Poster Reprint

ASMS 2026
ThP 365

Optimizing Ion Transfer Across Pressure Stages in a Dual-Field Converging Multipole (Cyclone) Ion Guide

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Introduction

Cyclone Ion Guide

Maximizing ion transfer from the atmospheric pressure interface to the quadrupole mass analyzer is critical for maximizing LC/MS performance. The dual field converging multipole (Cyclone) ion guide provides strong radial confinement and ion beam compression across more than three orders of magnitude of pressure reduction from the inlet within a reduced axial distance, enabling compact instrument architectures without compromising sensitivity. Ion transmission through this ion guide depends on RF amplitude, frequency, and gas flow conditions, with low *m/z* ions particularly sensitive to parameter selection. Furthering previous characterization work on the influence of electronics, we implemented a pressure-tunable manifold system to systematically evaluate ion transmission behavior across pressure stages, yielding new insights for optimizing performance in current and future mass spectrometers.

The Cyclone ion guide (shown in Figure 1) consists of 6 inner rods forming the core hexapole of the device and 6 outer rods positioned around the larger entrance end of the inner multipole. Two out-of-phase high frequency RF voltages are applied alternatingly to the inner rods, which form a hexapolar field shape. A single-phase low frequency RF voltage is applied to the outer 6 rods which work with the inner rods to form a primarily dodecapolar field shape inside the device. The Cyclone ion guide has a decreasing inscribed radius and spans 3 decreasing pressure stages.

Figure 1. Cyclone Ion Guide.

Experimental

Vacuum Stages with Adjustable Pressure

Ion transmission was characterized experimentally on a highly modified Ultivo QQQ instrument (G6465B) (shown in Figure 2) containing a custom manifold designed to introduce nitrogen at adjustable flow-rates into specific vacuum stages. Vacuum gauges were used as feedback to optimize pressures for each vacuum stage. The Cyclone ion guide was controlled natively using fixed RF voltages determined from previous studies. Abundance of ions with various *m/z* ratios is recorded at multiple pressure settings in MS1 or MS2 filtering mode. Experimental measurements are accompanied by ion trajectory modeling via SimION and were utilized to characterize ion transmission as a function of pressure to maximize collisional cooling and overall ion transmission, while minimizing trapping.

Ions with mass-to-charge ratio below *m/z* 1500 were generated using an electrospray ion source with ESI-L calibrant mix.

