Tetrahedron, 1964, Vol. 20, pp. 1185 to 1209. Pergamon Press Ltd. Printed in Northern Ireland

MASS SPECTRA AND ORGANIC ANALYSIS—II

MASS SPECTRA OF AROMATIC ETHERS IN WHICH THE OXYGEN FORMS PART OF A RING[1]

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(*Received* 1 *January* 1964)

Abstract—The mass spectra of a number of phenyl ethers in which the oxygen atom forms part of a heterocyclic ring have been measured. There is a strong tendency for stable aromatic heterocyclic ions to be formed without ring fission, although other fragmentation processes occur in the reduced compounds, these frequently involving ring fission and subsequent recyclization. Evidence for the existence of the dehydrotropylium and dehydrobenzene ions is presented. It is suggested that ions that are stabilized by the operation of the so-called "*ortho*-effect" are generally cyclic, and derivatives of one of these ions, the dioxymethylene ions of mass 122, have been examined.

Résumé—Les spectres de masse d'un certain nombre d'éthers aromatiques ont été mesurés; dans ces composés, l'oxygène est situé dans un anneau hétérocyclique. Il y a une forte tendance à la formation d'ions hétéroaromatiques stables, quoique d'autres voies de fragmentation existent dans le cas des composés hydrogénés, lesquelles comportent souvent scission d'un anneau suivie de recyclisation. Des témoignages sont présentés pour soutenir l'existence d'ions de déhydrotropylium et de déhydrobenzène. Nous suggérons que les ions qui sont stabilisés par suite de l'effet appelé "l'effet ortho" sont généralement cycliques, et des dérivés d'un de ceux-ci, l'ion de dioxyméthylène de masse 122, ont été examinés.

IN VIEW of the renewed interest shown in the mass spectra of aromatic ethers,[2,3] we should like to present the results we have obtained over the past two years in connection with some heterocyclic oxygen compounds. We shall first discuss the behaviour of heterocyclics that readily give rise to stable heterocyclic ions without ring fission, before passing to the reduced heterocyclics where ring fission may also occur. We have also found a number of interesting new types of fragmentation patterns occurring in cases where the more "normal" paths have been blocked. Finally we have examined a number of methylenedioxy compounds where there is little tendency for the heterocyclic part of the molecule to be changed at all. In the course of the discussion we shall have occasion to refer frequently to the well-known "*ortho*-effect",[4–7] in connection with which we shall refer to our own work on acyclic aromatic ethers in so far as this concerns observations that have not already been published by other workers.

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[1] Part I of our mass spectroscopic studies may be considered as B. Willhalm, A. F. Thomas, M. Stoll and E. G. E. Hawkins, *Helv. Chim. Acta* **46**, 2098 (1963).

[2] C. S. Barnes and J. L. Occolowitz, *Austral. J. Chem.* **16**, 219 (1963).

[3] Z. Pelah, J. M. Wilson, M. Ohashi, H. Budzikiewicz and C. Djerassi, *Tetrahedron* **19**, 2233 (1963).

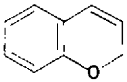
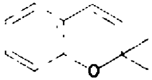
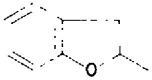
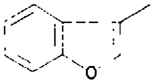
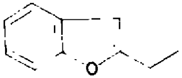
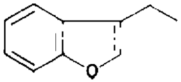
[4] G. Spiteller, *Monatsh.* **92**, 1142, 1147 (1961).

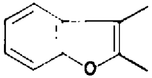
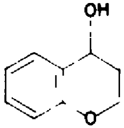
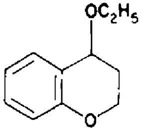
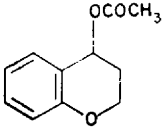
[5] F. W. McLafferty and R. S. Gohlke, *Analyt. Chem.* **31**, 2076 (1959); F. W. McLafferty, *Ibid.* **31**, 83 (1959); E. M. Emery, *Ibid.* **32**, 1495 (1960).

[6] K. Biemann, *Mass Spectrometry, Organic Chemical Applications* pp. 113–115. McGraw-Hill (1962).

[7] H. E. Lumpkin and D. E. Nicholson, *Analyt. Chem.* **32**, 74 (1960).

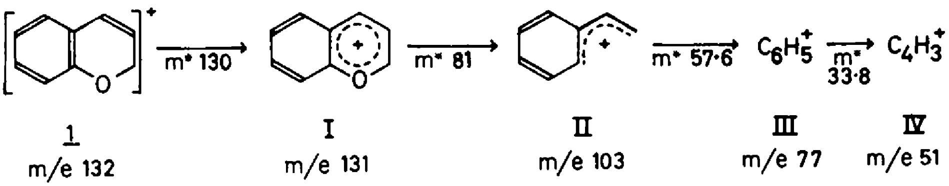
TABLE 1

	Formula	m/e 160	150	149	146	145	133	132	131	115	104	103	91	78	77	51	Other fragments
1								48	100	—	1	8	—	6	12	14	66:2·8% 65·5:1·7%
2		13	—	—	11	100	—	—	—	7·4	—	—	4.1	—	—	—	144:2·3% 127:1·5% 72·5:3·2%
3								79	100	—	3	10	—	5·5	11	14	66:5·5% 65·5:2·3%
4								94	100	—	6·2	18	—	9	16	17	66:6·2%
5					39	6·2	—	10	100	5·7	—	3·2	2·4	—	10	6	65·5:1·6% 89:2·3%
6					45	6·9	—	9·4	100	6·7	—	8·5	—	—	10	—	

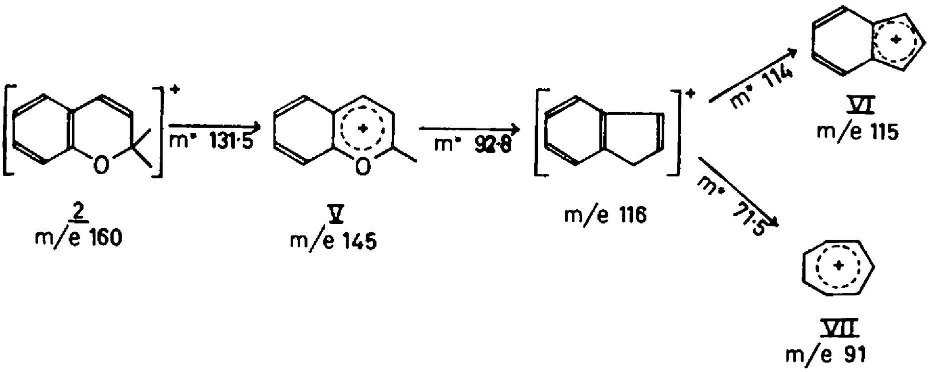
7				100	74	—	10	96	16		7·7	10	2·5	12	13	144:4·1% 127:2·5% 117:6% 89:3·4%
8		100	56	—	—	18	38	85	—	12	13	—	8	30	24	See table 2.
9		9	12	—	—	100	40	68	—	6	12	—	8	32	17	See table 2. (178:59%)
10		18	6	—	—	28	58	100	—	3·6	8	—	—	—	11	See table 2. (192:18%)

The fragmentation undergone by chrom-3-ene (1) is one of the simplest, and is illustrated in Scheme 1,[8] Table 1 giving the relative importance of the fragments in this and similar compounds. It is characterized by the stability of the chromenyl cation (I) which is accompanied by the doubly charged ion at m/e 65·5. Further breakdown of this occurs by loss of carbon monoxide to a fragment of mass 103 (II) which then readily loses acetylene once to the phenyl cation (III) then again to the ion IV. 2,2-Dimethylchrom-3-ene (2, Scheme 2) loses a methyl group to give the methylchromenyl ion (V) which is even more stable than the chromenyl ion (the doubly charged ion at m/e 72·5 from V being nearly double the importance of that at 65·5 from I), and it undergoes fission in many different ways to give a multitude of fragments from m/e 91 to m/e 128, mostly 1 % or less of the base peak (V), though those corresponding to ions of high stability tend to be somewhat more important, such as the indenyl (VI) and tropylium (VII) ions. The methyl- and ethyl-benzofurans (3, 4 and 5, 6) follow the same path as chrom-3-ene, the 3-substituted compounds being the more stable, and probably having the 3-methylenebenzofuranyl ion (VIII) as an alternative structure to the chromenyl ion. 2,3-Dimethylbenzofuran (7) must rearrange to both the chromenyl (I) and 4-methyl-chromenyl ions, loss of CO (28 mass units) from the latter (IX) giving a fragment at m/e 117, which loses 2H to

Scheme 1



Scheme 2



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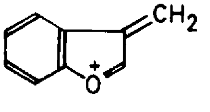
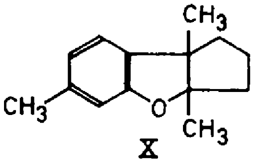
[8] The fragmentation patterns illustrated as "Schemes" have solid arrows to represent transitions confirmed by the existence of a metastable peak, the value of which is shown underneath or alongside the arrow; hypothetical transitions are shown with dotted arrows. In the tables, fragments are quoted as percentages of the most important fragment. Fragments under 1 % are not quoted, and fragments of 1–5 % are not invariably quoted. No correction for isotopes has been made.

