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Research Article

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Differentiation of methyl naphthoate isomers on the basis of CID MS/MS spectra of their metal cation complexes

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ABSTRACT

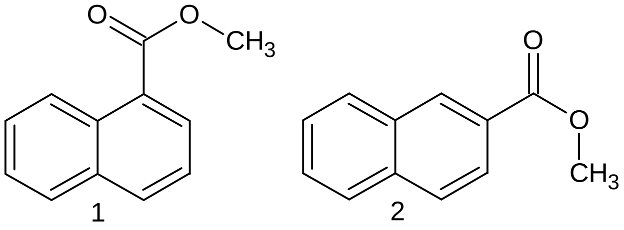
Gas phase decomposition of metal cation complexes of methyl naphthoate isomers were studied by using collision induced dissociation tandem mass spectrometry with electrospray as a method for generation of ions in the gas phase (ESI-CID-MS/MS). From among the metal cations used, lithium, calcium and zinc complexes were found to be useful for differentiation of methyl naphthoate isomers. For lithium and calcium complexes, the differentiation can be made on the basis of relative abundances of fragment ions. For zinc complexes there was a significant qualitative difference between the CID MS/MS spectrum of methyl 1-naphthoate and the CID MS/MS spectrum of methyl 2-naphthoate.

Keywords: methyl naphthoate, isomer, metal cation, electrospray, tandem mass spectrometry.

INTRODUCTION

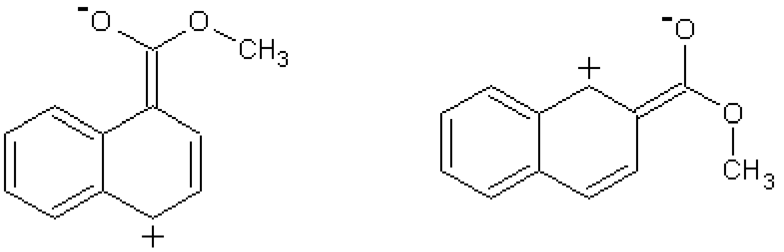
Isomers have exactly the same masses, however, the mass spectrometric fragmentation pathways of their metal complexes may be different. The differences in the gas phase behavior may be useful in isomeric differentiation as demonstrated by a number of papers. Isomers can be differentiated on the grounds of the mass spectrometric fragmentation pathways of their metal complexes for flavonoid derivatives [1-3], sugars [4-6] and other compounds [7-12].

Methyl naphthoate isomers (scheme 1) can be differentiated on the basis of the nuclear magnetic resonance spectroscopy (NMR spectroscopy) or electron ionization mass spectrometry (EI-MS) [13-15]. In this paper we wanted to check if the isomers can be also differentiated on the basis of CID MS/MS spectra of their metal cation complexes.



Scheme 1. Isomers of methyl naphthoate, 1 - methyl 1-naphthoate, 2 - methyl 2-naphthoate

It can be taken for granted that complexes between **1** or **2** and a metal cation are formed thanks to the metal-oxygen interaction and the metal-aromatic ring interaction (cation-π interaction). Ester group is a moderately electron withdrawing substituent and electron withdrawing properties of this group can be easily rationalized by respective resonance structures. For **1** it is possible to propose four aromatic resonance structures, whereas for **2** it is possible to propose only two aromatic resonance structures. Scheme 2 shows exemplary aromatic resonance structures.



Scheme 2. Exemplary aromatic resonance structures of 1 and 2

Because of the above presented resonance effect it is expected that **1**-metal cation complexes and **2**-metal cation complexes will show different behavior in the gas phase thus under mass spectrometric conditions. The different behavior will be a consequence of differences in the aromatic ring-metal cation interactions and oxygen atom-metal cation interactions for complexes of **1** and **2**.

EXPERIMENTAL SECTION

Mass spectra were taken on a Waters/Micromass (Manchester, UK) Q-tof Premier mass spectrometer (software MassLynx V4.1, Manchester, UK). The sample solutions, containing about 10^{-5} mol/dm^3 of one of the methyl naphtoate and about 10^{-5} mol/dm^3 of respective metal nitrate in methanol/water 1/1, were infused into the ESI source by a syringe pump at a flow rate of 5 ml/min. The electrospray voltage was 2.7 kV and the cone voltage - 30 V. The source temperature was 80^{o}C and the desolvation temperature was 250^{o}C. Nitrogen was used as the cone gas and desolvating gas at the flow-rates of 50 and 200 l/h, respectively. Argon was used as a collision gas at the flow-rate 0.5 ml/min in the T-wave collision cell. This flow rate resulted in the collision cell pressure of about 0.5 Pa. The applied collision energy (laboratory frame), the most important parameter for CID-MS/MS experiments, is indicated in each CID-MS/MS spectrum shown.

RESULTS AND DISCUSSION

We have taken into account the complexes of alkali metal cations (Li^+, Na^+, K^+, Rb^+, Cs^+) alkali earth metal cations (Ca^{2+}, Ba^{2+}) and one transition metal cation, namely Zn^{2+}.

