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Polyfluorination Using IF_5

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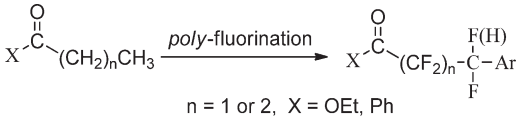

The polyfluorination of α-(arylthio)carbonyl compounds was achieved by a successive application of polyfluorination using IF_5, Friedel−Crafts arylation, and desulfurizing fluorination using IF_5. Three to six fluorine atoms were selectively introduced to the carbons located between the aromatic ring and the carbonyl group.

Introduction

Polyfluoro compounds are widely used in our lives as plastics, paints, water-repellents, and so on.[1] Polyfluoro compounds containing 2−3 polyfluorinated carbons are currently attracting attention as functional materials.[2] They are prepared by a "building block method," where the available polyfluoro compounds are used for making the polyfluorinated part of the target molecules.[2a,3] However, an appropriate building block for the synthesis of a target molecule is not always available, and a multistep synthesis is often required to obtain the target molecule from the available building block. If the selective introduction of the multifluorine atoms to the particular carbons in the molecule were possible, the partially polyfluorinated molecules could be prepared more easily, and we would no longer need to look for suitable building blocks. However, only a few methods are known for the introduction of multiple fluorine atoms to the particular carbons of a molecule.[4] Recently, the deoxyfluorination reaction of α-diketones by SF_4,[2b] DAST,[2b] or Deoxofluor[5] was used for introducing four fluorine atoms to the adjacent carbons. However, the method is effective only when the carbonyl group is attached to the aromatic ring; otherwise, the yield is low. Previously, we found that in the reaction of aryl alkyl sulfides with IF_5, three to seven fluorine atoms were introduced into the alkyl group of the sulfides.[6] In the reaction, the arylthio group migrated on the alkyl chain, and only the arylthio group attached carbons were fluorinated. Therefore, we can selectively introduce multiple fluorine atoms on the appropriate carbons by this reaction. Quite recently, we have also found a desulfurizing difluorination reaction of benzylic sulfides by IF_5, where oxidative fluorination and desulfurizing fluorination reactions occur successively in the benzylic sulfides to yield *gem*-difluoro compounds.[7] On the basis of these two findings, we have planned a new polyfluorination method to introduce multiple fluorine atoms to the carbons located between the carbonyl group and the aromatic ring.

In our plan, (α-arylthio)carbonyl compounds (**2**), which are easily accessible from the corresponding carbonyl compounds, are used as the starting material.[8] By the reaction with IF_5, three ($n = 2$) or five ($n = 3$) fluorine atoms can be introduced to **2**, and the arylthio group can be migrated to the terminal carbon to yield a polyfluorinated sulfide (**3**).[6] An aryl group is introduced to the terminal carbon of **3** by a

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(2) (a) Kirsch, P.; Huber, F.; Lenges, M.; Taugerbeck, A. *J. Fluorine Chem.* **2001**, *112*, 69. (b) Kirsch, P.; Bremer, M.; Huber, F.; Lannert, H.; Ruhl, A.; Lieb, M.; Wallmichrath, T. *J. Am. Chem. Soc.* **2001**, *123*, 5414. (c) Hird, M.; Goodby, J. W.; Lewis, R. A.; Toyne, K. J. *Mol. Cryst. Liq. Cryst.* **2003**, *401*, 115.

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(4) (a) Zupan, M.; Pollak, A. *J. Org. Chem.* **1974**, *39*, 2646. (b) Gregorcic, A.; Zupan, M. *J. Org. Chem.* **1979**, *44*, 4120. (c) Mcewen, W. E.; Guzikowski, A. P.; Wolf, A. P. *J. Fluorine Chem.* **1984**, *25*, 169. (d) Rozen, S.; Brand, M. *J. Org. Chem.* **1986**, *51*, 222. (e) York, C.; Prakash, G. K. S.; Olah, G. A. *J. Org. Chem.* **1994**, *59*, 6493. (f) Gatenyo, J.; Rozen, S. *J. Fluorine Chem.* **2009**, *130*, 332.

(5) (a) Singh, R. P.; Majumder, U.; Shreeve, J. M. *J. Org. Chem.* **2001**, *66*, 6263. (b) Chang, Y.; Tewari, A.; Adi, A.-I.; Bae, C. *Tetrahedron* **2008**, *64*, 9837.

(6) Ayuba, S.; Fukhara, T.; Hara, S. *Org. Lett.* **2003**, *5*, 2873.

(7) Fukuhara, T.; Hara, S. *Synlett* **2009**, 198.

(8) Trost, B. M. *Chem. Rev.* **1978**, *78*, 363.

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SCHEME 1. Plan for Polyfluorination of 2

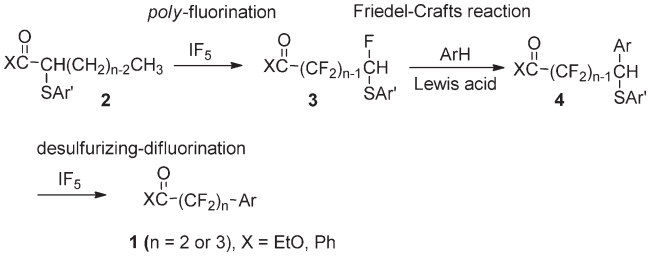
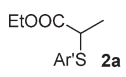
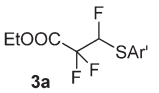
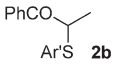
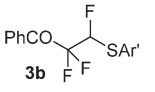
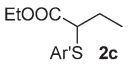
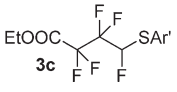


TABLE 1. Polyfluorination of Sulfides 2 Using IF_5[a]

Sulfide 2	IF_5 / 2	Conditions	Product	Yield of 3 (%)[b]
	2.2	rt, 24h		96[c]
	1.8	rt, 20h		64
	3.8	rt, 48h		76

[a] If otherwise not mentioned, CH_2Cl_2 was used as solvent. [b] Isolation yield based on **2** used. [c] Hexane was used as solvent. Ar = 4-chlorophenyl.

Friedel–Crafts reaction. As the terminal carbon of **3** is substituted by an arylthio group that stabilizes the carbocation, the aryl group must be introduced at the terminal carbon to yield benzylic sulfide (**4**).[9] By the reaction of **4** with IF_5, oxidative fluorination and desulfurizing fluorination can be successively induced to yield the target molecule **1** that contains four (n = 2) or six (n = 3) fluorine atoms between the aryl group and the carbonyl group (Scheme 1).[7]

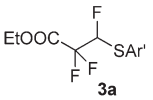
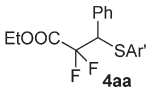
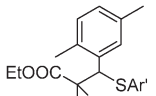
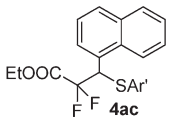
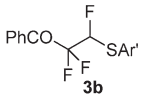
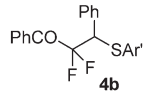
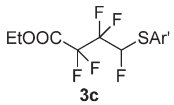
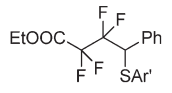
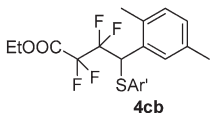
Results and Discussion

Ethyl 2-(4-chlorophenylthio)propionate (**2a**), 2-(4-chlorophenylthio)propiophenone (**2b**), and ethyl 2-(4-chlorophenylthio)butanoate (**2c**) were used for the polyfluorination reaction using IF_5. In the reaction with **2a**, migration of the arylthio group to the terminal carbon and polyfluorination took place to yield trifluorinated product (**3a**) in 96% yield. Similarly, from **2b** and **2c**, trifluorinated product (**3b**) and pentafluorinated product (**3c**) were obtained in 64% and 76% yield, respectively (Table 1).

