Electron impact multiple ionization of C^+, N^+ and O^+ ions.

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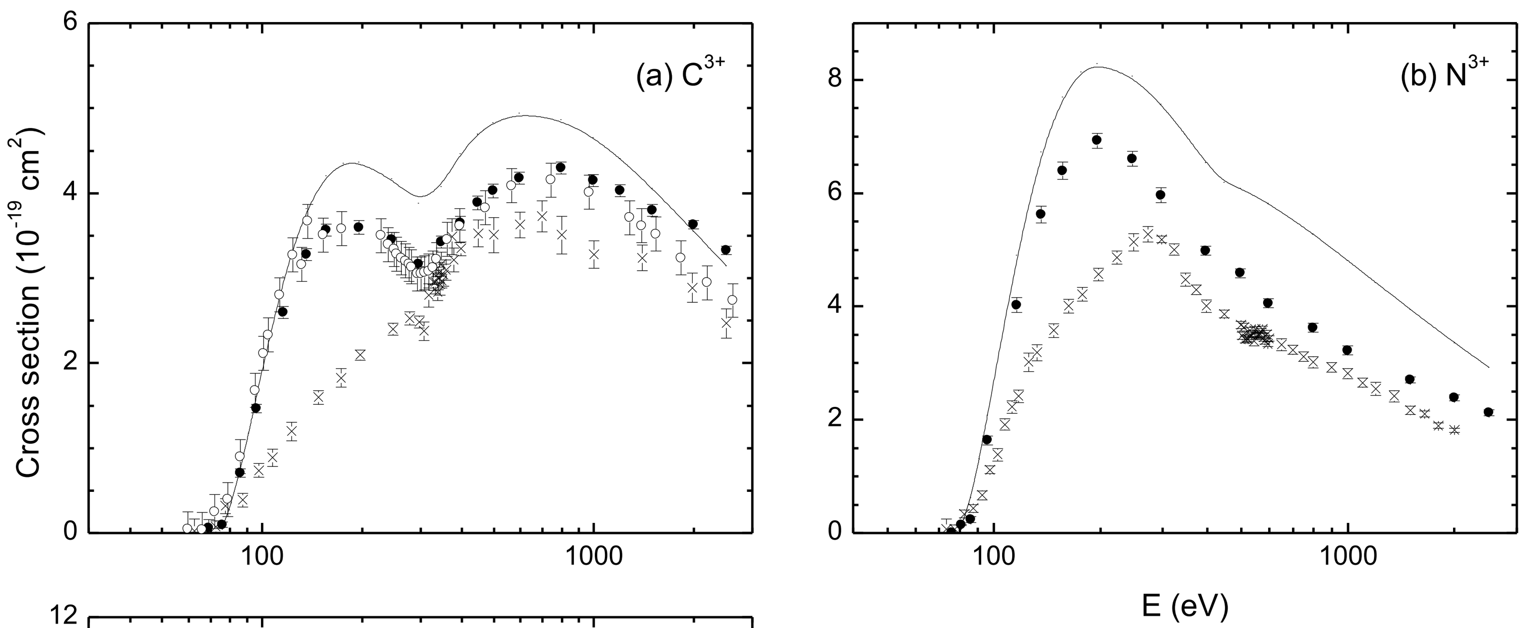
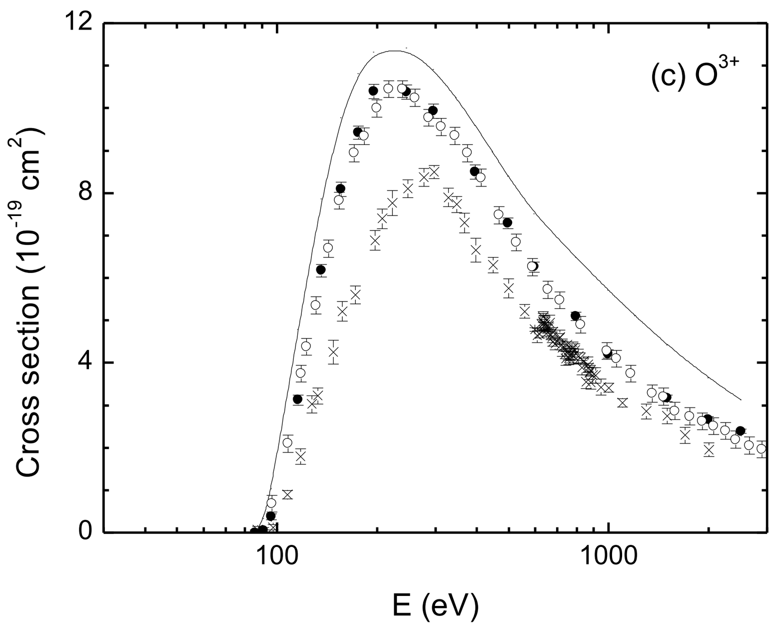
In the present study the animated crossed electron-ion beams method [1] is applied for measurement of absolute cross sections for electron impact single and multiple ionization of C^+, N^+ and O^+ ions at incident electron energy values up to 2.5 keV.