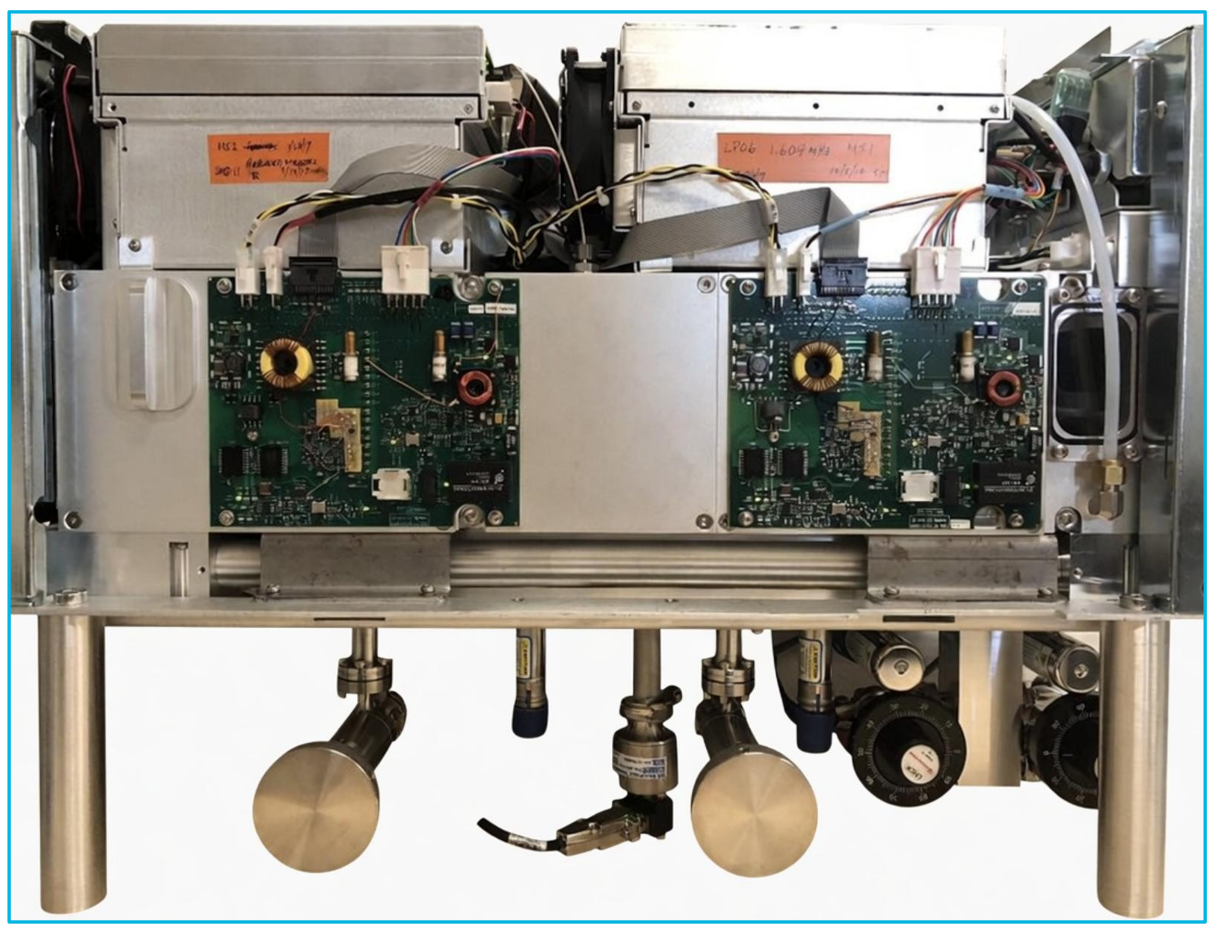


Figure 2. Modified Ultivo QQQ.

Increased P2 Pressure = Reduced Abundance

Normalized ion abundance is presented as a function of pressure in each stage. As shown in Figure 3, ion abundances were minimally impacted by pressure in the first high pressure stage (P2; see Figure 5) of the Cyclone ion guide from 424 mTorr to 627 mTorr. This behavior is attributed to gas dynamics dominated by a supersonic gas jet in this stage, which is relatively insensitive to background gas pressure. Larger *m/z* abundances decreased at a higher rate when the pressure increased from 627 mTorr to 787 mTorr.

Increased P3 Pressure = Reduced Abundance

As shown in Figure 4, ion abundances decreased as the pressure increased in the middle vacuum stage (P3; see Figure 5) of the Cyclone ion guide. This suggests that sufficient ion-neutral collisions are likely present to cool the ion beam at standard (~3 mTorr) operating pressures. The decrease in abundance with increasing pressure is attributed to increased pressure in the high vacuum stage containing MS1 analyzer.

