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

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

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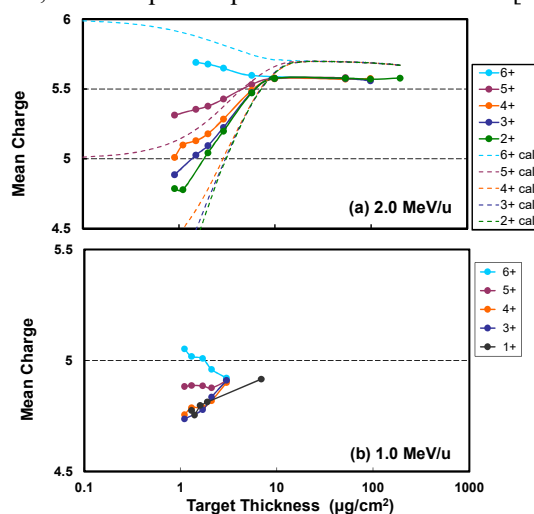
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**Synopsis** After our observation of “quasi-equilibrium” in charge-state evolution for 2.0 MeV/u sulfur ions after carbon foil penetration, we have extended the initial ions to 1.0 and 2.0 MeV/u carbon ions. A significant quasi-equilibrium was observed 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  $6.9 \mu\text{g}/\text{cm}^2$  (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  $100 \mu\text{g}/\text{cm}^2$  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  $3.0 \mu\text{g}/\text{cm}^2$  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

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- [3] Imai M *et al* 2015 *Nucl. Instr. and Meth. B* **354** 172

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