

**$\alpha$ -Fluorinated Ethers. I. Aryl Fluoroalkyl Ethers<sup>1</sup>**

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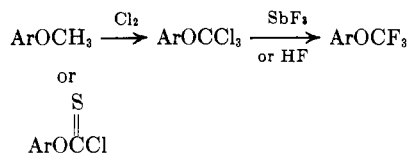
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The reaction of sulfur tetrafluoride with aryl fluoroformates or perfluoroalkyl esters is a new, general, and direct method for synthesis of aryl perfluoroalkyl ethers. The chemical and physical properties of these ethers are discussed. In particular, the perfluoroalkoxy groups are shown to possess exceptional stability as aromatic substituents.

Aryl trifluoromethyl ethers have been synthesized by the reaction of hydrogen fluoride or antimony fluorides with aryl trichloromethyl ethers, which were in turn prepared by chlorination of anisoles or phenyl esters of chlorothiocarbonic acid.<sup>2</sup> Although these methods are fairly general, the aromatic substituents

This class of  $\alpha$ -fluorinated ethers is hydrolyzed by acid and decomposes on standing if not pure. Aryl tetrafluoroethyl ethers are readily obtained by the base-catalyzed addition of phenols to tetrafluoroethylene<sup>7</sup> and appear to have stability more nearly comparable to that of the trifluoro- than that of the difluoroanisoles.

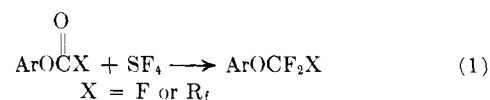


are limited to inert groups such as nitro, halogens, and acid halides. A very low yield of phenyl trifluoromethyl ether has been obtained along with fluorobenzene by the irradiation of trifluoromethyl hypofluorite (CF<sub>3</sub>OF) in benzene.<sup>3</sup> The trifluoromethoxy group was shown to be stable to normal chemical transformations of the aromatic ring such as reduction of nitro groups, hydrolysis of nitriles, diazotization of amino groups, and nitration (*ortho-para* orientation).<sup>2,4</sup> Potential dyes<sup>4b</sup> and pharmaceutical chemicals<sup>5</sup> containing the OCF<sub>3</sub> group also have been reported.

Aryl difluoromethyl ethers have been prepared by reaction of phenols with difluorocarbene generated from chlorodifluoromethane or dibromodifluoromethane.<sup>6</sup>

**Results and Discussion**

**Synthesis.**—The reaction of sulfur tetrafluoride<sup>8</sup> with aryl fluoroformates<sup>9</sup> or perfluoroalkyl esters<sup>10</sup> provides a general direct synthesis of aryl perfluoroalkyl ethers (eq. 1). The reaction was run in a "Hastelloy"-lined pressure vessel at autogeneous pressure and



required a temperature of 160 to 175° for several hours with anhydrous hydrogen fluoride as catalyst. In most cases, the product was obtained in a yield of 50 to 80% and was isolated by distillation in a high state of purity after removal of hydrogen fluoride with sodium fluoride or a base wash. Examples of this reaction are given in Table I.

As a convenient procedure for the preparation of aryl trifluoromethyl ethers, phenols were treated with

(1) This work was reported in preliminary form by W. A. Sheppard, *J. Am. Chem. Soc.*, **83**, 4860 (1961).

(2) (a) British Patent 765,527 (1957); (b) L. M. Yagupolsky, *Dokl. Akad. Nauk SSSR*, **105**, 100 (1955); *Chem. Abstr.*, **50**, 11270 (1956); (c) N. N. Iarovenko and A. S. Vasileva, *J. Gen. Chem. USSR*, **28**, 2539 (1958).

(3) J. A. C. Allison and G. H. Cady, *J. Am. Chem. Soc.*, **81**, 1089 (1959).

(4) (a) L. M. Yagupolsky and V. I. Troitskaya, *J. Gen. Chem. USSR*, **27**, 587 (1957); (b) L. M. Yagupolsky and M. S. Marenets, *ibid.*, **27**, 1479 (1957); (c) L. M. Yagupolsky and V. I. Troitskaya, *ibid.*, **31**, 845 (1961).

(5) (a) L. M. Yagupolsky and V. I. Troitskaya, *ibid.*, **30**, 3102 (1960); (b) French Patent 1,245,552 (1960); (c) B. Blank and J. F. Kerwin, U. S. Patent 3,021,368 (1962).

(6) (a) T. G. Miller and J. W. Thanassi, *J. Org. Chem.*, **25**, 2009 (1960); (b) R. F. Clark and J. H. Simons, *J. Am. Chem. Soc.*, **77**, 6618 (1955).

(7) (a) D. C. England, L. R. Melby, M. A. Dietrich, and R. V. Lindsey, Jr., *ibid.*, **82**, 5116 (1960); (b)  $\alpha$ , $\alpha$ -difluoro-perhalogenalkyl aryl ethers, ArOCF<sub>2</sub>CCL<sub>3</sub>, were reported by H. Hahn, *Ber.*, **96**, 48 (1963), prepared by chlorination of ArOCF<sub>2</sub>CCL<sub>3</sub>H [from base-catalyzed addition of phenols to 1,1-dichloro-2,2-difluoroethylene, E. T. McBee and R. O. Bolt, *Ind. Eng. Chem.*, **39**, 412 (1947); U. S. Patent 2,516,403 (1950); *Chem. Abstr.*, **45**, 2964 (1951)].

(8) (a) C. W. Tullock, F. S. Fawcett, W. C. Smith, and D. D. Coffman, *J. Am. Chem. Soc.*, **82**, 539 (1960); (b) W. R. Hasek, W. C. Smith, and V. A. Engelhardt, *ibid.*, **82**, 543 (1960).

(9) H. J. Emeleus and J. F. Wood, *J. Chem. Soc.*, 2183 (1948).

(10) (a) R. F. Clark and J. H. Simons, *J. Am. Chem. Soc.*, **75**, 6305 (1953); (b) M. Green, *Chem. Ind. (London)*, 435 (1961).

TABLE I  
PREPARATION OF ARYL PERFLUOROALKYL ETHERS FROM FLUOROFORMATES OR PERFLUOROALKYL CARBOXYLATES<sup>a</sup>

$$\text{ArO} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} \text{R}_f + \text{SF}_4 \xrightarrow{\text{HF}} \text{ArOCF}_2\text{R}_f \quad (\text{R}_f = \text{F or } (\text{CF}_2)_n\text{F})$$

Reactant (ester of formate), g. (mole)	SF <sub>4</sub> , g. (mole)	HF, g.	Product	Yield		
				G.	%	
$\text{C}_6\text{H}_5\text{O} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} \text{F}$	264 (1.89)	216 (2.0)	0	$\text{C}_6\text{H}_5\text{OCF}_3$	19	6
$\text{C}_6\text{H}_5\text{O} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} \text{F}$	183 (1.30)	150 (1.4)	10	$\text{C}_6\text{H}_5\text{OCF}_3$	213	81
$\text{C}_6\text{H}_5\text{O} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} \text{F}$	183 (1.30)	150 (1.4)	10	$\text{C}_6\text{H}_5\text{OCF}_3$	120	57
$\text{C}_6\text{H}_5\text{O} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} \text{F}$	183 (1.30)	150 (1.4)	10	$\text{C}_6\text{H}_5\text{OCF}_3$	13	7
$2\text{-O}_2\text{NC}_6\text{H}_4\text{O} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} \text{F}$	24 (0.13)	16 (0.15)	6	$2\text{-O}_2\text{NC}_6\text{H}_4\text{OCF}_3$	18.5	69
$2,4\text{-Br}_2\text{C}_6\text{H}_3\text{O} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} \text{F}^b$	20 (0.067)	8 (0.074)	3	$2,4\text{-Br}_2\text{C}_6\text{H}_3\text{OCF}_3$	6.9	32
$\text{C}_6\text{H}_5\text{O} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} \text{CF}_3$	28.5 (0.15)	19 (0.18)	7	$\text{C}_6\text{H}_5\text{OCF}_2\text{CF}_3$	19.4	61
$4\text{-O}_2\text{NC}_6\text{H}_4\text{O} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} \text{CF}_3$	23.5 (0.10)	15 (0.14)	5	$4\text{-O}_2\text{NC}_6\text{H}_4\text{OCF}_2\text{CF}_3$	17.8	69
$3\text{-O}_2\text{NC}_6\text{H}_4\text{O} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} \text{CF}_3$	155 (0.66)	86 (0.80)	25	$3\text{-O}_2\text{NC}_6\text{H}_4\text{OCF}_2\text{CF}_3$	142	83
$\text{C}_6\text{H}_5\text{O} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} (\text{CF}_2)_2\text{CF}_3$	22.5 (0.078)	10 (0.10)	7	$\text{C}_6\text{H}_5\text{O}(\text{CF}_2)_3\text{CF}_3$	<1.9	<sup>c</sup>
$4\text{-O}_2\text{NC}_6\text{H}_4\text{O} \begin{array}{c} \text{O} \\ \parallel \\ \text{C} \end{array} (\text{CF}_2)_2\text{CF}_3$	33.5 (0.10)	15 (0.14)	5	$4\text{-O}_2\text{NC}_6\text{H}_4\text{O}(\text{CF}_2)_3\text{CF}_3$	10.7	30