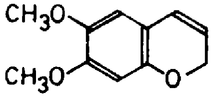
give the stable mass 115 (presumably indenyl, VI). This path (Scheme 3) would appear to be unlikely from any ion where methyl is attached in the α-position to the heteroatom (such as V, for instance). On this basis, we should expect the important fragment at m/e 159 reported in the mass spectrum of aplysinol (X)[9] to be the 4,7-dimethylchromenyl ion which should then follow a path similar to IX. Somewhat similar types of fragmentation have been suggested to account for more complex methoxychromenyl ions[10] though the situation is complicated here by the ready loss of 15 mass units (rather than 1 unit) from the chromene (XI) to the stable quinonoid ion (XII) as Reed and his colleagues suggested and as the work of Barnes and Occolowitz[2] and ourselves supports.



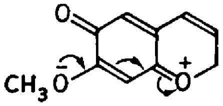
VIII
m/e 131



X

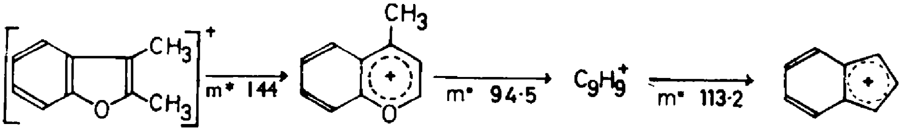


XI
m/e 192



XII
m/e 177

Scheme 3



I
m/e 146

IX
m/e 145

m/e 117

VI
m/e 115

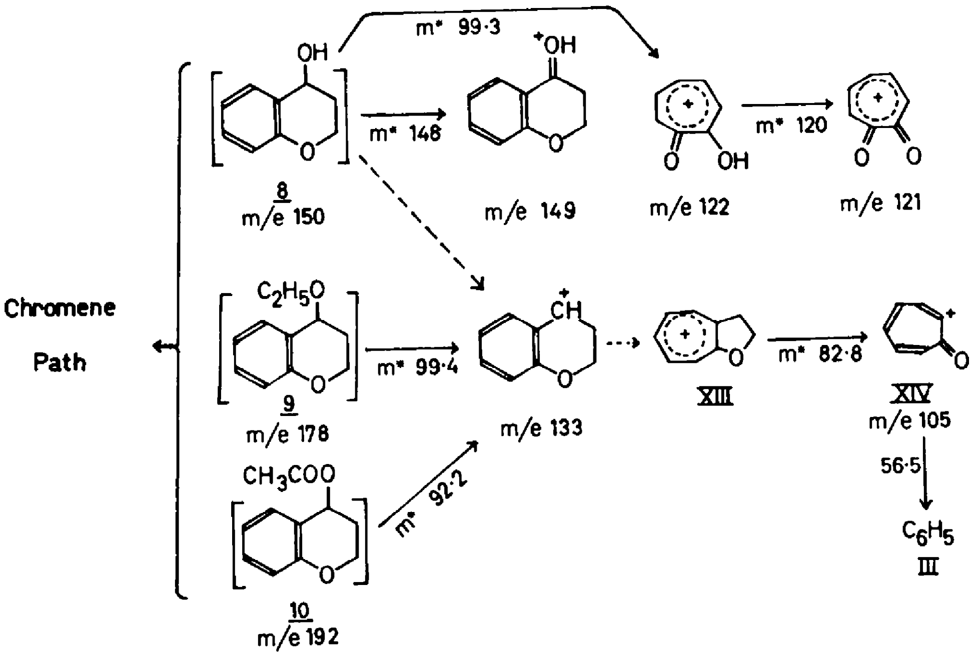
The link between the chromenes and benzofurans and their reduced analogues is provided by the chromans that are oxygenated at C-4, three examples of which are shown in Table 1 and Table 2. The two types of fission are well illustrated by 4-ethoxychroman (9). This ion can lose ethanol to give chromene (1) and thence the important fragment at m/e 131 (I), but it also undergoes the more usual ether fission to give the fragment at m/e 133, which must be of some stability, since it is even observed in the spectrum of 4-acetoxychroman (10). The subsequent fate of this fragment is shown in scheme 4. We have written the fragment in question (XIII) as a tropylium ion, partly by analogy with known ring expansions of benzylium ions, but also because we have good evidence to suppose that in certain other fragmentations (see the methylenedioxy compounds, Table 6 and Scheme 16) the fragment at m/e 105 (XIV) is a troponium ion. It should be noted that the metastable peak at about m/e 99·3 certainly corresponds to the transition of mass 150 → 122 in the spectrum of chroman-4-ol (8), but could also correspond to the transition in the ethyl ether (9) of 178 → 133.

The loss of ethylene from the heterocyclic ring is illustrated in Table 2 (where the chroman-4-ol derivatives have again been listed), and is most marked in the spectra of the chroman-4-ones, where a very simple path is again followed (Scheme 5).

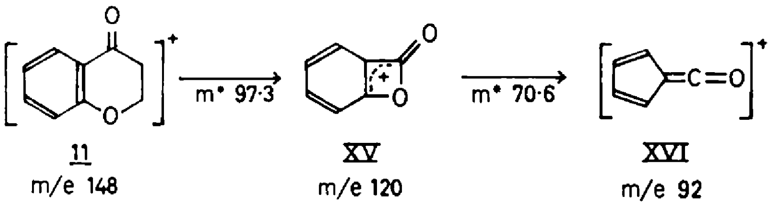
[9] S. Yamamura and Y. Hirata, *Tetrahedron* **19**, 1485 (1963).

[10] R. I. Reed, W. K. Reid and J. M. Wilson, *Advances in Mass Spectrometry* Vol. 2, p. 416. Pergamon Press (1963). Almost throughout this publication, the chromenyl ions are erroneously described as "chromans", though these have quite a different pattern, as we show in the present publication.

Scheme 4



Scheme 5



It is noteworthy that the fragment (XV) at m/e 120 is not dihydrobenzofuran (19) (which could be formed by loss of CO), since this has a different breakdown pattern involving loss of one hydrogen, although a less important path does go through the fragment of mass 92 (Scheme 6).

