Mass Spectral Studies of Alkyl Methanesulfonates

WILLIAM E. TRUCE AND LARRY W. CHRISTENSEN[1]

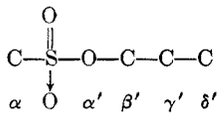
Department of Chemistry, Purdue University, Lafayette, Indiana

Received August 10, 1967

The mass spectral fragmentation patterns of several alkyl, cycloalkyl, and aryl methanesulfonates have been recorded and studied. Deuterium-labeling experiments have been conducted to determine the origin of the hydrogens involved in several interesting rearrangements to sulfonyl oxygen. The mechanistic implications of these data are discussed in terms of the stereochemistry of the transition state and the stability of the product ion formed through rearrangement.

In continuing studies on the mass spectral fragmentation patterns of tetracoordinated sulfur compounds, a series of alkyl methanesulfonates was prepared and examined under mass spectral conditions. It was of interest to determine if rearrangements analogous to those involving the alkane portion of the sulfonate esters would also occur with involvement of the alkyl moiety of the ester.[2]

The mechanisms suggested for the observed rearrangements are supported by deuterium-labeling studies. In discussing the rearrangements and fragmentations of these esters, the position of the atoms will be designated as



An α cleavage will mean cleavage of the C–S bond and an α' cleavage of the S–OR bond, etc. A substituent referred to as an α substituent will be borne on the α carbon. The convention proposed by Budzikiewicz, Djerassi, and Williams[3] for denoting electron shifts will be used. A fishhook (↷) will indicate the movement of a single electron; an arrow (⇝) will denote the movement of an electron pair. Table I indicates the esters that have been studied and will be discussed. Mass spectra are given in Figures 1–7.

TABLE I
CH_3SO_3R

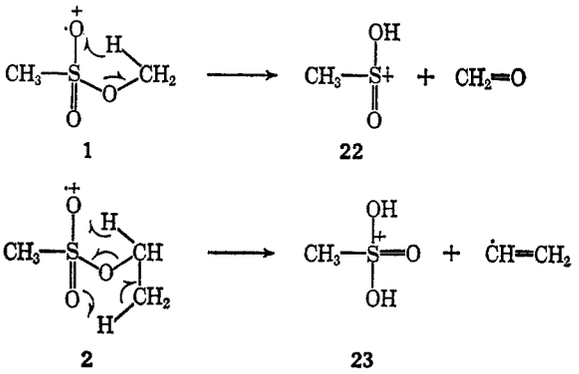
	R	Registry no.	Bp, °C (mm)
1	CH_3	66-27-3	78 (10)
2	CH_2CH_3	62-50-0	78 (7.5)
3	$CH_2CH_2CH_3$	1912-31-8	120 (28)
4	$CH_2(CH_2)_2CH_3$	1912-32-9	96 (4.1)
5	$CH_2(CH_2)_3CH_3$	6968-20-3	93–94 (2.5)
6	$CH_2(CH_2)_4CH_3$	16156-50-6	86 (1.5)
7	$CH_2(CH_2)_5CH_3$	16156-51-7	94–95 (1.0)
8	$CH_2(CH_2)_6CH_3$	16156-52-8	95–96 (0.50)
9	$CH(CH_3)_2$	3409-44-7	54–55 (0.75)
10	$CH_2CH(CH_3)_2$	16156-53-9	63–64 (1.0)
11	$CH(CH_3)CH_2CH_3$	16156-54-0	57–58 (1.0)
12	$CH_2CH_2CH(CH_3)_2$	16156-55-1	60–61 (0.65)
13	Cyclohexyl	16156-56-2	84 (0.77)
14	Cyclopentyl	16156-57-3	70–71 (0.75)
15	CH_2—C≡CH	16156-58-4	67 (1.0)
16	Phenyl	16516-59-5	Mp 59°
17	*o*-Tolyl	1009-01-4	80.5 (0.20)
18	*m*-Tolyl	1077-02-7	84 (0.55)
19	$CD_2CH(CH_3)_2$	16156-60-8	76 (2.6)
20	$CD_2CH_2CH_3$	16156-61-9	76–77 (2.6)
21	$CH_2CD_2CH_3$	16156-62-0	76–77 (2.6)
22	$CH_2CH_2CD_3$	16156-63-1	58–59 (0.60)

(1) L. W. C. thesis contains the complete spectra of those esters not presented here.

(2) W. E. Truce, R. W. Campbell, and G. D. Madding, *J. Org. Chem.*, **32**, 308 (1967).

Results and Discussions

It has been found that, in addition to hydrogen migrations from the alkane portion of methyl alkanesulfonates, hydrogen is also transferred from the alkyl portion of both methyl and ethyl methanesulfonate to the sulfonyl oxygens with simultaneous α' or β' cleavage. Methyl methanesulfonate (**1**) and ethyl methanesulfonate (**2**) give prominent ions at *m/e* 80 (**22**) and *m/e* 97 (**23**), respectively. The following mechanisms were proposed and supported by labeling experiments.



