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Mass Spectra of Chlorinated Veratroles (1,2-Dimethoxybenzenes)

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The behaviour of all nine chlorinated veratroles (1,2-dimethoxybenzenes) under electron impact has been investigated. The most common fragmentation processes are interpreted using metastable ion analysis and deuterium labelled compounds. For all compounds studied, the most common fragmentation route seems to be the primary loss of a methyl radical followed by loss of carbon monoxide. The ion formed has a well-known quinonoid structure and fragments by several routes elucidated by metastable ion analysis. In general, the spectra of the positional isomers are shown to be practically similar and it is apparent that e.g. the 3- and 4-chloro isomers can be differentiated only from the abundance ratio of the $[M-CH_3-CO-CH_3]^{+\cdot}$ and $[M-CH_3-CO-H_2O]^+$ ions.

INTRODUCTION

Chlorinated veratroles (1,2-dimethoxybenzenes) have been of great interest as biomethylation products of chlorinated guaiacols (*o*-methoxyphenols).[1-3] Tetrachloroveratrole has been detected as one of the metabolites of pentachlorophenol by an isolate of a *Mycobacterium species*.[4] Weiss *et al.* have also identified tetrachloroveratrole as pentachlorophenol metabolite in soil and rice.[5] Recent studies[6] indicate that chloroveratroles are responsible for unpleasant odour and taste even in very low concentrations in fish and water.

Routine gas chromatography/mass spectrometry (GC/MS) technique has been frequently used for identification of chloroveratroles in various environmental samples and model compound mixtures.[7-12] In some of these studies, the samples containing chlorocatechols (1,2-benzenediols) and chloroguaiacols have been methylated before analysis and then the amounts of chlorinated veratroles have been used for determination of individual chlorophenolics by GC/MS. For example, trace amounts of chloroveratroles have been detected in a sample from river water in England,[10] in sewage effluent from an activated sludge plant[11] and in the receiving waters of a kraft pulp and paper mill.[12] More recently, Veijanen *et al.* have presented the study of the simultaneous mass fragmentographic determination and odour detection of chloroveratroles (including also chloroanisoles) in fish tissue.[13]

Some papers have been published concerning the mass spectral properties of veratrole and other aromatic phenyl methyl ethers.[14-21] Barnes *et al.*[14,15] have studied the fragmentation of anisole, guaiacol and dimethoxybenzenes, for example. Florencio *et al.*[16,17] have performed detailed investigations in an attempt to elucidate the mechanisms of some primary and secondary reactions in substituted phenyl methyl ethers. In those studies they have applied e.g. collisional activation spectra, labelled homologues of the model compounds and metastable ion characteristics. To our knowledge, however, no systematic mass spectroscopic investigation of chlorinated veratroles has been reported. As a continuation of our previous studies with chlorinated aromatics[21-23] this work shows the mass spectral fragmentations of all possible chloroveratroles under electron impact. The possible differences in the spectra of the positional isomers are examined and discussed.

EXPERIMENTAL

Veratrole (**1**) and chlorinated veratroles (**2-10**) were synthesized from catechol and chlorinated catechols applying the following methylation method: catechol (or chlorocatechol) (0.01 mol) was dissolved in 10 cm^3 of acetone and the solution was refluxed with five grams of K_2CO_3 for 5 min, 4 cm^3 of iodomethane added dropwise and the mixture stirred at 60 °C for 5 hours. Water (15 cm^3) was added and the mixture was extracted twice with 10 cm^3 of diethyl ether. After washing twice with 0.1 M NaOH solution and then with distilled water the combined ether extracts were evaporated to dryness. The residue was used for mass spectrometric experiments. The same procedure with acetone-d_6 and iodomethane-d_3 was applied for the preparation of deuteriated veratroles.

