Role of the plasma-electrode bias and the transverse magnetic field upon H- ion extraction in the negative ion source

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Introduction / Background

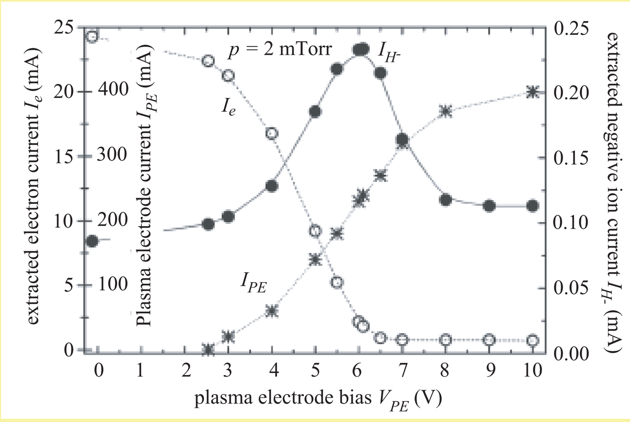

Fig. 1. Experimental results in ECR driven Camembert III ion source with a "weak" magnetic field of 20G at maximum[1]

[1] P. Svarnas *et al*, IEEE TPS, 35, 1156 (2007)

Using negative ion sources is a very promising way to produce the neutral beams required for future nuclear fusion reactors. In this study, we focus on the extraction physics of H^- ions in negative ion sources, by using a PIC2D3V method to analyse the motion of charged particles self-consistently. It was shown experimentally that a peak of extracted H^- current exists for an optimum bias voltage on the plasma electrode (PE), in the presence of a weak transverse magnetic field (see Fig. 1). The interpretation of these results requires to clarify the physical mechanisms involved in H^- ion and electron extraction, which are closely linked. A parametric study also shows the influence of the electron diffusion across the magnetic field.

Simulation model

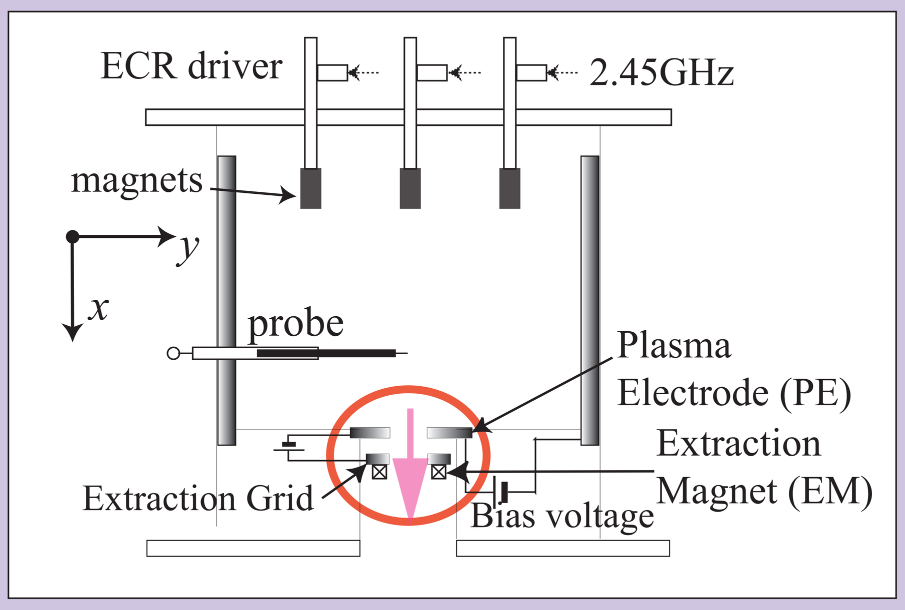

Fig. 2. ECR driven negative ion source [1].