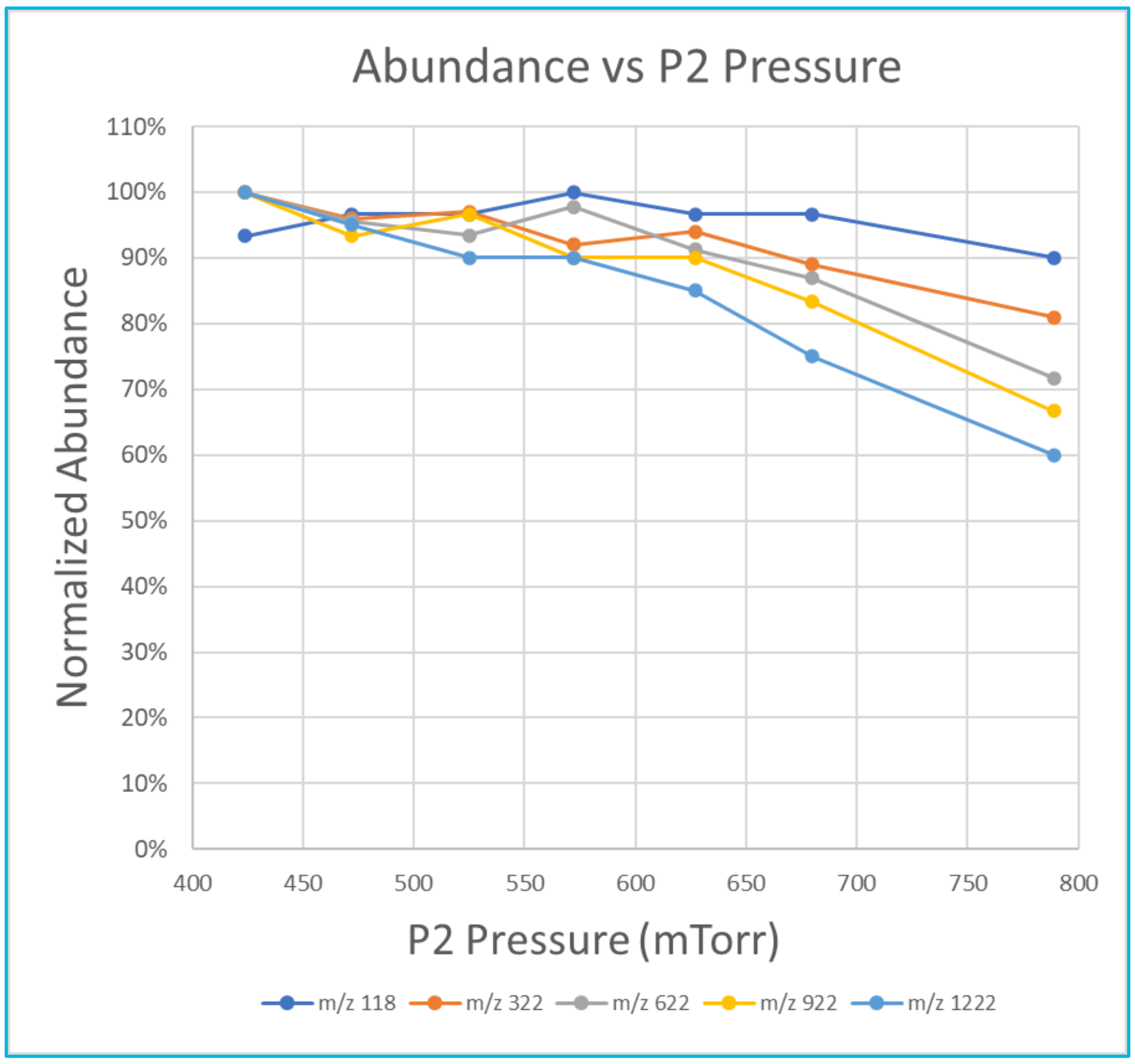


Figure 3. P2 Abundance vs Pressure.