The spectra were recorded on a Varian MAT-212 mass spectrometer using the following operating conditions: ion accelerating voltage, 3 kV, trap current 100 μA; ionizing energy, 70 eV and ion source temperature, ~220 °C. The spectra were recorded by the GC/MS technique with an SE-30 quartz capillary column (25 m × 0.22 mm i.d.) under operating conditions shown in Ref. 24. The first field free region (1st FFR) metastable ions were obtained by linked scans using the direct insertion technique and a Varian Metascan unit. All mass spectral data were acquired and processed on a Spectro System MAT-188.

RESULTS AND DISCUSSION

The mass spectra of the following compounds were investigated: veratrole (**1**), 3-chloroveratrole (**2**),

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Table 1. The most characteristic peaks in the 70 eV mass spectra of veratrole and chloroveratroles, *m/z* (relative abundance, %). Ions containing ^{37}Cl are not shown

Fragment ion	Compound 1	2	3	4	5	6	7	8	9	10
$[M]^{+\cdot}$	138 (100)	172 (100)	172 (100)	206 (100)	206 (86)	206 (100)	206 (100)	240 (92)	240 (100)	274 (75)
$[M-15]^+$	123 (31)	157 (73)	157 (72)	191 (80)	191 (100)	191 (76)	191 (70)	225 (100)	225 (89)	259 (79)[a]
$[M-43]^+$	95 (23)	129 (19)	129 (26)	163 (19)	163 (23)	163 (13)	163 (22)	197 (23)	197 (13)	231 (20)
$[M-46]^{+\cdot}$	92 (2)	126 (2)	126 (2)	160 (5)	160 (3)	160 (4)	160 (4)	194 (–)	194 (2)	228 (–)
$[M-58]^{+\cdot}$	80 (2)	114 (12)	114 (6)	148 (20)	148 (12)	148 (31)	148 (5)	182 (19)	182 (25)	216 (33)
$[M-61]^+$	77 (11)	111 (8)	111 (7)	145 (8)	145 (6)	145 (5)	145 (12)	179 (4)	179 (4)	213 (–)
$[M-65]^+$	—	107 (2)	107 (1)	141 (5)	141 (5)	141 (8)	141 (2)	175 (2)	175 (6)	209 (–)
$[M-71]^+$	67 (2)	101 (3)	101 (5)	135 (2)	135 (1)	135 (4)	135 (4)	169 (6)	169 (4)	203 (–)
$[M-73]^+$	65 (2)	99 (8)	99 (11)	133 (8)	133 (9)	133 (7)	133 (10)	167 (6)	167 (5)	201 (4)
$[M-78]^{+\cdot}$	—	94 (21)	94 (29)	128 (57)	128 (43)	128 (51)	128 (54)	162 (65)	162 (48)	196 (40)
$[M-79]^+$	—	93 (37)	93 (46)	127 (38)	127 (32)	127 (35)	127 (32)	161 (24)	161 (19)	195 (14)
$[M-86]^{+\cdot}$	52 (1)	86 (6)	86 (6)	120 (5)	120 (9)	120 (9)	120 (5)	154 (5)	154 (6)	188 (5)
$[M-93]^+$	—	79 (12)	79 (22)	113 (31)	113 (14)	113 (16)	113 (22)	147 (30)	147 (16)	181 (14)
$[M-95]^+$	—	77 (5)	77 (5)	111 (7)	111 (5)	111 (7)	111 (4)	145 (4)	145 (5)	179 (2)
$[M-97]^+$	—	75 (7)	75 (10)	109 (7)	109 (6)	109 (6)	109 (6)	143 (3)	143 (4)	177 (–)
$[M-106]^{+\cdot}$	—	66 (2)	66 (4)	100 (4)	100 (4)	100 (3)	100 (4)	134 (–)	134 (1)	168 (–)
$[M-107]^+$	—	65 (19)	65 (37)	99 (31)	99 (24)	99 (24)	99 (32)	133 (32)	133 (21)	167 (19)
$[M-109]^+$	—	63 (8)	63 (15)	97 (14)	97 (11)	97 (11)	97 (13)	131 (12)	131 (8)	165 (8)
$[M-119]^+$	—	53 (3)	53 (3)	87 (2)	87 (2)	87 (2)	87 (2)	121 (3)	121 (5)	155 (–)
$[M-121]^+$	—	51 (12)	51 (18)	85 (19)	85 (14)	85 (17)	85 (11)	119 (15)	119 (13)	153 (14)
$[M-122]^{+\cdot}$	—	50 (4)	50 (8)	84 (5)	84 (3)	84 (4)	84 (3)	118 (1)	118 (1)	152 (–)
$[M-131]^+$	—	—	—	75 (8)	75 (6)	75 (9)	75 (6)	109 (7)	109 (8)	143 (5)
$[M-143]^+$	—	—	—	63 (6)	63 (8)	63 (6)	63 (12)	97 (5)	97 (5)	131 (4)
$[M-144]^{+\cdot}$	—	—	—	62 (8)	62 (7)	62 (7)	62 (8)	96 (10)	96 (6)	130 (7)
$[M-156]^{+\cdot}$	—	—	—	50 (13)	50 (11)	50 (11)	50 (15)	84 (23)	84 (11)	118 (16)
$[M-163]^+$	—	—	—	43 (1)	43 (1)	43 (2)	43 (2)	77 (12)	77 (7)	111 (15)
$[M-179]^+$	—	—	—	—	—	—	—	61 (8)	61 (5)	95 (8)
$[M-187]^+$	—	—	—	—	—	—	—	53 (3)	53 (4)	87 (9)
$[M-189]^+$	—	—	—	—	—	—	—	51 (1)	51 (1)	85 (8)

