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Reactions of oxalyl fluoride with electrophiles

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Abstract

The reactions of oxalyl fluoride with electrophiles in the presence of alkali metal fluoride were carried out. In the reaction with CF_3CH_2OTf ($Tf = CF_3SO_2$) or CH_3CH_2OTf, the synthesis of di-ether ($ROCF_2CF_2OR$) and mono-ether ($ROCF_2COF$) was achieved. The difference of the reactivities between these two compounds was discussed from the result of DFT calculations. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Oxalyl fluoride; Cesium fluoride; 1,2-Bis(2,2,2-trifluoroethoxy)-1,1,2,2-tetrafluoroethane; DFT calculation

1. Introduction

We have developed hydrofluoroethers (HFEs) as alternatives to chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) [1]. HFEs have almost zero ozone depleting potential (ODP) due to no chlorine atom in the molecules [2]. Many low global warming potential (GWP) compounds belong to HFEs.

One of the efficient methods to prepare HFEs is the reaction of perfluoroalkyl acyl fluoride with electrophiles in the presence of alkali metal fluoride [3]. In this viewpoint, oxalyl fluoride [4–8] is an interesting reagent because it has two carbonyl fluoride groups, which can be transformed to ether groups, in the molecule. Mono-ether is obtained from the reaction of one of carbonyl fluoride groups, and di-ether is obtained from the reaction of both groups. But few reactions of oxalyl fluoride to give ethers have been reported [9–11]. Moreover, the yield of di-ether was low or moderate, and the formation of mono-ether was not reported although it should be an intermediate of di-ether. In this paper, the synthesis of mono- and di-ether was achieved and the effect of the electrophiles was discussed.

2. Results and discussion

2.1. Reactions of oxalyl fluoride with CF_3CH_2OTf

The reactions of oxalyl fluoride (**1**) with CF_3CH_2OTf (**2**) [12][1] in the presence of alkali metal fluoride gave not only mono-ether (**3**) and di-ether (**4**) but also 1,1,1,2-tetrafluoroethane (**5**) (Scheme 1). After the reaction, methanol was added to the reaction mixture to change the reactive acyl fluoride of **3** to methyl ester.

In this reaction, CsF is more effective than KF (Table 1, Entries 1 and 2). It is due to the difference of the stability of the alkoxide salts; that is, the cesium alkoxide is more stable than potassium alkoxide [13]. Even if the reaction was carried out with KF at high temperature, the yield and the selectivity were still low (Table 1, Entry 3). In the reaction using CsF for a short period, the yields of the products were low (Table 1, Entry 4). The selectivity of products depends on the molar ratio of **1** and **2** and CsF (Table 1, Entries 5, 6 and 7). The more **1** was added, the more **3** was obtained. To add an excess amount of CsF was not efficient because a large amount of fluorinated product **5** was obtained. To prepare alkoxide in advance, **1**, CsF and diglyme were

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[1] The preparation and reactivity of **2** have been reported by Burdon and Mcloughlin [12]. In this paper, **2** was prepared by other method and MS and NMR data were shown in Section 3.

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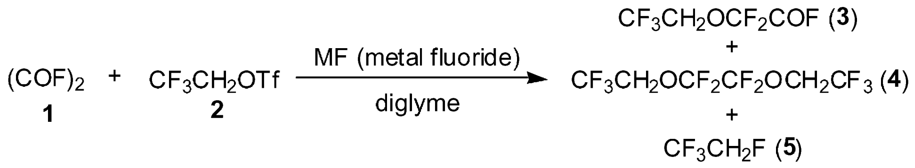


Scheme 1. Reactions of oxalyl fluoride with CF_3CH_2OTf.

Table 1
Reactions of oxalyl fluoride with CF_3CH_2OTf[a]

Entry	MF	Molar ratio of **1**:**2**:MF	Temperature (°C)	Time (h)	Yield (%) from **2**[c]		
					3	**4**	**5**
1	CsF	1:2:4	RT	24	1	49	21
2	KF	1:2:4	RT	72	4	6	3
3	KF	1:2:4	70	24	16	17	16
4	CsF	1:2:4	RT	3	5	11	7
5	CsF	2:2:4	RT	24	12	56	19
6	CsF	2:2:8	RT	24	1	19	76
7	CsF	5:2:4	RT	24	45	11	40
8[b]	CsF	2:2:4	RT	24	11	58	19

[a] **1** was added to the mixture of **2**, MF and diglyme.

