Storage-Ring Merged Beams Experiments on Electron–Ion Recombination: Benchmarking and Accuracy Limits

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Ion storage rings are a powerful tool for measuring inelastic electron–ion collision rates, using merged ion and electron beams. Such measurements yield benchmark data for important atomic and molecular ions, offering high resolution in the collision energy and good accuracy for absolute cross-section values. This way, the results contribute to the understanding of the underlying physics mechanisms and can verify theoretical calculations, including their scaling to other systems (such as, e.g., along isoelectronic sequences for atomic ions).

The main experimental focus is electron recombination with positive atomic and molecular ions [1, 2]. Also ionization cross sections are measured [3] and deexcitation of internal levels by electron collisions was observed for molecules [4]. After an overview of the technique, we discuss some results that demonstrate the degree of quantitative control reached in the measurements, and identify aspects critical for best accuracy.

In merged-beams experiments, collision energies can be tuned from the milli-eV range up to a keV or more, changing the beam energies. The geometrical overlap and the beam currents can be defined with good accuracy, and the reactions are detected with high efficiency using event-by-event counting. For comparisons with theoretical cross sections at high energy resolution, collision velocity distributions specific to the merged-beams situation are used [5]. Control of metastable internal states of the interacting ions is gained by the extended storage time of the ions and by investigating time-dependent variations of the reaction rates.

In finding the rate coefficients from measured product-counting rates, monitoring the stored ion beam intensity plays an important role. Absolute reaction rates can in some cases be determined also from electron-induced ion loss rates [6]. Careful modeling of the electron–ion collision zone improves the accuracy in extracting absolute cross sections and energy dependences [5]. The detection efficiency of reaction products can reduced when they are highly excited or when the electron-induced reactions lead to large momentum transfer to the products. Finally, the populations of internal quantum states in the stored ions need to be considered carefully. Often, rate equation models using lifetime data of metastable levels are used to simulate the state populations. In some studies, also the modification of the internal state populations by inelastic electron collisions may become relevant. The discussion will consider results from magnetic ion storage rings. A short outlook will be given to planned merged beams experiments at a cryogenic electrostatic storage ring [7].

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