Polyfluoroether Derivatives via Nucleophilic Fluorination of Glyoxal Hydrates with Deoxofluor

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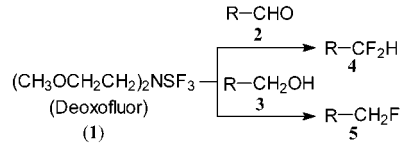
Various glyoxal hydrates have been reacted with Deoxofluor [$(CH_3OCH_2CH_2)_2NSF_3$]. In concentrated solutions of dichloromethane, Deoxofluor (**1**) efficiently fluorinates a variety of glyoxal hydrates, $RCOCHO{\cdot}H_2O$ (R = 4-methoxyphenyl, 3,4-methylenedioxyphenyl, 4-methylphenyl, 4-fluorophenyl, phenyl, 2-thienyl, methyl) (**6a**−**g**) to form polyfluoroethers **7a**−**g** and **8a**−**g** as meso and racemic mixtures (∼1:1) in good yields. The meso and racemic compounds were separated by flash chromatography and characterized. When the reactant comprised two different glyoxal hydrates, mixed polyfluoroethers (**9h**−**j**) were observed as the major products. The yields of the mixed polyfluoroethers depend on the ratio of the two different glyoxal hydrates used. Reactions of some other hydrates, such as hydrindantin dihydrate (**10**) and 1,1,1,5,5,5-hexafluoro-2,2,4,4-pentanetetrol (**11**), were also studied with Deoxofluor to give a cyclic polyfluoroether (**12**) and *β*-ketoamine (**13**), respectively. When the reactions of **6a**−**d** were carried out under very dilute conditions, difluoro aldehydes (**14a**−**d**) or tetrafluoroalkanes (**15a**−**d**) were formed rather than polyfluoroethers. Reactions of concentrated solutions of nonhydrated glyoxals (**16k**−**m**) in methylene chloride with Deoxofluor produced the tetrafluoroalkanes (**18k**−**m**) in good yields with only trace amounts of difluoroaldehydes (**17k**−**m**) being found. The structures of **7a** (meso), **8b** (racemic), and **12** have been confirmed by single-crystal X-ray analysis.

Introduction

Synthetic and structural aspects of organofluorine compounds derived directly from nonfluorinated precursors by using fluorinating agents have been the focal points of vigorous research as evidenced by the appearance of a large number of publications.[1] Because fluorine is the element with highest electronegativity and its van der Waals radius is close to that of hydrogen, the incorporation of a fluorine atom or a fluorine-containing group into organic molecules alters their physical, chemical, and biological properties dramatically, making them suitable for diverse applications in material sciences and agrochemistry, as well as in the pharmaceutical industry.[2−5] The biological activity and numerous commercial applications of organofluorine compounds have encouraged interest in developing synthetic methods for selective and efficient incorporation of fluorine or fluorinated groups into organic compounds under mild reaction conditions. While a wide variety of methods have been developed for introducing one or more fluorine atoms into organic compounds,[6] the use of Deoxofluor as a nucleophilic fluorinating reagent is gaining in popularity.[7−9] Conversion of a simple system such as an aldehyde (**2**) or a ketone (**3**) into the corresponding difluoro derivative

Scheme 1



(**4** and **5** respectively) using Deoxofluor [$(CH_3OCH_2CH_2)_2NSF_3$], and DAST [$(CH_3CH_2)_2NSF_3$], is well explored (Scheme 1).[10]

Deoxofluor appears, in some cases, to be a more effective fluorinating reagent than DAST, and it is easier to handle than sulfur tetrafluoride.[7−9] The greater reac-

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(1) (a) Lal, G. S.; Pez, G. P.; Syvret, R. G. *Chem. Rev.* **1996**, *96*, 1737−1755. (b) Umemoto, T. *Ibid.* 1757−1777. (c) Prakash, G. K. S.; Yudin, A. K. *Chem. Rev.* **1997**, *97*, 757−777. (d) Taylor, S. D.; Kotoris, C. C.; Hum, G. *Tetrahedron* **1999**, *55*, 12431−12477. (e) Singh, R. P.; Shreeve, J. M. *Tetrahedron* **2000**, *56*, 7613−7632.

(2) For the general applications of organofluorine compounds see: *Organofluorine Chemistry: Principles and Commercial Applications*; Banks, R. E., Smart, B. E., Tatlow, J. C., Eds.; Plenum: New York, 1994.

(3) For the use of organofluorine compounds in medicinal and biomedical chemistry, see: (a) *Biomedical Frontiers of Fluorine Chemistry*; Ojima, I., McCarthy, J. R., Welch, J. T., Eds.; ACS Symposium Series 639; American Chemical Society: Washington, DC, 1996. (b) *Organic Chemistry in Medicinal Chemistry and Biomedical Applications*; Filler, R., Ed.; Elsevier: Amsterdam, 1993. (c) Welch, J. T.; Eswaraksrishnan, S. *Fluorine in Bioorganic Chemistry*; John Wiley and Sons: New York, 1991. (d) Filler, R.; Kirk, K. Biological Properties of Fluorinated Compounds. In *Chemistry of Organic Fluorine Compounds II: A Critical Review*; Hudlicky, M., Pavlath, A. E., Eds.; ACS Monograph 187; American Chemical Society: Washington, DC, 1995; pp 1011−1022. (e) Elliot, A. J. Fluorinated Pharmaceuticals. In *Chemistry of Organic Fluorine Compounds II: A Critical Review*; Hudlicky, M., Pavlath, A. E., Eds.; ACS Monograph 187; American Chemical Society: Washington, DC, 1995; pp 1119−1125. (f) Sholoshonok, V. A., Ed. *Enantiocontrolled Synthesis of Organo-Fluorine Compounds: Stereochemical Challenge and Biomedical Targets*; John Wiley and Sons: New York, 1999.

(4) For the use of organofluorine compounds in agrosciences, see: (a) Cartwright, D. Recent Developments in Fluorine-Containing Agrochemicals. In *Organofluorine Chemistry: Principles and Commercial Applications*; Banks, R. E., Smart, B. E., Tatlow, J. C., Eds.; Plenum: New York, 1994; pp 237−257. (b) Lang, R. W. In *Fluorinated Agrochemicals*. In *Chemistry of Organic Fluorine Compounds II*; Hudlicky, M., Pavlath, A. E., Eds.; ACS Monograph 187; American Chemical Society: Washington, DC, 1995; pp 1143−1148.

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tivity of Deoxofluor with substrates such as β-diketones has been observed recently,[9a] and we have extended the scope of Deoxofluor to polyfunctional compounds.[9a] Recently, we reported a new route to polyfluoro ethers from aryl glyoxal hydrates.[11] We now present full details of the reactions of alkyl, aryl, and mixed glyoxal hydrates and other hydrates with Deoxofluor. DAST and Deoxofluor have been compared as well as the effect of solvents on the yield of meso and racemic compounds.

Results and Discussion

Deoxofluor is a very useful reagent[7−9] for introducing a difluoro or tetrafluoro moiety into organic molecules. During the course of our studies on nucleophilic perfluoroalkylation,[12] it was realized that the reactions of Deoxofluor with di- and polycarbonyl systems could provide a straightforward route to the corresponding tetrafluoro and polyfluorinated compounds in a single step. With dicarbonyl compounds, various substrates were selected in which the two carbonyl groups are located in different chemical environments.[9a] With glyoxal hydrates, the products were meso and racemic mixtures of polyfluoroethers in an approximately 1:1 ratio, as described below.

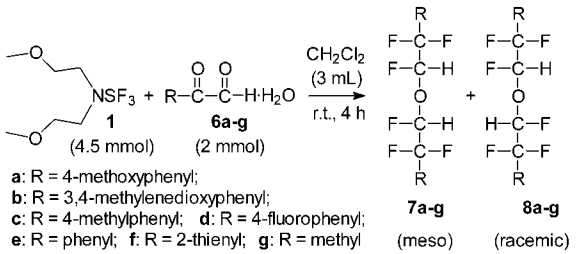
Reaction of Deoxofluor with Aryl or Alkyl Glyoxal Hydrates. First, **6a** (2 mmol) was treated with Deoxofluor (1.5 mmol) in 3 mL of dichloromethane to determine the relative reactivities of the two carbonyl groups at room temperature. The product was a mixture of four compounds. Two were polyfluoro ethers **7a** and **8a**. The other two products were the difluoro aldehyde (**14a**) and tetrafluoro alkane derivative (**15a**). When the reaction was carried out in a 1:2.25 molar ratio (substrate/Deoxofluor), the only products were **7a** and **8a** in about a 1:1 ratio. The reactivity of **6a** with Deoxofluor was then determined in different solvents under identical reaction conditions (Table 1). In diethyl ether, the yields of polyfluoroethers were higher than with monoglyme, tetrahydrofuran, and toluene. However, dichloromethane and chloroform were far superior. The ratio of meso and racemic products was about 1:1 in all the solvents (Table 1). Since the yields of the polyfluoroethers were best in methylene chloride as solvent, various glyoxal hydrates (**6b**−**g**) were also converted into the corresponding polyfluoroethers (**7b**−**g** and **8b**−**g**) in good yields (Scheme 2, Table 2). Compounds **7g** and **8g** were volatiles and difficult to separate from dichloromethane and also from each other. Products were characterized by GCMS and NMR.