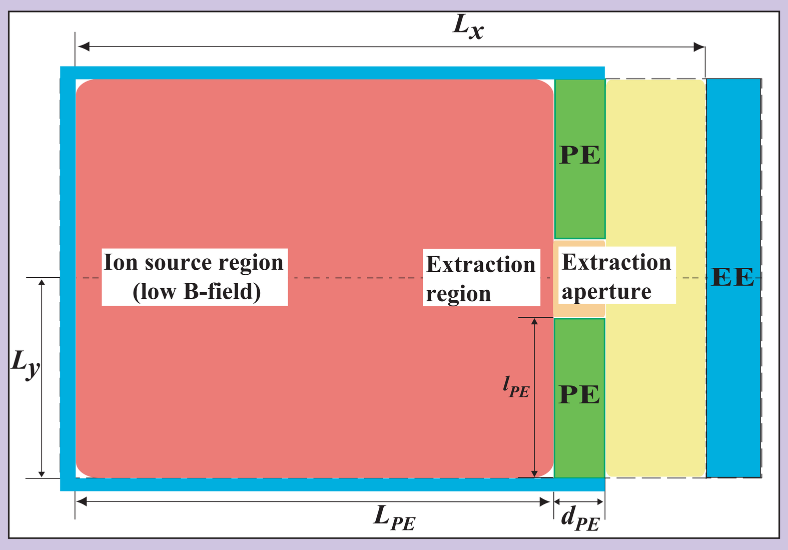

Fig. 3. 2D slab geometry.

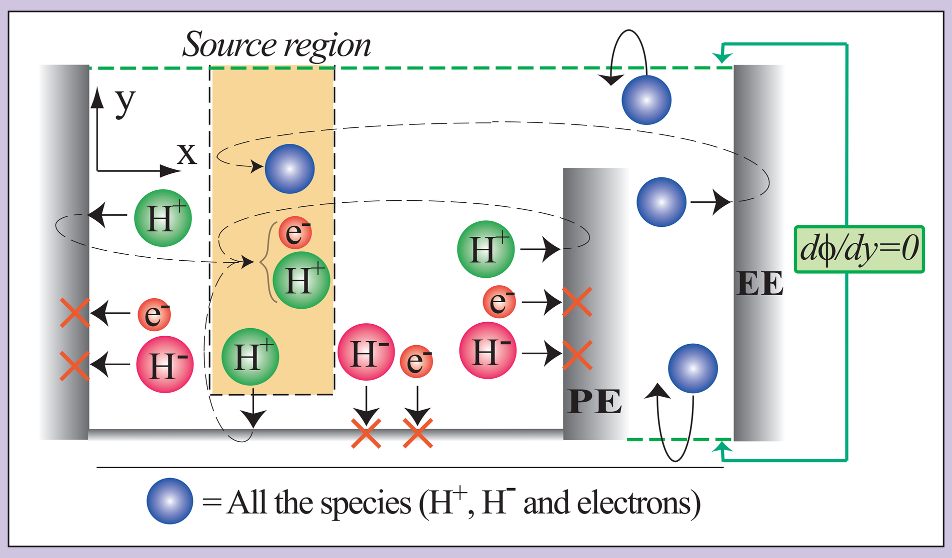

Fig. 4. Boundary conditions.

- Only half of the geometry is used as the calculation domain.
- The magnetic field satisfies the condition $r_{Le} << L_x$, $r_{LH+}, r_{LH-} >> L_y$

Table 1. Numerical parameters.

Electron temperature T_e	1.0 eV
H^+ ion temperature $T_{H+}=T_{H-}$	0.25 eV
Initial electron temperature n_e	10^{16} m^{-3}
Initial densities ratio $n_{H+} : n_e : n_{H-}$	10 : 9 : 1
Electron Debye length	7.43 x 10^{-5} m
Electron plasma frequency	6.64 x 10^{9} s^{-1}

Table 2. System parameters.

