Journal of Inclusion Phenomena and Molecular Recognition in Chemistry **24:** 163–173, 1996.

Review Article

Mass Spectrometry of Crown Ethers

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(Received: 12 February 1996)

Abstract. The mass spectra of benzo-15-crown-5 and benzo-18-crown-6 were investigated by mass spectrometry with different inlet systems, such as direct introduction, gas chromatography and liquid chromatography inlets. Different ionisation methods such as electron impact, chemical ionisation, electron capture or negative ion chemical ionisation were also studied. The results and the specific problems encountered for this group of substances are discussed based on the spectra obtained.

Key words: Crown ethers, mass spectra, electron impact, chemical ionisation, negative ion chemical ionisation.

1. Introduction

Mass spectrometry, utilised in organic chemistry to identify the products of syntheses and to determine the purity of substances, has also been used succesfully for supramolecules [1]. However, large molecules, particularly those showing binding properties, are difficult to investigate. This paper deals with the analysis of some benzo-crown ethers of polar and relatively macro structures [2] by mass spectrometry. The results obtained depend on the structure of the crown, the method used [3] and the problems resulting from its behaviour as an inclusion compound. The results were obtained from benzo-15-crown-5 (benzo-pentaoxa-cyclo-pentadecane) and benzo-18-crown-6 (benzo-hexaoxa-cyclo-octadecane). General details of the methods used have been described elsewhere [4].

Work on the complexation in solution of crown ethers with a variety of cations using electrospray mass spectrometry has been reported recently by Colton *et al.* [5]. Benzo-crown ether derivatives were not however studied in this work.

* Author for correspondence.
Presented at the Sixth International Seminar on Inclusion Compounds, Istanbul, Turkey, 27–31 August, 1995.

2. Experimental

The crown ethers were obtained from Fluka, purified by column chromatography over silica with chloroform as eluent, then dried *in vacuo* at 40 °C.

A Fisons Trio 1000 quadrupole mass spectrometer was used in electron impact (EI), chemical ionisation (CI), electron capture or negative ion chemical ionisation (NICI) mode. The source temperature was 230 °C. EI, CI and NICI spectra were obtained with an electron energy of 70 eV. Methane served as the CI medium as well as the moderating gas for CI and NICI. All scans were recorded with one scan per second, scanning from m/z = 50 to m/z = 700. The substances were introduced into the ion source using a Fisons desorption chemical ionisation (DCI) device, a Fisons 800 gas chromatograph (GC) or a Fisons liquid chromatography (LC) thermospray/plasmaspray interface.

2.1. Introduction with the DCI device

The substances were dissolved in ethyl acetate, acetone or their mixtures with hexane and applied, with a microsyringe, onto the DCI wire which was then introduced, after evaporation of the solvent, into the ion source. Once in the ion source, an electrical potential was applied to the wire. An initial current of 50 mA was used which was increased at a rate of 500 mA/min to 900 mA. This resulted in the wire being heated, and the substances evaporated and ionised in the CI mode. This is one of the softest ionisation methods, producing excellent mass information with very limited fragmentation. However absolutely pure samples are needed. It is very difficult or impossible with mixtures, or when impurities are present, to separate the different substances by differentially increasing the voltage on the wire. The ion source temperature, combined with the vacuum, volatilizes most of the substances even without applying a voltage on the DCI wire. The application of a current to the DCI wire mainly increases ionisation and produces a high yield of ions, in addition to the differential evaporation effect.

2.2. GC introduction

The pre-separation of a mixture can be carried out using GC. The GC was equipped with a DB-5 capillary column (15 m × 0.25 mm I.D., 0.25 μm film thickness) (Fisons Instruments). Helium was used as the carrier gas and the splitless Grob injector was kept at 260 °C. The temperature programme of the column was 1 min at 70 °C then increasing at 30 °C/min. to 300 °C where it remained for 10 min. The GC column was inserted directly into the ion source and the EI, CI or NICI mode was used for ionisation.

