A Remarkable Solvent Effect on the Reductive Silylation of Carboxylic Esters. Preparation of 1,1-Bis(trimethylsilyl)-1-alkanols

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1,1-Bis(trimethylsilyl)-1-alkanols were obtained in good yields when ethyl esters of the corresponding carboxylic acids were treated with sodium suspension and chlorotrimethylsilane in refluxing tetrahydrofuran followed by acidic hydrolysis.

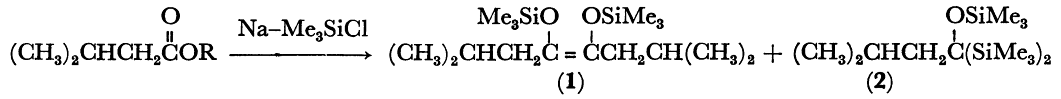
Various carboxylic esters undergo facile reductive dimerization to afford the corresponding 1,2-bis(trimethylsiloxy)alkenes **1** on treatment with alkali metals such as lithium, sodium, or potassium–sodium alloy in the presence of chlorotrimethylsilane.[1] Bloomfield and Owsley who have studied this type of reaction extensively,[2] suggested that the conventionally adopted mechanism involving dimerization of the radical species is not operative, the reaction proceeding through the nucleophilic attack of the radical anion **3** (Scheme 1) initially formed on the carboxylic ester, followed by several steps. In connection with these reactions, we have found that trimethylsilyl carboxylates give the trimethylsilyl ethers of the corresponding 1,1-bis(trimethylsilyl)-1-alkanols **2** exclusively by a similar treatment in refluxing tetrahydrofuran (THF);[3] several synthetic reactions with use of 1,1-bis(trimethylsilyl)-1-alkanols[4] were developed. In order to establish a precise procedure for the preparation of such kind of alcohols, reductive silylation reactions of various esters have been studied in detail.

$$\text{R-CO}_2\text{R}' \begin{cases} \longrightarrow \text{Me}_3\text{SiO-CR=CR-OSiMe}_3 & \textbf{1} \\ \longrightarrow \text{R-C(SiMe}_3)_2\text{-OSiMe}_3 & \textbf{2} \end{cases}$$

For studying the difference between reaction paths **1** and **2**, trimethylsilyl and ethyl esters of 3-methylbutyric acid were employed as substrates, and their reactions with metallic sodium in the presence of chlorotrimethylsilane were examined by using benzene, ether, tetrahydrofuran (THF), or 1,2-dimethoxyethane (DME) as the reaction solvent, since benzene and ether are usually employed for the preparation of 1,2-bis(trimethylsiloxy)alkenes **1**. The reactions were performed with commercial sodium suspension in order to eliminate the effect due to the difference in the grade of dispersion of reducing agent. It was found that the solvent plays a crucial role in deciding the reaction path and **1** or **2** can be prepared selectively through a similar procedure simply by changing the reaction solvent (Table 1). Thus, when tetrahydrofuran or dimethoxyethane was used as a solvent, the type **2** product, silyl ether of 1,1-bis(trimethylsilyl)-3-methyl-1-butanol, was obtained exclusively from both of the starting esters, whereas the reactions with the same esters in benzene or ether afforded the type **1** product, 4,5-bis(trimethylsiloxy)-2,7-dimethyl-4-octene, as the major products. In the latter case, addition of dibenzo-18-crown-6 to the reaction system resulted in appreciable enhancement of the formation of **2**, both types of products being obtained in fair yields. No marked difference in product distribution was observed between the reactions of trimethylsilyl and ethyl esters when the same solvent was employed.

The results indicate that the predominant factor for determining the reaction paths is attributable mainly to the different behavior of the anion radical **3** depending on the solvent. In a non-polar solvent such as benzene or ether, the anion radical **3** seems to react with the parent carboxylic ester preferentially to yield the 1,2-disiloxyalkene type of product **1** *via* the reaction paths proposed by Bloomfield and Owsley.[2] On the contrary, chlorotrimethylsilane seems to be a more efficient anion acceptor in a polar solvent such as tetrahydrofuran or 1,2-dimethoxyethane, trapping the anion radical **3** to afford the corresponding 1-alkoxy-1-(trimethylsiloxy)alkyl radical **4**. Radical **4** thus formed can not participate in the formation of the 1,2-disiloxyalkene **1**, according to the mechanism of Bloomfield and Owsley, which accounts for exclusive formation of **2**. The only available reaction path for radical **4** is expected to be a further one electron reduction with metallic sodium which yields the anionic species **5** (Scheme 1). Silylation of **5** with the chlorosilane would lead to the formation of 1-alkoxy-1-(trimethylsiloxy)alkyltrimethylsilane **6**.