<sup>a</sup> Reactions run in "Hastelloy"-lined pressure vessel of 140-, 240-, or 1000-ml. capacity at autogenous pressure. Normal heating pattern was 2 hr. successively at each temperature of 100, 150, and 160 or 175°. <sup>b</sup> See ref. 18. <sup>c</sup> Product not isolated in pure form. Characterized by F<sup>19</sup> n.m.r. analysis in pentane solution.

carbonyl fluoride<sup>9,11</sup> in an autoclave at 100°; without isolation of the fluoroformate intermediate, the sulfur tetrafluoride then was added, and the reaction mixture was heated for several hours at 150–175°. The hydrogen fluoride by-product from the carbonyl fluoride reaction served as catalyst for the sulfur tetrafluoride reaction. For example, the yield of ether from phenol and *m*- and *p*-nitrophenols was 60 to 80% over-all for the two steps. The reaction is applicable to substituted phenols, including hydroquinone and resorcinol, provided that substituents on the aromatic ring do not react with hydrogen fluoride or sulfur tetrafluoride. The ethers prepared by the two-step method are listed in Table II.

Trifluoroacetate and heptafluorobutyrate esters of phenols were prepared from the corresponding anhydride<sup>10</sup> or acid chloride (the latter in the presence of a tertiary amine). By reaction of these esters with sulfur tetrafluoride (hydrogen fluoride catalyst) as described previously, the new aryl pentafluoroethyl and heptafluorobutyl ethers were obtained. This method appears to be general for the preparation of aryl perfluoroalkyl ethers. However, the yield of ether dropped with

increasing chain length of the perfluoroalkyl group; thus, *p*-nitrophenyl nonafluoro-*n*-butyl ether was obtained in only 30% yield compared to 80% and 69% for the corresponding trifluoromethyl and pentafluoroethyl ethers, respectively.

Phenyl chloroformate also reacted with sulfur tetrafluoride in the presence of hydrogen fluoride, but the yield of phenyl trifluoromethyl ether was only a few per cent.

From a limited exploration of conditions, it is concluded that the temperature for the sulfur tetrafluoride reaction is critical. At temperatures below 150° the carbonyl group reacted to only a small extent, and the major portion of the fluoroformate or ester was recovered. At temperatures over 175° the formation of tar increased, and the yield of ether decreased. It is considered likely that the main side reactions leading to tars are Friedel-Crafts-type condensations (see the subsequent discussion of by-products). The yield of ether was also extremely low if hydrogen fluoride was not used as a catalyst and in one experiment where titanium tetrafluoride replaced hydrogen fluoride tar formation became predominant.

The amount of hydrogen fluoride generally used, particularly when it was present as by-product in the fluoroformate preparation, is greatly in excess of that needed as a catalyst. It is possible that the hydrogen

(11) M. W. Farlow, E. H. Mann, and C. W. Tullock, *Inorg. Syn.*, **6**, 155 (1960). A convenient synthesis of carbonyl chloride from sodium chloride and phosgene in acetonitrile is described by F. S. Fawcett, C. W. Tullock, and D. D. Coffman, *J. Am. Chem. Soc.*, **84**, 4275 (1962).

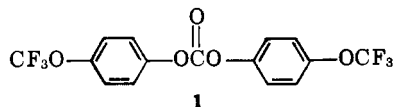
TABLE II  
 PREPARATION OF ARYL TRIFLUOROMETHYL ETHERS BY TWO-STEP METHOD FROM PHENOLS<sup>a</sup>

Phenol, g. (mole)	$\text{ArOH} + \text{COF}_2 \xrightarrow{\text{HF}} \text{ArOCF}_2 + \text{COF}_2 \xrightarrow{\text{SF}_4} \text{ArOCF}_3$			Product	Yield	
	COF <sub>2</sub> , g. (mole)	SF <sub>4</sub> , g. (mole)	G.		%	
C <sub>6</sub> H <sub>5</sub> OH	235 (2.5)	200 (3.0)	270 (2.5)	C <sub>6</sub> H <sub>5</sub> OCF <sub>3</sub>	375-437	46-62 <sup>b</sup>
4-C <sub>6</sub> H <sub>4</sub> (OH) <sub>2</sub>	55 (0.50)	100 (1.5)	120 (1.1)	4-C <sub>6</sub> H <sub>4</sub> (OCF <sub>3</sub> ) <sub>2</sub>	68.4	56
					13	7
3-C <sub>6</sub> H <sub>4</sub> (OH) <sub>2</sub>	16.5 (0.15)	25 (0.38)	35 (0.32)	3-C <sub>6</sub> H <sub>4</sub> (OCF <sub>3</sub> ) <sub>2</sub>	6.4	17
4-O <sub>2</sub> NC <sub>6</sub> H <sub>4</sub> OH	139.1 (1.0)	100 (1.5)	120 (1.1)	4-O <sub>2</sub> NC <sub>6</sub> H <sub>4</sub> OCF <sub>3</sub>	166.4	81
3-O <sub>2</sub> NC <sub>6</sub> H <sub>4</sub> OH	65 (0.47)	50 (0.75)	60 (0.55)	3-O <sub>2</sub> NC <sub>6</sub> H <sub>4</sub> OCF <sub>3</sub>	73.9	76
4-CH <sub>3</sub> C <sub>6</sub> H <sub>4</sub> OH	27 (0.25)	25 (0.38)	30 (0.28)	4-CH <sub>3</sub> C <sub>6</sub> H <sub>4</sub> OCF <sub>3</sub>	12.0	27
3-CH <sub>3</sub> C <sub>6</sub> H <sub>4</sub> OH	108 (1.0)	90 (1.35)	130 (1.2)	3-CH <sub>3</sub> C <sub>6</sub> H <sub>4</sub> OCF <sub>3</sub>	16.2	9
					72.9	38
4-ClC <sub>6</sub> H <sub>4</sub> OH	32 (0.25)	25 (0.38)	30 (0.28)	4-ClC <sub>6</sub> H <sub>4</sub> OCF <sub>3</sub>	28.4	58
					4.9	11
3-ClC <sub>6</sub> H <sub>4</sub> OH	32 (0.25)	25 (0.38)	30 (0.28)	3-ClC <sub>6</sub> H <sub>4</sub> OCF <sub>3</sub>	22.7	46
2-ClC <sub>6</sub> H <sub>4</sub> OH	32 (0.25)	25 (0.38)	30 (0.28)	2-ClC <sub>6</sub> H <sub>4</sub> OCF <sub>3</sub>	8.4	17
4-BrC <sub>6</sub> H <sub>4</sub> OH	34.6 (0.20)	20 (0.30)	24 (0.22)	4-BrC <sub>6</sub> H <sub>4</sub> OCF <sub>3</sub>	13.2	27.4
					7.8	18
3-BrC <sub>6</sub> H <sub>4</sub> OH	43.2 (0.25)	25 (0.38)	32 (0.30)	3-BrC <sub>6</sub> H <sub>4</sub> OCF <sub>3</sub>	10.8	18
4-FC <sub>6</sub> H <sub>4</sub> OH	15 (0.13)	15 (0.22)	17 (0.16)	4-FC <sub>6</sub> H <sub>4</sub> OCF <sub>3</sub>	10.1	42
3-FC <sub>6</sub> H <sub>4</sub> OH	15 (0.13)	15 (0.22)	17 (0.16)	3-FC <sub>6</sub> H <sub>4</sub> OCF <sub>3</sub>	7.7	32
	35 (0.14)	25 (0.38)	33 (0.30)		2.5 (no solvent)	5
					31.0 (solvent, 40 g. of C <sub>6</sub> H <sub>6</sub> NO <sub>2</sub> )	56
	35 (0.17)	30 (0.45)	40 (0.37)		3.1	5

<sup>a</sup> Reactions run in "Haselloy-lined pressure vessel of 140-, 240-, or 1000-ml. capacity at autogenous pressure. Normal heating pattern was 1 hr. at 100° followed by 2 to 3 hr. at 140° (or higher temperatures above phenol melting point) for the COF<sub>2</sub> reaction; 2 hr. successively at 100, 140, or 150°, and 160 or 175° for the SF<sub>4</sub> reaction. <sup>b</sup> See ref. 18. <sup>c</sup> Boiling point 93° (30 mm.), characterized by F<sup>19</sup> n.m.r. analysis only.

