

Versatile application of trifluoromethyl triflate [☆]

Alexander A. Kolomeitsev ^{a,b,*}, Mikhail Vorobyev ^b, Hartmut Gillandt ^c

^a Institute of Inorganic and Physical Chemistry, University of Bremen, Leobener Strasse, 28334 Bremen, Germany

^b Hansa Fine Chemicals GmbH, Fahrenheitstr. 1, 28359 Bremen, Germany

^c SciChem GmbH, Fahrenheitstr. 1, 28359 Bremen, Germany

Received 17 September 2007; revised 31 October 2007; accepted 20 November 2007

Available online 23 November 2007

Abstract

Hydrolytically stable and easy to handle trifluoromethyl triflate was found to be a liquid reservoir of ‘masked’ difluorophosgene. Anhydrous F⁻ sources cleave the S–O bond in trifluoromethyl triflate yielding quantitatively the trifluoromethanolate salts, being useful trifluoromethoxy group carriers. Reaction of trifluoromethanolates with in situ generated from *o*-trimethylsilylphenyl triflate benzyne leads to (trifluoromethoxy)benzene and fluorobenzene (ratio 85:15). Whereas an addition of trifluoromethanethiolate anion across a triple bond of benzyne leads to [(trifluoromethyl)sulfanyl]benzene solely.

© 2007 Elsevier Ltd. All rights reserved.

Keywords: Trifluoromethyl triflate; Trifluoromethanolates; Trifluoromethyl ethers; Arynes; Delocalized lipophilic cations

Organic triflates are of great interest and wide utility in organic synthesis.² However, trifluoromethyl trifluoromethanesulfonate, CF₃OSO₂CF₃, (TFMT, **1**)³ was the subject of just a few controversial reports.^{4–6} Though **1** is a commercially available compound, it can be simply prepared from triflic acid or its anhydride.³ Contrary to the relatively unstable alkyl triflates, **1** (bp 20 °C) is a thermally stable and a resistant to hydrolysis compound. Principally, **1** has a potential to be either CF₃ or CF₃SO₂ transfer reagent. Trifluoromethylation of pyridine was observed by Olah and Ohyama (path A, Fig. 1).⁴ Whereas Martin and Taylor found out that reactions of **1** with diverse nucleophiles resulted in the quantitative fragmentation of **1** to CF₃SO₂F and COF₂ (path B).⁶ This limits the synthetic utility of **1**. An attempt to obtain CsOCF₃ from **1** and CsF also failed.⁶

Alkyl, aryl, and heteroaryl trifluoromethyl ethers are important intermediates in the synthesis of liquid crystals, which are used in active matrix liquid crystal displays, as

pesticides, and for drug design.⁷ The oxidative desulfurization–fluorination of alkyl xanthates is the most widely used procedure for the synthesis of primary AlkOCF₃ derivatives on laboratory and semi-industrial scale.⁷ It includes an operation with huge excesses of highly toxic and flammable carbon disulfide, methyl iodide and Py/HF (Olah’s reagent). Unfortunately, in the case of the most synthetically useful secondary alcohols the yield of trifluoromethyl ethers is low. The method does not work at all in the case of benzyl alcohols.⁷ It was also anticipated that the reactions of (Me₂N)₃S⁺ –OCF₃ (TAS⁺ –OCF₃), prepared from a toxic COF₂ and TASF, with alkyl triflates and some alkyl bromides would produce AlkOCF₃ compounds. However, an operation with carbonyldifluoride limits the laboratory application.⁸

In dramatic contrast to alkali metal methanolates, the respective trifluoromethanolates exist in equilibrium with

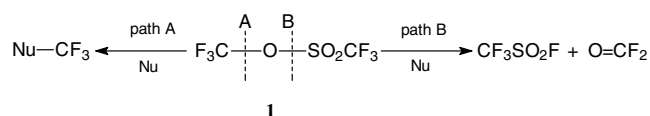


Fig. 1.

[☆] See Ref. 1.

* Corresponding author. Tel.: +49 (0) 421 218 91 72; fax: +49 (0) 421 173 10 80.