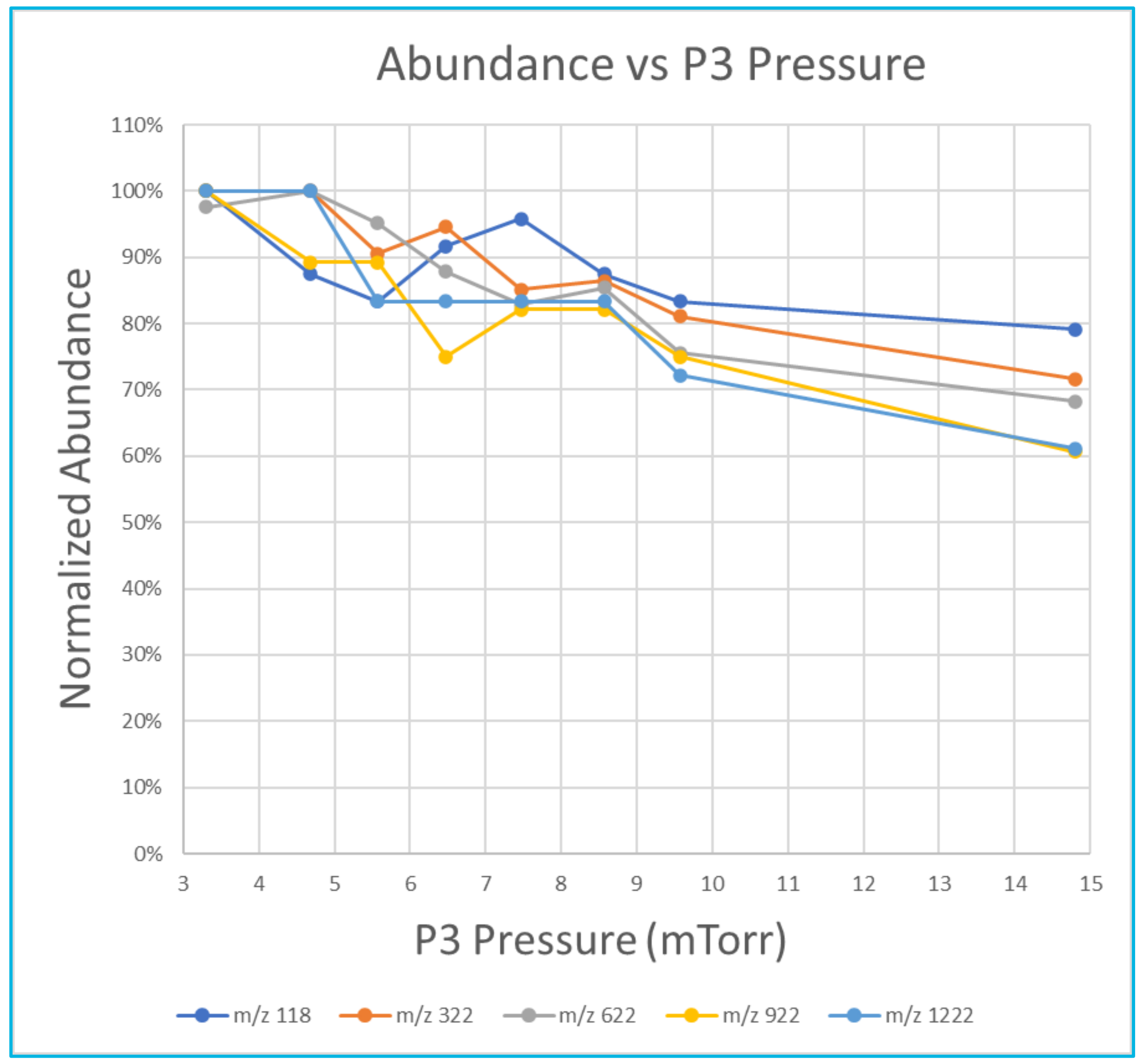
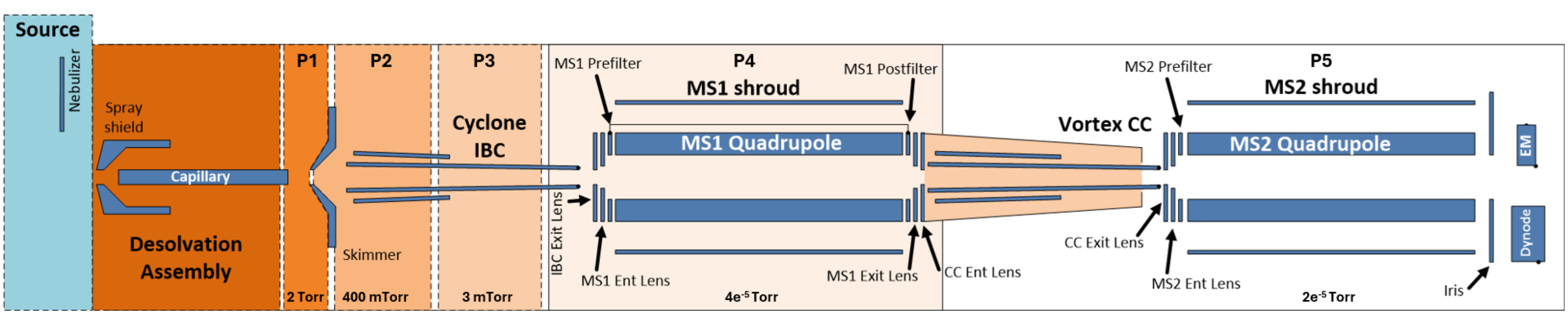


Figure 4. P3 Abundance vs Pressure.



Results and Discussion

Downstream Stages are Impacted by Upstream Pressures

It is impossible to isolate each pressure stage from one another because every stage is connected to the neighboring stage via an orifice. As the pressure increases in an upstream stage, the pressure will also increase in the downstream, lower-pressure stages.

Pressure measurements were also made in the P4 high vacuum stage. See Figure 5. Figure 6 shows that as the P3 pressure increased, the P4 pressure also increased.