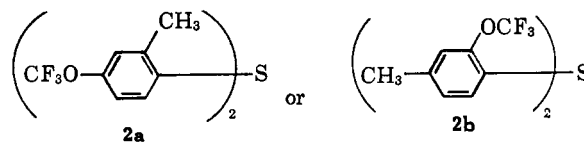
fluoride also may serve as a solvent.<sup>12</sup> The use of an inert solvent such as nitrobenzene also was found necessary for the reaction of high-melting phenols, such as 4,4'-dihydroxydiphenyl sulfone. It is concluded that the reactants must be liquids or in solution for the reaction with carbonyl fluoride or sulfur tetrafluoride to proceed to completion at a reasonable rate.

As by-products in several reactions, small amounts of the fluoroformate intermediates were isolated as a higher boiling fraction after distillation of the trifluoromethyl ethers. From hydroquinone the main by-product was the carbonate, **1**, and as expected its relative



amount compared to 1,4-bis(trifluoromethoxy)benzene increased when the molar ratio of COF<sub>2</sub> to hydroquinone was decreased. An unusual by-product was formed in

the reaction of *m*-cresol. Only a 10% yield of the normal product, *m*-tolyl trifluoromethyl ether, was isolated; the main product in 40% yield was a sulfide which, on basis of analysis and spectral properties, was assigned one of two structures, **2a** or **2b**.



Structure **2a** is preferred since the OCF<sub>3</sub> group directs electrophilic reagents predominantly to the *para* posi-

(12) The use of hydrogen fluoride as a catalyst was demonstrated in the original report on the use of sulfur tetrafluoride as a fluorinating agent; see ref. 8b. Recently, D. C. Martin and F. Kagan, *J. Org. Chem.*, **27**, 3164 (1962), described the reaction of sulfur tetrafluoride with the carbonyl functions of steroids and stated that high yields of fluorinated steroids were obtained only when the sulfur tetrafluoride contained 20% hydrogen fluoride. In discussing these results, the authors commented that the concentration of hydrogen fluoride was critical.



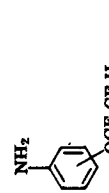
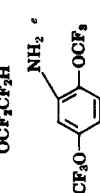
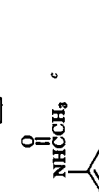
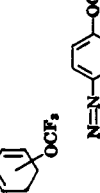
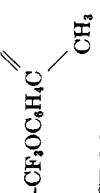
	$\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right\}$	1.4636	100 (6.6)	F3 (89)	46.0	46.5	3.38	3.53	36.3	35.7	N, 6.7	6.8
		1.4600	96 (5.7)	E (70)	46.0	46.3	3.38	3.47	46.0	46.3	35.7	N, 6.7
		1.4120	70 (20)	F3 (55)	36.8	37.3	1.93	2.08				
	$\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right\}$	92.6-93.2		F (97)					26.0	26.5	N, 6.4	6.0
		113-114		F (93)	49.4	49.7	3.68	3.80	26.0	25.9		
	$\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right\}$	110-110.4		F (95) <sup>y</sup>	61.4	61.6	3.44	2.92	17.2	16.7	N, 8.4	8.7
		1.4144	131	D	54.6	54.9	4.01	4.34	32.4	32.8		
$\text{CH}_3\text{C}_6\text{H}_4\text{OCF}_3$	$\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right\}$	1.4128	134-135	D	54.6	54.7	4.01	4.19	32.4	32.1		
		1.4210	98 (65)	E (49)					36.5	36.6		
$\text{CH}_3\text{C}_6\text{H}_4\text{OCF}_2\text{CF}_2\text{H}$	$\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right\}$	1.4197	94 (53)	E (56)					36.5	36.7		
		1.4477	82-83 (8)	F (60) <sup>g</sup>	52.4	52.5	4.40	4.50				
$p\text{-CF}_3\text{OC}_6\text{H}_4\text{CHCH}_3$ $p\text{-CF}_3\text{OC}_6\text{H}_4\text{CH}=\text{CH}_2$ $p\text{-CF}_3\text{OC}_6\text{H}_4\text{CH}_2\text{OH}$	$\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right\}$	1.4476	60 (21)	F (32) <sup>a</sup>	57.4	58.1	3.74	4.01				
		175-175.5	108 (25)	F (39) <sup>s</sup>	50.0	50.2	3.67	3.84				
$p\text{-CF}_3\text{OC}_6\text{H}_4\text{C}=\text{NNHC}_6\text{H}_5$ 	$\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right\}$	1.4956	140 (2.3)	F6 (26-30)	42.4	42.7	2.00	2.32	25.1	24.8	Cl, 23.5	23.4
		1.4978	58 (0.06)	F6 (16)	33.0	33.2	1.54	1.65	17.4	17.0	Cl, 43.2	44.0
$\text{CF}_3\text{OC}_6\text{H}_4\text{CO}_2\text{H}$	$\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right\}$	1.4986	107 (0.7)	D	46.9	47.1	2.89	2.80			Mol. wt., 328	314
		91.4-92.0		F4b (42), F4c (58)	46.6	46.7	2.45	2.70	27.7	27.5	S, 8.4	8.3
$\text{HCF}_2\text{CF}_2\text{OC}_6\text{H}_4\text{CO}_2\text{H}$	$\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right\}$	152.2-153.8		F4a (46), F4c (66)	46.6	47.0	2.45	2.61	27.7	27.6	Neut. equiv., 206	204, 205
		127.4-128.6		F4b (38)	45.4	45.4	2.54	2.41	2.73	2.64		
$\text{FC}_6\text{H}_4\text{OCF}_2$	$\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right\}$	177.4-178.4		F4b (55)	45.4	45.6	2.54	2.92	31.9	31.7	Neut. equiv., 238	238, 233
		1.3914	105	D	46.7	46.7	2.24	2.22	31.9	32.0	Neut. equiv., 238	237
$\text{FC}_6\text{H}_4\text{OCF}_2$	$\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right\}$	1.3912	108	D	46.7	46.4	2.24	2.56	42.2	41.7		

TABLE III (Continued)

