Die Elementaranalysen wurden im mikroanalytischen Laboratorium der ETHZ (Leitung: *W. Manser*) ausgeführt. Die NMR.-Spektren wurden in unserer Instrumentalabteilung (Leitung für NMR.-Service: Prof. *J. F. M. Oth*) aufgenommen. Die Aufnahme der Massenspektren erfolgte unter der Leitung von Herrn PD Dr. *J. Seibl.*

LITERATURVERZEICHNIS

[1] *J. Ehrenfreund, M. P. Zink & H. R. Wolf,* Helv. *57,* 1098 (1974).
[2] *M. P. Zink & H. R. Wolf,* Chimia *28,* 23 (1974).
[3] *J. Bricout, R. Viani, F. Müggler-Chavan, J. P. Marion, D. Reymond & R. H. Egli,* Helv. *50,* 1517 (1967).
[4] *M. L. Mihailović & Ž. Čeković,* Synthesis *1970,* 209.
[5] *M. L. Mihailović, Ž. Čeković, J. Stanković, N. Pavlović, S. Konstantinović & S. Djokić-Mazinjanin,* Helv. *56,* 3058 (1973).
[6] *Y. Nakatani & T. Yamanishi,* Tetrahedron Letters *1969,* 1995.
[7] *C. F. Seidel, D. Felix, A. Eschenmoser, K. Biemann, E. Palluy & M. Stoll,* Helv. *44,* 598 (1961).
[8] *M. Winter & P. Enggist,* Helv. *54,* 1891 (1971).
[9] *Y. R. Naves & P. Ardizio,* Helv. *32,* 206 (1949).
[10] *R. Ratcliffe & R. Rodehorst,* J. org. Chemistry *35,* 4000 (1970).
[11] *M. L. Mihailović & R. E. Partch,* in «Selective Organic Transformations», Vol. 2, S. 97 ff., herausgegeben von D. S. Thyagarajan, Wiley-Interscience, New York–London 1972.
[12] *R. Criegee,* in «Oxidation in Organic Chemistry», Teil A, S. 277 ff., herausgegeben von K. B. Wiberg, Academic Press, New York–London 1965.
[13] *S. Moon & L. Haynes,* J. org. Chemistry *31,* 3067 (1966).
[14] *E. S. Gould,* in «Mechanismus und Struktur in der organischen Chemie», S. 598, Verlag Chemie, Weinheim 1964.
[15] *B. R. von Wartburg, H. R. Wolf & O. Jeger,* Helv. *56,* 1948 (1973).
[16] *G. Ohloff & S. Mignat,* Liebigs Ann. Chemie *652,* 115 (1962).
[17] *A. J. Vogel,* in «Practical Organic Chemistry», Longmans 1966, S. 191.
[18] *M. Mousseron-Canet & J. C. Mani,* Bull. Soc. chim. France *1966,* 3285.
[19] *L. C. King,* J. Amer. chem. Soc. *66,* 894 (1944).
[20] *R. T. Arnold, K. Murai & R. M. Dodson,* J. Amer. chem. Soc. *72,* 4193 (1950).

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123. Use of Dimethylsilyl Ethers for Characterizing Primary Aliphatic Alcohols: A Comparison of Mass Spectrometric Fragmentation of Di- and Trimethylsilyl Derivatives

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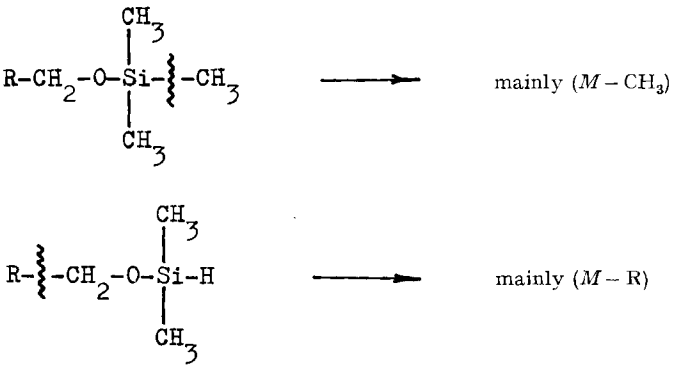
(2. IV. 74)

