Transmission Characteristics of RF-Only Devices: Quadrupoles and Octupoles as Ion Pipes

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RF-only ion pipes are used in various applications, such as collision cells for collision induced dissociation, for collisional damping of ion beams into smaller cross sectional areas, and for simply transporting ions from one part of a vacuum system to another in a differentially pumped system. In a RF-only quadrupole or octupole system, there is a certain correspondence between transmission efficiency, mass, and RF voltage. This transmission function for a quadrupole is not flat, rather there exists for each mass an optimum RF voltage that yields the maximum transmission (nominally at half of the corresponding resolving RF voltage). It is commonly held that the transmission function for a given mass in an octupole covers a wider voltage range than in a quadrupole (i.e. for a given RF voltage, there is a wider range of masses transmitted). In this work, we investigate the exact nature of the transmission functions for RF-only quadrupoles and octupoles, focusing on the relative flatness of the transmission curves, and on the correspondence between optimum RF voltage and mass. Is there a linear correspondence between mass and optimum RF voltage?

I. INTRODUCTION

In this presentation, we compare the transmission characteristics between an octupole (o) and quadrupole (q) of similar inscribed radius when they are used as an ion pipe and as the collision cell in an MS/MS (QqQ and QoQ) system. Octupole dimensions were chosen such that the rods were large enough to accommodate reasonable sized screws, and to match the inscribed radius of the quadrupole.

The quadrupole is made of four 9.5 mm rods with 4.25 mm inscribed radius while the octupole is made of eight 3 mm rods with 4.5 mm inscribed radius. For comparison, the RF voltage levels for the octupole are labeled to correspond with the equivalent voltage to reach the indicated mass level for a resolving quadrupole. Photographs of the octupole and quadrupole are shown in Figures 1 and 2.

II. EXPERIMENTAL

Data acquisition and instrument control is done by the Merlin data system from Extrel. The octupoles and quadrupoles are powered by Extrel 150-QC quadrupole power supplies operated at either 1.2 or 2.1 MHz. The ions for characterizing the RF-only devices are created by an axial molecular beam electron impact ionizer. Ion transmission through the octupole and quadrupole are compared under the same tuning parameters for the ionizer.

For the characterization of the ion pipe/collision cell in the MS/MS (QqQ and QoQ) system, the first and the third quadrupoles are operated in the resolving RF/DC mode and are set to transmit the same ions. All the tuning parameters for the ionzer and focusing lenses are kept the same during the comparison experiments. Thus, the difference in ion transmission between the QoQ and QqQ system only comes from the RF-only device.

III. RESULTS AND DISCUSSION

Figure 3 compares the Ar^+ ion transmission through the octupole and the quadrupole ion pipe. With the octupole, the maximum transmission is achieved at a lower RF level and the transmission curve is extended to higher RF levels. The RF Level on the octupole is expressed in the equivalent amu unit for the quadrupole.

Figure 4 compares the transmission curves for the octupole operated at 2.1 and 1.2 MHz. Higher RF frequency provides a wider transmission range as a function of the applied RF voltage. Figure 5 shows the relative transmission vs. the RF level for the quadrupole ion pipe in the QqQ system. The first and the third quadrupoles are operated in the resolving RF/DC mode to transmit only the ions indicated on the corresponding transmission curves.

Figure 6 shows the corresponding curves for the octupole

Figure 1. End view of 8.5 mm diameter rod quadrupole mass filter.

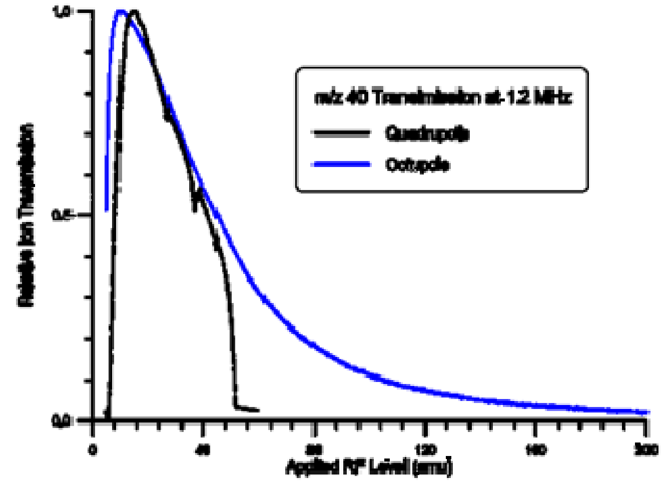

Figure 3. Ar^+ transmission: octupole vs. quadrupole.

in the QoQ system. Consistent with the results shown in Figure 3, the ion transmission curves are extended to higher RF levels with the octupole.

