Exam 4
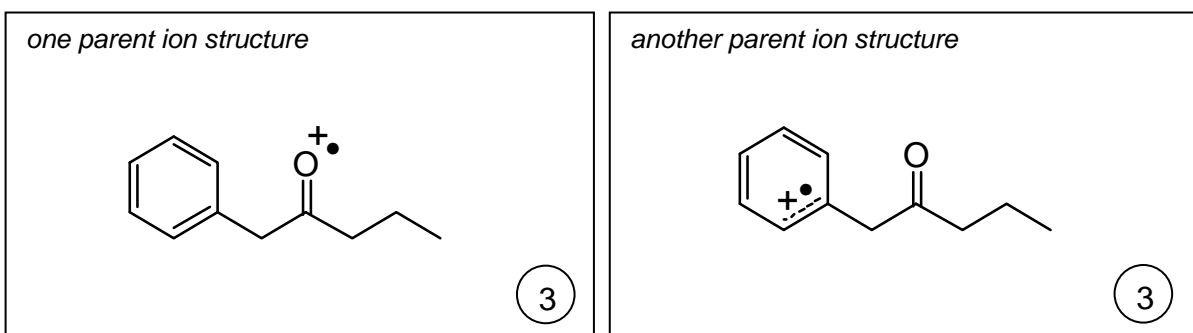**Answer Key**

Exam 4 Mean: 67
Exam 4 Median: 71
Exam 4 St. Dev.: 17

1. A peak corresponding to the parent ion (with $m = 162$) is visible in the mass spectrum. In the boxes below, illustrate the two most prevalent parent ion structures. In each structure, make sure you indicate the precise location of ionization in the molecule.

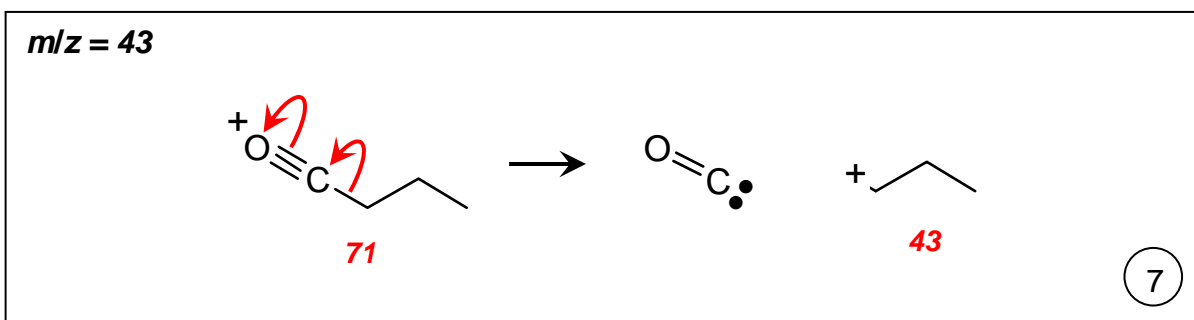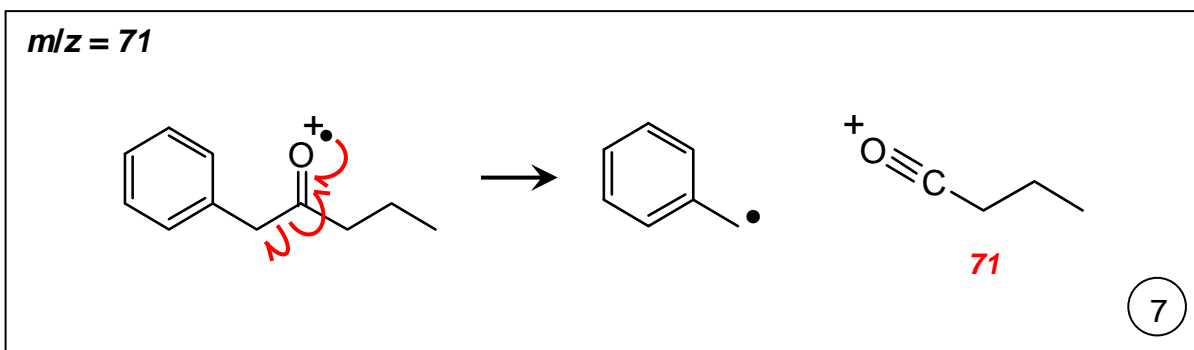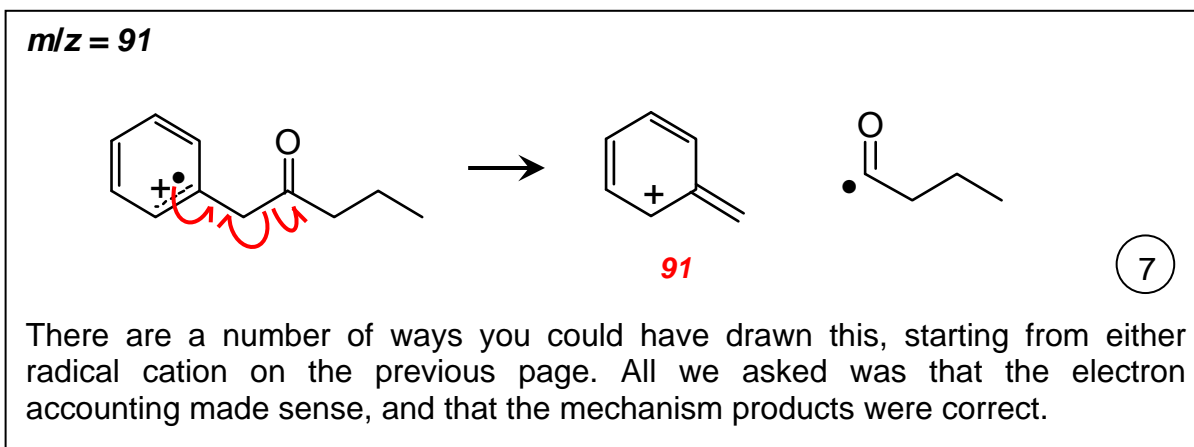| *one parent ion structure*	*another parent ion structure*
③	③