Summary. Mass spectral fragmentation patterns of dimethylsilyl (DMS) ethers of primary unbranched, branched, and secondary unbranched aliphatic alcohols in the C_5 to C_{10} range are compared with those of the corresponding trimethylsilyl (TMS) derivatives. Unlike their TMS analogues, DMS ethers of primary alcohols exhibit pronounced rupture of the C—C bond adjacent to the oxygen atom within the alkyl moiety (loss of an alkyl radical R) in marked preference to

cleavage within the silyl substituent (loss of CH_3). Within this class of compounds, complementary preparation of DMS derivatives can therefore be used to establish or to confirm the site, and thus the primary nature of the hydroxyl group, whereas preparation of TMS ethers may be of advantage in deducing molecular size. For the derivatives of secondary alcohols this diagnostically useful difference in fragmentation behaviour is not observed.

Replacement of acidic hydrogen atoms ($-OH$, $-NH$, $-SH$) in polar organic compounds by trimethylsilyl (TMS) substituents has become routine in many laboratories dealing with natural or synthetic products. Ease of preparation, favorable gas chromatographic properties and characteristic mass spectral fragmentation contribute to the eminent role TMS derivatives play in present-day analysis of such compounds by mass spectrometry (MS.) or gas chromatography (GC.), or combinations thereof (GC./MS.). In contrast, reports on a similar use of dimethylsilyl (DMS) derivatives are as yet scarce, although preliminary results suggested closely analogous fragmentation, [1–3] including comparable propensity toward migration of the silyl moiety over large molecular distances [2]. As an exception to this analogy, DMS derivatives of some simple aliphatic alcohols had, however, been noted to behave substantially differently from their TMS counterparts by exhibiting suppressed α-cleavage with respect to the oxygen atom within the silyl moiety in favor of a pronounced α-cleavage within the alkyl residue [4]:



Since $(M - CH_3)^+$ ions commonly serve to establish molecular size and $(M - R)^+$ ions to locate hydroxyl functions, differences such as these are not only of principal mechanistic interest, but also of considerable practical value in characterizing alcohols by conversion to TMS and/or DMS ethers. Furthermore, a good understanding of the fragmentation of dimethylsilyl derivatives of simple compounds is a prerequisite to their use in the study of more complex molecules, such as steroids, where their employment may be of significant practical value.

Experimental. – In order to explore this behavior in detail, 16 representative compounds, *viz.* primary unbranched (5) and branched (2) as well as secondary unbranched (9) alcohols with carbon atom numbers ranging from 5 to 10 (pentanols to decanols), were converted to their DMS and TMS derivatives by reaction with bis(dimethylsilyl)- and bis(trimethylsilyl)acetamide, respectively. Mass spectral analysis was carried out using a *Varian* MAT CH 7 combined GC./MS. system. Columns used were 1.5 m × 2 mm i.d. glass packed with 3% SE-30 or 3% OV-17 on 100/120 mesh Supelcoport. Spectra were taken cyclically over the entire GC. peak and were

normalized, corrected for total ion current variations and plotted by means of a *Varian* MAT SS-100 Data System with a *Varian* Statos 21 recorder.

Results. – Indeed, for *primary alcohols*, $(M - CH_3)^+$ ions are found to dominate the spectra in the TMS series almost invariably (base peaks in compounds II to VII, Table 1), yet to be of only modest intensities (10–20%) in the corresponding DMS

Table 1. *Relative Abundances of* $(M-CH_3)^+$ vs. $(M-R)^+$ *Ions in DMS and TMS Derivatives of* Primary Aliphatic Alcohols

Compound	DMS Derivative $(M-CH_3)/(M-R)$	TMS Derivative $(M-CH_3)/(M-R)$
1-pentanol (I)	21/100	75/21
1-hexanol (II)	13/100	100/21
1-heptanol (III)	17/100	100/24
1-octanol (IV)	20/100	100/24
1-decanol (V)	13/100	100/25
2-methyl-1-butanol (VI)	11/64	100/45
3-methyl-1-butanol (VII)	13/81	100/40

series. *Vice versa*, $(M - R)^+$ ions constitute prominent peaks in the DMS ethers (*m/e* 89, base peaks in I to V), whereas in the TMS analogues they amount to little more than 20% relative abundance (*m/e* 103). In the branched primary alcohols VI and VII, this contrasting behavior is somewhat less pronounced, probably as a result of enhanced secondary decomposition of $(M - CH_3)^+$ ions, *e.g.* to *m/e* 75 ($\overset{+}{HO}=SiMe_2$, base peaks in both types of derivatives), by elimination of the alkyl chain. These features are also illustrated by Fig. 1 and 2, which reproduce the full mass spectra of the DMS and TMS ethers of *n*-hexanol (II) and 2-methyl-1-butanol (VI), respectively.