E-mail address: kolomeitsev@uni-bremen.de (A. A. Kolomeitsev).

alkali metal fluoride and difluorophosgene. Therefore, in nucleophilic displacement reactions these species can either transfer CF_3O unit, or provide a fluoride ion. Due to electron-withdrawing effect of pseudo halogen CF_3O group, the trifluoromethanol^{9a,b} itself, prepared at low temperature from dangerous to handle CF_3OCl and HF , is a strong O–H acid (gas-phase acidity $\Delta H^0 = 329.8$ kcal/mol).¹⁰ Because of rapid elimination of HF , it decomposes readily above -20°C .⁹ Quite recently, the results on a mild generation of CF_3OH from CF_2O and HF (maximum equilibrium concentration of CF_3OH ca. 33 mol %) were reported.^{9c} Insoluble in aprotic solvents cesium trifluoromethanolate was found to be the only reasonably stable perfluorinated alkali metal methanolate.¹¹

Nevertheless, the in situ generation of potassium and cesium trifluoromethanolate in industrially important processes has been postulated¹² and easily soluble in aprotic solvents perfluoroalkanolates with lipophilic and delocalized lipophilic cations were utilized as facile $\text{R}_\text{F}\text{O}^-$ transfer carriers.^{8,13,14} Therefore, our first objective was to provide a new and convenient means of access to the stable CF_3O^- transfer reagents, which allows to exclude an operation with a toxic difluorophosgene.

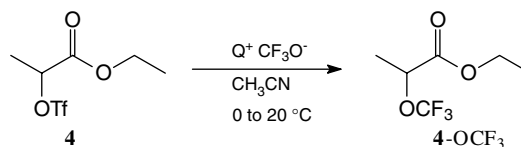
This Letter reports: (1) a convenient access to the trifluoromethanolate from **1**; (2) their application as trifluoromethoxy carriers in nucleophilic displacement reactions; (3) the first results obtained with CF_3O^- anion (also with CF_3S^-) in addition reactions across a triple bond of in situ generated arynes. We have found that treatment of **1** with covalent **2a**,¹⁵ and ionic anhydrous F^- sources **2b–i**^{13,14,16–18} in CH_3CN (CH_2Cl_2 or diglyme) affords trifluoromethanolate **3a,f–i**, which are stable in solvent media, and trifluoromethanolate **3b–e**, which are stable in solid state and easily soluble in CH_3CN or CH_2Cl_2 (Scheme 1). After the separation of $\text{CF}_3\text{SO}_2\text{F}$ the solvent was removed in vacuum and the residues were washed with ether and dried in vacuum at -30°C for 3 h, providing salts **3b–e** in 97–99% yield (Scheme 1).²⁰ Surprisingly, salt **3a** can be distilled in static vacuum along with the solvent used.

Salts **3a–c,e** were also synthesized alternatively via COF_2 (Caution! COF_2 is extremely corrosive to human tissue. All work with this gas should be conducted in an efficient hood) reaction with **2a–c,e**, respectively.²¹

Under mild reaction conditions (CH_3CN , 0°C for 1 h, then 20°C for 2 h), salt **3b** readily reacted with the ethyl 2-((trifluoromethyl)sulfonyl)oxypropanoate (**4**) yielding, after a simple work up, the ethyl 2-(trifluoromethoxy)pro-

Table 1

Salts **3a,b,d,e–g** in reaction with **4** (^{19}F NMR study, yield of **4-OCF₃**, versus internal PhCF_3)



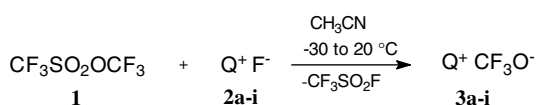
Entry	$\text{Q}^+ \text{CF}_3\text{O}^-$	4-OCF₃ (%)	4-F (%)
1		99	0
2	$(\text{Me}_2\text{N})_3\text{C}^+ \text{CF}_3\text{O}^-$ 3b	96	2
3	$(\text{Me}_2\text{N})_3\text{S}^+ \text{CF}_3\text{O}^-$ 3d	87	9
4	$\text{Me}_4\text{N}^+ \text{CF}_3\text{O}^-$ 3e	95	<2
5	$\text{Et}_3\text{NH}^+ \text{CF}_3\text{O}^-$ 3f	43	30
6	$\text{Cs}^+ \text{CF}_3\text{O}^-$ 3g	74	15

panoate (**4-OCF₃**) in 87% isolated yield (^{19}F NMR yield 96%, Table 1, entry 2). A similar result was obtained also via in situ generation of **3b** followed by the separation of $\text{CF}_3\text{SO}_2\text{F}$ and the addition of **4** (Table 2, entry 2).²²

Properties of the salts **3a,b,d,e–g** in reaction with **4** were compared. The reagents **3a–c,e** were selected as the CF_3O -carriers of choice (high ^{19}F NMR yield of **4-OCF₃** and chemoselectivity). Reactions (Table 1) were conducted on 1 mmol scale with 1.1 mmol of **3a,b,d,e–g** in 1.5 mL CH_3CN at 0°C (for 0.5 h), then at 20°C for 12 h. Reagents **3a–c,i** were applied to the synthesis of trifluoromethyl ethers from the functionalized secondary triflates **4**, **5**, benzyl bromide **6**, primary triflate **7**, and iodide **8** (Table 2).^{23,25,26}

