Theoretical investigation of the charge transfer processes of heavy ions at intermediate energies interacting with a plasma

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The influence of the plasma properties, like plasma density, temperature and ionization degree, on the development of the charge state distribution of a heavy ion beam interacting with this plasma was investigated theoretically by a Monte-Carlo code.

The charge transfer processes in plasma are quite different compared to those in cold matter due to the presence of free electrons and ionized atoms. In cold matter, the dynamic balance of the projectile charge state is mainly governed by impact ionization of the projectile and recombination with bound target electrons (non-radiative electron capture, NREC).

In plasma, the ionization processes are the same, but the rates increase significantly due to a reduced screening of the target nucleus potential. As in a plasma, the number of bound electrons is reduced, which consequently suppresses NREC, the recombination processes with free electrons, like radiative electron capture (REC), dielectronic recombination (DR) and three-body recombination (3BR), become more dominant. However, due to the much smaller cross sections for free electron capture processes, the recombination rates in plasma are typically dropping with higher ionization degrees. In addition, the plasma density is changing the mean free path length of the projectile ions which leads to higher collision rates and in consequence to increasing ionization rates with raising density.

The charge state of the projectile ion is determined by the ionization and recombination rates which are balancing each other out. After a certain interaction time in the plasma the charge state distribution reaches an equilibrium and a mean charge state can be determined. For our study we used an Ar^{16+} ion as projectile with an energy of 4 MeV/u interacting with a plasma column of 200 g/cm^{-2}. As shown in Fig. 1, the plasma parameter space varies from electron temperatures from 10 eV to 200 eV and ion densities of 10^{18} cm^{-3} to 10^{23} cm^{-3}.

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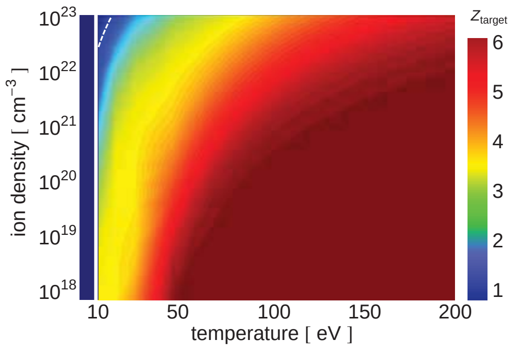

Figure 1: The plasma parameter space investigated in our study. The ionization degree of the carbon plasma is calculated by solving the saha equation.

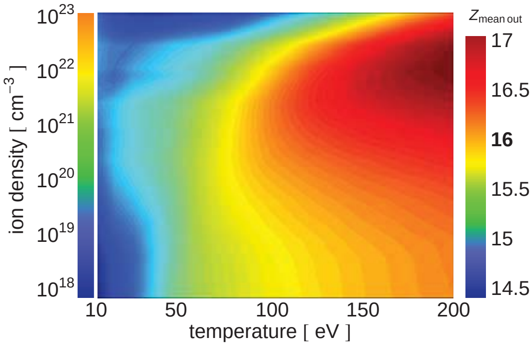

Figure 2: Mean charge state of an Ar^{16+} ion beam after interacting with 200 μg/cm^2 carbon plasma.

The calculated mean charge state in plasma compared to cold gas of the same density (color bar on the left side) is shown in Fig. 2. At hight temperatures one can clearly see the "density effect" where the charge state increases with higher densities. At low densities the temperature dependency, the so called "plasma effect" shows the reduction of the charge state to lower temperatures. As expected, in a hot plasma, the projectile mean charge state increases compared to the equilibrium charge state in cold matter of the same density. However, at low plasma temperatures, where a partly ionized plasma is predominant, both effects are compensating each other and even a decrease of the mean charge state in plasma compared to cold matter can be observed (e.g. $\rho = 5 * 10^{20}$ cm^{-3}, $T = 10$ eV to 50 eV). At detailed description of the code can be found in [1]. The code was benchmarked with experimental results [2]. This work was supported by the Helmholtz International Center for Fair and HGS-Hire.

References

[1] A. Frank, PhD-Thesis, TU-Darmstadt, (2012)

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doi:10.15120/GR-2014-1-PNI-PP-06