Experimental Studies on Interactions of Atomic Ions with Single Electrons

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Collisions of single electrons with atomic ions can lead to recombination, elastic scattering, excitation or ionization [1]. The most important quantities characterizing such processes in ionized gases are the temperature-dependent plasma rate coefficients α_{if} for transitions from an initial state i to a final state f. The temperature range of interest in the context of fusion plasmas is from essentially zero to hundreds of millions of Kelvins. Charge states of atoms with atomic numbers Z possibly playing a role in a fusion plasma range from 0 to Z where only the heaviest contaminants in the plasma cannot be fully stripped of electrons. Hence, experiments have to cover an extremely wide range of parameters.

Recombination of a single electron with an ion can happen as a direct radiative recombination or in a multi-step resonance process including single or multiple excitation of the ion plus capture of the electron and subsequent relaxation by photoemission. Elastic scattering and excitation can also be the result of a direct or a resonant multi-step process but with an electron ejected instead of photons. Electron-impact single or multiple ionization can proceed via direct knock-off of electrons or via (direct or resonant) excitation to an intermediate autoionizing state with subsequent emission of electrons. The indirect contributions produce rich structures in the energy dependence of the associated cross sections.

Crossed- and merged-beams experiments have provided a wealth of data on recombination and ionization of ions in a wide range of charge states while measurements on elastic scattering and electron-impact excitation of ions remain to be scarce. Much of the progress accomplished over the last decades has been made possible by the use of heavy-ion storage rings. This is particularly true for recombination of highly charged ions for which the interaction of cold beams of electrons with stored and cooled ions in a merged-beams configuration provides the method of choice to study cross sections and resonance energies. The most precise measurements on electron-impact ionization of ions were performed using crossed-beams arrangements which have the advantage of relatively low cost and high availability. Total relative uncertainties of colliding-beams cross-section data are typically 10±5 %. Statistical uncertainties have been reduced even to the 0.01 % level in some cases.

Problems in most beams experiments arise from the possible presence of mixtures of electronic levels in the parent ion beam used for cross-section measurements. Storage rings allow for relatively long delay times between the production of a desired ion charge state and the start of a measurement so that excited states can decay. However, these delay times are limited by the lifetimes of the stored ion beams and, therefore, long-lived excited states can also be present in an ion beam prepared for storage-ring measurements. As a result, cross-section data from colliding beams experiments may have additional uncertainty.

Recent experimental results on recombination and ionization will be presented to illustrate the present status of the field. By employing the principle of detailed balance independent cross-checks can be made between results of electron-ion recombination and photoionization experiments. The remarkable agreement of absolute cross-section results obtained with very different experimental arrangements provides proof for the validity of both measurements.

[1] A. Müller, Adv. At. Mol. Opt. Phys. **55** (2008) 293-417