Table 1. Effect of Solvent on the Yields of Meso and Racemic Polyfluoro-Ethers at Room Temperature[a]

6a (mmol)	deoxofluoro (mmol)	solvent (3 mL)	%[b] of meso (**7a**)	%[b] of racemic (**8a**)	yield (%)[c] (**7a** + **8a**)
2	1.5	dichloromethane	51	49	30
2	4.5	dichloromethane	50	50	93
2	4.5	chloroform	49	51	90
2	4.5	diethylether	46	54	70
2	4.5	monoglyme	52	48	60
2	4.5	tetrahydrofuran	49	51	65
2	4.5	toluene	48	45	54

[a] All the reactions were carried out in 3 mL of solvent for 4 h. [b] Percentages of meso and racemic ratio are based on GCMS. [c] Isolated yield as a mixture of meso and racemic products.

Scheme 2



A literature survey revealed that DAST has not been studied with glyoxal hydrates. Using DAST, reaction with **6a** was carried out under conditions similar to those used with Deoxofluor. Meso and racemic products (**7a**, **8a**) in an approximately 1:1 ratio were formed in 82% isolated yield, but a slightly longer reaction time was required. Moreover, trace amounts of an impurity, CH_3O−4-C_6H_4−COCOF were identified in the ^{1}H NMR and ^{19}F NMR spectra as well as in the mass spectrum. This impurity was not observed with Deoxofluor. The meso and racemic compounds (Table 2) were separated by flash chromatography using a methylene chloride/pentane mixture (1:2) as eluting solvent and characterized. The structures of **7a** and **8b** have been confirmed by single-crystal X-ray analysis.

Reactions of Deoxofluor with Mixed Glyoxal Hydrates. Mixed polyfluoroethers (**9h**−**j**) were also produced in good yield when a mixture of two different glyoxal hydrates (**6a** and **6c**,**f**,**g**) reacted with Deoxofluor

(5) The ability of fluorine to change the properties of organic molecules has been discussed extensively elsewhere. For example see: Smart, B. E., *Characteristics of C−F systems*. In *Organofluorine Chemistry*: *Principles and Commercial Applications*, Banks, R. E.; Smart, B. E.; Tatlow, J. C. Eds.; Plenum: New York, 1994; pp 57−82.

(6) For general discussion on the synthesis of organofluorine compounds, see: (a) Olah, G. A.; Prakash, G. K. S.; Chambers, R. D. *Synthetic Fluorine Chemistry*: Wiley and Sons: New York, 1992. (b) Furin, G. G. *Synthetic Aspects of the Fluorination of Organic Compounds*; Harwood Academic Publisher: London, 1991. (c) Furin, G. G. Introduction of Fluorine by N−F Compounds. In *Methods of Organic Chemistry (Houben-Weyl) Organo-Fluorine Compounds*; Georg Thieme Verlag: Stuttgart, New York, 1999; pp 432−499. (d) Taylor, S. D.; Kotoris, C. C.; Hum, G. *Tetrahedron* **1999**, *55*, 12431−12477. (e) McClinton, M. A.; McClinton, D. A. *Tetrahedron* **1992**, *48*, 6555−6666. (f) Rozen, S. *Chem. Rev.* **1996**, *96*, 1717−1736. (g) Wilkinson, J. A. *Chem. Rev.* **1992**, *92*, 505−519. (h) Rozen, S.; Mishani, E. *J. Chem. Soc., Chem. Commun.* **1994**, 2081. (i) Rozen, S.; Mishani, E.; Bar-haim, A. *J. Org. Chem.* **1994**, *59*, 2918. (j) Middleton, W. J.; Bingham, E. M. *J. Org. Chem.* **1980**, 45, 2883−2887. (k) Rozen, S.; Lerman, O.; Kol, M.; Hebel, D. *J. Org. Chem.* **1985**, *50*, 4753−4758.

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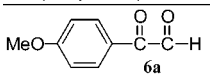
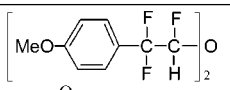
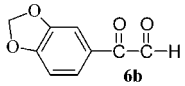
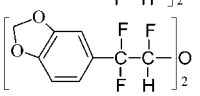
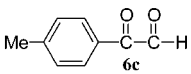
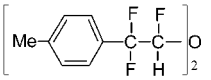
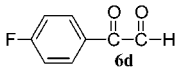
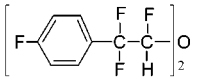
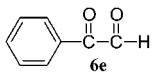
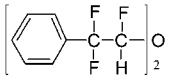
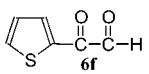
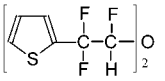
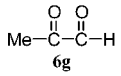
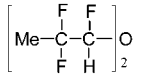
(11) Singh, R. P.; Shreeve, J. M. *Org. Lett.* **2001**. *17*, 2713−2715.

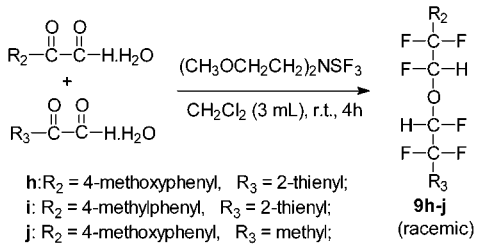
(12) (a) Singh, R. P.; Kirchmeier; R. L.; Shreeve, J. M. *J. Org. Chem.* **1999**, *64*, 2579−2581. (b) Singh, R. P.; Cao, G.; Kirchmeier; R. L.; Shreeve, J. M. *J. Org. Chem.* **1999**, *64*, 2873−2876. (c) Singh, R. P.; Kirchmeier, R. L.; Shreeve, J. M. *Org. Lett.* **1999**, *1*, 1047−1049. (d) Singh, R. P.; Shreeve; J. M. *J. Org. Chem.* **2000**, *65*, 3241−3243. (e) Singh, R. P., Kirchmeier, R. L.; Shreeve, J. M. *Inorg. Chem.* **2000**, *39*, 375−377.

Table 2. Reaction of Various Glyoxal Hydrates with Deoxofluor at Room Temperature[a]

substrate (as hydrates)	product[b]	Yield (%)[c] meso	racemic
 **6a**		**7a** (48)	**8a** (45)
 **6b**		**7b** (47)	**8b** (44)
 **6c**		**7c** (47)	**8c** (46)
 **6d**		**7d** (45)	**8d** (45)
 **6e**		**7e** (45)	**8e** (46)
 **6f**		**7f** (44)	**8f** (46)
 **6g**		**7g**[d] (21)	**8g**[d] (24)

[a] All the reactions were carried out in 2 mmol of substrate and 4.5 mmol of Deoxofluor in 3 mL of dichloromethane. [b] Meso and racemic products were separated by flash chromatography and characterized by spectroscopic analysis. [c] Isolated. [d] GC yield.

Scheme 3

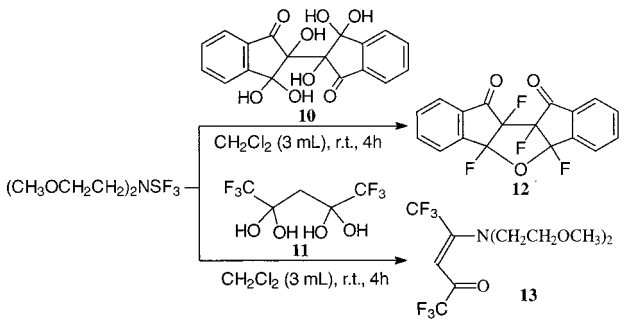


in minimum solvent (Scheme 3). The yields of the crossed polyfluoroethers depend on the ratio of the two glyoxal hydrates used.