Unfortunately, no $\text{S}_\text{N}2\text{Ar}$ trifluoromethoxylation occurred with **3b, e**. 4-Nitrobenzene-1,2-dicarbonitrile **9** readily undergoes fluorodenitration with **3b** to give **9-F**. Selective nucleophilic substitution of chlorine by fluoride (halex) occurs in the reaction of 2,4-dinitrochlorobenzene **10** with **3e**. Due to activation by two nitro groups the chloride is the most mobile leaving group in the multiply substituted substrate **10** (Table 2, entries 7 and 8). In this respect the behavior of **3b,e** differs from the reactivity of the related ionic trifluoromethanethiolates $\text{Q}^+\text{CF}_3\text{S}^-$ being highly efficient CF_3S -transfer reagents in the case of both aliphatic and aromatic nucleophilic substitution reactions.²⁷ No reaction occurs at all upon heating of 1-iodo-4-nitrobenzene **11** with CH_3CN solution of the copper trifluoromethanolate, CF_3OCu , **3j** (Table 2, entry 9). A solution of **3j** ($\delta_\text{F} -24.3$ ppm, br s, $\Delta_{1/2} = 374$ Hz) was obtained similarly to synthesis of CF_3SCu by treating of salt **3i** ($\delta_\text{F} -22.1$ ppm, br s, $\Delta_{1/2} = 277$ Hz) with CuBr in CH_3CN followed by the filtration of the quantitatively precipitated AgBr .²⁸

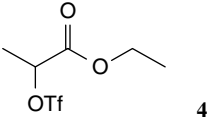
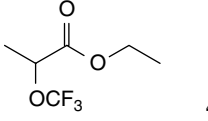
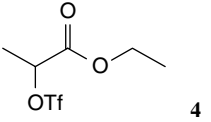
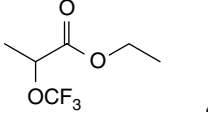
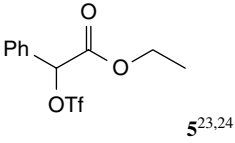
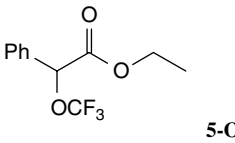
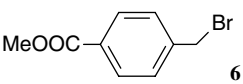
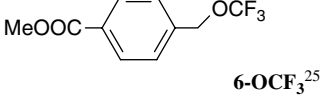
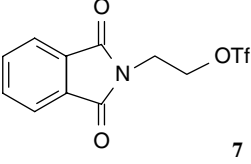
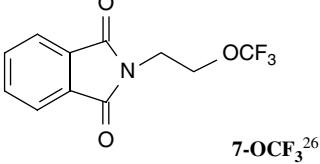
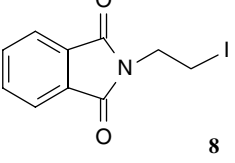
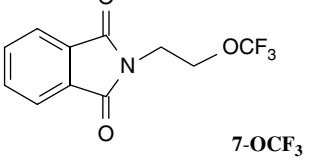
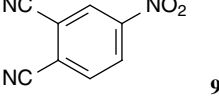
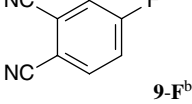
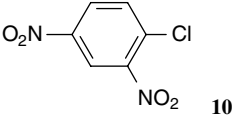
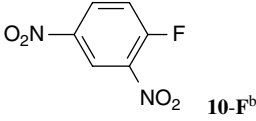
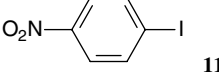
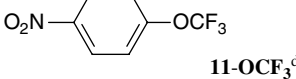
In contrast, the addition of the trifluoromethanolate anion across a triple bond of arynes²⁹ does lead to aryl trifluoromethyl ethers. In the reaction between *o*-trimethylsilylphenyl triflate (**12**) and **3c** (3 equiv) in CH_3CN /ether



$\text{Q}^+ \text{F}^- = [(\text{CH}_2\text{NMe})_2\text{CF}_2]$ (DFI) (a), $(\text{Me}_2\text{N})_3\text{C}^+ \text{Me}_3\text{SiF}_2^-$ (b), $[(\text{CH}_2\text{NMe})_2\text{CNMe}_2]^+ \text{Me}_3\text{SiF}_2^-$ (c), $(\text{Me}_2\text{N})_3\text{S}^+ \text{Me}_3\text{SiF}_2^-$ (d), Me_4N^+ (e), $\text{Et}_3\text{N}^+/\text{HF}$ (f), CsF (g), KF (s.d.) (h), AgF (i)

Scheme 1.

