

Laser cooling of He* for studies of ultracold reactive collisions in supersonic beams

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Counterintuitively, ion-molecule reactions (IMR) proceed with high rate coefficients, and may even increase, in the $T \rightarrow 0$ K limit. This makes them a key driving mechanism of astrochemistry [1] and an ideal platform to test quantum effects in ultracold reactive collisions in the laboratory. Until recently, experimental studies of IMRs below ~ 10 K have been nearly impossible due to ion-heating by stray electric fields.

We are building an experiment to study quantum scattering effects in the $\text{He}^+ + \text{N}_2$ reaction, in the $E_{\text{coll}}/k_{\text{B}} \sim 1$ mK – 1 K collision energy range, using pulsed supersonic beams [2]. To reach these exceptionally low energies, we: (i) substitute the He^+ ion with a helium Rydberg atom [$\text{He}(n)$, where n is the principal quantum number] in order to avoid heating from stray electric fields [3, 4], (ii) use frequency-chirped laser cooling of helium in order to tune the relative velocities of the colliding particles, and thus the collision energy, and (iii) study the reactions with the $\text{He}(n)$ and N_2 particles produced in the same supersonic beam (intrabeam collisions).

We present our first experimental measurements of a cold dense supersonic beam of helium atoms in the metastable $(1s)(2s) \ ^3\text{S}_1$ state (referred to as He^*), produced by thin-needles electric discharge at the orifice of a short-pulse valve. We also present the results of a particle-trajectory Monte Carlo simulation demonstrating the capability of laser light, resonant with the $(1s)(2s) \ ^3\text{S}_1 \rightarrow (1s)(3p) \ ^3\text{P}_2$ transition in He at 1083 nm and counterpropagating to the atomic beam, to decelerate the He^* atoms and significantly compress their phase-space distribution, enabling the ultracold collision regime.

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