Compound	M.p., °C., and/or $n_D^{20}$	B.p., °C. (mm.)	Method of preparation (% yield) <sup>51</sup>	Carbon <sup>52</sup>		Hydrogen		Fluorine		Other	
				Calcd.	Found	Calcd.	Found	Calcd.	Found	Calcd.	Found
$\text{ClC}_6\text{H}_4\text{OCF}_3$ $\left\{ \begin{array}{l} \textit{ortho} \\ \textit{meta} \\ \textit{para} \end{array} \right.$	1.4362 1.4338 1.4338	144.5 140	D D	42.8	43.0	2.05	2.45	29.0	28.8	Cl, 18.0	18.0
$\text{BrC}_6\text{H}_4\text{OCF}_3$ $\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right.$	1.4586 1.4586	81 (100) 80 (50)	D D	42.8	43.2	2.05	2.36	29.0	28.7	Cl, 18.0 Br, 33.2	17.9 33.5
2,4- and 3,4- $\text{Br}_2\text{C}_6\text{H}_3\text{OCF}_3^d$	1.5068	76-79 (7)	F2					23.7	23.8	Br, 33.2	33.1
$\text{CF}_3\text{O}-\text{C}_6\text{H}_3(\text{Br})-\text{OCF}_3$	1.4148	58.5 (20)	F2b (22-30)	29.6	30.1	0.93	1.20	17.8	18.1	Br, 50.0	50.2
$\text{CF}_3-\text{C}_6\text{H}_3(\text{Br})-\text{OCF}_3$								24.6	24.4	Br, 35.1	34.6
$\text{HOC}_6\text{H}_4\text{OCF}_3$ $\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right.$	1.4571	110 (30)	F2b (15-22)	23.8	24.0	0.50	0.65	39.6	39.9	Br, 28.2	28.1
$\text{HOC}_6\text{H}_3(\text{OCF}_3)_2$ $\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right.$	1.4436 1.4469	69.5 (12) 92 (25)	F (45) <sup>f</sup> F (80) <sup>f</sup>	47.2	47.3	2.83	3.05	32.0	32.1		32.1
$\text{HOC}_6\text{H}_4\text{OCF}_2\text{CF}_3$ $\left\{ \begin{array}{l} \textit{meta} \\ \textit{para} \end{array} \right.$	1.4125 62.6-64.2	84 (14) 89 (20)	F (44) <sup>g</sup> F (44) <sup>g</sup>	42.1	42.8	2.21	2.43	41.7	41.1		41.1
$(p\text{-CF}_3\text{O}-\text{C}_6\text{H}_4)_2$	1.4643	111.5 (3.3) 252	D	55.8	56.2	2.81	2.93	33.7	33.2	Mol. wt., 338	289
$m\text{-}(\text{CF}_3\text{O}-\text{C}_6\text{H}_4)_2$	1.5048 (glass at -40)	143 (0.95)	F7 (61)	49.8	50.2	2.28	2.56	26.5	26.7		
$m\text{-}(\text{CF}_3\text{CF}_2\text{O}-\text{C}_6\text{H}_4)_2$	1.4700 (glass at -30)	129 (0.25)	F7 (56)	47.2	47.7	2.11	2.27	34.8	34.4		
$(p\text{-CF}_3\text{OC}_6\text{H}_4\text{O})_2\text{C}=\text{O}$	57.5-59	111 (4)	D	47.2	47.7	2.11	2.27	29.8	30.0	Mol. wt., 382	373
$(p\text{-CF}_3\text{OC}_6\text{H}_4)_2\text{SO}_2$	107.5-108	154 (6)	D	43.5	43.5	2.09	2.11	29.5	28.8	S, 8.3	8.4
$p\text{-CF}_3\text{OC}_6\text{H}_4\text{HgCl}$	246.6-251.5	136 (0.7)	F (15) <sup>m</sup>	49.0	49.5	2.35	2.62	14.4	14.3	Hg, 50.5	49.1
$(m\text{-CF}_3\text{OC}_6\text{H}_4)_2\text{Si}$	1.4915 (glass at -30)	107-109 (0.7)	F5 (32)	47.6	47.5	2.28	2.50	33.9	33.1	Si, 4.2	4.0
$(p\text{-CF}_3\text{OC}_6\text{H}_4)_2\text{SiCl}_2$	1.4790	150 (1.0)	F (6) <sup>n</sup>	49.0	49.5	2.35	2.62	27.1	27.8	Si, 6.7	6.8
$(p\text{-CF}_3\text{OC}_6\text{H}_4)_2\text{P}$	1.5088		F (56) <sup>o</sup>	47.6	47.5	2.28	2.50	33.3	33.2	P, 6.0	6.0
$(p\text{-CF}_3\text{OC}_6\text{H}_4)_2\text{P}=\text{O}$	91.6-94.0		F (77) <sup>p</sup>					32.2	32.2	P, 5.9	5.7
Fluoroformates											
$\text{O}_2\text{NC}_6\text{H}_4\text{OCF}$ $\left\{ \begin{array}{l} \textit{ortho} \\ \textit{para} \end{array} \right.$	1.5094 39-39.5	96.5 (107) 88 (0.75)	A (68) <sup>q</sup> A (39)	45.4	45.8	2.18	2.35	10.3	10.2		
$p\text{-BrC}_6\text{H}_4\text{OCF}$	1.5166	65 (1.5)	D	38.4	38.8	1.84	2.06	8.7	8.4		
2,4- $\text{Br}_2\text{C}_6\text{H}_3\text{OCF}^e$		117-118 (15)	A (73)	6.4	6.3	6.4	6.3	6.4	6.3	Br, 53.7	53.9

Chemical Structure	Fluorocarboxylates		24.3	23.7	N, 6.0	6.3
	92 (1.2)	B1 (88)				
$O_2NC_6H_4OCCF_3$ (meta)	41-41.6	B1 (88)	24.3	23.7	N, 6.0	6.3
$O_2NC_6H_4OCCF_3$ (para)	1.4751	B1 (72), B2 (35)	24.3	23.7	N, 6.0	6.3
$p-O_2NC_6H_4OC(CF_2)_2CF_3$	1.4285	B2 (76) <sup>g</sup>				

<sup>a</sup> Compounds reported in this table also were characterized by infrared, ultraviolet, F<sup>19</sup> and H<sup>1</sup> n.m.r. spectra. <sup>b1</sup> Letter and numbers refer to procedure listed in Experimental. Yields in preparation by methods C and D are reported in Tables I and II. Where appropriate, references to typical literature procedures for compounds prepared by method F are given in footnotes. <sup>b2</sup> It has been observed in compounds containing C, F, and other elements that the C analysis is often 0.4 to 0.7% high, although not reproducibly so. <sup>c</sup> These compounds have been claimed previously in the Russian literature, ref. 2 and 4. <sup>d</sup> See Ref. 17. <sup>e</sup> See Ref. 18. <sup>f</sup> Diazotized *p*-trifluoromethoxyaniline coupled to β-naphthol, B. C. McKusick, R. E. Heckert, T. L. Cairns, D. D. Coffman, and H. F. Mower, *J. Am. Chem. Soc.*, **80**, 2806 (1958). <sup>g</sup> Grignard reagent from *p*-bromophenyl trifluoromethyl ether added to acetaldehyde, "Organic Syntheses," Coll. Vol. III, John Wiley and Sons, Inc., New York, N. Y., 1955, p. 200. <sup>h</sup> Corresponding alcohol was dehydrated over potassium persulfate or the acetate was pyrolyzed, M. W. Renoll, *J. Am. Chem. Soc.*, **68**, 1159 (1946). <sup>i</sup> Grignard reagent from *p*-bromophenyl trifluoromethyl ether added to formaldehyde, "Organic Syntheses," Coll. Vol. I, John Wiley and Sons, Inc., New York, N. Y., 1941, p. 188. <sup>j</sup> Friedel-Crafts reaction of acetyl fluoride with aluminum chloride on phenyltrifluoromethyl ether. Acetophenone product isolated as phenylhydrazone. <sup>k</sup> Hydrolysis of diazotized aniline, "Organic Syntheses," Coll. Vol. I, John Wiley and Sons, Inc., New York, N. Y., 1941, p. 404. <sup>l</sup> Basic hydrolysis of bis(*p*-trifluoromethoxyphenyl)carbonate. <sup>m</sup> Diazotized *p*-trifluoromethoxyaniline coupled with mercuric chloride in presence of copper powder, "Organic Syntheses," Coll. Vol. II, John Wiley and Sons, Inc., New York, N. Y., 1943, p. 432. <sup>n</sup> Prepared from Grignard reagent of *p*-bromophenyl trifluoromethyl ether with silicon tetrachloride. Lower boiling fraction was shown to contain *p*-trifluoromethoxyphenyltrichlorosilane and a large fraction of higher boiling material was shown to be a mixture of the dichlorosilane with tris(*p*-trifluoromethoxyphenyl)chlorosilane. <sup>o</sup> Prepared from corresponding Grignard reagent with phosphorus trichloride, F. G. Mann and E. J. Chaplin, *J. Chem. Soc.*, 527 (1937). <sup>p</sup> Oxidized phosphine with 30% hydrogen peroxide. <sup>q</sup> Characterized only by infrared, ultraviolet, and n.m.r. (F<sup>19</sup> resonance at +1 c.p.s. at 40 Mc./sec. reference to CF<sub>3</sub>CO<sub>2</sub>H) spectra. <sup>r</sup> Characterized only by infrared, ultraviolet, and n.m.r. analyses.

tion. The formation of this sulfide is postulated to occur *via* a Friedel-Crafts-type reaction of thionyl fluoride with tolyl trifluoromethyl ether, followed by an oxidation-reduction reaction with the remaining thionyl fluoride. As an analogy, the reaction of anisole with thionyl chloride is reported to give 4,4'-bis(methoxy)-diphenyl sulfide.<sup>18</sup> In sulfur tetrafluoride chemistry, this is the first example of formation of a sulfide in reactions with an aromatic derivative.

The preparation of *o*-nitrophenyl trifluoromethyl ether also requires special comment. Because of hydrogen bonding of the OH with NO<sub>2</sub>, carbonyl fluoride does not react with the phenol unless sodium fluoride is used as a base. In this case, the intermediate fluoroformate must be isolated and charged into a clean autoclave with hydrogen fluoride and sulfur tetrafluoride.

For comparison purposes a number of aryl tetrafluoroethyl ethers also have been synthesized by the literature procedure.<sup>7</sup> The fluoroalkyl ethers prepared in this work are tabulated in Table III, and physical properties and analytical data are given.

**Physical and Spectral Properties.**—The melting points, boiling points, and densities of selected aryl fluoroalkyl ethers are summarized in Table IV and compared with those of anisole, phenetole, and benzotrifluoride. In this series, as is generally recognized, the complete replacement of aliphatic hydrogen by fluorine causes a marked decrease in boiling point. For OCF<sub>3</sub> groups a melting point decrease also is observed, and this phenomenon is particularly significant when the OCF<sub>3</sub> group is in the *meta* position in aromatic derivatives. It also is noted that the density of the ethers increases with increasing fluorine content. These ethers are all colorless and have a sweetish odor with typical aromatic character.