The maximum cross sections for the multiply-charged products C^{q+} (q = 2 – 4) is found to range from 2.3×10^{-20} cm² (for C^{4+}) up to 6.3×10^{-17} cm² (for C2+); for N^{q+} (q = 2 – 5) they range from 3.0×10^{-22} cm² (for N^{5+}) up to 5.1×10^{-17} cm² (for N^{2+}) and, lastly, for O^{q+} (q = 2 – 5) they range from 5.5×10^{-22} cm² (for O^{5+}) up to 5.2×10^{-17} cm² (for O^{2+}).

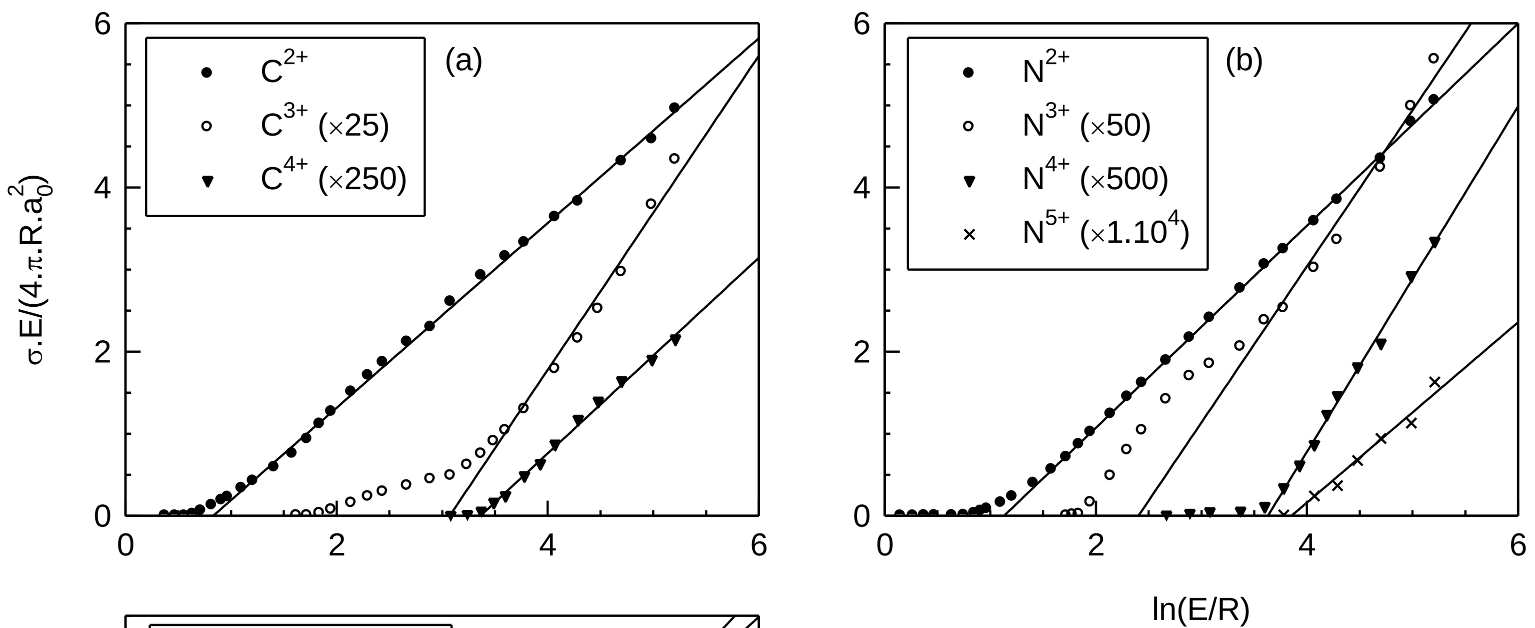
The corresponding threshold energies are determined to satisfactorily compare to spectroscopic values.