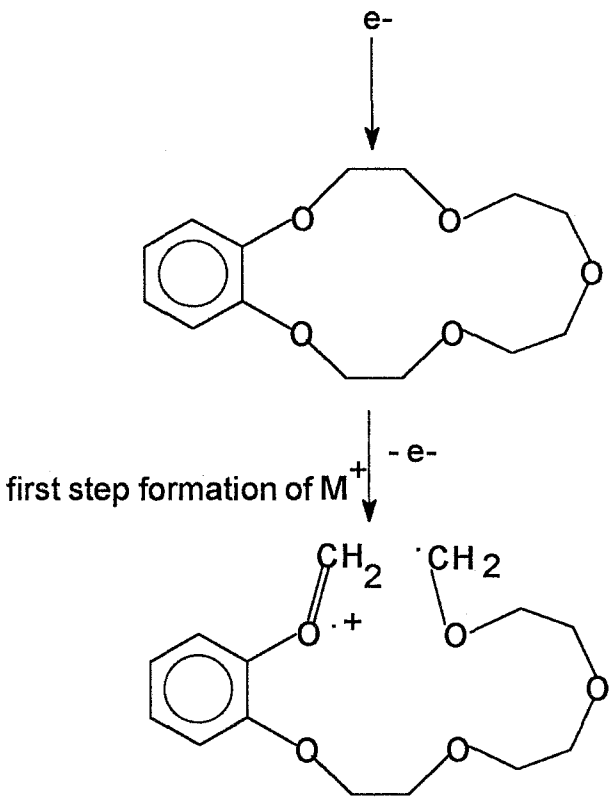

Figure 1. First step of the alpha fragmentation of benzo-15-crown-5.

2.3. INTRODUCTION THROUGH THE LC INTERFACE

LC or HPLC can also be used for pre-separation of a mixture. Apolar elution systems have to be used for crown ethers to avoid interaction of the crown ethers with the cations present in polar solvents. The LC interface has therefore to be used in plasmaspray mode in order to produce the necessary large amount of ions. Only the use of polar solvents provides a sufficient ionisation in thermospray mode. The eluent of the LC column, a mixture of methanol : water = 70 : 30, reaches the ion source through a heated capillary (220 °C) where it is evaporated. It leaves this capillary as a supersonic jet of very small droplets in an evacuated tube, which is continuously pumped down to a modest vacuum. The solvent molecules diffuse away, the droplets get smaller and are electrically charged by the discharge electrode (200 eV). The spray is generated thermally, the ions, positive as well as negative, are mainly generated by the plasma.

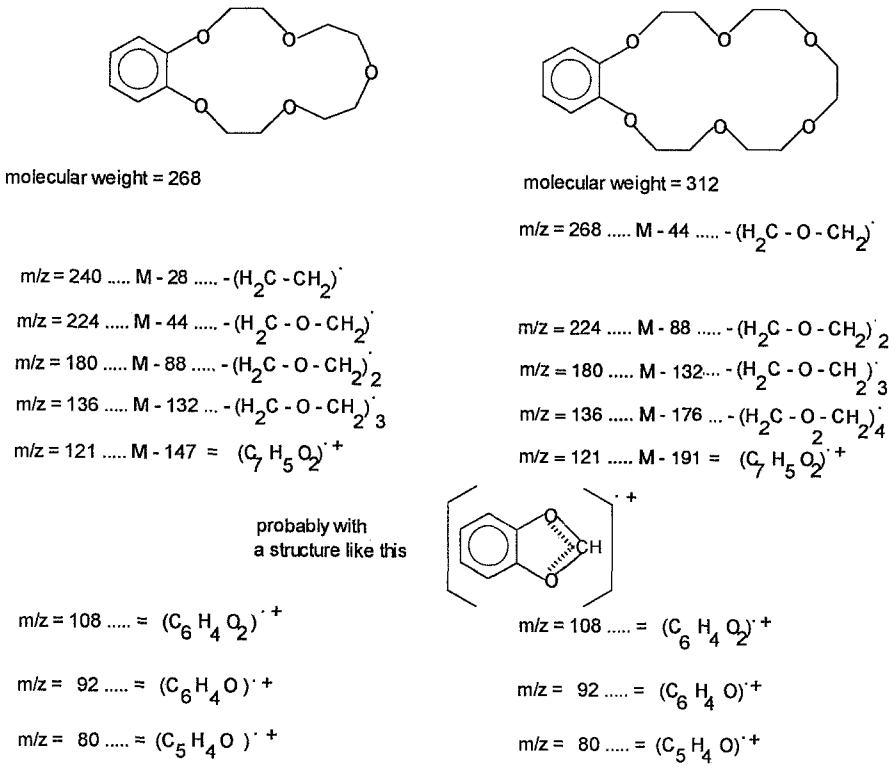

Figure 2. Structure and fragmentation patterns of benzo-15-crown-5 (left) and of benzo-18-crown-6 (right).