Further characteristic differences between the two series of derivatives are observed for $(M - 1)$, $(M - 2)$ and $(M - 17)$ peaks. While in the DMS compounds the corresponding $(M - 1)^+$ and $(M - 17)^+$ ions carry substantial portions of ion current

Table 2. *Relative Abundances of* $(M-CH_3)^+$ vs. $(M-R^1)^+$ *and* $(M-R^2)^+$ *Ions in DMS and TMS Derivatives of* Secondary Aliphatic Alcohols

Compound	DMS Derivatives $(M-CH_3)/(M-R^1)/(M-R^2)$ [a]	TMS Derivatives
2-pentanol (VIII)	10/100 [b]	18/77 [b]
3-pentanol (IX)	4/92 [c]	8/75 [c]
2-hexanol (X)	5/100 [b]	17/100 [b]
3-hexanol (XI)	3/47/58	8/43/54
2-heptanol (XII)	7/100 [b]	11/100 [b]
3-heptanol (XIII)	3/37/70	7/42/70
4-heptanol (XIV)	3/100 [c]	6/87 [c]
2-decanol (XV)	3/100 [b]	7/100 [b]
5-decanol (XVI)	3/81/100	4/47/58

a) Except when equal, R^1 denotes the smaller, R^2 the larger substituent.
b) $(M-CH_3)^+$ and $(M-R^1)^+$ ions coincide and are given as sum.
c) $(M-R^1)^+$ and $(M-R^2)^+$ ions are identical.