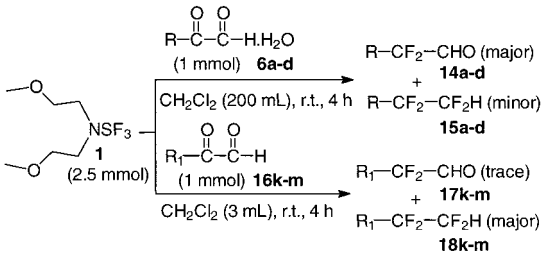
With a 1:1 molar ratio of glyoxal hydrates at room temperature, a mixture of three polyfluoroethers was obtained with the crossed polyfluoroether in highest yield. Crossed polyfluoroethers were also a mixture of two isomers (*RR* + *SS* and *RS* + *SR*) in an approximately 1:1 ratio. As in the case of symmetrical polyfluoroethers, the two isomers are the meso and racemic, but meso is not possible with crossed polyfluoroethers. These two distereomers, which could be a mixture of *RR* and *SS*, and a mixture of *RS* and *SR*, were separable by flash chromatography. Since the ^{19}F NMR chemical shifts of meso and racemic products in symmetrical polyfluoroethers were found to be different, the racemic product of mixed polyfluoro ethers was distinguishable from another racemic isomer (*RR* + *SS*).

Reaction of Deoxofluor with Hydrindantin Dihydrate (10) and 1,1,1,5,5,5-Hexafluoro-2,2,4,4-pentanetetrol (11) in High Concentration. When the reaction of Deoxofluor was carried out with hydrindantin dihydrate (**10**), the product was a cyclic fluorinated ether (**12**) in 65% yield. The structure of **12** has been confirmed by single-crystal X-ray analysis. The formation of **12** under acidic conditions is not surprising due to the presence of carbonyl and hydroxyl groups adjacent to each other in **10**.[13] Due to the symmetrical nature of **10** the cyclic ether ring can be expected to form on either side of the molecule, resulting in a similar product (**12**). The X-ray crystal structure suggests that once the first cyclic ether ring is formed, the remaining carbonyl and hydroxyl moieties are separated at too great a distance to allow formation of the second cyclic ether ring. Reaction of Deoxofluor with 1,1,1,5,5,5-hexafluoro-2,2,4,4-pentanetetrol (hexafluoroacetylacetone dihydrate) (**11**) led to the formation of the β-ketoenamine (**13**) in 60% yield, without formation of either a cyclic or acyclic ether (Scheme 4).

Scheme 4



Scheme 5



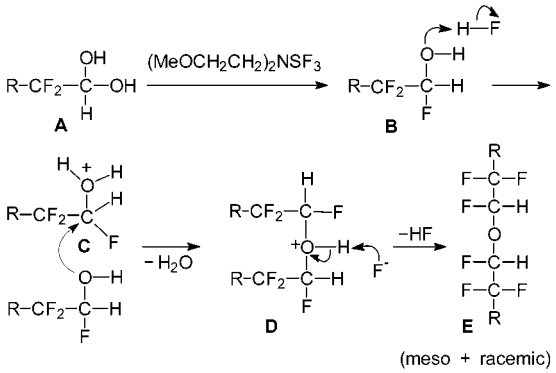
a: R = 4-methoxyphenyl; **b**: R = 3,4-methylenedioxyphenyl;
c: R = 4-methylphenyl; **d**: R = 4-fluorophenyl;
k: R_1 = 4-cyclohexylphenyl, **l**: R_1 = 4-biphenyl; **m**: R_1 = 4-nitrophenyl

Reaction of Deoxofluor with Nonhydrated Glyoxals in Dilute Solutions. When the reactions described in Scheme 2 were carried out under very dilute conditions, difluoroaldehydes or tetrafluoroalkanes were formed rather than polyfluoroethers. For example, the reaction of **6a** (1 mmol) with Deoxofluor (**1**) (2.5 mmol) in methylene chloride (200 mL) at 25 °C for 4 h afforded a mixture of **14a** (75%) and **15a** (25%) (Scheme 5). Under similar reaction conditions, various arylglyoxal hydrates (**6b**−**d**) also gave a mixture of **14b**−**d** as major and **15b**−**d** as minor products (Scheme 5). Reaction of concentrated solutions of nonhydrated aryl glyoxals (**16k**−**m**) in methylene chloride with Deoxofluor produced the tetrafluoroalkanes (**18k**−**m**) in very good isolated yields, whereas only trace amounts of difluoroaldehydes (**17k**−**m**) were found (Scheme 5).

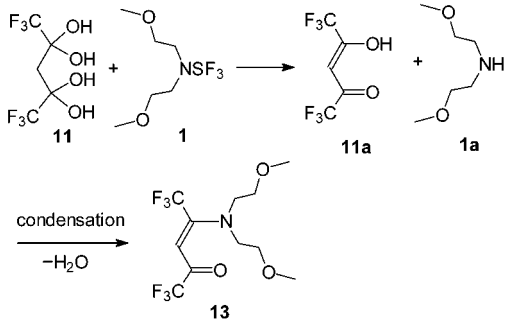
Reaction Mechanism of Polyfluoro Ether Formation. While the mechanism for the formation of difluoroaldehydes or tetrafluoroalkanes is similar to that of the reaction between simple aldehydes and ketones with Deoxofluor,[8] the mechanism for the formation of fluorinated symmetrical or mixed polyfluoroethers is proposed in Scheme 6. It is known that Deoxofluor fluorinates alcohols, ROH, to produce the corresponding fluorinated

(13) Nicolaou, K. C.; Hwang, C. K.; Nugiel, D. A. *J. Am. Chem. Soc.* **1989**, *111*, 4136−4137.

Scheme 6



Scheme 7



derivative, R−F. When **A** reacts, a fluorinated alcohol (**B**) is formed which is unstable with respect to loss of HF or which can reacts under highly concentrated conditions with HF to give an unstable intermediate **C**. **B** attacks at the highly electrophilic carbon of **C**, resulting in intermediate **D**. Under acidic conditions (HF), the formation of ether **E** is not surprising. Under very dilute conditions, if appropriate nucleophiles are not available, the intermediates, **B**, **C** and **D** easily decompose. Nonhydrated aryl glyoxals do not form polyfluoro ethers even when water is present in the reaction mixture.

Mechanism for the Formation of *β*-Ketoenamine (13). The formation of the *β*-ketoamine (**13**) is rationalized in Scheme 7. Deoxofluor (**1**) dehydrates **11** to produce anhydrous hexafluoroacetylacetone (**11a**) which exists almost totally in enolic form. The presence of **11a** was detected by GCMS at the end of the reaction. The formation of secondary amine (**1a**) is always observed when Deoxofluor undergoes hydrolysis. The enol tautomer easily undergoes a condensation reaction[14] with **1a** to produce *β*-ketoamine (**13**) as the main product. Recently, we reported[9a] that under anhydrous reaction conditions simple *β*-diketones with Deoxofluor produced vicinal difluoroenones in good

yields. No vicinal difluoroamine formation was observed in the present reaction indicating that the condensation reaction proceeds more rapidly producing the *β*-ketoamine as the main product.

X-ray Crystal Structures of 7a, 8b, and 12. Compounds **7a**, **8b**, and **12** were crystallized from a mixture of pentane and methylene chloride and their structures were confirmed by single-crystal X-ray analyses. They crystallize in the following respective space groups: *Pna*2(1), *P*2(1)/*c* and *C*2/*c*. All compounds form discrete molecular units; however, in the solid state, hydrogen bonding links the molecules and forms supramolecular entities.

Compounds **7a** and **8b** are similar in structure. Compound **8b** exits as two independent molecules in the asymmetric unit unlike **7a**, which is unique. The aromatic moiety in each unit is linked by the same fluorinated ether unit $-CF_2C(H)FOC(H)FCF_2$. Compound **7a** assumes a meso configuration whereas **8b** has a racemic arrangement. The aromatic moieties in each are not parallel with respect to each other. The angle between the ring planes is 41.4° for **7a**, 99.9 and 104.1° for **8b**. This may be due to the difference in intermolecular hydrogen bonding. Compound **12** is a cyclic ether with one-half of the molecule in the asymmetric unit. The fluorine atoms on the linking five-membered ether unit are eclipsed but there is little distortion from planarity.