TABLE IV

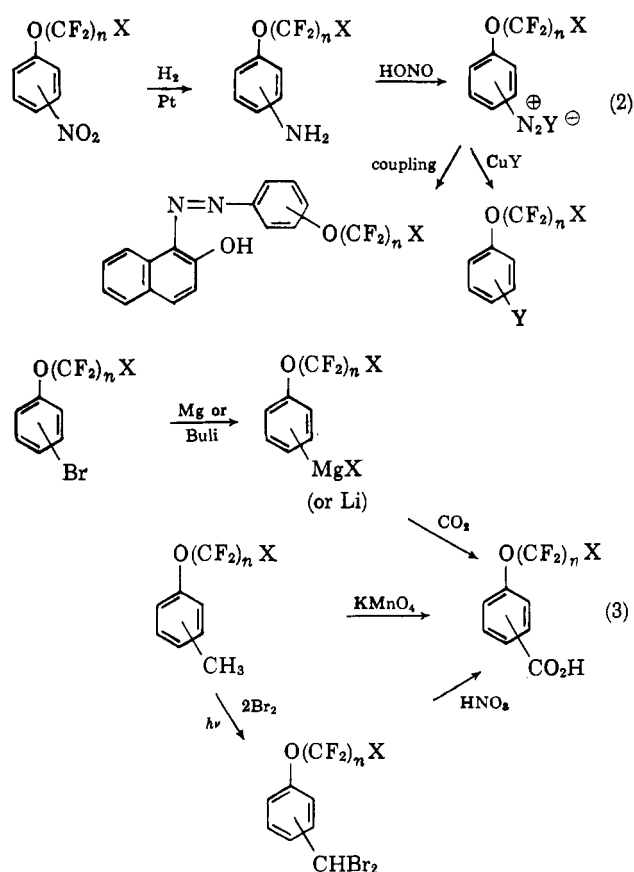
PHYSICAL PROPERTIES OF ARYL FLUOROALKYL ETHERS			
X of C <sub>6</sub> H <sub>4</sub> X (or C <sub>6</sub> H <sub>3</sub> X <sub>2</sub> )	M.p., °C.	B.p., °C.	Density, d <sub>4</sub> <sup>25</sup>
OCH <sub>3</sub>	-37	155	1.00
OCH <sub>2</sub> CH <sub>3</sub>	-30	172	0.97
CF <sub>3</sub>	-29	102	1.19
OCF <sub>3</sub>	-50	106	1.23
OCF <sub>2</sub> CF <sub>3</sub>	-29	115	1.30
OCF <sub>2</sub> CF <sub>2</sub> H <sup>1</sup>		147	
OCF <sub>2</sub> H <sup>1</sup>		145	
		(Extrapolated)	1.18
<i>m</i> -(OCH <sub>3</sub> ) <sub>2</sub>	-52	217	1.08
<i>m</i> -(OCF <sub>3</sub> ) <sub>2</sub>	-55	123	1.41

The infrared spectra of these ethers show typical strong C-O absorption at 7.8 to 8 μ and very strong C-F absorption in the 8-9-μ region. The remainder of the spectra contains absorption typical of the aromatic nucleus and substituents. The ultraviolet spectra are in general similar to those of the corresponding tolyl derivatives. The F<sup>19</sup> n.m.r. spectra of aryl trifluoromethyl ethers show a single resonance in the region of -700 to -800 c.p.s. at 40 Mc./sec. with reference (external) to CF<sub>2</sub>ClCF<sub>2</sub>Cl (no solvent). This resonance is approximately 1600 c.p.s. downfield to that of a normal CF<sub>3</sub> group. In some cases, a small amount of spin-spin coupling (about 1 c.p.s.) between the ortho-H

(13) F. Loth and A. Michaelis, *Ber.*, **37**, 2543 (1894).

and the  $F^{19}$  was noted. The pentafluoroethyl group has resonances at +814 and +769 c.p.s. with relative intensity of 2 to 3. The downfield shift of the fluorines on the carbon adjacent to oxygen is apparent also in the spectra for the aryl nonafluoro-*n*-butyl ethers which have the normal *n*-heptafluoropropyl group resonances ( $CF_2$  at +2347 c.p.s.) and the  $OCF_2$  resonance at +618 c.p.s. Quantitative correlations of the  $F^{19}$  n.m.r. chemical shifts with substituents and quantitative measurements that show that the perfluoroalkoxy groups are halogen-like in inductive and resonance effects on the aromatic ring and adjacent groups are described in other publications.<sup>1,14</sup>

**Chemical Properties.**—The inert character of the  $OCF_3$  group when attached to an aromatic residue was indicated in earlier reports.<sup>2,4</sup> Numerous additional chemical transformations clearly have demonstrated the unusual stability of the  $OCF_3$  group to strong acids and bases (including organometallic reagents) as well as to strong oxidizing and reducing conditions. Representative reactions for preparation and reactions of the anilines and preparation of benzoic acids are shown by eq. 2 and 3. In general, yields were comparable to those of analogous reactions described in the literature. The  $OCF_2CF_3$ ,  $OCF_2CF_2CF_2CF_3$ , and  $OCF_2CF_2H$  groups, when attached to the aromatic ring, although not examined so thoroughly, also appear to have



stability comparable with that of the  $OCF_3$  group. The thermal stability of the aryl trifluoromethyl ethers is exceptional, and these compounds do not show extensive degradation in the gas phase (as determined by

mass spectrometric analysis) until heated to approximately  $600^\circ$  in a sealed nickel tube.

In substitution studies on the aryl perfluoroalkyl ethers, it was found that the  $OR_i$  group orients an attacking electrophilic reagent to the *ortho-para* positions. Nitration of phenyl trifluoromethyl ether at room temperature with fuming nitric acid in concentrated sulfuric acid gave approximately an equal mixture of mono- and dinitration products. The mononitro product was shown by gas chromatographic analysis, with conformation from spectral (infrared, ultraviolet, and n.m.r.) analysis, to be *para*, and no trace was detected of *ortho* or *meta* isomers (a synthetic mixture of *o*-, *m*-, and *p*-nitrophenyl trifluoromethyl ether was cleanly separated by gas chromatography on a column of 20% diglyceride on Columpak). The dinitro product was shown by spectral analysis to have 2,4-orientation.<sup>15</sup> Bromination in the presence of iron catalyst also gives only *para* orientation for the monobromo derivative. If excess bromine is used, dibromination also occurs; from gas chromatographic and spectral analysis, it was shown that the dibromophenyl trifluoromethyl ether is a mixture of 2,4 and 3,4 isomers in the ratio of two to one. Mononitration of *p*-chlorophenyl trifluoromethyl ether gave the two possible isomers in approximately equal amounts. From these experiments it is concluded that the  $OCF_3$  group is very similar to the halogens (in particular bromine and chlorine) in its influence on the aromatic system to substitution by an electrophilic reagent.

The over-all deactivating effect of the  $OCF_3$  group, analogous to that of the halogens, also is reflected in the low yield obtained in a Friedel-Crafts acylation and in the forcing conditions required for condensation with chloral.

In the bromination of 1,4-bis(trifluoromethoxy)benzene with excess bromine, a mixture of recovered starting material, monobromo and dibromo products, was formed. The dibromo derivative proved to be almost solely the 2,5 isomer by virtue of only a single fluorine resonance in the n.m.r. spectrum (two resonances are observed for the monobromo product and are expected also for the 2,6-dibromo isomer).

Because of the exceptional chemical and thermal stability combined with a good liquid range for the aryl perfluoroalkyl ethers, a series of stable fluids containing perfluoroalkoxy groups was prepared also. In particular, the phenylene ethers substituted with perfluoroalkoxy groups were found to have better properties over-all as stable fluids than the unsubstituted derivative.

## Experimental

**Materials.**—The phenols were purchased from Eastman Kodak Company or other chemical supply houses. Carbonyl fluoride was prepared by the recently reported synthesis from phosgene and sodium fluoride in acetonitrile.<sup>11</sup> Sulfur tetrafluoride was obtained from Organic Chemicals Department, E. I. du Pont de Nemours and Company, Wilmington, Delaware. Trifluoroacetic anhydride, trifluoroacetyl chloride, and heptafluorobutyryl chloride were purchased from Columbia Organic Chemicals. Anhydrous hydrogen fluoride was purchased from Harshaw Chemical Company. Sodium hydride, as a 53% dispersion in

(14) W. A. Sheppard, *J. Am. Chem. Soc.*, **85**, 1314 (1963); D. R. Eaton and W. A. Sheppard, *ibid.*, **85**, 1310 (1963).

(15) Since completion of this work, similar results were reported for the nitration of phenyl trifluoromethyl ether in the Russian literature.<sup>16</sup> The orientation of the nitro groups was proven by classical chemical methods only.



mineral oil, was obtained from Metal Hydrides, Inc., Beverly, Massachusetts.