[b] **2** was added to the mixture of **1**, MF and diglyme.

[c] Yields were determined by NMR.

mixed before adding **2**. However, the yields of products were unchanged (Table 1, Entries 5 and 8).

2.2. Solvent effect

The reactions of **1** with **2** in various solvents were carried out (Table 2). In the reaction of trifluoroacyl halide in the presence of alkali metal fluoride, glyme-type solvents are often used because the yields are usually high [14–16]. Diglyme and tetraglyme gave good yields of products (Table 2, Entries 1 and 2). In using DMF as the solvent, **3** and **4** were detected by GC and NMR, however, there were many other products that were difficult to identify (Table 2, Entry 3). In the complex product $CF_3OCH_2CF_3$ was detected. It has been reported that oxalyl fluoride decomposed in the presence of KF and generated COF_2 [17]. It was considered that $CF_3OCH_2CF_3$ was obtained by the reaction of COF_2 with **2**. In using acetonitrile or THF as solvent, the reaction did not proceed effectively (Table 2, Entries 4 and 5).

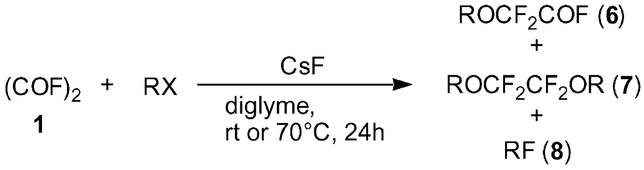
Table 2
Solvent effect on the reaction of oxalyl fluoride with CF_3CH_2OTf[a]

Entry	Solvent	Recovery of **2** (%)	Yield (%) from **2**[c]		
			3	**4**	**5**
1	Diglyme	5	12	56	19
2	Tetraglyme	0	10	63	18
3[b]	DMF	0	–	–	–
4	CH_3CN	83	5	7	6
5	THF	100	0	0	0

[a] **1** (2.0 mmol) was added to the mixture of **2** (2.0 mmol), CsF (4.0 mmol) and solvent (5 ml).

[b] Complex products.

[c] Yields were determined by NMR.



Scheme 2. Reactions of oxalyl fluoride with electrophiles.

2.3. Reactions of oxalyl fluoride with electrophiles

The reactions of **1** with some electrophiles were carried out (Scheme 2, Table 3). In the reaction of **1** with CF_3CH_2OTs (Ts = p-$CH_3C_6H_4SO_2$), CF_3CH_2OMs (Ms = CH_3SO_2) or CF_3CH_2I, neither **6** nor **7** were obtained (Table 3, Entries 2–4). In the reactions of **1** with CH_3CH_2OTf, the selectivity of the products was different from that in the reaction with CF_3CH_2OTf. In using 0.5 or 1.0 equimolar amount of **1** to CF_3CH_2OTf, di-ether (**7**) was the main product (Table 3, Entries 1 and 6). On the other hand, in the reaction of **1** with CH_3CH_2OTf, mono-ether (**6**) was the main product in using 1.0 equimolar amount of **1** to CH_3CH_2OTf, and di-ether (**7**) was the main product in using 0.5 equimolar amount of **1** to CH_3CH_2OTf (Table 3, Entries 5 and 7).

In the reactions of oxalyl fluoride with CF_3CH_2OTf and CH_3CH_2OTf, the selective synthesis of mono- and di-ethers was achieved. In the reaction with CH_3CH_2OTf, the selectivity can be controlled by using theoretical amount of oxalyl

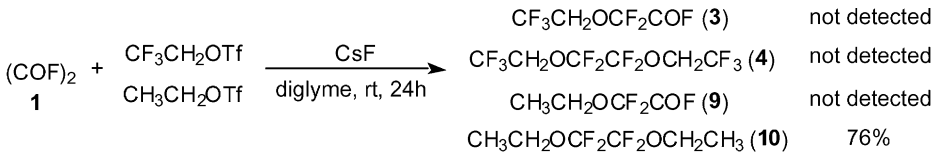
Table 3
Reactions of oxalyl fluoride with electrophiles[a]

Entry	RX	Molar ratio of **1**:RX:CsF	Temperature (°C)	Yield (%) from RX[c]		
				6	**7**	**8**
1	CF_3CH_2OTf	1:1:2	RT	12	56	19
2	CF_3CH_2OTs	1:1:2	70	0	0	0
3	CF_3CH_2OMs	1:1:2	70	0	0	0
4	CF_3CH_2I	1:1:2	70	0	0	20
5	CH_3CH_2OTf	1:1:2	RT	71	18	4
6[b]	CF_3CH_2OTf	1:2:4	RT	1	49	21
7[b]	CH_3CH_2OTf	1:2:4	RT	9	78	9

[a] **1** (2.0 mmol) was added to the mixture of RX (2.0 mmol), CsF (4.0 mmol) and diglyme (5 ml).