The McLafferty rearrangement to give ion **23** is postulated to go through a 3,2,1-bicyclic transition state. Precedence for this type of transition state can be found in the proposed transfer of two hydrogens in propyl and higher esters of aliphatic and aromatic carboxylic acids.[4] It was of interest to determine if results similar, with regard to site specificity, to those obtained for double hydrogen rearrangement from the alkyl portion of carboxylic acid esters would be obtained for methanesulfonic acid esters. For one of the most characteristic fragmentation processes for carboxylic acid esters, *i.e.*, transfer of two hydrogens from the alkyl portion of the ester with loss of the alkyl residue, it had originally been thought, as a result of work on *sec*-butyl acetate, that β and γ hydrogens were exclusively involved.[5] However, McFadden[6] as well as Benz and Biemann[7] concluded, using deuterium-

(3) H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Mass Spectrometry of Organic Compounds," Holden-Day, Inc., San Francisco, Calif., 1967, p 3.

(4) F. W. McLafferty and T. S. Gohlke, *Anal. Chem.*, **31**, 2076 (1959).

(5) F. W. McLafferty and M. C. Hamming, *Chem. Ind.* (London), 1366 (1958).

(6) D. R. Black, W. H. McFadden, and J. W. Corse, *J. Phys. Chem.*, **68**, 1237 (1964).

(7) W. Benz and K. Biemann, *J. Amer. Chem. Soc.*, **86**, 2375 (1964).

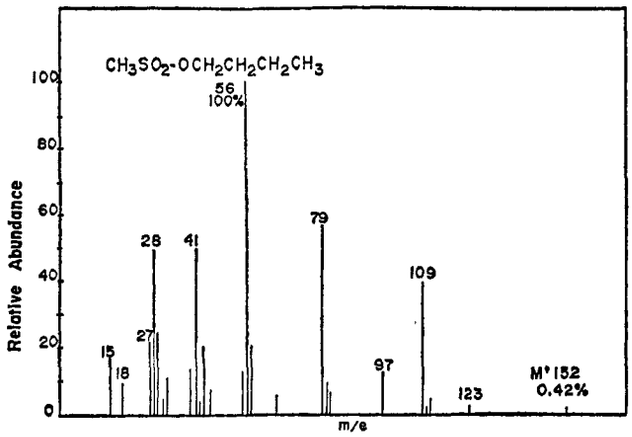


Figure 1.—*n*-Butyl methanesulfonate.

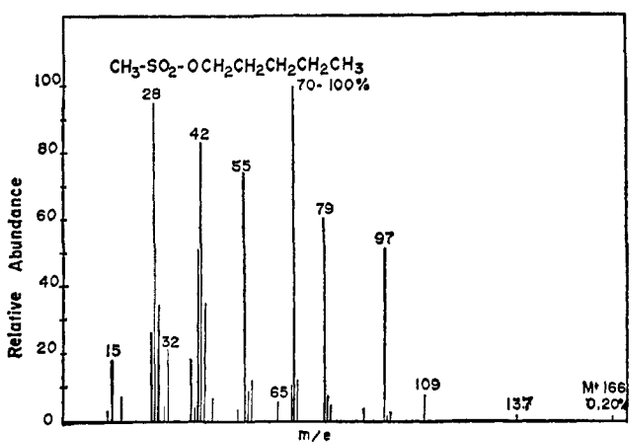


Figure 2.—*n*-Pentyl methanesulfonate.

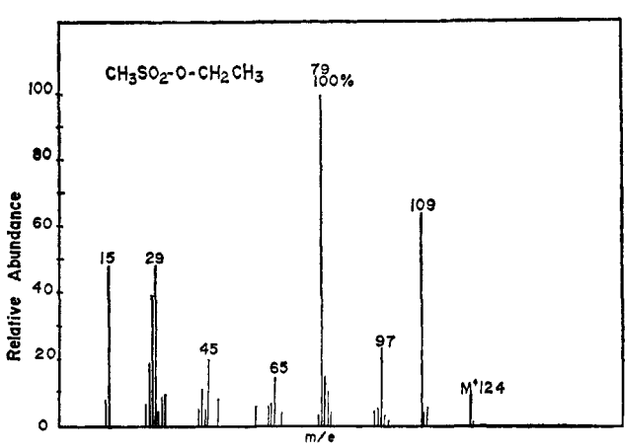
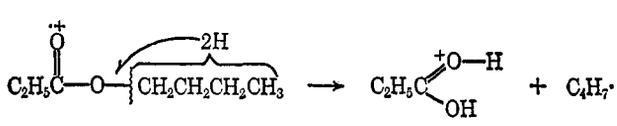


Figure 3.—Ethyl methanesulfonate.

labeled *n*-butyl and *n*-amyl esters, that the first proton in this rearrangement comes specifically from the γ position and the second proton is abstracted in a random manner from the other possible positions. Djerassi and Fenselau have since shown conclusively that the itinerant hydrogens come mostly, but not entirely, from C-2 and C-3 in butylcarboxylic acid esters.[8]



(8) C. Djerassi and C. Fenselau, *J. Amer. Chem. Soc.*, **87**, 5756 (1965).