The aryl group was introduced to the terminal carbon of **3** by the Friedel–Crafts reaction using $SnCl_4$ as Lewis acid.[9] As expected, the arylation of **3a**–**c** with various aromatic compounds occurred selectively at the terminal carbon to give the corresponding arylated sulfides (**4aa**–**4cb**) in a fairly good yield (Table 2).

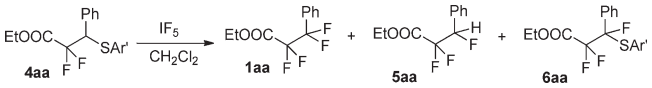
(9) For the Friedel–Crafts-type alkylation of aromatic compounds using alkyl fluorides, see: (a) Olah, G. A.; Farooq, O.; Farnia, S. M. F.; Wu, A. *J. Org. Chem.* **1990**, *55*, 1516. (b) Aoyama, M.; Hara, S. *Tetrahedron* **2009**, *65*, 3682. For the Friedel–Crafts-type alkylation using α-halosulfides, see: (c) Tamura, Y.; Choi, H. D.; Shindo, H.; Ishibashi, H. *Chem. Pharm. Bull.* **1982**, *30*, 915. (d) Arai, K.; Ohara, Y.; Iizumi, T.; Takakuwa, Y. *Tetrahedron Lett.* **1983**, *24*, 1531. (e) Uneyama, K.; Momota, M. *Tetrahedron Lett.* **1989**, *30*, 2265. (f) Uneyama, K.; Momota, M.; Hayashida, K.; Itoh, T. *J. Org. Chem.* **1990**, *55*, 5364.

TABLE 2. Friedel–Crafts Arylation of Sulfide 3[a]

3	Aromatic compound	Product	Yield of 4 (%)[b]
	Benzene		92
	p-Xylene		93
	Naphthalene		94[c]
	Benzene		95
	Benzene		95
	*p*-Xylene		98

[a] If otherwise not mentioned, the reaction was carried out in an aromatic compound (2 mL) at room temperature for 15 h using 1.5 equiv of $SnCl_4$ to **3** (0.5 mmol). [b] Isolated yield based on **3**. [c] The reaction was carried out in CH_2Cl_2 (3 mL) using 0.5 mmol of **3** and 1 g of naphthalene. Ar′ = 4-chlorophenyl.

TABLE 3. Desulfurizing Difluorination of 4aa Using IF_5



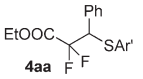
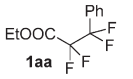
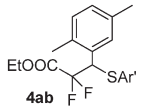
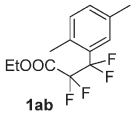
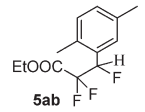
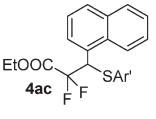
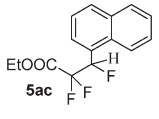
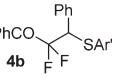
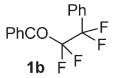
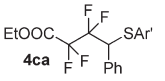
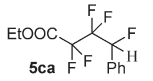
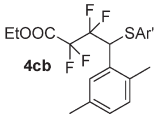
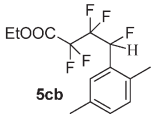
			yield (%)[a]		
entry	reagent	condition	1aa	5aa	6aa
1	IF_5 (1.5 equiv)	rt, 45 h	60	32	0
2	IF_5/Et_3N-3HF (1.5 equiv)	rt, 24 h	25	0	75
3	IF_5/Et_3N-3HF (1.5 equiv)	rt, 192 h	99	0	0
4	(i) IF_5/Et_3N-3HF (1.5 equiv) (ii) IF_5 (0.8 equiv)	rt, 40 h rt, 24 h	92 (92)	0	0

[a] ^{19}F NMR yield based on **4aa**, in parentheses, isolated yield. Ar′ = 4-chlorophenyl.

The desulfurizing difluorination of ethyl 2,2-difluoro-3-phenyl-3-(4-chlorophenylthio)propionate (**4aa**) was performed using IF_5 at room temperature, and the desired tetrafluoro product (**1aa**) was obtained in 60% yield with an unexpected trifluoro product (**5aa**) (32% yield) (entry 1 in Table 3). In our plan, ethyl 2,2,3-trifluoro-3-phenyl-3-(4-chlorophenylthio)propionate (**6aa**) is initially formed by the oxidative fluorination of **4aa**; the subsequent substitution of the arylthio group with the fluoride gives **1aa** selectively.[7] However, in fact, the substitution reaction of the arylthio group with the fluoride took place from the beginning, and the formation of **5aa** competed with that of **6aa**. To prevent

the formation of **5aa**, we used a less reactive reagent, IF_5/Et_3N-3HF.[10] In the reaction of **4aa** with IF_5/Et_3N-3HF at room temperature for 24 h, the formation of **1aa** (25%) and **6aa** (75%), and the absence of **5aa** were confirmed from an ^{19}F NMR analysis (entry 2). By the application of IF_5/Et_3N-3HF, the formation of **5aa** could be prevented as expected, and the oxidative fluorination product **6aa** was mainly formed. When the reaction was continued under the conditions for 192 h, **1aa** was selectively formed in a quantitative yield (entry 3). When IF_5 was further added to the reaction mixture of **6aa** and IF_5/Et_3N-3HF, the substitution of the arylthio group in **6aa** with the fluoride could be accelerated, and **1aa** could be obtained in 92% yield in a short reaction time (entry 4).

TABLE 4. Desulfurizing Fluorination of Sulfide 4 Using IF_5[a]

Entry	Sulfide **4**	Method[b]	Condition	Product	Yield (%)[c]
1	 **4aa**	Method A	rt, 192 h	 **1aa**	(99)
2	 **4ab**	Method B	rt, 144 h	 **1ab**  **5ab**	72 (27)
3	**4ab**	Method C	rt, 24 h	**5ab**	94
4	 **4ac**	Method A	0 °C, 24 h	 **5ac**	85
5	 **4b**	Method A	rt, 40 h	 **1b**	84
6	 **4ca**	Method D	40 °C, 72 h	 **5ca**	88[d]
7	 **4cb**	Method C	rt, 48 h	 **5cb**	84

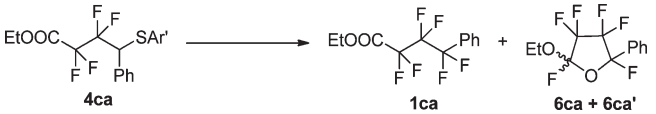
[a] If otherwise not mentioned, CH_2Cl_2 was used as solvent. [b] Method A: 1.5 equiv of IF_5/Et_3N-3HF. Method B: 1.5 equiv of IF_5/2(Et_3N-3HF). Method C: 0.8 equiv of IF_5. Method D: 3equiv of IF_5. [c] Isolated yield based on **4**; in parentheses, ^{19}FNMR yield. [d] Hexane was used as solvent. Ar′ = 4-chlorophenyl.

Similarly, from 3-(4-chlorophenylthio)-2,2-difluoro-1,3-diphenylpropan-1-one (**4b**), the tetrafluoro product (**1b**) was obtained in 84% yield by the reaction with IF_5/Et_3N-3HF (Method A) (entry 5 in Table 4). However, in the reaction of ethyl 3-(4-chlorophenylthio)-3-(2,5-dimethylphenyl)-2,2-difluoropropanoate (**4ab**), which has an electron-rich aromatic group, the substitution of the arylthio group with the fluoride is fast and the trifluoro product (**5ab**) was mainly formed even in the reaction with IF_5/Et_3N-3HF (Method A). When IF_5/2(Et_3N-3HF) was used as the fluorination reagent (Method B), ethyl 3-(2,5-dimethylphenyl)-2,2,3,3-tetrafluoropropanoate (**1ab**) was obtained as the main product (entry 2). On the other hand, the trifluoro product **5ab** can be selectively prepared by using IF_5; **5ab** was obtained in 94% yield (Method C) (entry 3). Similarly, the trifluoro product (**5ac**) could be selectively obtained from the naphthyl-group-attached substrate (**4ac**) under the condition of Method A (entry 4). In the reaction of tetrafluorinated sulfides (**4ca** and **4cb**) with IF_5 (Methods D and C), the pentafluoro products (**5ca** and **5cb**) could be selectively obtained in 88% and 84% yield, respectively (entries 6 and 7).