In EI-MS, electrons are typically ejected from the highest-energy filled orbital(s). In this molecule, the highest-energy orbitals with electrons to give are definitely the two O lone-pair orbitals (which give the same radical-cation). The next-highest filled orbitals—probably not far below the lone-pairs—are aromatic π orbitals. (The Hückel diagram for benzene has two filled orbitals higher than a typical π orbital, and one lower.)
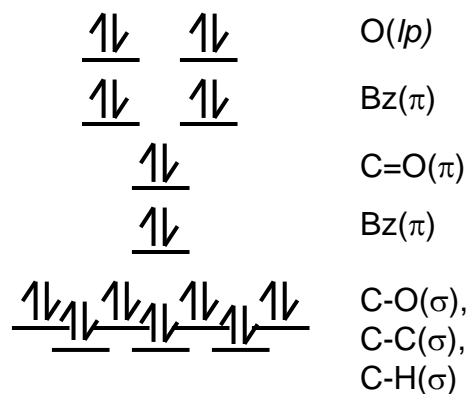
Rubric: 3 points each structure. (6 points total.) *No partial credit.*

2. In the boxes below, draw mechanisms (using "electron pushing") that explain the fragmentation of the parent ion into fragment ions with m/z = 91, 71, and 43. Use either of the parent ion structures on the previous page as your starting material.

$m/z = 91$

91

(7)

There are a number of ways you could have drawn this, starting from either radical cation on the previous page. All we asked was that the electron accounting made sense, and that the mechanism products were correct.

$m/z = 71$

71

(7)

$m/z = 43$

71

43

(7)

Rubric: (7 points each box; 21 points total)
In each box,
3 points for drawing correct ion structure.
1 point for drawing correct radical fragment.
3 points for electron pushing.
   You don't need to have pushed electrons exactly like me, but the accounting needs to be correct.

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3. Though you can't really see it in the EI-MS spectrum, there is a small peak at $m/z = 163$. Relative to the peak at $m/z = 162$, how intense would you expect the peak at $m/z = 163$ to be? Answer to within 1%.

12 %

(4)

The probability of an ion being 1 amu heavier is essentially equal to the sums of probabilities of each atom in the ion being heavier. (With larger ions, you have to subtract away the probability of finding two or more heavier isotopes in the molecule, but for a molecule this small, that probability is tiny, so we'll ignore it here.)