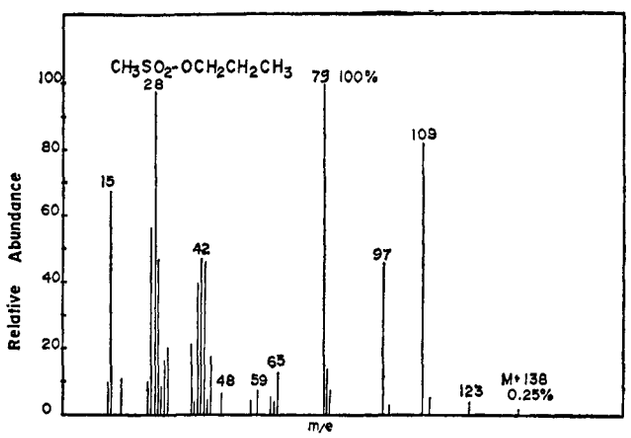


Figure 4.—*n*-Propyl methanesulfonate.

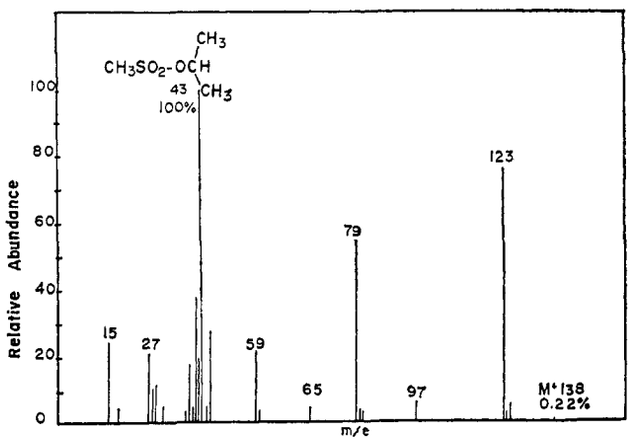


Figure 5.—2-Propyl methanesulfonate.

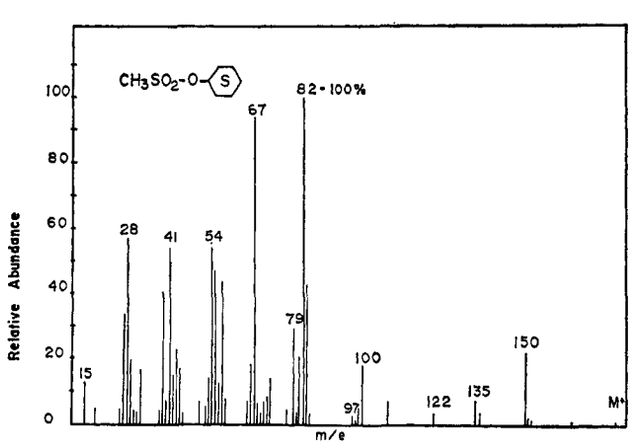


Figure 6.—Cyclohexyl methanesulfonate.

In the present work it was indeed found that all of the unbranched primary alkyl esters (**2**–**8**) gave the double hydrogen rearrangement ion **23**, in relative abundance of 13–53%. Deuterium labeling shows that hydrogens from other than the β' and γ' positions are involved which is similar to the conclusions reached by Djerassi[8] for carboxylic acid esters. The deuterium-labeled compounds (**20**–**22**) indicate that a different mechanism is operative for hydrogen transfer with the propyl ester compared with the ethyl ester since the β' and γ' hydrogens are not exclusively involved in the rearrangement. Indeed, Table II shows that in *n*-propyl methanesulfonate (**3**) the hydrogens involved

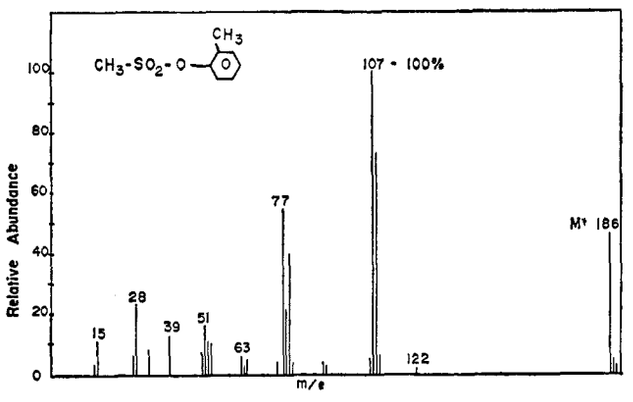


Figure 7.—*o*-Methyl benzene methanesulfonate.

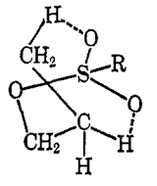
TABLE II

Compound[a]	*m/e* 97	*m/e* 98	*m/e* 99	Σ
$CH_3SO_3CH_2CH_2CH_3$	45.7	1.27	2.72	49.7
$CH_3SO_3CD_2CH_2CH_3$	28.2	19.2	3.78	51.2
$CH_3SO_3CH_2CD_2CH_3$	20.7	27.4	2.79	50.9
$CH_3SO_3CH_2CH_2CD_3$	2.54	42.6	1.73	46.8

[a] Base peak ion (**25**), *m/e* 79.