All three compounds form intermolecular hydrogen bonds ranging from 3.308(9) to 3.335(9) Å. Compounds **7a** and **12** form one-dimensional "ribbons" along the *c*- and *b*-axes, respectively. Compound **8b** has a more complicated synthon with both oxygen atoms of the methoxyphenyl groups involved in intermolecular bonding with a hydrogen atom on the linking fluoroalkyl ether chain and with a hydrogen atom of the methyl group.

Conclusion

At high concentration, the reaction of Deoxofluor with various glyoxal hydrates at room temperature provides a direct route to a mixture of meso and racemic polyfluoro- ethers (∼1:1) in good yields. They were easily separable by simple flash chromatography using a dichloromethane and pentane mixture as an eluting solvent. Reactions of a mixture of two different glyoxal hydrates with Deoxofluor produced mixed polyfluoroethers as the major product. Under very dilute conditions, polyfluoroethers were not formed but rather difluoroaldehydes or tetrafluoro derivatives were obtained. Reactions of concentrated solutions of nonhydrated glyoxals with Deoxofluor in methylene chloride produced the tetrafluoro derivatives in good yields with only trace amounts of difluoro products. Thus, depending on the concentration of the reactants and the degree of hydration of the glyoxal, fluorinated ethers or tetrafluoro and difluoro derivatives are selectively produced. A cyclic polyfluoro ether formed when hydrindantin dihydrate was reacted with Deoxofluor.

Experimental Section

All reactions were performed under dry nitrogen. Arylglyoxals were obtained from SynChem Co. and were used as received. Deoxofluor was a gift from Air Products and Chemical, Inc. ^{1}H, ^{19}F, and ^{13}C NMR spectra were recorded in $CDCl_3$ on a spectrometer operating at 500, 470, and 125 MHz, respectively. Chemical shifts are reported in ppm relative to the appropriate standards; $CFCl_3$ for ^{19}F, and TMS for ^{1}H and ^{13}C NMR spectra. IR spectra were recorded using KBr pellets for solids and neat films using KBr plates. Mass spectra were measured on an electron impact 70 eV spectrometer.

X-ray Crystallographic Measurement. Crystals of compounds **7a** and **8b** were removed from the flasks and covered with a layer of hydrocarbon oil. A suitable crystal was selected, attached to a glass fiber and placed in the low-temperature nitrogen stream.[15] A crystal of **12** was mounted at room

(14) *Enamines: Synthesis, Structure, and Reactions*; Cook, A. G., Ed.; Marcel Dekker: New York, 1969.

(15) Hope, H. *Progr. Inorg. Chem.* **1995**, *41*, 1−12.

temperature. Data of **7a** and **8b** were collected near 203 K and for **12** near 303 K using a Siemens SMART instrument (Mo Kα radiation, $\lambda = 0.710\ 73$ Å) equipped with a Siemens LT-2A low-temperature device. The SHELXTL v. 5.10 program package was used for structure solution and refinement.[16] An absorption correction was applied for **7a**, **8b** and **12** using SADABS.[17] The structures were solved by direct methods and refined by full matrix least squares procedures. All non-hydrogen atoms were refined anisotropically. Further details are provided in the Supporting Information.

Reaction of Glyoxal Hydrates with Deoxofluor at Low Concentration. In a typical experiment, an arylglyoxal hydrate (2 mmol) was dissolved in dichloromethane (3 mL), and Deoxofluor (4.5 mmol) was added dropwise at room temperature. The reaction mixture was stirred at 25 °C for 4 h. The reaction was quenched by the slow addition of aqueous $NaHCO_3$ solution until effervescence was complete. The dichloromethane layer was separated and dried over anhydrous $MgSO_4$. The dried solution was filtered and the solvent removed at reduced pressure. The product was purified by flash chromatography. The same procedure was used to prepare the mixed polyfluoroethers.

Bis[2-(4-methoxyphenyl)-1,2,2-trifluoroethyl]ether (meso) (7a): yield 48%; mp 75 °C; IR (KBr pellet) 2955, 1640, 1614, 1580, 1513, 1453, 1412, 1305, 1251, 1180, 1135, 1089, 1029, 979, 827, 750 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −109.70 (ABX pattern, 4F, $J_{F-F} = 265$ Hz), −138.27 (doublet of multiplets, 2F, $J = 59$ Hz); ^1H NMR ($CDCl_3$) δ 3.82 (s, 6H), 5.58 (doublet of multiplets, 2H, $J = 59$ Hz), 6. 88 (d, 4H, $J = 11$ Hz), 7.35 (d, 4H, $J = 8.8$ Hz); ^{13}C NMR ($CDCl_3$) δ 55.3, 107.1 (doublet of triplets, $J = 236.2$ Hz, $J = 42.5$ Hz), 113.6, 116.2 (triplet of doublets, $J = 246$ Hz, $J = 30.8$ Hz), 122.4 (t, $J = 25.1$ Hz), 128.0 (t, $J = 6.3$ Hz), 161.5; MS (EI) *m/z* (species, rel int) 395 ($M^+ + H$, 2), 394 (M^+, 8), 375 ($M^+ - F$, 1), 189 ($MeOC_6H_4CF_2$-CFH^+, 3), 157 ($MeOC_6H_4CF_2^+$, 100), 139 ($MeOC_6H_4CF^+ + H$, 19). Anal. Calcd for $C_{18}H_{16}F_6O_3$: C, 54.83; H, 4.09. Found: 54.55; H, 3.99. X-ray crystallographic data: crystal system, orthorhombic; space group, *Pna*2(1); unit cell dimensions, $a = 27.473(2)$ Å, $b = 9.5895(7)$ Å, $c = 6.3057(5)$ Å, $\alpha = 90°$, $\beta = 90°$, $\lambda = 90°$; $Z = 4$; $F(000) = 856$; crystal size $= 0.28 \times 0.09 \times 0.05$ mm^3; $R1$ (all data) $= 0.0715$, wR2 $= 0.1163$. Selected bond lengths (Å): F(1)−C(8) = 1.394(5), F(3)−C(9) = 1.378(5), O(1)−C(2) = 1.377(4), O(1)−C(1) = 1.424 (6), O(3)−C(9) = 1.391(5), O(3)−C(4) = 1.408(6). Selected bond angles (deg): C(2)−O(1)−C(1) = 104.6(3), C(9)−O(3)−C(10) = 116.0(3), F(2)−C(8)−F(1) = 105.6(3), F(2)−C(8)−C(9) = 104.5(4), F(2)−C(8)−C(5) = 110.9(4), F(3)−C(9)−O(3) = 108.3(3), O(3)−C(9)−C(8) = 107.3(3).

Bis[2-(4-methoxyphenyl)-1,2,2-trifluoroethyl]ether (racemic) (8a): yield 45%; mp 71 °C; IR (KBr pellet) 2960, 1610, 1514, 1456, 1417, 1379, 1305, 1257, 1176, 1135, 1083, 1029, 980, 829, 749 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −110.40 (ABX pattern, 4F, $J_{F-F} = 268$ Hz), −145.98 (doublet of multiplets, 2F, $J = 60$ Hz); ^1H NMR ($CDCl_3$) δ 3.82 (s, 6H), 5.64 (doublet of multiplets, 2H, $J = 60$ Hz,), 6. 87 (d, 4H, $J = 8.7$ Hz), 7.28 (d, 4H, $J = 7$ Hz); ^{13}C NMR ($CDCl_3$) δ 55.3, 103.5 (doublet of triplets, $J = 236$, 42.5 Hz), 113.4, 117.1 (triplet of doublets, $J = 246$, 27.7 Hz), 122.5 (t, $J = 25.1$ Hz), 128.1 (t, $J = 6.3$ Hz), 161.4; MS (EI) *m/z* (species, rel int) 395 ($M^+ + H$, 2), 394 (M^+, 7), 375 ($M^+ - F$, 1), 189 ($MeOC_6H_4CF_2CFH^+$, 4), 157 ($MeOC_6H_4$-CF_2^+, 100), 139 ($MeOC_6H_4CF^+ + H$, 20); HRMS calcd for $C_{18}H_{16}F_6O_3$ 394.1004, found 394.0992.

