Mass Selective Axial Ejection in a Low Pressure Linear Ion Trap in the Presence of Nonlinear RF Fields

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QTRAP® Technology. Mass Selective Axial Ejection Linear Ion Trap on a Triple Quad backbone

The axial ejection linear ion trap
- operates in the low $10^{-5}$ Torr pressure regime
- ions emerge from the end of the device.

$QqQ$ linear ion trap geometry combines all of the features of a conventional triple quadrupole mass spectrometer and a linear ion trap.

Enhanced Product Ion Scan (EPI) Diagram

– precursor ion selection in Q1
– beam type fragmentation in the collision cell Q2
– trap products and the un-fragmented precursor ions in Q3
– analytical scan - Linear Ion Trap mass scan

QTRAP® 6500/5500 System Ion Path
Multi Target Screening

- A predefined list of compounds is looked for in a Multiple Reaction Monitoring (MRM) experiment.

- Once a compound is detected above a defined threshold an EPI scan is collected and compared against a library.

- Dynamic exclusion of compounds where MS/MS spectra are already acquired allows the data collection of co-eluting compounds.

Required Mass accuracy:
0.1 Da or better.

Experimental Sequence of a Multi Target Screening (MTS) approach
Space charge causes loss of
- mass assignment
- peak shape
- relative intensities

More sensitive MS/MS systems will exacerbate this issue as we strive to lower our overall limits of detection.
Effects of Space Charge – QTRAP® 6500.
DFT turned OFF.

X 30 ions
Δ m > 0.4 Da

Zoom

X 30 ions
Methods to Mitigate Space Charge Effects in RF Ion Traps

Goal is to maintain spectral fidelity with increasing ion population.

Can use:

- ‘dynamic fill time‘ (DFT) or Automated Gain Control, but increased cycle times thus loss of chromatographic resolution

- Tandem ions traps, amenable for large mass range scans (Guna and Londry, Anal. Chem. 2011, 83, 6363-6367)

- Internal Calibration (Remes and Schwartz ASMS 2012 MP30-706)

- Nonlinear Fields
Nonlinear RF Fields in Ion Traps.

- 3D Ion Traps – ejection slit, stretched or asymmetric configurations (Stafford, Syka, Franzen, Wang, Cooks)

- Radial Ejection LIT - slit, stretched, non-hyperbolic rods (rectilinear), asymmetric applied RF fields (Schwartz, Cooks, Welsh)

- Axial Ejection LIT – round rods, asymmetric rods (Hager, Douglas)

- Toroidal IT – curvature (Austin, Lammert)

*Practical Aspects of Ion Trap Mass Spectrometry Series. CRC Press. Editors Raymond E. March, John Francis James Todd*
Mass Selective Axial Ejection. QTRAP® Technology

- mass-selective axial ejection (MSAE) of ions takes advantage of the RF fringing fields, at the end of the linear quadrupole, to convert radial ion excitation into axial ejection.

- the higher the radial amplitude the stronger the axial force experienced by the ions.

\[
\langle E_{z,\text{quad}} \rangle_{\text{RF}} = \left| \frac{\partial f}{\partial z} \right| \frac{m \Omega^2}{8e} q_x^2 (X^2 + Y^2)
\]

Dehmelt approx.:
\[
x = X + \delta_x
\]

Londry and Hager, JASMS, 2003, 14, 1130-1147
Nonlinear High Capacity Linear Ion Trap (NHCT) Research Prototype.

Schematic of the Electrical/Mechanical set-up of the NHCT.

The RF on the T-electrodes was generated by a signal generator, phase-locked to the main RF and amplified by an amplifier.
Nonlinear High Capacity Ion Trap. RF fields.

RF Voltage in Excitation Plane. Main RF voltage
884 V_{p-p}
Z 2.4mm from the Exit Lens

RF Potential due to the Auxiliary Electrodes
y = 0.0002x^6 + 1E-06x^5 - 0.0117x^4 - 2E-05x^3 + 0.0104x^2 - 5E-05x + 2.3137
RF Electric Field. z 2.4mm.

Electric Field due to Auxiliary Electrodes

\[ y = 6\times10^{-8}x^6 - 0.0003x^5 - 3\times10^{-6}x^4 + 0.0096x^3 + 3\times10^{-5}x^2 - 0.0047x - 3\times10^{-6} \]
Ion Motion Frequency vs. Auxiliary RF

![Graph showing the relationship between ion motion frequency and auxiliary RF with different amplitudes (0 Vp-p, 25 Vp-p, 50 Vp-p, 75 Vp-p).]
Effects of Space Charge – QTRAP® 6500.
DFT turned OFF.

X 30 ions
\[ \Delta m > 0.4 \text{ Da} \]
Effects of Space Charge – NHCT. DFT turned OFF.

Δm < 0.1 Da

X 30 ions

Zoom
QTRAP® 6500 vs NHCT

QTrap® 6500

NHCT

- x30 Ions
Mass Accuracy is retained for large populations of ions.

NHCT

7k ions

70k ions

700k ions
Intra-Scan Dynamic Range. NHCT

- 7k ions
- 70k ions
- 700k ions
Mass Shift of the 213Da peak vs. Total Number of Ions present in the trap. RF Voltage on the T electrodes was 60 Vp-p.
Influence of the Auxiliary Electrodes RF voltage on Mass Shift. Scan Rate 10 kDa/s. 4cm long NHCT.
Searching for impurities. Fendiline & Flusilazol mixture

Fendiline: Flusilazol 100,000:1

316.206 Th: 316.1076 Th
Higher order fields increase the space charge immunity of the trap by at least a factor of $x_{10}$.

Applicable to all of the applications that use trap scans (e.g., MIDAS Workflows)

Improvements, at large ion populations, in:

– Mass assignment and Resolution
– Spectral Quality
– Intra-scan dynamic range
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Questions and Answers