in the rearrangement to give ion **23** come approximately 38% of the time from the β',δ' carbons, 56% of the time from the γ',δ' carbons, and less than 5% of the time from the β',γ' carbons. The low abundance of the ion at *m/e* 99 eliminates any substantial contribution to ion **23** by way of transfer of two hydrogens from the same carbon. It can be concluded therefore that sulfonic acid esters like carboxylic acid esters do not transfer hydrogen only through five- and six-membered-ring transition states, but substantial contributions are made by hydrogen transfer through seven-membered-ring transition states. Molecular models show that the conformation for the γ',δ'-hydrogen transfer through a 3,2,2-bicyclic transition state is neither badly eclipsed nor strained (Chart I). Hence, it is feasible even though it involves a seven-membered ring which is infrequently found in mass spectral literature.[5,8-10]

CHART I
γ',δ'-HYDROGEN MIGRATION
via 3,2,2-BICYCLIC TRANSITION STATE



A difference, however, should be noted in the behavior of ethylcarboxylic acid esters and ethyl alkanesulfonates. The results of deuterium-labeling experiments for carboxylic ethyl esters show that almost complete scrambling of the ethoxyl hydrogens occurs for both the single and double hydrogen rearrangement.[11,12] However, with ethyl methanesulfonate scrambling was not observed.[2]

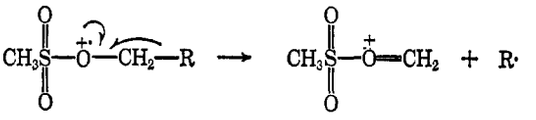
(9) W. H. McFadden, L. E. Boggs, and R. G. Buttery, *J. Phys. Chem.*, **70**, 3516 (1966).
(10) N. C. Rol, *Rev. Trav. Chim.*, **84**, 413 (1965).
(11) A. G. Harrison and E. G. Jones, *Can. J. Chem.*, **43**, 960 (1965).
(12) E. V. Godbole and P. Kebarle, *Trans. Faraday Soc.*, **58**, 1897 (1962).

A comparison of the mass spectra of ethyl methanesulfonate and *n*-propyl methanesulfonate (Figures 3 and 4) indicates a general trend, *i.e.*, as the alkyl group becomes longer in going from **2** to **8**, ion **22** (single hydrogen transfer, α' cleavage) becomes less abundant and ion **23** (double hydrogen transfer, β' cleavage) becomes more abundant.

s-Alkyl methanesulfonates (**9**, **11**) do not show abundant ions (<6%) at either *m/e* 80 (**22**) or *m/e* 97 (**23**) (Figure 5). Presumably β' cleavage to form the secondary carbonium ion becomes more favorable than any process involving hydrogen transfer. Indeed, *m/e* 43 from β' cleavage is the base peak (R.A. = 100) for isopropyl methanesulfonate (**9**).

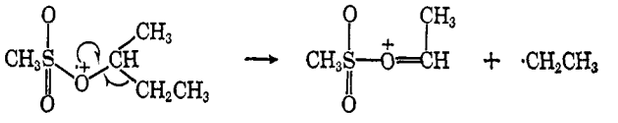
$$[CH_3SO_3CHMe_2]^{\cdot+} \longrightarrow Me_2\dot{C}H\ (m/e\ 43) + CH_3SO_3\cdot$$

Another mode of fragmentation which may give rise to hydrogen rearrangement is γ' cleavage.[13]



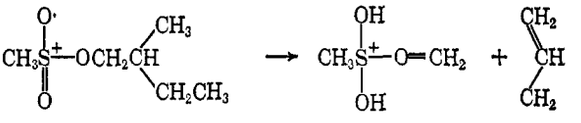
24 (*m/e* 109)

Ion **24**, *m/e* 109, occurs in all primary esters, while in the secondary esters such as 2-butyl methanesulfonate (**11**) the largest alkyl chain is lost preferentially to give the corresponding ion at *m/e* 123.[14] Ion **25** is the base peak in the spectrum of **11**. However, with



11 **25** (*m/e* 123)

a branched primary ester such as isobutyl methanesulfonate (**10**), not only is ion **24** present (R.A. = 25%), but also an ion appears as *m/e* 111 (R.A. = 77%).



10 **26** (*m/e* 111)

The mass spectrum of **19** in which the two β' hydrogens of isobutyl methanesulfonate are replaced by deuterium shows that the two β' hydrogens are retained in ion **24** (Table III).

A seven-membered-ring transition state is presumably involved in the rearrangement to form ion **26**. However, deuterium labeling to establish firmly the origin of this ion has not been carried out. In addition isobutyl methanesulfonate (**10**) gives an

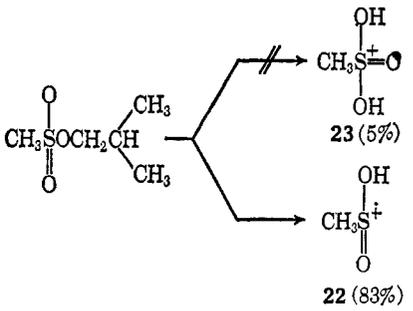
(13) See, for example, ref 3, Chapters 4 and 6.
(14) F. W. McLafferty, *Anal. Chem.*, **29**, 1782 (1957).