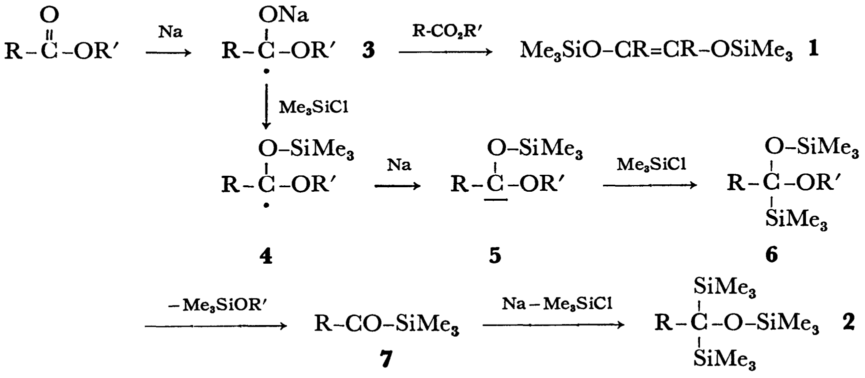
TABLE 1. SOLVENT DEPENDENCE OF THE REDUCTIVE SILYLATION OF ESTER



$$(\text{CH}_3)_2\text{CHCH}_2\overset{\text{O}}{\overset{\|}{\text{C}}}\text{OR} \xrightarrow{\text{Na–Me}_3\text{SiCl}} \underset{(\mathbf{1})}{(\text{CH}_3)_2\text{CHCH}_2\overset{\text{Me}_3\text{SiO}}{\text{C}}=\overset{\text{OSiMe}_3}{\text{C}}\text{CH}_2\text{CH}(\text{CH}_3)_2} + \underset{(\mathbf{2})}{(\text{CH}_3)_2\text{CHCH}_2\overset{\text{OSiMe}_3}{\text{C}}(\text{SiMe}_3)_2}$$

R	Product	THF	DME	Benzene[a)]	Benzene	Ether
SiMe$_3$	**1**	—	—	36	62	65
	2	91	88	52	4	2
Et	**1**	5	—	48	68	68
	2	93	91	41	—	—

a) The reaction was performed in the presence of dibenzo-18-crown-6 (an equimolar amount with the ester).



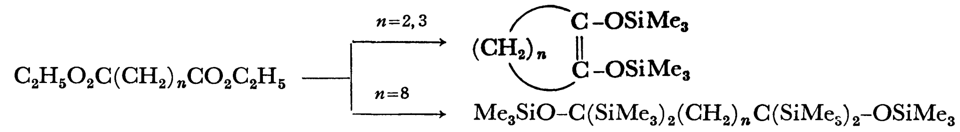
Scheme 1.

This type of product was isolated by Picard *et al.* through the reaction of the corresponding ester with metallic lithium–chlorotrimethylsilane system at low temperature.[5] At a temperature of refluxing tetrahydrofuran, **6** would decompose through removal of alkyl trimethylsilyl ether to yield the corresponding acyltrimethylsilane **7**, which undergoes further reductive silylation to give **2** as the final product. Actually, 3-methylbutyltrimethylsilane was converted into the corresponding **2** by a separate experiment under similar reaction conditions.[6]

We examined the reductive silylation reactions of ethyl esters of various carboxylic acids. All the reactions were performed in a preparative scale (*ca.* 0.2 mol) with a sodium suspension prepared in the usual manner. The results are given in Table 2. All the mono-esters examined afford the corresponding **2** in good yields, without appreciable concomitant formation of type **1** product, when the reactions are carried out at the temperature of refluxing tetrahydrofuran. As compared with the results in Table 1, the yields of the products are smaller, the corresponding acyltrimethylsilanes **7**

