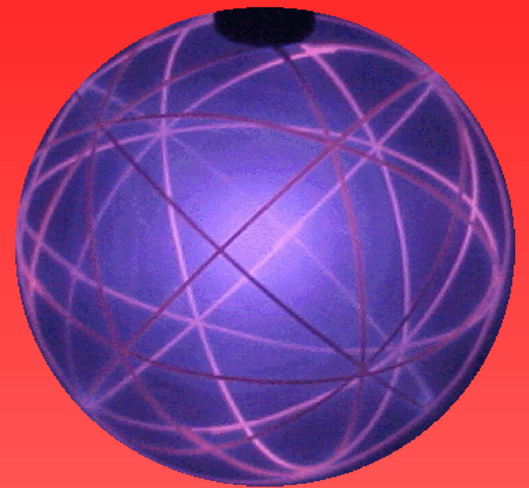
Negative Ions in IEC Devices

D. R. Boris, G. L. Kulcinski, J. F. Santarius

University of Wisconsin-Madison Fusion Technology Institute

Presented at the International Conference On Plasma Science – San Diego, CA - 3rd, June, 2009



Abstract:

A magnetic deflection energy analyzer and Faraday trap diagnostic have been used to make measurements of divergent deuterium anion flow in the inertial electrostatic confinement experiment at the University of Wisconsin – Madison (UW – IEC) [J. F. Santarius, G. L. Kulcinski, R. P. Ashley, D. R. Boris, B. B. Cipiti, S. K. Murali, G. R. Piefer, R. F. Radel, I. E. Radel, and A. L. Wehmeyer, Fusion Sci. Technol. 47, 1238 (2005)]. This device confines high energy light ions in a spherically symmetric, electrostatic potential well. Deuterium anion current densities as high as 8.5 μA/cm² have been measured at the wall of the UW-IEC device, 40 cm from the surface of the device cathode with a detector assembly of admittance area 0.7 cm². Energy spectra obtained using a magnetic deflection energy analyzer diagnostic indicate the presence of D_2^-, and D^- ions produced through thermal electron attachment near the device cathode, as well as D- ions produced via charge transfer processes between the anode and cathode of the device.

Introduction

➢Hydrogen anions are a much studied subject that holds important implications for ion sources involved in high energy accelerators, ion beam surface treatments, as well as neutral beam injection schemes for fusion plasmas

➢ There are two processes of hydrogen anion formation that are particularly relevant for IEC devices, thermal electron attachment and charge transfer.

➢ $$D_2 + e \rightarrow D_2^{-(m)} \rightarrow D^- + D \qquad (1)\ \text{Thermal electron attachment}$$

➢where the meta-stable lifetime τ = ~1 *fs* to ~1 *ms* depending on rotational state of the molecular anion.