CID MS/MS spectra of alkali metal cation complexes

The signals of complexes formed between **1** and larger alkali metal cations (Rb^+, Cs^+) were quite abundant, however, the signals of complexes formed between **2** and larger alkali metal cations were weak. It means that the latter complexes are not stable and a comparison of CID MS/MS spectra of ions $[\mathbf{2}+Rb]^+$, $[\mathbf{2}+Cs]^+$ with ions $[\mathbf{1}+Rb]^+$, $[\mathbf{1}+Cs]^+$ does not make sense.

For smaller alkali metal cations the complexes of stoichiometry 1:1 and 2:1 were observed with comparable abundances for both **1** and **2**. The CID MS/MS spectra of complexes of stoichiometry 1:1 (e.g. ions $[\mathbf{1}+Na]^+$, $[\mathbf{2}+Na]^+$) did not show any fragment ions. It means that we deal with the loss of metal cation which has low m/z value and cannot be detected because of apparatus limitations. The CID MS/MS spectra of complexes of stoichiometry 2:1 (e.g. ions $[\mathbf{1}_2+Na]^+$, $[\mathbf{2}_2+Na]^+$) show the loss of a neutral molecule of methyl naphthoate producing complex of stoichiometry 1:1 as fragment ion (e.g. ions $[\mathbf{1}+Na]^+$, $[\mathbf{2}+Na]^+$).

We found that CID MS/MS spectra of lithium complexes of stoichiometry 2:1, obtained at low collision energy, are different for isomers **1** and **2**. Figure 1 shows the CID MS/MS spectra of ions $[\mathbf{1}_2+Li]^+$ and $[\mathbf{2}_2+Li]^+$ obtained at collision energies 4, 5, 7 and 8 eV as representative examples.

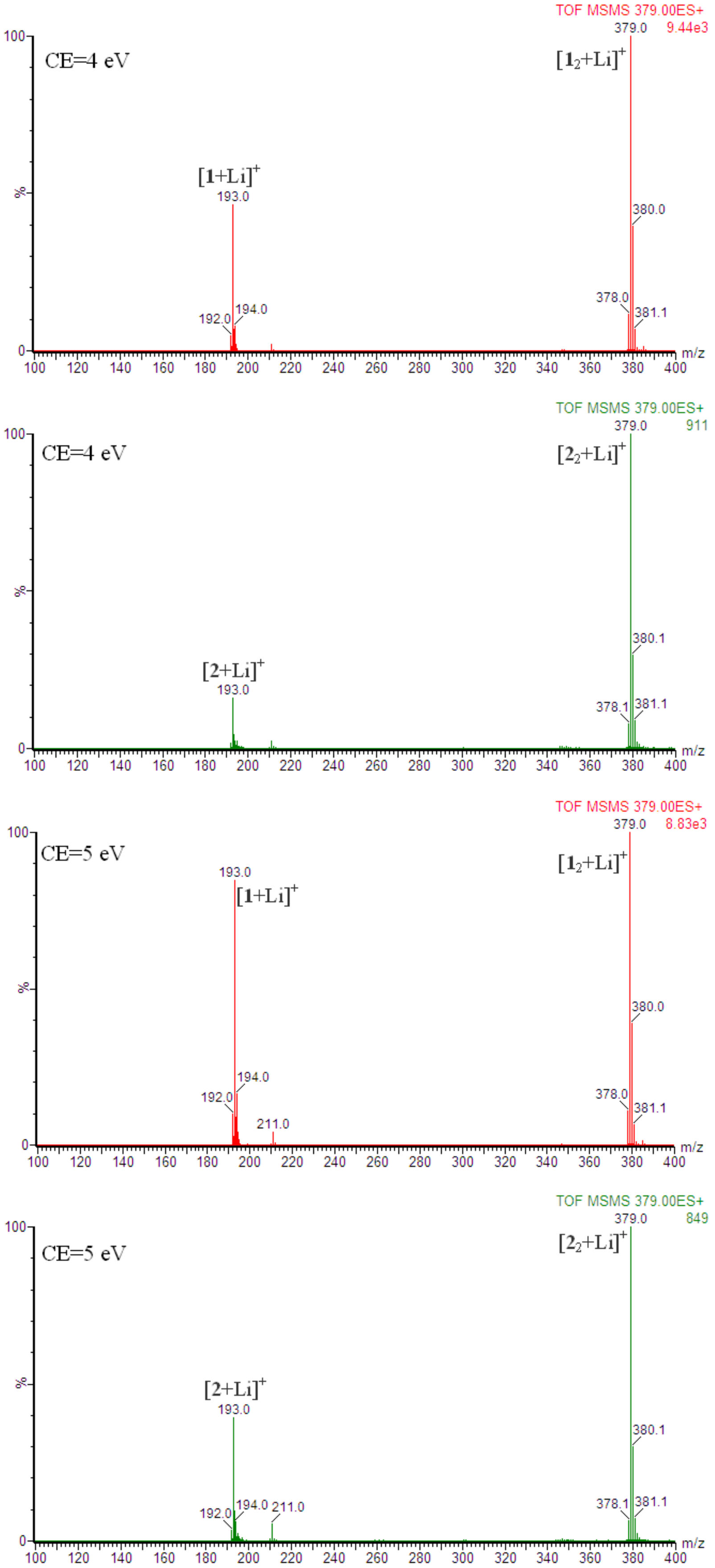


Figure 1a. CID MS/MS spectra of ions $[1_2+Li]^+$ and $[2_2+Li]^+$ obtained at collision energies (CE) 4 and 5 eV