3. Results and Discussion

All the spectra obtained with the different introduction and ionisation methods are nearly identical for both benzo-crown ethers, namely benzo-15-crown-5 (benzopentaoxacyclopentadecane) (Bz15C5) and benzo-18-crown-6 (benzohexaoxacyclooctadecane) (Bz18C6). The first step is most probably an alpha fragmentation with a localisation directed by the benzene ring as shown in Figure 1. This gives the molecular ion which, by alpha fragmentation, is further decomposed into smaller fragments (Figure 2).

Bz18C6 (MW = 312) analysed with DCI using methane as the ionisation gas gives the spectrum shown in Figure 3. The (M+1) = 313 peak is clearly present but there are two higher masses recorded with m/z = 385 and m/z = 433 which are not adducts from the ionisation gas. There are three possible reasons for these peaks: (i) the substance introduced by DCI has a molecular weight of 433 and gives fragments with m/z = 385 and m/z = 313, (ii) a mixture of three or more different substances is being analysed, or (iii) the ions with m/z = 433 and m/z

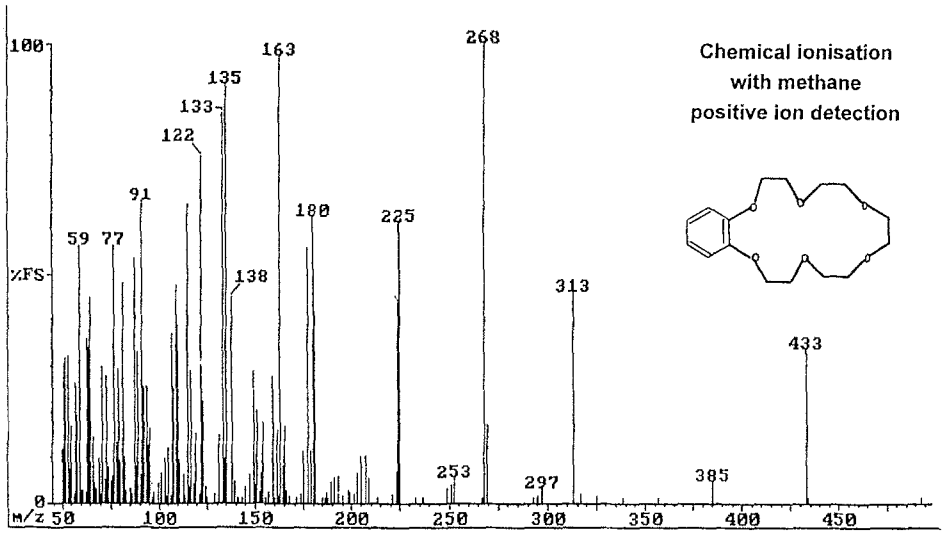

Figure 3. Spectrum of benzo-18-crown-6 (molecular weight = 312) obtained with the DCI device and CI mode after gas chromatographic separation. The $(M+1)^+$ ion with $m/z = 313$ is clearly visible and also the 2 ions with $m/z = 385$ and $m/z = 433$.

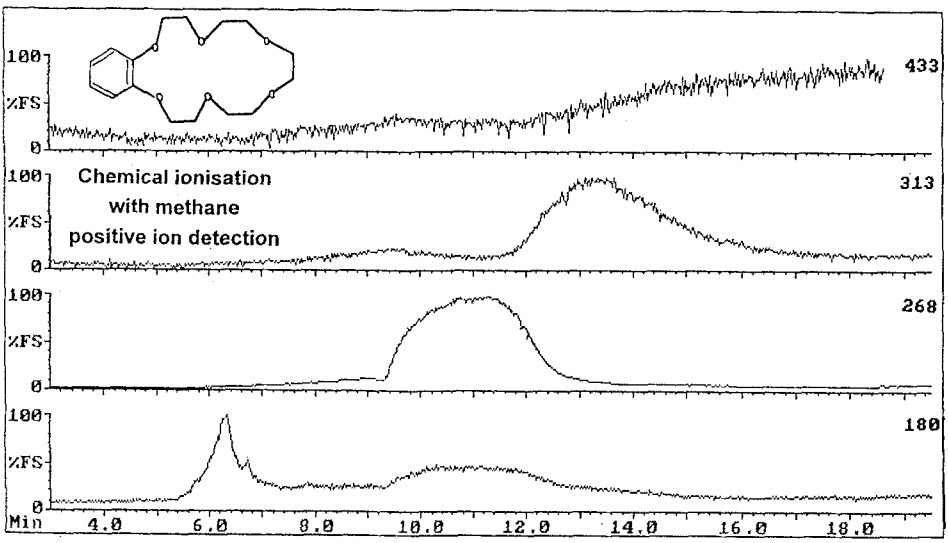

Figure 4. Mass chromatogram of benzo-18-crown-6 detected in CI mode, with the traces of the ions with $m/z = 180$, $m/z = 268$, $m/z = 313$ and $m/z = 433$.

