

Study of $C^{2+}2X^{-}$ Organic Salts by Simultaneous Use of Fast Atom Bombardment Mass Spectrometry and Tandem Mass Spectrometry. Chemical Reactivity in the Gaseous Phase

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The observed fragmentations in collisionally activated dissociation (CAD) spectra of CX^{+} adduct ions formed in the fast atom bombardment (FAB) mass spectra of $C^{2+}2X^{-}$ bisammonium salts are the same as those previously put forward to account for the FAB mass spectra of these compounds. Thus, substitution and elimination reactions occur in the gaseous phase between X^{-} anions and C^{2+} cations, this being a new example of chemical reactivity in the gaseous phase in mass spectrometry. Furthermore, it was established that charge-remote fragmentations of these $C^{2+}2X^{-}$ salts observed by mass spectrometry provide ions which allow aliphatic chain identification. These ions are as abundant in the FAB mass spectra as in the CAD spectra. © 1997 by John Wiley & Sons, Ltd.

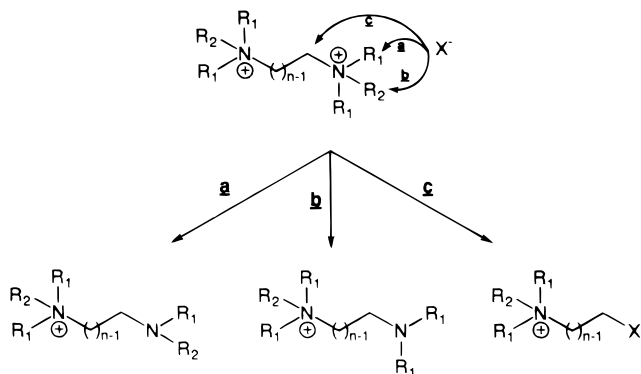
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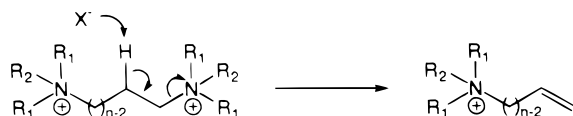
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INTRODUCTION

The study of fast atom bombardment (FAB) mass spectra of $C^{2+}2X^{-}$ organic salts allowed us previously¹ to explain the formation of various ions by substitution (Scheme 1) and elimination (Scheme 2) reactions which implied the presence of an X^{-} counterion and a C^{2+} doubly charged ion.



Scheme 1



Scheme 2

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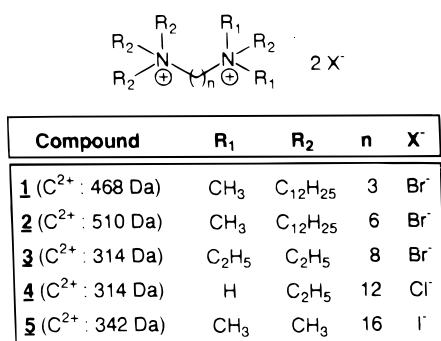
Addition of potassium iodide to a $C^{2+}2Br^{-}$ salt-matrix (glycerol or *m*-nitrobenzyl alcohol) solution gave rise in the spectrum to ions resulting from reactions between I^{-} and C^{2+} . In particular, two new ions were observed: the CI^{+} adduct ion and an ion formed from a substitution reaction (process *c*, Scheme 1).

In the present work, we studied the collisionally activated dissociation (CAD) spectra of CX^{+} adduct ions in order to examine possible reactivity in the gaseous phase during which the necessary reaction energy is furnished by collision of the studied ion with gas molecules in the collision cell. During collision, there is a transformation of kinetic energy into internal energy.² The interest in such a study of chemical reactivity in the gaseous phase lies in the fact that it concerns naked ions, i.e. unsolvated.