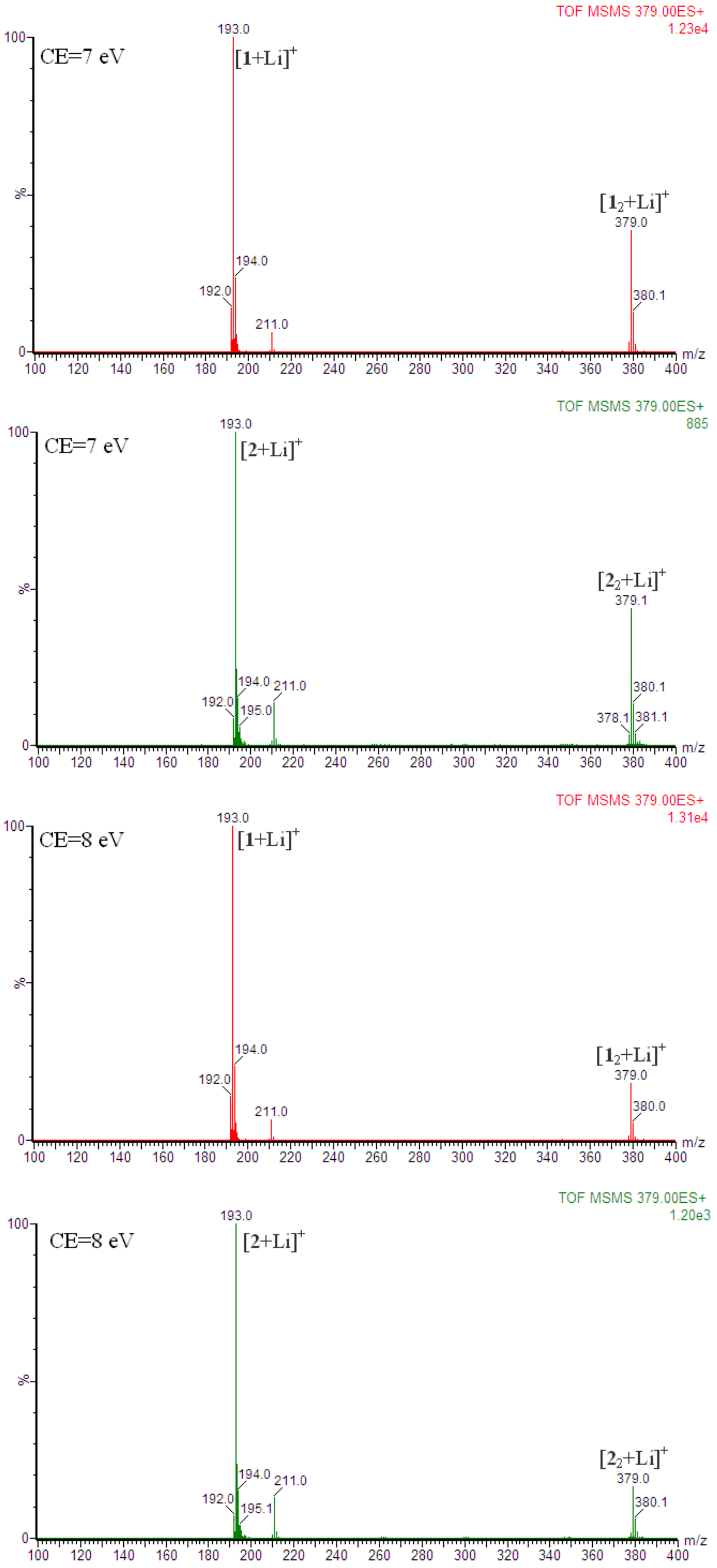
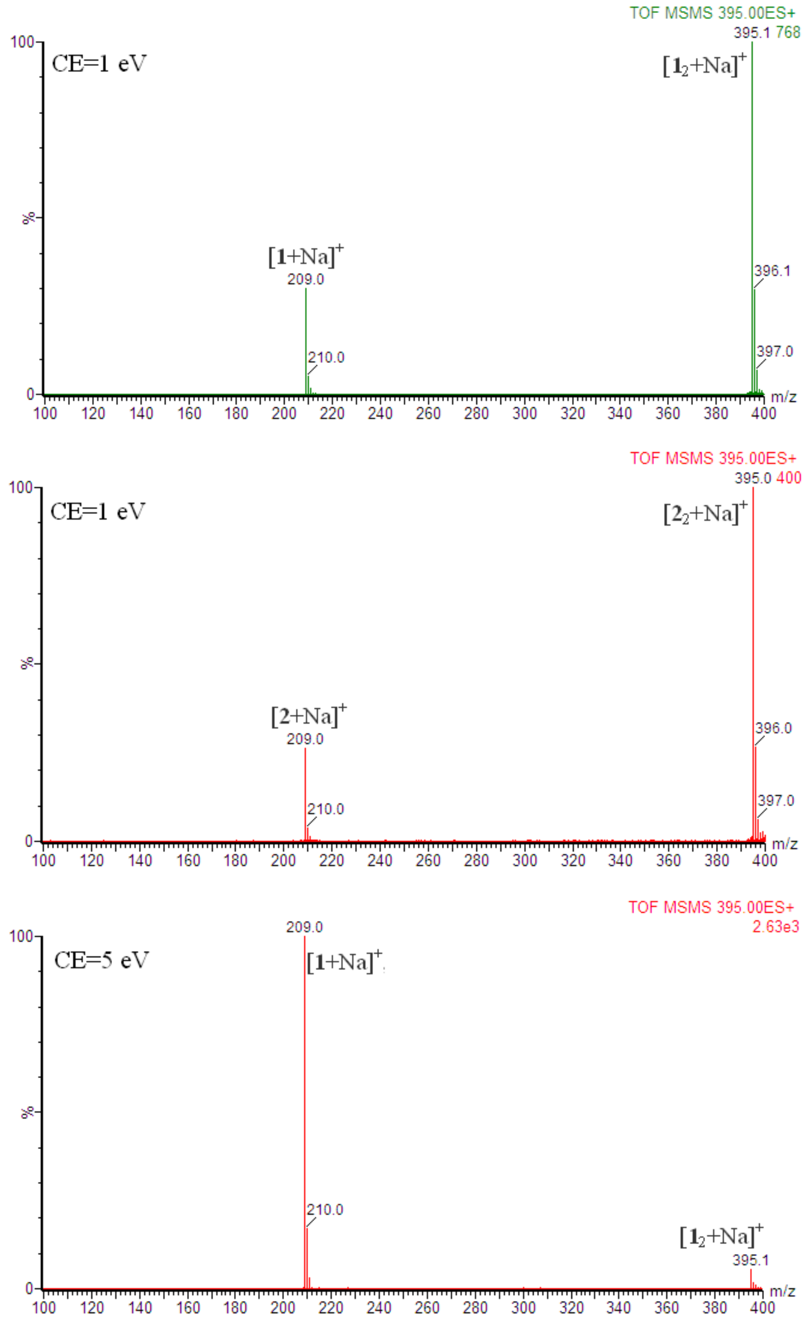