= 385 are formed in the ion source by initial fragmentation of Bz15C6 followed by a recombination. The combination of a fragment ion, with $m/z = 121$ (Figure 2) with the intact molecule, could be responsible for the ion with $m/z = 433$. In order to clarify this question, the substance was analysed by GC-MS, the spectra

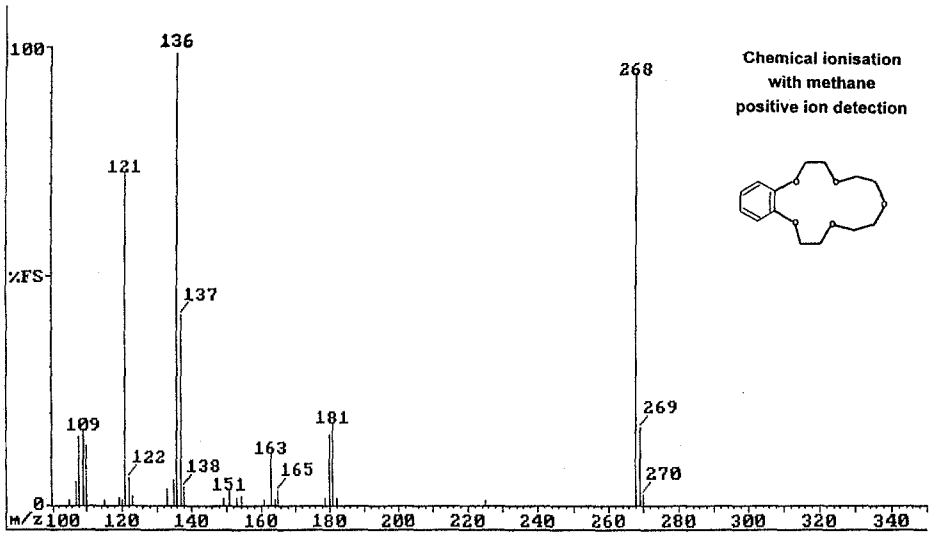

Figure 5. Spectrum of benzo-15-crown-5 obtained by DCI or CI mode after gas chromatographic separation. Methane is used as the CI gas at the usual pressure.

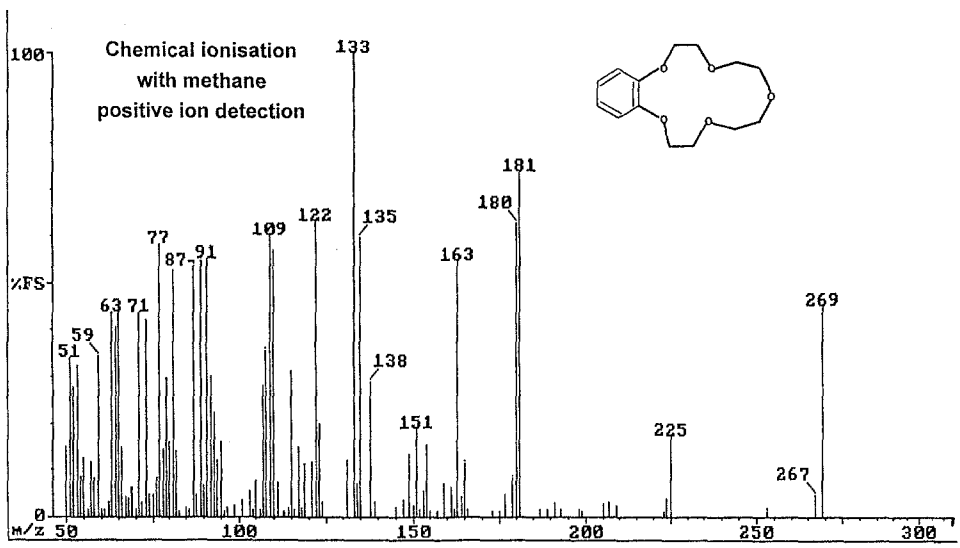

Figure 6. Spectrum of benzo-15-crown-5 after gas chromatographic separation in CI mode but with reduced methane pressure, EI instead of CI source.

again being recorded in the CI mode. In the mass chromatogram (Figure 4) the traces corresponding to ions with m/z = 180, m/z = 268 and m/z = 313 showed peaks with different retention times and suggested that a mixture of different crown ethers was being analysed. The spectrum of the peak in the mass chromatogram with m/z = 313 however, was identical to that obtained by DCI (Figure 3). This