RESULTS

Our preliminary work¹ involved the study of the FAB mass spectra of compounds 1 and 2. The present study with compounds 3–5 was undertaken in order to investigate cross-reactivity for the mixture of two compounds (see below). Each of these compounds must possess a dication and an anion, each of which should be different from the cation and the anion of the other compounds (Scheme 3).

The choice of the matrix is the key step in a FAB mass spectrometric (MS) experiment. Previously, we have established that the best matrix for bisammonium salt analysis is *m*-nitrobenzyl alcohol (NBA). Therefore,



Scheme 3

FAB mass spectra of compounds 3–5 were recorded with this matrix (Table 1). Under bombardment, NBA decomposes and species resulting from this degradation can interfere in the FAB mass spectrum of the studied compound. Three such literature results are given below. NBA degradation leads to proton formation, which is responsible for the formation of $[M + H]^+$. Thus the use of deuterated NBA gives rise to the formation of the $[M + D]^+$ ion.³ Owing to its oxidation properties the NBA matrix can inhibit reduction phenomena in FABMS. The properties can possibly lead to $[M + 16]^+$ ion formation during the study of compound M.⁴ Also, the NO_2^- ion is formed from matrix degradation, explaining the existence of $[M + \text{NO}_2]^-$ ions in the negative ion mass spectrum of compound M.⁵ During the FABMS study of 3 and 5, the presence of NO_2^- may be observed in the matrix, accounting for formation of the mono-charged ion $[\text{C}^{2+}\text{NO}_2^-]^+$, m/z 360 (compound 3: abundant ion) and m/z 388 (compound 5: ion of low abundance).

For compounds 3–5, the FAB mass spectra and CX^+ adduct ion (m/z 393, 3; m/z 349, 4; m/z 469, 5) CAD

spectra were compared. For each product, this comparison indicates that the same fragment ions are observed (see Figs 1 and 2 for compounds 4). The formation of these ions, except those resulting from charge-remote fragmentation (CRF) processes, has already been described.¹ Fragmentations can be classified into four types (see Table 1): nucleophilic substitution by X^- (see Scheme 1), Hofmann elimination reaction (see Scheme 2), characteristic immonium ion formation of fixed groups on nitrogen (m/z 86, 3; m/z 86 and 72, 4; and m/z 58, 5) and CRF process.

The following point concerning the CRF process should be noted. In comparison with compounds 1 and 2 (for which FAB mass spectra have previously been studied¹), compounds 3, 4 and 5 possess a longer aliphatic chain between the two positively charged sites (the number of methylene groups is 8, 12 and 16, respectively). Gross and co-workers⁶ and Adams⁷ have shown that the presence of an aliphatic chain near a localized charge leads to the appearance in the spectrum of an ion series formed by CRF, implying C—C bond breaking. As all C—C bonds of the chain have approximately the same energy, CRF leads to an ion series separated by 14 Da. The ions at the two extremities in the series are that resulting from Hofmann elimination and an immonium ion: 3, m/z 212–86; 4, m/z 240–86; 5, m/z 282–58.

Ions formed by CRF are as abundant in FAB mass spectra as in CAD spectra (compare Figs 1 and 2). This result is not in accordance with most studies concerning this fragmentation pathway (see, e.g., Refs 6 and 7), in which it was found that the use of tandem mass spectrometry (ms/ms) is necessary since charge-remote fragmentations take place if an additional internal energy furnished by collision is communicated to the precursor

Table 1. CAD spectra (m/z) of adduct ions CX^+

Compound	Ion CX^+	Nucleophilic substitution (Scheme 1)	Hofmann elimination (Scheme 2)	Immonium ions (see text)	CRF (see text)
3	393	285: $[\text{C} - \text{C}_2\text{H}_5]^+$ 292: $[\text{C} + \text{BrN}(\text{C}_2\text{H}_5)_3]^+$	212: $[\text{C} - \text{H} - \text{N}(\text{C}_2\text{H}_5)_3]^+$	86	212–86
4	349	313: $[\text{C} - \text{H}]^+$	240: $[\text{C} - \text{H} - \text{NH}(\text{C}_2\text{H}_5)_2]^+$	86; 72	240–86
5	469	327: $[\text{C} - \text{CH}_3]^+$ 410: $[\text{C} + \text{IN}(\text{CH}_3)_3]^+$	282: $[\text{C} - \text{H} - \text{N}(\text{CH}_3)_3]^+$	58	282–58