Bis[2-(3,4-methylenedioxyphenyl)-1,2,2-trifluoroethyl]-ether (meso) (7b): yield 47%; mp 89 °C; IR (KBr pellet) 2900, 1607, 1500, 1442, 1362, 1296, 1257, 1112, 1031, 933, 904, 869, 803, 768, 740, 682, 664 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −109.47 (ABX pattern, 4F, $J_{F-F} = 267$ Hz), −138.22 (doublet of multiplets, 2F, $J = 56$ Hz); ^1H NMR ($CDCl_3$) δ 5.57 (doublet of multiplets, 2H, $J = 56$ Hz), 5.96 (q, 4H, $J = 1.5$ Hz), 6.80 (d, 2H, $J = 8$ Hz), 6.85 (d, 2H, $J = 1.7$ Hz), 6.93 (d, 2H, $J = 8$ Hz); ^{13}C NMR ($CDCl_3$) δ 101.6, 107.1 (doublet of triplets, $J = 238.5$, 42.8 Hz), 108.0, 116. 9 (triplet of doublets, $J = 247$, 31 Hz), 120.9 (t, $J = 7$ Hz), 123.8 (t, $J = 25.1$ Hz), 147.6, 149.8 (t, $J = 1.5$ Hz); MS (EI) *m/z* (species, rel int) 423 ($M^+ + H$, 4), 422 (M^+, 22), 183 ($OCH_2OC_6H_3CF_2C^+$, 2), 171 ($OCH_2OC_6H_3CF_2^+$, 100), 153 ($OCH_2OC_6H_3CF^+ + H$, 17), 125 ($C_6H_3CF_2^+$, 4); HRMS calcd for $C_{18}H_{12}F_6O_5$ 422.0589, found 422.0567.

Bis[2-(3,4-methylenedioxyphenyl)-1,2,2-trifluoroethyl]-ether (racemic) (8b): yield 44%; mp 92 °C; IR (KBr pellet) 2899, 1604, 1500, 1441, 1364, 1300, 1264, 1232, 1078, 1037, 929, 902, 806, 761, 648 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −109.92 (ABX pattern, 4F, $J_{F-F} = 60$ Hz), −145.94 (doublet of multiplets, 2F, $J = 61$ Hz); ^1H NMR ($CDCl_3$) δ 5.63 (doublet of multiplets, 2H, $J = 60$, 2 Hz), 6.00 (q, 4H, $J = 1.5$ Hz), 6.79 (d, 2H, $J = 1.7$ Hz), 6.81 (s, 2H), 6.87 (d, 2H, $J = 8$ Hz); ^{13}C NMR ($CDCl_3$) δ 101.6, 103.3 (doublet of triplets, $J = 236.5$, 41.3 Hz), 107.1 (t, $J = 6.2$ Hz), 107.9, 115.8 (triplet of doublets, $J = 246$, 27.3 Hz), 121.0 (t, $J = 7$ Hz, 123.9 (t, $J = 25.2$ Hz), 147.6, 149.7; MS (EI) *m/z* (species, rel int) 423 ($M^+ + H$, 3), 422 (M^+, 17), 183 ($OCH_2OC_6H_3CF_2C^+$, 15), 171 ($OCH_2OC_6H_3CF_2^+$, 100), 153 ($OCH_2OC_6H_3CF^+ + H$, 25), 125 ($C_6H_3CF_2^+$, 6). Anal. Calcd for $C_{18}H_{12}F_6O_5$: C, 51.20; H, 2.86. Found: 51.08; H, 3.17. X-ray crystallographic data: crystal system, monoclinic; space group, $P2_1/c$; unit cell dimensions, $a = 16.423(5)$ Å, $b = 19.824(6)$ Å, $c = 10.778(4)$ Å, $\alpha = 90°$, $\beta = 97.097(6)°$, $\lambda = 90°$; $Z = 8$; $F(000) = 1616$; crystal size $= 0.34 \times 0.09 \times 0.05$ mm^3; $R1$ (all data) $= 0.2675$, wR2 $= 0.1806$. Selected bond lengths (Å): C(1)−O(1) = 1.410(5), C(8)−F(2) = 1.364(8), C(9)−O(2) = 1.393(7), C(28)−O(5) = 1.380(7). Selected bond angles (deg): C(1)−C(1)−C(3) = 125.9(7), F(2)−C(8)−F(1) = 105.4(6), F(2)−C(8)−C(5) = 110.4(6), F(3)−C(9)−O(2) = 108.1(6), O(2)−C(9)−C(8) = 106.9(6), O(2)−C(10)−F(4) = 110.1(6), C(28)−O(5)−C(27) = 116.1(5).

Bis[2-(4-methyphenyl)-1,2,2-trifluoroethyl]ether (meso) (7c): yield 47%; mp 62 °C; IR (KBr pellet) 2954, 1921, 1667, 1608, 1414, 1355, 1291, 1128, 1065, 815, 748, 729, 675 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −110.62 (ABX pattern, 4F, $J_{F-F} = 266$ Hz), −138.42 (doublet of multiplets, 2F, $J = 59$ Hz); ^1H NMR ($CDCl_3$) δ 3.82 (s, 6H), 5.60 (doublet of multiplets, 2H, $J = 59$ Hz), 7.19 (d, 4H, $J = 7.9$ Hz), 7.31 (d, 4H, $J = 8.1$ Hz); ^{13}C NMR ($CDCl_3$) δ 21.35, 107.2 (doublet of triplets, $J = 236.5$, 41.8 Hz), 116.2 (triplet of doublets, $J = 246.1$, 30.7 Hz), 126.4 (t, $J = 6.5$ Hz), 127.7 (t, $J = 24.5$ Hz), 128.9, 141.1; MS (EI) *m/z* (species, rel int) 362 (M^+, 11), 323 ($M^+ - HF_2$, 1), 173 ($MeC_6H_4CF_2CFH^+$, 5), 141 ($MeC_6H_4CF_2^+$, 100), 123 (MeC_6H_4-$CF + H$, 15), 91 ($MeC_6H_4^+$, 8); HRMS calcd for $C_{18}H_{16}F_6O$ 362.1105, found 362.1097.

Bis[2-(4-methylphenyl)-1,2,2-trifluoroethyl]ether (racemic) (8c): yield 46%; mp 60 °C; IR (KBr pellet): 2958, 1916, 1617, 1509, 1413, 1373, 1137, 1087, 988, 820, 738 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −110.96 (ABX pattern, 4F, $J_{F-F} = 268$ Hz), −145.96 (doublet of multiplets, 2F, $J = 57$ Hz); ^1H NMR ($CDCl_3$) δ 2.39 (s, 6H), 5.66 (doublet of multiplets, 2H, $J = 57$ Hz), 7.16 (d, 4H, $J = 8.5$ Hz), 7.24 (d, 4H, $J = 11.5$ Hz); ^{13}C NMR ($CDCl_3$) δ 21.3, 103.5 (doublet of triplets, $J = 236.2$, 42.5 Hz), 116.1 (triplet of doublets, $J = 246$, 27.8 Hz), 127.5 (t, $J = 24.6$ Hz), 128.8 (t, $J = 6.3$ Hz), 141.0; MS (EI) *m/z* (species, rel int) 362 (M^+, 7), 323 ($M^+ - HF_2$, 1), 173 ($MeC_6H_4CF_2CFH^+$, 4), 141 ($MeC_6H_4CF_2^+$, 100), 123 ($MeC_6H_4CF^+ + H$, 17), 91 ($MeC_6H_4^+$, 10). Anal. Calcd for $C_{18}H_{16}F_6O$: C, 59.67; H, 4.41. Found: 59.68; H, 4.34.

Bis[2-(4-fluorophenyl)-1,2,2-trifluoroethyl]ether (meso) (7d): yield 45%; IR (KBr film) 2916, 1611, 1516, 1303, 1280, 1240, 1137, 1088, 1059, 1044, 841, 750 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −109.40 (m, 2F), −110.12, (ABX pattern, 4F, $J_{F-F} = 268$ Hz), −138.31 (doublet of multiplets, 2F, $J = 59$ Hz); ^1H NMR ($CDCl_3$) δ 5.63 (doublet of multiplets, 2H, $J = 59$ Hz), 7.0 (m, 4H), 7.41 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 106.6 (doublet of triplets, $J = 236.7$, 42.0 Hz), 115.4, 115.5, 116.1 (triplet of doublets, $J = 246.0$, 30.5 Hz), 128.7 (t, $J = 9.2$ Hz); MS (EI) *m/z* (species, rel int) 370 (M^+, 7), 177 ($FC_6H_4CF_2CFH^+$, 9), 145 ($FC_6H_4CF_2^+$, 100), 127 ($FC_6H_4CF^+ + H$, 31), 95 ($FC_6H_4^+$, 7); HRMS calcd for $C_{16}H_{10}F_8O$ 370.0604, found 370.0594.

