§17. Multiple Ionization of Atoms and Ions by Electron Impact

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Multiple Ionization (MI) of atoms and positive ions by electron impact is considered. Semiempirical formulae for MI cross sections σ_n are proposed on the basis of the available experimental data and the assumption of the Bethe-Born dependence of σ_n on the incident electron energy E. For ejection of three or more electrons from the target σ_n has the form:

$$\sigma_n = a(n)\, N^{b(n)} \left(\frac{Ry}{I_n}\right)^2 \left(\frac{u}{u+1}\right)^c \frac{\ln(u+1)}{u+1} 10^{-18}\ cm^2$$

$$u = E / I_n - 1, \quad n \geq 3,$$

where N is the total number of the target electrons, I_n is the minimal ionization energy required to ionize n electrons from the target.

The fitting parameters a, b and c were evaluated from experimental data. For neutral targets (z=0), one has c=1 and for ions (z≥1), c = 0.75. Fitting parameters a and b for $3 \leq n \leq 10$ are given in Table 1. For n > 10 one can use the asymptotic values: $a(n) \cong 1350/n^{5.7}$, b(n) = const=2.00. It is seen that MI cross section falls off approximately as $\sigma_n \propto n^{-6}$.

Table 1. Parameters a and b as a function of n.

n	a	b	n	a	b
3	6.30	1.20	7	0.021	2.00
4	0.50	1.73	8	0.0096	2.00
5	0.14	1.85	9	0.0049	2.00
6	0.049	1.96	10	0.0027	2.00

A comparison of MI cross sections described by semiempirical formulae suggested with experimental data for neutral atomic targets from Ne up to U and ejection up to 13 electrons and with those for positive ions from Ar^+ up to W^{4+} with ejection up to 4 electrons shows that in the most cases the accuracy of the present formulae is a factor of 2 or even better. Typical examples of MI cross sections of atoms and ions are shown in Figures.

In general, the formulae suggested are very simple and describe the dependence of σ_n on three independent atomic parameters: the minimal ionization energy I_n, the total number of the target electrons N and the number of ejected electrons n. These formulae can be used for estimation of multiple-ionization cross sections for an arbitrary atomic or ionic target in a wide range of the incident electron energy up to E = 10 keV.