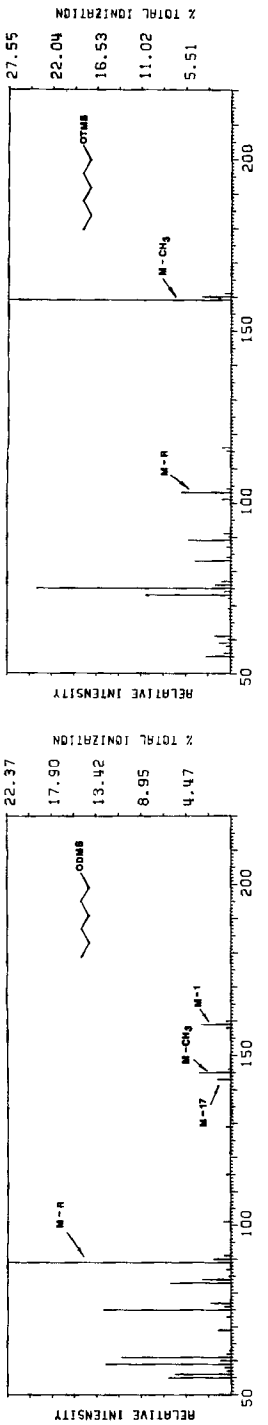


Fig. 1. *Mass Spectra of DMS and TMS Ethers of* n*-Hexanol (II)*

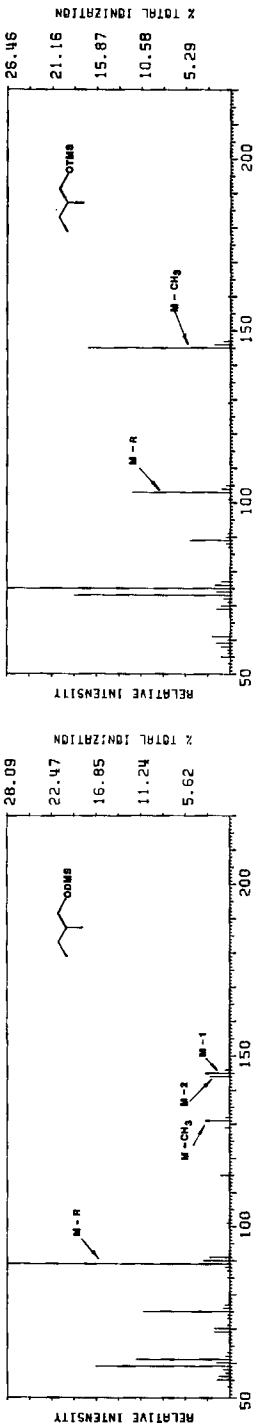


Fig. 2. *Mass Spectra of DMS and TMS Ethers of 2-Methyl-1-butanol (VI)*

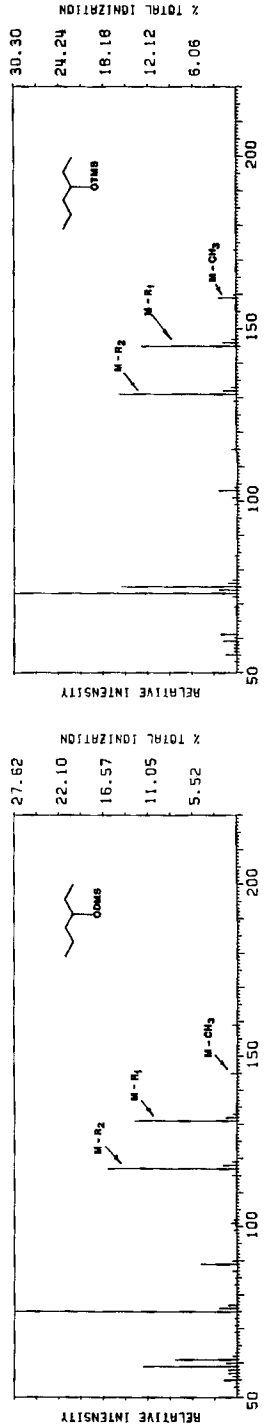


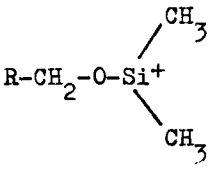
Fig. 3. *Mass Spectra of DMS and TMS Ethers of 3-Hexanol (XI)*

(5 to 20% relative abundance), they are considerably reduced (less than 1%) in their TMS counterparts. Details of the origin and the genesis of these ions (sequential loss of H_2 and a CH_3 radical is indicated by metastable peaks) have not yet been established.

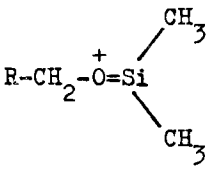
Inspection of the spectra of the derivatives of *secondary alcohols* (compounds VIII to XVI, Table 2) shows that in the DMS series the strong tendency toward preferential cleavage within the alkyl chain is still preserved. Of the two substituents R^1 and R^2, which can be lost in this case, the larger (R^2) will be ejected preferentially (XI, XIII and XVI) to an extent that loss of CH_3 (R^1) from the chain in 2-alkanols practically fails to contribute to this mode of cleavage (X, XII, XV). However, TMS derivatives no longer behave substantially differently: in contrast to TMS ethers of primary alcohols, ($M - R$) peaks are now quite pronounced at the expense of $(M - CH_3)^+$ ions to a degree rendering spectral patterns of DMS and TMS derivatives largely analogous. This is also borne out by Fig. 3, reproducing the spectra of DMS and TMS 3-hexanol (XI).

Similarly, the extensive analogy between DMS and TMS ethers persists for the $(M - 1)^+$, $(M - 2)^+$ and $(M - 17)^+$ ions. While significant in DMS, yet virtually absent in TMS derivatives of primary alcohols, weak ($M - 1$) peaks (1 to 3% relative intensity) are exhibited by most secondary alcohols in both types of ethers. ($M - 2$) and ($M - 17$) peaks are missing in either class.