To obtain the hexafluoro product (**1ca**), **4ca** was subjected to the reaction with IF_5/Et_3N-3HF for 63 h, followed by IF_5 for 45 h, and the expected product **1ca** was obtained in 22% yield (entry 1 in Table 5). However, the main product of the reaction was unexpectedly a cyclic ether (a mixture of stereoisomers, **6ca** and **6ca′**, 39% and 27%, respectively),[11] which must be formed by the attack of the carbonyl oxygen on the arylthio-group-substituted carbon in the desulfurizing fluorination step, as shown in Scheme 2. We carried out the reaction under various conditions to prevent the cyclization reaction and succeeded in improving the yield of **1ca** slightly but failed to prevent the formation of the cyclic ethers **6ca** and **6ca′** (entries 2 and 3).

Next, we attempted to convert the cyclic ether **6ca** and **6ca′** to **1ca**. By the treatment of the cyclic ether with BF_3 etherate, the cleavage of the ether bond occurred and a ketone (**7ca**) was obtained in 89% yield. From **7ca**, the hexafluoro product

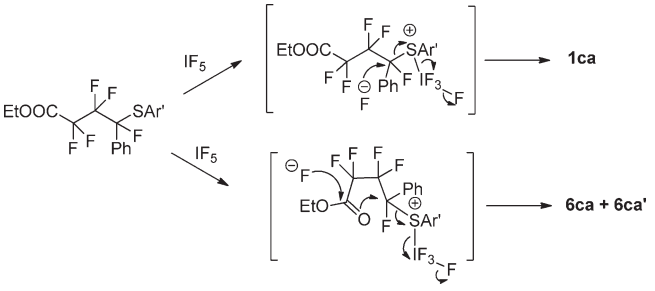
TABLE 5. Desulfurizing Difluorination of 4ca



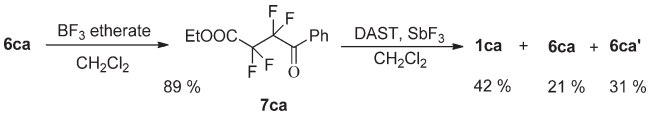
				yield (%)[a]		
entry	reagent	solvent	condition	**1ca**	**6ca**	**6ca′**
1	(i) IF_5/Et_3N-3HF (3.0 equiv) (ii) IF_5 (0.8 equiv)	CH_2Cl_2	rt, 63 h rt, 45 h	22	39	27
2	(i) IF_5/Et_3N-3HF (3.0 equiv) (ii) IF_5 (0.8 equiv)	hexane	rt, 63 h 40 °C, 45 h	39	36	25
3	IF_5/Et_3N-3HF (3.0 equiv)	CH_2Cl_2	rt, 168 h	30	39	28

[a] ^{19}F NMR yield based on **4ca**. Ar′ = 4-chlorophenyl.

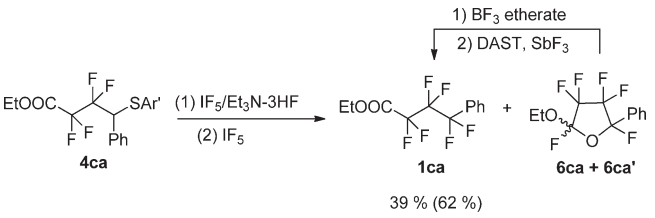
SCHEME 2. Mechanism of the Formation of 1ca and 6ca (6ca′)



SCHEME 3



SCHEME 4



1ca was obtained in 42% yield by the reaction with DAST-SbF_3, although the cyclization to **6ca** and **6ca′** competitively occurred under the conditions (Scheme 3).

Consequently, **1ca** was totally prepared in 62% yield from **4ca** (Scheme 4).

Summary

Polyfluoro compounds having three to six fluorine atoms on the adjacent carbons located between the carbonyl and the aryl group were selectively prepared by the successive application of polyfluorination using IF_5, Friedel−Crafts arylation, and desulfurizing fluorination using IF_5 to 2-(arylthio)carbonyl compounds. In the desulfurizing fluorination step, one or two fluorine atoms were introduced to the terminal carbon depending on the substituted aryl group or the desulfurizing fluorination reagent.

Experimental Section

General Methods. Et_3N-3HF was purchased from a commercial source. IF_5 was supplied by Asahi Glass Co., Ltd. The reaction using IF_5 or DAST was perfoemed in a Teflon FEP centrifuge tube with a tight screw cap.

IF_5/5CH_2Cl_2. As IF_5 is liquid of high hygroscopicity and low viscosity, it was used as a solution of CH_2Cl_2. From a cylinder, IF_5 was transferred through a Teflon tube into a Teflon bottle under an N_2 atmosphere. After measuring the amount of IF_5 in the bottle, a 5 molar amount of CH_2Cl_2 was added at room temperature. It should be carefully handled with Teflon equipment in a bench hood.

IF_5/Et_3N-3HF {IF_5/2(Et_3N-3HF)}. From a cylinder, IF_5 was transferred through a Teflon tube into a Teflon bottle under an N_2 atmosphere. After measuring the amount of IF_5 in the bottle, a 1 (or 2) molar amount of Et_3N-3HF was added at room temperature. It should be carefully handled with Teflon equipment in a bench hood.

Ethyl 3-(4-Chlorophenylthio)-2,2,3-trifluoropropanoate (3a). In a Teflon reactor with a tight screw cap, IF_5/5CH_2Cl_2 (730 mg, 1.13 mmol), **2a** (127 mg, 0.52 mmol), and hexane (3 mL) were introduced at 0 °C, and mixture was stirred at room temperature for 24 h. The mixture was poured into water (10 mL), neutralized with aq $NaHCO_3$, and extracted with Et_2O (20 mL × 3). The combined organic layer was washed with aq $Na_2S_2O_3$, dried over $MgSO_4$, and concentrated under reduced pressure. Purification by column chromatography (silica gel/hexane−EtOAc) gave **3a** (149 mg) in 96% yield; IR (neat) 2987, 1779 (C=O), 1477, 1014 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.38 (t, J = 7.3 Hz, 3H), 4.40 (q, J = 7.2 Hz, 2H), 5.97 (ddd, J = 50.8, 11.9, 10.0 Hz, 1H), 7.36 (d, J = 8.5 Hz, 2H), 7.49 (d, J = 8.5 Hz, 2H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −114.66 (ddd, $^2J_{F-F}$ = 269.8 Hz, $^3J_{F-F}$ = 21.9 Hz, $^3J_{F-H}$ = 10.1 Hz, 1F), −115.72 (ddd, $^2J_{F-F}$ = 269.8 Hz, $^3J_{F-F}$ = 20.5 Hz, $^3J_{F-H}$ = 11.9 Hz, 1F), −167.49 (ddd, $^2J_{F-H}$ = 51.0 Hz, $^3J_{F-F}$ = 21.9 Hz, $^3J_{F-F}$ = 20.8 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.8, 63.8, 99.3 (ddd, $^1J_{C-F}$ = 232.1 Hz, $^2J_{C-F}$ = 29.5 Hz, $^2J_{C-F}$ = 28.0 Hz), 111.1 (td, $^1J_{C-F}$ = 259.9 Hz, $^2J_{C-F}$ = 30.4 Hz), 128.6 (d, $^3J_{C-F}$ = 1.9 Hz), 129.6 (2C), 134.8 (d, $^4J_{C-F}$ = 1.9 Hz, 2C), 135.9, 161.3 (t, $^2J_{C-F}$ = 30.9 Hz); HRMS (EI) calcd for $C_{11}H_{10}ClF_3O_2S$, 298.0042, found 298.0038.

