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Probing ions from deeply embedded plasmas: From simulation to realization
Investigation of a novel long distance ion transfer unit

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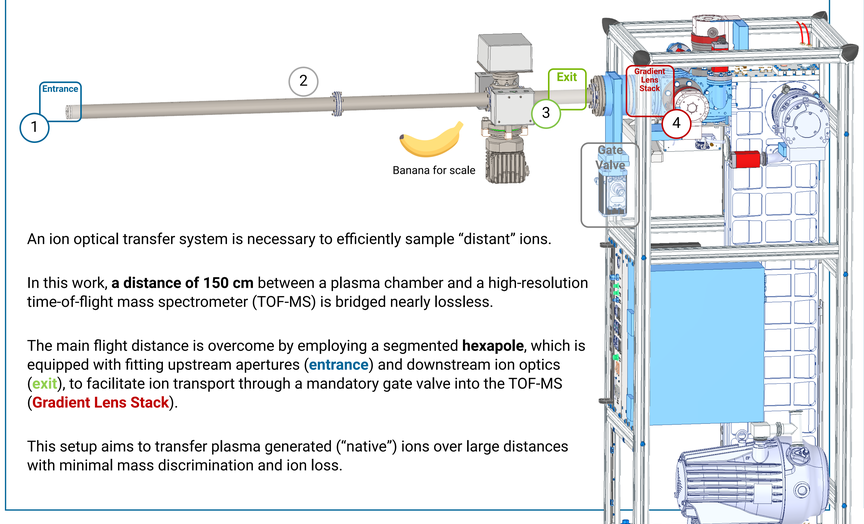
Why everyone* needs an ion highway like this



An ion optical transfer system is necessary to efficiently sample “distant” ions.

In this work, **a distance of 150 cm** between a plasma chamber and a high-resolution time-of-flight mass spectrometer (TOF-MS) is bridged nearly lossless.

The main flight distance is overcome by employing a segmented **hexapole**, which is equipped with fitting upstream apertures (**entrance**) and downstream ion optics (exit), to facilitate ion transport through a mandatory gate valve into the TOF-MS (**Gradient Lens Stack**).

This setup aims to transfer plasma generated (“native”) ions over large distances with minimal mass discrimination and ion loss.

Transfer Elements

The ion transfer system consists of 5 individually biased main transfer hexapoles and matching apertures shown in the following.

The entire transfer stage was planned and simulated with the SIMION program package[1]. The resulting trajectories are shown on the right for each element.

[1] D. A. Dahl, Int. J. Mass Spectrom., vol. 200, no. 3., pp. 3–25

TL;DR

The transfer stage guides ions through

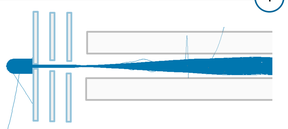
- **an Entrance Einzel lens** to focus ions into the Hexapole
- **a Segmented Hexapole** to guide ions in a multipole motion
- **an Exit Einzel** lens to accelerate/focus ions through the Gate Valve
- **a Gate Valve**
- **a Gradient Lens Stack** to decelerate/ focus ions into the TOF-MS

Entrance

1

An **Einzel lens** consisting of three electrodes to

1. **focus and guide ions** into hexapolar field
2. **restrict gas flow** through first electrode to reduce pressure inside the hexapole
   (note: entrance plate needs to be grounded)



Hexapole

2

A segmented **hexapole** consisting of 5 segments, each 30 cm long, with decreasing DC bias voltage.

The hexapole was built by Fasmatech (Athens).

Exit

3

An **Einzel lens** consisting of three electrodes **accelerates ions** from the hexapole exit and focuses them to traverse the unguided 4 cm long region within the gate valve.

Gate Valve

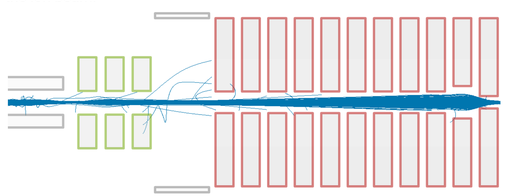
A **Gate Valve** is mandatory due to plasma chamber regulations and allows swift separation of the two systems for maintenance or in case of unexpected behavior (e.g., pressure increase, run-off situations).

The valve creates a mostly field free region of 4 cm in which the ions have to be efficiently transferred.

Gradient Lens Stack

4

A **Gradient Lens Stack** with integrated **Einzel lens** collecting ions downstream of the gate valve.
Reduction of the kinetic energy of the ions prior to mass analyzer entry and focusing of the ion beam.



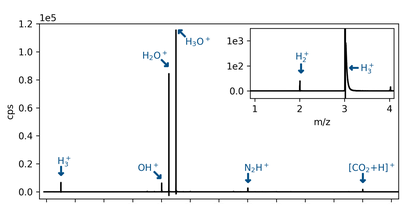
It actually works!

Experimental Set-Up

- RF power applied to electrode in vacuum chamber.
- RF electrode opposite to grounded entrance plate.
- Alternating electric field ionizes gas in chamber.
- Collisions between electrons and gas atoms/ molecules.
- Plasma created with free electrons, ions, and neutral particles present.
- Oscillating electric field sustains plasma by accelerating electrons/ions for further ionization events.

Mass spectra recorded with ignited H_2-Plasma

A mass spectrum recorded with the set up described on the left is shown below (plasma ignited).



This clearly demonstrates the full functionality of the transfer stage, and thus provides information about the composition of the plasma species.

Kinetic Energy Scan for H_2-Plasma Constituents

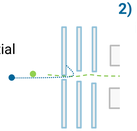
This setup allows for numerous analyses of different plasmas. An example is shown here, where we used the Einzel lens to perform an energy scan for individual ionic plasma constituents to determine their kinetic energy distribution.

In this experiment, the potential of the inner lens electrode is gradually increased to positive values. Once the potential of this electrode exceeds the kinetic energy of the plasma ions moving toward the hexapole, the ions won’t be able to overcome the potential energy barrier, causing the count rate (cps) to decrease. Ions with higher kinetic energy are able to pass the einzel lens and thus enter the hexapole for further transport to the TOF MS.

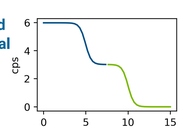
An exemplary analysis is shown below

1) Calculated ion trajectories

8 V electrode potential
5 eV ion
10 eV ion

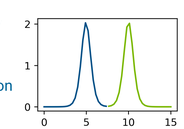


2) Detected ion signal



3) Derived energy Distribution

(Derivation of ion signal)

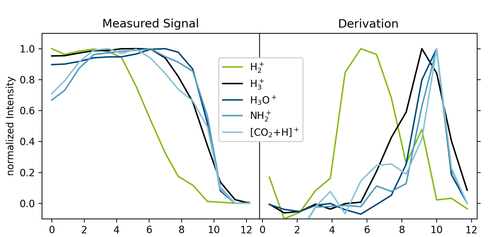


Results

The kinetic energy of the primary ionization product H_2^+ is lower than the kinetic energy of any reaction products.

We are still investigating these results, and speculate at this point that

- H_2^+ can be sampled only *before* any collision with H_2 occurred, i.e. is located close to the orifice upon creation and thus experiences only low RF amplitudes
- The reaction products H_3^+, H_3O^+, N_2H^+, $[CO_2+H]^+$ are created further away from the orifice as they result from collisions with e.g. H_2 and thus experienced larger RF amplitudes upon sampling — resulting in increased acceleration into transfer



*who is trying to sample native plasma ions using mass spectrometry, but cannot get close to the plasma chamber and is called upon to use a gate valve for emergency chamber isolation