Electrogenerated Acid-Assisted Preparation of Ethers from Aldehydes and Ketones

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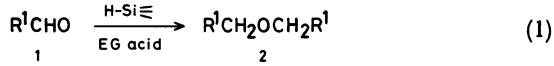
Synopsis. Symmetrical and unsymmetrical ethers are prepared from carbonyl compounds and alkoxytrimethylsilanes in the presence of hydrosilane by using an electrogenerated acid catalyst.

Hydrosilane has been investigated as a good reducing agent for the preparation of ethers from carbonyl compounds in the presence of strong acids such as trifluoroacetic acid,[1] trimethylsilyl triflate,[2] and boron trifluoride etherate.[3] However, these acids have their own problems about their preparation and handling in a practical sense. Recently, trityl perchlorate has also been shown to work as an effective catalyst for the same synthetic purpose.[4]

On the other hand, we have reported that electrogenerated acid (EG acid) played a role of catalyst for the acetalization of ketones[5] and the transesterification of glycerides.[6] Now, we found that when a mixture of carbonyl compounds and alkoxytrimethylsilane was treated with EG acid[7] in situ in the presence of hydrosilane (H-Si ≤) in dichloromethane, the corresponding ethers were obtained as a sole product.

All experiments were carried out using platinum electrodes in a simple undivided cell. A mixture of aldehyde and hydrosilane (1.2 equiv.) in dichloromethane containing lithium perchlorate and tetrabutylammonium perchlorate was electrolyzed to give the symmetrical ether only by passing a small quantity of electricity (Eq. 1). Under the same conditions, the electrolysis of the carbonyl compounds with alkoxysilanes afforded the corresponding unsymmetrical ethers (Eq. 2).



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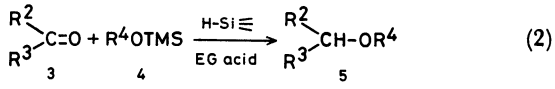

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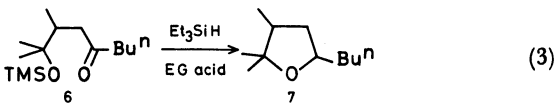
As shown in Table 1, we have examined the conversion by using triethylsilane and phenyldimethylsilane as reducing agents, but no significant differences were observed. The present procedure is well-suited for the preparation of alkyl and benzyl ethers. Unsymmetrical ethers could be obtained when allyl-, propargyl-, and 3-phenylpropyl-substituted alkoxysilanes were used as nucleophiles. The results are summarized in Table 2. Phenol trimethylsilyl ether, however, did not work in a similar fashion. Activated carbonyl groups such as α,β-enones and β-keto esters can be led to the corresponding ethers. It is interesting to note that unprotected hydroxy ketones did not give any desired ethers, the siloxy ketone **6**, however, undergoes intramolecular version to give the corresponding tetrahydrofuran ring **7** (Eq. 3). Above results reveal that EG



(3)

Table 1. EG Acid-Assisted Preparation of Symmetrical Ethers from Aldehydes

Run	Compound	R^1	H-Si ≤[a]	F/mol	Yield/%
1	**2a**	C_6H_5-	A	0.22	91.0
2	**2a**	C_6H_5-	B	0.07	95.7
3	**2b**	4-$CH_3C_6H_4$-	B	0.04	94.5
4	**2c**	4-ClC_6H_4-	B	0.04	86.3
5	**2d**	n-C_6H_{13}-	B	0.15	91.8

a) A: Et_3SiH, B: $PhSi(Me)_2H$.

Table 2. EG Acid-Assisted Preparation of Unsymmetrical Ethers from Aldehydes and Ketones

Run	Compound	R^2	R^3	R^4	H-Si ≤[a]	F/mol	Yield/%
6	**5a**	C_6H_5-	H	$C_6H_5(CH_2)_3$-	B	0.06	98.8
7	**5b**	C_6H_5-	H	CH_2=$CHCH_2$-	A	0.20	71.2
8	**5c**	C_6H_5-	H	CH≡CCH_2-	A	0.06	95.0
9	**5d**	C_6H_5-	H	-$(CH_2)_2$-	B	0.34	63.2[b]
10	**5e**	C_6H_5CH=CH-	H	CH_2=$CHCH_2$-	A	0.45	51.1
11	**5f**	C_6H_5CH=CH-	H	CH≡CCH_2-	A	0.30	49.8
12	**5g**	C_6H_5-	CH_3	$C_6H_5(CH_2)_3$-	B	0.15	79.9
13	**5h**	C_2H_5-	CH_3	$C_6H_5(CH_2)_3$-	B	0.30	94.8
14	**5i**	n-C_6H_{13}-	H	$C_6H_5(CH_2)_3$-	B	0.06	81.9
15	**5j**	-CH_2COOMe	CH_3	$C_6H_5(CH_2)_3$-	A	0.20	86.6[c]

a) A: Et_3SiH, B: $PhSi(Me)_2H$. b) Dibenzyl ether was obtained in 27.4% yield. c) The amount of $LiClO_4$ used was 0.3 molar equivalent.

acid is sufficient to activate carbonyl functions for the formation of ether linkages. Furthermore, EG acid can entry in a new class of acid catalyst, because arbitrarily controlable electricity can reflect the nature of EG acid generated in the medium.