Table 2
Reactions of reagents **3a–c,e,i,j** with electrophiles **4–11**

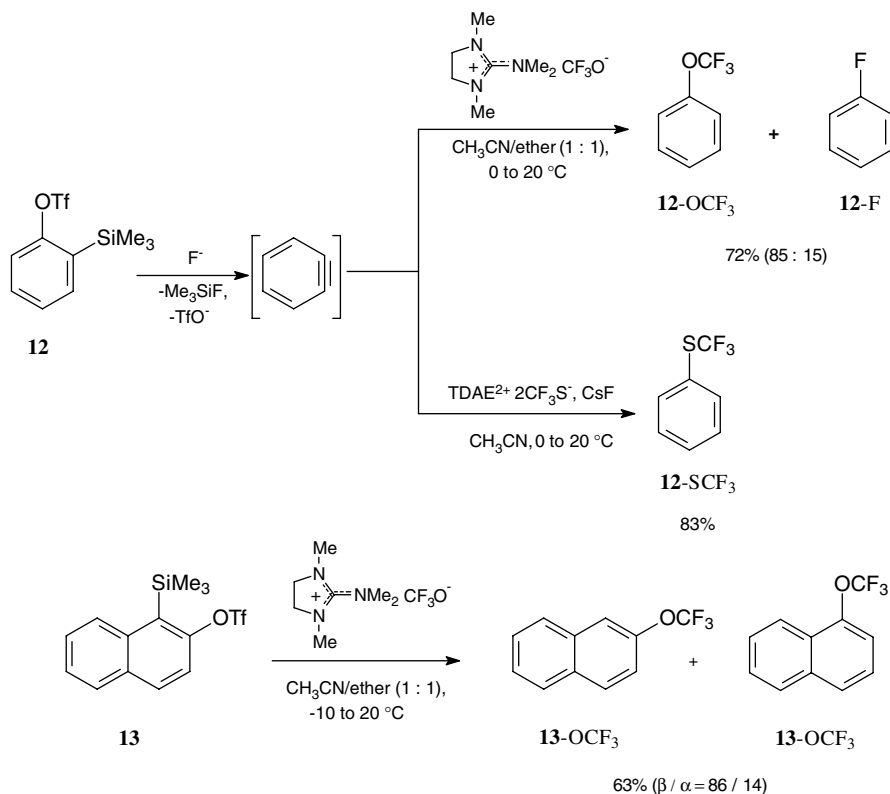
Entry	Reagent	Substrate	Products	Isolated (^{19}F NMR) yield ^a
1	3a	 4	 4-OCF₃	81(99)
2	3b	 4	 4-OCF₃ ²²	87(96)
3	3c	 5 ^{23,24}	 5-OCF₃ ²³	57(71)
4	3i	 6	 6-OCF₃ ²⁵	87(99)
5	3c	 7	 7-OCF₃ ²⁶	91(99)
6	3i	 8	 7-OCF₃	85(97)
7	3b	 9	 9-F ^b	87(96)
8	3e	 10	 10-F ^b	81(95)
9	3j^c	 11	 11-OCF₃ ^d	0

^a Characterized by ^1H , ^{13}C , and ^{19}F NMR methods and the molecular formulas for the novel compounds **4–6-OCF₃**^{22,23,25} were confirmed by HRMS method.

^b Reactions were performed in CH_3CN (20 °C for 12 h) with 2 equiv of **3b** (entry 7) and **3e** (entry 8), respectively.

^c **3j** was generated from **3i** and CuBr in CH_3CN at 20 °C.

^d Reaction was conducted in CH_3CN with 2 equiv of **3j** (80 °C for 12 h).



Scheme 2.

(1:1) we obtained the mixture (85:15) of (trifluoromethoxy)benzene **12-OCF₃** and fluorobenzene **12-F** in overall 72% yield (GC–MS, ¹⁹F NMR yield 90%) (Scheme 2). Comparable results were obtained in the presence and absence of CsF (2 equiv) as fluorodesilylating agent. On the contrary, the reaction of **12** with trifluoromethanethiolate salt²⁷ TDAE²⁺ 2SCF₃⁻ (or Me₄N⁺CF₃S⁻)/CsF system in CH₃CN led to [(trifluoromethyl)sulfanyl]benzene **12-SCF₃** solely (83%, ¹⁹F NMR 99%, no PhF was found).³⁰

Mechanistically, the process comprises the generation of benzyne from **12** and F-anion source (CsF or **3c**), followed by an addition of CF₃O⁻ (or CF₃S⁻) anion across a triple bond of benzyne to form (trifluoromethoxy)benzenide or [(trifluoromethyl)sulfanyl]benzenide anions, and then an abstraction of proton by these anions from the surrounding to afford the target products **12-OCF₃** and **12-SCF₃**, respectively (Scheme 2).