TABLE III

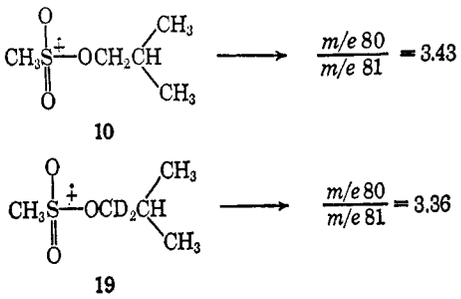
Compound[a]	m/e 109	110	111	112	113	Σ
$CH_3SOCH_2CH(CH_3)_2$	25.2	15.7	77.1	2.63	3.71	123.4
$CH_3SOCD_2CH(CH_3)_2$	1.02	1.36	33.8	18.2	33.0	87.4

[a] Base peak at *m/e* 43 for each ester.

abundant ion at *m/e* 80 (22) but very little ion **23**, *m/e* 97. Comparing isobutyl methanesulfonate (**10**)

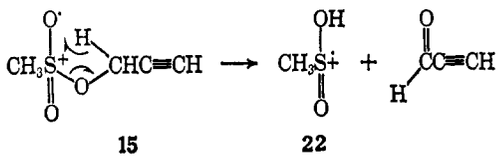


with its β'-deuterated analog (**19**) indicates, by the constant ratio of *m/e* 80 to *m/e* 81, that the β' hydrogens are not predominantly involved in the rearrangement to give ion **22** for this ester. This is in contrast



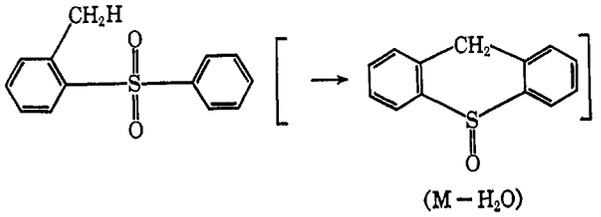
to methyl methanesulfonate which gives ion **22** by transfer of one β' hydrogen.[2]

One unsaturated ester was examined, propargyl methanesulfonate (**15**), which gave a *m/e* 80 ion (R.A. = 57%).

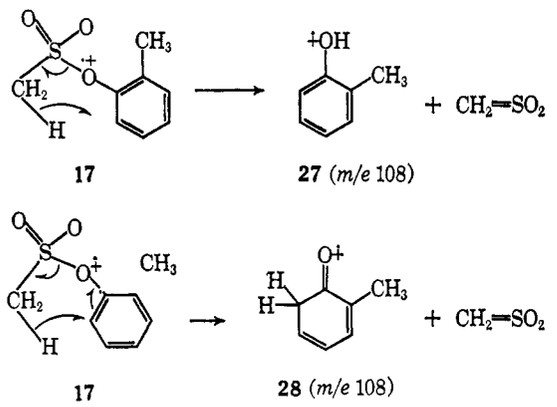


The two cycloalkyl methanesulfonates investigated, **13** and **14**, did not show ions corresponding to hydrogen migration to sulfonyl oxygen. If a model is constructed of cyclohexyl methanesulfonate (**13**), it would appear that the stereochemical requirements for the transfer of two hydrogens from the 2 and 6 positions of the cyclohexyl ring are adequately met. However, this rearrangement does not take place to any appreciable extent (Figure 6). Rupture of the β' bond to form the secondary cyclohexyl ion and subsequent fragmentation of the ring itself must be energetically favorable. The main fragmentation patterns then for the cycloalkyl esters arise from the fragmentation of the cycloalkyl ring itself.[15,16]

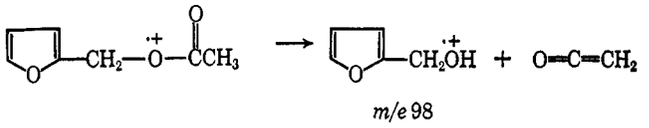
Finally, several aryl methanesulfonates were prepared and their mass spectra examined. These esters were examined for possible hydrogen transfer from *ortho* methyl substituents. This type of rearrangement has been observed for several diaryl sulfones, where migration occurred through a six-membered-ring transitions state.[17] However, in *o*-methyl-



phenyl methanesulfonate rearrangement of an *o*-methyl hydrogen would have to proceed through a seven-membered-ring transition state. No specific hydrogen rearrangements to give either an ion at *m/e* 80 (hydrogen transfer with α' cleavage) or an ion at *m/e* 96 (hydrogen transfer with β' cleavage) occurred. An examination of Figure 7, however, reveals an ion at *m/e* 108 (R.A. = 75%) which could be the molecular ion of *o*-cresol. This ion could arise by either of the following mechanistic pathways, involving a four- or six-membered-ring transition state, respectively. Either



mode of rearrangement would involve the novel elimination of a neutral molecule of sulfene.[18] An analogy to this mode of rearrangement would be the postulated elimination of ketene in the following ester.[19] With



(15) R. I. Reed, "Applications of Mass Spectrometry to Organic Chemistry," Academic Press Inc., London, 1966, Chapter 3.

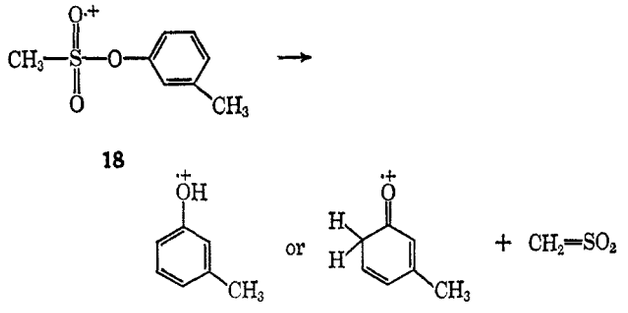
(16) J. H. Beynon, "Mass Spectrometry and its Application to Organic Chemistry," Elsevier Publishing Co., Amsterdam, 1960.