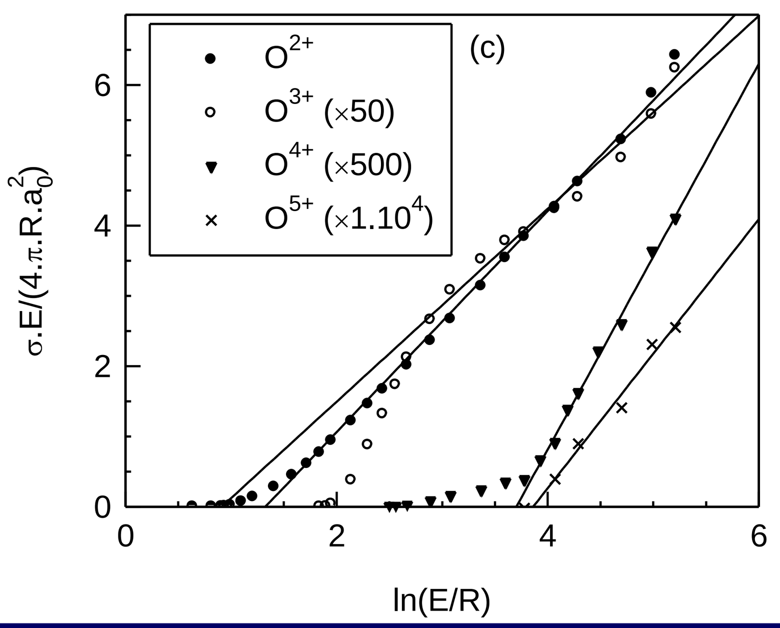




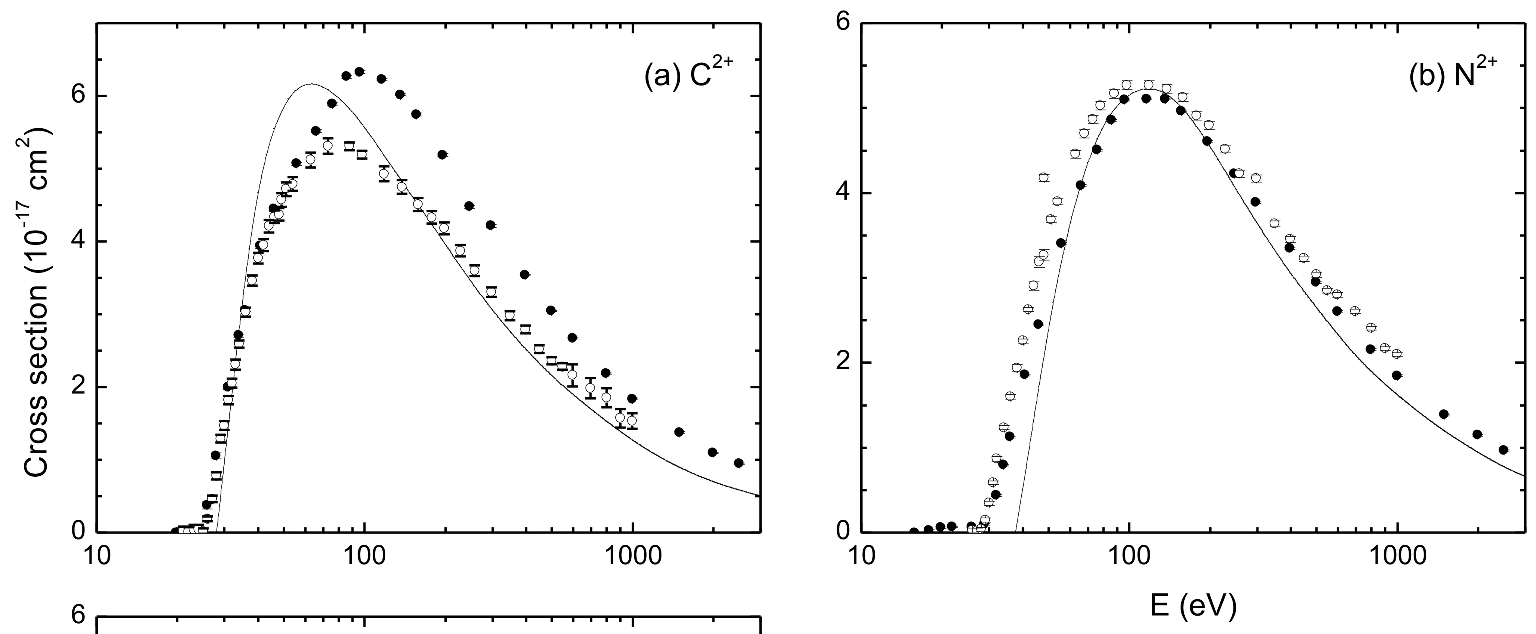
Cross sections for electron impact double ionization of (a) C^+, (b) N^+ and (c) O^+: present experimental results (•), measurements of Zambra et al (×), measurements of Westermann et al (○), semi-empirical model of Talukder et al (- -), and semi-empirical formula (—).