Mesh cell size	$\Delta x = \lambda_{De}$, $\Delta y = 0.5\,\lambda_{De}$
System size	$Lx=85\,\lambda_{De}$, $Ly=50\,\lambda_{De}$
Time step	$\Delta t = 0.1/\omega_{pe}$

Influence of the PE bias

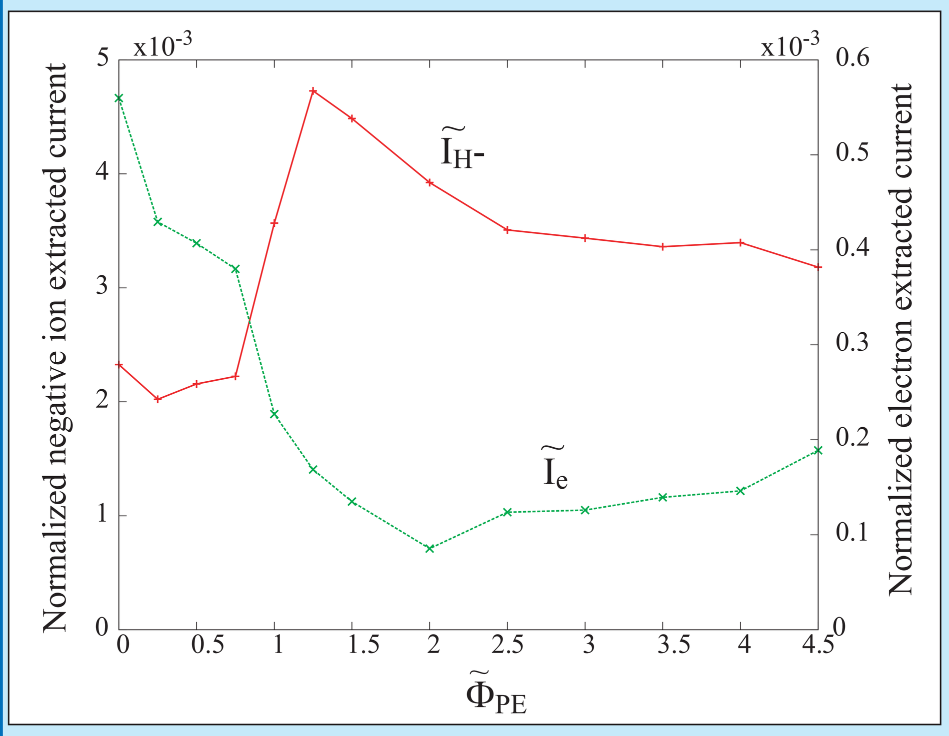

Fig. 5: Influence of the PE bias upon extracted H^- and electron currents.

The extracted H- ion current has a peak for an optimum bias, and decreases after.

The extracted electron current is significantly reduced by the PE bias.