(17) S. Meyerson, H. Drews, and E. K. Fields, *Anal. Chem.*, **36**, 1294 (1964).

(18) (a) G. Opitz, M. Kleeman, D. Bucher, G. Walz, and K. Reith, *Angew. Chem. Intern. Ed. Engl.*, **5**, 594 (1966); (b) J. F. King and T. Durst, *J. Amer. Chem. Soc.*, **87**, 5684 (1965); (c) W. E. Truce and R. W. Campbell, *ibid.*, **88**, 3599 (1966).

(19) K. Biemann, "Mass Spectrometry: Organic Chemical Applications," McGraw-Hill Book Co., Inc., New York, N. Y., 1962, pp 111, 112.

m-tolyl methanesulfonate (**18**) the corresponding *meta* isomer at *m/e* 108 is the base peak in the spectrum.



18

m/e 108

Aside from this rearrangement, the main fragmentation pattern for aryl methanesulfonates arises from simple β' cleavage with retention of charge on the aromatic moiety and subsequent fragmentation of the aryl ring itself.[15]

Experimental Section

We are indebted to Professor F. W. McLafferty and his staff for determining and helping us to interpret the mass spectra which were recorded on a Hitachi RMU-6A instrument using a heated inlet system, ionization energy of 80 eV, inlet temperature of 185°. Also, several representative compounds were run at an inlet temperature of 50° and source temperature of 60°, and the spectra were compared to those taken at the higher temperatures to determine if these compounds were thermally stable. All of the esters thus tested proved to be thermally stable. All esters gave physical constants consistent with literature values and were purified by vpc through a silicon S.E. 30 (150°) column when fractional distillation left purity in doubt. Nmr spectra were recorded on a Varian A-60 spectrometer with TMS as internal standard.

General Procedure for Preparation of Alkyl Methanesulfonates.—To a solution of 0.13 mol of triethylamine (Matheson Coleman and Bell reagent), and 0.13 mol of alcohol in 200 ml of benzene (Baker Spectrophotometric reagent) contained in a dry 500-ml three-neck flask equipped with an addition funnel, nitrogen inlet, calcium chloride drying tube, and a magnetic stirrer was slowly added with cooling and stirring a solution of 0.10 mol of methanesulfonyl chloride in 50 ml of benzene. The mixture was stirred overnight under nitrogen, and the precipitated triethylamine hydrochloride was filtered. The filtrate was washed several times with dilute hydrochloric acid and dried over sodium sulfate, and the solvent was removed under reduced pressure. The resulting ester was then distilled *in vacuo* through a 10-cm Vigreux column.

Modification of the Above Procedure for the Preparation of Secondary Alkyl Methanesulfonates.—The procedure was identical except that the esters were distilled under the lowest possible pressure in the presence of 0.5 g of $CaCO_3$ to minimize decomposition. The esters were then stored over 1 g of $NaHCO_3$ in which case they were reasonably stable.

Preparation of Propanol-1,1-d_2.—In a three-neck 500-ml flask equipped with a reflux condenser fitted with a calcium chloride drying tube, dropping funnel, and mechanical stirrer was mixed 200 ml of diethyl ether distilled from $LiAlH_4$ and 3.1 g (0.13 mol) of $LiAlD_4$. The resulting slurry was heated under reflux for 1 hr. Then 9.63 g (0.13 mol) of propanoic acid in 50 ml of Et_2O was added over a period of 2 hr with cooling. After addition was complete the reaction was allowed to run overnight under gentle reflux. The reaction mixture was cooled and an excess (25 ml) of methyl carbitol was added slowly. After this addition was complete the reaction mixture was distilled to give 4.3 g (81%) of n-$CH_3CH_2CD_2OH$, bp 99–101°.

Preparation of n-Propyl-β',β'-d_2 Methanesulfonate.—To a solution of 6.59 g (0.065 mol) of triethylamine and 4.3 g (0.069 mol) of propanol-1,1-d_2 in 100 ml of benzene was slowly added a solution of 5.72 g (0.05 mol) of methanesulfonyl chloride in 25 ml of benzene. The mixture was stirred for 8 hr and worked up in the usual manner to give 4.37 g (63%) of propyl-β',β'-d_2 methanesulfonate: bp 76–77° (2.6 mm); nmr ($CDCl_3$), τ 9.01 (t, 3), 8.30 (q, 2), 7.08 (s, 3).

