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Titel: Ion-molecule reactions below 1 K

Abstract:

The study of ion-molecule reactions at low collision energies ($E_{\text{coll}}$) or low temperatures below $E_{\text{coll}}/k_B = 10$ K is experimentally challenging because stray electric fields in the reaction volume heat up the ion samples. A potential difference of 1 mV across a reaction region of 1 cm accelerates the ions to 1 meV, which corresponds to heating them up to about 12 K. To overcome this problem and study ion-molecule reactions below 10 K, we have developed a new method, in which the ion molecule reaction takes place within the orbit of a Rydberg electron at high values of the principal quantum number $n$. In high-$n$ Rydberg states, the Rydberg electron only very weakly interacts with the ion core, so that it does not significantly influence the ion-molecule reaction but shields the ions from heating by stray electric fields. Instead of studying exothermic and barrier-free ion-molecule reactions of the type 

$$I_1^+ + M_1 \rightarrow I_2^+ + M_2,$$

we thus study the reactions 

$$I_1^- + M_1 \rightarrow I_2^- + M_2,$$

in which $I_1^+$ and $I_1^-$ represent atoms or molecules in high Rydberg states. To reach very low collision energies we use chip-based Rydberg-Stark decelerators and deflectors to merge cold supersonic beams of $I_1^+$ and $M_1$ and to vary the relative velocity of $I_1^-$ and $M_1$ [1]. Monitoring the product yield as a function of the relative mean velocity of the two beams, we obtain the relative reaction cross sections as a function of the collision energy [2]. At temperatures below 1 K, we find that the reaction rate coefficients deviate from those estimated with Langevin-type capture models. The deviations become particularly large when $M_1$ has a permanent dipole moment, but are also noticeable when it has a quadrupole moment.

The talk will present studies of reactions of $H_2^+$ and He$^+$ ions ($I_1^-$) with neutral molecules such as $N_2$, $H_2$, $CH_3F$ and $CH_4$ ($M_1^-$) at collision energies down to below 1 K. The observed low-temperature behaviour will be discussed in terms of the electric dipole and quadrupole moments of $M_1$.


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