$$D_3^+ + D_2 \rightarrow D^- + 2D^+ + 2D \qquad (2)$$

$$D_2^+ + D_2 \rightarrow D^- + 2D^+ + D \qquad (3)$$

$$D^{fast} + D_2 \rightarrow D^- + D^+ + D \qquad (4)$$

$$D^+ + D_2 \rightarrow D^- + 2D^+ \qquad (5)$$

Charge Transfer process relevant at energies > few keV

Inertial Electrostatic Confinement Schematic

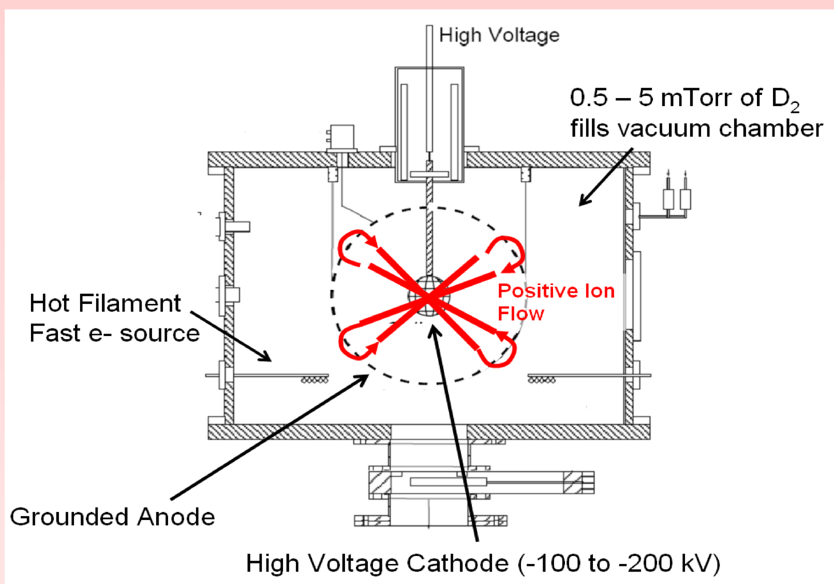


Figure 1: IEC Schematic w/ positive ion flow

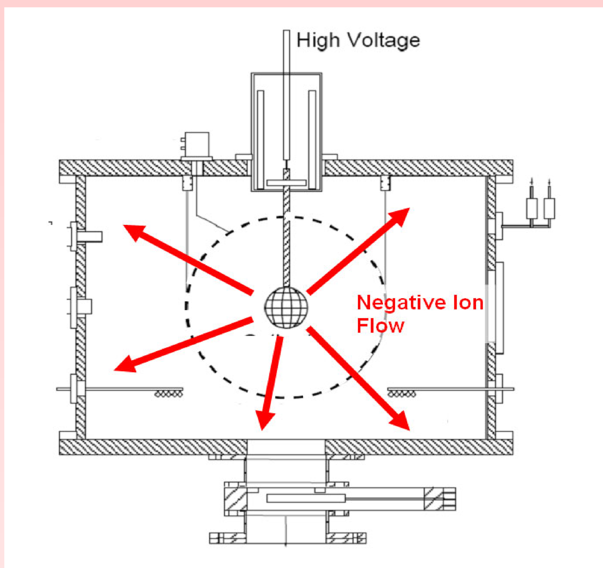


Figure 2: IEC Schematic w/ negative ion flow

•By placing a smaller spherical cathode grid inside a grounded anode grid, ions produced outside the anode can be accelerated to fusion relevant energies. (See Figure 1). This confinement approach produces a non-Maxwellian plasma with increased ion density toward the center of the spherical geometry. The IEC concept is of particular interest in the arena of non-electric applications for fusion.

•In this geometry the likelihood of producing negative ions through charge transfer is qualitatively significant since the mean free path of positive ions can be much larger than the device dimensions. Negative ions will be divergently accelerated into the walls of the vacuum vessel.

Diagnostics for Negative Ion Detection

- Faraday Trap

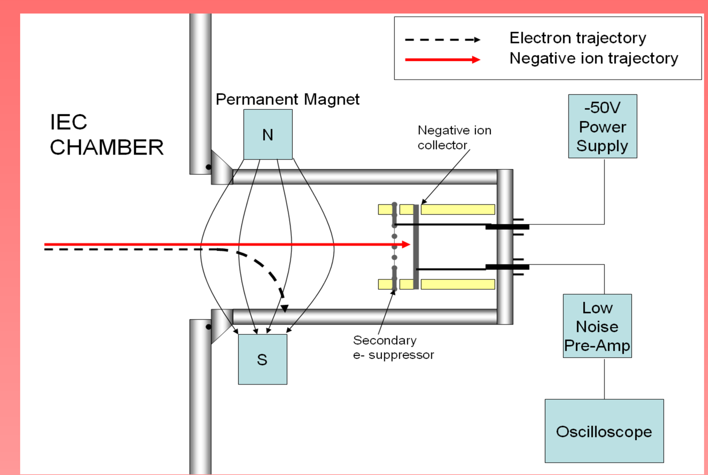


Figure 3: Faraday Trap Schematic

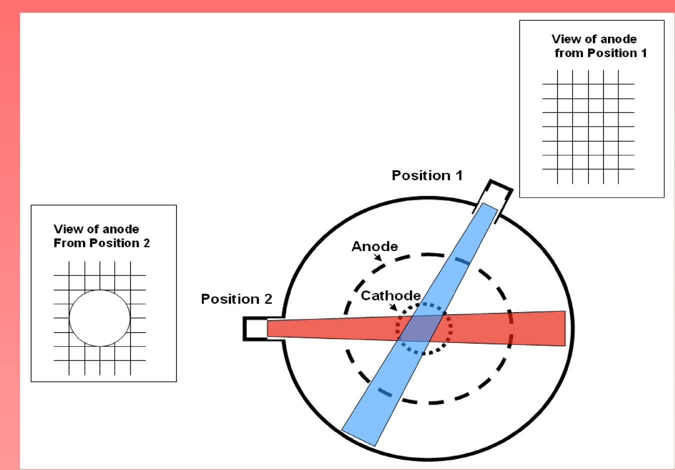


Figure 4: Faraday Trap Positions

➢The Faraday trap diagnostic operates by collecting negative ions on a 0.7 cm² aluminum current collection plate

➢Suppression of secondary electron emission from the plate is achieved with a transparent steel mesh biased to -50 V relative to the collection plate.

➢Provides an absolute measure of anion flux at a given location.