**A. Preparation of Fluoroformates.**—A modification of the literature procedure<sup>9</sup> was employed. The phenol was charged in a "Hastelloy"-lined pressure vessel (140-, 240-, or 1000-ml. capacity). The vessel was cooled in Dry Ice, evacuated, and a 25 to 50% molar excess of  $\text{COF}_2$  was added. The reactants were heated under autogenous pressure for 1–4 hr. at 100 to 200°. The product was dissolved in an inert solvent, normally methylene chloride, and stirred in a polyethylene bottle with a molar excess of sodium fluoride powder or pellets until the hydrogen fluoride was removed. The solution was filtered and distilled. The fluoroformate, if liquid, was fractionated at reduced pressure or, if solid, was recrystallized. For preparation of *o*-nitrophenyl fluoroformate, it was found necessary to charge a molar amount of NaF powder in the pressure vessel with the reactants. The fluoroformates not described previously in the literature are listed in Table III.

**B. Preparation of Aryl Fluoroalkylcarboxylates.**—Two procedures were employed. (1) The reaction of the phenol with trifluoroacetic anhydride was carried out as described in the literature.<sup>10a</sup> (2) The phenol and an equimolar amount of pyridine was dissolved in ether and a slight molar excess of trifluoroacetyl chloride was bubbled into the solution, or heptafluorobutyl chloride was added dropwise with stirring. The pyridine hydrochloride was separated by suction filtration, and the product distilled (or recrystallized if solid). The esters not previously reported in the literature are listed in Table III.

**C. Preparation of Aryl Perfluoroalkyl Ethers from the Fluoroformate or Perfluoroalkyl Ester.**—The aryl fluoroformate or perfluoroalkyl ester was charged into a "Hastelloy"-lined pressure vessel (140-, 240-, or 1000-ml. capacity). The vessel was cooled in Dry Ice, evacuated, and anhydrous hydrogen fluoride and sulfur tetrafluoride were added. The reactants were then heated under autogenous pressure, generally for 2-hr. successive periods at temperatures of 100, 150, and 175°. The product was treated with sufficient sodium fluoride (powder or pellets) to remove all of the hydrogen fluoride (or alternatively washed with water and sodium bicarbonate solution) and fractionated. Normally a 45-cm. spinning-band column was employed for the distillation and the product was obtained in an exceptionally high state of purity (for phenyl trifluoromethyl ether better than 99.9% pure as determined by gas chromatographic analysis). The reactions run by this route are summarized in Table I, and the ethers are described in Table III.

**D. Preparation of Trifluoromethyl Ethers. General Two-Step Procedure from Phenols.**—The phenol was treated with 25 to 50% molar excess of  $\text{COF}_2$  as described in section A; generally the reactions were heated under autogenous pressure at 100° for 1 hr. and at 130 to 150° for 2–3 hr. The vessel was first cooled to 0° to vent the excess  $\text{COF}_2$ ; then, after cooling to -80°, 10 to 20% molar excess of  $\text{SF}_4$  was added. The reactants were heated under autogenous pressure and the product worked up as described in section C. The reactions run by this method are summarized in Table II, and the ethers are listed in Table III.

**E. Preparation of Aryl Tetrafluoroethyl Ethers.**—The procedure described previously<sup>7a</sup> was employed with the following modifications.<sup>16</sup> The phenol (0.25 to 0.50 mole) was dissolved in 150 ml. of dimethoxyethane (glyme), and 10 to 20 molar % of 53% sodium hydride dispersion in mineral oil was added. When the reaction was complete, the solution was diluted with 150 ml. of dimethylformamide and transferred to the reactor. The tetrafluoroethylene reaction was carried out as described<sup>7a</sup> and the product worked up in the normal manner.

**F. Reactions of Aryl Perfluoroalkyl Ethers (on the Aromatic Ring).**—A number of reactions involving the aromatic ring of aryl trifluoromethyl ethers have been described in the Russian literature.<sup>2,4,5</sup> Also in many reactions, standard conditions (such as described in "Organic Syntheses") were employed to carry out classical conversions on the ring or on substituents. Consequently, experimental details are provided only where conditions are unusual or important. The perfluoroalkyl ethers, with physical properties and analytical data, are listed in Table III, along with the methods of preparation (including references to literature methods where pertinent) and yields also are given.

**1. Nitration. a. Phenyl Trifluoromethyl Ether.**—A mixture of 4.86 g. (0.030 mole) of phenyl trifluoromethyl ether with

18 ml. of concentrated sulfuric acid was placed in a 35-ml. flask fitted with a thermometer, magnetic stirrer, and addition funnel with a Drierite guard tube. Approximately 5 ml. of fuming nitric acid was added dropwise to the mixture with stirring while the temperature was maintained between 20° and 30° by an ice bath. The reaction was extremely exothermic during addition, and after the addition was completed and the ice bath removed, a slight exothermic reaction continued. After approximately 30 min., the mixture was poured over approximately 100 g. of cracked ice, and the product extracted in ether. The ether extracts were washed with 15% sodium hydroxide solution, then with water, and dried over anhydrous magnesium sulfate. The product was distilled through a 30-cm. spinning-band column to obtain 2.9 g. (47%) of *p*-nitrophenyl trifluoromethyl ether, b.p. 82° (9.7 mm.),  $n_D^{25}$  1.4659, and 2.7 g. (36%) of 2,4-dinitrophenyl trifluoromethyl ether, b.p. 106–107° (2 mm.),  $n_D^{25}$  1.4969.

The lower boiling fraction was characterized as *p*-nitrophenyl trifluoromethyl ether. Infrared and gas chromatographic analysis of this sample showed it to contain no *ortho* or *meta* isomer. (Authentic samples of *o*-, *m*-, and *p*-nitrophenyl trifluoromethyl ethers were employed for comparison and synthetic mixtures of the three isomers were readily separated on a 2-m. column of 20% diglyceride on 40- to 60-mesh Columpak heated at 150°.) The 2,4-dinitrophenyl trifluoromethyl ether was characterized by elemental analyses and n.m.r., ultraviolet, and infrared spectra.

**b. *p*-Chlorophenyl Trifluoromethyl Ether.**<sup>17</sup>—A solution of 11.39 g. (0.0574 mole) of *p*-chlorophenyl trifluoromethyl ether in 25 ml. of concentrated sulfuric acid was nitrated with 5 g. of fuming nitric acid as described previously. The chloronitrophenyl trifluoromethyl ether, b.p. 65° (1.1 mm.) was obtained in a yield of 10.0 g. (72%) and was shown to be approximately a 50:50 mixture of the 2- and 3-nitro-4-chlorophenyl trifluoromethyl ether by  $F^{19}$  n.m.r. analysis.

**2. Bromination. a. Phenyl Trifluoromethyl Ether.**<sup>18</sup>—A mixture of 143 g. (0.89 mole) of phenyl trifluoromethyl ether and 3 g. of iron powder was heated to reflux with stirring, and 50 ml. (155 g., 0.97 mole) of bromine was added rapidly. The reaction mixture was then cooled, decanted, and taken up in pentane. The pentane solution was washed successively with 50-ml. portions of 6 *N* hydrochloric acid, 10% sodium bisulfite, and saturated sodium chloride solutions, dried, and distilled. The *p*-bromophenyl trifluoromethyl ether, b.p. 155°, was obtained in a yield of 175 g. (82%) and was characterized as *para* isomer only by gas chromatographic and spectral comparison to an authentic sample prepared by method D. If an excess of bromine was used, dibromophenyl trifluoromethyl ether, b.p. 76–79° (7 mm.),  $n_D^{25}$  1.5068, was obtained as a by-product and was shown to be a mixture of 2,4- and 3,4-dibromo isomers in ratio 2:1, respectively, by  $F^{19}$  n.m.r. and gas chromatographic analysis employing for comparison an authentic sample of 2,4-dibromophenyl trifluoromethyl ether prepared by method D.

**b. 1,4-Bis(trifluoromethoxy)benzene.**—A mixture of 49.2 g. (0.20 mole) of 1,4-bis(trifluoromethoxy)benzene and 1.5 g. of iron powder was heated to reflux, and 24 g. (0.15 mole) of bromine was added over a period of approximately 15 min. The reaction mixture was stirred and refluxed overnight. An additional 16 g. (0.10 mole) of bromine was added and refluxing continued for an additional 36 hr. The reaction was cooled, and the product extracted in pentane. The pentane solution was washed, in turn, with 80 ml. of 6 *N* hydrochloric acid, 120 ml. of 10% sodium bisulfite solution, and saturated sodium chloride solution. The pentane solution was dried over magnesium sulfate, filtered, and distilled. A total of 21.5 g. (44%) of 1,4-bis(trifluoromethoxy)benzene, b.p. 49.5° (20 mm.), was recovered. A second fraction of 14.4 g. (22%), b.p. 58.5° (20 mm.),  $n_D^{25}$  1.4148, was characterized as 2-bromo-1,4-bis(trifluoromethoxy)benzene. The third fraction of 13.1 g. (16%), b.p. 110° (30 mm.),  $n_D^{25}$  1.4571, was characterized as 2,5-dibromo-1,4-bis(trifluoromethoxy)benzene. In a second run on double the scale, the yields were recovered starting material, 38%; monobromo product, 30%; and dibromo product, 15%. The dibromo derivative was found to have a single  $F^{19}$  n.m.r. resonance (-360 c.p.s. with internal reference to  $\text{CF}_2\text{ClCF}_2\text{Cl}$

(17) We are indebted to Dr. W. W. Prichard of this laboratory for this experiment.

