Charge-state evolution for 1.0 and 2.0 MeV/u C, S, and W ions after C-foil penetration and their application to a benchmark of collision cross sections

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Synopsis Equilibrium and pre-equilibrium charge-state distributions of 1.0 MeV/u C and W ions after C-foil penetration were measured after our measurements for 2.0 MeV/u C and S ions. We propose to make use of simulation results using several cross-section sets and models as a benchmark of these cross-section sets.

Equilibrium and pre-equilibrium charge-state distributions for 1.0 MeV/u C^{q+} (q = 1, 3–6) and W^{q+} (q = 13, 15, 28–30, 38) ions after penetrating C-foils have been investigated experimentally after our measurements using 2.0 MeV/u S^{q+} (q = 6–16) and C^{q+} (q = 2–6) initial ions[1,2]. In the previous, charge-state distributions, mean charge-states, and distribution widths for projectile ions without K-shell holes, S^{q+} (q = 6–14), once coincided at a target thickness of 6.9 μg/cm^2 (12.3 in mean charge-state), showing a "quasi-equilibrium," and simultaneously evolved to establish the real equilibrium (12.68 in mean charge-state) when the foil thickness was further increased, whereas those for projectile ions with K-shell hole(s), $S^{15,\ 16+}$, evolved directly to the real equilibrium, established at a target thickness of around 100 μg/cm^2 or greater. Similar but weak quasi-equilibrium was also observed for 2.0 MeV/u C-ions.

In the present measurements, we observed a significant quasi-equilibrium for 1.0 MeV/u C+C collisions, where the mean charge-states for $C^{1,\ 3,\ 4+}$ initial ions coincided even at the thinnest measured foil thickness and evolved simultaneously until the real equilibrium of 4.9 established at around 3.0 μg/cm^2 in the target thickness.

Simulations using the ETACHA[3] and BREIT[4] codes as well as a solution of simple rate equations showed the quasi-equilibrium was brought by a difference between the reaction-rates for K- and L-shell processes. Those comparisons proved that the set of cross-sections ETACHA generates were rather good, but an empirical formula better predicted the equilibrium charge-state distributions. Thus we started to simulate charge-state evolutions using several cross-section sets and collision models as an evaluation of these sets of cross-sections by grading scores about the reproducibility of pre-equilibrium charge-state evolutions as well as equilibrium charge-state distributions.

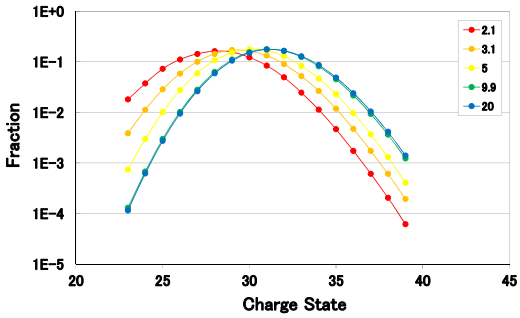

Figure 1. Charge-state distributions for W^{13+} projectile ions after penetration of C-foils of 2.1 (red), 3.1 (orange), 5.0 (yellow), 9.9 (green) and 20 (blue) μg/cm^2 in thickness. Note those for 9.9 and 20 μg/cm^2 almost coincided.

References

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