[b] **1** (1.0 mmol) was added to the mixture of RX (2.0 mmol), CsF (4.0 mmol) and diglyme (5 ml).

[c] Yields were determined by NMR.



Scheme 3. Competitive reaction of oxalyl fluoride with CF_3CH_2OTf and CH_3CH_2OTf.

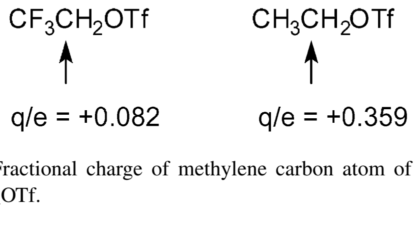
fluoride. But in the reaction with CF_3CH_2OTf, di-ether was obtained predominantly even in the reaction with the same molar amount of oxalyl fluoride, and an excess amount of oxalyl fluoride was necessary to synthesize the mono-ether. It is supposed that the mono-ether $CF_3CH_2OCF_2COF$ could form the alkoxide with CsF easier than the mono-ether $CH_3CH_2OCF_2COF$ by the electron withdrawing CF_3 group.

2.4. Competitive reaction of oxalyl fluoride with CF_3CH_2OTf and CH_3CH_2OTf

To clarify the difference of reactivity of the two electrophiles, the competitive reaction was carried out. The reaction was carried out as follows: a small amount of oxalyl fluoride (0.5 mmol) was added to the mixture of CF_3CH_2OTf (2.0 mmol) and CH_3CH_2OTf (2.0 mmol) and CsF (4.0 mmol) and diglyme (5 ml). As a result, the product derived from oxalyl fluoride was only $CH_3CH_2OCF_2CF_2OCH_2CH_3$ (**10**) (Scheme 3). This result means that the electrophilic reactivity of CH_3CH_2OTf toward the alkoxide from oxalyl fluoride and CsF was much higher than that of CF_3CH_2OTf. It is considered that the higher electrophilicity of CH_3CH_2OTf made the yields of mono- and di-ethers higher.

2.5. DFT calculation

It is natural that the steric hindrance is one of the reasons for the difference of the electrophilic reactivity between CF_3CH_2OTf and CH_3CH_2OTf. To consider the electrostatic effect of the two electrophiles, density functional theory (DFT) calculations were carried out. The atomic positions in the molecule and their fractional charge values were obtained by using B3LYP/6-31G* and B3LYP/6-311G(2d,p) with CHELPG method [18]. The calculation showed the fractional charge of the methylene carbon atom of CH_3CH_2OTf is more positive than that of CF_3CH_2OTf (Scheme 4). It was concluded that the electrophilic reactivity of CF_3CH_2OTf and CH_3CH_2OTf depends on the fractional charge of the carbon atom that is attacked by nucleophiles in addition to the steric hindrance.



Scheme 4. Fractional charge of methylene carbon atom of CF_3CH_2OTf and CH_3CH_2OTf.

3. Experimental details

All of the organic reagents and solvents were purified prior to use. Oxalyl fluoride was used without purification. CsF and KF were dried by heating at 300 °C under vacuum for 6 h and stored in the dry box. ^1H and ^{19}F NMR were measured with JNM-EX270 (JEOL, 270 MHz) using TMS and $CFCl_3$ as an internal standard and $CDCl_3$ as a solvent. MS spectra were measured with the Hewlett-Packard 5790 series system equipped with a jet separator for the 5890A GC.

3.1. Preparation of 2,2,2-trifluoroethyl trifluoromethanesulfonate (2)

Under N_2 atmosphere, sodium hydride (325 mmol) and ether (150 ml) were placed in a 500 ml three-neck flask with a dropping funnel. 2,2,2-Trifluoroethanol (300 mmol) was added over a period of 30 min at 0 °C. The reaction mixture was warmed up to ambient temperature and stirred for 1 h. Trifluoromethanesulfonyl chloride (294 mmol) was added over a period of 30 min at 0 °C. The reaction mixture was warmed up to ambient temperature again and stirred for 1 h. The reaction mixture was poured into water and the organic layer was separated. The aqueous layer was extracted with ether (100 ml). The combined organic layer was washed with aqueous saturated $NaHCO_3$ (50 ml) and dried with $MgSO_4$. The product was purified by distillation and 0.225 mol (77%) of **2** was obtained.