3-(4-Chlorophenylthio)-2,2,3-trifluoro-1-phenylpropan-1-one (3b). In a Teflon reactor with a tight screw cap, IF_5/5CH_2Cl_2 (1.16 g, 1.8 mmol), **2b** (278 mg, 1.00 mmol), and CH_2Cl_2 (4 mL) were introduced at 0 °C, and mixture was stirred at room temperature for 20 h. The mixture was poured into water (10 mL), neutralized with aq $NaHCO_3$, and extracted with Et_2O (20 mL × 3). The combined organic layer was washed with aq $Na_2S_2O_3$, dried over $MgSO_4$, and concentrated under reduced pressure. Purification by column chromatography (silica gel/hexane−EtOAc) gave **3b** (212 mg) in 64% yield; IR (neat) 1701 (C=O), 1477, 1013 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 6.19 (ddd, J = 50.9, 11.9, 10.1 Hz, 1H), 7.35 (d, J = 8.6 Hz, 2H), 7.50−7.55 (m, 4H), 7.69 (t, J = 7.6 Hz, 1H), 8.09 (d, J = 7.7 Hz, 2H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −107.81 (ddd, $^2J_{F-F}$ = 292.8 Hz, $^3J_{F-F}$ = 21.5 Hz, $^3J_{F-H}$ = 10.1 Hz, 1F), −109.66 (ddd, $^2J_{F-F}$ = 292.7 Hz, $^3J_{F-F}$ = 19.4 Hz, $^3J_{F-H}$ = 11.8 Hz, 1F), −166.90 (ddd, $^2J_{F-H}$ = 51.0 Hz, $^3J_{F-F}$ = 20.8 Hz, $^3J_{F-F}$ = 19.8 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 99.7 (ddd, $^1J_{C-F}$ = 231.4 Hz, $^2J_{C-F}$ = 29.7 Hz, $^2J_{C-F}$ = 26.8 Hz), 114.0 (ddd, $^1J_{C-F}$ = 265.6 Hz, $^1J_{C-F}$ = 262.8 Hz, $^2J_{C-F}$ = 29.0 Hz), 128.8 (2C), 129.3 (d, $^3J_{C-F}$ = 1.7 Hz), 129.6 (2C), 130.0 (t, $^4J_{C-F}$ = 3.6 Hz, 2C), 131.7 (t, $^3J_{C-F}$ = 2.2 Hz), 134.6 (d, ^4J = 1.9 Hz, 2C), 134.8, 135.6, 187.3 (t, $^2J_{C-F}$ = 28.7 Hz); HRMS (EI) calcd for $C_{15}H_{10}ClF_3OS$ 330.0093, found, 330.0091.

Ethyl 4-(4-Chlorophenylthio)-2,2,3,3,4-pentafluorobutanoate (3c)[6]. The reaction was performed as above using IF_5/5CH_2Cl_2 (2.42 g, 3.74 mmol), **2c** (257 mg, 0.99 mmol), and CH_2Cl_2 (4 mL) at room temperature for 48 h. Purification by column chromatography (silica gel/hexane−EtOAc) gave **3c** (262 mg) in 76% yield; IR (neat) 2987, 1776 (C=O), 1013 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.38 (t, J = 7.1 Hz, 3H), 4.41 (q, J = 7.1 Hz, 2H), 5.98 (ddd, J = 50.3, 16.6, 5.1 Hz, 1H), 7.37 (d, J = 8.7 Hz, 2H), 7.52 (d, J = 8.7 Hz, 2H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −165.48 to −156.19 (m, 1F), −124.84 (ddd, $^2J_{F-F}$ = 279.5 Hz, $^3J_{F-F}$ = 17.1 Hz, $^3J_{F-F}$ = 17.1 Hz, 1F), −120.22 (ddd, $^2J_{F-F}$ = 276.5 Hz, $^3J_{F-F}$ = 7.3 Hz, $^3J_{F-F}$ = 3.7 Hz, 1F), −119.38 (dd, $^2J_{F-F}$ = 276.5 Hz, $^3J_{F-F}$ = 8.5 Hz, 1F), −117.42 (ddm,

(10) Previously, IF_5/Et_3N-3HF was used for the oxidative fluorination reaction of the sulfides; see: Ayuba, S.; Yoneda, N.; Fukuhara, T.; Hara, S. *Bull. Chem. Soc. Jpn.* **2002**, *75*, 1597.

(11) The cyclic ethers (**6ca** and **6ca′**) are separable by silica gel column chromatography, but their stereochemical identification is difficult.

$^2J_{F-F}$ = 279.8 Hz, $^3J_{F-F}$ = 21.2 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.7, 64.3, 98.1 (ddd, $^1J_{C-F}$ = 229.9 Hz, $^2J_{C-F}$ = 33.9 Hz, $^2J_{C-F}$ = 24.8 Hz), 108.5 (tt, $^1J_{C-F}$ = 265.1 Hz, $^2J_{C-F}$ = 33.1 Hz), 112.7 (dddt, $^1J_{C-F}$ = 264.7 Hz, $^1J_{C-F}$ = 260.9 Hz, $^2J_{C-F}$ = 29.8 Hz, $^2J_{C-F}$ = 29.8 Hz), 128.2 (d, $^3J_{C-F}$ = 1.4 Hz), 129.8 (2C), 135.2 (d, $^4J_{C-F}$ = 1.4 Hz, 2C), 136.2, 159.5 (t, $^2J_{C-F}$ = 29.8 Hz); HRMS (EI) calcd for $C_{12}H_{10}ClF_5O_2S$ 348.0010, found 348.0006.

Ethyl 3-(4-Chlorophenylthio)-2,2-difluoro-3-phenylpropanoate (4aa). Under N_2 atmosphere, $SnCl_4$ (195 mg, 0.75 mmol) was added at room temperature to a mixture of **3a** (149 mg, 0.50 mmol) and benzene (1 mL). After stirring at room temperature for 15 h, the mixture was poured into water (10 mL), neutralized with aq $NaHCO_3$, and extracted with Et_2O (20 mL × 3). The combined organic layer was dried over $MgSO_4$ and concentrated under reduced pressure. Purification by column chromatography (silica gel/hexane−EtOAc) gave **4aa** (164 mg) in 92% yield; IR (neat) 2984, 1773 (C=O), 1476, 1095 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.20 (t, J = 7.2 Hz, 3H), 4.16−4.25 (m, 2H), 4.62 (dd, J = 17.2, 14.2 Hz, 1H), 7.20−7.32 (m, 9H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −105.19 (dd, $^2J_{F-F}$ = 257.9 Hz, $^3J_{F-H}$ = 14.0 Hz, 1F), −108.91 (dd, $^2J_{F-F}$ = 257.9 Hz, $^3J_{F-H}$ = 17.2 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.7, 57.2 (t, $^2J_{C-F}$ = 23.5 Hz), 63.1, 114.6 (t, $^1J_{C-F}$ = 258.2 Hz), 128.6 (2C), 128.8, 129.2 (2C), 129.5 (t, $^4J_{C-F}$ = 1.2 Hz, 2C), 131.3, 133.5 (d, $^3J_{C-F}$ = 2.9 Hz), 134.7, 134.8 (2C), 163.0 (t, $^2J_{C-F}$ = 32.6 Hz); HRMS (EI) calcd for $C_{17}H_{15}ClF_2O_2S$ 356.0449, found 356.0434.