Experimental

General Procedure for the Symmetrical Ether 2. A mixture of aldehyde **1** (1.0 mmol), hydrosilane (1.2 mmol), *n*-Bu_4NClO_4 (0.1 mmol), and $LiClO_4$[8] (0.1 mmol) was dissolved in CH_2Cl_2 (3 ml) in an undivided cell. The resulting solution was electrolyzed under constant current (1.67 mA cm^{-2}) with two platinum foil electrodes (1.5 cm^2) at room temperature. After the completion of the reaction, one drop of triethylamine was added and the solution was concentrated. The residue was chromatographed on SiO_2 to give the symmetrical ether.

General Procedure for the Unsymmetrical Ether 5. A mixture of carbonyl compound **3** (1.0 mmol), alkoxysilane **4** (1.2 mmol), *n*-Bu_4NClO_4 (0.1 mmol), and $LiClO_4$ (0.1 mmol) was dissolved in CH_2Cl_2 (3 ml) in an undivided cell. The mixture was electrolyzed under constant current (1.67 mA cm^{-2}) with platinum electrodes at ambient temperature. After 5 min, hydrosilane (1.2 mmol) was added dropwise and the electrolysis was continued. After the completion of the reaction, the same workup and purification as above afforded the corresponding unsymmetrical ether.

Preparation of the Tetrahydrofuran Derivative 7. A mixture of the siloxy ketone **6** (27 mg, 0.1 mmol), triethylsilane (0.12 mmol), $LiClO_4$ (0.03 mmol) and *n*-Bu_4NClO_4 (0.03 mmol) was dissolved in CH_2Cl_2 (3 ml) in an undivided cell. The solution was electrolyzed under constant current (1.33 mA cm^{-2}) with platinum electrodes at ambient temperature. After 20 min, the same workup and purification as above afforded the compound **7** (13 mg) in 71.0% yield.

Spectral and Physical Data. 2a: Bp 125.0—126.5 °C/2.0 mmHg (1 mmHg=133.322 Pa); IR (neat) 2920, 1602, 1090 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=4.52 (s, 4H, CH_2), 7.28 (s, 10H, C_6H_5).

2b: Mp 60—62 °C; IR (Nujol) 2905, 1115 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=2.33 (s, 6H, CH_3), 4.48 (s, 4H, CH_2), 7.16 (s, 10H, C_6H_5).

2c: Mp 44—45 °C; IR (Nujol) 2920, 1600, 1120 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=4.47 (s, 4H, CH_2), 7.24 (s, 8H, C_6H_4).

2d: Bp 82—85 °C/1.5 mmHg; IR (neat) 2945, 2921, 1110 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.60—1.05 (m, 6H, CH_3), 1.05—2.00 (broad, 20H, CH_2), 3.38 (m, 4H, CH_2).

5a: Bp 80—83 °C/1—2.0 mmHg; IR (neat) 2920, 2855, 1605, 1100 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.60—2.15 (m, 2H, CH_2), 2.45—2.85 (m, 2H, CH_2), 3.42 (t, J=6 Hz, 2H, CH_2O), 4.42 (s, 2H, CH_2O), 7.10 (s, 5H, C_6H_5), 7.22 (s, 5H, C_6H_5).

5b: Bp 80—82 °C/2.0 mmHg; IR (neat) 1640, 1600, 1100 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=3.87—4.08 (m, 2H, CH_2), 4.47 (s, 2H, CH_2), 5.00—5.45 (m, 2H, CH_2=), 5.63—6.27 (m, 1H, CH=), 7.26 (s, 5H, C_6H_5).

5c: Bp 77—80 °C/1.5 mmHg; IR (neat) 3280 (≡C-H), 2845, 2110 (C≡C), 1090 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=2.46 (t, J=2.5 Hz, 1H, ≡C-H), 4.18 (d, J=2.5 Hz, 2H, CH_2), 4.60 (s, 2H, CH_2), 7.34 (s, 5H, C_6H_5).

5d: Bp 118—120 °C/1.5 mmHg; IR (neat) 2920, 2845, 1605, 1100 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=3.17 (s, 4H, CH_2), 4.57 (s, 4H, CH_2), 7.31 (s, 10H, C_6H_5).