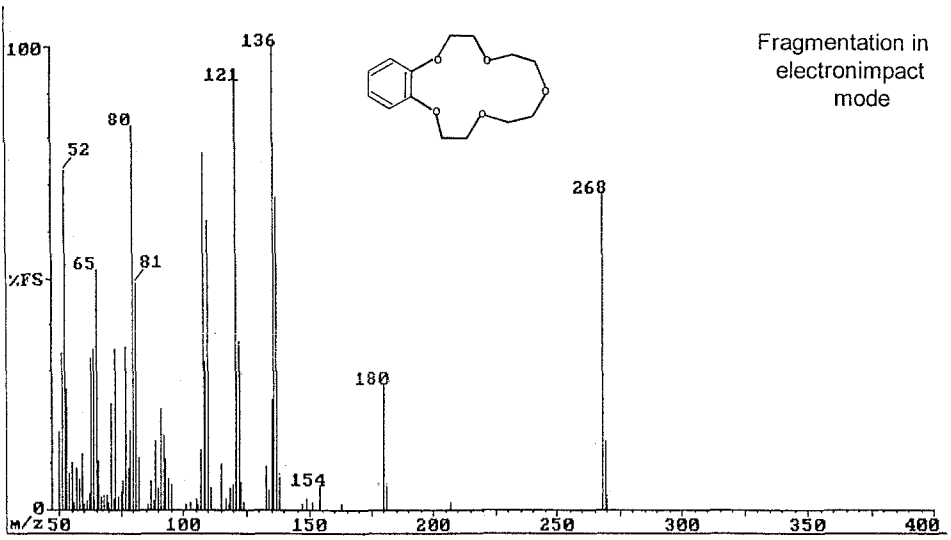

Figure 7. Spectrum of benzo-15-crown-5 after gas chromatographic separation in EI mode.

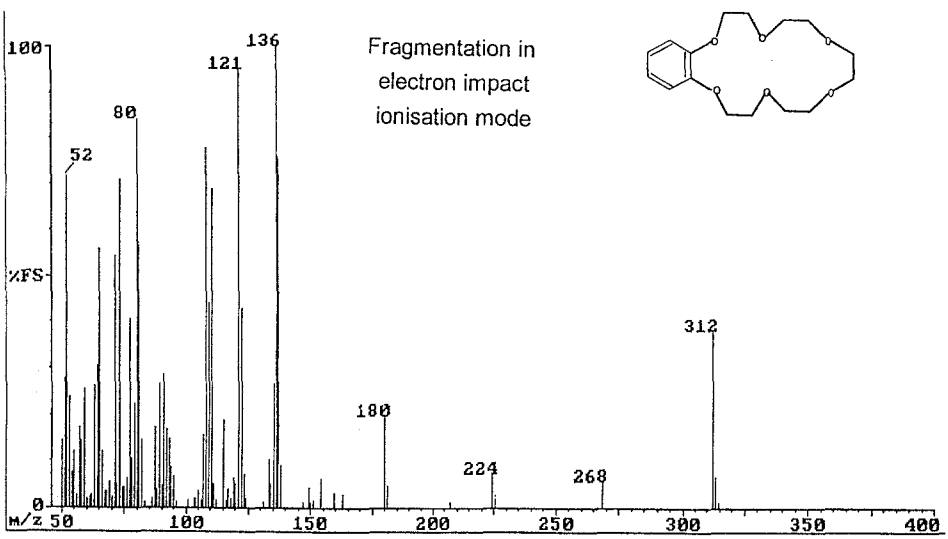

Figure 8. Spectrum of benzo-18-crown-6 after gas chromatographic separation in EI mode.

indicates that the 385 and 433 peaks result from fragmentation and recombination in the ion source.

Bz15C5 (MW = 268) was also analysed by GC-MS and spectra were recorded in the CI mode. Two peaks were obtained in the chromatogram, one from ions with $m/z = 180$ and one from ions with $m/z = 268$. The spectrum of the peak in the mass chromatogram corresponding to ions with m/z = 268 showed the expected low