In Figure 7, the ion transmission curves for the quadrupole are re-plotted against the quadrupole Mathieu parameter q. As expected, all the transmission curves exhibit a high cut-off at the same q value of about 0.9.   Some strong beating patterns can be observed in the transmission curves as well as a loss of ion transmission in low RF level for ion masses of about 69 amu and higher. Such beating patterns are commonly associated with either narrow ranges of ion energy or high ion energy through the quadrupole.

Figure 8 shows the corresponding transmission curves for the octupole in ‘quadrupole-equivalent q’ in the QoQ system. From Figure 8, it can be seen that the transmissions curves extend well beyond the quadrupole cut-off q value of about 0.9. It is also evident from these figures that the transmission curves are much smoother than the ones for the quadrupole and no beating patterns are observed.

Figure 9 plots the minimum RF level as a function of transmitted ion mass when the desired transmission efficiency is at least 85% of the maximum transmission for the quadrupole. This optimum voltage (RF level) increases as a function of the selected ion mass, but falls off from the linear curve at higher masses.

Figure 10 shows the corresponding minimum RF level for octupole transmission as a function of the ion mass.   The RF

Figure 2. End view of 3 mm diameter rod octupole mass filter. Inscribed radius is 4.5 mm.

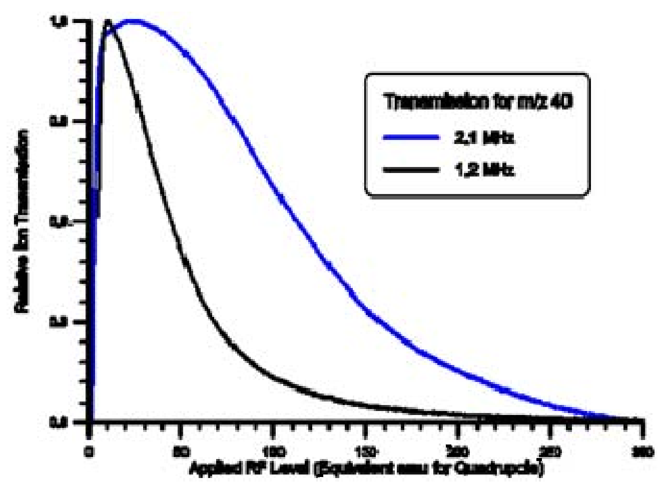

Figure 4. Octupole ion transmission vs. RF frequency.

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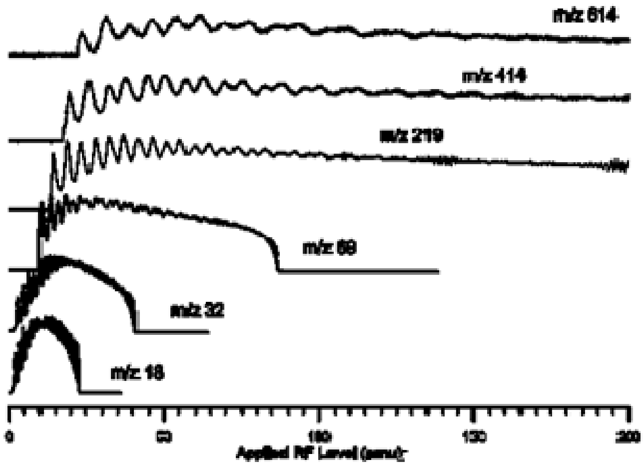

Figure 5. Relative transmission vs. RF level for quadrupole ion pipe in QqQ.

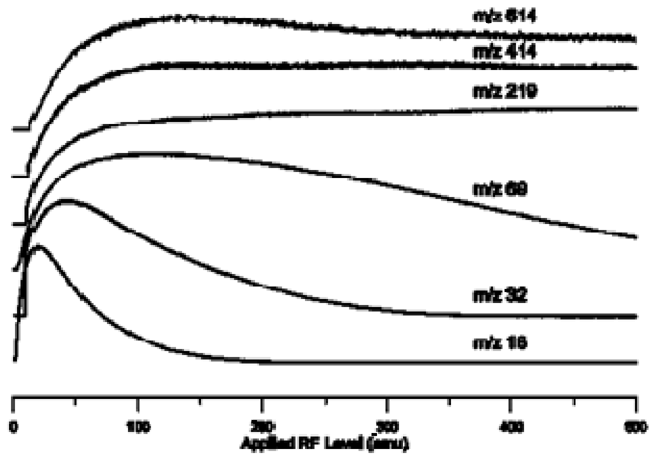

Figure 6. Relative transmission vs. RF level for octupole ion pipe in QoQ.

level is expressed in terms of the equivalent amu unit for quadrupole. It is important to notice that the minimum RF level required for up to 85% of the maximum transmission remains almost constant above the mass of 219 amu.

IV. CONCLUSIONS

1). For a given RF voltage, an octupole will transmit ions of a wider mass range than a quadrupole.

2). When the octupole operating frequency is increased, ions of a given mass will have good transmission over a wider voltage range than at the lower frequency.

