Quantifying the rate for rare events using trapped ions

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Synopsis We use the flipping rate of a five-ion pyramidal crystal inversion of laser cooled Ca ions to validate the Kramers-Langer theory.

Rare events are processes which occur on timescales which are far longer than the timescales intrinsic to the system under study. These are hard to study systematically since the statistics for such systems are hard to obtain under controlled circumstances. In thermal equilibrium, such rare events arise when thermal fluctuation cause the system to change state. The foundational theoretical work to understand such systems, was provided by Kramers [1] and generalized to multi-dimensional systems by Langer [2] and the overall framework for the rate of change of a system in a metastable state requires goes by the name of the Kramers-Langer theory. The testing of this theory requires a system close to thermal equilibrium, with a controllable energy landscape.

Laser cooled and trapped Ca ions, which self organise into a cluster, provide an ideal system to experimentally verify the theory [3, 4] . Laser cooled ions are close to thermal equilibrium, and the energy landscape is completely determined. The flip rate of the pyramid, between the equally probable up and down pyramid, as a function of a precisely controllable barrier height is then used to determine the agreement between the flip rates predicted by the Kramers-Langer formulation and the Molecular-Dynamics simulations with the experimentally determined theory parameters. The agreement is very close. This is then used to determine the temperature of the 5-ion pyramidal crystal [5]. It is also shown that permutation symmetry plays an important role in pyramidal inversion, which is experimentally demonstrated by breaking the permutation symmetry by working with isotopically mixed crystals. This work therefore demonstrates the power of simple mesoscopic atomic physics systems to extend far beyond the confines of the field.

References

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