$P(^{13}C)$ = (relative abundance of ^{13}C in nature) × (# of C atoms in molecule)
= (1.08%) × (11)
= (11.88%)

$P(^{2}H)$ = (relative abundance of ^{2}H in nature) × (# of H atoms in molecule)
= (0.011%) × (14)
= (0.15%)

$P(^{17}O)$ = (relative abundance of ^{17}O in nature) × (# of O atoms in molecule)
= (0.04%) × (1)
= (0.04%)

$P_{total} = P(^{13}C) + P(^{2}H) + P(^{17}O) = 12\%$

4. The parent peak in the EI-MS is much smaller than the fragment peaks. How might the EI-MS experiment be conducted differently to reduce fragmentation, and increase the relative intensity of the parent peak? (Do *not* propose an alternate ionization method; keep this an EI-MS experiment.)

Reduce the electron beam voltage. The EI-MS shown in the exam was collected with the EI beam at 70 kV. (You didn't know this, but the detail wasn't important to solving the problem.) If the beam voltage were reduced to, say, 15 kV, there would be much less fragmentation. Unfortunately, there would be less ionization as well, so overall signal intensity would probably be lower.

(7)

Rubric:
No need for all this text; "reduce the electron beam voltage" is enough.

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M $[C_{45}H_{48}N_7O_3]^{3+}$ ($m = 734.38$)
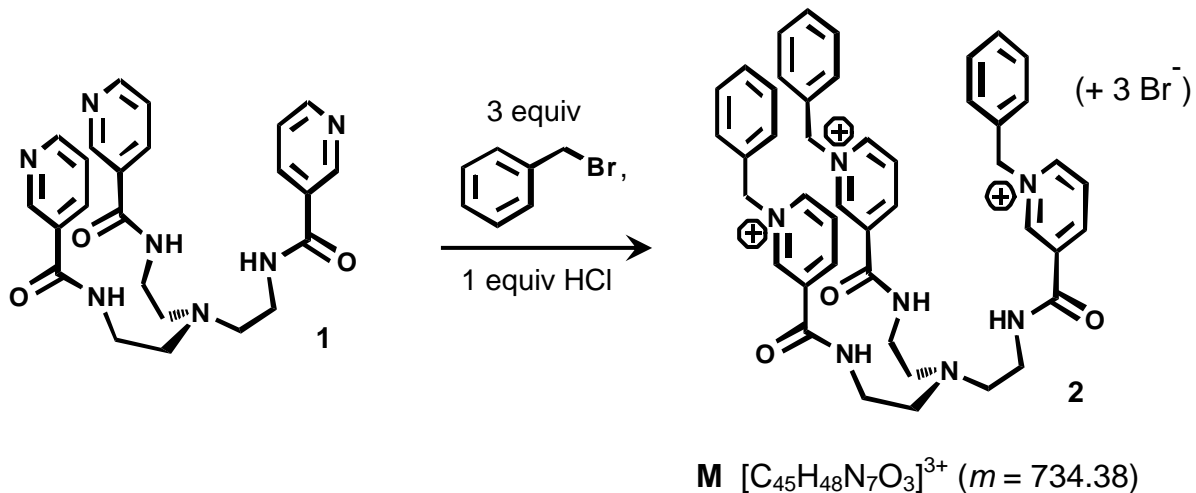
5. Electrospray ionization can ionize neutral molecules by protonating them, but Deanna's product is already ionic, so it doesn't need to be ionized; the ion should be directly visible in the mass spectrum. I gave you the mass (m) of ion **M** in the problem; in order to calculate m/z, all you have to do is divide m by the charge z. Ion **M** has a charge of 3+.

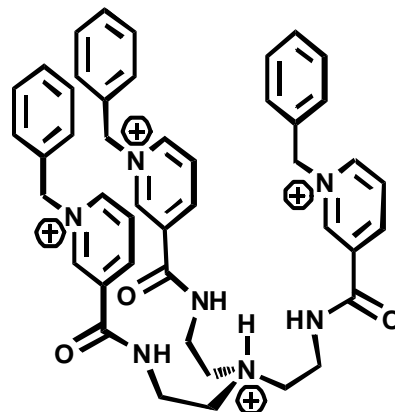$$m/z \; (\mathbf{M}) = (734.38)/(3) = \boxed{244.8 \text{ Da}} \; \textcircled{4}$$

If **M** were to be protonated at the central nitrogen, it would become a tetracation, with a charge of 4+. Its mass would also increase by 1.008 Da. So,

$$m/z \; (\mathbf{M} + H^+) = (735.39)/(4) = \boxed{183.8 \text{ Da}} \; \textcircled{4}$$