Scheme 6

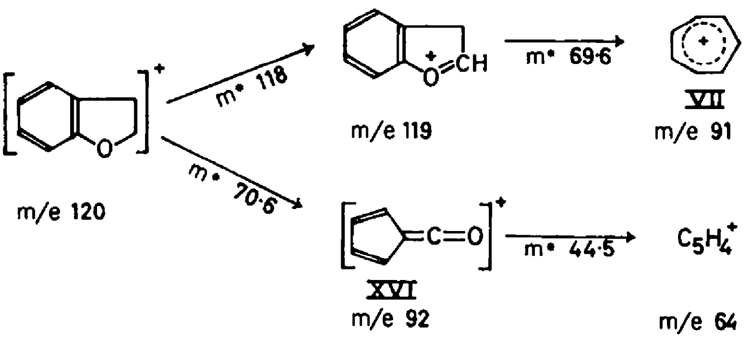


TABLE 2

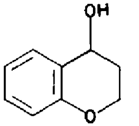
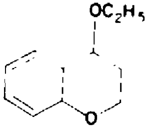
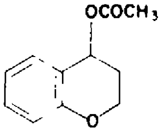
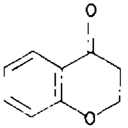
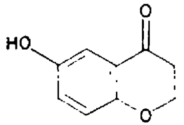
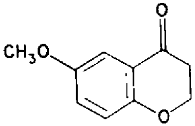
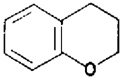
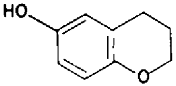
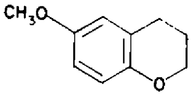
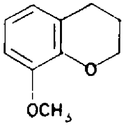
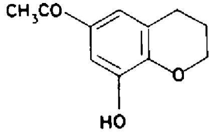
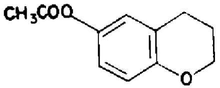
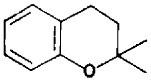
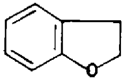
	Formula	164	150	149	136	135	133	122	121	120	119	108	107	105	91	79	78	77	65	53	51	Other fragments
		m/e																				
8			100	56	—	—	18	48	68	—	—	—	16	17	—	—	8	30	—	—	24	See table 1
9			9	12	—	—	100	27	34	—	—	—	18	40	—	—	8	32	—	—	17	See table 1 (178:59%)
10			18	6	—	—	28	4	6	—	—	—	4	22	—	—	—	—	—	—	—	See table 1 (192:18% 71:17% 43:11%)
11					—	—	—	—	9	100	—	—	—	—	2	—	—	1	5	—	—	148:74% 92:53% 64:16% 63:14%
12		95	—	—	100	4	—	—	—	—	—	28	3·5	—	—	5	3·5	—	—	14	9	82:11% 80:22% 52:20%

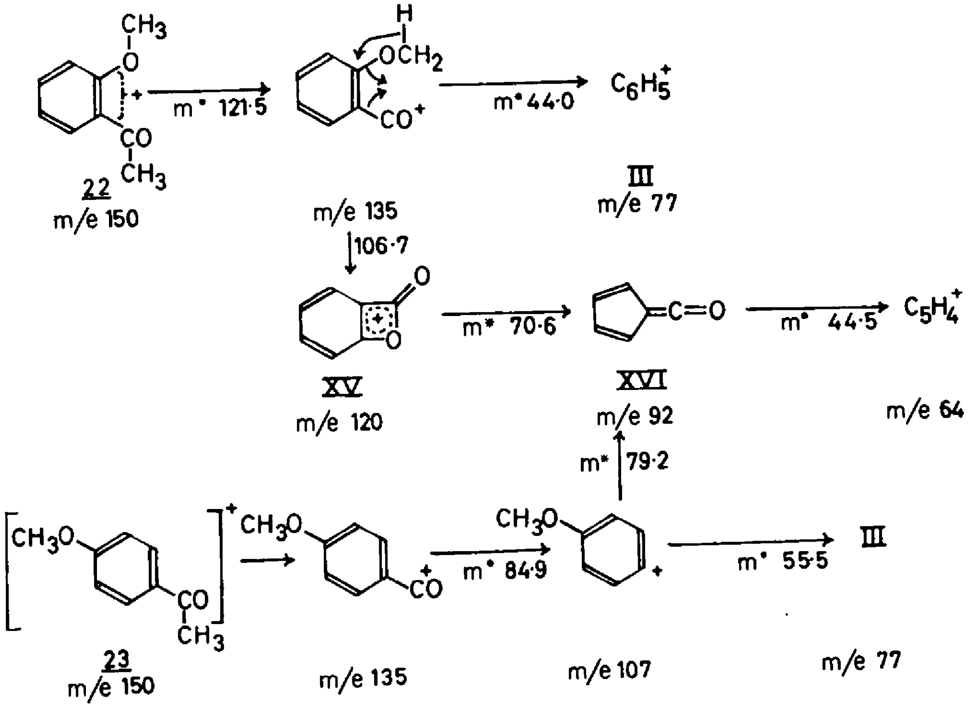
TABLE 2 (*contd.*)

	Formula	m/e 164	150	149	136	135	133	122	121	120	119	108	107	105	91	79	78	77	65	53	51	Other fragments
13		—	89	—	—	24	—	14	—	—	—	—	33	—	3	25	—	—	—	14	11	178:100% 94:6·5%
14							26	—	—	—	22	—	7	11	19	6	33	14	3·5	—	14	134:100% 115:8·5% 106:20%
15			100	6	—	13	4·5	40	4·5	—	—	—	12	—	—	3·5	—	7·5	8	5	5	94:24%
16		100	—	53	31	—	—	—	6·5	—	—	14	6·5	—	7	5·5	7	13	11	—	7	138:17% 123:6·5%
17		100	12	23	16	12	5	4	25	—	—	5	10	7	9	5	6·5	16	16	—	9	131:7% 106:9% 93:7·5%

18			—	19	—	—	—	—	2·5	—	—	—	—	—	4	—	1	7	5	3	4	192:38% 177:100% 103:5% 43:18% 93:6%
19		—	100	4	—	9	2·5	26	—	—	—	—	3·5	3·5	2	—	—	4·5	4	—	—	192:11% 43:20%
20			—	—	—	—	6·7	—	—	—	7·5	9·5	100	1	8·5	3·5	8	10	—	—	—	162:42% 147:38%
21									9	100	26	—	—	—	73	—	—	—	10	—	—	92:16% 90:7·5% 89:10%

Some confirmation of the interpretation of fragment XV at m/e 120 from chromanone (11) was obtained by measurements on the methoxyacetophenones. The values found from the spectra are given in Table 3, from which it is notable that only *o*-methoxyacetophenone possesses a fragment at m/e 120 (albeit small, the main path being direct loss from the fragment at m/e 135 of $C_2H_2O_2$ (glyoxal?) to the phenyl ion (III)[11]). Unless this is a cyclic structure, one would expect the *para*- but not the *meta*-substituted analogue to be roughly equally stabilized (as is the case with the fragment at m/e 135, shown as percent total ionization in the first column of the Table). This is not the case, so we prefer to write the degradation as in Scheme 7.

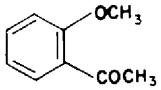
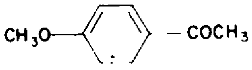
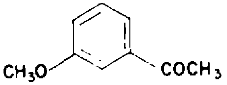
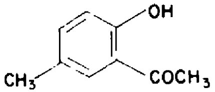
Scheme 7



The loss of a two-carbon fragment such as we have been discussing in connection with the chromanones occurs to some extent in all the reduced heterocyclic ethers we have examined, but is not often the only pathway. Chroman (14), for instance, passes through what is probably the same ion (XVII) as that observed in the spectrum of dihydrobenzofuran (21) (Scheme 8, path A), as well as by loss of C_2 (path B) that occurs both with and without hydrogen transfer to give the fragments at m/e 106 and 107. The latter fragment is presumably the same as the one of this mass observed in the spectrum of the methoxytoluenes[2] and 2-hydroxy-5-methylacetophenone (25, Table 3), and we prefer a tropylium structure for it, in view of the fact that it is formed from 6-hydroxychroman (15) (Scheme 9) via the hydroxydihydrobenzofuran ion

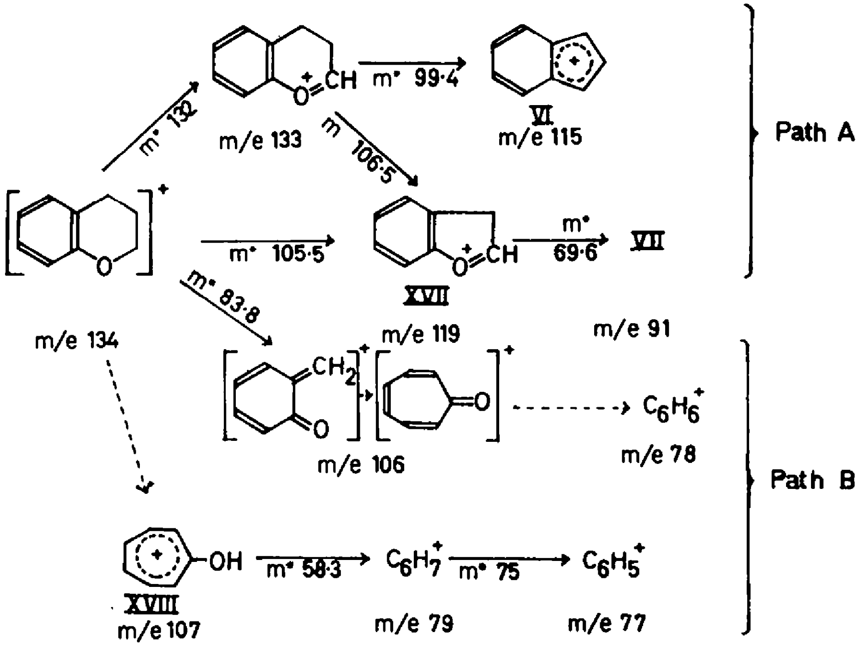
[11] We are somewhat reluctant to ascribe the metastable peak at m/e 44·0 to this transition since it seemed to be insufficiently broad for the loss of such a large group, but it is distinctly separate from the peak at 44·5, and, moreover, disappears from the spectra of *m*- and *p*-methoxyacetophenone.