Ethyl 3-(4-Chlorophenylthio)-3-(2,5-dimethylphenyl)-2,2-difluoropropanoate (4ab). The reaction was performed as above using **3a** (596 mg, 2.00 mmol), *p*-xylene (4 mL), and $SnCl_4$ (782 mg, 3.00 mmol) at room temperature for 15 h. Purification by column chromatography (silica gel/hexane−EtOAc) gave **4ab** (714 mg) in 93% yield; IR (neat) 2982, 1775 (C=O), 1475, 1093, 1054 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.14 (t, J = 7.0 Hz, 3H), 2.23 (s, 3H), 2.27 (s, 3H), 4.12−4.18 (m, 2H), 4.92 (t, J = 16.0 Hz, 1H), 6.99−7.04 (m, 2H), 7.16−7.23 (m, 3H), 7.27−7.29 (m, 2H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −105.28 (dd, $^2J_{F-F}$ = 258.2 Hz, $^3J_{F-H}$ = 14.4 Hz, 1F), −106.29 (dd, $^2J_{F-F}$ = 257.9 Hz, $^3J_{F-H}$ = 16.9 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.5, 19.0, 20.8, 52.2 (t, $^2J_{C-F}$ = 21.6 Hz), 62.9, 115.0 (t, $^1J_{C-F}$ = 257.5 Hz), 128.9 (2C), 129.2, 129.6, 130.2, 131.4, 131.6, 133.2, 134.7, 135.2 (2C), 135.8, 163.1 (t, $^2J_{C-F}$ = 32.6 Hz); HRMS (EI) calcd for $C_{19}H_{19}ClF_2O_2S$ 384.0762, found 384.0758.

Ethyl 3-(4-Chlorophenylthio)-2,2-difluoro-3-(naphthalen-1-yl)-propanoate (4ac). Under N_2 atmosphere, $SnCl_4$ (197 mg, 0.76 mmol) was added at room temperature to a mixture of **3a** (149 mg, 0.50 mmol) and naphthalene (1.0 g, 7.8 mmol) in CH_2Cl_2 (3 mL). After stirring at room temperature for 15 h, the mixture was poured into water (10 mL), neutralized with aq $NaHCO_3$, and extracted with Et_2O (20 mL × 3). The combined organic layer was dried over $MgSO_4$, and concentrated under reduced pressure. Purification by column chromatography (silica gel/hexane−EtOAc) gave **4ac** (191 mg) in 94% yield; IR (neat) 2983, 1769 (C=O), 1314, 1050 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.00 (t, J = 7.2 Hz, 3H), 4.04−4.10 (m, 2H), 5.60 (t, J = 15.2 Hz, 1H), 7.15−7.24 (m, 4H), 7.40−7.60 (m, 4H), 7.82−8.00 (m, 3H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −104.90 (dd, $^2J_{F-F}$ = 255.5 Hz, $^3J_{F-H}$ = 14.4 Hz, 1F), −105.77 (dd, $^2J_{F-F}$ = 255.5 Hz, $^3J_{F-H}$ = 15.5 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.4, 51.0 (t, $^2J_{C-F}$ = 24.0 Hz), 63.0, 115.1 (t, $^1J_{C-F}$ = 258.2 Hz), 122.3, 125.2, 125.9, 126.8, 127.6, 129.0 (2C), 129.1, 129.2, 129.3, 131.1, 131.2, 133.6, 134.8 (2C), 135.2, 163.1 (t, $^2J_{C-F}$ = 32.6 Hz); HRMS (EI) calcd for $C_{21}H_{17}ClF_2O_2S$ 406.0606, found 406.0604.

3-(4-Chlorophenylthio)-2,2-difluoro-1,3-diphenylpropan-1-one (4b). The reaction was performed as above using **3b** (165 mg, 0.50 mmol), benzene (2 mL), and $SnCl_4$ (195 mg, 0.75 mmol) at room temperature for 15 h. Purification by column chromatography (silica gel/hexane−EtOAc) gave **4b** (185 mg) in 95% yield; IR (neat) 3063, 1703 (C=O), 1179, 1050 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.87 (dd, J = 19.5 Hz, 12.4 Hz, 1H), 7.17−7.23 (m, 4H), 7.30−7.37 (m, 5H), 7.47 (t, J = 7.5 Hz, 1H), 7.62 (t, J = 7.3 Hz, 1H), 7.97 (d, J = 8.0 Hz, 2H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −97.51 (dd, $^2J_{F-F}$ = 279.1 Hz, $^3J_{F-H}$ = 12.6 Hz, 1F), −104.11 (dd, $^2J_{F-F}$ = 279.4 Hz, $^3J_{F-H}$ = 19.4 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 56.9 (t, $^2J_{C-F}$ = 22.8 Hz), 117.7 (t, $^1J_{C-F}$ = 261.1 Hz), 128.5 (2C), 128.5 (2C), 128.6 (2C), 129.1 (2C), 129.7 (2C), 129.8 (t, $^3J_{C-F}$ = 2.9 Hz), 131.6, 132.6 (t, $^3J_{C-F}$ = 2.2 Hz), 134.0 (d, $^4J_{C-F}$ = 1.9 Hz), 134.2, 134.5 (2C), 134.5, 189.2 (t, $^2J_{C-F}$ = 29.7 Hz); HRMS (EI) calcd for $C_{21}H_{15}ClF_2OS$ 388.0500, found 388.0500.

Ethyl 4-(4-Chlorophenylthio)-2,2,3,3-tetrafluoro-4-phenylbutanoate (4ca). The reaction was performed as above using **3c** (550 mg, 1.58 mmol), benzene (5 mL), and $SnCl_4$ (625 mg, 2.40 mmol) at room temperature for 15 h. Purification by column chromatography (silica gel/hexane−EtOAc) gave **4ca** (609 mg) in 95% yield; IR (neat) 2986, 1773 (C=O), 1316, 1095 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.32 (t, J = 7.2 Hz, 3H), 4.27 (q, J = 7.2 Hz, 2H), 4.57 (dd, J = 19.0, 12.4 Hz, 1H), 7.20−7.33 (m, 9H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −109.09 (dd, $^2J_{F-F}$ = 274.0 Hz, $^3J_{F-H}$ = 12.6 Hz, 1F), −114.31 (dd, $^2J_{F-F}$ = 274.1 Hz, $^3J_{F-H}$ = 19.0 Hz, 1F), −117.45 (d, $^2J_{F-F}$ = 277.7 Hz, 1F), −118.28(d, $^2J_{F-F}$ = 277.7 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.5, 55.5 (t, $^2J_{C-F}$ = 23.0 Hz), 63.8, 106.3−119.2 (m, 2C), 128.4 (2C), 128.7 (2C), 129.1 (2C), 129.39, 131.1, 133.4 (d, $^3J_{C-F}$ = 3.8 Hz), 134.8, 135.0 (2C), 159.9 (t, $^2J_{C-F}$ = 30.2 Hz); HRMS (EI) calcd for $C_{18}H_{15}ClF_4O_2S$ 406.0417, found 406.0418.

