Beam Lifetimes of Fast Positive Ions

V.P. Shevelko[1)], D. Böhne[2)], O. Brinzanescu[2)], M. Rau[2)], Th. Stöhlker [2,3)]
Lebedev Physics Institute (Russia)[1)], GSI-Darmstadt (Germany)[2)] , IKF University of Frankfurt (Germany)[3)]

The intensity and lifetime of low-charged ion beams in acceleration devices, such as synchrotrons or storage rings, critically depends on the charge exchange cross-sections for collisions with residual-gas atoms or moleculs. In the present study, the charge-changing cross sections σ_{tot} and beam lifetimes τ for stored many-electron ions, Mg^{1+}, Ar^{2+}, Pb^{29+}, U^{4+}, U^{10+} and U^{28+}, and energies in the range of E = 1 – 100 MeV/u were calculated and compared with experimental data recently obtained at SIS/GSI [1, 2]. For the calculation, the following formulas have been applied:

$$\sigma_{tot}(v) = \Sigma_T Y(Z_T)\,[\,\sigma_{ec}(v) + \sigma_{ion}(v)] \qquad (1)$$

$$\sigma_{ion}(v) = Z_T^{\,2}\,\sigma_p(v) + Z_T\,\sigma_e(v) \qquad (2)$$

$$\tau(v) = [\rho \times v \times \sigma_{tot}(v)]^{-1}, \qquad (3)$$

where v is the projectile velocity, σ_{ec} is the one-electron capture cross section of the target electrons, σ_{ion} is the single electron ionization cross section of the projectile, $\sigma_{p,e}$ are proton- and electron-impact ionization cross sections, respectively, Z_T is the nuclear charge of the target atom, ρ and $Y(Z_T)$ are the total density and the fractions of the residual gas atoms. The sum over T runs over all residual gas components. Note, that in contrast to highly charged heavy-ion beams, the low ionization potentials of low-charged projectiles give rise to large ionization cross-sections whereas electron capture into the fast moving ions can almost be neglected. In order to provide reliable cross-section estimates for ionization, the ionization potentials for all electron shells must be considered in the calculation. The latter, was performed in the framework of the non-relativistic Plane Wave Born approximation whereas the ionization potentials were taken from Ref. [3,4]. For completeness also electron capture into the projectile was taken into account by applying a semiempirical formula given in Ref. [5]. According to experimental and theoretical estimations of the rest gas conditions in the SIS/GSI [4], the following gas pressure and residual gas mixure were assumed:

$$\rho = (6.4 \pm 1.3) \times 10^{-11}\ \text{mbar} \qquad (4)$$

$$Y(H_2) = 77\ \%,\ \ Y(N_2) = 20\ \%,\ Y(Ar) = 3\ \%. \qquad (5)$$

Here, it is important to stress that in particular the uncertainty of the quoted Ar concentration is rather large. On the other hand, due to the Z_T^2-scaling of the loss-cross sections (see Eq. (2)), such high-Z components in the residual are of crucial importance for beam lifetime.

In Figs. 1 and 2 calculated values for total charge-exchange cross sections and lifetimes, Eqs. (1)-(5), are given and compared with experimental data. As can be seen in the figures, the theoretical estimates may differ by up to a factor of 2 to 3 from the experimental findings. This variance can be explained by the overall uncertainties introduced by i) the simplicity of the approximations used and ii) the uncertainty in the measured residual-gas pressure and its components (see [6] for details). To make more definite conclusions, future experiments are required where the gas pressure and the residual gas fractions are measured simultaneously with the beam lifetimes.

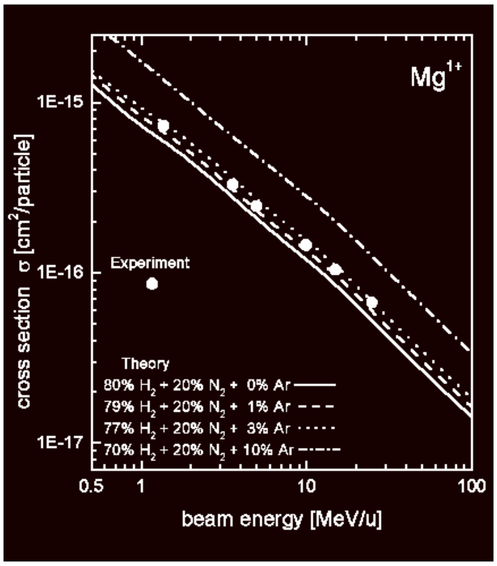

Fig. 1: Effective charge exchange cross sections for Mg^{+} ions as function of beam energy. Experimental data are taken from Ref. [2].

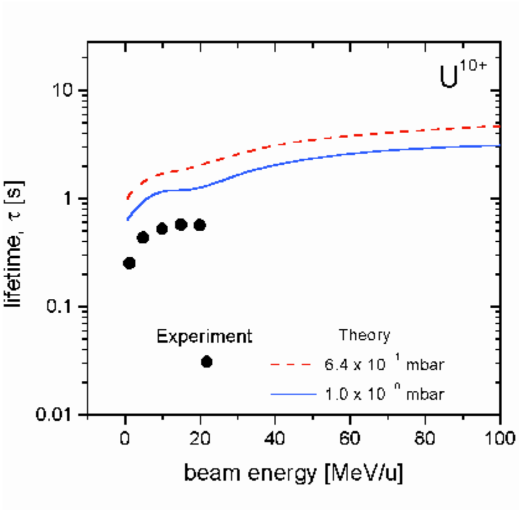

Fig. 2: Lifetime of U^{10+} ions as function of beam energy. Experimental data are taken from Ref. [1].

References

[1] K. Blasche et al., GSI Scientific Report 1996, p. 159 (Darmstadt 1997).
[2] P. Strehl, H. Reeg, D. Wilms, unpublished (SIS/GSI, Darmstadt 1997) .
[3] T.A. Carlson et al., At. Data Nucl. Data Tables 2, 63 (1970).
[4] K. Rashid et al., At. Data Nucl. Data Tables 40, 365 (1988).
[5] A.S. Schlachter et al., Phys. Rev. A 27 , 3372 (1983) .
[6] V.P. Shevelko, D. Böhne, Th. Stöhlker, Nucl. Instrum. Methods A, (1997), submitted .