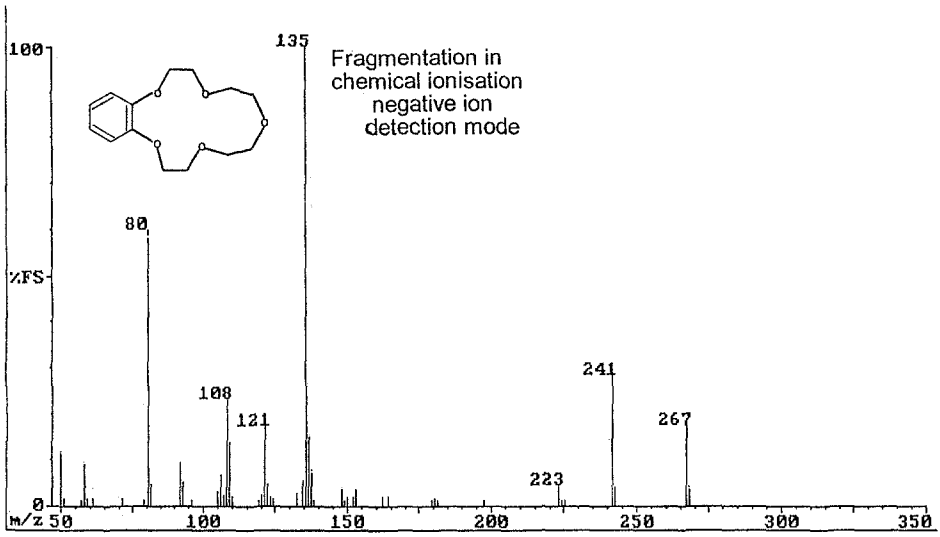

Figure 9. Spectrum of benzo-15-crown-5 after gas chromatographic separation in NICI mode.

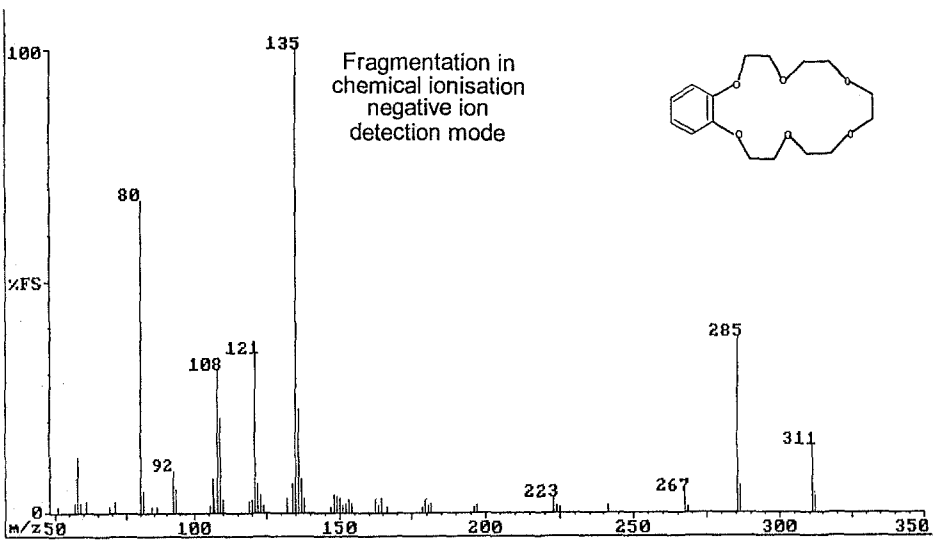

Figure 10. Spectrum of benzo-18-crown-6 after gas chromatographic separation in NICI mode.

fragmentation and the M^+ ion ($m/z = 268$) as the base peak (Figure 5). The (M+1) ($m/z = 269$) ion was only detectable at a lower methane pressure in the ion source. This, however, resulted in a higher fragmentation and also in the formation of the (M + 1) and (M − 1) ions (Figure 6). In contrast to Bz18C6 no ions with masses higher than (M + 1) could be detected. Analysing both substances by GC–MS and recording spectra in the EI mode showed the fragmentation pattern (Figures 7 and 8) outlined in Figures 1 and 2.