A reaction of CF₃O⁻ (**3c**, 3 equiv) with 1-trimethylsilylnaphthyl 2-trifluoromethanesulfonate^{29b} **13** (Scheme 2) in CH₃CN/ether (1:1) afforded in 63% yield the mixture (86:14) of 2- and 1-(trifluoromethoxy)-naphthalenes, **13-β** and **13-α**, respectively.^{31,32}

In summary, the proposed difluorophosgene free trifluoromethoxylation protocol can be easily adopted for laboratory synthesis of diverse functionalized trifluoromethyl ethers. Reactions of in situ generated arynes with trifluoromethanolate and trifluoromethanethiolate anions represent a promising laboratory route to R_FO- and R_FS-arenes. The results on a gentle straightforward transforma-

tion of alcohols into alkyl trifluoromethyl ethers by the usage of CF₃OSO₂CF₃ or COF₂ will be published in due course.

Acknowledgments

We are grateful to Dr. N. Ignatiev (Merck KGaA) for providing trifluoromethanesulfonic acid and Mrs. Dorit Kemken and Dr. Thomas Dülcks (University of Bremen) for obtaining the high resolution mass spectra and GC–MS measurements.

References and notes

- (a) Difluorophosgene free trifluoromethoxylation reactions of *sp*²- and *sp*³-hybridized carbon were presented: Kolomeitsev, A. In 18th Winter Fluorine ACS Conference, January 14–19, 2007, St. Petersburg Beach, Florida, USA. Book of Abstracts: O110; (b) Kolomeitsev, A. In 18th International Symposium on Fluorine Chemistry, 30th July–4th August 2006, Bremen, Germany. Book of Abstracts: Lecture Org, p 125; (c) Kolomeitsev, A. In Conference on Knowledge-based Materials and Technologies for Sustainable Chemistry, 1–5th June 2005, Tallinn, Estonia. Book of Abstracts: O45.
- Metal-Catalyzed Cross-Coupling Reactions*; de Meijere, A., Diederich, F., Eds.; Wiley VCH, 2004; Vols. 1&2.
- TFMT is a stable not fuming when exposed to air liquid (bp 20 °C): (a) Nofle, R. E.; Cady, G. H. *Inorg. Chem.* **1965**, *4*, 1010–1012; (b) Oudrhiri-Hassani, M.; Brunel, D.; Germani, A. *J. Fluorine Chem.* **1986**, *32*, 163–178.
- Olah, G. A.; Ohyama, T. *Synthesis* **1976**, 319–320.
- Kobayashi, Y.; Yoshida, T.; Kumadaki, I. *Tetrahedron Lett.* **1979**, *40*, 3865–3866.