Discussion. – The marked reciprocity of ion current distribution between $(M - CH_3)^+$ and $(M - R)^+$ fragments in the two types of derivatives in *primary alcohols* can be rationalized as follows. It might be assumed that the prominence of the $(M - CH_3)^+$ fragments in the trimethylsilyl compounds is generally not so much a consequence of operation of true α-cleavage triggered by the oxygen atom (as is usually implied), as of plain rupture of one of the Si-CH_3 bonds due to release of steric crowding. In this event, resonance structure **A**, a siliconium ion, would be a more realistic representation of this fragment than the customarily written oxonium structure **B**:



A



B

This assumption would be in accordance with the generally low tendency of silicon atoms to form double bonds by p,p-orbital overlap (such as implied in **B**), and with the tendency of ions of such structure to undergo internal interaction with other donor functions present in R. New-bond formation [5] and, as a sequel, migration of functional groups [6–9] is likely to result. Inefficient stabilization of the charge on the silicon atom through oxygen, *i.e.* enhanced *Lewis* acid character in comparison with $-O=\overset{+}{C}\!\!<$ analogues, is reflected for such fragments also in the ease with which oligomeric ions such as $Me_3Si-\overset{+}{O}=SiMe_2$ (*m/e* 147) are formed in the presence of more

than one TMS group in the molecule [5–11]. Steric release would conceivably be of much less importance in the dimethylsilyl compounds, a fact that would, of course, favor formation of $(M - R)^+$ ions over $(M - CH_3)^+$, as observed.

For the TMS ethers of *secondary alcohols*, differences in energy requirements for cleavage within the alkyl and silyl substituents are apparently reversed, as compared to TMS derivatives of primary alcohols. Disappearance of specific fragmentation is obviously due to facilitated α-cleavage of the C–C bond at the secondary carbon atom, with the result that $(M - R)^+$ ions are now generated in preference to $(M - CH_3)^+$ not only in DMS, but also in TMS derivatives.

Conclusion. – In view of the lack of well-marked α-cleavage within the alcohol moiety for *primary alcohols* when relying on the standard use of TMS ethers (*m/e* 103 ranging from only 21 to 25% in I to V), supplementary preparation of DMS derivatives may offer advantages in characterizing compounds of unknown structure. By analyzing samples of both derivatives, information on molecular size as well as the position of the hydroxyl function can be derived from 'diagnostic' $(M - CH_3)$ and $(M - R)$ peaks of the desired optimal prominence, respectively, and double-checked through the redundancy of pertinent data. This approach of twofold derivatization promises, however, rather limited advantage with *secondary alcohols*, except when corroborating critical structural information, *e.g.* in the presence of unknown impurities. By using either derivative, determination of the position of the hydroxyl group as the generally more important, yet otherwise less easy-to-obtain, structural parameter is in this class of alcohols fortunately largely straight-forward.

These results further suggest, of course, that in more complex larger molecules, such as sterols etc., DMS ethers may be of similar usefulness in attempts of structure elucidation by small-scale analysis of impure materials, when used in parallel with TMS ethers. Additionally, in cases of closely analogous fragmentation, DMS compounds may also find use in *mass fragmentography*, since ions formed by TMS ethers occasionally interfere with chemical or column background, thus jeopardizing quantitative applications of this novel and widely used technique of trace analysis.

BIBLIOGRAPHY

[1] *G. Petersson & O. Samuelson*, Svensk Papperstidn. *71*, 731 (1968).
[2] *D. H. Hunneman & W. J. Richter*, Org. Mass Spectrom. *6*, 909 (1972).
[3] *J. B. Westmore, D. C. K. Lin, K. K. Ogilvie, H. Wayborn & J. Berestiansky*, Org. Mass Spectrom. *6*, 1243 (1972).
[4] Unpublished observations from our laboratories.
[5] *W. Richter, M. Vecchi, W. Vetter & W. Walther*, Helv. *50*, 364 (1967).
[6] *W. J. Richter & A. L. Burlingame*, Chem. Commun. 1158 (1968).
[7] *P. Capella & C. M. Zorzut*, Analyt. Chemistry *40*, 1458 (1968).
[8] *J. A. McCloskey, R. N. Stillwell & A. M. Lawson*, Analyt. Chemistry *40*, 233 (1968).
[9] *W. J. Richter, B. R. Simoneit, D. H. Smith & A. L. Burlingame*, Analyt. Chemistry *41*, 392 (1969).
[10] *O. S. Chizhov, N. V. Molodtsov & N. K. Kochetkov*, Carbohydrate Res. *4*, 273 (1967).
[11] *J. Dieckman, J. B. Thomson & C. Djerassi*, J. org. Chemistry *33*, 2271 (1968).