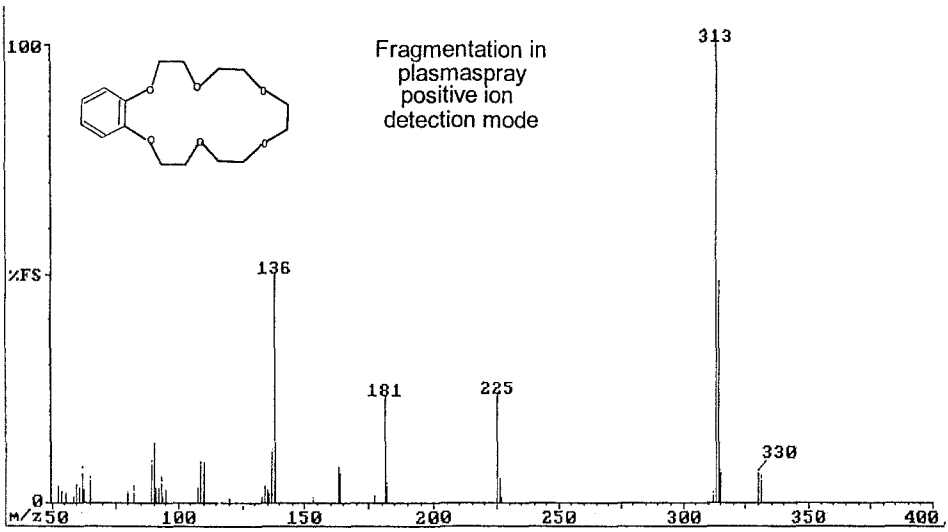

Figure 11. Spectrum of benzo-18-crown-6 obtained in plasmaspray positive ion detection mode.

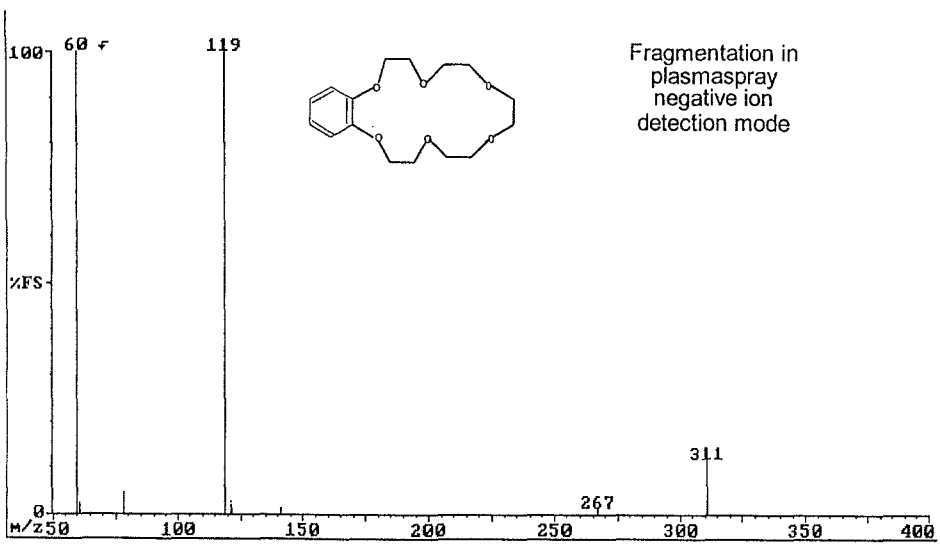

Figure 12. Spectrum of benzo-18-crown-6 obtained in plasmaspray mode detecting negative ions. 50-fold multiplication of the signals with m/z higher than 70.

In NICI mode (Figures 9 and 10) the loss of 1 proton, resulting in a $(M - 1)^-$ ion was observed. The two ions with an m/z higher than the molecular weight observed in the spectrum of Bz18C6, when analysed in the CI mode (Figure 3), were not, however, detectable under identical GC conditions but running the MS in EI or NICI mode. The two peaks in the ion chromatograms with m/z = 180

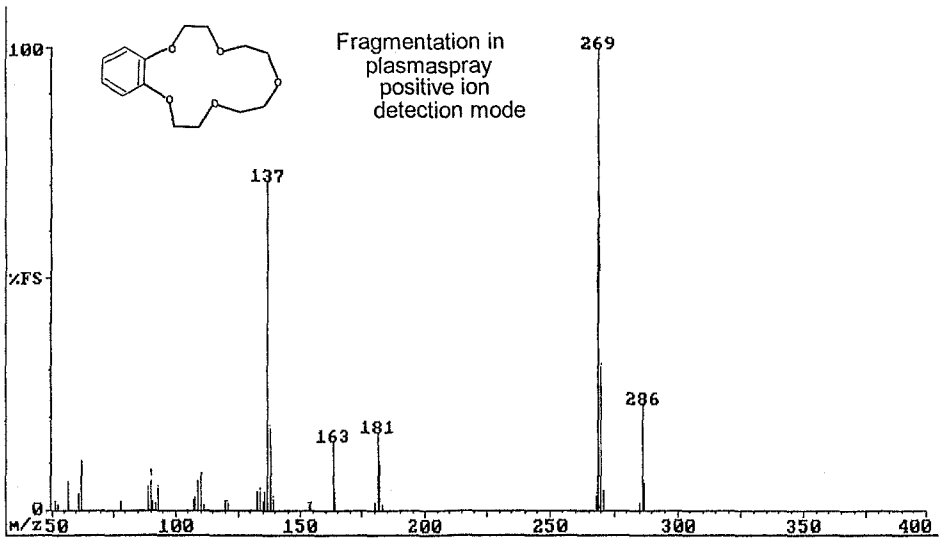

Figure 13. Spectrum of benzo-15-crown-5 obtained in plasmaspray mode detecting positive ions.