Ethyl 4-(4-Chlorophenylthio)-4-(2,5-dimethylphenyl)-2,2,3,3-tetrafluorobutanoate (4cb). The reaction was performed as above using **3c** (1.046 g, 3.00 mmol), *p*-xylene (6 mL), and $SnCl_4$ (1.17 g, 4.49 mmol) at room temperature for 15 h. Purification by column chromatography (silica gel/hexane−EtOAc) gave **4cb** (1.28 g) in 98% yield; IR (neat) 2985, 1772(C=O), 1476, 1313 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.31 (t, J = 7.2 Hz, 3H), 2.17 (s, 3H), 2.28 (s, 3H), 4.22 (q, J = 7.2 Hz, 2H), 4.87 (dd, J = 18.3, 13.6 Hz, 1H), 7.01 (s, 2H), 7.18−7.28 (m, 5H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −108.12 (dd, $^2J_{F-F}$ = 273.0 Hz, $^3J_{F-H}$ = 13.3 Hz, 1F), −113.78 (dd, $^2J_{F-F}$ = 273.0 Hz, $^3J_{F-H}$ = 18.3 Hz, 1F), −117.84 (d, $^3J_{F-F}$ = 38.1 Hz, 2F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.5, 18.9, 20.6, 50.1 (t, $^2J_{C-F}$ = 22.5 Hz), 63.8, 106.3−119.6 (m, 2C), 129.0 (2C), 129.3, 129.9 (d, $^3J_{C-F}$ = 3.8 Hz), 130.3, 131.2, 131.5 (d, $^4J_{C-F}$ = 3.8 Hz), 133.1, 135.0, 135.5 (2C), 135.8, 160.0 (t, $^2J_{C-F}$ = 30.4 Hz); HRMS (EI) calcd for $C_{20}H_{19}ClF_4O_2S$ 434.0730, found 434.0730.

Ethyl 2,2,3,3-Tetrafluoro-3-phenylpropanoate (1aa)[12]. To IF_5/Et_3N-3HF (300 mg, 0.78 mmol) in a Teflon reactor with a tight screw cap was added **4aa** (178 mg, 0.50 mmol) in CH_2Cl_2 (3 mL) at 0 °C. The mixture was stirred at room temperature for 40 h, and the complete consumption of **4aa** was confirmed by GC analysis. Then, IF_5/5CH_2Cl_2 (250 mg, 0.39 mmol) was added, and the reaction mixture was stirred at room temperature for another 24 h. The mixture was poured into water (10 mL), neutralized with aq $NaHCO_3$, and extracted with Et_2O (20 mL × 3). The combined organic layer was washed with aq $Na_2S_2O_3$, dried over $MgSO_4$, and concentrated under reduced pressure. Purification by column chromatography (silica gel/hexane−EtOAc) gave **1a** (115 mg) in 92% yield; IR (neat) 2989, 1777 (C=O), 1322, 1170 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.35 (t, J = 7.2 Hz, 3H), 4.39 (q, J = 7.3 Hz, 2H), 7.47−7.59 (m, 5H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −112.10 (t, $^3J_{F-F}$ = 6.1 Hz, 2F), −119.44 (t, $^3J_{F-F}$ = 6.2 Hz, 2F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.4, 63.6, 109.3 (tt, $^1J_{C-F}$ = 263.3 Hz, $^2J_{C-F}$ = 39.5 Hz), 115.6 (tt, $^1J_{C-F}$ = 255.4 Hz, $^2J_{C-F}$ = 31.9 Hz), 126.6 (tt, $^3J_{C-F}$ = 6.5 Hz, $^4J_{C-F}$ = 1.2 Hz, 2C), 128.4, 129.4

(12) Yang, Z.-Y. *J. Fluorine Chem.* **2004**, *125*, 763.

(t, $^2J_{C-F}$ = 24.4 Hz), 131.5 (t, $^4J_{C-F}$ = 2.7 Hz, 2C), 160.2 (t, $^2J_{C-F}$ = 30.7 Hz); HRMS (EI) calcd for $C_{11}H_{10}F_4O_2$ 250.0617, found 250.0616.

Ethyl 3-(2,5-Dimethylphenyl)-2,2,3,3-tetrafluoropropanoate (1ab). The reaction was performed as above using IF_5/2(Et_3N-3HF) (408 mg, 0.75 mmol) and **4ab** (205 mg, 0.5 mmol) in CH_2Cl_2 (4 mL) at room temperature for 144 h. From ^{19}F NMR analysis of the crude mixture, **5ab** was found to be formed in 27% yield. Purification by column chromatography (silica gel/hexane−EtOAc) gave **1ab** (94 mg) in 74% yield; IR (neat) 2987, 1772(C=O), 1317 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.37 (t, J = 7.2 Hz, 3H), 2.34 (s, 3H), 2.44 (t, J = 3.0 Hz, 3H), 4.40 (q, J = 7.2 Hz, 2H), 7.14 (d, J = 7.9 Hz, 1H), 7.20 (d, J = 7.9 Hz, 1H), 7.28 (s, 1H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −106.96 to −106.96 (m, 2F), −108.51 to −108.57 (m, 2F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.6, 19.80−20.0 (m), 20.5, 63.6, 111.0 (tt, $^1J_{C-F}$ = 261.8, $^2J_{C-F}$ = 41.0 Hz), 117.2 (tt, $^1J_{C-F}$ = 254.7, $^2J_{C-F}$ = 33.2 Hz), 132.0 (t, $^4J_{C-F}$ = 1.5 Hz), 127.1 (t, $^2J_{C-F}$ = 22.2 Hz), 128.6 (tt, $^3J_{C-F}$ = 7.1, $^4J_{C-F}$ = 1.4 Hz), 132.3, 134.7 (t, $^3J_{C-F}$ = 2.4 Hz), 135.3, 160.5 (t, $^2J_{C-F}$ = 30.5 Hz); HRMS (EI) calcd for $C_{13}H_{14}F_4O_2$ 278.09299, found 278.09305.

Ethyl 3-(2,5-Dimethylphenyl)-2,2,3-trifluoropropanoate (5ab). The reaction was performed as above using IF_5/5CH_2Cl_2 (505 mg, 0.78 mmol) and **4ab** (201 mg, 0.49 mmol) in CH_2Cl_2 (4 mL) at room temperature for 24 h. Purification by column chromatography (silica gel/hexane−EtOAc) gave **5ab**(120 mg) in 94% yield; IR (neat) 2986, 1777 (C=O), 1308, 1075 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.35 (t, J = 7.4 Hz, 3H), 2.34 (s, 6H), 4.38 (q, J = 7.2 Hz, 2H), 6.05 (ddd, J = 43.5, 17.3, 4.4 Hz, 1H), 7.09−7.15 (m, 2H), 7.30 (s, 1H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −113.63 (ddd, $^2J_{F-F}$ = 270.8 Hz, $^3J_{F-F}$ = 13.3 Hz, $^3J_{F-H}$ = 4.7 Hz, 1F), −121.69 (ddd, $^2J_{F-F}$ = 271.9 Hz, $^3J_{F-F}$ = 15.7 Hz, $^3J_{F-H}$ = 15.7 Hz, 1F), −192.92 (dt, $^2J_{F-H}$ = 43.5 Hz, $^3J_{F-F}$ = 14.4 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.4, 18.3, 20.5, 63.2, 87.4 (ddd, $^1J_{C-F}$ = 180.1 Hz, $^2J_{C-F}$ = 32.6 Hz, $^2J_{C-F}$ = 24.9 Hz), 112.4 (ddd, $^1J_{C-F}$ = 262.5 Hz, $^1J_{C-F}$ = 253.0 Hz, $^2J_{C-F}$ = 33.1 Hz), 128.2 (d, $^4J_{C-F}$ = 7.7 Hz), 128.6 (d, $^3J_{C-F}$ = 19.2 Hz), 129.7 (d, $^2J_{C-F}$ = 26.8 Hz), 130.5 (d, $^3J_{C-F}$ = 12.9 Hz), 133.6 (d, $^4J_{C-F}$ = 3.8 Hz), 135.5, 162.3 (dd, $^2J_{C-F}$ = 32.6 Hz, $^2J_{C-F}$ = 29.0 Hz); HRMS (EI) calcd for $C_{13}H_{15}F_3O_2$ 260.1024, found 260.1024.

