§15. Rate Coefficient of Electron Impact Ionization for Electron Truncated Maxwellian Distribution – Single Electron Temperature –

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Around a floating wall, which is negatively charged because of lighter electrons, electrons with higher energy than a wall potential are absorbed to a target plate. Electron impact ionization for the electron truncated Maxwellian distribution was studied according to the Lotz formula [1]. A floating potential of a target wall ϕ_f immersed in plasma is determined by the condition of the equal particle flux of ions and electrons,

$$e\phi_f / T_e = 0.5\ln(2\pi m_e / Z_i m_i), \qquad (1)$$

where e, m_e, m_i, and T_e is the unsigned charge on an electron, the electron mass, the ion mass, and the electron temperature at the sheath entrance, respectively. Here the low ion temperature is neglected compared to the electron one. The electrons with higher energy overcome this potential and are absorbed to the wall. On the other hand the slower electrons are repelled by this negative potential. These effects make the truncation of electron velocity distribution to the direction from the wall. The normalized truncated Maxwellian electron distribution function is expressed as:

$$f_e(\vec{v}) = \frac{2}{1+\mathrm{erf}(\sqrt{\varepsilon_c / T_e})}\left(\frac{m_e}{2\pi T_e}\right)^{3/2} \exp\left(-\frac{m_e}{2T_e}v^2\right), \qquad (2)$$

where erf is the error function.

The rate coefficient of electron impact ionization due to the truncated electron velocity distribution is calculated according to the Lotz formula [1]. The empirical formula of a cross-section is:

$$\sigma_{iz}^{LZ}(|\vec{v}|) = \sum_j^N a_j \zeta_j \frac{\ln(\varepsilon/\chi_j)}{\chi_j \varepsilon}\{1 - b_j \exp[-c_j(\varepsilon/\chi_j - 1)]\}, \qquad (3)$$

where ε, χ_j, and ζ_j are the energy of an impact electron, the binding energy of electrons in the j-th shell, the number of equivalent electrons in the j-th shell, and a_j, b_j, and c_j denote the individual constants which have to be determined by a reasonable guess. This formula has good agreements with the experimental data.

In the case the truncated energy is larger than the binding energy of electrons in the j-th shell, $\varepsilon_c = -e\phi_f \geq \chi_j$, the rate coefficient is expressed as follows:

$$\begin{aligned}
<\sigma v>_{tc} = &\sqrt{\frac{8}{\pi m_e}} \frac{2}{1+\mathrm{erf}(\sqrt{\varepsilon_c/T_e})} \frac{1}{T_e^{3/2}} \\
&\sum_j a_j \zeta_j \{-\frac{T_e}{\chi_j} E_i(-\frac{\chi_j}{T_e}) + \frac{b_j \exp(-c_j)}{\chi_j/T_e + c_j} E_i[-(\chi_j/T_e + c_j)] \\
&+ \frac{T_e}{2\chi_j} E_i(-\frac{\varepsilon_c}{T_e}) - \frac{b_j \exp(-c_j)}{2(\chi_j/T_e + c_j)} E_i[-\frac{\varepsilon_c}{\chi_j}(\chi_j/T_e + c_j)] \\
&+ \frac{1}{2}\sqrt{\frac{\varepsilon_c}{\chi_j}\frac{T_e}{\chi_j}} G(\frac{T_e}{\chi_j}, \frac{\varepsilon_c}{T_e}) - \frac{T_e}{2\chi_j} \exp(-\frac{\varepsilon_c}{T_e}) \ln(\frac{\varepsilon_c}{\chi_j}) \\
&- \frac{b_j \exp(-c_j)}{2} \sqrt{\frac{\varepsilon_c}{\chi_j}} \frac{1}{\sqrt{\frac{\chi_j}{T_e} + c_j}} G[\frac{\chi_j}{T_e} + c_j, \frac{\varepsilon_c}{\chi_j}(\frac{\chi_j}{T_e} + c_j)] \\
&- \frac{1}{\chi_j/T_e + c_j} \exp[-\frac{\varepsilon_c}{\chi_j}(\chi_j/T_e + c_j)] \ln(\frac{\varepsilon_c}{\chi_j})\}
\end{aligned} \qquad (4)$$

where E_i is the exponential function and the function of G is defined as:

$$G(a,b) = \int_b^\infty dt \exp(-t) \ln(at) / \sqrt{t}. \qquad (5)$$

On the other hand the truncated energy is lower than the binding energy of electrons in the j-th shell, $\varepsilon_c = -e\phi_f < \chi_j$, the rate coefficient is obtained as:

$$\begin{aligned}
<\sigma v>_{tc} = &\sqrt{\frac{8}{\pi m_e}} \frac{2}{1+\mathrm{erf}(\sqrt{\varepsilon_c/T_e})} \frac{1}{T_e^{3/2}} \\
&\sum_j a_j \zeta_j \{-\frac{T_e}{\chi_j} E_i(-\frac{\chi_j}{T_e}) + \frac{b_j \exp(-c_j)}{\chi_j/T_e + c_j} E_i[-(\chi_j/T_e + c_j)] \\
&+ \sqrt{\frac{\varepsilon_c}{\chi_j}\frac{T_e}{\chi_j}} G(\frac{T_e}{\chi_j}, \frac{\varepsilon_c}{T_e}) - \frac{b_j \exp(-c_j)}{\sqrt{\frac{\chi_j}{T_e} + c_j}} G[\frac{1}{\frac{\chi_j}{T_e} + c_j}, \frac{\varepsilon_c}{\chi_j}(\frac{\chi_j}{T_e} + c_j)]\}
\end{aligned} \qquad (6)$$

In case of the higher electron temperature, the difference is quite small; e.g. for T_e = 10 eV the ratios are 0.97, 0.93, and 0.99 for hydrogen, helium, and argon plasma, respectively. On the other hand at the lower electron temperature the difference are appreciable, e.g. for T_e = 1 eV these ratios are reduced to 0.72, 0.68, and 0.76, respectively. In the detached plasma condition at the divertor wall, where the plasma temperature is as low as few eV, this effect might be important to investigate the interaction between plasma and neutrals.

References
1) Lotz, W., Zeitschrift Phys. **216** (1968) 241.