- Magnetic Deflection Energy Analyzer

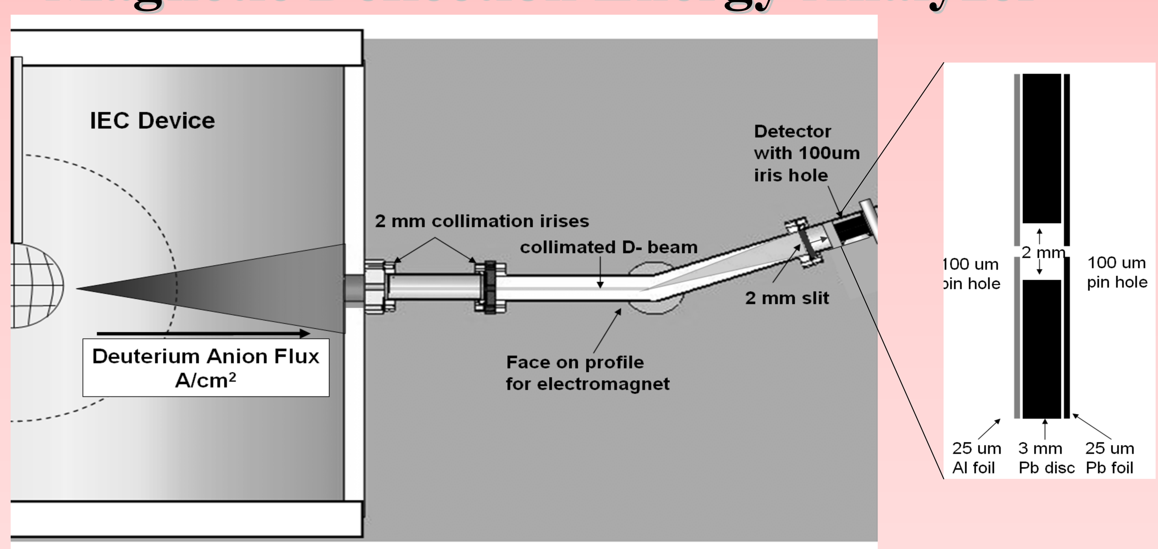


Figure 5: Schematic of magnetic deflection energy analyzer

➢Deuterium anions leaving the UW-IEC are collimated by a pair of 2 mm irises

➢This beam of deuterium anions is then passed through a variable electromagnet which causes the beam to deflect in a direction perpendicular to both the velocity of the beam and the applied magnetic field.

➢The magnetic field will separate the anion energy spectrum by the charge to mass ratio of the incident anions.

➢Once the anions have been deflected by the electromagnet they will continue towards the detector until they encounter a smaller lead iris with a diameter of 100 µm. This iris samples a narrow portion of the resulting fan-shaped beam of anions, consequently isolating a narrow band of the velocity spectrum of deuterium anions emanating from the IEC device.

Experimental Results

- Faraday Trap

➢Deuterium anion current densities as high as 8.5 µA/cm² have been measured at the wall of the UW-IEC device, 40 cm from the surface of the device cathode with the Faraday trap

➢Pressure scans showed a peak in anion current at 2 mTorr of background pressure (Figure 6)

➢Measurements taken at varying cathode voltage showed the current density to be non-linearly dependent on cathode voltage (Figure 7).

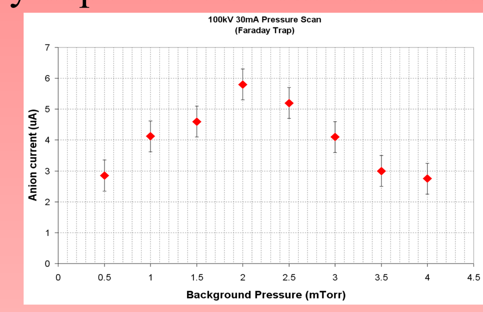


Figure 6: The pressure scan illustrates how the deuterium anion current detected in the Faraday trap has a maximum for 2 mTorr of background gas. This is due to increasing neutral pressure resulting in increasing anion creation up to 2 mTorr with further increases in background pressure resulting in attenuation of the anion flux to the detector.

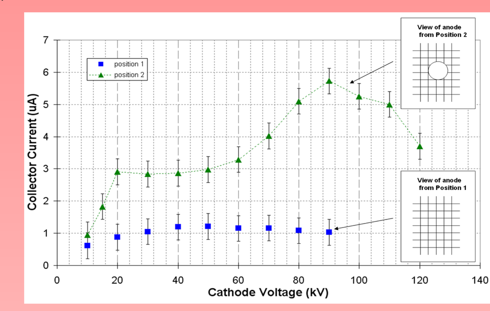


Figure 7: Position 1 shows a sub-linear dependence of Faraday trap collector current on voltage, with a maximum between 40-50 kV. Position 2 shows a greater than linear dependence of collector current on voltage with a maximum at 90 kV. At both positions the cathode current was 30 mA and the background pressure was 2 mTorr.