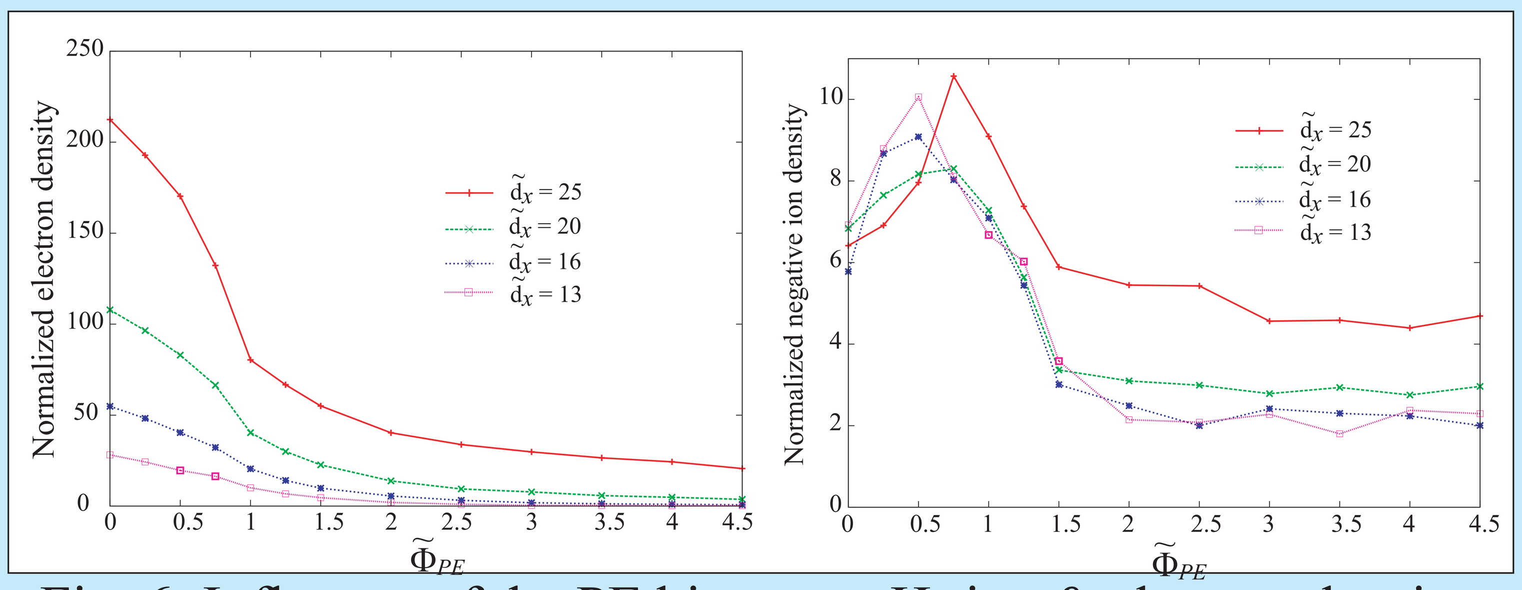

Fig. 6: Influence of the PE bias upon H^- ion & electron density taken at 4 distances from the extraction aperture.

The depletion of electron population with the PE bias continuously attracts H- ions in the extraction region.