TABLE 2. PREPARATION OF 1,1-BIS(TRIMETHYLSILYL)-1-ALKANOL, $R-C(SiMe_3)_2OH$, FROM ETHYL CARBOXYLATE, $R-CO_2C_2H_5$

R	Bp °C/mmHg	Yield	IR (neat) cm^{-1}; NMR (CCl_4)	Molecular formula
C_2H_5	85—87/15	62	3500, 1240, 820; 0.10 (18H, s, $SiCH_3$), 0.80 (1H, s, OH), 0.85 (3H, t, J=8 Hz, CH_3) 1.80 (2H, q, J=8 Hz, CH_2).	$C_9H_{24}OSi_2$
n-C_3H_7	93—95/10	65	3500, 1250, 840; 0.10 (18H, s, $SiCH_3$), 0.80 (1H, s, OH), 0.87 (3H, t, J=8 Hz, C-CH_3) 1.10—2.10 (4H, m, aliphatic CH)	$C_{10}H_{26}OSi_2$
n-C_5H_{11}	105—107/5	65	3440, 1235, 840; 0.06 (18H, s, $SiCH_3$), 0.85 (1H, s, OH), 0.95 (3H, t, J=6 Hz, C-CH_3), 1.10—1.85 (8H, broad, aliphatic CH).	$C_{12}H_{30}OSi_2$
n-C_7H_{15}	106—108/3	65	3450, 1240, 840; 0.05 (18H, s, $SiCH_3$), 0.85 (1H, s, OH), 0.97 (3H, t, J=6 Hz, C-CH_3), 1.10—1.87 (12H, broad, aliphatic CH)	$C_{14}H_{34}OSi_2$
$C_6H_5CH_2CH_2$	127—130/2	64	3430, 1245, 845; 0.13 (18H, s, $SiCH_3$), 0.95 (1H, s, OH), 1.80—2.20 (2H, m, $PhCH_2$), 2.60—2.95 (2H, m, $PhCH_2$), 7.20 (5H, s, aromatic CH)	$C_{15}H_{28}OSi_2$
$CH_2{=}CH(CH_2)_8$	139—142/3	70	3420, 1250, 845; 0.05 (18H, s, $SiCH_3$), 0.85 (1H, s, OH), 1.05—1.80 (14H, broad, aliphatic CH), 2.05 (2H, m, C=C–CH_2), 4.87 (1H, d, J_{ac}=11 Hz, H_a of ${}^{H_a}_{H_b}\!\!>\!C{=}C\!<\!{}^{H_c}_{C}$), 4.92 (1H, d J_{bc}= 16 Hz, H_b), 5.12—6.00 (1H, m, H_c)	$C_{17}H_{38}OSi_2$
$(CH_3)_2CHCH_2$	120—122/20	66	3500, 1260, 850; 0.10 (18H, s, $SiCH_3$), 0.82 (1H, s, OH), 1.00 (6H, d, J=6 Hz, CH $(C\underline{H}_3)_2$), 1.10 (1H, m, $CH_2C\underline{H}$ $(CH_3)_2$), 1.60 (2H, d, J=5 Hz, $C\underline{H}_2CH(CH_3)_2$)	$C_{12}H_{28}OSi_2$
$(CH_3)_2CH$	114—115/30	66	3500, 1250, 860, 840; 0.10 (18H, s, $SiCH_3$), 0.80 (1H, s, OH), 1.00 (6H, d, J=7 Hz, CH $(C\underline{H}_3)_2$), 1.60 (1H, m, $C\underline{H}(CH_3)_2$)	$C_{10}H_{26}OSi_2$
n-$C_4H_9(C_2H_5)CH$	98—101/0.25	68	3450, 1250, 840; 0.13 (18H, s, $SiCH_3$), 0.70 (1H, s, OH), 0.95 (3H, t, J=7 Hz, C–CH_3), 1.00 (3H, t, J=7 Hz, C–CH_3), 1.15—2.10 (9H, m, aliphatic CH).	$C_{14}H_{34}OSi_2$
$-(CH_2)_8-$	173—176/0.3	56	3450, 1245, 840; 0.03 (36H, s, $SiCH_3$), 0.73 (2H, s, OH), 1.10—1.85 (16H, broad, aliphatic CH).	$C_{22}H_{54}O_2Si_2$



Scheme 2.

being formed as by-products. This can be attributed to the decreased activity of sodium suspension. Silyl ethers **2** usually undergo facile acidic hydrolysis to afford the corresponding 1,1-bis(trimethylsilyl)-1-alkanols in high yields. The only exceptional case was that with the silyl ether of 2,2-dimethyl-1,1-bis(trimethylsilyl)-1-propanol,[7] which could not be hydrolyzed even under severe reaction conditions.