[a] Base peak at *m/z* 261 containing one ^{37}Cl atom.

4-chloroveratrole (**3**), 3,4-dichloroveratrole (**4**), 3,5-dichloroveratrole (**5**), 3,6-dichloroveratrole (**6**), 4,5-dichloroveratrole (**7**), 3,4,5-trichloroveratrole (**8**), 3,4,6-trichloroveratrole (**9**) and tetrachloroveratrole (**10**) and the corresponding hexadeuterio homologues, viz. 1,2-dimethoxy-d_3-chlorobenzenes.

The most characteristic fragment ions in the electron impact mass spectra of compounds (**1**–**10**) are presented in Table 1. Figure 1 illustrates the spectra of **2** and **3** and their deuterated homologues **2′** and **3′**. The fragmentation pathways of **2** based on the metastable ions are shown in Scheme 1.

As shown previously with chlorinated guaiacols[21] and catechols,[22] the molecular ion peak of veratroles is also intense, even the base peak, except for **5** and **8** (Table 1). The metastable ion analysis, as presented for **2** in Scheme 1, showed only one primary fragmentation reaction, viz. the loss of a methyl radical. Other primary fragmentations, e.g. the losses of $CH_3O^{\cdot}$ or $Cl^{\cdot}$ could not be detected with linked scans, the fragmentations occurring to some extent in the ion source, however (Fig. 1). The $[M-CH_3]^+$ ion *b* is very stable due to its quinonoid structure (Scheme 2), the fragmentation giving an intense peak with all chloroveratroles (base peak in **5** and **8**) as is evident in Table 1 and Fig. 1.

The secondary fragmentations from the $[M-CH_3]^+$ ion follow two routes, viz. the elimination of carbon monoxide (84%) and formyl chloride (16%), with the relative intensities of the metastable peaks in the case of **2** (Scheme 1) given in parentheses. It has been previously proved[17] that veratrole loses CO via a route leading to the formation of a protonated phenol ion and it seems evident that with chloroveratroles the ion formed would be a protonated chlorophenol ion *f* as presented in Scheme 2. This ion fragments by several pathways, namely with the losses of $CH_3^{\cdot}$, H_2O, CO, $HCOH$, $Cl^{\cdot}$, HCl and HCOCl (Scheme 1). The elimination of HCl seems to be the most prominent with all isomers, but the structural isomers are, however, undifferentiated based on this fragmentation. Figure 1 shows that with deuterated monochloroveratroles **2′** and **3′** the corresponding ion *f* losses both HCl and DCl, the loss of the latter being more favourable, however.