Ethyl 2,2,3-Trifluoro-3-(naphthalen-1-yl)propanoate (5ac). The reaction was performed as above using IF_5/Et_3N-3HF (540 mg, 1.41 mmol) and **4ac** (380 mg, 0.94 mmol) in CH_2Cl_2 (4 mL) at 0 °C for 24 h. Purification by column chromatography (silica gel/hexane−EtOAc) gave **5ac** (225 mg) in 85% yield; IR (neat) 2986, 1768 (C=O), 1306 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.31 (t, J = 7.2 Hz, 3H), 4.35 (q, J = 7.2 Hz, 2H), 6.63 (ddd, J = 43.3, 16.1, 5.1 Hz, 1H), 7.52−7.60 (m, 3H), 7.74 (d, J = 7.2 Hz, 1H), 7.90−8.02 (m, 3H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −113.99 (ddd, $^2J_{F-F}$ = 269.4 Hz, $^3J_{F-F}$ = 12.2 Hz, $^3J_{F-H}$ = 5.0 Hz, 1F), −121.82 (dt, $^2J_{F-F}$ = 269.8 Hz, $^3J_{F-F}$ = 15.8 Hz, 1F), −194.44 (ddd, $^2J_{F-H}$ = 43.1 Hz, $^3J_{F-F}$ = 15.4 Hz, $^3J_{F-F}$ = 12.9 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.5, 63.4, 87.8 (ddd, $^1J_{C-F}$ = 182.5 Hz, $^2J_{C-F}$ = 31.9 Hz, $^2J_{C-F}$ = 25.9 Hz), 112.4 (ddd, $^1J_{C-F}$ = 263.5 Hz, $^1J_{C-F}$ = 263.5 Hz, $^2J_{C-F}$ = 32.8 Hz), 122.8, 124.8, 125.9, 126.3 (d, $^2J_{C-F}$ = 19.2 Hz), 126.6 (d, $^3J_{C-F}$ = 9.6 Hz), 126.8, 128.8, 130.7 (d, $^4J_{C-F}$ = 1.9 Hz), 130.8 (d, $^3J_{C-F}$ = 3.1 Hz), 133.4, 162.3 (dd, $^2J_{C-F}$ = 32.6 Hz, $^2J_{C-F}$ = 29.7 Hz); HRMS (EI) calcd for $C_{15}H_{13}F_3O_2$ 282.0868, found 282.0866.

2,2,3,3-Tetrafluoro-1,3-diphenylpropan-1-one (1b). The reaction was performed as above using IF_5/Et_3N-3HF (320 mg, 0.84 mmol) and **4b** (198 mg, 0.51 mmol) in CH_2Cl_2 (3 mL) at room temperature for 40 h. Purification by column chromatography (silica gel/hexane−EtOAc) gave **1b** (121 mg) in 84% yield; IR (neat) 3068, 1701 (C=O), 1151 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.49−7.67 (m, 8H), 8.09 (d, J = 7.6 Hz, 2H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −110.42 (t, $^3J_{F-F}$ = 12.9 Hz, 2F), −113.63 (t, $^3J_{F-F}$ = 12.2 Hz, 2F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 112.1 (tt, $^1J_{C-F}$ = 265.9 Hz, $^2J_{C-F}$ = 39.0 Hz), 116.1 (tt, $^1J_{C-F}$ = 254.9 Hz, $^2J_{C-F}$ = 31.6 Hz), 126.8 (tt, $^3J_{C-F}$ = 6.5 Hz, $^4J_{C-F}$ = 1.2 Hz, 2C), 128.4 (2C), 128.7, 129.8 (t, $^2J_{C-F}$ = 24.4 Hz), 130.3 (t, $^4J_{C-F}$ = 3.6 Hz, 2C), 131.4 (t, $^4J_{C-F}$ = 1.4 Hz, 2C), 132.5 (t, $^3J_{C-F}$ = 1.4 Hz), 134.8, 186.0 (t, $^2J_{C-F}$ = 26.3 Hz); HRMS (EI) calcd for $C_{15}H_{10}F_4O$ 282.0668, found 282.0669.

Ethyl 2,2,3,3,4-Pentafluoro-4-phenylbutanoate (5ca). The reaction was performed as above using IF_5/5CH_2Cl_2 (1.01 g, 1.56 mmol) and **4ca** (202 mg, 0.50 mmol) in hexane (3 mL) at 40 °C for 72 h. Purification by column chromatography (silica gel/hexane−EtOAc) gave **5ca** (124 mg) in 88% yield; IR (neat) 2989, 1776 (C=O), 1316, 1170, 1142 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.38 (t, J = 7.2 Hz, 3H), 4.41 (q, J = 7.2 Hz, 2H), 5.80 (ddd, J = 44.3, 18.5, 3.8 Hz, 1H), 7.45 (s, 5H). ^{19}F NMR (376 MHz, $CDCl_3$) δ −119.50 (dd, $^2J_{F-F}$ = 277.3 Hz, $^3J_{F-F}$ = 10.0 Hz, 1F), −121.06 (dt, $^2J_{F-F}$ = 276.9 Hz, $^3J_{F-F}$ = 5.4 Hz, 1F), −121.29 (dm, $^2J_{F-F}$ = 286.2 Hz, 1F), −128.77 (ddd, $^2J_{F-F}$ = 285.9 Hz, $^3J_{F-F}$ = 18.0 Hz, $^3J_{F-F}$ = 15.5 Hz, 1F), −194.07 (dm, $^1J_{F-H}$ = 44.2 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.4, 64.0, 88.5 (ddd, $^1J_{C-F}$ = 184.0 Hz, $^2J_{C-F}$ = 33.3 Hz, $^2J_{C-F}$ = 23.2 Hz), 109.0 (tt, $^1J_{C-F}$ = 264.7 Hz, $^2J_{C-F}$ = 33.1 Hz), 110.1−116.2 (m), 127.7 (d, $^3J_{C-F}$ = 7.2 Hz, 2C), 128.5, 130.1 (d, $^2J_{C-F}$ = 20.6 Hz), 130.3 (d, $^4J_{C-F}$ = 1.9 Hz, 2C), 159.8 (t, $^1J_{C-F}$ = 29.7 Hz); HRMS (ESI) calcd for $C_{12}H_{11}F_5O_2Na$ 305.0577, found 305.0580.

Ethyl 4-(2,5-Dimethylphenyl)-2,2,3,3,4-pentafluorobutanoate (5cb). The reaction was performed as above using IF_5/5CH_2Cl_2 (350 mg, 0.54 mmol) and **4cb** (308 mg, 0.71 mmol) in CH_2Cl_2 (4 mL) at room temperature for 48 h. Purification by column chromatography (silica gel/hexane−EtOAc) gave **5cb** (185 mg) in 84% yield; IR (neat) 2987, 1777 (C=O), 1316, 1172, 1101 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.39 (t, J = 7.3 Hz, 3H), 2.31 (s, 3H), 2.35 (s, 3H), 4.42 (q, J = 7.3 Hz, 2H), 6.09 (dd, J = 44.1, 20.3 Hz, 1H), 7.09−7.16 (m, 2H), 7.32 (s, 1H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −120.36 (ddd, $^2J_{F-F}$ = 276.2 Hz, $^3J_{F-F}$ = 10.4 Hz, $^3J_{F-H}$ = 2.9 Hz, 1F), −121.40 (dm, $^2J_{F-F}$ = 286.3 Hz, 1F), −121.91 (dt, $^2J_{F-F}$ = 276.2 Hz, $^3J_{F-F}$ = 5.4 Hz, 1F), −129.69 (dddd, $^2J_{F-F}$ = 287.3 Hz, $^3J_{F-F}$ = 17.2 Hz, $^3J_{F-F}$ = 15.8 Hz, $^4J_{F-F}$ = 1.8 Hz, 1F), −193.83 to −193.59 (m, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.5, 18.3 (d, $^4J_{C-F}$ = 3.4 Hz), 20.6, 63.9, 85.1 (ddd, $^1J_{C-F}$ = 181.6 Hz, $^2J_{C-F}$ = 34.7 Hz, $^2J_{C-F}$ = 22.8 Hz), 109.1 (tt, $^1J_{C-F}$ = 264.4 Hz, $^2J_{C-F}$ = 33.8 Hz), 110.5−116.6 (m), (dddt, $^1J_{C-F}$ = 265.4 Hz, $^1J_{C-F}$ = 253.9 Hz, $^2J_{C-F}$ = 29.9 Hz, $^2J_{C-F}$ = 29.5 Hz), 128.2 (d, $^2J_{C-F}$ = 11.5 Hz), 128.3 (d, $^3J_{C-F}$ = 9.6 Hz), 130.5, 130.8 (d, $^4J_{C-F}$ = 1.9 Hz), 133.7 (d, $^3J_{C-F}$ = 5.3 Hz), 135.7, 159.9 (t, $^2J_{C-F}$ = 30.0 Hz); HRMS (ESI) calcd for $C_{14}H_{15}F_5O_2$ 310.0992, found 310.0997.

