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State-to-state measurements of low-energy ion-molecule and ion-ion collisions by three dimensional momentum imaging[1]

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While the measurement of total absolute cross sections remains challenging, the insight provided by differential cross sections and branching ratios is invaluable to assess the quality of theoretical predictions. Satisfactory agreement at the latter level gives better confidence in the proper identification of the reaction mechanism and key parameters. The three dimensional imaging of molecular dissociation, and more generally, the determination of all momentum vectors of the reaction products, gives direct access to the differential quantities of interest. For the prototype reaction of a proton colliding with H_2, the secondary H_2^+ current may be recorded to provide the total charge transfer yield. The dissociative charge transfer of the product ions with alkali targets leaves a characteristic signature in the total kinetic energy imparted to the H fragments. Its measurement is readily achieved by coincident detection on position sensitive detectors [1]. This allows us to extract vibrational populations as a function of collision energy. A resonant enhancement of the charge transfer around 45 eV/amu is observed, that leaves the molecular ion in its vibrational ground state [2]. Those observations are supported by state-of-the-art calculations. We have similarly explored the ionization of molecular oxygen by proton and alpha particle impact, at velocities characteristic of the solar wind. A somewhat more involved vibrational analysis of the O_2^+ cations [3] indicates a Franck-Condon like vibrational population of the ground electronic state from 50 eV to 10 keV, unlikely to modify the branching ratios of dissociative recombination, itself responsible for airglow emissions. More interestingly, a significant population of the $^4\Pi_u$ excited state is measured at velocities typical of the fast solar wind. Finally, we shall address the implementation of three dimensional imaging in merged ion-ion beam studies. Mutual neutralization involving anions and cations is a very efficient process, characterized by a uniquely defined initial state and a limited range of final states readily identified by the total kinetic energy released to the products. Detailed branching ratios may be obtained at near zero collision energy where the reaction rate is maximum and the system behaves as a quasi-molecule undergoing in flight dissociation. As an example, we shall discuss the mutual neutralization of C^+ and various anions of the second and third row of the periodic table [4]. [1] X. Urbain et al., Rev. Sci. Instrum. 86, 023305 (2015). [2] X. Urbain et al., Phys. Rev. Lett., 111, 203201 (2013). [3] A. Dochain and X. Urbain, EPJ Web of Conferences 84, 05001 (2015). [4] R. F. Nascimento et al., J. Phys. Conf. Ser. 635, 022043 (2015).

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