Figure 1b. CID MS/MS spectra of ions $[1_2+Li]^+$ and $[2_2+Li]^+$ obtained at collision energies 7 and 8 eV

As clearly seen in Figure 1, at collision energies 3 and 4 eV, the relative abundances of fragment ions [**1**+Li]$^+$ are higher than those of fragment ions [**2**+Li]$^+$. In other words, the CID MS/MS spectra of lithium complexes of stoichiometry 2:1, obtained at low collision energies can be used for differentiation of methyl naphthoate isomers. However at collision energies 7 and 8 eV the CID MS/MS spectra of ions [$\mathbf{1}_2$+Li]$^+$, [$\mathbf{2}_2$+Li]$^+$ are practically identical. Thus, these spectra cannot be used for differentiation of methyl naphthoate isomers.

Figure 2 shows the CID MS/MS spectra of ions [$\mathbf{1}_2$+Na]$^+$, [$\mathbf{2}_2$+Na]$^+$ obtained at collision energies 2, and 5 eV as representative examples.



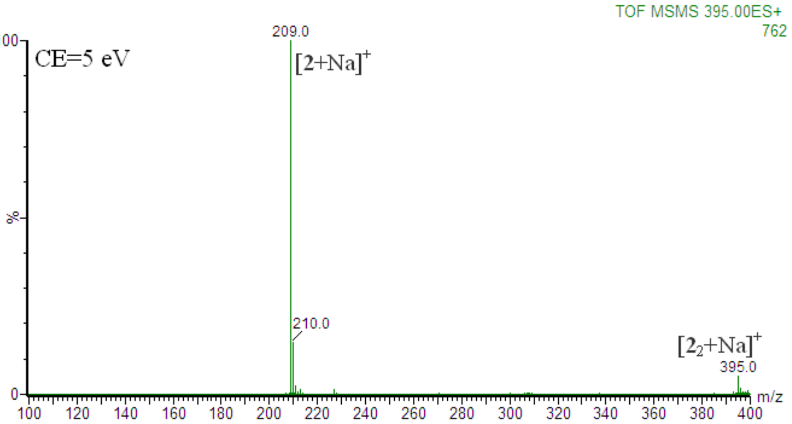
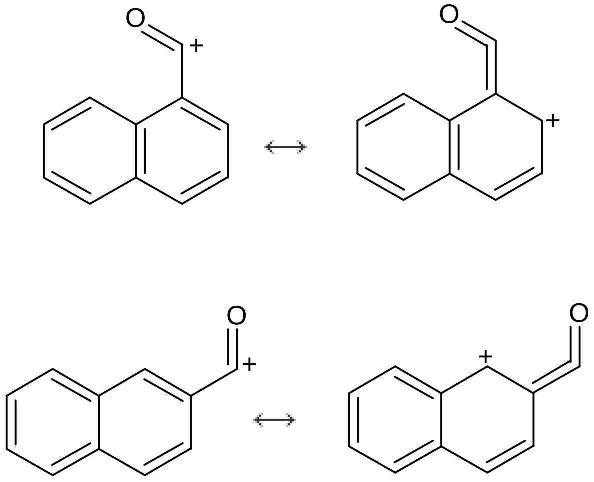


