Contribution ID: **109** Type: **Hot Topic Talk**

Reactive tunneling and vibrational quenching collisions in a cryogenic multipole trap

Thursday, 28 September 2023 15:25 (20 minutes)

Quantum tunneling reactions play an important role in chemistry when classical pathways are energetically forbidden [1]. Binary collisions of atomic with molecular hydrogen belong to the most fundamental molecular systems and are simple enough to be theoretically investigated using first-principle calculations. The rate of the tunneling reaction $H_2 + D^- \rightarrow H^- + HD$ has been calculated [2] but has until now lacked verification. Here we present high-sensitivity measurements of the reaction rate carried out in a cryogenic 22-pole ion trap. A deviation of the reaction rate from linear scaling, which is observed at high H_2 densities, can be traced back to previously unobserved heating dynamics in radiofrequency ion traps. Our measured value agrees with quantum tunneling calculations, serving as a benchmark for molecular theory and advancing the understanding of fundamental collision processes [3].

Further work has focused on inelastic collisions of C_2^-, which has been proposed as a candidate for laser cooling due to the existence of multiple stable electronic states. We have demonstrated vibrational state control of C_2^- via a novel scheme that uses optical pumping in conjunction with inelastic collisions of H_2 and measured the vibrational quenching rate [4]. Additionally, we precisely determined the proposed laser-cooling transitions of C_2^-. We resolve the spin-rotation splittings and use it to perform accurate thermometry in our newly-developed wire trap [5].

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[3] Wild, R., Nötzold, M., Simpson, M., Tran, T. D., Wester, R. Tunnelling measured in a very slow ion–molecule reaction. Nature (2023).
[4] Nötzold, M., Wild, R., Lochmann, C., Rahim, T., Melath, S. P., Mant, B., Franz, J., Gianturco, F., Wester, R. (in preparation)
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Session Classification: Thursday Hot Topics