Instantaneous charge state of Uranium projectiles in fully ionized plasmas from energy loss experiments

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The instantaneous charge state of uranium ions traveling through a fully ionized hydrogen plasma has been theoretically studied and compared with an energy loss experiment. For this purpose, two different methods to estimate the instantaneous charge state of the projectile have been employed: (1) rate equations using ionization and recombination cross sections, and (2) equilibrium charge state formulas for plasmas. The equilibrium charge state of projectiles in plasmas is not always reached, and therefore, a non-equilibrium or an instantaneous description of the projectile charge is necessary. The charge state of projectile ions cannot be measured, except after exiting the target, and experimental data remain very scarce. The knowledge of the charge state of heavy ions is of significance on accelerator, fusion plasma physics and high energy density physics applications.

1. Introduction

The inertial confinement fusion driven by heavy ion beams is one of the method to obtain energy using fusion reactions. Understanding the physics of heavy ions traveling through plasmas is an important topic in plasma physics. Heavy ions possess good features to heat small samples of matter reaching the necessary temperature and density for the nuclear fusion takes place.

On the other hand, conventional stripping techniques are limited in their applicability, e.g. short lifetime in foil stripper and lower efficiency in gas stripper. To reach long lifetime and higher efficiency, the use of plasma as a stripping medium has been studied. In stripper devices, one of the most important thing is the prediction of the final charge state distribution of the ion beam and its total energy loss, which the presented work focuses on.

2. Theoretical model

For a projectile traveling through a target, the charge fraction distribution is usually calculated as,

$$\frac{dF_q(t)}{dt} = \sum_{q'\neq q} \alpha(q' \to q)F_{q'}(t) - \sum_{q'\neq q} \alpha(q \to q')F_q(t) \qquad (1)$$

where F_q is the projectile fraction with charge state q and the α are the ionization and recombination rates [1].

On the other hand, the instantaneous charge state can be also estimated by a simple analytic equiation:

$$Q(x) = Q_{eq} - (Q_{eq} - Q_0)\exp\left(-\frac{x}{\lambda_{ion}}\right) \qquad (2)$$

where x is the plasma length, Q_{eq} is the equilibrium charge state and Q_0 is the initial charge state. λ_{ion} is the ionization length estimated from [2].

The energy loss of the projectile is estimated in the RPA approximation as described in [3].

3. Results

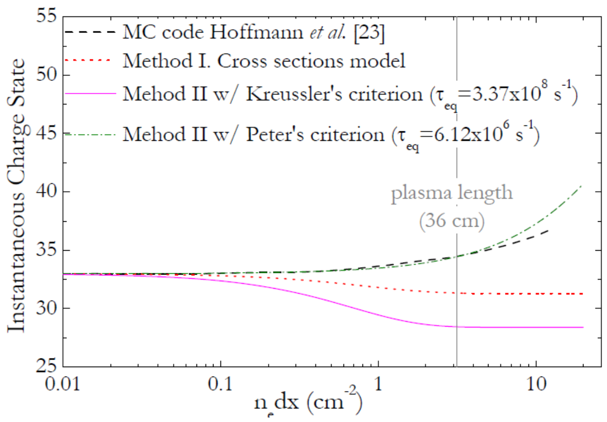

Fig.1: Instantaneous charge state of U ions in a H plasma.

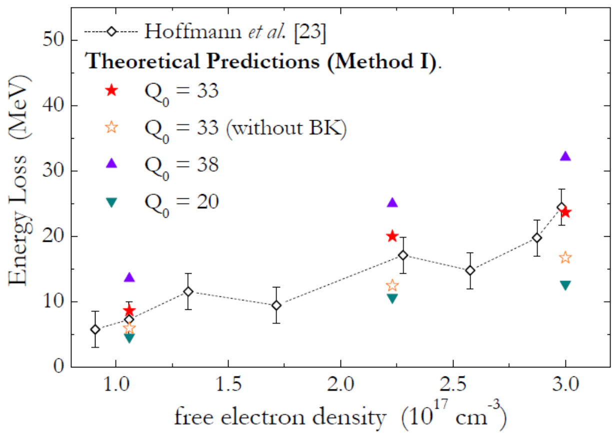

Fig. 2: Energy loss of U ions in a H plasma as a function of plasma density for several initial charge states.

4. References

[1] T. Peter and J. Meyer-ter-Vehn, Phys. Rev. A 43, 2015 (1991).

[2] R. Morales and M.D. Barriga-Carrasco (sent to Phys. Plasmas, accepted).

[3] M.D. Barriga-Carrasco, D. Casas and R. Morales, Phys. Rev. E 93, 033204 (2016).