5e: Bp 95—97 °C/2.0 mmHg; IR (neat) 2900, 2840, 1640 (C=C), 1110 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=3.90—4.12 (m, 4H, CH_2), 4.91—5.49 (m, 2H, =CH_2), 5.61—6.75 (m, 3H, =C-H), 6.96—7.57 (m, 5H, C_6H_5). Anal. ($C_{12}H_{14}O$) C, H.

5f: Bp 110—120 °C/2.0 mmHg; IR (neat) 3270 (≡C-H), 2100 (C≡C), 1095 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=2.41 (t, J=2.5 Hz, 1H, ≡C-H), 5.95—6.85 (m, 2H, CH=CH), 7.01—7.46 (m, 5H, C_6H_5). Anal. ($C_{12}H_{12}O$) C,H.

5g: Bp 130—132 °C/1—2.0 mmHg; IR (neat) 2965, 2830, 1605, 1105 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.45 (d, J=6 Hz, 3H, CH_3), 1.60—2.09 (m, 2H, CH_2), 2.48—2.84 (m, 2H, CH_2), 3.32 (t, J=6 Hz, 2H, CH_2), 4.37 (q, J=6 Hz, 1H, CH), 7.20 (s, 5H, C_6H_5), 7.31 (s, 5H, C_6H_5) ; Anal. ($C_{17}H_{20}O$) C, H.

5h: Bp 96—98 °C/2.0 mmHg; IR (neat) 2970, 2920, 1600, 1090 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.90 (t, J=7 Hz, 3H, CH_3), 1.12 (d, J=6 Hz, 3H, CH_3), 1.20—2.12 (m, 4H, CH_2, CH_2), 2.50—2.88 (m, 2H, CH_2), 3.05—3.70 (m, 3H, CH, CH_2), 7.20 (s, 5H, C_6H_5); Anal. ($C_{13}H_{20}O$) C, H.

5i: Bp 80—83 °C/1—2.0 mmHg; IR (neat) 2955, 2925, 1605, 1110 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.87 (m, 3H, CH_3), 1.31 (broad, 10H, CH_2), 1.50—2.10 (m, 2H, CH_2), 2.47—2.86 (m, 2H, CH_2), 3.37 (t, J=6 Hz, 2H, CH_2), 7.22 (s, 5H, C_6H_5); Anal. ($C_{16}H_{26}O$) C, H.

5j: Bp 85 °C/1.5 mmHg; IR (neat) 2970, 2940, 1735 (C=O), 1600, 1100 (C-O-C) cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.19 (d, J=6 Hz, 3H, CH_3), 1.64—2.10 (m, 2H, CH_2), 2.45 (d, d, J=6 Hz, 6 Hz, 2H, CH_2), 2.50—2.80 (m, 2H, CH_2), 3.42 (d, t, J=2.5 Hz, 6 Hz, 2H, CH_2), 3.65 (s, 3H, CH_3), 3.50—4.00 (m, 1H, CH), 7.18 (s, 5H, C_6H_5); Anal. ($C_{14}H_{20}O_3$) C, H.

7: IR (neat) 2960, 2940, 2830, 1140, 1070 cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.7—2.5 (m, 21H), 3.7—4.4 (m, 1H).

References

1) a) M. P. Doyle, D. J. DeBruyn, and D. A. Kooistra, *J. Am. Chem. Soc.*, **94**, 3659 (1972); b) M. P. Doyle, D. J. DeBruyn, S. J. Dnnellyl, D. A. Kooistra, A. A. Odubela, C. T. West, and S. M. Zommebelt, *J. Org. Chem.*, **39**, 2740 (1974); c) D. N. Kursanov, Z. N. Parnes, and N. M. Loim, *Synthesis*, **1974**, 633.

2) R. Noyori, S. Murata, and M. Suzuki, *Tetrahedron*, **37**, 3899 (1981).

3) M. P. Doyle, C. T. West, S. T. Donnelly, and C. C. Mcosker, *J. Organomet. Chem.*, **117**, 129 (1976).

4) J. Kato, N. Iwasawa, and T. Mukaiyama, *Chem. Lett.*, **1985**, 1743.

5) S. Torii and T. Inokuchi, *Chem. Lett.*, **1983**, 1349.

6) S. Torii, T. Inokuchi, K. Kondo, and H. Ito, *Bull. Chem. Soc. Jpn*, **58**, 1347 (1985).

7) S. Torii, Electroorganic Syntheses Part I, Oxidations Methods and Applications, Verlag Chemie, Weinheim (1985).

8) Both commercially available and recrystallized $LiClO_4$ and *n*-Bu_4NClO_4 were dried just before use.