6. Taylor, S. L.; Martin, J. C. *J. Org. Chem.* **1987**, *52*, 4148–4156.
7. (a) Leroux, F.; Jeschke, P.; Schlosser, M. *Chem. Rev.* **2005**, *105*, 827–856; and references cited therein; (b) Shimizu, M.; Hiyama, T. *Angew. Chem., Int. Ed.* **2005**, *44*, 214–231.
8. Farnham, W. B.; Smart, B. E.; Middleton, W. J.; Calabrese, J. C.; Dixon, W. J. *J. Am. Chem. Soc.* **1985**, *107*, 4565–4567.
9. (a) Seppelt, K. *Angew. Chem., Int. Ed.* **1977**, *16*, 322; (b) Kloeter, G.; Seppelt, K. *J. Am. Chem. Soc.* **1979**, *101*, 347–349; (c) Christie, K. O.; Hegge, J.; Hoge, B.; Haiges, R. *Angew. Chem., Int. Ed.* **2007**, *46*, 6155–6158.
10. Burk, P.; Koppel, I.; Rummel, A.; Trummal, A. *J. Phys. Chem. A* **2000**, *104*, 1602–1607.
11. Redwood, M. E.; Willis, C. J. *Can. J. Chem.* **1965**, *43*, 1893–1897.
12. (a) Prakash, G. K. S.; Hu, J.; Olah, G. A. *ARKIVOC* **2003**, 104–119; (b) Kawashima, T.; Mori, I.; Ohashi, M.; Tamura, T. JP 2003081919 0046180 (to Central Glass Co.), March, 19, 2003.
13. Kolomeitsev, A. A.; Bissky, G.; Barten, J.; Kalinovich, N.; Lork, E.; Rösenthaller, G.-V. *Inorg. Chem.* **2002**, *41*, 6118–6124.
14. (a) Cheburkov, Y.; Lillquist, G. *J. Fluorine Chem.* **2002**, *118*, 123–126; (b) Zhang, H.; Seppelt, K. *Inorg. Chem.* **1997**, *36*, 5689–5693.
15. 2,2-Difluoro-1,3-dimethylimidazolidine, DFITM (**2a**): Hayashi, H.; Sonoda, H.; Fukumura, K.; Nagata, T. *Chem. Commun.* **2002**, 1618–1619.
16. Anhydrous Me₄NF: Christie, K. O.; Wilson, W. W.; Wilson, R. D.; Bau, R.; Feng, J. *J. Am. Chem. Soc.* **1990**, *112*, 7619–7625; In this work Me₄NF was prepared by easily to scale up method disclosed in: Kolomeitsev, A.; Seifert, F. U.; Roesenthaller, G.-V. *J. Fluorine Chem.* **1995**, *71*, 74–76.
17. **3i** was previously synthesized on mg scale by reaction of dangerous to handle CF₃OCl with Me₄N⁺Cl and characterized by IR/Raman spectra: Minkwitz, R.; Broechler, R. *Z. Naturforsch. B* **1997**, *52*, 401–404.
18. Synthesis of (CF₃)₂N⁻ salts from bis(trifluoromethyl)perfluoroalkanesulfonamides was claimed: Hilarius, V.; Buchholz, H.; Sartori, P.; Ignatiev, N.; Kucherina, A.; Datsenko, S. WO 2000046180 (to Merck patent G.m.b.H., Germany), August, 10, 2000.
19. (a) The all operations with the reagents **2a–i** and **3a–i** were performed in oven-dried glassware under an atmosphere of dry nitrogen. CF₃SO₂F was quantitatively collected in a cooled with liquid nitrogen trap at the reduced temperature (–30 °C) and pressure (3 Torr). For application of CF₃SO₂F in organic synthesis as fluorinating or CF₃SO₂ transfer reagent see: Nagamori, M.; Narizuka, S. JP 2007119355 (to Central Glass Co., Ltd), May, 17, 2007; Desmarreau, D. D.; Witz, M. *J. Fluorine Chem.* **1991**, *52*, 7–12.
20. *Tris(dimethylamino)methylum trifluoromethanolate* (**3b**). Into a Schlenk vessel (500 mL) containing a magnetically stirred solution of 10.1 g (39.6 mmol) of (Me₂N)₃C⁺Me₃SiF₂⁻ (**2b**)¹³ in 75 mL of CH₃CN cooled till –30 °C was condensed 8.6 g (39.6 mmol) of **1**. The vessel was closed and during a period of 2 h the reaction temperature was raised from –30 °C to ambient temperature. The vessel was cooled again till –35 °C and CF₃SO₂F was pumped off in vacuum (3 Torr, for ca. 5 min) into a trap cooled with liquid nitrogen to afford a solution of **3b** in CH₃CN. Then the mixture was warmed to 0 °C and the solvent was removed in vacuo and the residue was washed with diethyl ether (1 × 70 mL) to leave a colorless solid, which was dried in vacuo 0.05 Torr at –30 °C for 3 h to furnish 8.9 g (98%) of **3b**, purity 99.5%, mp 197–199 °C (from CH₃CN/ether at –30 °C). ¹H NMR (200.13 MHz, CD₃CN, 20 °C): δ 2.93 (s, 18H, CH₃); ¹³C NMR (50.32 MHz, CD₃CN, 20 °C): δ 39.7 (CH₃)₂N⁺; 163.3 (C⁺); the carbon atom from CF₃O⁻ is not observed at 20 °C; ¹⁹F NMR (188.31 MHz, CD₃CN, 20 °C): δ –21.2 (br s, *A*_{1/2} = 370 Hz, 3F, CF₃). Anal. Calcd for C₈H₁₈F₃N₃O: C, 41.91; H, 7.91; N, 18.33. Found: C, 41.73; H, 8.06; N, 18.43.