The peaks formed by the losses of a methyl radical and a water molecule from ion *f* seem to be the most characteristic for distinguishing the positional isomers by means of their EI mass spectra (Fig. 1). With all isomers having the chlorine substituent(s) adjacent to the methoxyl group(s), i.e. in compounds **2**, **4**, **5**, **6**, **8**, **9** and **10**, the $[M-CH_3-CO-CH_3]^+$ peak is more intense than the $[M-CH_3-CO-H_2O]^+$ peak. This $[M-58]^{+\cdot}/[M-61]^+$ ratio is maximal with the *o,o′*-isomers (**6**, **9** and **10**). Veratrole, **3** and **7**, i.e. the compounds without an *o*-chlorine atom, show the higher $[M-61]^+$ peaks in their spectra as is evident in Table 1. The greatest disparity between the intensities of the peaks are shown with **7** (excluding veratrole). Similar trends are shown in the spectra of **2′** and **3′**, where the

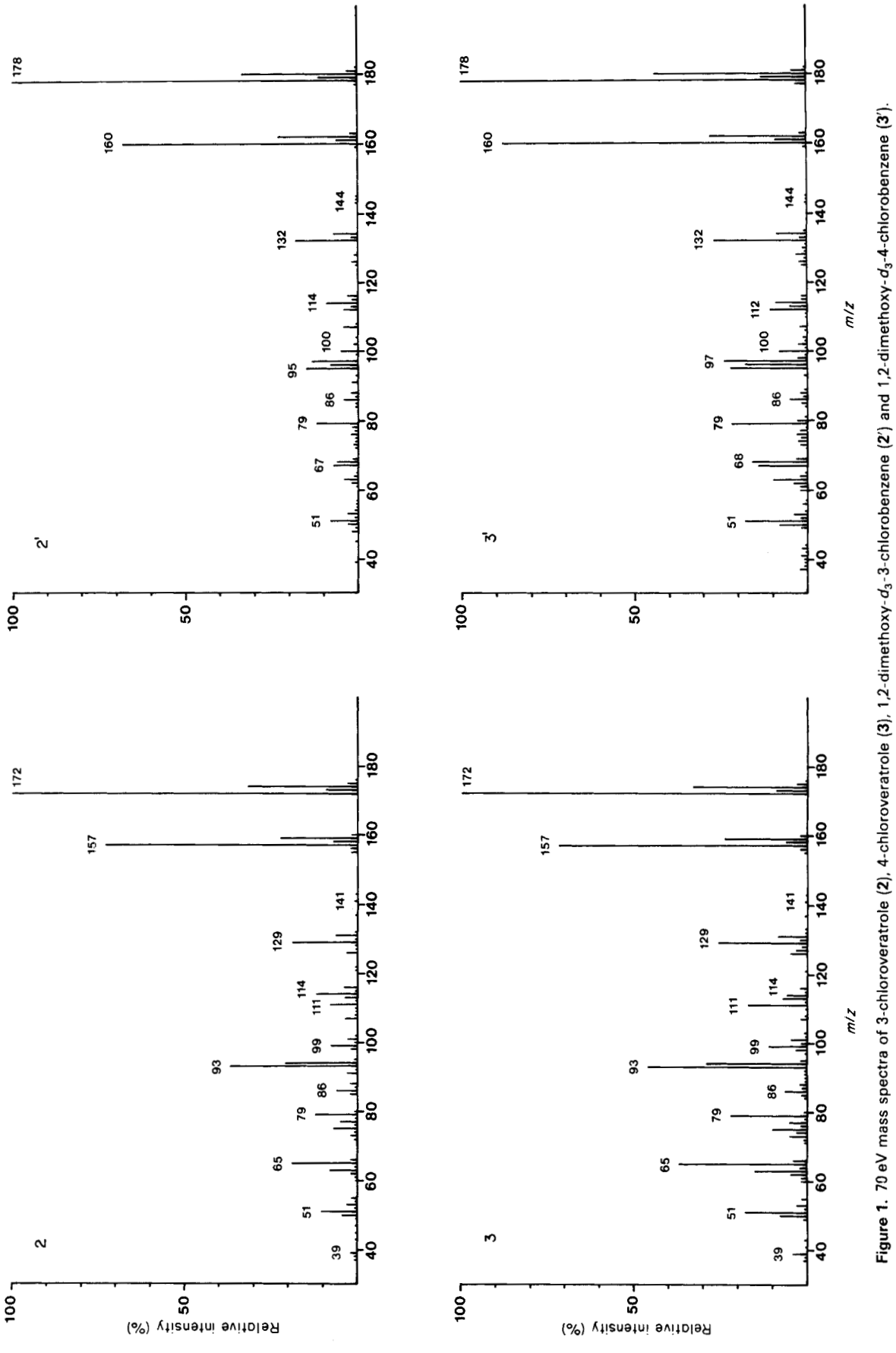
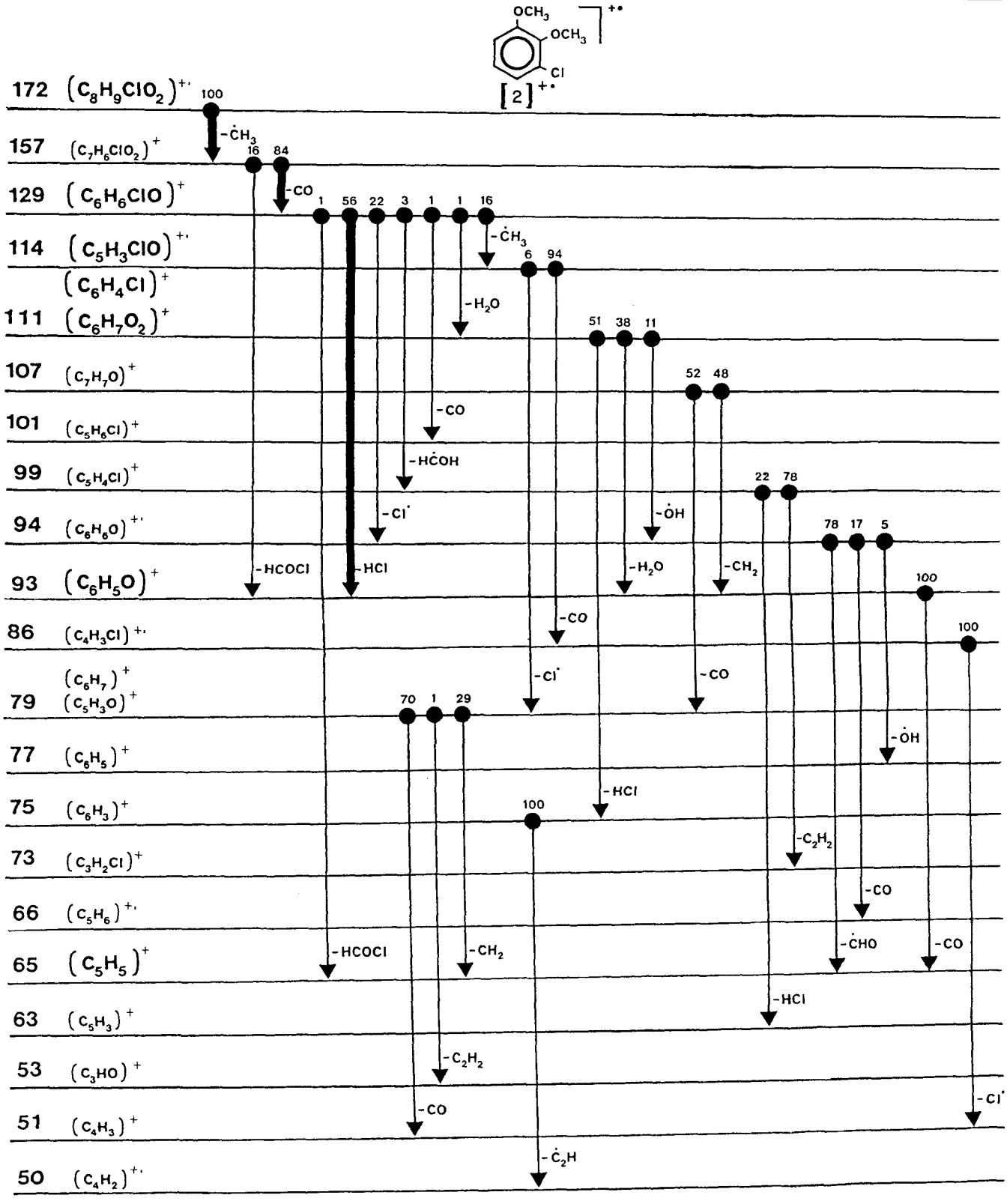
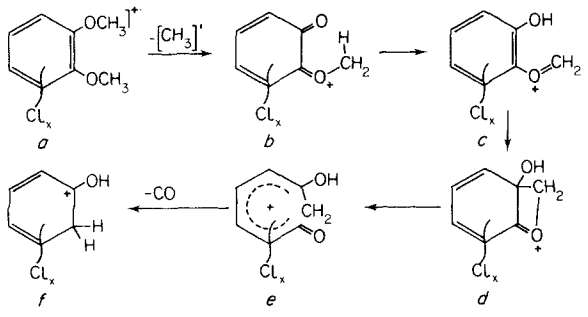