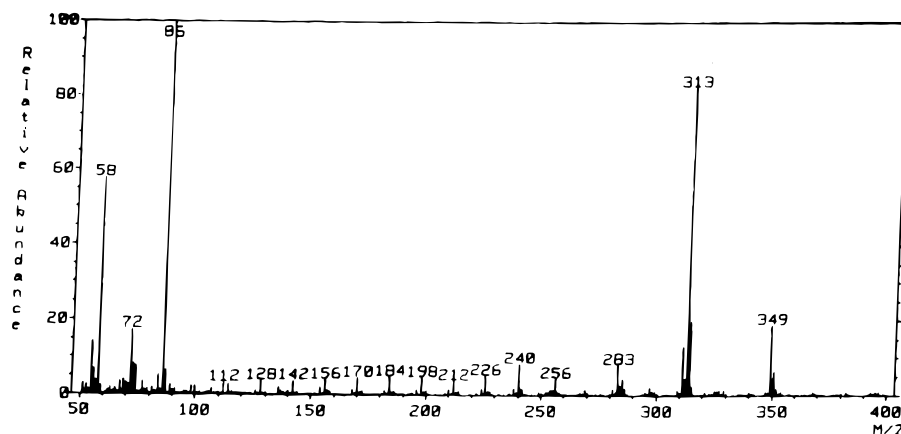


Figure 1. FAB mass spectrum of compound 4. Matrix: NBA.