21. *2-(Dimethylamino)-1,3-dimethylimidazolidin-2-ylum trifluoromethanolate* (**3c**). The compound was alternatively prepared from carbonyldifluoride and 2-dimethylamino-1,3-dimethylimidazolium difluoro-silicate (**2c**)¹³ in CH₂Cl₂ following the published method for **3d**.⁸ Colorless powder, yield 98%, mp 122–124 °C (from CH₃CN/ether at –30 °C). ¹H NMR (200.13 MHz, CD₃CN, 20 °C): δ 2.92 (s, 6H, CH₃); 3.03 (s, 6H, CH₃); 3.59 (s, 4H, CH₂); ¹³C NMR (50.32 MHz, CD₃CN, 20 °C): δ 36.6 (CH₃); 40.3 [(CH₃)₂N⁺]; 50.1 (CH₂); 164.3 (C⁺); the carbon atom from CF₃O⁻ is not observed at 20 °C; ¹⁹F NMR (188.31 MHz, CD₃CN, 20 °C): δ –23.7 (br s, *A*_{1/2} = 540 Hz, CF₃, 3F). Anal. Calcd for C₈H₁₆F₃N₃O: C, 42.29; H, 7.10; N, 18.49. Found: C, 42.41; H, 7.37; N, 18.71.
22. *Ethyl-2-(trifluoromethoxy)propanoate* (**4-OCF₃**). To a cooled with ice and magnetically stirred solution of **3b** in 37 mL CH₃CN, prepared from **1** (17.6 mmol) and **2b** (17.6 mmol) in situ as is described in Ref. 20, was added in one portion 4.0 g (16.0 mmol) of triflate **4**. The temperature was raised to 20 °C within 1 h and the mixture stirred for 2 h. The mixture was poured into sodium hydrocarbonate solution (3%, 50 mL) and extracted with pentane (3 × 50 mL). The combined organic extracts were washed with water and dried over MgSO₄. The final purification by distillation under reduced pressure gave the indicated compound (3.3 g, 87.4%) as a colorless liquid with bp 61–62 °C/ 55 Torr. ¹H NMR (200.13 MHz, CDCl₃): δ 1.29 (t, ³J_{HH} = 7.3 Hz, 3H, CH₃); 1.51 (d, ³J_{HH} = 7.2 Hz, 3H, CH₃); 4.24 (q, ³J_{HH} = 7.3 Hz, 2H, CH₂), 4.82 (q, ³J_{HH} = 7.2 Hz, 1H, CH); ¹³C NMR (50.32 MHz, C₆D₆): δ 14.0 (CH₃), 18.5 (CH₃), 61.4 (CH₂), 72.6 (q, ³J_{CF} = 2, 8 Hz, CH), 122.5 (q, ¹J_{CF} = 257.4 Hz, CF₃); 169.7 (C=O); ¹⁹F NMR (188.31 MHz, CDCl₃): δ –61.1 (s, CF₃). HRMS (EI) calcd for C₆H₉F₃O₃ (M⁺): 186.05007. Found: 186.05038.
23. *Ethyl phenyl(trifluoromethoxy)acetate* (**5-OCF₃**). Triflate **8** was generated following Effenberger's method.²⁴ Triflic anhydride (1.6 g, 5.6 mmol) was added to a stirred solution of (*R/S*) ethyl hydroxy(phenyl)acetate (0.9 g, 5 mmol) in CH₂Cl₂ (55 mL) at –78 °C. At the mentioned temperature the mixture was consequently treated with 0.71 g (5.9 mmol) of 2,4,6-trimethylpyridine (collidine) and solution of the in situ generated (similarly to Ref. 20) from **1** and **2c** trifluoromethanolate **3c** (2.84 g, 12.5 mmol) in CH₃CN (20 mL) and was slowly (within 6 h) warmed up till 20 °C. After aqueous (basic) work up the crude product, contaminated with 5-F impurity, was purified by column chromatography (hexane/ethyl acetate 10: 1) to give the title product **5-OCF₃** (0.71 g, 57%) as a colorless oil. ¹H NMR (200.13 MHz, CDCl₃): δ 1.26 (t, ³J_{HH} = 7.3 Hz, 3H, CH₃); 4.25 (m, 2H, CH₂); 5.54 (s, 1H, CH), 7.37–7.52 (m, 5H, Ar-H); ¹³C NMR (50.32 MHz, CDCl₃): δ 14.3 (CH₃), 62.6 (CH₂), 77.4 (q, ³J_{CF} = 2, 8 Hz, CH), 121.9 (q, ¹J_{CF} = 257.3 Hz, CF₃); 127.5, 129.3, 130.1, 133.7 (C_{Ar}H), 167.9 (C=O); ¹⁹F NMR (188.31 MHz, CDCl₃): δ –60.5 (s, CF₃). HRMS (EI) calcd for C₁₁H₁₁F₃O₃ (M⁺): 248.06603. Found: 248.06523.
24. Effenberger, F.; Burkard, U.; Willfahrt, J. *Angew. Chem., Int. Ed.* **1983**, *22*, 65–66.
25. *Methyl 4-[(trifluoromethoxy)methyl]benzoate* (**6-OCF₃**). Yield 87%. Colorless liquid with bp 79–81 °C/ 0.1 Torr. ¹H NMR (200.13 MHz, CDCl₃): δ 3.58 (s, 3H, CH₃); 4.44 (s, 2H, CH₂); 6.84–6.93 (m, 2H, Ar-H); 8.02–8.10 (m, 2H, Ar-H); ¹³C NMR (50.32 MHz, CDCl₃): δ 52.6 (ester CH₃), 68.6 (q, ³J_{CF} = 3.4 Hz, CH₂), 122.1 (q, ¹J_{CF} = 255.9 Hz, CF₃), 127.8, 130.5, 131.0, 139.1 (C_{Ar}H), 166.9 (C=O); ¹⁹F NMR (188.31 MHz, CDCl₃): δ –60.5 (s, CF₃). HRMS (EI) calcd for C₁₀H₉F₃O₃ (M⁺): 234.05038. Found: 234.05077.
26. *N-[2-(Trifluoromethoxy)ethyl]phthalimide* (**7-OCF₃**). Yield 91% (from the triflate **7**). Colorless solid with mp 77–78 °C (lit. mp 77–77.4 °C).²⁶ The ¹H, ¹⁹F and ¹³C NMR data for **7-OCF₃** were identical to those found for the prepared by desulfurization–fluorination method⁷ compound: Blazejewski, J.-C.; Anselmi, E.; Wakselman, C. *J. Org. Chem.* **2001**, *66*, 1061–1063.
27. (a) Kolomeitsev, A. A.; Médebielle, M.; Kirsch, P.; Lork, E.; Rösenthaller, G.-V. *J. Chem. Soc., Perkin Trans. 1* **2000**, 2183–2185; (b) Kirsch, P.; Rösenthaller, G.-V.; Bissky, G.; Kolomeitsev, A. A. DE 10254597 (to Merck patent G.m.b.H., Germany), July, 3, 2003; (c) Kolomeitsev, A. A.; Rösenthaller, G.-V.; Chabanenko, K. Yu.; Yagupolskii, Yu. L. *Synthesis* **1994**, 145–146.

