Controlling chemical reactions of a single particle

Carlo Sias*, Lothar Ratschbacher, Christoph Zipkes, and Michael Köhl
Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK

The hybrid system of trapped atoms and ions offers key advantages for studying chemical reactions at the most elementary level: ion traps have a large potential well depth in order to trap the reaction products, while the absence of a Coulomb-barrier allows the particles to collide at short internuclear distance. Here, we report on the experimental tuning of the exchange reaction rates of a single trapped ion with ultracold neutral atoms by exerting control over both their quantum states. We observe the influence of the hyperfine state on chemical reaction rates and branching ratios and monitor the kinematics of the reaction products.

The hybrid atom-ion trap

In the same physical location, we trap $^{174}$Yb$^+$ single ions in a radio-frequency Paul trap and $^{87}$Rb neutral atoms in a magnetic or in an optical dipolar trap.

Physical processes

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<th>CHARGE EXCHANGE:</th>
<th>COLLISIONAL QUENCHING:</th>
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<td>Yb$^+$ + Rb$^+$</td>
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Tuning the reactions

Changing the state of the ion and the atoms we are able to tune the inelastic collision rate by up to 5 orders of magnitude!

Interactions in the presence of light

We tune the inelastic collision rate by varying the 935nm re-pumping light detuning.

We verify the linearity of the reaction rate. The measured exponent is $0.98 \pm 0.02$.

The level scheme

We prepare the Yb$^+$ ions in a number of excited states, while the neutral atoms are prepared in the hyperfine F=1 or F=2 state.

Time sequence

With a 2-ion crystal mass spectrometry available

The model

We model the inelastic collisions making use of three assumptions:
- An inelastic process happens only in a Langevin-type collision
- The characteristic collision time is shorter than the radiative lifetime
- Inelastic collisions can only be exothermic

Inelastic Loss Rate: $\gamma_i = \frac{2\pi}{\hbar} C_i \mid u_n \mid \sum_x p_x \epsilon_x$ $p_x$ occupation probability of state $x$ $\epsilon_x$ state dependent proportionality constant

Collisions in real time

By using resonant light, we are able to observe the inelastic collisions as they happen in real time

Collisional Quenching

We directly observe quenching of the ion due to collisions with neutral atoms.