^1H NMR: δ: 4.71 (2H, q, $J = 7.4$ Hz, CH_2); ^{19}F NMR: δ: −74.5 (3F, br, CF_3SO_2), −74.7 (3F, tq, $J = 7.4$, 1.1 Hz, CF_3CH_2); m/e: 163 ($M - CF_3^+$), 133 ($CF_3SO_2^+$), 99 ($CF_3CH_2O^+$), 83 ($CF_3CH_2^+$), 69 (CF_3^+).

3.2. A typical experimental procedure for the reaction of oxalyl fluoride with electrophiles

CsF (4.0 mmol) was placed in a stainless-steel reactor equipped with a stop valve (volume: 25 ml) in the dry box (Table 1, Entry 1). The reactor was heated under vacuum to remove moisture from CsF and the reactor. CF_3CH_2OTf (2.0 mmol) and diglyme (5 ml) were placed into the reactor in the dry box. After cooling with liquid N_2, oxalyl fluoride (1.0 mmol) was introduced to the reactor with a vacuum line. The reactor was warmed up to ambient temperature and stirred for 24 h. Products were fractionated through traps at −78 and −196 °C. After fractionations, methanol (10 mmol) was introduced to the −78 °C trap with a vacuum line. The structures of the products were determined by GC–MS, ^1H

and ^{19}F NMR spectra. The ratio of the products was determined by ^{1}H and ^{19}F NMR spectra.

3.2.1. Methyl ester of **3**: methyl 2,2-difluoro-2-(2,2,2-trifluoroethoxy)acetate

^{1}H NMR: δ: 3.95 (3H, s), 4.32 (2H, q, $J = 7.9$ Hz); ^{19}F NMR: δ: -74.8 (3F, tt, $J = 2.3$, 7.9 Hz), -81.0 (2F, q, $J = 2.3$ Hz); *m/e*: 189 ($M - F^+$), 149 ($CF_3CH_2OCF_2^+$), 83 ($CF_3CH_2^+$), 69 (CF_3^+).

3.2.2. 1,2-Bis(2,2,2-trifluoroethoxy)-1,1,2,2-tetrafluoroethane (**4**)

^{1}H NMR: δ: 4.31 (4H, q, $J = 7.8$ Hz); ^{19}F NMR: δ: -75.0 (6F, tt, $J = 2.3$, 7.8 Hz), -91.2 (4F, q, $J = 2.3$ Hz); *m/e*: 279 ($M - F^+$), 229 ($M - CF_3^+$), 149 ($CF_3CH_2OCF_2^+$), 83 ($CF_3CH_2^+$), 69 (CF_3^+).

3.2.3. Methyl ester of **9**: methyl 2-ethoxy-2,2-difluoroacetate

^{1}H NMR: δ: 1.34 (3H, t, $J = 7.1$ Hz), 3.90 (3H, s), 4.05 (2H, q, $J = 7.1$ Hz); ^{19}F NMR: δ: -80.1 (2F, s); *m/e*: 126 ($M - C_2H_4^+$), 95 ($CH_3CH_2OCF_2^+$), 59 ($COOCH_3^+$), 29 ($CH_3CH_2^+$), 15 (CH_3^+).

3.2.4. 1,2-Diethoxy-1,1,2,2-tetrafluoroethane (**10**)

^{1}H NMR: δ: 1.34 (6H, t, $J = 7.1$ Hz), 4.04 (4H, q, $J = 7.1$ Hz); ^{19}F NMR: δ: -91.1 (4F, s); *m/e*: 95 ($CH_3CH_2OCF_2^+$), 29 ($CH_3CH_2^+$).

3.3. Competitive reaction of oxalyl fluoride with CF_3CH_2OTf and CH_3CH_2OTf

CsF (4.0 mmol) was placed in a stainless-steel reactor equipped with a stop valve (volume: 25 ml) in the dry box. The reactor was heated under vacuum to remove moisture from CsF and the reactor. CF_3CH_2OTf (2.0 mmol) and CH_3CH_2OTf (2.0 mmol) and diglyme (5 ml) were placed into the reactor in the dry box. After cooling by liquid N_2, oxalyl fluoride (0.5 mmol) was introduced to the reactor with a vacuum line. The reactor was warmed up to ambient temperature and stirred for 24 h. Products were fractionated through traps at -78 and -196 °C. After fractionations, methanol (10 mmol) was introduced to -78 °C trap with a vacuum line. The ratio of the products was determined by ^{1}H and ^{19}F NMR spectra.