- Magnetic Deflection Energy Analyzer

➢A sample energy spectrum from the magnetic deflection energy analyzer is shown in Figure 8. The energy spectrum can be deconvolved into 5 separate Gaussian peaks indicating a variety of phenomena at work resulting in anion formation.

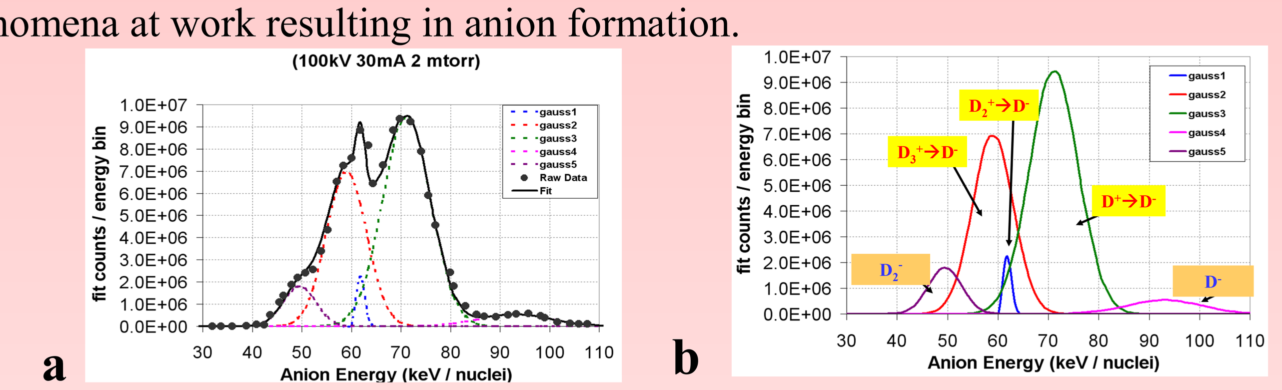


Figure 8: Sample energy spectrum shows three peaks from charge transfer reactions and two resulting from thermal electron attachment at the cathode.

➢The evolution of the anion energy spectra with pressure and voltage is shown in Figure 9

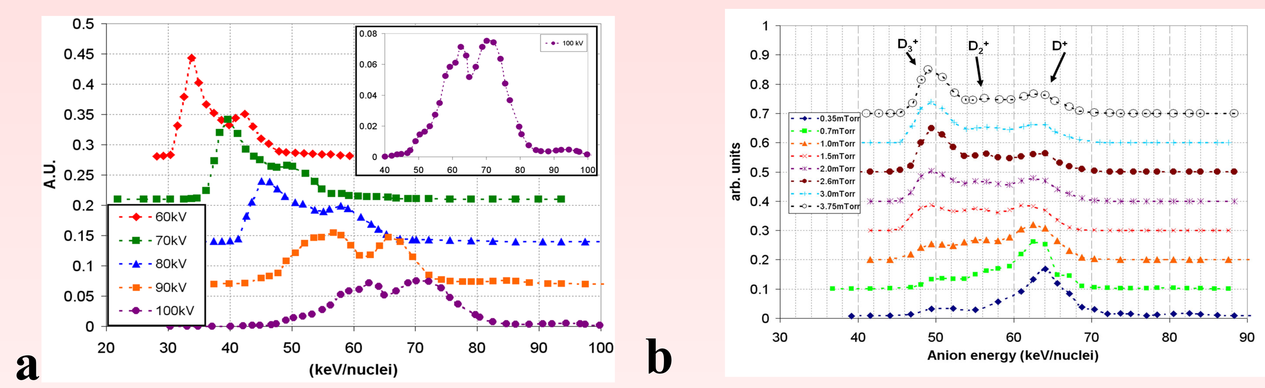


Figure 9: (a) Evolution of energy spectra with cathode voltage (30 mA cathode current, 2 mTorr) (b) Evolution of energy spectra with background pressure (90 kV cathode voltage, 30 mA cathode current).

Conclusion

Using a magnetic deflection energy analyzer, deuterium anions resultant from both charge transfer and thermal electron attachment processes have been measured in the UW IEC device. In addition, long lived molecular deuterium anions have been measured with metastable lifetimes of at least 0.5 µs. These molecular anions were detected with the full cathode energy, indicating that they originated near the hot cathode at the center of the IEC device. A Faraday trap diagnostic was used to corroborate the data from the magnetic deflection energy analyzer and to make measurements of deuterium anion current at two positions around the UW IEC device. This diagnostic indicated that the deuterium anion current was highly variable with angular position, indicating a strong dependence on device geometry. In addition anion current densities of 8.5 µA/cm² were measured with the Farday trap. Further work is recommended to more definitively map the angular dependence of deuterium anion intensity, and to determine the extent to which IEC devices can produce molecular hydrogenic anions.

Contact Information:

Dave Boris: drboris@wisc.edu