Figure 1. 70 eV mass spectra of 3-chloroveratrole (**2**), 4-chloroveratrole (**3**), 1,2-dimethoxy-d_3-3-chlorobenzene (**2'**) and 1,2-dimethoxy-d_3-4-chlorobenzene (**3'**).



Scheme 1. The fragmentation pathways of 3-chloroveratrole (**2**) based on the 1st FFR metastable ions. The numbers indicate the relative intensities (% of the sum) of the peaks obtained from the mother ion with linked scan.



Scheme 2

losses of $\dot{C}D_3$ (m/z 114), H_2O (m/z 114), HDO (m/z 113) and D_2O (m/z 112) are evident. The losses of $\dot{C}H_2D$ or $\dot{C}HD_2$ are not shown, the results being in accord with those reported earlier with veratrole.[17] A change in the ratio mentioned above as compared with that in **2** and **3** is due to two different fragment ions at the same m/z value 114 (Fig. 1).

The additional secondary fragmentations of **2** and generally also of the other isomers follow the routes shown in Scheme 1. With increasing chlorination of the compounds, the additional losses of $\dot{C}l$ and HCl are self-evident (Table 1), occurring with the positional isomers in the same manner, however, giving no new information for the distinguishing of the compounds as presented above.

CONCLUSIONS

The present data show that the chlorine atom(s) adjacent to the methoxyl group(s) hinder the elimination of H_2O but promote the loss of $\dot{C}H_3$ from the $[M-CH_3-CO]^+$ ion. Without the partially deuterated chloro isomers, i.e. 1-methoxy-2-methoxy-d_3-chlorobenzenes it is impossible to state which methyl radical with respect to the Cl ring substituent(s) is primarily lost, or the accurate structures of the fragment ions formed presented in Scheme 2. Thus, a further study with the related isomers would be of interest.

From its practical point of view, the differentiating of trace amounts of chloroveratroles e.g. in complex environmental samples without model compounds may be difficult due to their similar electron impact mass spectra. However, our previous gas chromatographic studies[24] with chlorinated veratroles show that all isomers can be separated on a low-polarity SE-30 capillary column, the compounds having similar mass spectra may be identified from their elution order and the retention indices reported. The retention data are also shown on a highly polar OV-351 capillary column, but the use of this phase is not recommended due to its low thermal stability and the overlapping of the peaks of **8** and **10**. However, our final conclusion is that pure authentic reference chloroveratrole model compounds must be available for unambiguous qualitative and quantitative GC and GC/MS analysis of trace amounts of chloroveratroles in complex environmental samples.

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