Decrease of extracted H^- current after the peak

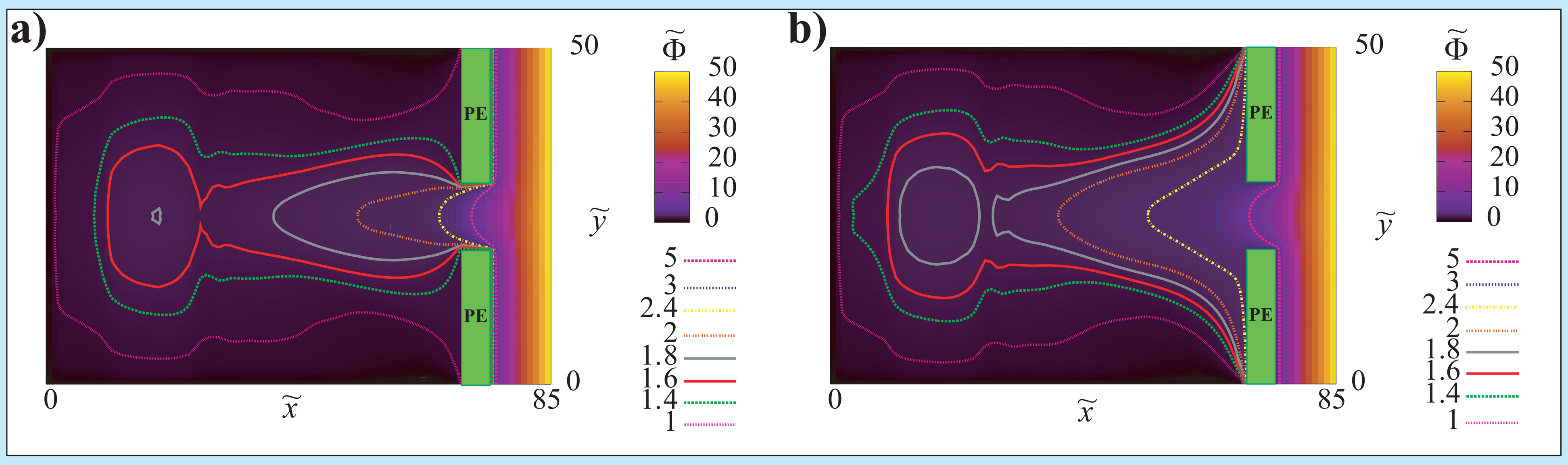

Fig. 7: Contour plot of the potential profile for a) $\tilde{\Phi}_{PE}$=1.25, and b) $\tilde{\Phi}_{PE}$=2.5.

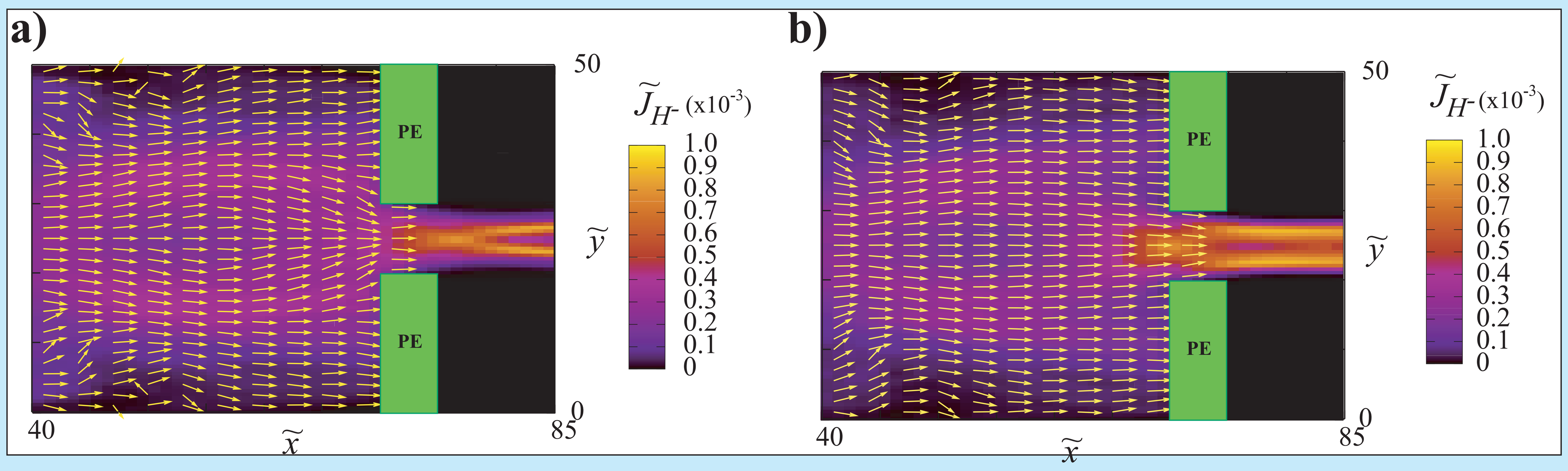

Fig. 8: Spatial profile of the H- plasma current density, for a) $\tilde{\Phi}_{PE}$=1.25, and b) $\tilde{\Phi}_{PE}$=2.5. The local directions of the current density vectors are shown by arrows.

The mushroom-shaped plateau of potential widens and disappears when the PE bias overcomes the plasma potential,

→ The direction of the electric force changes.

→ The funnelling effect disappears, many H^- ions are collected by the PE.

H^- ions are accumulated at low bias in the extraction region, and their density increases. When the PE bias is high enough, H^- ions are accelerated towards the extraction channel. Their residence time and density decrease, while the extracted current rapidly increases.