TABLE 3

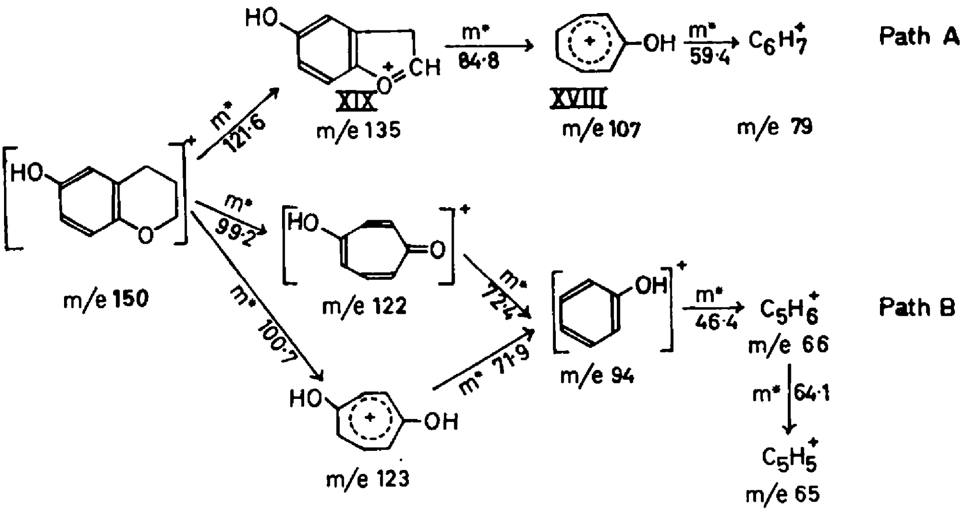
	Formula	Importance of m/e 135	m/e												
		$\frac{135^+}{\sum_{27}}$	150	135	120	107	105	92	79	77	64	63	51	50	43
22		42%	20	100	3·1	—	3·2	13	—	34	5·1	5·3	5·8	3·4	11
23		41%	39	100	—	14	—	17	—	29	8·5	6·2	2·6	3·6	9·4
24		30%	53	100	—	39	—	18	—	32	11	8·7	4·7	5·3	23
25		39%	50	100	—	19	1	—	4·3	15	—	1·9	5·9	1·8	12

(XIX) of mass 135, from which loss of CO will occur more readily from the heterocycle than from the benzene ring; that is to say it corresponds to the path A fission of chroman in Scheme 8. Path B is also followed, leading to the fragments at m/e 122 and 123, though both these lead in turn to phenol, which suffers degradation as has previously been described.[12]

Scheme 8



Scheme 9



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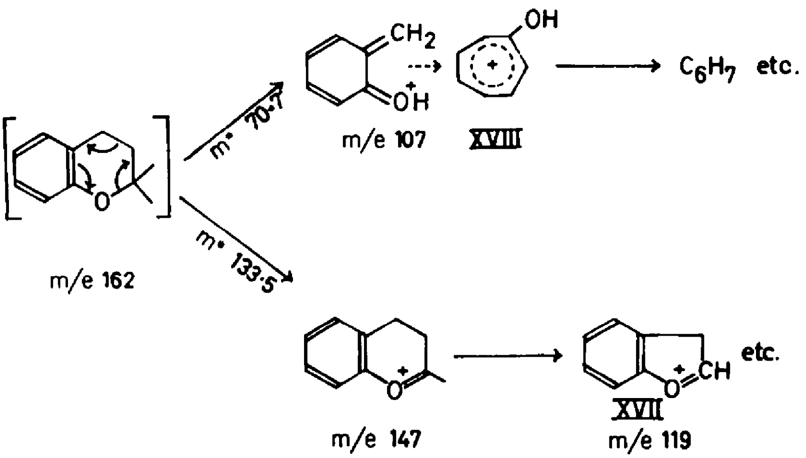
[12] T. Aczel and H. E. Lumpkin, *Analyt. Chem.* 32, 1819 (1960).

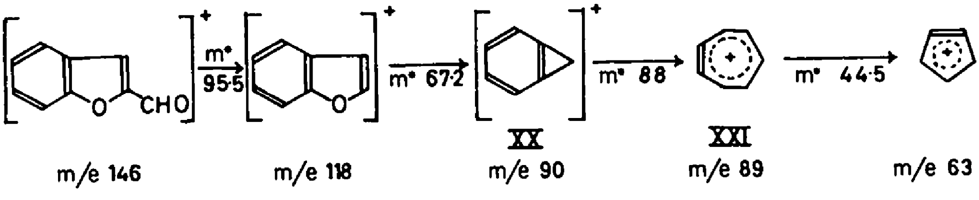
2,2-Dimethylchroman ((20), Scheme 10) is interesting in that it is the aromatic analogue of a dihydropyran we have already mentioned elsewhere,[13] and like the dihydropyran, undergoes the path B fission but only with hydrogen transfer to give the fragment at m/e 107 (XVIII) just discussed.

Scheme 10



Having outlined the fragmentation patterns for those compounds which have more hydrogen than is required for the formation of stable aromatic ions, we now wish to discuss the pattern that we have found to occur in those compounds where insufficient hydrogen is available for these ions. The first compound we observed to possess this type of mass spectrum was 2-formylbenzofuran ((27), Scheme 11) (shown, together with the other compounds we shall mention in this section, in Table 4). Like all aldehydes it has an important fragment at one mass unit less than the parent, but also loses carbon monoxide to yield benzofuran, which again loses carbon monoxide, the product readily losing one hydrogen to a stable ion of mass 89. The exact structure to be allotted to these ions is debateable, but we feel that the cyclic dehydrotropylium structure (XXI) is the most reasonable for the fragment at m/e 89 (and perhaps the cyclopropene, XX, for mass 90), especially in view of its stability as a doubly charged species (m/e 44·5) which might be less strained, there now being no further need to accommodate the extra p-orbitals of the triple bond. The same fragment at m/e 89 is observed in the mass spectrum of 2-acetylbenzofuran ((28), Scheme 12), when it is formed by the unusual loss of C_2O_2 from the fragment(XXII) of mass 145, confirmed by the very prominent broad metastable peak at about m/e 54·6. Since there are few important peaks in this spectrum, this metastable peak can

Scheme 11



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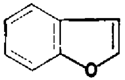
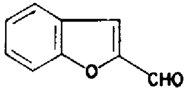
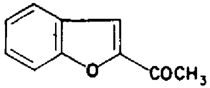
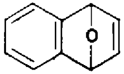
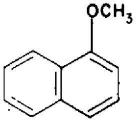
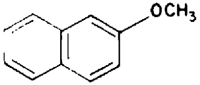
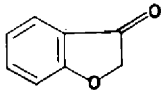
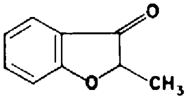
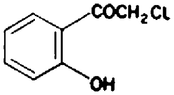
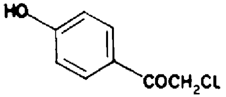
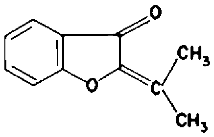
[13] A. F. Thomas and M. Stoll, *Chem. & Ind.* 1491 (1963).