Figure 2. CID MS/MS spectra of ions [1$_2$+Na]$^+$ and [2$_2$+Na]$^+$

As clearly seen in Figure 2, the spectra obtained for sodium complexes of **1** and **2** are practically identical. Thus the CID MS/MS spectra of complexes of stoichiometry 2:1 with sodium cation cannot be used for differentiation of methyl naphthoate isomers. Analogical results as for sodium complexes were obtained for 2:1 potassium complexes.

CID MS/MS spectra of alkali earth metal cation complexes

For the solutions containing alkali earth metal cations and isomers **1** or **2**, doubly charged, abundant, complexes of stoichiometry 3:1 were detected (ions [**1**$_3$+Ca]$^{2+}$, [**1**$_3$+Ba]$^{2+}$, [**2**$_3$+Ca]$^{2+}$, [**2**$_3$+Ba]$^{2+}$). In the first step of fragmentation the complexes of stoichiometry 3:1 lose a neutral organic molecule producing the complexes of stoichiometry 2:1 (ions [**1**$_2$+Ca]$^{2+}$, [**1**$_2$+Ba]$^{2+}$, [**2**$_2$+Ca]$^{2+}$, [**1**$_2$+Ba]$^{2+}$). In the next step of fragmentation we deal with charge separation reactions producing singly charged ions [$C_{10}H_7CO$]$^+$ and the ions composed of an organic molecule, metal cation and methoxyl anion (ions [**1**+$CaOCH_3$]$^+$, [**1**+$BaOCH_3$]$^+$, [**2**+$CaOCH_3$]$^+$, [**2**+$BaOCH_3$]$^+$). The latter can also lose the organic molecule producing ions composed of metal cation and methoxyl anion (ion [$BaOCH_3$]$^+$). Exemplary resonance structures of ions [$C_{10}H_7CO$]$^+$ are shown in scheme 3.



Scheme 3. Exemplary resonance structures of ions [$C_{10}H_7CO$]$^+$

Figure 3 shows the CID MS/MS spectra of ions [**1**$_3$+Ca]$^{2+}$ and [**2**$_3$+Ca]$^{2+}$. As clearly shown in Figure 3, the gas phase decompositions of these two ions are substantially different with respect to relative abundances of fragment ions.