Influence of electron diffusion

Electron diffusion across the magnetic field has been considered through a 1D random-walk process in the *x*-direction. However, diffusive effect might have been overestimated, notably because the magnetic field is not transverse everywhere. We compare several cases, where D is the reference diffusion coefficient used in the PE bias study.

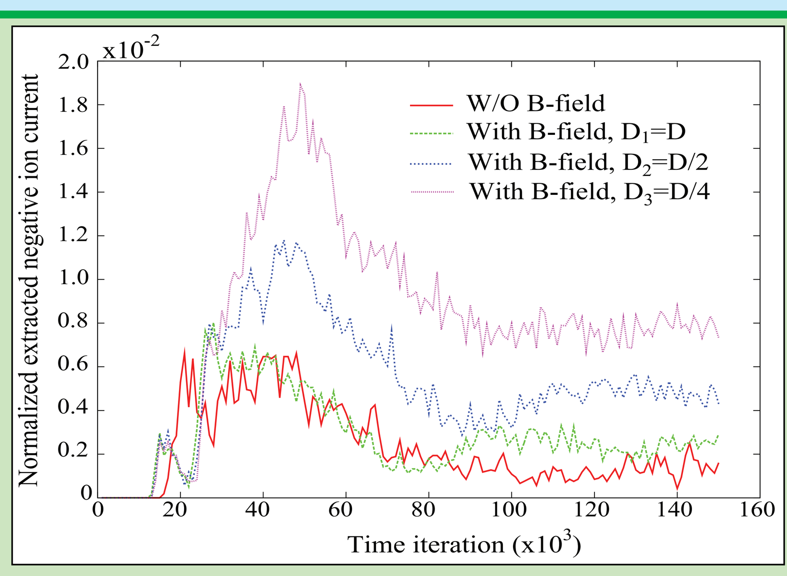

Fig. 9: Time evolution of extracted H- ion currents, without PE bias.

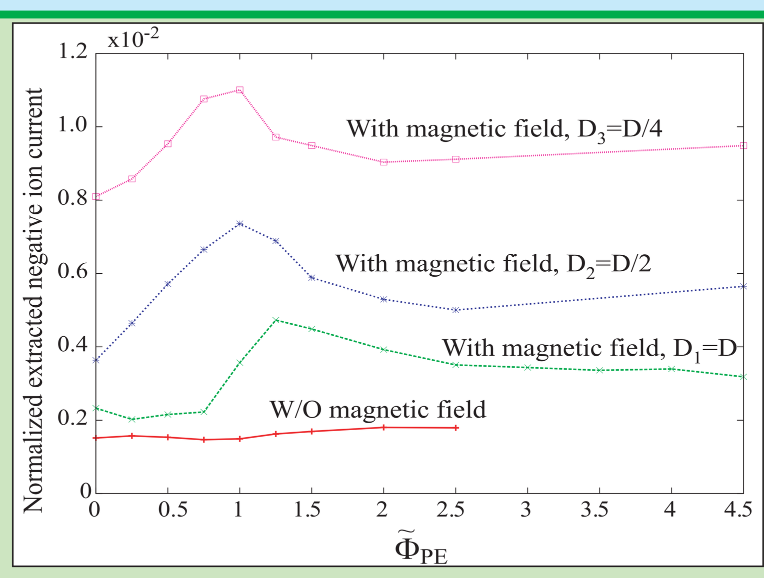

Fig. 10: Influence of the PE bias upon extracted H- currents.

- Decreasing the electron diffusion coefficient across the B-field reduces the attractive force of H- ions in the extraction region, and the extracted current is reduced.
- The mechanism leading to the peak is however not affected, except in the case without magnetic field.

Conclusion

The extracted H- ion current has a peak for a optimum value of PE bias, and the extracted electron current is significantly reduced. The underlying mechanism is the opening of the equipotential lines when the PE bias overcomes the plasma potential, leading H- ions to be collected by the PE instead of being extracted by the funnelling effect. Reducing the electron diffusion coefficient across the magnetic field does not affect this mechanism.