Negative Ion Studies in an IEC Fusion Device

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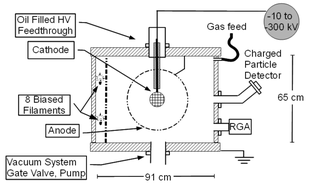
Conclusions:

- VICTER Code simulates negative ion creation and transport in IEC devices and shows the preponderance of negative ions are produced by atomic fast neutrals.
- Azimuthal scans show jets with a negative ion current exist in the IEC device, and this profile is sensitive to the system parameters

Inertial Electrostatic Confinement Apparatus



The IEC device produces an unique environment for the production of negative ions. Electrostatic fields accelerate nuclei to keV energies, relevant for negative ion production via (dissociative) charge exchange reaction. At the center of the cathode a focusing of ions produces an electrostatic well that traps cold electrons as well as produce a population of excited neutral molecules. These together produce negative ions via electron attachment.

Negative Ion Creation Reactions

Charge Exchange

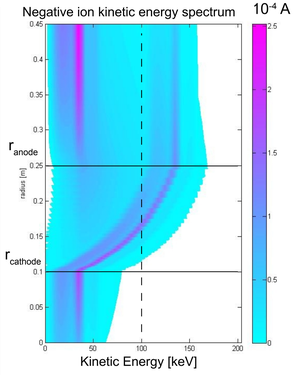
$$D + D_2 \rightarrow D^- + D_2^+$$
$$D + D_2 \rightarrow D^- + D^+ + D^+ + e^-$$
$$D_2^+ + D_2 \rightarrow D^- + D^+ + D_2$$
$$D^+ + D_2 \rightarrow D^- + 2D^+$$
$$D_2^+ + D_2 \rightarrow D^- + D^+ + D_2^+$$
$$D_3^+ + D_2 \rightarrow D^- + D_2^+ + D_2^+$$

A variety of energetic particles undergo charge exchange with background gas, producing energetic negative ions.

Electron Attachment

$$D_{2,(v)} + e^- \rightarrow D_2^- \rightarrow D^- + D \qquad D_{2,(v,J)} + e^- \rightarrow (D_2^-)_m$$

Within the cathode of the IEC a population of cold electrons can attach to excited neutrals to produce negative ions.



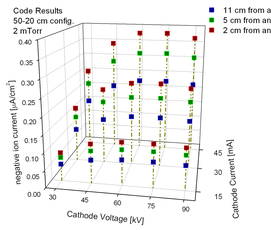
100 kV – 30 mA on cathode
50 cm diameter anode –
20 cm diameter cathode
2 mTorr chamber pressure

VICTER Code Simulates Negative Ion Creation and Transport in the IEC device.

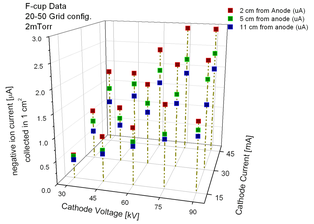
The **Volterra Integral Code for Transport in Electrostatic Reactors** (VICTER) Code is a 1-D simulation of ion and fast neutral current transport in an IEC device (see poster #93).

A negative ion function has been added that calculates negative ion current and energy spectrum.

VICTER Code results

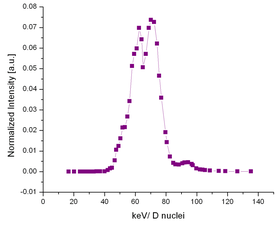


Radial negative ion measurements



The simulated total negative ion current (left) as a function of radius follow similar trends with data collected by a Faraday cup (right), though the 1-D code cannot account for variation in space or electron attachment.

