On Including Electron Effects

In VICTER

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Review of VICTER 2.0

- Focuses on atomic and molecular physics of D⁰, D₂⁰, D⁺, D₂⁺, D₃⁺, D⁻, and D₂⁻.
- D⁺, D₂⁺, and/or D₃⁺ ions enter from the source region outside the anode.
- Ion – neutral interactions dominate over ion – ion interactions.
- Ions and neutrals, except D₃⁺, can be created in the intergrid and cathode regions by impact ionization, charge exchange, electron capture, stripping, and dissociation of fast ions in collisions with the background gas.
- Interactions occur without momentum transfer between nuclei; v≠0 daughter products travel at the same speed as parent.
- Collisionless ion motion occurs between interactions.
Non-Spherical, 1-D Geometries are Treated

Code can model planar, cylindrical, or spherical geometry (all 1D; quantities vary with “radius”).

Cylindrical geometry

Planar geometry (edge view)
Vacuum or Child-Langmuir Electrostatic Potentials Are Assumed between Grids

- Flat potential assumed in the cathode and source regions.
Deuterium Atomic and Molecular Processes Included in VICTER 2.0

\[
\begin{align*}
D^+ + D_2 &\rightarrow D + D_2^+ & \text{charge exchange of } D^+ \\
D^+ + D_2 &\rightarrow D^+ + \ldots & \text{stationary } D^+ \text{ production} \\
D^+ + D_2 &\rightarrow D_2^+ + \ldots & \text{stationary } D_2^+ \text{ production} \\
D_2^+ + D_2 &\rightarrow \text{ various products} & \text{destruction of } D_2^+ \\
D_2^+ + D_2 &\rightarrow D^+ + \ldots & \text{fast } D^+ \text{ production} \\
D_2^+ + D_2 &\rightarrow D^+ + \ldots & \text{stationary } D^+ \text{ production} \\
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D_3^+ + D_2 &\rightarrow D_2^+ + \ldots & \text{stationary } D_2^+ \text{ production}
\end{align*}
\]

- Some of these processes are sums over various reaction channels.
- Negative ions, fast neutral atoms and molecules form by analogous processes.
Now What’s New

• Adding electron kinetics to VICTER
• Computing the electron energy spectra
• Including the feedback of the electrons on the ion kinetics
Modeling Electron Kinetics

• Free electrons generated at the cathode by secondary emission.

\[ S_c = \sum_{\text{species}} \int F_s(E) \gamma_{\text{sec}}(s, E) dE \]

• Additional electrons generated at v = 0 in the intergrid region by ion impact and electron impact ionization.

• Electrons are accelerated outward by the electrostatic potential.
The electron source term in the intergrid region satisfies a Volterra equation

\[ S_e(r) = A_e(r) + \int_{cathode}^{r} K_e(r, r') S_e(r') dr' \]

where

\[ K_e(r, r') = n_{gas} \sigma_{ei} (E_e(r, r')) \]

\[ E_e(r, r') = -e\varphi(r) + e\varphi(r') \]

and \( A_e(r) \) = electron source due to ionization of background gas by secondary electron and ion impact ionization.
From the electron source term we generate the electron energy spectrum,

\[ F_e(r, E)dE = \text{number of electrons passing through the radius } r \text{ per second with kinetic energy between } E \text{ and } E+dE. \]
Electron Ionization Affects the Ion Kinetics

• Electron ionization creates more ions in the intergrid region

\[ A_s(r) = \text{old value} + n_{\text{gas}} \int F_e(r, E) \sigma_{es}(E) dE \]

where \( A_s(r) \) is the inhomogeneous term in the ion Volterra equations.

• Consequently, the ion and electron kinetic equations have to be solved simultaneously.
Iterative Numerical Solution Procedure

Start

Initialize energy spectra

Solve ion equations

Solve electron equations

Update energy spectra

Converged?

no

yes

Compute fast neutrals

Compute neutron production

Store output

Post-process

Done
Parameters for a Sample Calculation

• Spherical geometry
• Cathode radius = 10 cm
• Anode radius = 25 cm
• Cathode potential = -70 kV
• Deuterium gas at 2.5 mTorr
• Cathode current = 30 mA
Electron Energy Spectrum
(at two different radii)
Electron Current at the Anode Radius

- From secondary emission at cathode: 17.5 mA
- From ion impact ionization in the intergrid region: 3.5 mA
- From electron impact ionization in the intergrid region: 4.3 μA

Conclusion – for typical Homer IEC parameters, electron impact ionization in the intergrid region is negligible.
Electron Ionization of D$_2$
Electron Mean Free Path at 2.5 mTorr

\[ \lambda_e = \frac{1}{n_{\text{gas}} \sigma_{\text{ioniz}}} \]

At 100 eV, \( \lambda_e = 1.25 \) m

At one grid point from the cathode (1.5 mm away), the electron energy is 1.7 keV and their mean free path is 100 m.
Summary

• Electron ionization in the intergrid region has been added to VICTER.
• Initial results show that ionization by electrons in the intergrid region is not important at typical IEC parameters.
• A difficulty with the approach so far is that the peak in the electron impact ionization cross section is not well-resolved. A non-uniform energy mesh for the electrons is needed.
Thank you for your attention.