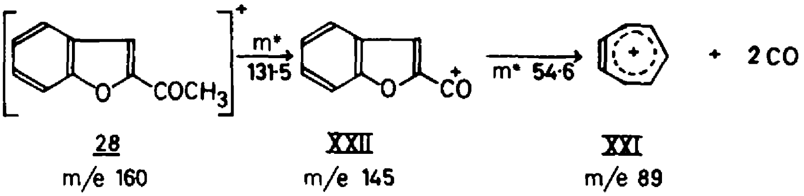
TABLE 4

	Formula	m/e																	Other fragments
		160	158	146	145	144	143	128	127	118	116	115	90	89	79	64	63	62	
26										100	—	—	33	30	—	4·4	16	6·5	105:1·3%
27				100	84	—	—	—	—	6	—	—	12	35	—	3·9	17	8·1	
28		50	—	—	100	—	—	—	—	2·9	—	—	6	34	—	1	13	6	43:13%
29						63	—	5·2	—	18	67	100	4	13	—	—	13	—	
30			100	—	—	4·1	38	4·3	5·3	—	8·9†	80	—	6·4	3·7	—	7·7	2·6	
31			100	—	—	—	6·4	10	4·7	—	7·4	73	—	4·3	2·9		6·5	2·2	

		134	133	121	115	105	104	93	78	77	76	65	63	62	51	50	
<u>32</u>		100	15	—	—	81	26	—	10	31	63	—	6·1	3·5	10	30	
<u>33</u>		—	31	11	—	36	56	2·5	2	13	48	8	10	3·5	6·5	20	148:100% 147:12%
<u>34</u>		100	14	13	—	73	24	2	9·5	29	58	—	—	—	9·5	29	170: < 1%
<u>35</u>		—	—	100	—	—	—	22	—	3	—	18	—	—	—	—	170:5%
<u>36</u>		—	—	14	9	4	—	—	—	9·5	13	—	—	—	—	—	See Fig. 1.

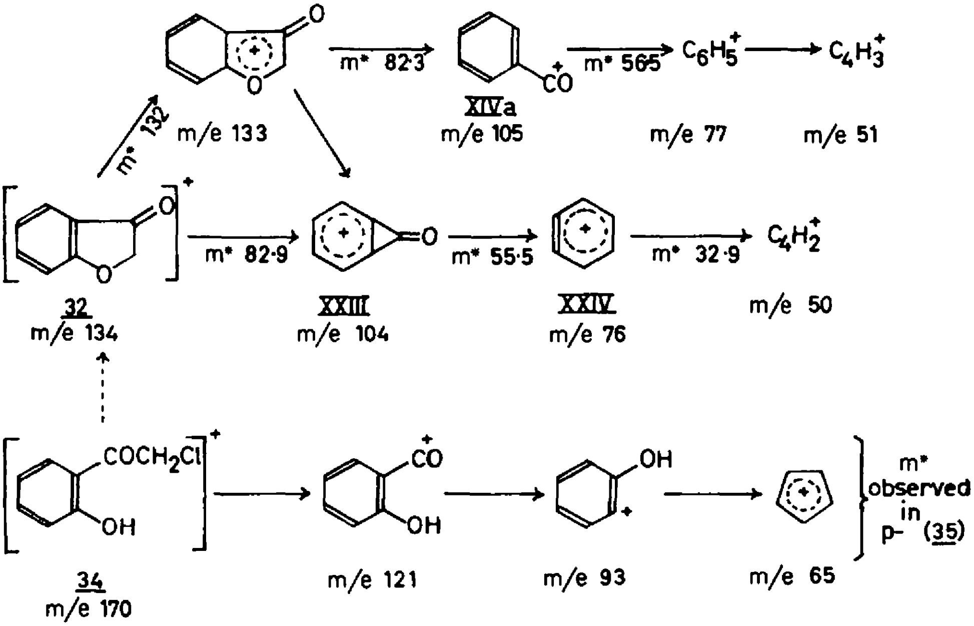
hardly be associated with any other fragmentation. Scheme 12 illustrates the breakdown, the same path being followed by the ion of mass 145 observed in the aldehyde (27) spectrum. The fragment (XXI) is found, though to a somewhat lesser extent, in all the mass spectra we have examined of compounds giving rise to an important indanyl ion (VI) at m/e 115, such as 1,4-dihydro-1,4-epoxynaphthalene and α- and β-naphthol methyl ethers.[14] There is even a trace of this ion quoted by Barnes and Occolowitz[2] in the methoxytoluenes and in a few compounds in Table 1 (especially 2,3-dimethylbenzofuran, 7).

Scheme 12



By placing a carbonyl group in the C-3 position of the benzofuran nucleus (dihydrobenzofuran-3-one, 32), we were able to block this path of degradation, when we found that the main path was by loss of CHO to give a fragment at m/e 105 (XIVa)—which we have not here written as a troponium ion (XIV), since it appears to be more stable than in cases where we suppose XIV to be produced (see Schemes 4 and 16)—this then losing CO to the phenyl ion. Another path is also available, by which formaldehyde is first lost, and the resulting fragment of mass 104 (XXIII) then

Scheme 13



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[14] Our observations on these compounds are quoted in part by Biemann (Ref. 5, p. 140); we take this opportunity to publish fuller data. See also Ref. 3, which appeared after this paper was written.

loses carbon monoxide to give the fragment of m/e 76, that has also been observed in the mass spectrum of phthalic anhydride,[15] and which it is difficult to formulate otherwise than as a dehydrobenzene ion (XXIV).[15a] We have also included in Table 4 one of the most striking "ortho-effects" we have encountered, namely that of 2-hydroxy-ω-chloroacetophenone (34), which breaks down almost entirely by initial loss of HCl to dihydrobenzofuran-3-one (32) despite the normally ready loss

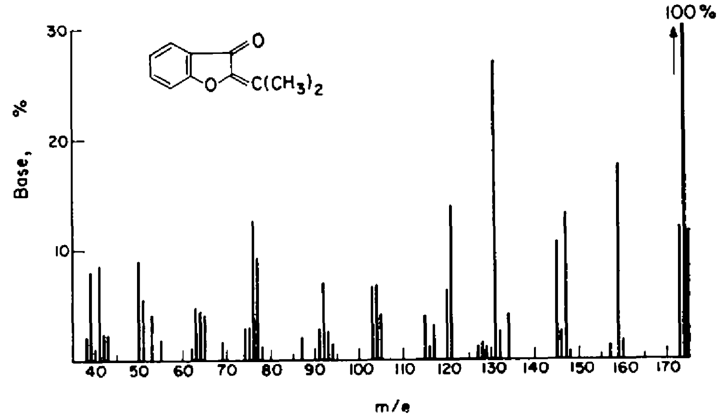
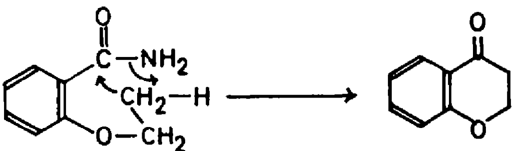


FIG. 1

of the CH_2Cl group.[1] The *para*-substituted isomer (35) undergoes a normal degradation, forming its most important fragment at m/e 121 by loss of CH_2Cl. The latter is definitely not a bicyclic ion, and this fact casts some doubt on the exact formulation of the fragment of the same mass observed in the mass spectrum of chroman-4-ol (8) (Scheme 4), since it is not impossible that these ions are the same.

In the light of Scheme 13, it was not difficult to predict the fragmentation pattern of 2-methyldihydrobenzofuran-3-one (33) which is similar to 32, but different from the pattern that Spiteller found for a fragment, also of mass 148, in the mass spectrum of *o*-ethoxybenzamide.[4] Because of the similarity of the significant fragments observed by Spiteller to those of chromanone (11) we believe cyclization occurred not to a 5-membered, but to a 6-membered ring:



11

2-Isopropylidenedihydrobenzofuran-3-one (36) turned out to have a very complex fragmentation pattern (Fig. 1) following many of the routes we have described, but about which it would be unwise to be precise without using labelled atoms. The most

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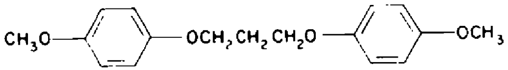
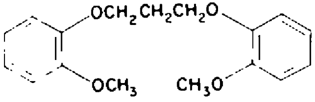
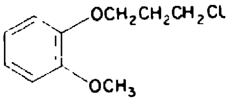
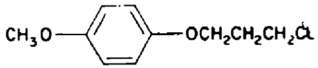
[15] J. H. Beynon, *Mass. Spectrometry* p. 374. Elsevier (1960).