Preparation of Propanol-2,2-d_2, $CH_3CD_2CH_2OH$.—A solution of 25.0 g (0.212 mol) of methylmalonic acid (Mallinckrodt), 20 g (1.0 mol) of deuterium oxide (Columbia Organic Chemicals, 99.7%), and 20 ml of dioxane (distilled from sodium) was stirred for 48 hr at room temperature. The solvent was then removed at room temperature *in vacuo*, and the residue dried *in vacuo* over phosphorus pentoxide. This procedure was repeated for a total of three times. The product was then decarboxylated by heating with stirring at 140° until the evolution of CO_2 stopped (about 24 hr). The crude acid was distilled *in vacuo* to give 15.5 g (0.204 mol) of propanoic-2,2-d_2 acid. This acid (10 g, 0.13 mol) was taken up in 10 ml of Ansul ether 141 (distilled from $LiAlH_4$) and slowly added with stirring to a cooled slurry of 4.94 g (0.130 mol) of lithium aluminum hydride in 100 ml of Ansul ether 141. The mixture was stirred overnight, and then excess methyl carbitol (25 ml) was added. The product was distilled from the reaction mixture. This material was redistilled to give 6.38 g (79%) of propanol-2,2-d_2, bp 100–101°.

Preparation of Propyl-2,2-d_2 Methanesulfonate.—To a solution of 4.35 g (0.043 mol) of triethylamine and 2.67 g (0.043 mol) of propanol-2,2-d_2 in 75 ml of dry benzene was slowly added 4.35 g (0.038 mol) of methanesulfonyl chloride in 10 ml of benzene. The mixture was stirred overnight under nitrogen, and then worked up in the usual manner. The ester was distilled *in vacuo* and collected in the amount of 4.9 g (92%): bp 84–85° (6.0 mm); nmr, τ 9.05 (s, 3), 7.10 (s, 3), and 5.98 (s, 2).

Preparation of Propanol-3,3,3-d_3.—A solution of 104 g (1.0 mol) of malonic acid (Mallinckrodt), 50 g (2.50 mol) of deuterium oxide (98%), and 100 ml of dioxane (distilled from sodium) was stirred for 48 hr at room temperature. The solvent was removed at room temperature *in vacuo* and the residue dried *in vacuo* over phosphorus pentoxide. This procedure was repeated for a total of three times. This product was then decarboxylated by heating at 145° until CO_2 evolution stopped. The crude acetic-d_4 acid (18.9 g, 0.30 mol) was added slowly to 44.0 g (0.34 mol) of thionyl chloride cooled to 10–15°. After the addition was complete, the reaction mixture was heated gently for 0.5 hr and the product distilled. The original distillate was redistilled to give 20.3 g (84%) of CD_3COCl, bp 52–53° (760 mm).[20] CD_3COCl (16.3 g, 0.20 mol) was added slowly to a cold solution of diazomethane in ether (prepared from bis(N-methyl-N-nitroso)-terephthalamide).[21] A brisk evolution of nitrogen occurred, and the solution was allowed to stand at 0°.[22] The ether was removed from the reaction mixture at 5–10° *in vacuo* leaving a bright yellow liquid (diazo ketone) which was taken up in 200 ml of methanol. To this solution was added a few drops of a mixture prepared by adding 9.2 g (0.04 mol) of silver benzoate to 30 ml of triethylamine.[23] Nitrogen was evolved immediately and the solution turned black. When the nitrogen evolution slowed down, more of the silver benzoate solution was added. A total of 2.65 l. of nitrogen was evolved. The mixture was filtered and then distilled on a Todd column to give 11.6 g (0.110 mol) of methyl propionate-3,3,3-d_3, bp 78–79° (756 mm). This ester was reduced with $LiAlH_4$ in Ansul ether 141 to give 6.05 g (87%) of propanol-3,3,3-d_3, bp 100.5–101.5° (753 mm).

Preparation of Propyl-3,3,3-d_3 Methanesulfonate.—To a solution of 5.15 g (0.051 mol) of triethylamine and 3.22 g (0.051 mol) of propanol-3,3,3-d_3 in 100 ml of dry benzene was slowly added 4.81 g (0.042 mol) of methanesulfonyl chloride in 15 ml of benzene. The mixture was stirred overnight and worked up in the usual manner. Distillation *in vacuo* gave 3.78 g (64%) of ester: bp 110.5–111.5° (20.0 mm); nmr, τ 8.25 (q, 2), 7.10 (s, 3), 5.95 (q, 2).

Preparation of Isobutyl-1,1-d_2 Methanesulfonate.—To a slurry of 2.1 g (0.05 mol) of $LiAlD_4$ in 50 ml of Ansul ether 141 (distilled from $LiAlH_4$) was slowly added 4.4 g (0.05 mol) of isobutyric acid

(20) B. Helferich and W. Schaefer, "Organic Syntheses," Coll. Vol. I, John Wiley and Sons, Inc., New York, N. Y., 1964, p 147.

(21) Th. J. DeBoer and H. J. Backer, "Organic Syntheses," Coll. IV, John Wiley and Sons, Inc., New York, N. Y., 1963, p 250.

(22) W. E. Bachman and W. S. Staure, "Organic Reactions," John Wiley and Sons, Inc., New York, N. Y., 1942.

(23) M. S. Newman and P. F. Beal, III, *J. Amer. Chem. Soc.*, **72**, 5163 (1950).

in 25 ml of Ansul ether 141. The reaction mixture was allowed to stir overnight at 70°. Excess methyl carbitol was added and the product distilled to give 2.3 g (61%) of isobutyl-1,1-d_2 alcohol, bp 108–109°.