3.) RF-only quadrupoles exhibit extreme oscillations of maxima and minima over a given voltage range for a given mass. In contrast, octupoles exhibit a much smoother curve over a broader voltage range.

4.) The calibration of optimum RF voltage as a function of mass for a quadrupole ion pipe is not linear, rather, for higher masses, slightly less voltage is required than would be predicted by a linear model.

5.) The optimum RF voltage for an octupole tends to be independent of mass for ions above a certain mass threshold.

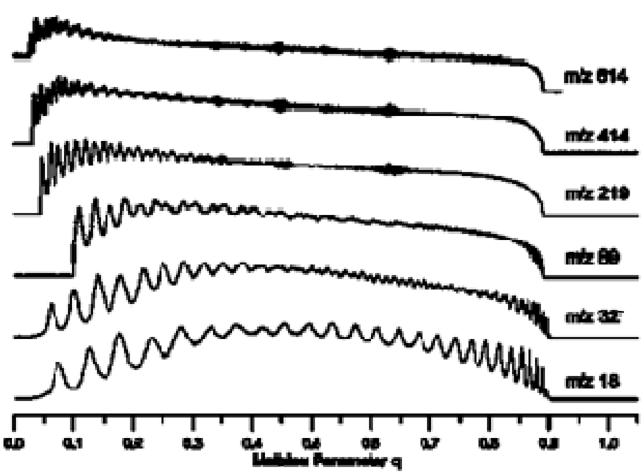

Figure 7. Relative transmission vs. q for quadrupole ion pipe in QqQ.

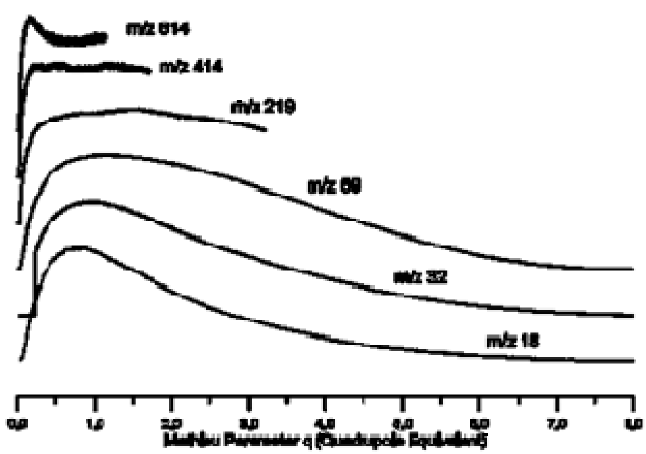

Figure 8. Relative transmission vs. q for octupole ion pipe in QoQ.

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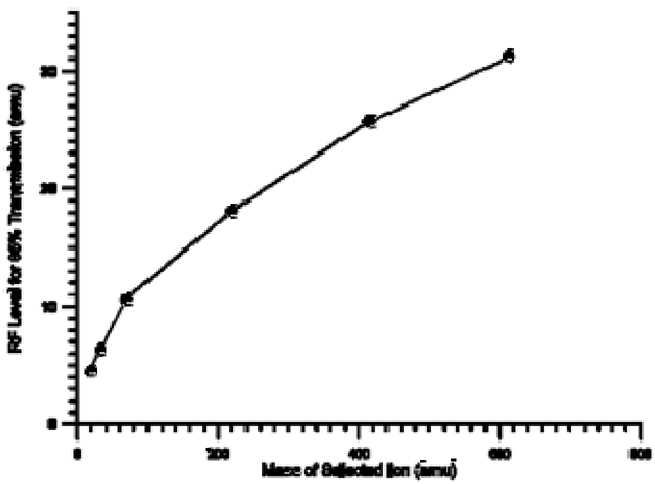

Figure 9. Minimum RF level for 85% transmission in QqQ.

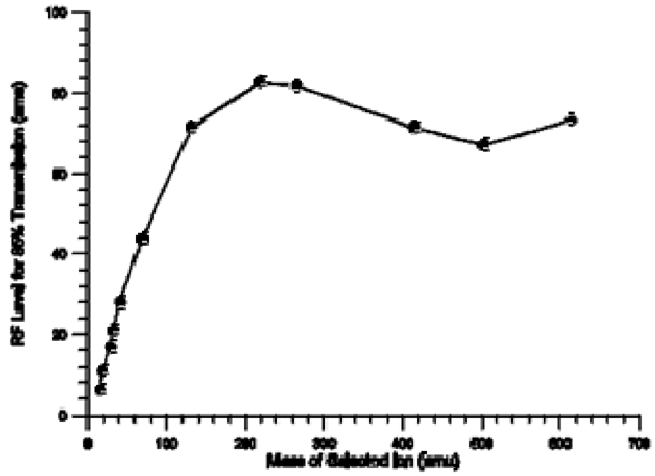

Figure 10. Minimum RF level for 85% transmission in QoQ.

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