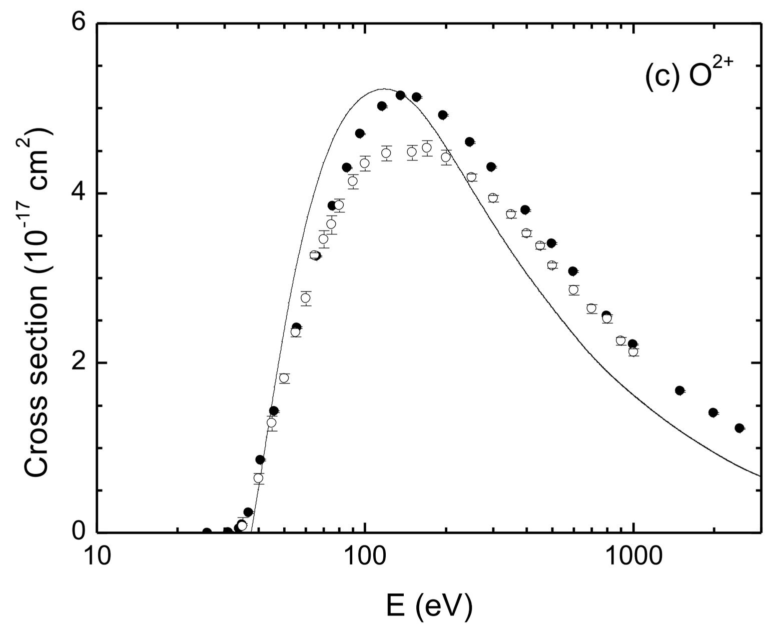
The Bethe-Fano plot show that for reasonably high energy of the incident electron, the quantity nE_i linearly depends on $\ln E_i$, according to the Bethe formulae. The Born approximation in the interaction between a fast electron and an ion turns out to be sufficient already at impact energies of only about 1 keV.





