§12. Double Electron Removal under Highly-Ionized Ion Impact

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The double-electron process plays a significant role in many fields. Double electron ionization of two-electron systems, in particular of helium atom, under various particle impact is one of the most basic topics relevant to investigating the electron correlation effects. Recently similar importance is emphasized in the double electron detachment (ionization) from negative hydrogen ions (H^-) both in basic aspects as well as in many applications.

1) Double ionization of helium atoms[1)]

The most important issues in double electron ionization of helium atoms in multiply charged ion impact are a) proper choice of the correlated two-electron wavefunctions of target atoms and b) reasonable approximation of the continuum wavefunctions on the final channels. For these, we have chosen the asymptotic values of the shake-off ratios and the generalized Volkov-Keldish states used in the one-electron rearrangement process.

Using these approximations, we have developed the independent-event model where, under multiply charged ion impact, the double ionization cross sections are assumed to be given as the sum of those for the one-step shake-off (SO) processes and the two-step (TS) processes, without much strong interference between them.

The final results of double-to-single electron ionization cross section ratio, R, obtained in the present analysis are given in a simple analytic form as a function of the projectile charge, q, and their velocity, v, valid only for the parameter $q/v^2 < 1$:

$$R = R_{SO} + (q/v)^2 I/L \qquad (1)$$

$R_{SO} = 0.0023$, $I = 0.442\exp(-2.1q/v^2 - 2.16/v)$, $L = 1.448 + \ln\{v^2/(1-\beta^2)\} - \beta^2$, $\beta = v/c$ (c : the velocity of light).

The present formula can reproduce the observed results quite well over a wide range of projectiles covering C^{6+} to U^{90+} ions. However, as seen in the formula above, it is important to note that it is not possible to scale the these ratios in any single form, as the results indicate that the the ratios depend on both v/q and v^2/q terms.

2) Double electron detachment from negative hydrogen ions[2)]

The electron detachment from H^- ions is the most important issue in the formation of intense neutral hydrogen beams which are going to be used in neutral beam injection (NBI) in many fusion devices. The best conversion efficiencies of H^- ions into neutral H beam depend not only upon the single electron detachment but also upon the double electron detachment which theoretical investigation is the present purpose.

The principles of the present theoretical treatments are very similar to those in double ionization of neutral helium atoms as described above, with having two electrons in different shells, namely the inner (1s)- and outer (1s')-shells with different continuum wavefunctions.

With the assumption that one-step shake-off and two-step (so-called TS-2) processes are dominant in double electron detachment from H^- ions, neglecting their interference, the final double electron detachment cross sections are given as the sum of those for the two processes above :

$$\sigma_{dd} = R_{SO}\sigma_{sd} + \sigma_{TS}$$

where R_{SO} is the shake-off ratio whose value observed in electron impact is varied from 0.004 to 0.0023 and σ_{sd} and σ_{TS}, the single-electron detachment and two-step cross sections, respectively, are expressed as follows :.

$$\sigma_{sd} = 51.6(q/v)^2\ln\{2.03v^2/(1+0.139v^2)^{1/2} + 1.01\} \qquad (2)$$

$$\sigma_{TS} = 2.9(q/v)^4\exp(-0.41q/v^2 - 1.1/v) \qquad (3)$$

in the units of 10^{-16} cm^2. The present formula for single-electron detachment cross sections have been shown to properly describe the observed values[3)] but presently no experimental result has been reported on double electron detachment from H^- ions.

References

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