, as shown first by measurements at GSI [2, 8], and by later results from ANU [3–5, 9–15]. Inter-relationships of different measurements, and background to the results presented here are given in recent conference proceedings [16–20].

2 Experimental Setup

The detector configuration used at the Australian National University (ANU) to measure MAD is shown in Fig.1. It consists of two or three large area multi-wire proportional counters (MWPC). They detect reaction products from the interaction of the pulsed beam with targets typically 50-200 μg/cm^2 in thickness, oriented with the normal to the target face at 60° to the beam. This eliminates shadowing of the detectors by the target frame. The average en-

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