First Step Benchmark of Inelastic Collision Cross Sections for Heavy Ions using Charge State Evolutions after Target Penetration

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In present plasma modelings, a set of accurate cross-sections is essential to checking the validity of introduced models for complicated phenomena taking place in fusion plasmas. Although the number of studies devoted to cross-section measurements has been notably decreased recently, immense improvements of computer power have brought new developments in theoretical procedures, which have synergistically realized more complicated calculations in more details, and the lack of directly-comparable experimental data for that detailed partial cross-sections, or even for total cross-sections, came to be a serious problem.

We propose here to make use of simpler phenomena consisted of various inelastic collision processes, whose model is well-established, as a first order benchmark of the validity of a set of cross-sections. In penetrating through targets, ions change their charge-states until they establish the equilibrium charge-state distribution, in which increases and decreases in population of each charge-state balance each other and the population seems to remain unchanged. Ratios of neighboring equilibrium charge-state fractions are equivalent to ratios of total single-electron capture and loss cross-sections between those charge-states, which has been used in checking consistency of these cross-sections. Before establishing the equilibrium, fractions for each *nl*-substate dynamically change accordingly to a set of rate-equations

$$\frac{dF_i(x)}{dx} = \sum_j F_j(x)\sigma_{ji} - \sum_j F_i(x)\sigma_{ij}, \quad \sum_i F_i(x) = 1,$$

where $F_i(x)$ denotes the fraction of specific *i*-substate at the penetration depth x, and σ_{ij} denotes collision cross-section or transition rate from substate *i* to *j*, i.e., those for excitation, collisional and radiative de-excitations, ionization, and charge transfer processes.

There exist several codes solving these *nl*-substate oriented rate-equations, whose results can be compared with experimental charge-state fractions after summed up to. The BREIT code [1] is a complete solver of these rate-equations, requiring separate input of the cross-sections, while the ETACHA code [2] treats 60 orbital-states up to n = 4 shell (with some approximation for higher *n* shells), through calculating the single-transfer cross-sections in the code. Comparison with experimental charge-state evolutions for 2.0 MeV/u C^{q+} (q = 2–6) and S^{q+} (q = 6–16) ions through C-foil targets [3] proved that the set of cross-sections ETACHA uses were rather good, although an empirical formula [4] better predicted the equilibrium charge-state distributions. The pre-equilibrium charge-state evolutions were quantitatively-well reproduced, but it was also suggested that inclusion of multiple-transfer cross-sections is needed when charge-state of penetrating ion is far separated from the equilibrium charge-state.

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