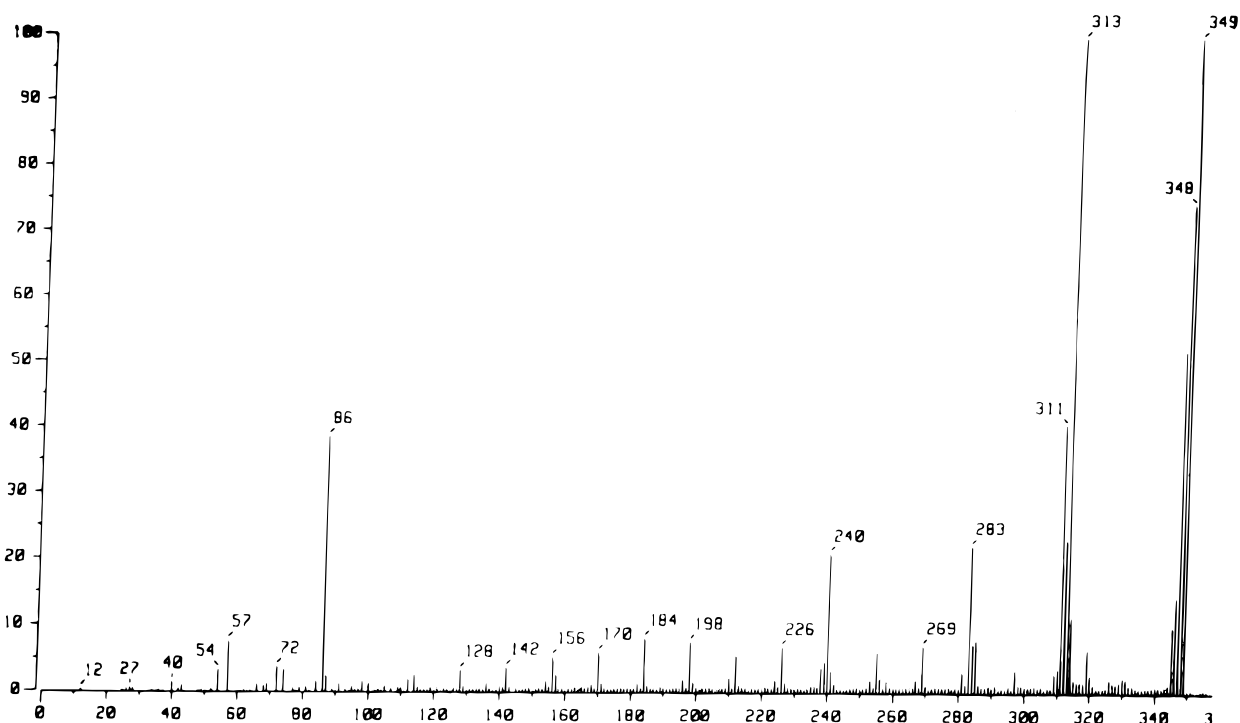


Figure 2. CAD spectrum of ion of m/z 349 (compound 4).

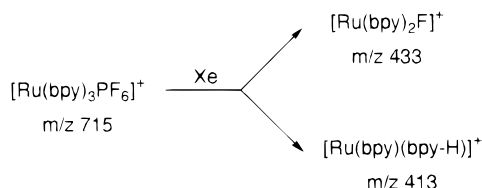
ion. Recently, Traldi and co-workers⁸ reported a similar result to ours (presence of ions formed by CRF with notable abundance in the FAB mass spectra) during a study of the FAB mass spectra of ammonium salts.

Therefore, this work shows by examination of CAD spectra of CX^+ adduct ions that chemical reactivity in the gaseous phase involving substitution and elimination reactions occurs when the necessary energy for the reaction is furnished during collision by transformation of kinetic energy into internal energy.²

A similar reactivity was noted by studying the FAB mass spectra of ruthenium complexes.⁹ The action of fluoride anions on the doubly charged cation was considered to account for the formation of ions of m/z 433 and 413 in the CAD spectrum of the m/z 715 ion: $[Ru(bpy)_3PF_6]^+$ (bpy = bipyridine) (Scheme 4).

Previously, it has been established that in the condensed phase there is chemical reactivity between the anion and the doubly charged cation involving substitution and elimination.¹⁰ The present work shows that similar reactivity also occurs in the gaseous phase, thus conforming to an observation made previously.⁹

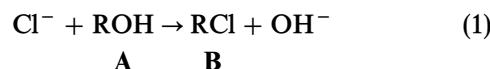
It should be noted that previously, the simultaneous employment of chemical ionization and MS/MS¹¹ allowed a wide variety of acid-catalysed reactions in the gaseous phase to be carried out: Fischer indole synthesis,¹² pinacol transposition,¹³ Beckmann rearrangement¹⁴ and aldol condensation.¹⁵ Addi-



Scheme 4

tionally, this work shows that it is possible to study two new reaction categories in the gaseous phase: nucleophilic substitution (Scheme 1) and elimination (Scheme 2) by FABMS of $C^{2+}2X^{-}$ organic salts.

Mass spectrometry applied to the study of ions in the gaseous phase is an appropriate technique for the investigation of reactivity in the absence of a solvent. More precisely, the use of MS/MS permits ion selection in a field-free region¹¹ of the analyser and the study of its reactivity initiated by collision. However, a limitation is that the mass spectrum is constituted from mono-charged species. For example, it is not possible to study the reaction described by Eqn (1) by MS because the starting material A and product B are both neutral compounds unobservable by MS unless a new ionization process occurs.

