§18. A Formula for Multiple Ionization Cross-Sections

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Multiple ionization (MI) of atoms and atomic ions by electron impact

$$e + A^{q+} \rightarrow e + A^{(q+m)+} + me \quad (1)$$

is one of the processes governing the charge-composition history and spectral intensity of radiation in nonequilibrium plasmas, especially in low-density plasmas and plasmas affected by electron beams. Here, q=0,1,2... is the charge of a target particle and m is the number of electrons ejected in one collision. At present, there is no analytical expression for the MI cross-sections, except for the formula by Gryzinski[1] for direct double ionization. The analysis of MI cross sections $\sigma_{q,m}(\varepsilon)$ shows that the cross-sections satisfy two scaling relations in the energy ranges $1 \le x \le x_i$ and $x > x_a$. Here, ε is the kinetic energy of the relative motion of a projectile electron and a target ion, $x = \varepsilon/I_{q,m}$ is the kinetic energy in threshold units, and $I_{q,m}$ is the minimal energy required for ejection of m electrons from the ion A^{q+}. Based on experimental data, one may assume

$$I_{q,m} = \sum_{k=q}^{q+m-1} I_k, \quad (2)$$

where I_k is the ionization potential of the ion A^{k+}. The accuracy of this expression is to within a few percent. The energy x_i is the indirect MI threshold, and x_a is the minimal energy sufficient to involve most of MI channels.

Based on the observed scaling, we derived a general formula for the MI cross-sections[2]. Our expression contains *no* fitting parameters and, we beleive, has satisfactory predicting power. We expect that the accuracy of the predicted cross-section will be within a factor of 3 in the ranges $1 < x \le x_i$ and $x > x_a$ except for $x \approx 1$ where the accuracy may be less because of some inaccuracy in Eq. (2).

In Figures 1 and 2 calculated MI cross-sections (dotted and solid lines for two energy intervals) are compared with the experimental data by Bolorizadeh e.a., Freund e.a., Krishnakumar and Srivastava, Lebius e.a. taken from the NIFS Atomic Database.

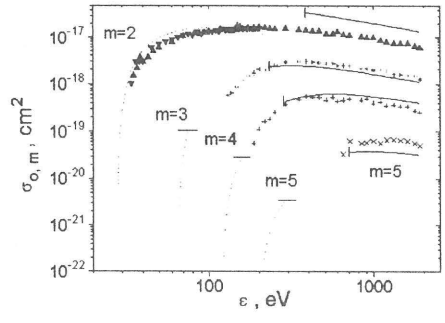

Fig. 1. MI cross-sections for atoms of copper.

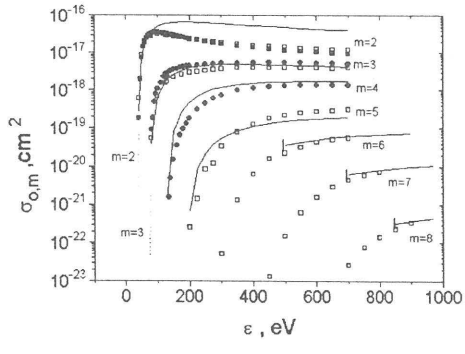

Fig. 2. MI cross-sections for atoms of krypton.

References

1) Gryzinsky, M. Phys. Rev. 138 (1965) A305
2) Fisher V. et al. Preprint WIS (1994), to be published