6. As the problem points out, neither of the m/z values above are observed in the ESI mass spectrum. Deanna did observe peaks at much higher m/z values, however. With a molecule this big, made from C, H, N and O atoms, you will expect to see M+1 and even M+2 peaks due to uncommon isotopes in each ion--a ^{13}C here, a ^{15}N there, etc. But isotope peaks due to these isotopes should still be smaller than the main M peak. Looking at the close-ups attached to the back of the exam, only the
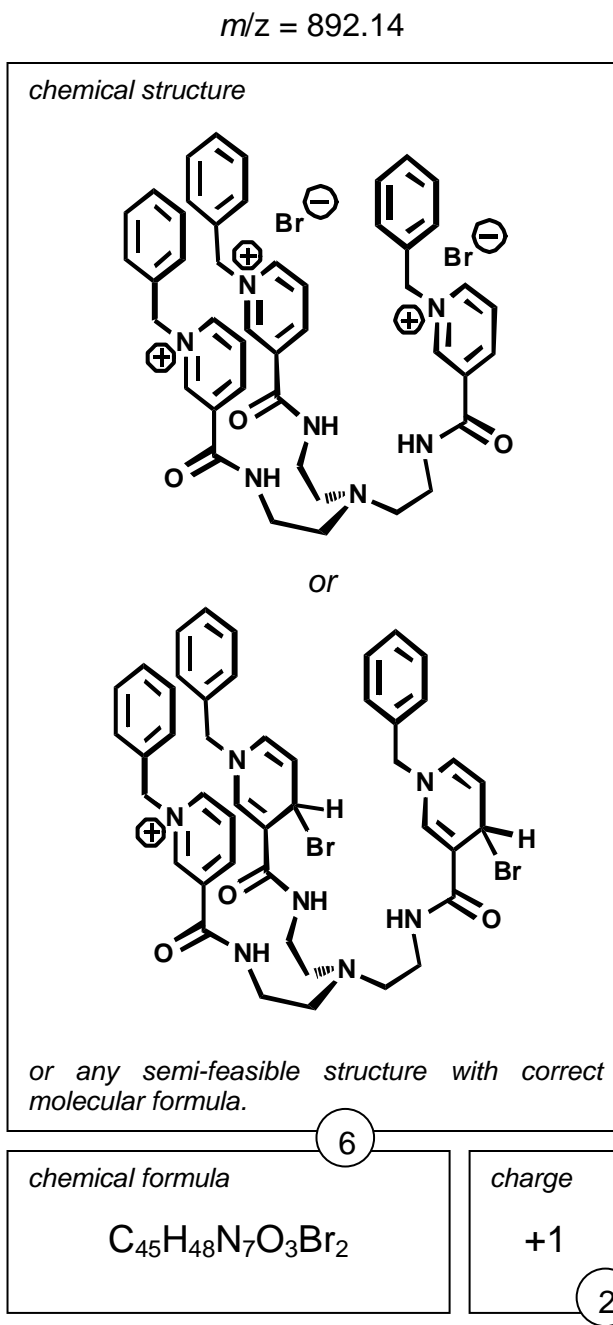
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close-up of the $m/z = 552$ peak looks this way; the others are weirdly alternating, with a tall M peak, a short M+1 peak, a tall M+2 peak, etc. This suggests that there must be at least one A+2 atom in each of the other ions, and possibly more. In Deanna's reaction, there were two such atoms: Cl (75% ^{35}Cl, 25% ^{37}Cl), and Br (50% ^{79}Br, 50% ^{81}Br). I think only Br can manage to create the M+2 and M+4 intensity observed in the isotope patterns, so we'll consider it exclusively.

In the $m/z = 892$ closeup, the ratio of M / M+2 / M+4 peak intensities is 1:2:1, suggesting 2 Br atoms in the molecule. (Then, the M+1 / M+3 / M+5 intensities are probably just these times ~50% for the probability of finding ^{13}C in the molecule.) What happens if we take Deanna's proposed product and add two bromine atoms? We would get

$C_{45}H_{48}N_7O_3Br_2$:
m = 734.38 + 2(78.9)
   or 734.38 + (78.9 + 80.9)
   or 734.38 + 2(80.9)
  = 892.2 *or* 894.2 *or* 896.2

Those are exactly the m/z values we're looking for in the highest-mass closeup. That must mean that the charge on this set is +1, and that two electrons were added along with the two Br atoms. That's consistent with two bromide ions adding to M. There are a couple of ways this might happen. First, and most likely, the two bromide ions could just be associated with the trication somehow. This is unusual, in that Br⁻ is not a very good Lewis donor, and should dissociate during electrospray (and be attracted to the positively-charged nozzle). But maybe the Br's get trapped inside the cage somehow. I don't know.

