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Demystifying the Fusion Mechanism in Heavy-Ion Collisions Leading to the Formation of Superheavy Nuclei

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We discuss the current understanding of the heavy-ion fusion mechanism through the lens of multidimensional stochastic dynamics. Recent developments, including a six-dimensional Langevin formalism with unconstrained motion in mass asymmetry, provide a realistic description of energy dissipation, shape evolution, and angular momentum effects. This approach captures the transition into the overdamped regime, where rapid neck formation and shape equilibration occur, offering excellent agreement with experimental fusion cross-sections and spin distributions. The method has been successfully applied to the formation of heavy and superheavy nuclei [Phys. Lett. B 862 (2025) 139302]. In parallel, a complementary framework based on a four-dimensional biased random walk in deformation space has been developed, where the fusion pathway is guided by the density of available states. By treating the dipole moment as an explicit shape degree of freedom and introducing an auxiliary reference frame located at the neck, this approach enables access to previously unattainable fusion configurations. The method accurately describes fusion probabilities for reactions involving medium-mass projectiles and a 208 Pb target, shedding light on the fusion hindrance mechanism and strengthening predictive models for superheavy element synthesis [Phys. Rev. C 109, L061603 (2024)].

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