(18) We are indebted to Dr. P. E. Aldrich of this laboratory for the experiment.

(16) We would like to thank Dr. D. C. England of this laboratory for suggesting these modifications.

at 40 Mc./sec.). split into a doublet, and a single proton resonance split into a quadruplet ( $J_{HF} = 1.2$  c.p.s.). This spectra is consistent only with the 2,5 isomer since the 2,6 isomer would show two chemically shifted  $F^{19}$  resonances, one of which should be split into a triplet. (The monobromo product shows two equal  $F^{19}$  resonances at  $-363$  and  $-341$  c.p.s. with reference to  $CF_2ClCF_2Cl$  at 40 Mc./sec.)

**3. Reduction of Nitro Group. Aminophenyl Perfluoroalkyl Ethers.**—The general procedures are illustrated by the following examples.

a.—A solution of 7.75 g. (0.030 mole) of *p*-nitrophenyl pentafluoroethyl ether in 100-ml. absolute ethanol containing 0.036 mole of hydrogen chloride was hydrogenated at approximately 3 atm. pressure in a Parr apparatus using 0.30 g. of platinum oxide as catalyst. The theoretical amount of hydrogen was absorbed in a few minutes. The catalyst was removed by filtration, and the alcohol solution evaporated under nitrogen. The residual solid was triturated with 100 ml. of ether and filtered. The pentafluoroethoxyaniline hydrochloride was obtained as white platelets in a yield of 6.0 g. (87%). The free aniline was obtained by adding the hydrochloride to an excess of stirred 10% solution of sodium carbonate layered with ether. The aniline obtained from the dried ether extract was distilled, b.p.  $95^\circ$  (22 mm.).

b.—*m*-Nitrophenyl trifluoromethyl ether (36.3 g., 0.175 mole) in 50 ml. of absolute alcohol with 1 g. of 5% palladium-on-charcoal catalyst was reduced in a pressure vessel at  $50^\circ$  and 69 atm. of hydrogen; approximately the theoretical amount of hydrogen was absorbed. The resulting reaction mixture was filtered to remove catalyst and distilled to obtain 26.8 g. (92.5%) of *m*-aminophenyl trifluoromethyl ether, b.p.  $89^\circ$  (20 mm.),  $n_D^{20}$  1.4633.

**4. Carboxyphenyl Perfluoroalkyl Ethers.**—As shown in eq. 3, three different procedures were employed for the preparation of the acids. The stability of the  $OR_f$  to organometallic reagents and strong oxidizing conditions is illustrated by these methods.

a. **Carbonation of Grignard Reagent.**—The Grignard reagent was prepared in the normal manner by addition of 8.1 g. (0.036 mole) of *p*-bromophenyl trifluoromethyl ether in 15 ml. of ether to 1.0 g. (0.042 g.-atom) of magnesium turnings in 5 ml. of ether. The reaction was exothermic, and the bromo derivative was added at a rate sufficient to maintain reflux. After addition was complete, the reaction mixture was stirred at room temperature for 30 min. and then cooled to  $-5^\circ$  in an ice-acetone bath. Dry carbon dioxide was passed over the stirred solution. An exothermic reaction resulted, and the temperature increased to approximately  $0^\circ$ . Hydrolysis was accomplished with 15 ml. of 6 *N* sulfuric acid, and the product was separated by ether extraction. The crude product was obtained as oily white crystals (yield, 9.5 g.). The *p*-trifluoromethoxybenzoic acid was recrystallized several times from hexane to constant m.p.  $153.2$ – $153.8^\circ$ .

b. **Permanganate Oxidation.**—A mixture of 5.64 g. (0.032 mole) of *m*-trifluoromethoxytoluene with 12.0 g. (0.076 mole) of potassium permanganate dissolved in 140 ml. of water was gradually heated to reflux with stirring. The mixture was refluxed overnight until all of the permanganate color had disappeared. Unchanged starting material (2.0 g., 39%) was removed by distillation of approximately 100 ml. of water from the reaction mixture. The remaining dark aqueous mixture was treated with sulfur dioxide until all of the manganese dioxide had dissolved. A white crystalline solid was filtered from the solution and washed thoroughly with water. The crude *m*-trifluoromethoxybenzoic acid was obtained in a yield of 2.77 g. (42%) and was recrystallized from hexane to constant m.p.  $91.4$ – $92.0^\circ$ .

c. **Bromination, Hydrolysis, and Oxidation.**—A solution of 8.80 g. (0.05 mole) of *p*-tolyl trifluoromethyl ether and 16.0 g. (0.10 mole) of bromine in 100 ml. of carbon tetrachloride was irradiated under reflux overnight with a G. E. sun lamp. At the end of this time, the bromine color had disappeared and considerable hydrogen bromide evolution had occurred. The carbon tetrachloride was evaporated at room temperature under a nitrogen stream, and 75 ml. of concentrated nitric acid was added. The mixture was stirred vigorously overnight, bromine gradually evolved, and finally the product separated from the aqueous phase as a solid. The mixture was poured into several 100 ml. of ice-water, and the solid product was separated by suction filtration and washed thoroughly with water. The yield of *p*-tri-

fluoromethoxybenzoic acid, recrystallized from hexane, m.p.  $153$ – $154^\circ$ , was 6.8 g. (66%).

**5. Tetrakis(trifluoromethoxyphenyl)silane.**—A solution of butyllithium in ether was prepared in the usual way from 13.7 g. (0.10 mole) of butyl bromide, 1.53 g. (0.22 g.-atom) of lithium wire, and 30 ml. of ether. To this was added dropwise a solution of 24.1 g. (0.10 mole) of *m*-trifluoromethoxybromobenzene in 20 ml. of ether keeping the reaction temperature at  $0^\circ$ . After the mixture had been stirred for approximately 2 hr. (the solution turned yellowish in color), a solution of 3.1 g. (0.018 mole) of silicon tetrachloride in 20 ml. of ether was added dropwise. A very exothermic reaction resulted, and the temperature was maintained at 0 to  $5^\circ$  with an acetone-ice bath. The solution was allowed to warm gradually to room temperature overnight and was then hydrolyzed with 25 ml. of 5% hydrochloric acid solution. The ether layer was separated, and the aqueous phase extracted with additional portions of ether. The combined ether extracts were dried over magnesium sulfate, filtered, and evaporated under nitrogen. The residue of pale yellow oil was fractionated on a 30-cm. spinning-band column. Tetrakis(*m*-trifluoromethoxyphenyl)silane, b.p.  $136^\circ$  (0.7 mm.), was obtained in a yield of 5.4 g. (32%). A forecut of 4.4 g. of material, b.p.  $106$ – $136^\circ$  (0.7 mm.), was shown to contain saturated C-H and is believed to be a mixture containing chiefly tris(trifluoromethoxyphenyl)butylsilane. The tetrakis(*m*-trifluoromethoxyphenyl)silane is a glass at  $-80^\circ$  and becomes fluid at approximately  $-30^\circ$ . The open tube boiling point is  $352^\circ$ , and the silane is stable to reflux in a tube open to the air. Although this silane is considerably more volatile than tetraphenylsilane (b.p.  $530^\circ$ , m.p.  $273.5^\circ$ ), it has a much lower melting point so that the over-all liquid range is extended significantly. No reference has been found to any other tetraarylsilane which is a liquid at room temperature.

**6. 1,1,1-Trichloro-2,2-bis(trifluoromethoxyphenyl)ethane.**—Sulfuric acid (50 g., 98–100%) was placed in a 100-ml. flask fitted with a thermometer, magnetic stirrer, and dropping funnel with a Drierite guard tube. A solution of 3.68 g. (0.025 mole) of anhydrous chloral and 8.1 g. (0.050 mole) of phenyl trifluoromethyl ether was added dropwise to the sulfuric acid with stirring. After addition was almost complete, an exothermic reaction occurred, and the temperature increased to  $40^\circ$ . The solution was stirred overnight and then poured into 25 ml. of methylene chloride. The methylene chloride layer was separated, and the sulfuric acid further extracted with methylene chloride. The combined methylene chloride extracts were washed with water and 10% sodium carbonate solution and dried over anhydrous sodium sulfate. The methylene chloride was distilled, and the residue fractionated through a 30-cm. spinning-band column to obtain 2.9 g. (26%), b.p.  $134$ – $140^\circ$  (2.3 mm.),  $n_D^{20}$  1.4952, of 1,1-bis(trifluoromethoxyphenyl)-2,2,2-trichloroethane. In a large-scale preparation, a lower boiling by-product was identified as 1,1,1-trifluoro-2-(trifluoromethoxyphenyl)ethane, b.p.  $58^\circ$  (0.06 mm.). If 96% sulfuric acid was used in the condensation, only this by-product was isolated. This by-product must result from a reduction of an intermediate by the chloral. It is suggested that this reduction can compete successfully with the normal condensation reaction because of deactivation by the trifluoromethoxy group.