To a solution of 3.04 g (0.030 mol) of triethylamine and 2.28 g (0.030 mol) of isobutyl-1,1-d_2 alcohol in 75 ml of dry benzene was added 2.86 g (0.025 mol) of methanesulfonyl chloride in 10 ml of benzene. The mixture was stirred overnight and worked up in the usual manner. The ester was distilled *in vacuo* giving 1.4 g (28%) of isobutyl-1,1-d_2 methanesulfonate: bp 58–59° (0.60 mm); nmr, τ 9.00 (d, 6), 8.00 (m, 1), 7.02 (s, 3).

Acknowledgment.—This investigation was supported by Public Health Service Grant No. CA-04536-08 and the U. S. Army Medical Research and Development Command under Contract No. DA-49-193-MD-2949.

Mass Spectrometry in Structural and Stereochemical Problems. CLIV.[1] Electron Impact Promoted Fragmentation of Alkyl Tetrahydropyranyl Ethers and Thioethers[2]

STEPHEN J. ISSER, A. M. DUFFIELD, AND CARL DJERASSI

Department of Chemistry, Stanford University, Stanford, California 94305

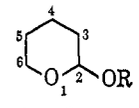
Received January 3, 1968

In view of the importance of tetrahydropyranyl ethers as protecting groups for alcohols, there was undertaken a study of the principal modes of fragmentation subsequent to electron impact of alkyl tetrahydropyranyl ethers and thioethers using specifically deuterated derivatives and high resolution mass spectrometry.

Tetrahydropyranyl ethers have been used in synthetic organic chemistry as base-stable, acid-labile protecting groups for hydroxylic functions. Although much research has been completed on the mass spectrometric fragmentation of alcohols,[3] ethers,[4] and thioethers,[5] only a preliminary description[6] of the processes following electron impact of alkyl tetrahydropyranyl ethers has been published. The present communication records the results of a detailed study, using specifically deuterated analogs supplemented by high resolution mass spectrometry, of the fragmentation of alkyl tetrahydropyranyl ethers and thioethers.

Discussion of Mass Spectra

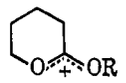
n-Alkyl Tetrahydropyranyl Ethers.—Ethyl and n-butyl tetrahydropyranyl ethers (I and II) were prepared



I, R = C_2H_5
II, R = n-C_4H_9

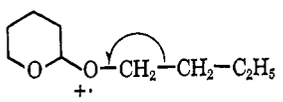
as typical representatives of this class of compound and their respective mass spectra are reproduced at both 70 and 12 eV in Figures 1, 1a, 2, and 2a. It was found necessary to use an all-glass heated inlet system in the determination of these spectra since we observed partial pyrolysis of these compounds to a mixture of dihydropyran (strong molecular ion at m/e 84) and the respective alcohol when using a metal heated inlet system.

The mass spectra (Figures 1 and 2) of ethyl and n-butyl tetrahydropyranyl ether (I and II) contain weak molecular ion peaks which are surpassed in intensity by an M − 1 species. Deuterium labeling established that the hydrogen atom eliminated in this process must originate from C-2 of the pyran ring as no loss of deuterium was observed in the analogs labeled in the alkyl chain or at C-3, C-4, or C-6 of the pyran ring. Therefore this ion can be represented by a.

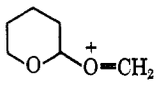


a, M − 1

α cleavage relative to the aliphatic ether oxygen atom is responsible (Table I) for the formation of the low abundance ion (represented by b) at mass 115 in the spectrum (Figure 2) of II and a metastable peak was recognized to verify this decomposition of the molecular ion.

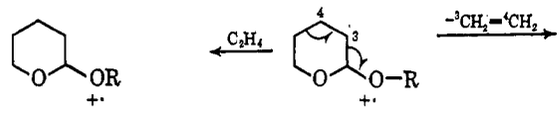


II



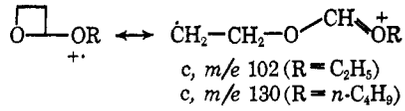
b, m/e 115

A peak of low abundance at m/e 102 (M − 28) in the spectrum (Figure 1) of ethyl tetrahydropyranyl ether (I) was shown by deuterium labeling to originate from loss of C-3 and C-4 of the pyranyl ring (c, 80%) supplemented by elimination of the alkyl chain less a terminal hydrogen atom (d, 20%). The analogous peak at m/e 130 in the spectrum (Figure 2) of the n-butyl homolog was less intense but 50% of its ion contribution arose from a process similar to I → c, the remainder of



d, m/e 102 (R = H)
d, m/e 130 (R = C_2H_5)

I, R = C_2H_5
II, R = n-C_4H_9



c, m/e 102 (R = C_2H_5)
c, m/e 130 (R = n-C_4H_9)

(1) For paper CLIII, see W. Carpenter, Y. M. Sheikh, A. M. Duffield, and C. Djerassi, *Org. Mass Spectry.*, 1, 3 (1968).

(2) Financial assistance from the National Institutes of Health (Grants No. GM 11309 and AM 04257) is gratefully acknowledged.

(3) For a recent review of the mass spectrometry of alcohols, see H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Mass Spectrometry of Organic Compounds," Holden-Day, Inc., San Francisco, Calif., 1967, Chapter 2.

(4) See ref 3, Chapter 6.

(5) See ref 3, Chapter 7.

(6) See ref 3, pp 478, 479.