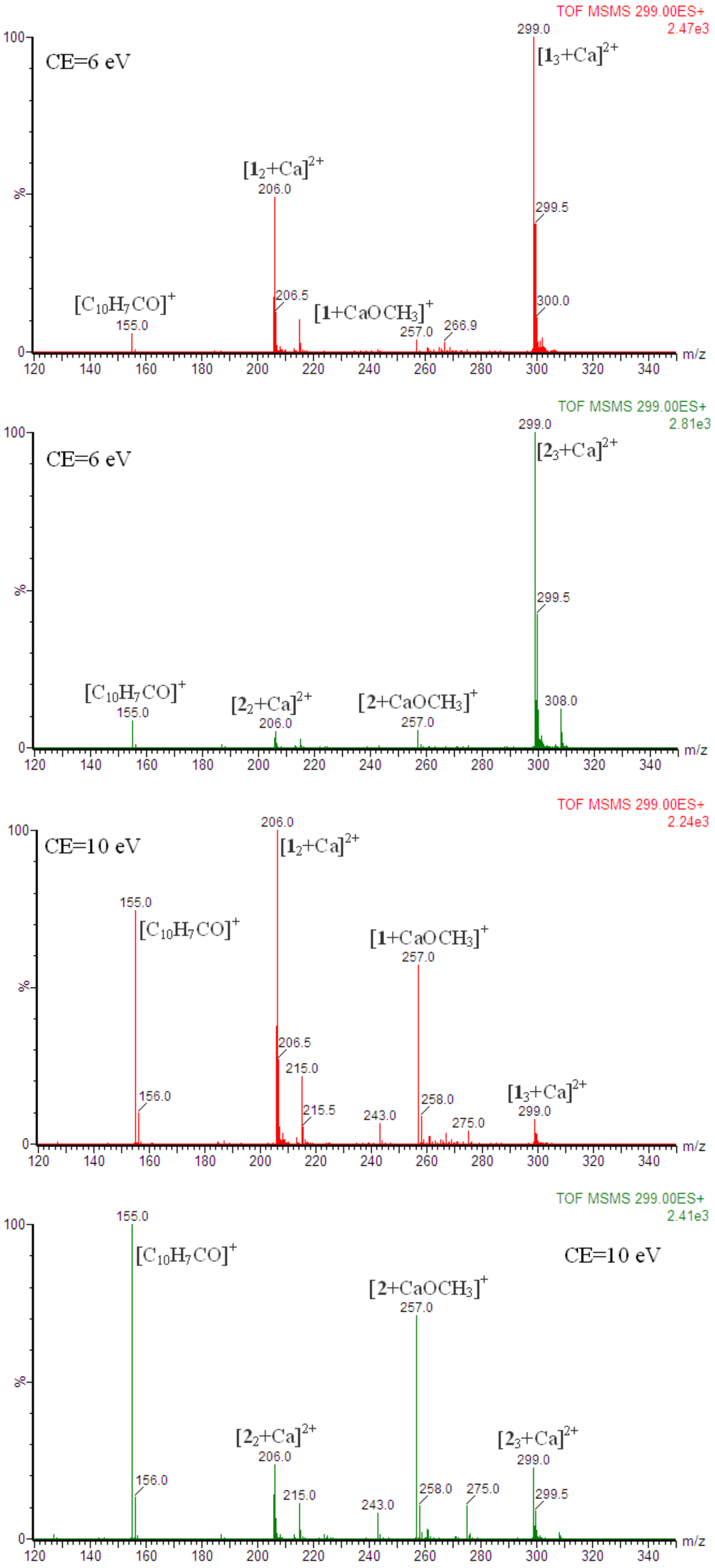
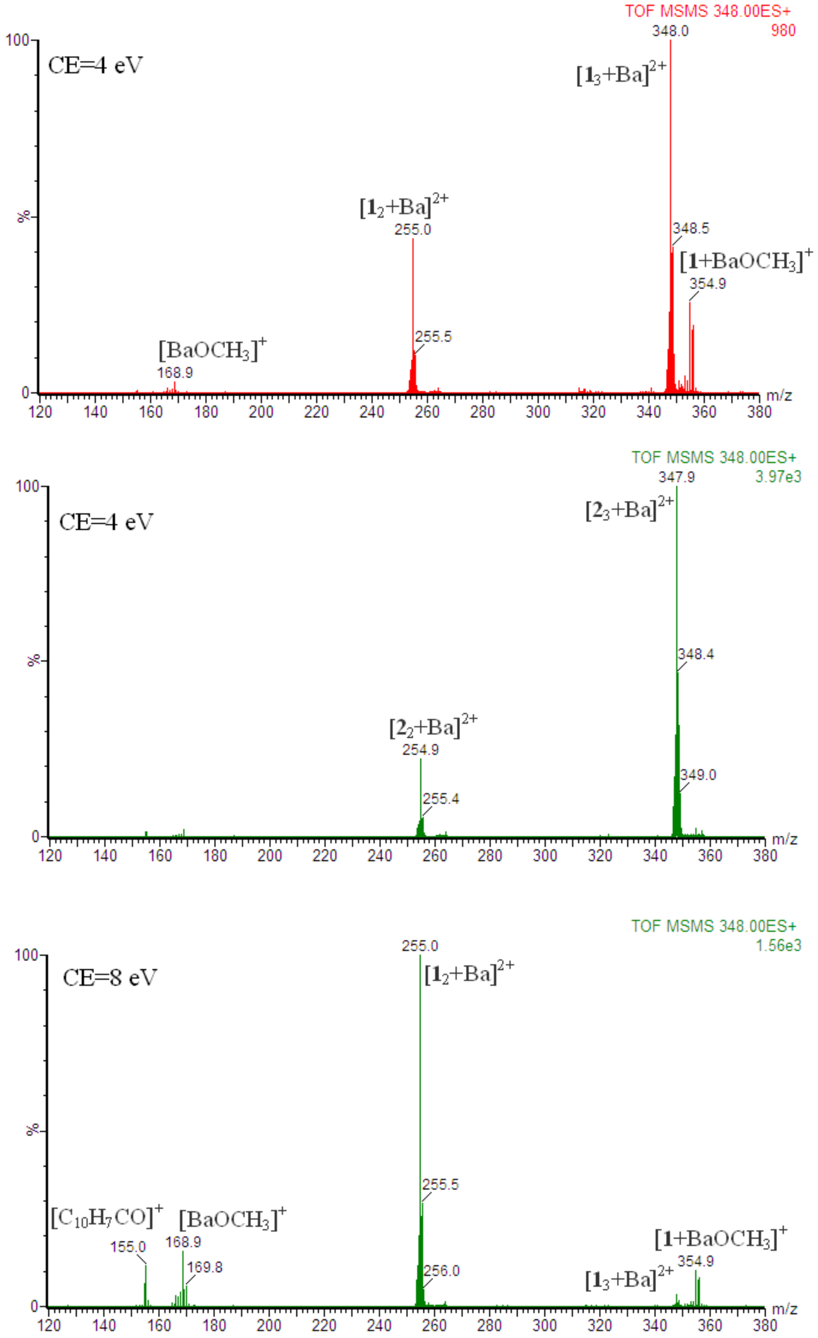


Figure 3. CID MS/MS spectra of ions $[1_3+Ca]^{2+}$ and $[2_3+Ca]^{2+}$

The differences are observed in both low and high collision energies and they are pronounced enough to be useful for differentiation of isomers **1** and **2**.