**7. *m*-Bis(*m*-trifluoromethoxyphenoxy)benzene.**—A solution of 10.2 g. (0.057 mole) of *m*-trifluoromethoxyphenol in 30 ml. of toluene was mixed with 3.8 g. (0.068 mole) of potassium hydroxide in a Dean-Stark apparatus and heated to reflux for several hours until all the water had been removed as an azeotrope. Approximately 15 ml. of toluene was distilled, and 6.76 g. (0.827 mole) of *m*-dibromobenzene and 0.5 g. of cupric carbonate were added to the reaction mixture. The temperature was gradually raised to  $200^\circ$ , and the remaining toluene distilled. The reaction mixture was then heated under reflux at  $220$ – $240^\circ$  overnight. After cooling, the product was extracted from the pasty dark solid with several portions of ether. The ether extracts were evaporated, and the residual oil distilled to obtain a total of 7.59 g. (61%) of *m*-bis(*m*-trifluoromethoxyphenoxy)benzene, b.p.  $138$ – $143^\circ$  (0.59 mm.),  $n_D^{20}$  1.5048. This product turned to a glass at  $-80^\circ$  and was a mobile liquid to approximately  $-40^\circ$ . The open tube boiling point was  $336^\circ$ . The product obtained previously had a slight odor of phenol and was purified further by distillation from anhydrous sodium carbonate. For comparison the parent *m*-bis(phenoxy)benzene has m.p.  $47$ – $48^\circ$  and b.p.  $372^\circ$ .

**G. Pyrolysis Experiments.**<sup>19</sup>—Samples of the aryl perfluoroalkyl ethers were distilled into an evacuated 10-ml. stainless steel pressure vessel connected to the inlet system of a mass spectrometer. The vessel was heated for 20-min. periods in succession at temperatures of 400, 475, 550, 625 and 700°. After each period, a sample was removed for mass spectrometric analysis, and the per cent decomposition and major decomposition products were determined. In this study,  $C_6H_5OCF_3$ ,  $C_6H_5OCF_2CF_3$ ,  $C_6H_5OCF_2CF_2H$ , and  $p-(CF_3O)_2C_6H_4$  were compared with benzotrifluoride and fluorobenzene. In each case a measurable amount of decomposition (5 to 10%) was noted between 550 and 570°. At 625° the decomposition was 60–70% for the pentafluoro- and tetrafluoroethyl ethers, but only 30 to 40% for the other compounds in the series. The initial course of decomposition in all cases appeared to be formation of biphenyls. For the ethers, formation of carbon monoxide, carbon dioxide, and fluorobenzene derivatives becomes significant at higher temperatures.

**H. Spectral Properties.**—A description of the infrared and

(19) A qualitative study of the stability of derivatives of perfluorobenzene was described recently by L. A. Wall, R. E. Donadia, and W. J. Pummer, *J. Am. Chem. Soc.*, **82**, 4846 (1960).

n.m.r. spectra of the aryl perfluoroalkyl ethers was presented in the discussion. The ultraviolet spectra of these ethers are in general very similar to those of corresponding toluene derivatives, as illustrated by the following examples in Table V.

TABLE V

	$\lambda_{max} m\mu (\log \epsilon)$			
$C_6H_5OCF_3^a$	267 (2.2)	264 (2.4)	255 (2.2)	249 (2.2)
$C_6H_5CH_3^b$	268 (2.4)	262 (2.5)	255 (2.4)	248 (2.2)
$p-C_6H_4(OCF_3)_2^a$		269 (2.5)	264 (2.6)	259 (2.5)
$p-C_6H_4(CH_3)_2^b$	275 (2.7)	268 (2.7)	261 (2.5)	256 (2.3)

<sup>a</sup> The solvent was isooctane. <sup>b</sup> Literature value.

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## $\alpha$ -Fluorinated Ethers. II. Alkyl Fluoroalkyl Ethers<sup>1</sup>

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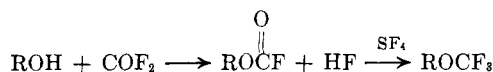
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Aliphatic alcohols are converted to the corresponding trifluoromethyl ethers by reaction with carbonyl fluoride and treatment of the resulting fluoroformate with sulfur tetrafluoride. This reaction has synthetic value only when the alcohol is substituted with a deactivating substituent in the  $\beta$ -position. The scope and extensions of this reaction and the physical and chemical properties of these ethers, particularly trifluoromethyl vinyl ether and substituted ethyl trifluoromethyl ethers, are described.

Perfluoroalkyl ethers have been prepared in low yield by electrolytic fluorination.<sup>2</sup> Other methods useful for preparation of  $\alpha$ -fluorinated ethers are base-catalyzed additions of alcohols to fluoroolefins and fluoride exchange reactions with chlorinated ethers. However, none of these methods is generally useful for the preparation of alkyl trifluoromethyl ethers.<sup>3</sup>

### Results and Discussion

**Synthesis.**—The new general method for preparation of aryl trifluoromethyl ethers described in the previous paper<sup>1</sup> has been extended to the aliphatic series.



Alcohols were converted to the corresponding fluoroformates by reaction with carbonyl fluoride<sup>4,5</sup> in an

(1) Paper I: W. A. Sheppard, *J. Org. Chem.*, **29**, 1 (1964).

(2) A general review describing synthesis and properties of fluoroalkyl ethers is presented in (a) A. M. Lovelace, D. A. Rausch, and W. Postelnek, "Aliphatic Fluorine Compounds," Reinhold Publishing Corp., New York, N. Y., 1958, Chap. V, p. 155; (b) M. Hudlicky, "Chemistry of Organic Fluorine Compounds," The MacMillan Co., New York, N. Y., 1962, pp. 141 and 238. (c) K. Weissmermel and M. Lederer, *Ber.*, **96**, 77 (1963), describe preparation of  $\alpha$ -fluorinated ethers by addition of *t*-butyl hypochlorite to fluoroolefins.

(3) A trichlorodimethyl ether has been treated with antimony trifluoride to give a trifluorodimethyl ether, H. S. Booth and P. E. Burchfield, *J. Am. Chem. Soc.*, **57**, 2070 (1935). No proof of structure was presented, but, on the basis of physical properties (see Discussion) and ease of hydrolysis, the structure must have been  $FCH_2OCF_2H$  and not  $CH_3OCF_3$  as suggested in ref. 2a.

(4) Fluoroformates also may be obtained by fluoride ion exchange on chloroformates (ref. 2b, page 111).

autoclave at 100 to 200°. In a second step, the fluoroformates were converted to trifluoromethyl ethers by reaction with sulfur tetrafluoride<sup>6</sup> at 150 to 200°. In general, the intermediate fluoroformate was not isolated, and the hydrogen fluoride by-product from the first step served as a catalyst and/or solvent for the sulfur tetrafluoride reaction. In one case where the fluoroformate was isolated, anhydrous hydrogen fluoride was added with the sulfur tetrafluoride, since it had been shown with aryl fluoroformates and other carbonyl derivatives<sup>1</sup> that hydrogen fluoride is necessary to catalyze the conversion to the respective  $\alpha$ -fluorinated ethers and difluoro derivatives.

This reaction is useful as a synthetic method only if the  $\beta$ -carbon is substituted with one or more electron-withdrawing groups, such as F, Cl, Br,  $OCF_3$  (or  $OCF_2$ ), and fluoroalkyl groups. Although methanol afforded methyl trifluoromethyl ether, other aliphatic alcohols composed of only hydrocarbon chains gave tars or carbonaceous products. With one electro-negative substituent, the overall yield of ether from alcohol was in the range of 30 to 40% but increased to 50 to 60% when three deactivating substituents were present in the  $\beta$ -position. These reactions are summarized in Table I, and the trifluoromethyl ethers,

(5) Carbonyl fluoride was prepared by a convenient new synthesis from sodium fluoride and phosgene in acetonitrile as described by F. S. Fawcett, C. W. Tullock, and D. D. Coffman, *J. Am. Chem. Soc.*, **84**, 4275 (1962).

(6) (a) C. W. Tullock, F. S. Fawcett, W. C. Smith, and D. D. Coffman, *ibid.*, **82**, 539 (1960); (b) W. R. Hasek, W. C. Smith, and V. A. Engelhardt, *ibid.*, **82**, 543 (1960).