Bis[2-(4-fluorophenyl)-1,2,2-trifluoroethyl]ether (racemic) (8d): yield 45%; IR (KBr film) 2920, 1611, 1515, 1305, 1282, 1240, 1163, 1089, 1061, 841, 742 cm^{-1}; ^{19}F NMR ($CDCl_3$)

(16) Sheldrick, G. M. *SHELXTL: Version 5.10, structure determination software*; Bruker AXS Inc.: Madison, WI, 1998.

(17) Sheldrick, G. M. *SADABS: an empirical absorption correction program*; Bruker AXS Inc.: Madison, WI, 1999.

δ −109.54 (m, 2F), −110.78 (ABX pattern, 4F, J_{F-F} = 268 Hz), −145.43 (doublet of multiplets, 2F, J = 60 Hz); ^{1}H NMR ($CDCl_3$) δ 5.66 (doublet of multiplets, 2H, J = 60 Hz), 7.0 (m, 4H), 7.32 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 103.4 (doublet of triplets, J = 237.5, 41.5 Hz), 115.3, 115.4, 116.0 (triplet of doublets, J = 246.0, 30.0 Hz), 128.8 (t, J = 9.0 Hz); MS (EI) *m/z* (species, rel int) 370 (M^+, 7), 177 ($FC_6H_4CF_2CFH^+$, 7), 145 ($FC_6H_4CF_2^+$, 100), 127 ($FC_6H_4CF^+$ + H, 27), 95 ($FC_6H_4^+$, 6); HRMS calcd for $C_{16}H_{10}F_8O$ 370.0604, found 370.0581.

Bis(2-phenyl-1,2,2-trifluoroethyl)ether (meso) (7e): yield 45%; IR (KBr film) 2945, 1604, 1595, 1450, 1409, 1346, 1300, 1278, 1137, 1060, 983, 847, 761, 698 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −110.99 (ABX pattern, 4F, J_{F-F} = 268 Hz), −138.31 (doublet of multiplets, 2F, J = 59 Hz); ^{1}H NMR ($CDCl_3$) δ 5.63 (doublet of multiplets, 2H, J = 59 Hz), 7.2−7.5 (m, 10H); ^{13}C NMR ($CDCl_3$) δ 107.1 (doublet of triplets, J = 236.8, 41.1 Hz), 116. 8 (triplet of doublets, J = 246.2, 30 Hz), 126.4 (t, J = 3.8 Hz), 128.2, 130.3 (t, J = 23.2 Hz), 130.9; MS (EI) *m/z* (species, rel int) 334 (M^+, 10), 159 ($PhCF_2CFH^+$, 12), 127 ($PhCF_2$, 100), 109 ($PhCHF^+$, 27), 77 (Ph^+, 10); HRMS calcd for $C_{16}H_{12}F_6O$ 334.0793, found 334.0786.

Bis(2-phenyl-1,2,2-trifluoroethyl)ether (racemic) (8e): yield 46%; IR (KBr film) 2963, 104, 1595, 1445, 109, 1368, 1296, 1278, 1133, 1060, 983, 843, 761, 689 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −111.43 (ABX pattern, 4F, J_{F-F} = 268 Hz), −145.73 (doublet of multiplets, 2F, J = 60 Hz); ^{1}H NMR ($CDCl_3$) δ 5.65 (doublet of multiplets, 2H, J = 60 Hz), 7.0−7.5 (m, 10H); ^{13}C NMR ($CDCl_3$) δ 103.5 (doublet of triplets, J = 236.6, 42 Hz), 116.5 (triplet of doublets, J = 246.1, 30.0 Hz), 126.5 (t, J = 6.3, Hz), 127.9, 130.3 (t, J = 23.2 Hz), 130.8; MS (EI) *m/z* (species, rel int) 334 (M^+, 9), 159 ($PhCF_2CFH^+$, 10), 127 ($PhCF_2^+$, 100), 109 ($PhCHF^+$, 26), 77 (Ph^+, 10); HRMS calcd for $C_{16}H_{12}F_6O$ 334.0793, found 334.0791.

Bis(2-thienyl-1,2,2-trifluoroethyl)ether (meso) (7f): yield 44%; IR (KBr film) 2950, 1535, 1433, 1355, 1283, 1257, 1134, 1103, 1049, 952, 847, 826, 714 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −100.30 (ABX pattern, 4F, J_{F-F} = 273 Hz), −137.70 (doublet of multiplets, 2F, J = 60 Hz); ^{1}H NMR ($CDCl_3$) δ 5.66 (doublet of multiplets, 2H, J = 60 Hz), 7.01 (m, 2H), 7.26 (m, 2H), 7.42 (doublet of doublets, 2H, J = 5, 1.2 Hz); ^{13}C NMR ($CDCl_3$) δ 106.6 (doublet of triplets, J = 237.5, 41 Hz), 115.06 (triplet of doublets, J = 245, 31.5 Hz), 127.06, 128.97, 129.16 (t, J = 6 Hz), 131.1 (t, J = 29 Hz); MS (EI) *m/z* (species, rel int) 346 (M^+, 23), 133 ($SCH{=}CHCH{=}CCF_2^+$, 100), 165 ($SCH{=}CHCH{=}CCF_2CFH^+$, 8), 146 ($SCH{=}CHCH{=}CCF_2CH^+$, 8), 115 ($SCH{=}CHCH{=}CCF$ + H, 18); HRMS calcd for $C_{12}H_8F_6OS_2$ 345.9921, found 345.9917.

Bis(2-thienyl-1,2,2-trifluoroethyl)ether (racemic) (8f): yield 46%; IR (KBr film) 2962, 1535, 1433, 1281, 1132, 1094, 1045, 950, 823, 712 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −100.74 (ABX pattern, 4F, J_{F-F} = 273 Hz), −145.73 (doublet of multiplets, 2F, J = 60 Hz); ^{1}H NMR ($CDCl_3$) δ 5.73 (doublet of triplets, 2H, J = 60 Hz), 7.00 (m, 2H), 7.22 (m, 2H), 7.42 (dd, 2H, J = 5, 1.2 Hz); ^{13}C NMR ($CDCl_3$) δ 103.1 (doublet of triplets, J = 237.3, 41 Hz), 115.0 (triplet of doublets, J = 245, 30 Hz), 127.0, 128.97, 129.1 (t, J = 6 Hz), 131.3 (t, J = 29 Hz); MS (EI) *m/z* (species, rel int) 346 (M^+, 25), 133 ($SCH{=}CHCH{=}C{-}CF_2^+$, 100), 165 ($SCH{=}CHCH{=}CCF_2CFH^+$, 7), 146 ($SCH{=}CHCH{=}CCF_2CH^+$, 6), 115 ($SCH{=}CHCH{=}CCF$ + H, 20). Anal. Calcd for $C_{12}H_8F_6OS_2$: C, 41.62; H, 2.33. Found: 41.71; H, 2.50.

Bis(2-methyl-1,2,2-trifluoroethyl)ether (meso) (7g): ^{19}F NMR ($CDCl_3$) δ −108.45 (m, 4F), −121.22 (m, 2F); ^{1}H NMR ($CDCl_3$) δ 1.56 (m, 6H), 5.68 (m, 2H,); MS (EI) *m/z* (species, rel int) 210 (M^+, 1), 194 [M^+ − (CH_3 + H), 1], 97 ($CH_3CF_2CFH^+$, 100).

Bis(2-methyl-1,2,2-trifluoroethyl)ether (racemic) (8g): ^{19}F NMR ($CDCl_3$) δ −110.26 (m, 4F), −131.72 (m, 2F); ^{1}H NMR ($CDCl_3$) δ 1.60 (m, 6H), 5.85 (m, 2H); MS (EI) *m/z* (species, rel int) 210 (M^+, 1), 194 [M^+ − (CH_3 + H), 2], 97 ($CH_3CF_2CFH^+$, 100).