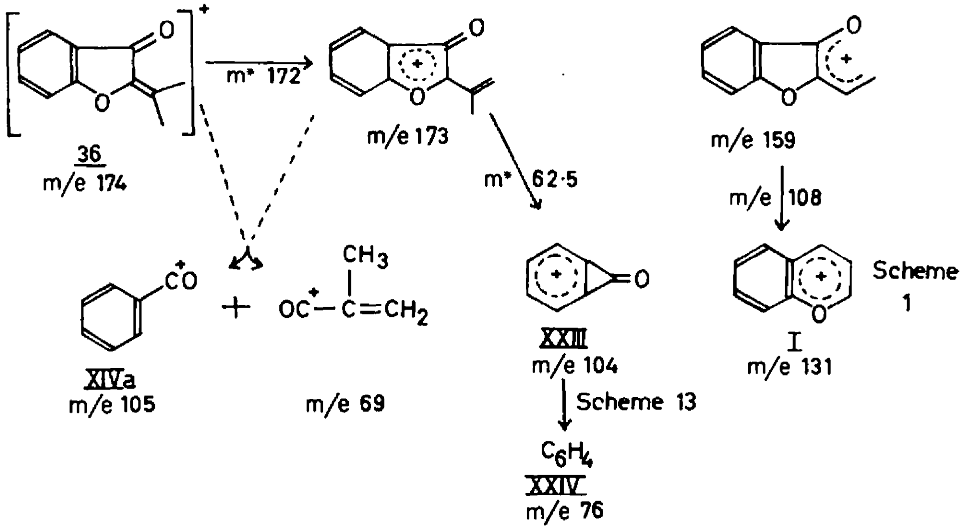
[15a] cf. I. P. Fisher and F. P. Lossing, 11th *Annual Conference on Mass Spectrometry*, Abstracts, p. 29. San Francisco (1963).

TABLE 5

Formula		m/e													
		288	200/202	165	164	137	124	123	122	109	107	95	92	81	77
40		63	—	100	63	80	31	51	—	31	29	—	—	—	0
39		44	—	100	20	55	21	30	36	(m/e	121:	9%)	—	—	
37			33	—	—	—	100	4·5	2	59	—	9	3	13	12
38			40	—	—	—	100	4·0	—	57	1·7	10	3·8	6	6·2

important of these routes appear to be either loss of a hydrogen atom to give an ion that can then follow the dehydrobenzene path (as does dihydrobenzofuran-3-one) or formation of the fragment at m/e 159, followed by loss of carbon monoxide to give the stable chromenyl ion (I). The molecule is an excellent example of the truth of Biemann's statement about the often unexpected behaviour of very stable molecules.[16]

Scheme 14



In order to prepare some of the chromans mentioned above, we required ω-chloropropoxyanisoles. There was nothing very unusual in their fragmentation patterns (which are shown in Table 5), but the by-product isolated during the preparation of the *ortho*-isomer, namely 1,3-di-(*o*-methoxyphenoxy)-propane (39) exhibited an important fragment at m/e 122 arising via mass 137 from the main fragment at m/e 165. (The latter, incidentally, we have written in cyclic form to account for its unexpected stability.) Scheme 15 shows the whole degradation. The point that appeared the most interesting was the fact that the fragment at m/e 137 (XXV) was actually more important in the case of the *para*-isomer than in that of the *ortho*-isomer, although this was not so if the sum of the fragments at m/e 137 and m/e 122 were considered together. This implied that the fragment at m/e 137 was not necessarily cyclic, but that the one at m/e 122 certainly was. It also suggested that the methylenedioxy group might be unusually stable with respect to other phenol ethers, and such indeed has proved to be the case, the *ortho*-effect being "built-in," as it were.

The methylenedioxy compounds we have examined are listed in Table 6. It can be seen that all the compounds able to furnish a methylenedioxytropylium (m/e 135, XXVII) do so with great ease, subsequent loss of formaldehyde leading to what must be the troponium ion (m/e 105, XIV). Owing to the stability of XXVII, the fragment of mass 105 is not easily formed, and we feel that this accounts for the apparent difference in intensity of this fragment between the methylenedioxy compounds and the chroman-4-ol derivatives shown in Scheme 4. In both cases the subsequent

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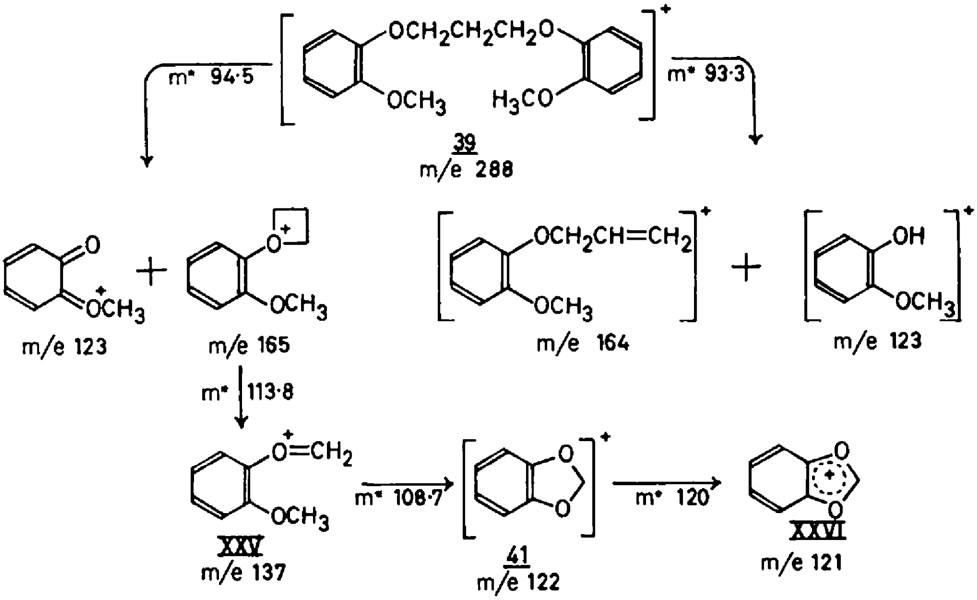
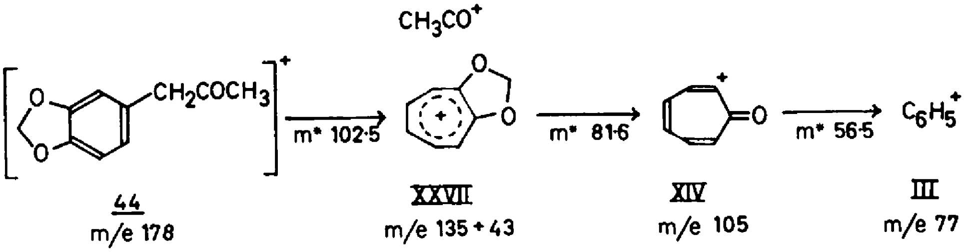
[16] Ref. 5, p. 140.

Scheme 15



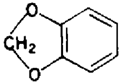
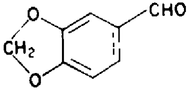
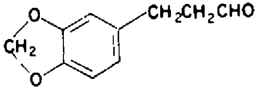
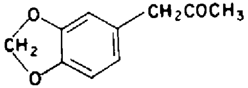
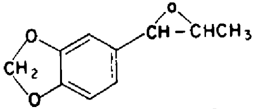
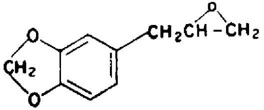
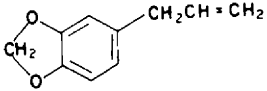
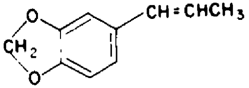
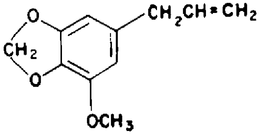
step is loss of CO to the stable phenyl ion (III). A typical path is that of methylene-3,4-dioxyphenylacetone (44) shown in Scheme 16.