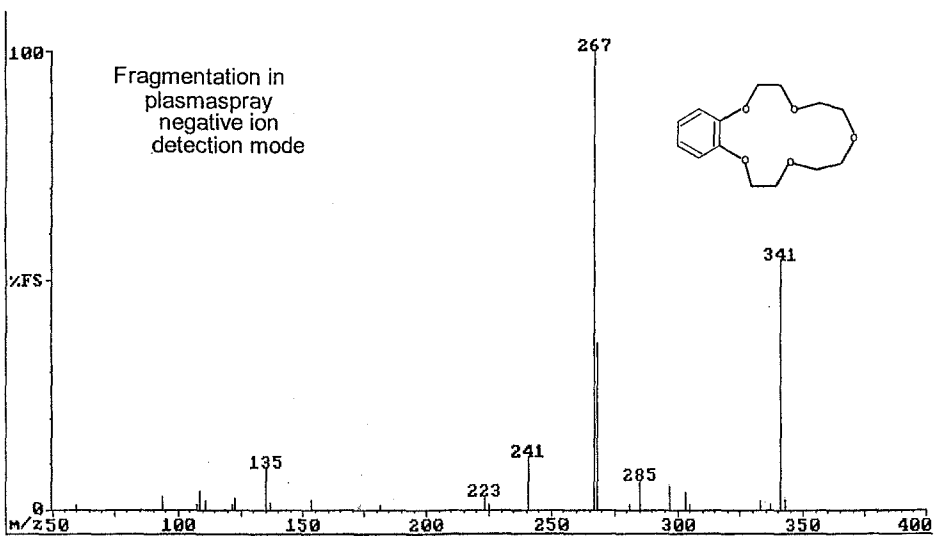

Figure 14. Spectrum of benzo-15-crown-5 in plasmaspray negative ion detection mode. Note the ion with m/z = 341 i.e. $(M+73)^-$.

and m/z = 268 were again detected. This probably indicates that the peaks in the mass chromatograms with an m/z lower than the molecular mass result from a degradation in the injection port of the GC, whereas the higher ones are produced, under specific conditions, in the ion source by fragmentation and recombination.

Both crown ethers were also introduced through the LC interface to avoid thermal decomposition which can occur in the injection port of the GC. Positive and negative ions were detected in the plasmaspray mode. In positive ion detection mode Bz18C6 gave a spectrum with the $(M+1)^+$ ion (m/z = 313) as the base peak (Figure 11). An ion with m/z = 330 is formed by the addition of water to the molecule. The other intense fragments correspond to those observed in the other ionisation modes. The base peak m/z = 60, recorded in negative ion detection mode (Figure 12), is the small fragment $(O—CH_2—CH_2—O)^-$. The higher fragments, with m/z = 119 and m/z = 311 $(M-1)^-$, are only visible after 50-fold multiplication. Bz15C5 showed in plasmaspray positive ion mode a spectrum similar to that of Bz18C6 with $(M+1)^+$ m/z = 269 as the base peak, $(M+18)^+$ as the adduct of water together with some of the usual fragments (Figure 13). The spectrum of the negative ions, taken in plasmaspray mode under exactly the same conditions as were used for Bz18C6, was quite different (Figure 14). The $(M-1)^-$ ion with m/z = 267 was the base peak, an additional ion appears with m/z = 341, having 50% of its intensity. This corresponds to an addition of 73 mass units to the molecule and may result from the combination with a lower neutral fragment.

These results clearly show that it is really difficult to get full information about the molecular weight and the structure of a crown ether using only one mode of introduction into the ion source of a mass spectrometer or one ionisation mode. This is explained by the structure of such molecules having a great affinity to include other substances or to bind them on selective sites and by their very specific fragmentation behaviour. The fact that the inclusion of a compound into a crown ether depends on its size makes the different ionisation and fragmentation behaviour of structurally similar substances such as Bz15C5 and Bz18C6 understandable. Nevertheless it is demonstrated that mass spectrometry gives good information about molecular weight and molecular structure if different introduction modes and different ionisation modes are employed. This has also been observed in other studies [6] and a detailed review on this topic will be published shortly [7].

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