Alternately, two Br atoms could be covalently bound to the molecule. For example, they could add to the pyridinium rings--I find this pretty unlikely, but it is one of many structures that is consistent with covalent Br addition to the molecule.

$m/z = 892.14$

chemical structure

or

or any semi-feasible structure with correct molecular formula.

⑥

chemical formula

$C_{45}H_{48}N_7O_3Br_2$

charge

+1

②

Looking at the next highest closeup, m/z = 722, once again we have an M / M+2 pattern, but this time it's just 50:50 in intensity ratio, suggesting just one Br. If we just removed one Br⁻ from the structure on the previous page, we get

$C_{45}H_{48}N_7O_3Br^{2+}$:
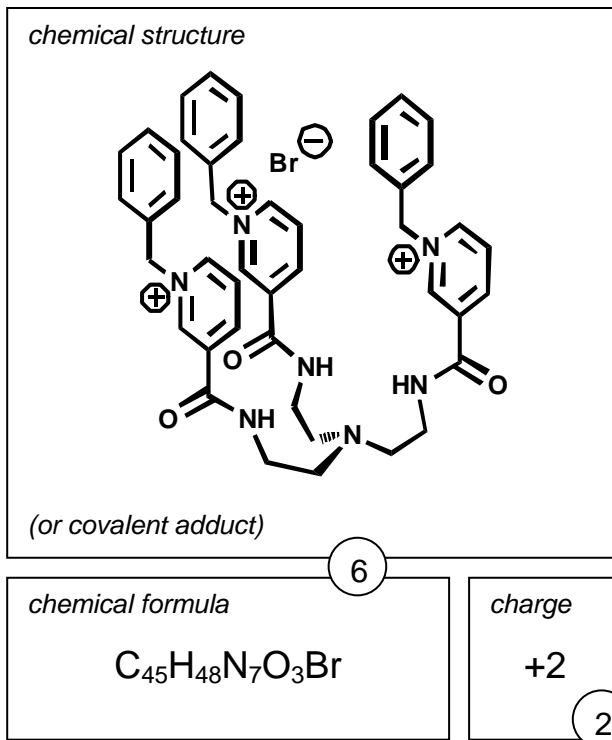m = 734.38 + 78.9
   or 734.38 + 80.9
   = 813.3 *or* 815.3;

m/z = 406.7 or 407.7.

That doesn't explain the next highest closeup—not even close—but it does explain the one at m/z = 406. In fact, it also explains another oddity of the m/z = 406 closeup: unlike the others, this closeup has isotope peaks every 0.5 Da instead of every 1.0 Da. That can only happen if the isotope series represents a 2+ ion.
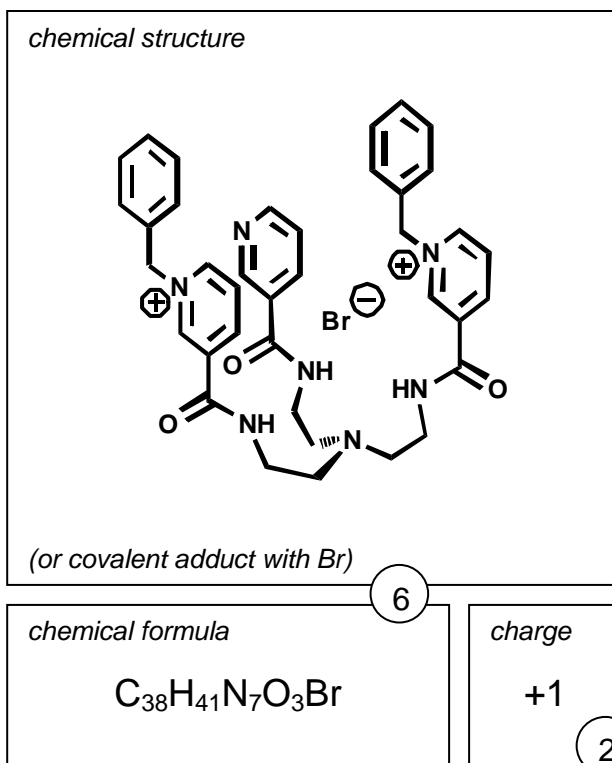
So what about that m/z = 722 closeup? In the problem text, I suggested that peaks in the mass spectrum could be due to under-alkylated products. Could we think up a product that had only one Br, and less than three benzyl groups? So, the resulting ion is related to the M ion by having one fewer benzyl groups, one fewer Br. This means Deanna's suspicions were correct--there was indeed some incompletely benzylated product in her reaction mixture.

