Negative Ion Studies in an IEC Fusion Device

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Outline

- Historical development
- Review of negative ion physics in the IEC device
- Negative ion modeling in the VICTER code
- Negative ion spatial measurements
- Future work
Historical Development

Negative ions first measured in the IEC on October 3, 2008 via the Magnetic Deflection Energy Analyzer (MDEA) by D. Boris.
- Negative ion current energy spectra at the wall of the IEC as a function of cathode voltage, current, and gas pressure characterized.
- Negative ion currents confirmed by “Faraday trap”.

11th US-Japan IEC Workshop on October 13, 2009
- First reporting of significant negative ion currents in the IEC by D. Boris.
- Plans for mobile Faraday cup for spatial measurement of negative ions made.
- Cross sections assembled for modeling of negative ion creation and propagation.

12th US-Japan IEC Workshop October 21, 2010
- Initial modeling of negative ion propagation.
- Faraday cup constructed and installed in the IEC for radial measurements of negative ions.
- Radial profiles of negative ions on jet and off jet measured at numerous cathode voltages, currents, and pressures.
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Negative ions are formed in the IEC by charge exchange or electron attachment.

\[
\begin{align*}
D + D_2 &\rightarrow D^- + D_2^+ \\
D + D_2 &\rightarrow D^- + D^+ + D^+ + e^- \\
D_2 + D_2 &\rightarrow D^- + D_2^+ + D_2 \\
D^+ + D_2 &\rightarrow D^- + 2D^+ \\
D_2^+ + D_2 &\rightarrow D^- + D^+ + D_2^+ \\
D_3^+ + D_2 &\rightarrow D^- + D_2^+ + D_2^+ \\
\end{align*}
\]

Underline denotes fast species.

\[
D_{2,(v)} + e^- \rightarrow D_2^- \rightarrow D^- + D \\
D_{2,(v,J)} + e^- \rightarrow (D_2^-)_m
\]
Negative ion current creation and propagation added to VICTER code.

Main code calculates ion and fast neutral energy spectra at all radii. Negative ion subroutine calculates creation of negative ions from these spectra.

Propagation is considered from sources in three categories:
(1) Currents that are born inward and can overcome the potential well, passing through the center of the device.
(2) Currents that are born inward and cannot overcome the potential well, being reflected before reaching the cathode.
(3) Currents that are born outward.

Fast neutral currents from negative ions calculated as negative ions are attenuated.

Fusion from negative ions and daughter fast neutrals calculated.

Negative ion subroutine treats negative ions as a perturbation on the positive-ion and neutral currents.

The VICTER code is not equipped to calculate currents from electron attachment.
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VICTER code output shows negative ion energy spectra evolution with radius.

Voltage: 100 kV, Current: 30 mA, 2 mTorr

![Graph showing the relationship between kinetic energy and radius for the given conditions.](image-url)
VICTER code output shows negative ion energy spectra evolution with radius.

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Negative ions born in the cathode undergo no acceleration
The VICTER code output shows negative ion energy spectra evolution with radius.

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Negative ions in the inter-grid region gain kinetic energy from to the cathode potential as they travel outwards, some current gaining more energy than the cathode potential energy due to a tandem accelerator like process.
VICTER code output shows negative ion energy spectra evolution with radius.

Outside the anode the negative ions undergo no acceleration. Negative ion population with more energy than cathode potential attenuate as they travel.
VICTER code output shows negative ion energy spectra evolution with radius.

Voltage: 100 kV, Current: 30 mA, 2 mTorr

Negative ion current seems to be born from fast neutrals faster than attenuation due to stripping collisions.
VICTER code results show similar radial trends to Faraday cup radial measurements.

**Voltage: 30 kV, Current: 15 mA, 2 mTorr**

![Graph showing radial trends with distance from anode](image)

- **11 cm from anode**
- **5 cm from anode**
- **2 cm from anode**
VICTER code results show similar radial trends to Faraday cup radial measurements.

VICTER code results

Faraday cup results – 1 cm$^2$ aperture
VICTER code results show similarities to Magnetic Deflection Energy Analyzer results.

**Voltage:** 100 kV, **Current:** 30 mA, **2 mTorr**

![Graph showing simulated negative ion spectra.](image)

- Simulated negative ion spectra
- 45 cm from device center
- 100 kV - 30 mA
- 50 cm anode - 20 cm cathode
- 2 mTorr
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**Experimental Result**

Voltage: 100 kV, Current: 30 mA, 2 mTorr

**Theory Result**

VICTER code

Simulated negative ion spectra
45 cm from device center
100 kV - 30 mA
50 cm anode - 20 cm cathode
2 mTorr

**Experimental Result**

Magnetic Deflection Energy Analyzer
The VICTER code can be a tool to examine the sources of negative ion energy spectra structure.

Voltage: 100 kV, Current: 30 mA, 2 mTorr

Negative ion spectra from each parent species
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Voltage: 100 kV, Current: 30 mA, 2 mTorr

Negative ion spectra from each parent species

Negative ion spectra from each grandparent species
VICTER code predicts negatives ions are a relevant source of fusion. 

Amount of fusion from negative ions is strongly dependent on background pressure. According to the VICTER code:

![Graph showing the relationship between background pressure and percent of total fusion from negative ions and fast neutrals from negative ions. The graph is labeled: 90 kV-30 mA, cathode 20 cm anode 50 cm. The x-axis represents background pressure in mTorr, ranging from 0 to 4. The y-axis represents the percent of total fusion from negative ions and fast neutrals from negative ions, ranging from 0 to 12. The graph is a smooth curve that increases as the background pressure increases.]
The Faraday cup has measured spatial negative ion current profiles in the IEC.
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Magnets and field
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Energetic negative ions

slow ions

Electrons
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Azimuthal scan shows negative ion currents corresponding to jets.

background pressure: 2 mTorr
Fine azimuthal negative ion profiles show jet dynamics sensitive to cathode voltage.

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Future Work

- Continue parametric simulations of negative ion spectra on VICTER code.
- Continue parametric studies of jet dynamics via azimuthal scans.
  - Anode-Cathode geometry
  - Cathode voltage
  - Cathode current
  - Background pressure
  - Negative ion current dependence on radius
- Attempt negative ion focusing using modified cathode.
VICTER code negative ion subroutine is producing interesting results for parametric studies.
- Code results showing trends reflected in experimental results
- Code under-predicting number and energy of negative ion current

Azimuthal scan of Faraday cup showing evidence of negative ion jet structure.
- Jet intensity and shape responds to cathode voltage and current

Negative ions are a useful way to improve our understanding of IEC device physics.
Questions?

Voltage: 100 kV, Current: 30 mA, 2 mTorr

background pressure: 2 mTorr
Magnetic Deflection Energy Analyzer diagram

Magnetic Deflection Energy Analyzer at various cathode voltages shows spectrum hardening.