Figure 4 shows the CID MS/MS spectra of ions $[\mathbf{1}_3\text{+Ba}]^{2+}$ and $[\mathbf{2}_3\text{+Ba}]^{2+}$. Although there are differences in the abundances of fragment ions, they are minor and gas phase decompositions of these two ions rather cannot be useful for differentiation of isomers **1** and **2**.



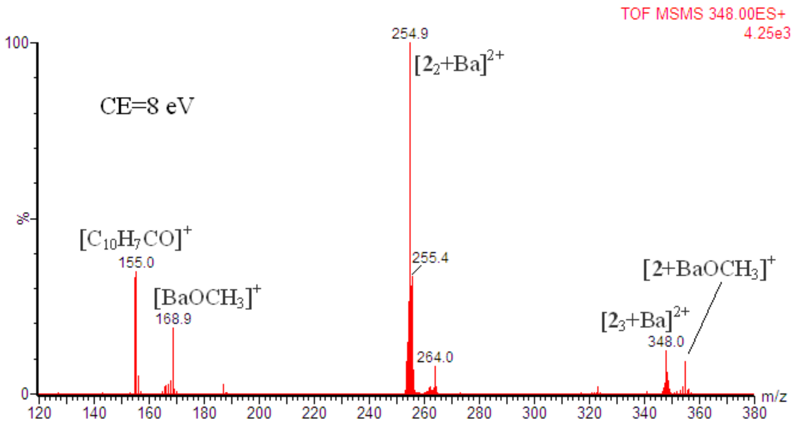
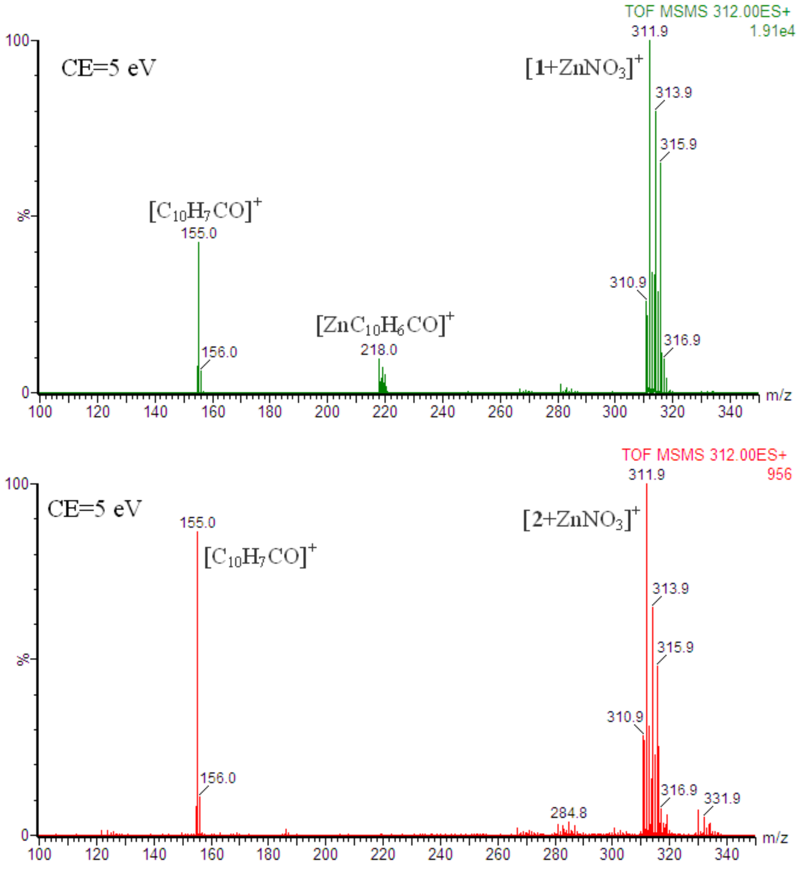


Figure 4. CID MS/MS spectra of ions [1_3+Ba]$^{2+}$ and [2_3+Ba]$^{2+}$

CID MS/MS spectra of zinc complexes

For the solutions containing isomers **1** or **2** and Zn(NO$_3$)$_2$ singly charged ions composed of organic molecule, zinc cation and counter ions were observed (ions [**1**+ZnNO$_3$]$^+$ and [**2**+ZnNO$_3$]$^+$). As shown in Figure 5, the fragmentation pathway detected for both ions is the formation of fragment ions [C$_{10}$H$_7$CO]$^+$.