2-Thienyl-2′-(4-methoxyphenyl)bis(1,2,2-trifluoroethyl)ether (9h): yield 26%; viscous liquid; IR (KBr pellet): 1616, 1517, 1434, 1308, 1280, 1257, 1209, 1178, 1134, 1091, 1032, 983, 937, 716 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −101.01 (m, 2F), −110.43 (ABX pattern, 2F, J_{F-F} = 290 Hz), −145.68 (doublet of multiplets, 1F, J = 62 Hz), −146.40 (doublet of multiplet, 1F, J = 62 Hz); ^{1}H NMR ($CDCl_3$) δ 3.78 (s, 3H), 5.57 (doublet of multiplets, 1H, J = 62 Hz), 5.77 (doublet of multiplets, 1H, J = 62 Hz), 6.84 (d, 2H, J = 8.9 Hz), 6.99 (m, 1H), 7.16 (m, 1H), 7.30 (d, 2H, J = 8.9 Hz), 7.41 (dd, 1H, J = 1.2, 5 Hz); MS (EI) *m/z* (species, rel int) 370 (M^+, 20), 351 (M^+ − F, 1), 332 (M^+ − 2F, 1), 157 ($MeOC_6H_4CF_2^+$, 100), 133 ($C_5H_3F_2^+$, 13). Anal. Calcd for $C_{15}H_{12}F_6O_2S$: C, 48.65; H, 3.27. Found: 48.47; H, 3.13.

2-Thienyl-2′-(4-methylphenyl)bis(1,2,2-trifluoroethyl)-ether (9i): yield 23%; viscous liquid; IR (KBr pellet): 1612, 1519, 1430, 1300, 1288, 1250, 1209, 1175, 1091, 1031, 988, 930, 713 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −101.00 (s, 2F), −111.25 (ABX pattern, 2F, J_{F-F} = 288 Hz), −145.85 (doublet of multiplets, 1F, J = 60 Hz), −146.47 (doublet of multiplet, 1F, J = 60 Hz); ^{1}H NMR ($CDCl_3$) δ 2.34 (s, 3H), 5.56 (doublet of multiplets, 1H, J = 60 Hz), 5.79 (doublet of multiplets, 1H, J = 60 Hz), 6.80−7.55 (m, 7H); MS (EI) *m/z* (species, rel int) 354 (M^+, 5), 165 ($C_4H_3SCF_2CFH$, 1), 141 ($MeC_6H_4CF_2^+$, 100), 91 (MeC_6H_4, 13). 83 (C_4H_3S + H, 6). Anal. Calcd for $C_{15}H_{12}F_6OS$: C, 50.84; H, 3.42. Found: 50.50; H, 3.60

2-Methyl-2′-(4-methoxyphenyl)bis(1,2,2-trifluoroethyl)ether (9j): yield 18%; viscous liquid; IR (KBr pellet) 2950, 1615, 1512, 1438, 1290, 1250, 1200, 1190, 1039, 976, 722 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −107.00 (m, 2F), −110.40 (ABX pattern, 2F, J_{F-F} = 278 Hz), −139.50 (doublet of multiplets, 1F, J = 58 Hz), −145.88 (doublet of multiplet, 1F, J = 60 Hz); ^{1}H NMR ($CDCl_3$) δ 1.50 (m, 3H), 3.34 (s, 3H), 5.54 (m, 1H), 5.65 (m, 1H), 7.37 (d, 2H, J = 8.8 Hz), 7.93 (d, 2H, J = 8.8 Hz); MS (EI) *m/z* (species, rel int) 302 (M^+, 5), 283 (M^+ − F, 1), 263 [M^+ − (HF + H), 1], 189 ($MeOC_6H_4CF_2CF_2H^+$, 4), 157 ($MeOC_6H_4CF_2^+$, 60), 59 (C_2FO^+, 100). Anal. Calcd for $C_{12}H_{12}F_6O_2$: C, 47.69; H, 4.00. Found: 47.57; H, 4.12.

3-Oxo-3′,2,2′,3,3′-Tetrafluorohydrindantin (12): yield 65%; mp 176 °C; IR (KBr pellet) 1750, 1600, 1465, 1339, 1273, 1190, 1087, 1028, 993, 933, 894, 837, 771, 710 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −111.48 (s, 1F), −181.09 (s, 1F); ^{1}H NMR ($CDCl_3$) δ 7.77 (m, 2H), 7.95(m, 6H); ^{13}C NMR ($CDCl_3$) δ 96.0 (doublet of doublet, J = 219.5, 31.5 Hz), 97.7 (doublet of doublet, J = 219.5, 31.5 Hz), 115.9, 117.9, 124.8, 133.3, 138.0, 143.9, 186.29 (doublet, J = 8.5 Hz), 186.39 (doublet, 8.5 Hz); MS (EI) *m/z* (species, rel int) 348 (M^+, 44), 329 (M^+ − F, 1), 272 [M^+ − (3F + HF), 1], 197 (M^+ − $C_8H_4FO_2$, 1), 151 ($C_8H_4FO_2^+$, 100). Anal. Calcd for $C_{18}H_8F_4O_3$: C, 62.08; H, 2.32. Found: C, 61.89; H, 2.12. X-ray crystallographic data: crystal system, monoclinic; space group, *C*2/*c*; unit cell dimensions, a = 15.338(2) Å, b = 7.7419(12) Å, c = 14.017(2) Å, α = 90°, β = 118.66(3)°, λ = 90°; Z = 4; $F(000)$ = 704; crystal size = 0.22 × 0.10 × 0.08 mm^3; $R1$ (all data) = 0.1201, wR2 = 0.1105. Selected bond lengths (Å): F(1)−C(8) = 1.359(3), F(1)−C(9) = 1.380(3), O(2)−C(8) = 1.392(3), C(8)−C(5) = 1.533(4). Selected bond angles (deg): C(8)−O(2)−C(831) = 113.1(3), O(1)−C(1)−C(9) = 123.4-(3), C(2)−C(1)−C(9) = 106.6(3), F(1)−C(8)−O(2) = 107.2(2), O(2)−C(8)−C(7) = 113.8(2), F(1)−C(8)−C(9) = 111.7(3), F(2)−C(9)−C(1) = 110.7(2).

1,1,1,5,5,5-Hexafluoro-4-bis(methoxyethyl)amino-3-en-2-one (13): yield 60%; viscous liquid; IR (KBr pellet) 2895, 1670, 1559, 1455, 1254, 1191, 1139, 1057, 794, 737 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −63.88 (s, 3F), −77.22 (s, 3F); ^{1}H NMR ($CDCl_3$) δ 3.24 (s, 6H), 3.42 (t, 4H, J = 5.2 Hz), 3.61 (t, 4H, J = 5.2 Hz), 5.90 (s, 1H); MS (EI) *m/z* (species, rel int) 324 (M^+ + H, 1), 278 (M^+ − CH_3OCH_2, 52), 59 ($CH_3OCH_2CH_2^+$, 100), 58 ($CH_3OCH_2CH^+$, 44), 45 ($CH_3OCH_2^+$, 19). Anal. Calcd for $C_{11}H_{15}F_6NO_3$: C, 40.87; H, 4.68. Found: C, 40.72; H, 4.80.

Reaction of Glyoxal Hydrates with Deoxofluor in Dilute Solutions. An arylglyoxal hydrate (1 mmol) was dissolved in dichloromethane (200 mL), and Deoxofluor (2.5 mmol) was added neat dropwise under vigorous stirring. The reaction mixture was stirred at 25 °C for 4 h. The reaction was quenched with aqueous $NaHCO_3$ solution. The dichloromethane layer was separated, dried over anhydrous $MgSO_4$, and filtered. The product was purified by flash chromatography using dichloromethane and pentane (1:1) solution as the solvent.

2,2-Difluoro-2-(4-methoxyphenyl)acetaldehyde (14a): yield 73%; viscous liquid; IR (KBr pellet) 2935, 1689, 1614, 1516, 1462, 1253, 1178, 1076, 980, 834 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −110.90 (d, 2F, J = 182.5 Hz); ^1H NMR ($CDCl_3$) δ 3.32 (s, 3H), 6.85 (d, 2H, J = 10.5 Hz), 7.41 (d, 2H, J = 8.5 Hz), 9.47 (t, 1H, J = 4 Hz); MS (EI) *m/z* (species, rel int) 186 (M^+, 20), 167 [M^+ − F, 10), 157 (M^+ − COH, 100), 126 [M^+ − (COH + OMe), 13], 107 ($MeOC_6H_4$, 6); HRMS calcd for $C_9H_8F_2O_2$ 186.0492, found 186.0481.

