Simulation of charge state distributions in stripper applications

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Abstract

The presented work focuses on theoretical studies of the interaction of an heavy ion beam with possible future charge stripping media. The main interest in the presented studies is the final charge state distribution of the ion beam in the context of charge stripping. Different models for solving the corresponding rate equations were developed, taking into account ionization, recombination and energy loss processes. In this report one example case relevant for GSI is presented.

Results

The model used for calculations in this section are mainly based on Ref. [1]. The presented example case relevant for GSI is uranium with 1.4 MeV/u and a desired charge state of q0 = 28. The rates for low atomic densities \( n < 10^{23} \text{m}^{-3} \) in different media are given in Fig. 1. All gas media do not achieve the desired equilibrium charge state, while in case of a hydrogen plasma the equilibrium charge state is actually higher than the desired charge state. Increasing the atomic density to larger than \( 10^{23} \text{m}^{-3} \) leads to the onset of the density effect (see Ref. [1]), increasing the equilibrium charge state.

To compare the charge state distribution widths of the different media the density was increased such that the charge state \( q_0 = 28 \) is achieved, as depicted in Fig. 2. For the hydrogen plasma the charge state distribution is not in equilibrium, as the desired charge state is smaller than the equilibrium one. This explains the larger charge state distribution width of the plasma stripping medium. In experiments a much broader charge state distribution for nitrogen gas is observed. This however can not easily be explained by the current model. The charge state distribution width can be approximated as

\[
\sigma^2 = \left( \frac{\alpha_{\text{ion}}'(q_0)}{\alpha_{\text{rec}}'(q_0)} - \frac{\alpha_{\text{ion}}(q_0)}{\alpha_{\text{rec}}(q_0)} \right)^{-1}
\]

Figure 1: Rates of uranium with 1.4 MeV/u in different gases and a plasma without density effect. Rising and falling curves are the sum of recombination and ionization rates respectively.

Figure 2: Widths of the charge state distribution for different media. Required atomic density of the gases are \( 4.65 \cdot 10^{26} \text{m}^{-3} \), \( 1.6 \cdot 10^{27} \text{m}^{-3} \) and \( 3.7 \cdot 10^{27} \text{m}^{-3} \) for hydrogen, helium and nitrogen respectively. The density of the hydrogen plasma was assumed to be \( 10^{23} \text{m}^{-3} \) for both electrons and protons.

This implies that either the shape or value of the rates has to be significantly different for nitrogen, or further effects broaden the distribution specifically for heavier gases. The influence of the mean energy loss in the charge stripping process is of minor importance for typical projectile and target parameters.

Outlook

Future studies intend to improve the calculation methods of the necessary cross section, and include detailed models for the gas and plasma conditions (e.g. inhomogeneities, multiple electron capture or loss, and ionization degree of the target). Furthermore comparisons are planned with charge state distributions achieved in the different plasma pinch and gas stripper experiments at GSI.

References