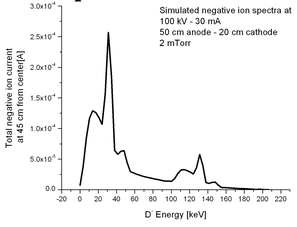
Measured negative ion energy spectrum



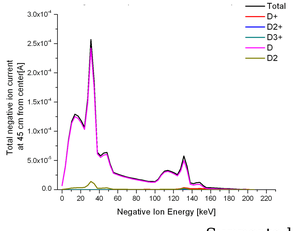
Measured energy spectrum (left) compared with VICTER results (right) show qualitative similarities in structure, but differences in the absolute energy persists.

Only the lower half of the energy spectrum was experimentally measured.

VICTER Code energy spectrum at wall



Negative ion sources

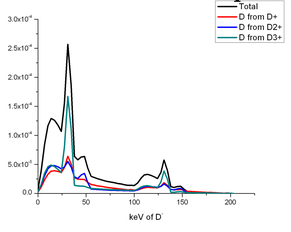


Multiple reactions can produce negative ions.

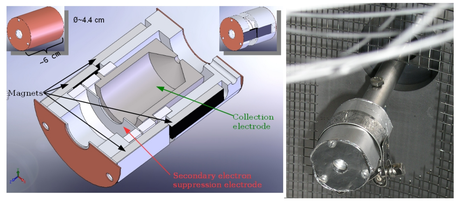
The VICTER Code has revealed the majority of negative ions are born from atomic fast neutrals (left).

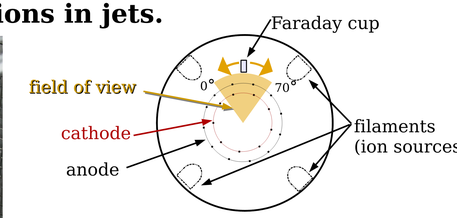
Decomposing the fast neutral sources producing negative ions (right) explains some of the structure of the energy spectrum.

Negative Ion production from each fast neutral parent



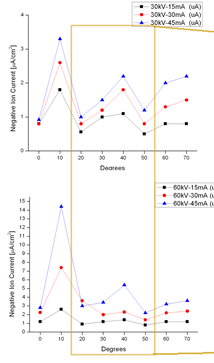
Azimuthal Scans with a Faraday cup show evidence of negative ions in jets.



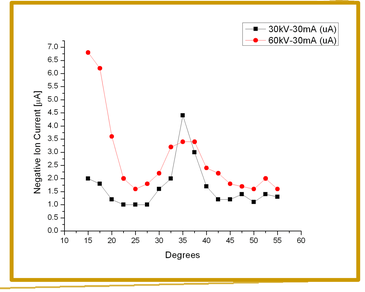


A Faraday Cup has been constructed for collection of keV energy negative ions. This Faraday cup is held in an azimuthal scanning mount, used to measure negative ion profiles in jets produced by the IEC device at the equator of the device. This system can sweep ~70°, measuring the negative ions in three jets: two near filaments acting as ion sources and one half way between two filaments.

Coarse resolution azimuthal scans



Fine resolution azimuthal scans at 30 mA



The coarse azimuthal scan shows jet structure.

Jet intensity is sensitive to the ion source placement, cathode voltage, and cathode current.

The fine resolution scan shows jet structure unexpectedly peaked in the 30 kV case that is not present in 60 kV case.

Abstract:
Understanding of negative ions in Inertial Electrostatic Confinement (IEC) fusion devices has made substantial progress since their discovery [1]. Modeling of negative ion formation and energy spectrum evolution has been achieved by incorporating a negative ion physics module in a 1-D integral transport simulation of an IEC device [2]. Study of negative ion current focusing by the IEC device electrostatic potential structure has been undertaken by measuring the negative ion current azimuthal profile about the equator of the IEC device at various radii. This data set also allows for an extrapolation of total negative ion current produced in an IEC device at the studied parameters, and informs discussion of application and significance of negative ions in IEC devices.

[1] D.R. Boris, et al., Phys. Rev. E. 80, 036408 (2009).
[2] G.A. Emmert and J.F. Santarius, Phys. Plasmas 17, 013503 (2010).

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