2,2-Difluoro-2-(3,4-methylenedioxyphenyl)acetaldehyde (14b): yield 67%; viscous liquid; IR (KBr pellet): 2950, 1682, 1620, 1507, 1470, 1175, 1075, 982, 840 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −111.50 (d, 2F, J = 182 Hz); ^1H NMR ($CDCl_3$) δ 3.32 (s, 3H), 6.00 (q, 2H, 1.5 Hz), 6.82 (d, 1H, J = 8 Hz), 6.82 (d, 1H, J = 1.7 Hz), 6.95 (d, 1H, J = 8 Hz), 9.50 (t, 1H, J = 4.5 Hz); MS (EI) *m/z* (species, rel int) 200 (M^+, 12), 181 [M^+ − F, 12), 171 (M^+ − COH, 100), 121 (M^+ − CF_2COH, 8). Anal. Calcd for $C_9H_6F_2O_3$: C, 54.01; H, 3.02. Found: C, 53.78; H, 2.94.

2,2-Difluoro-2-(4-methylphenyl)acetaldehyde (14c): yield 70%; viscous liquid; IR (KBr pellet) 2933, 1688, 1612, 1516, 1462, 1254, 1178, 1028, 981, 832 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −111.87 (d, 2F, J = 236 Hz); ^1H NMR ($CDCl_3$) δ 2.30 (s, 3H), 6.82 (d, 2H, J = 10.6 Hz), 7.44 (d, 2H, J = 8.5 Hz) 9.48 (t, 1H, J = 4 Hz); MS (EI) *m/z* (species, rel int) 170 (M^+, 2), 151 [M^+ − F, 15), 141 (M^+ − COH, 100), 126 [M^+ − (COH + Me), 2], 91 (MeC_6H_4, 21); HRMS calcd for $C_9H_8F_2O$ 170.0543, found 170.0549.

2,2-Difluoro-2-(4-fluorophenyl)acetaldehyde (14d): yield 65% (GC); MS (EI) *m/z* (species, rel int) 174 (M^+, 2), 155 [M^+ − F, 1), 145 (M^+ − COH, 100), 126 [M^+ − (COH + F), 29], 125 [M^+ − (COH + HF), 52], 95 (FC_6H_4, 34), 75 (C_6H_4, 58); ^{19}F NMR ($CDCl_3$) δ −111.99 (m, 2F), −110.24 (m, 1F); ^1H NMR ($CDCl_3$) δ 7.02 (m, 2H), 7.54 (m, 2H), 8.10 (t, 1H, J = 4 Hz). The product was volatile and difficult to separate from the solvent (methylene chloride).

1-(4-Methoxyphenyl)-1,1,2,2-tetrafluoroethane (15a): yield less than 2% as detected by GCMS; MS (EI) *m/z* (species, rel int) 208 (M^+, 5), 207 [M^+ − H, 15), 157 (M^+ − CF_2H, 97), 154 [M^+ − (Me + HF_2^+), 100], 126 [M^+ − (CF_2H + OMe), 13], 76 ($C_6H_4^+$, 10).

1-[2-(3,4-Methylenedioxyphenyl)]-1,1,2,2-tetrafluoroethane (15b): yield less than 2% as detected by GCMS; MS (EI) *m/z* (species, rel int) 222 (M^+, 46), 203 [M^+ − F, 5), 171 (M^+ − CF_2H, 100), 64 ($CF_2CH_2^+$, 71).

1-(4-Methylphenyl)-1,1,2,2-tetrafluoroethane (15c): yield less than 2% as detected by GCMS; MS (EI) *m/z* (species, rel int) 192 (M^+, 25), 173 (M^+ − F, 4), 141 (M^+ − CF_2H, 100), 91 (M^+ − CF_2CF_2H, 10).

1-(4-Fluorophenyl)-1,1,2,2-tetrafluoroethane (15d): yield less than 2% as detected by GCMS; MS (EI) *m/z* (species, rel int) 196 (M^+, 1), 195 (M^+ − H, 3), 175 [M^+ − (HF + H), 29], 156 (M^+ − 2HF, 10), 155 [M^+ − (2HF + H), 100], 145 (M^+ − CF_2H, 28), 127 ($C_6H_5CF_2$, 6).

Reactions of Glyoxals (Anhydrous) with Deoxofluor at High Concentration. Reactions of **16k**−**m** with Deoxofluor were carried out under conditions identical to those used for **6a**−**g**.

2,2-Difluoro-2-(4-cyclohexylphenyl)acetaldehyde (17k): yield less than 2% as detected by GCMS; MS (EI) *m/z* (species, rel int) 238 (M^+, 3), 209 [M^+ − CHO, 100), 127 ($C_6H_5CF_2$, 72), 83 (C_6H_{11}, 3).

2,2-Difluoro-2-(biphenyl)acetaldehyde (17l): yield less than 2% as detected by GCMS; MS (EI) *m/z* (species, rel int) 232 (M^+, 13), 203 (M^+ − CHO, 100), 152 [M^+ − (CF_2CHO + H), 10], 88 ($C_6H_4C^+$, 11).

2,2-Difluoro-2-(4-nitrophenyl)acetaldehyde (17m): yield less than 2% as detected by GCMS; MS (EI) *m/z* (species, rel int) 201 (M^+, 1), 172 (M^+ − CHO, 90), 127 [M^+ − (CHO + NO_2 + H), 72], 107 [M^+ − (CHO + F + NO_2), 10], 76 ($C_6H_4^+$, 5).

1-(4-Cyclohexylphenyl)-1,1,2,2-tetrafluoroethane (18k): yield 80%; IR (KBr film) 2955, 1538, 1430, 1356, 1280, 1257, 1131, 1100, 1045, 955, 847, 715 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −113.82 (ABX pattern, 2F), −134.77 (doublet of multiplets, 2F, J = 54 Hz); ^1H NMR ($CDCl_3$) δ 0.75−1.85 (m, 11H), 5.83 (triplet of multiplets, 1H, J = 54 Hz), 7.15−7.50 (m, 4H); MS (EI) *m/z* (species, rel int) 260 (M^+, 70), 241 (M^+ − F, 3), 209 (M^+ − CF_2H, 17), 159 ($C_6H_{11}C_6H_5^+$, 45), 127 ($C_6H_4^+$ + H, 19), 83 ($C_6H_{11}^+$, 2), 82 ($C_6H_{10}^+$, 8), 51 (CF_2H^+, 9); HRMS calcd for $C_{14}H_{16}F_4$ 260.1185, found 260.1191

4-(1,12,2-Tetrafluoroethyl)biphenyl (18l): yield 78%; IR (KBr film) 2962, 1542, 1428, 1355, 1279, 1135, 1102, 1048, 951, 845, 708 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −113.50 (ABX pattern, 2F), −134.22 (doublet of multiplets, 2F, J = 54 Hz); ^1H NMR ($CDCl_3$) δ 5.80 (triplet of multiplets, 1H, J = 54 Hz), 7.40−8.00 (m, 9H); MS (EI) *m/z* (species, rel int) 254 (M^+, 37), 235 (M^+ − F, 2), 216 (M^+ − 2F, 1), 203 (M^+ − CF_2H, 100), 101 ($CF_2CF_2H^+$, 15), 51 (CF_2H^+, 3); HRMS calcd for $C_{14}H_{10}F_4$ 254.0719, found 254.0695.

1-(4-Nitrophenyl)-1,1,2,2-tetrafluoroethane (18m): yield 80%; IR (KBr film) 3122, 1610, 1531, 1353, 1290, 1217, 1104, 995, 910, 856, 815, 763, 738, 706 cm^{-1}; ^{19}F NMR ($CDCl_3$) δ −113.60 (ABX pattern, 2F), −133.90 (doublet of multiplets, 2F, J = 54 Hz); ^1H NMR ($CDCl_3$) δ 5.97 (triplet of multiplets, 1H, J = 54 Hz), 7.74 (d, 2H, J = 8.7 Hz), 8.35 (d, 2H, J = 8.7H); ^{13}C NMR ($CDCl_3$) δ 109.8 (triplet of triplets, J = 250, 43 Hz), 114.8 (triplet of triplets, J = 248.1, 30.0 Hz), 123.7, 124.0, 128.0, 130.8, 135.6; (MS (EI) *m/z* (species, rel int) 223 (M^+, 29), 204 (M^+ − F, 2), 177 (M^+ − NO_2, 8), 172 (M^+ − CF_2H, 100), 127 ($C_6H_4CF_2^+$ + H, 66), 51 (CF_2H^+, 11), 50 (CF_2^+, 11); HRMS calcd for $C_8H_5F_4NO_2$ 223.0256, found 223.0259.

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Supporting Information Available: Crystal data and structure refinements, atomic coordinates, bond lengths, bond angles, anisotropic displacement parameters, hydrogen coordinates, and ORTEP drawings for **7a** and **8b** and **12**. This material is available free of charge via the Internet at http://pubs.acs.org.

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