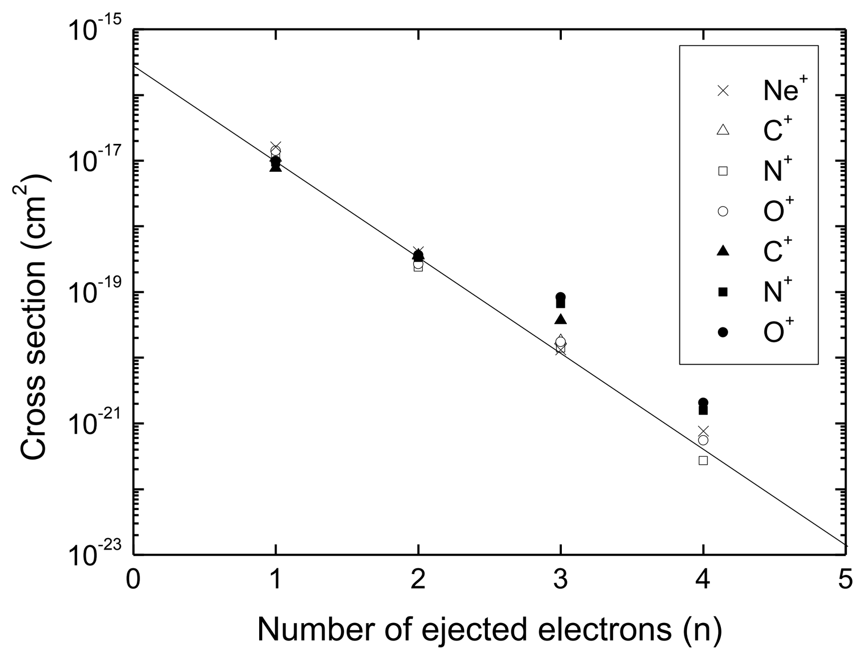
Bethe-Fano plots for X^{q+} ions produced by electron impact ionization of (a) C^+, (b) N^+ and (c) O^+: Straight lines result from the fitting procedure.





Cross sections for electron impact single ionization of (a) C^+, (b) N^+ and (c) O^+: present experimental results (•), measurements of Yamada et al (○) and calculations based on the CBE approximation using the ATOM code (—).

The cross section values for single ionization reasonably agree with the calculations using the Coulomb-Born approximation with exchange [2]. Those for multiple ionization are found to compare well with the semi-empirical model for q = 3 [3], but they appear to be notably overestimated by a semi-empirical Bethe- Born type formula when q > 3 [4].



Ionization cross sections for C^+, N^+, O^+ and Ne^+ plotted as a function of the number of ejected electrons at E = 1995.1 eV: measurements of Lecointre et al (×) and present experimental results (open symbols) together with CBE calculations using the ATOM code for n = 1 and semi-empirical formulas [3] and [4] for, respectively, n = 2 and n = 3, 4 (filled symbols).

The remarkable point is that, at a given incident electron energy, the sequence of single and multiple ionization cross sections is observed to decrease exponentially with respect to the number of ejected electrons:

$$\sigma_n = \sigma_1 \exp\left[-(n-1)/q_0\right]$$

where σ_1 is the single ionization cross section and the fitting parameter q_0 appears to be an effective charge. This peculiarity is also observable for neutral targets, and therefore seems to be a general feature common to any atomic or ionic target, but, up to now, it seems to have not receive any qualitative or quantitative theoretical treatment.

References

[1] P. Defrance *et al 1981 J. Phys. B: At. Mol. Phys.* **14 103**

[2] V. P. Shevelko and L. A. Vainshtein 1993 *Atomic Physics for Hot Plasmas (Bristol: Institute of* Physics Publishing)

[3] V. P. Shevelko *et al 2005 J. Phys. B: At. Mol. Opt. Phys.* ***38 525***

[4] V. P. Shevelko and H. Tawara 1995 *J. Phys. B: At. Mol. Opt. Phys.* ***28 L589***

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