Scheme 16

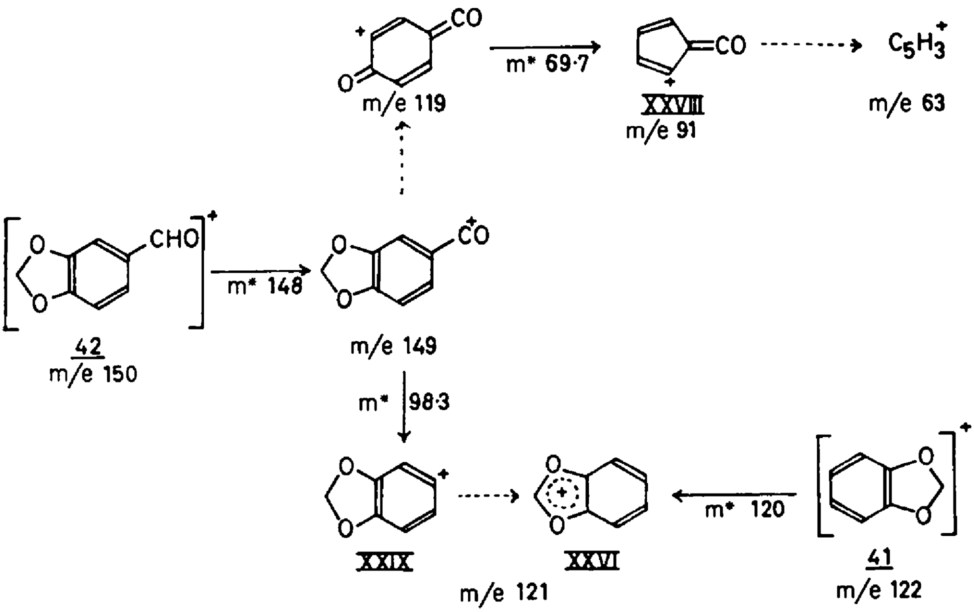


Those molecules in which formation of a tropylium ion (XXVII) is prevented retain their methylenedioxy group to a large extent, as can be seen in the case of piperonal (42), see Scheme 17, which exhibits only small peaks for a fragmentation involving loss of formaldehyde from the methylenedioxy group (at m/e 119 and 91, the latter of which we are strongly tempted to write as XXVIII) but larger peaks associated with its retention (at m/e 149 and 121). The fragment of m/e 121 (XXIX) arises from the fragment at m/e 149, but might rearrange to the ion (XXVI), which, although it must be of considerable stability (as shown by the mass spectrum of methylenedioxybenzene (41) in which it accounts for a third of the total ionization), appears to require a large amount of energy for its formation, loss of a single hydrogen occurring only in cases where no easy C—C cleavage can take place (such as piperonal, for instance). This is confirmed by the unusual importance of the doubly charged fragment at m/e 61, corresponding to the parent ion.

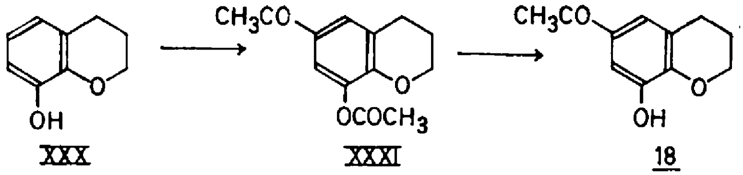
TABLE 6

	Formula	m/e																			Other fragments
		178	162	161	150	149	135	132	131	122	121	119	105	103	91	78	77	65	64	63	
41										73	100	—	—	—	—	—	1·7	9·5	1	24	66:5·5% 61:7·5%
42					87	100	—	—	—	—	27	6·5	—	—	11	—	—	16	—	28	62:11% 61:9%
43		40	—	—	8	—	100	—	—	22	—	—	7·5	—	14	—	23	10	—	—	
44		24	—	—	—	—	100	—	—	—	—	—	7·5	—	—	—	22	—	—	—	
45		27	—	—	—	10	100	—	—	—	—	3	7	—	5	—	21	—	—	—	
46		49	—	—	5	5	100	—	—	14	—	—	8	—	12	—	23	8·5	—	—	148:8% 147:9%
47			100	24	—	—	30	12	33	—	—	2	12	28	6	17	31	—	—	—	104:39%
48			100	26	—	—	15	10	31	—	—	2	8	36	8	17	23	—	—	—	
49		—	2·5	14	—	3	2·5	3	13	—	—	15	2·5	7	23	4	12	15	4·5	7	192:100% 177:4·5% 165·22% 147:10% 133:10% 79:9%

Scheme 17



There are a number of new compounds described above, and in so far as their chemistry is not unusual, they are merely described in the experimental section. The preparation of 6-acetyl-8-hydroxychroman (18) calls for some comment. Acetylation of the phenol (XXX) resulted in concomitant C-acylation. The product was ascribed the 6-acetyl-8-acetoxychroman structure (XXXI) on account of the fact that the two aromatic hydrogens gave signals in the NMR spectrum at 7·38 and 7·51 ppm, and had a coupling constant of about 2 cps. Coupling constants of *ortho* hydrogens are much higher, so the alternative structures (5,8- and 7,8-substituted) are excluded. The acetate of XXX is presumably formed first, this then acylating *para* to the heterocyclic oxygen atom. The unexpectedly ready C-acylation implies that in their preparation of 6-acetyl-7-acetoxychroman, Naylor *et al.*[17] did not need to use such drastic conditions as they describe (aluminium chloride in nitrobenzene).



EXPERIMENTAL

M.ps are corrected. Mass spectra were measured on an "Atlas" mass spectrometer, type CH-4, temp of ion source 260–275°. IR spectra were measured on a Perkin-Elmer model 21 or model 121. Gas chromatography was carried out using the F. and M. model 300, or on apparatus designed and constructed by E. Palluy of Firmenich et Cie.[13,16] NMR spectra were measured on a Varian model A-60 in CCl_4 with tetramethylsilane as internal reference, and UV spectra on an Optica model CF4-NI.

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[17] P. Naylor, G. R. Ramage and F. Schofield, *J. Chem. Soc.* 1190 (1958).

The following compounds were commercially available, and were purified by described methods; their purity was always checked by gas chromatography using one or more of the columns mentioned below: *o*-, *m*-, *p*-methoxyacetophenone (22–24), benzofuran (26), α- and β-naphthol methyl ethers (30 and 31), piperonal (42), safrole and isosafrole (47 and 48). The following were made by methods that have been described:

Formula	Compound	Purification*	Literature
1	Chrom-3-ene	C, A-1	18, 19, 20
2	2,2-Dimethylchrom-3-ene	C, A-2	21
3	2-Methylbenzofuran	A-1, A-2	22
4	2-Ethylbenzofuran	A-4	22, 23
5	3-Methylbenzofuran	A-1	24
6	3-Ethylbenzofuran		
7	2,3-Dimethylbenzofuran	A-3	22
8	Chroman-4-ol	B	20
10	Chroman-4-ol acetate	C	20
11	Chroman-4-one	C	25
13	6-Methoxychroman-4-one	C	26
14	Chroman	C, A-4	18
20	2,2-Dimethylchroman	C, A-2	21, 27
21	Dihydrobenzofuran	A-3	28
25	2-Hydroxy-5-methylacetophenone	B	30
27	2-Formylbenzofuran	A-3	22
28	2-Acetylbenzofuran	B	23
29	1,4-Dihydro-1,4-epoxynaphthalene	Sublimed	31
32	Dihydrobenzofuran-3-one	B	32
33	2-Methyldihydrobenzofuran-3-one	A-1	29
34	2-Hydroxy-ω-chloroacetophenone	steam dist., then B	32, 33
35	4-Hydroxy-ω-chloroacetophenone		

* The key to the purification methods is as follows: A signifies use of gas chromatography, A-1 on a carbowax column, A-2 on an Apiezon column, A-3 on a silicone oil nitrile column (GE XF-1150), A-4 on a silicone oil column. In general, no particular significance should be attached to the use of a particular stationary phase. B signifies recrystallization from hexane or hexane–benzene. C signifies distillation through a spinning band column.

[18] P. Maitte, *Ann. de Chim.* **9**, 431 (1954). The 4-ethoxychroman reported in this publication does not appear to have been pure.

[19] J. N. Chatterjea, *J. Indian Chem. Soc.* **36**, 76 (1959). We found Chatterjea's method to give a low yield of a very pure chrom-3-ene.

[20] W. E. Parham and L. D. Huestis, *J. Amer. Chem. Soc.* **84**, 813 (1962).

[21] L. I. Smith and P. M. Ruoff, *J. Amer. Chem. Soc.* **62**, 145 (1940).

[22] M. Bisagni, N. P. Buu-Hoi and R. Royer, *J. Chem. Soc.* 3689 (1955); Vu Thi Suu, N. P. Buu-Hoi and N. Dat Xuong, *Bull. Soc. Chim.* 1875 (1962).

[23] E. D. Elliott, *J. Amer. Chem. Soc*, **73**, 754 (1951).

[24] R. Stoermer and E. Barthelmes, *Ber. Dtsch. Chem. Ges.* **48**, 62 (1915); K. von Auwers, *Liebigs Ann.* **408**, 273 (1915).

[25] S. G. Powell, *J. Amer. Chem. Soc.* **45**, 2709 (1923).