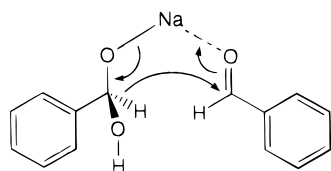


The interest in such MS studies is that the ions are naked, i.e. free of solvent. During the study of a reaction in organic chemistry involving an ion, it is necessary to bear in mind the fate of the ion, i.e. its eventual solvation, which may modify its reactivity. To illustrate this, let us consider two examples in supramolecular chemistry.¹⁶

(i) A reactivity enhancement is observed for the nucleophilic substitution reaction shown in Eqn (2), where cyanide ion is obtained by phase-transfer catalysis in the organic solvent rather than in the aqueous phase. In this environment, it is less solvated and consequently more reactive.



(ii) A reactivity decrease is noted for the addition of a crown ether in a Cannizzaro reaction. This addition,



Scheme 5

corresponding to a hydride anion transfer, gives rise to the formation of an intermediate with a Na^+ cation (Scheme 5). When the crown ether complexes this cation there is an appreciable decrease in yield because formation of the intermediate with Na^+ is not possible.

To illustrate this chemical reactivity in the gaseous phase between doubly charged cations and halide anions, we present an initial application. It involves the synthesis in the gaseous phase of an ion which is absent in the matrix. This was obtained from the FAB mass spectrum of two different salts, a C_12X_1 and C_22X_2 mixture. The FAB mass spectrum of this mixture exhibits the two expected adduct ions C_1X_1^+ and C_2X_2^+ and two additional adduct ions C_1X_2^+ and C_2X_1^+ . Each of the CAD spectra of the last two ions indicates a new C—X bond obtained by a *c* process (Scheme 1). For example, the results obtained for the study of the 3 + 5 mixture are detailed in Scheme 6.

CONCLUSION

This work has established that the same fragmentations as previously described in FAB and electrospray MS of organic salts $\text{C}^{2+}2\text{X}^-$ also take place in CAD of the CX^+ adduct ion. Thus, substitution and elimination

reactions involving X^- (counterion) and C^{2+} ion take place in the gaseous phase, this being a new category of chemical reaction in the gaseous phase as studied by MS. Previous results concerned acid-catalysed rearrangements.

Furthermore, for compounds containing a long aliphatic chain, the ions obtained by CRF are as abundant in the FAB mass spectra as in the CAD spectra. With one exception, this result is in conflict with the literature results and is of evident analytical interest because it is simple (and cheaper) to obtain a FAB than a CAD mass spectrum.

EXPERIMENTAL

The mass spectra were recorded by using an SX102 spectrometer (Jeol, Tokyo, Japan). Xenon was used in the FAB experiments. The beam energy of neutral atoms was set to 3 keV (emission current 20 mA). Instrument calibration was accomplished using Ultramark 1621 as a reference. Samples were placed on the target by dissolving them directly in the matrix (NBA, obtained from Aldrich).

CAD experiments were performed in the first field-free region of the spectrometer and product ion spectra were obtained by *B/E* scanning. The collision gas (helium) pressure was adjusted to 50% attenuation of the precursor ion beam.

The synthesis of the compounds will be described elsewhere.

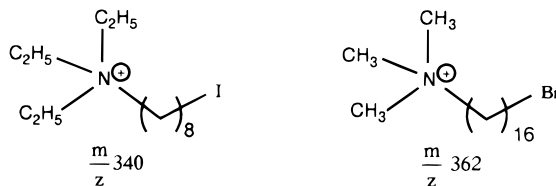
Mixture 3 + 5: $\text{C}_12\text{X}_1 + \text{C}_22\text{X}_2$

Compound 3: C_1^{2+} : 314 Da - X_1^- : 79 Da

Compound 5: C_2^{2+} : 342 Da - X_2^- : 127 Da

CAD spectrum of C_1X_2^+ ion: $\frac{m}{z}$ 441 (314 + 127): formation of ion $\frac{m}{z}$ 340 (see structure below)

CAD spectrum of C_2X_1^+ ion: $\frac{m}{z}$ 421 (342 + 79): formation of ion $\frac{m}{z}$ 362 (see structure below)



Scheme 6

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