28. Yagupolskii, L. M.; Kondratenko, N. V.; Sambur, V. P. *Synthesis* **1975**, 721–723.
29. For a mild generation of arynes from *o*-silylaryltriflates see: (a) Yoshida, H.; Morishita, T.; Fukushima, H.; Ohshita, J.; Kunai, A. *Org. Lett.* **2007**, 9, 3367–3370; and references cited therein; (b) Peña, D.; Pérez, D.; Guitián, D. *Angew. Chem., Int. Ed.* **2006**, 45, 3579–3581; and references cited therein; (c) Liu, Z.; Larock, R. C. *J. Org. Chem.* **2007**, 72, 583–588; and references cited therein.
30. [(Trifluoromethyl)sulfonyl]benzene **12-SCF₃**. To a magnetically stirred mixture of tetrakis(dimethylamino)ethanebis(ylum) bis(trifluoro-methanethiolate),^{27a} TDAE²⁺ 2CF₃S⁻ (4.02 g, 10 mmol) and CsF (3.04 g, 20 mmol) in CH₃CN (35 mL) at 0 °C in one portion was added triflate **12** (2.98 g, 10 mmol). The resulting suspension was stirred at 0 °C for 3 h and at room temperature overnight. The dark brown mixture was treated with sodium hydrocarbonate solution (3%, 25 mL) and extracted with pentane (3 × 30 mL). The organic phase was washed with brine (2 × 15 mL) and dried. Evaporation of the solvent afforded **12-SCF₃** as a light yellow liquid (1.85 g, purity 95%). Distillation under reduced pressure (bp 69–70 °C/100 Torr) provided the title product **12-SCF₃** (1.47 g, 83%). The ¹H, ¹⁹F, and ¹³C NMR data were identical to those found for the commercial compound (ABCR).
31. 1-(Trifluoromethoxy)naphthalene (**13-α**) and 2-(trifluoromethoxy)naphthalene (**13-β**). The mixture of regioisomers³² was obtained by the reaction of 1-trimethylsilylnaphthyl 2-trifluoromethanesulfonate **13** (0.26 g, 0.75 mmol) with **3c** (0.51 g, 2.25 mmol) in 2.5 mL of CH₃CN/ether (1:1) at –10 °C for 24 h followed by a stirring at 20 °C for 4 h. After basic work up the dark orange oily product (140 mg) was purified by preparative HPLC (RP-18, Kromasil, 16 μm, 100 Å, 250 × 50 mm, 83% MeOH–H₂O). Colorless oil, yield 99 mg (63%), purity 99%, contains 1 mol % of 1-fluoronaphthalene, ratio α/β 14:86. ¹³C NMR (50.32 MHz, CDCl₃): δ 118.6, 120.6, 121.1 (q, ¹J_{CF} = 257.2 Hz, CF₃), 126.8, 127.5, 128.2, 130.5, 132.2, 134.0, 147.3 (**13-β**); δ 116.9, 121.4 (q, ¹J_{CF} = 257.5 Hz, CF₃), 121.9, 123.7, 125.6, 127.3, 127.4, 128.3, 135.2, 145.7 (**13-α**). ¹⁹F NMR (188.31 MHz, CDCl₃): δ –58.6 (s, CF₃, minor isomer, -α); –58.9 (s, CF₃, major isomer, -β).
32. The 1- and 2-(trifluoromethoxy)naphthalenes were prepared recently: Schlosser, M.; Castagnetti, E. *Eur. J. Org. Chem.* **2001**, 3291–3997.