If she had a product with one too few benzyl groups, maybe she also had a product with two too few? If we just remove a benzyl group from the molecule on the right, we get a neutral species; can't see this by MS. But what happens if we remove one more

m/z = 407.62

chemical structure

(or covalent adduct)

chemical formula	charge
$C_{45}H_{48}N_7O_3Br$	+2

m/z = 722.18

chemical structure

(or covalent adduct with Br)

chemical formula	charge
$C_{38}H_{41}N_7O_3Br$	+1

bromine and one more benzyl group? This matches the isotope pattern for the $m/z = 552$ close-up, in that there are no A+2 atoms, just an A+1 peak corresponding to ^{13}C isotopes (and, to a lesser extent, deuterium, nitrogen and oxygen isotopes).

m/z = 552.23

chemical structure

⑥

chemical formula	*charge*
$C_{31}H_{34}N_7O_3$	+1

②
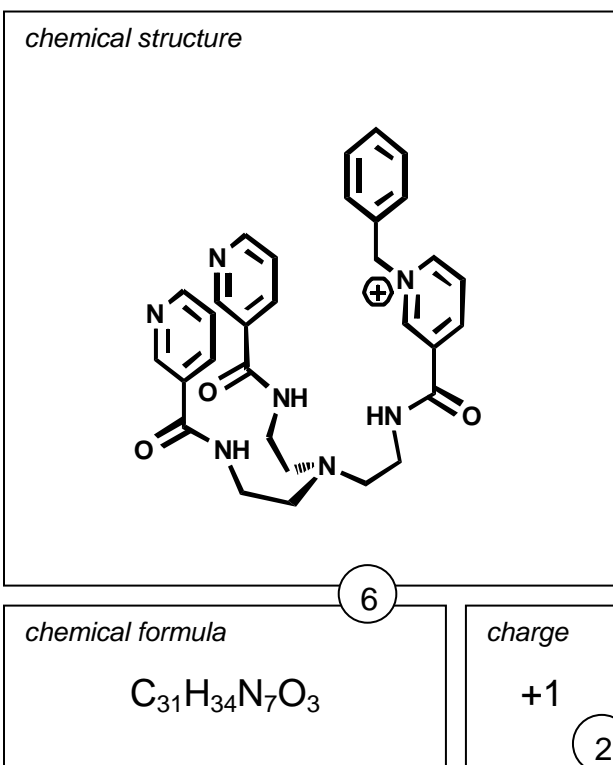
7. What might Deanna have done to observe the original M^{3+} peak she was looking for? Name and describe a mass spectrometry experiment she could have performed to confirm the presence of the M^{3+} ion in her product mixture.

Deanna didn't see the $m/z = 244.8$ peak she was looking for because, unexpectedly, there were still bromide ions associated with her molecule. One mass spectrometry experiment she could have done would be to try to knock the bromide atoms off via collision-induced dissociation (CID). To do this experiment, Deanna would select for $m/z = 892.14$ in the first quadropole, and then accelerate the selected ions into a CID chamber. Hopefully, collisions would knock the bromine atoms off. The resulting M^{3+} ions would enter a second quadropole to detect its mass.

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8. To achieve high mass resolution, mass selection modules are sometimes connected in series, so that a specific ion mass selected in a first module can be further refined in a second one. Reflectron time-of-flight modules offer extremely high mass resolution, but they are not directly compatible with quadropole selection. In ten words or less, why not?

> Quadropoles are *continuous* ion selectors; they generate a steady stream of ions at the selected mass. Time-of-flight mass resolvers, on the other hand, are inherently *pulsed*; ions in TOF-MS are accelerated at one start time and arrive at the detector at different finish times.
>
> (8)

Rubric: *(8 points this problem)*
4 points for quadropoles being continuous. *Just the word "continuous" or something similar is enough.*
4 points for TOF being pulsed, periodic, any synonym of that. *Again, no explanation necessary.*

9. What initial ion selection method would be compatible with subsequent reflectron time-of-flight resolution?

> ion trap
>
> (4)

The ion trap works like a quadropole, in that ions of a given mass follow a specific trajectory, but the ions can be ejected from the trap at a specific time. This makes the ion trap a pulsed ion resolver, compatible with pulsed TOF analysis.

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