[26] P. Pfeiffer, H. Oberlin and E. Kornermann, *Ber. Dtsch. Chem. Ges.* **58**, 1953 (1925).

[27] N. Campbell in *Chemistry of Carbon Compounds* (Edited by E. H. Rodd) Vol. IVB, p. 843. Elsevier (1959). The chromene (2) was reduced over Adams' platinum catalyst.

[28] Ref. 27, p. 179.

[29] R. Stoermer and Atenstadt, *Ber. Dtsch. Chem. Ges.* **35**, 3565 (1902).

[30] K. W. Rosenmund and W. Schnurr, *Liebigs Ann.* **460**, 83 (1927).

[31] H. Gilman and R. D. Gersich, *J. Amer. Chem. Soc.* **79**, 2628 (1957).

[32] K. Fries and W. Pfaffendorf, *Ber. Dtsch. Chem. Ges.* **43**, 212 (1910).

[33] F. Kunckell and F. Johannssen, *Ber. Dtsch. Chem. Ges.* **31**, 170 (1898).

Formula	Compound	Purification	Literature
41	Methylenedioxybenzene	A-1	34
43	β-(Methylene-3,4-dioxyphenyl)-propionaldehyde	C	35
44	Methylene-3,4-dioxyphenylacetone	C	36
46	Safrole epoxide	C	35, 36, 37
45	Isosafrole epoxide	C	
49	Myristicine	C	38

4-*Ethoxychroman* (9) was prepared from chroman (14) by the action of N-bromosuccinimide followed by sodium ethoxide in ethanol following the method described by Maitte.[18] Distillation yielded a fraction (b.p. 86–89° at 0·1 mm) still containing bromine. Chromatography in petrol (b.p. 30–50°) on alumina (Woelm, activity III) gave, first, a small fraction containing the impurities, then pure 4-ethoxychroman (purity checked by thin layer chromatography on silica gel, solvent hexane–chloroform 5:1, R_f 0·12). Gas chromatography on a silicone oil column left the compound practically unchanged. n_D^{20} 1·5292, d_4^{20} 1·0812. (Found: C, 73·98; H, 7·85. Calc. for $C_{11}H_{14}O_2$: C, 74·13; H, 7·92%).

1-o-*Methoxyphenoxy-3-chloropropane* (37) was obtained from the reaction of guaiacol with 1-bromo-3-chloropropane in the presence of sodium ethoxide[35] and twice distilled. b.p. 106° at 0·01 mm, n_D^{20} 1·5326, d_4^{20} 1·1578, then chromatographed in benzene on alumina (Woelm, activity I). (Found: C, 59·70; H, 6·44; Cl, 17·42. $C_{10}H_{13}O_2Cl$ requires: C, 59·84; H, 6·53; Cl, 17·58%).

1-p-*Methoxyphenoxy-3-chloropropane* (38) was made in the same way, b.p. 105° at 0·02 mm, n_D^{23} 1·5275, d_4^{23} 1·1580. (Found: C, 59·84; H, 6·80; Cl, 17·90. $C_{10}H_{13}O_2Cl$ requires: C, 59·84; H, 6·53; Cl, 17·58%). During the preparation of these compounds, the residues from the first distillations crystallized to give, respectively,

1,3-*Bis*-o-*methoxyphenoxypropane* (39), recrystallized from ethanol to m.p. 113° (Found: C, 71·06; H, 7·07%) and

1,3-*Bis*-p-*methoxyphenoxypropane* (40), recrystallized from ethanol, m.p. 89° (Found: C, 70·63; H, 6·80. $C_{17}H_{20}O_4$ requires: C, 70·81; H, 6·99%).

Chroman-6-ol (15) *and 6-methoxychroman* (16). 1-*p*-Methoxyphenoxy-3-chloropropane (50 g) and stannic chloride (5 g) were heated together for 6 hr at 160°. The mixture was separated into phenolic and neutral parts with 10% NaOH aq. Acidification of the alkaline solution yielded 22·5 g of a product, that after recrystallization several times from hexane had m.p. 99–100° (chroman-6-ol) (Found: C, 72·11; H, 6·55. $C_9H_{10}O_2$ requires: C, 71·98; H, 6·71%). λ_{max}^{KBr} 3·00 (OH); 6·17 (doublet, C=C), 12·27, 13·44, 13·75, 14·18 μ. The methyl ether was obtained by distillation of the residue (6 g) from the neutral fraction, or by methylation of the phenol with dimethyl sulphate and alkali. b.p. 92° at 0·05 mm, n_D^{23} 1·5471, d_4^{23} 1·114. (Found: C, 73·20; H, 7·50. $C_{11}H_{12}O_2$ requires: C, 73·14; H, 7·37%). $\lambda_{max}^{C_2H_5OH}$ 206, 230 and 294 mμ (ε_{max} 14,180, 6,162 and 3,497).

6-*Acetoxychroman* (19) was made from the phenol (15) and acetic anhydride with a drop H_2SO_4 and recrystallized from pentane, m.p. 51–52°. (Found: C, 68·92; H, 6·31. $C_{11}H_{12}O_3$ requires: C, 69·73; H, 6·29%).

8-*Methoxychroman* (17) was made in the same way as 6-methoxychroman by cyclization of 1-*o*-methoxy-phenoxy-3-chloropropane (37), and purified by chromatography on alumina (activity I). The chloro-compound was eluted first (with pentane–benzene 1:1) but there was considerable tailing resulting in some contamination of the chroman. A second chromatogram gave the pure chroman, b.p. 76° at 0·01 mm n_D^{20} 1·5532 d_4^{20} 1·134 (Found: C, 72·43; H, 7·25. $C_{10}H_{12}O_2$ requires: C, 73·14; H, 7·37%). $\lambda_{max}^{C_2H_5OH}$ 210 and 277 mμ (ε_{max} 15,396 and 1,848), shoulder at 225 mμ.

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[34] B. N. Ghosh, *J. Chem. Soc.* **107,** 1597 (1915); E. Mosettig and L. Jovanovic, *Monatsh.* 53/54, 433 (1929).

[35] cf. S. Gabriel, *Ber. Dtsch. Chem. Ges.* **25,** 416 (1892); Fourneau and Tiffeneau, *C.R. Acad. Sci., Paris,* **141,** 662 (1905).

[36] P. Hoering, *Ber. Dtsch. Chem. Ges.* **38,** 3481 (1905).

[37] The epoxides were prepared from safrole and isosafrole with perbenzoic acid in chloroform.

[38] V. M. Trikojus and D. E. White, *J. Chem. Soc.* 436 (1949).

6-Acetyl-8-hydroxychroman (18). The phenolic part of the previous cyclization, isolated as described for chroman-6-ol (15), did not crystallize. After distillation (b.p. 81–90 at 0·5 mm), the phenol was acetylated without purification, by heating 1 g with 1·5 g acetic anhydride and 3 drops conc. H_2SO_4 for 15 min on the steam bath. After cooling, pouring onto ice and isolation with pentane, *6-acetyl-8-acetoxychroman* crystallized, and was recrystallized from hexane, m.p. 107–108·5° (Found: C, 66·45; H, 5·93. $C_{13}H_{14}O_4$ requires: C, 66·65; H, 6·02%). The mass spectrum was very similar to that of the phenol (18, Table 2) except for the molecular ion (m/e 234, 7% of base) and the fragment at m/e 43 (40% of base).

Hydrolysis of the acetate with methanolic sodium hydroxide (5 min on the steam bath) gave 6-acetyl-8-hydroxychroman (18) which was crystallized from hexane. F 113·5–115° (Found: C, 68·74; H, 6·45. $C_{11}H_{12}O_3$ requires: C, 68·73; H, 6·71%).

2-Isopropylidenedihydrobenzofuran-3-one (36). Dihydrobenzofuran-3-one[22] (32, 1g), acetone (5 g) and $ZnCl_2$ (0·5 g) were heated in ethanol (10 ml) for 2 hr under reflux. The product was precipitated with water and recrystallized from pentane. F 172–174°. (Found: C, 75·71; H, 5·69. $C_{11}H_{10}O_2$ requires: C, 75·84; H, 5·79%).

Acknowledgements—The authors are happy to acknowledge a debt of gratitude to the director of research of Firmenich et Cie, Dr. Max Stoll, for his encouragement, and to Professor K. Biemann for useful suggestions during the preparation of the manuscript.