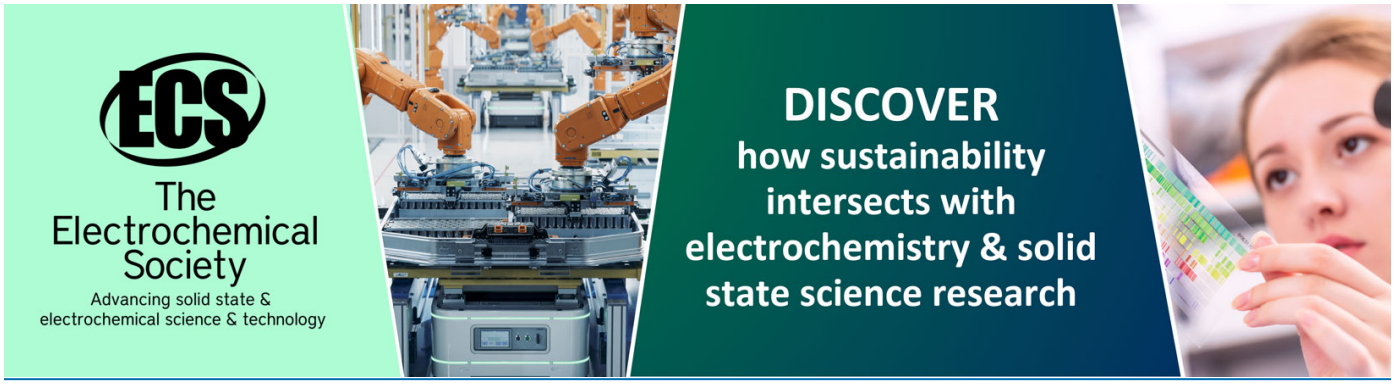
Quasi-equilibrium in charge-state evolution for 1.0 and 2.0 MeV/u carbon ions after carbon foil penetration



Quasi-equilibrium in charge-state evolution for 1.0 and 2.0 MeV/u carbon ions after carbon foil penetration

A M Imai[1 *], M Sataka[2], M Matsuda[3], S Okayasu[3], K Kawatsura[4], K Takahiro[5], K Komaki[6], H Shibata[7] and K Nishio[3]

[1]Department of Nuclear Engineering, Kyoto University, Kyoto 615-8540, Japan
[2]Research Facility Center for Science and Technology, University of Tsukuba, Ibaraki 305-8573, Japan
[3]Japan Atomic Energy Agency (JAEA), Tokai, Ibaraki 319-1195, Japan
[4]Theoretical Radiation Research Laboratory, Kyoto 606-0966, Japan
[5]Kyoto Institute of Technology, Kyoto 606-8585, Japan
[6]RIKEN, Wako, Saitama 351-0198, Japan
[7]The Institute of Scientific and Industrial Research, Osaka University, Osaka 567-0047, Japan

Synopsis After our observation of "quasi-equilibrium" in charge-state evolution for 2.0 MeV/u sulfur ions after carbon foil penetration, we have extended the initial ions to 1.0 and 2.0 MeV/u carbon ions. A significant quasi-equilibrium was observed for 1.0 MeV/u C+C collisions, where the equilibrium mean charge-state was 4.9, while for 2.0 MeV/u C+C collisions, where the equilibrium mean charge-states was 5.6, was a weak quasi-equilibrium.

Equilibrium and pre-equilibrium charge-state distributions for 1.0 and 2.0 MeV/u C^{q+} (q = 1–6) ions after penetrating carbon foils have been investigated experimentally after similar investigation of ours using 2.0 MeV/u S^{q+} (q = 6–16) initial ions[1]. In the previous measurements, 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. Simulations using the ETACHA code[2] 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.

In the present measurements, we have 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. As for 2.0 MeV/u collisions, whose equilibrium mean charge-state was 5.6, a weak quasi-equilibrium was observed.[3]

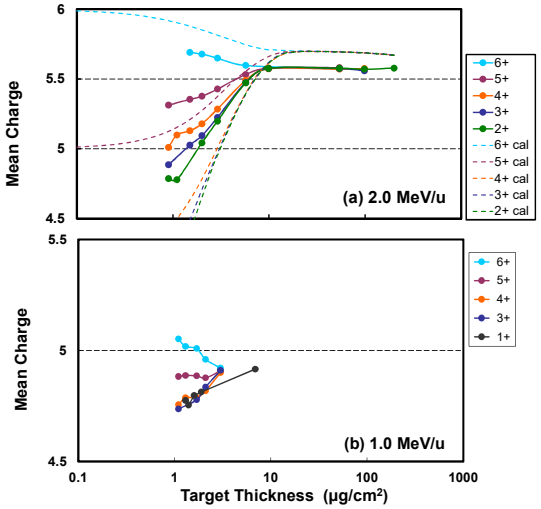


Figure 1. Mean charge-state evolution for (a) 2.0 and (b) 1.0 MeV/u C^{q+} (q = 1–6) initial ions after carbon foil penetration.

References

[1] Imai M *et al* 2009 *Nucl. Instr. and Meth. B* **267** 2675
[2] Lamour E *et al* 2015 *Phys. Rev. A* **92** 042703
[3] Imai M *et al* 2015 *Nucl. Instr. and Meth. B* **354** 172

* E-mail: imai@nucleng.kyoto-u.ac.jp