

Interaction of Fast Ion Beams with Low- and High-Density Targets

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Electron capture processes into excited states

$$X^{q+} + A \rightarrow X^{(q-1)+}(n) + A^+ \quad (1)$$

are considered in collisions of fast positive ions X^{q+} with low- and high-density targets A . In the case of a low-density, the electron-capture cross section $\sigma_{ec}(n)$ has a certain distribution over the principal quantum number n with a maximum at $n = n_{max}$ and asymptotic behavior $\sigma_{ec}(n) \approx n^{-3}$ at $n \gg n_{max}$. For Rydberg states $n \gg 1$, ions with the orbital quantum numbers $\ell = 0$ and 1 are created with the highest probability (see, e.g. [1]).

The distribution of σ_{ec} over n states depends not only on the relative velocity v and the atomic structure of colliding systems but also on the target density. In a dense target, the maximum possible principal quantum number n_{cut} which the $X^{(q-1)+}(n)$ ion can be created with, is limited because the population of highly excited n states is destroyed by ionization collisions with the target:

$$X^{(q-1)+}(n) + A \rightarrow X^{q+} + A + e^-. \quad (2)$$

The corresponding ionization rate is quite large: $v\sigma_{ion} \approx N \cdot n^4 \cdot Z_T^2$ where v is the relative velocity, Z_T and N are the nuclear charge and density of the target particles, respectively.

The value of n_{cut} can be estimated from equality condition of the radiative decay rate $A(n)$ to all low-lying states of the $X^{(q-1)+}$ ion and the ionization rate $v\sigma_{ion}(n)$ (see, e.g. [2]):

$$A(n_{cut}, n_0) = N \cdot \beta \cdot c \cdot \sigma_{ion}, \quad (3)$$

where n_0 is the ground state of the ion and $\beta = v/c$ is the relativistic factor. Equation (3) gives:

$$n_{cut} = n_0 + \Delta n, \quad (4)$$

$$\Delta n \approx Z_P \left(\frac{10^{18}}{Z_T^2 N [\text{cm}^{-3}]} \right)^{1/7} \left(\frac{E [\text{keV/u}]}{260 Z_P^2} \right)^{1/14}, \quad (5)$$

where E and Z_P are the projectile energy and ion charge.

As is seen from (5), the higher the target density and the target charge is, the lower is the maximum possible quantum number n_{cut} and, therefore, the lower is the total capture cross section $\sigma_{tot} = \sum_{n=n_0}^{n_{cut}} \sigma_{ec}(n)$. In Fig. 1, the electron-capture cross sections for collisions of bare Ni^{28+} ions with low- and high-density SiO_2 molecules are shown. (These reactions are now under experimental study at GSI). The cross sections were calculated by the CAPTURE code in the impact parameter representation described in [3]. At energies $E = 100 \text{ keV/u} - 10 \text{ MeV/u}$, the capture of L and M subshells of the low-density SiO_2 molecules (curve 1) is suppressed by the density effect (curve 2) leading mainly to the capture of K electrons. At energies $E > 10 \text{ MeV/u}$, both cross sections are approximately equal because only K electrons are captured in this energy range with the same $n_{max} \approx 3-4$.

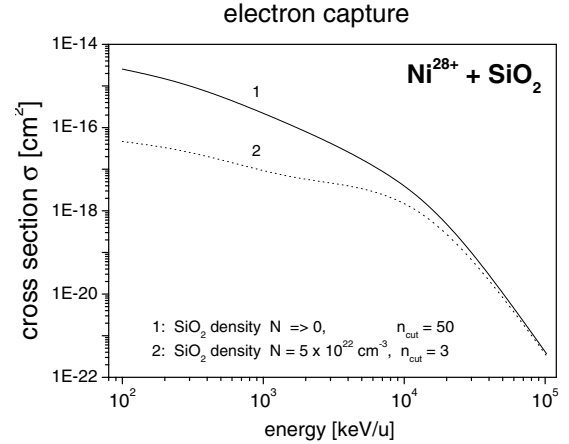


Figure 1: Influence of the target-density effect on the total electron-capture cross sections in $\text{Ni}^{28+} + \text{SiO}_2$ collisions: 1 – low-density target, 2 – high-density target (CAPTURE code, present work).

Due to the density effect considered, the average charge of the ion beam after the solid target is larger than that after a low-dense target. This problem was considered in [4] where collisions of U^{q+} ions with carbon foils were studied in the MeV/u energy regime.

In general, consideration of the charge-changing processes arising in collisions of fast beams with atomic and plasma targets [3]–[5] shows the following peculiarities:

1) the distribution of the projectiles over excited states after interaction with a target depend on the target density: interaction with high-density targets cuts off the maximum possible principal quantum numbers of the projectile after collision and *reduces* the total electron-capture cross sections,

2) the distribution over the quantum numbers nl of the projectile due to charge-changing collisions with a target defines the *spectroscopic* properties (radiative spectra) of the projectile,

3) account for the density effect together with the Coulomb distortion of the projectile wave functions and multi-electron processes allows one to describe the *mean charge* of the fast-ion beams penetrating through atomic and plasma targets.

References

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