In the reactions with diesters, succinic and glutaric esters gave type **1** products exclusively even when the reactions were carried out in tetrahydrofuran. This can be explained by assuming that the internal nucleophilic attack of the radical anion on the remaining ester carbonyl takes place preferentially since the favorable five- and six-membered intermediates are involved in these processes. In contrast, further elongation of the carbon chain dissecting two ester sites makes the above process less favorable, the corresponding **2** being obtained in good yield. For example, diethyl ester of decane-1,10-dicarboxylic acid could be converted into 1,1,10,10-tetrakins(trimethylsilyl)-1,10-decanediol in 56% yield through the reductive silylation reaction followed by acidic hydrolysis.

Organo-silicon compounds have recently been employed for synthetic purposes in various aspects.[8] The present procedure which provides a simple method for introducing two silyl groups into the same carbon is useful for the preparation of several other types of organo-silicon compounds.[4d–f]

Experimental

All the boiling points are uncorrected. IR spectra were recorded on a Hitachi 260-10 or a Hitachi EPIG3 spectrometer. NMR spectra were taken in a Vatian T-60 spectrometer, using dichloromethane as an internal standard. Elementary compositions of 1,1-bis(trimethyllsilyl)alkyl trimethylsilyl ethers were determined by means of high mass spectra, using a Hitachi RMU-7M mass spectrometer.

Materials. Tetrahydrofuran (THF), 1,2-dimethoxyethane (DME), ether, and benzene were purified shortly before use by drying and distillation over sodium-benzophenone or sodium. Chlorotrimethylsilane was purified by distillation over CaH_2. Esters were purified by distillation. Trimethylsilyl 3-methylbutyrate was prepared by treating the corresponding carboxylic acid with chlorotrimethylsilane in the presence of sidium hydride in tetrahydrofuran in 85% yield.

Two kinds of sodium suspensions were used. (A), a commercial, product (Alfa Ventron), was used after washing three times with hexane and then drying under reduced pressure. (B) was prepared in xylene, according to the usual procedure and was used after xylene had been removed by decantation and then evaporation under reduced pressure.

Reductive Silylation Reactions of Ehtyl or Trimethylsilyl 3-Methylbutyrate in Various Solvents. The ester (3 mmol) and bibenzyl (220 mg) in an appropriate solvent (3 ml) was added dropwise to sodium suspension A (0.03 g atom) suspended in the same solvent (5 ml) containing chlorotrimethylsilane (24 mmol) during a period of 45 min at room temperature under argon atmosphere. Exothermic reaction took place immediately and the temperature rose nearly to the refluxing point of solvent. After being stirred for 1.5 h, the yields were determined by GLC analysis [3 mm × 1 m column of 10% SE30 on Diasolid L, column temperature 110 °C] by comparison with the internal standard (bibenzyl). The results are given in Table 1.

Preparation of 1,1-Bis(trimethylsilyl)-1-aklanol. General Procedure: A tetrahydrofuran solution (100 ml) of an ethyl ester (0.2 mol) and chlorotrimethylsilane (174 g, 1.6 mol) was added to sodium suspension B (36.8 g, 1.6 g atom) suspended in boiling tetrahydrofuran (300 ml) during a period of 1 h under argon atmosphere. After addition had been completed, the reaction mixture was heated to refluxing for 30 min under stirring. The materials deposited were filtered off and the solvent was removed under reduced pressure. The residual oil was treated with 10 ml of 6 M hydrochloric acid in 200 ml of dioxane at 50 °C for 1 h, and was neutralized with aq $NaHCO_3$. The corresponding 1,1-bis(trimethylsilyl)-1-alkanol was obtained from the ether extracts after removal of the solvent, followed by distillation using Vigreux column (*ca.* 2 × 30 cm). Yields, boiling points, and spectral data are given in Table 2.

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6) In this experiment, a small amount of trimethylsilyl enol ether of the corresponding acyltrimethylsilane[4e] was also formed. The formation is attributable to the existence of sodium hydroxide formed on the surface of metallic sodium.

7) Trimethylsilyl 2,2-dimethylpropionate also afforded the corresponding type **2** product. We are indebted to Dr. J. P. Picard for his correction of our mistake in the preliminary report.[3]

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