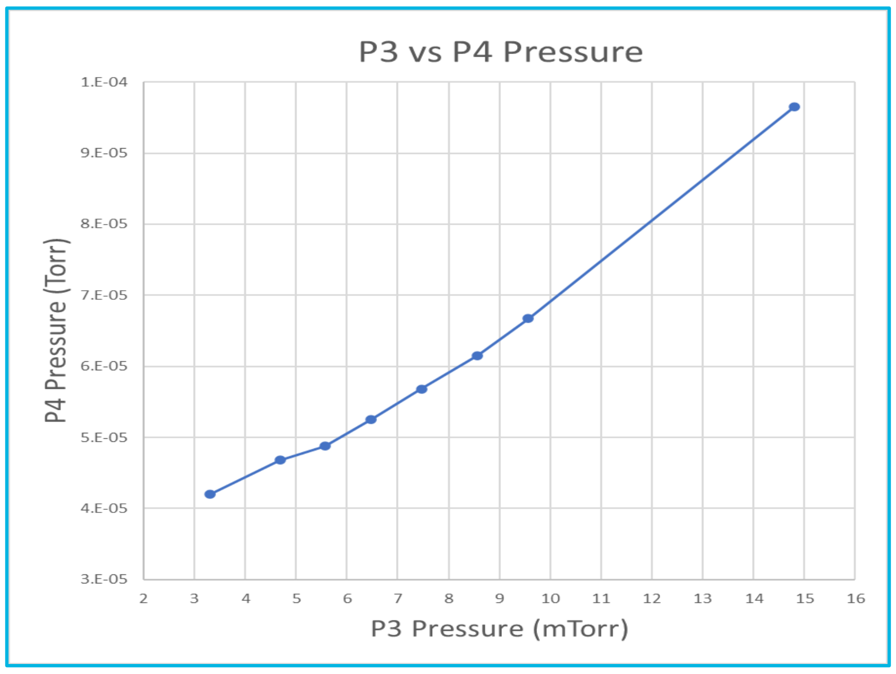


Figure 6. P3 vs P4 pressure when the P3 pressure is increased.

Increased P5 Pressure = Reduced Abundance

To provide further insight into ion transmission, nitrogen was also introduced into the P5 stage. The P5 high vacuum stage houses the MS2 mass analyzer and detector. See Figure 5. As shown in Figure 7, as the P5 pressure was increased, abundances across the *m/z* range decreased at a more substantial rate. This is attributed to increased scattering in the mass analyzer at elevated pressures.

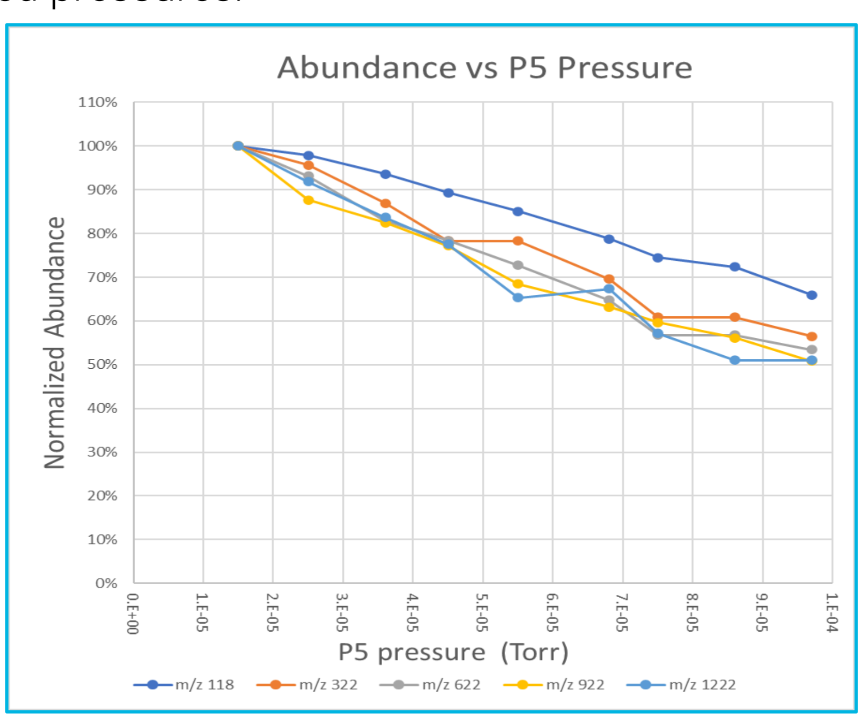


Figure 7. Abundance vs P5 Pressure

Conclusions

- Increasing the pressure in all stages resulted in decreased abundance for all *m/z* ranges.
- P2 pressures are dominated by supersonic expansion.
- Higher localized pressures in P2 and P3 likely dominate collisional cooling of the ion beam.

References

Bertsch JL, Newton KR, Howard L. US Patent No. 9,449,804 B2. Sep. 20, 2016.

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DE-014838

Published in USA, June 30, ,2026

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