3.4. Calculations

DFT calculations were carried out using Gaussian '94 [19]. The atomic positions in the molecule were obtained by using B3LYP/6-31G*. The fractional charge was calculated by using B3LYP/6-311G(2d,p) with CHELPG method.

4. Conclusion

We have demonstrated the reactions of oxalyl fluoride with electrophiles in the presence of alkali metal fluoride. In the reaction of oxalyl fluoride with CF_3CH_2OTf or CH_3CH_2OTf, the synthesis of mono-ether and di-ether was achieved. The reactivity of CH_3CH_2OTf toward alkoxide is much higher than that of CF_3CH_2OTf. DFT calculations supported the difference of the reactivity of the two electrophiles.

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References

[1] A. Sekiya, S. Misaki, J. Fluorine Chem. 101 (2000) 215–221.

[2] A.R. Ravishankara, A.A. Turnipseed, N.R. Jensen, S. Barone, M. Mills, C.J. Howard, S. Solomon, Science 263 (1994) 71–75.

[3] O. Scherer, et al., DE 1294949 (1967).

[4] C. Tullock, J. Org. Chem. 25 (1960) 2016–2019.

[5] N. Fukuhara, L. Bigelow, J. Chem. Soc. 63 (1941) 788–791.

[6] I.L. Knunyants, et al., J. Gen. Chem. USSR (Engl. Transl.) 37 (1967) 2485–2490.

[7] W.A. Herrmann, S.J. Eder, W. Scherer, Angew. Chem. 104 (1992) 1371–1373.

[8] K. Takata, M. Takesue, Y. Iseki, T. Sata, J. Fluorine Chem. 75 (1995) 163–168.

[9] V.W. Schwertfeger, G. Siegemund, Angew. Chem. 92 (1980) 123.

[10] M. Nishida, A. Vij, R.L. Kirchmeier, J.M. Shreeve, Inorg. Chem. 34 (1995) 6085–6092.

[11] Y. Yamamoto, N. Koike, A. Yoshida, T. Takaai, Jpn. Kokai Tokkyo Koho, JP 63225327 (88225337).

[12] J. Burdon, V.C.R. Mcloughlin, Tetrahedron 21 (1965) 1–4.

[13] M.E. Redwood, C.J. Willis, Can. J. Chem. 43 (1965) 1893–1898.

[14] Y. Goto, S. Yamashita, H. Ito, A. Suga, J. Mochizuki, N. Nagasaki, A. Sekiya, Jpn. Kokai Tokkyo Koho, JP 2589050.

[15] H. Ito, Y. Goto, S. Yamashita, A. Suga, J. Mochizuki, N. Nagasaki, A. Sekiya, Jpn. Kokai Tokkyo Koho, JP 2589959.

[16] H. Ito, Y. Goto, S. Yamashita, A. Suga, J. Mochizuki, N. Nagasaki, A. Sekiya, Jpn. Kokai Tokkyo Koho, JP 2589960.

[17] J.D.O. Anderson, W.T. Pennington, D.D. DesMarteau, Inorg. Chem. 32 (1993) 5079–5083.

[18] C.M. Breneman, K.B. Wiberg, J. Comp. Chem. 11 (1990) 361–373.

[19] M.J. Frisch, G.W. Trucks, H.B. Schlegel, P.M.W. Gill, B.G. Johnson, M.A. Robb, J.R. Cheeseman, T. Keith, G.A. Petersson, J.A. Montgomery, K. Raghavachari, M.A. Al-Laham, V.G. Zakrzewski, J.V. Ortiz, J.B. Foresman, J. Cioslowski, B.B. Stefanov, A. Nanayakkara, M. Challacombe, C.Y. Peng, P.Y. Ayala, W. Chen, M.W. Wong, J.L. Andres, E.S. Replogle, R. Gomperts, R.L. Martin, D.J. Fox, J.S. Binkley, D.J. Defrees, J. Baker, J.P. Stewart, M. Head-Gordon, C. Gonzalez, J.A. Pople, Gaussian, Inc., Pittsburgh, PA, 1995.