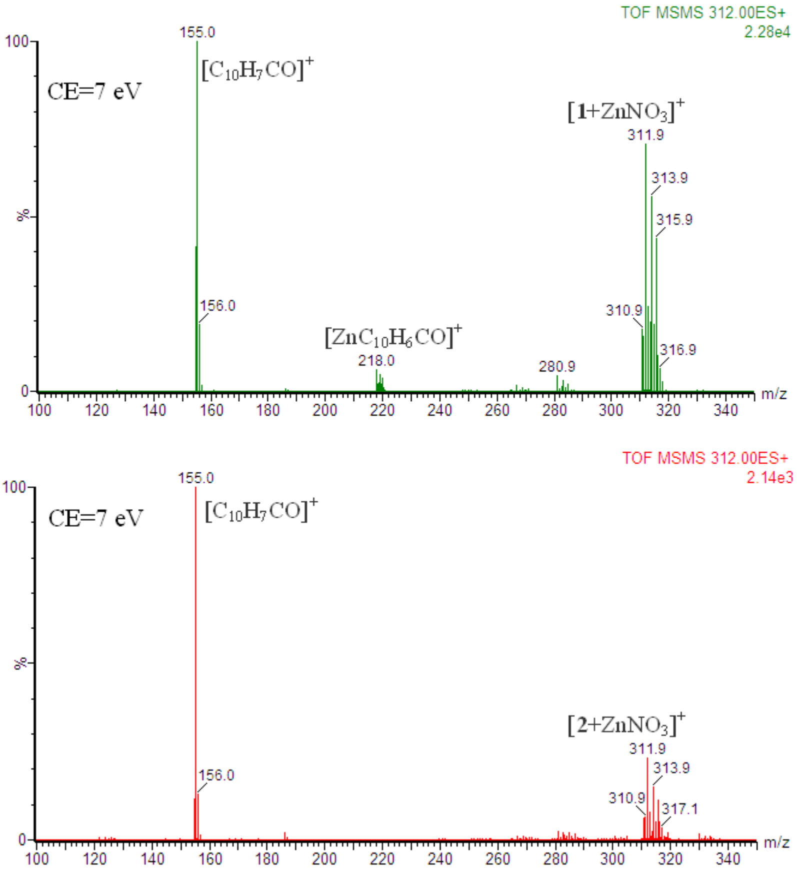
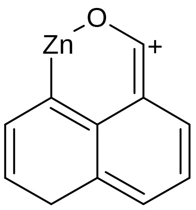


Figure 5. CID MS/MS spectra of ions $[1+ZnNO_3]^+$ and $[2+ZnNO_3]^+$

For ion [**2**+$ZnNO_3$]$^+$ it is the only observed decomposition. However, for ion [**1**+$ZnNO_3$]$^+$ there is the second fragmentation pathway consisting in the formation of zinc containing fragment ion at m/z 218. This fragment ion is formed by the loss of methoxyl radical and HNO_3 molecule or by the loss of methanol molecule and $^{\cdot}NO_3$ radical and its formula can be written as $[ZnC_{10}H_6CO]^+$. In other words, gas phase decompositions of ions [**1**+$ZnNO_3$]$^+$ and [**2**+$ZnNO_3$]$^+$ are qualitatively different. As described above the decompositions of lithium and calcium complexes of **1** and **2** were different with respect to relative abundances of fragment ions but were not different qualitatively. Therefore, the gas phase decompositions of ions [**1**+$ZnNO_3$]$^+$ and [**2**+$ZnNO_3$]$^+$ permit unambiguous differentiation of isomers **1** and **2**. The plausible structure of fragment ion at m/z 218 is shown in scheme 4. It is obvious that an analogical structure cannot be expected for isomer **2**.



Scheme 4. Plausible structure of ion at m/z 218

CONCLUSION

From among the complexes of alkali metal cations and alkali earth metal cations used in this work, the gas phase decomposition of lithium and calcium complexes seems to be useful for differentiation of isomers **1** and **2**. The differentiation can be made on the grounds of relative abundances of fragment ions. For the metal cations of lower radii the electrostatic interaction with organic molecule is stronger than for the metal cations of larger radii. Thus, for lithium and calcium cations, the interaction with isomers **1** and **2** is strong and specific enough to allow isomer differentiation.

Gas phase decomposition of zinc complexes seems to be even more useful for isomer differentiation than gas phase decomposition of lithium or calcium complexes, since there is a significant qualitative difference in the CID MS/MS spectra of zinc complexes. Namely in the CID MS/MS spectrum of ion $[\mathbf{1}+ZnNO_3]^+$ there is fragment ion at m/z 218 which can be assigned as $[ZnC_{10}H_6CO]^+$. This fragment ion is not observed in the CID MS/MS spectrum of ion $[\mathbf{2}+ZnNO_3]^+$.

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