Ethyl 2,2,3,3,4,4,4-Hexafluoro-4-phenylbutanoate (1ca)[13] and 2-Ethoxy-2,3,3,4,4,5-hexafluoro-5-phenyltetrahydrofuran (6ca and 6ca′). A mixture of IF_5/Et_3N-3HF (574 mg, 1.50 mmol) and **4ca** (203 mg, 0.50 mmol) in hexane (2 mL) was stirred at room temperature for 63 h. Then, IF_5/5CH_2Cl_2 (258 mg, 0.40 mmol) was added, and the reaction mixture was stirred at 40 °C for 45 h. After work-up operation, yields of **1ca** (39%), **6ca** (36%), and **6ca′** (25%) were determined by ^{19}F NMR using fluorobenzene as an internal standard. They can be isolated by column chromatography (silica gel/hexane−EtOAc) but were used for the next step without purification. **1ca**: IR (neat) 2991, 1778 (C=O), 1320, 1181 cm^{-1}, ^1H NMR (400 MHz, $CDCl_3$) δ 1.38 (t, J = 7.2 Hz, 3H), 4.41 (q, J = 7.2 Hz, 2H), 7.48−7.59 (m, 5H), ^{19}F NMR (376 MHz, $CDCl_3$) δ −111.00 (t, $^3J_{F-F}$ = 10.1 Hz, 2F), −118.89 (tt, $^3J_{F-F}$ = 10.1 Hz, $^3J_{F-F}$ = 2.5 Hz, 2F), −124.27 (t, $^3J_{F-F}$ = 2.5 Hz, 2F), ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.5, 64.2, 108.6 (ttt, $^1J_{C-F}$ = 266.8 Hz, $^2J_{C-F}$ = 32.1 Hz, 1.4 Hz),

(13) McLoughlin, V. C. R.; Thrower, J. *Tetrahedron* **1969**, *25*, 5921.

111.6−105.5 (m, 2C), 115.9 (tt, $^{1}J_{C-F}$ = 255.8 Hz, $^{2}J_{C-F}$ = 31.9 Hz), 126.8 (tt, $^{3}J_{C-F}$ = 6.7 Hz, $^{4}J_{C-F}$ = 1.4 Hz, 2C), 128.5 (2C), 129.1 (t, $^{2}J_{C-F}$ = 24.4 Hz), 131.8 (t, $^{4}J_{C-F}$ = 1.9 Hz), 159.4 (t, $^{2}J_{C-F}$ = 29.7 Hz); HRMS (ESI) calcd for $C_{12}H_{10}F_6O_2$ 300.05850, found 300.05852; **6ca** (a nonpolar isomer): IR (neat) 2992, 1455, 1008 cm^{-1}, ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.38 (t, J = 7.2 Hz, 3H), 4.09−4.17 (m, 2H), 7.47−7.57 (m, 5H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −83.14 to −83.21 (m, 1F), −108.67 to −108.79 (m, 1F), −123.12 (dddd, $^{2}J_{F-F}$ = 252.2 Hz, $^{3}J_{F-F}$ = 11.1 Hz, $^{3}J_{F-F}$ = 8.6 Hz, $^{4}J_{F-F}$ = 2.5 Hz, 1F), −125.55 (ddt, $^{2}J_{F-F}$ = 247.5 Hz, $^{3}J_{F-F}$ = 10.8 Hz, $^{3}J_{F-F}$ = 7.6 Hz, 1F), −135.21 (dm, $^{2}J_{F-F}$ = 247.9 Hz, 1F), −136.02 (ddddd, $^{2}J_{F-F}$ = 251.8 Hz, $^{3}J_{F-F}$ = 12.9 Hz, $^{3}J_{F-F}$ = 11.1 Hz, $^{3}J_{F-F}$ = 6.8 Hz, $^{4}J_{F-F}$ = 1.4 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.6, 61.8 (d, $^{3}J_{C-F}$ = 2.4 Hz), 110.1 (dddt, $^{1}J_{C-F}$ = 242.2 Hz, $^{2}J_{C-F}$ = 33.1 Hz, $^{2}J_{C-F}$ = 24.0 Hz, $^{3}J_{C-F}$ = 4.1 Hz), 110.7 (dddddd, $^{1}J_{C-F}$ = 279.3 Hz, $^{1}J_{C-F}$ = 269.0 Hz, $^{2}J_{C-F}$ = 33.8 Hz, $^{2}J_{C-F}$ = 27.1 Hz, $^{2}J_{C-F}$ = 22.8 Hz, $^{3}J_{C-F}$ = 2.2 Hz), 112.4 (ddddd, $^{1}J_{C-F}$ = 282.2 Hz, $^{1}J_{C-F}$ = 260.1 Hz, $^{2}J_{C-F}$ = 36.9 Hz, $^{2}J_{C-F}$ = 25.9 Hz, $^{2}J_{C-F}$ = 21.8 Hz), 117.2 (dtdd, $^{1}J_{C-F}$ = 258.7 Hz, $^{2}J_{C-F}$ = 26.1 Hz, $^{3}J_{C-F}$ = 6.7 Hz, $^{3}J_{C-F}$ = 1.0 Hz), 126.8 (dd, $^{3}J_{C-F}$ = 5.3 Hz, $^{4}J_{C-F}$ = 1.2 Hz, 2C), 128.7, 129.0 (d, $^{2}J_{C-F}$ = 27.1 Hz), 131.5 (d, $^{4}J_{C-F}$ = 1.9 Hz, 2C), HRMS (EI); calcd for $C_{12}H_{10}F_6O_2$ 300.0585, found 300.0583. **6ca′** (a polar isomer): IR (neat) 2992, 1455, 1195, 976 cm^{-1}, ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.42 (t, J = 7.2 Hz, 3H), 4.15−4.22 (m, 2H), 7.47−7.57 (m, 5H), ^{19}F NMR (376 MHz, $CDCl_3$) δ −83.81 to −83.83 (m, 1F), −110.44 (dt, $^{3}J_{F-F}$ = 13.6 Hz, $^{3}J_{F-F}$ = 7.2 Hz, 1F), −122.84 (dm, $^{2}J_{F-F}$ = 245.0 Hz, 1F), −123.47 (dtt, $^{2}J_{F-F}$ = 249.3 Hz, $^{3}J_{F-F}$ = 8.2 Hz, $^{4}J_{F-F}$ = 2.2 Hz, 1F), −132.82 (dm, $^{2}J_{F-F}$ = 249.3 Hz, 1F), −133.69 (dm, $^{2}J_{F-F}$ = 245.0 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.8, 62.1 (d, $^{3}J_{C-F}$ = 5.0 Hz), 110.1 (dddm, $^{1}J_{C-F}$ = 244.3 Hz, $^{2}J_{C-F}$ = 32.6 Hz, $^{2}J_{C-F}$ = 25.2 Hz), 110.9 (dddddd, $^{1}J_{C-F}$ = 277.4 Hz, $^{1}J_{C-F}$ = 273.3 Hz, $^{2}J_{C-F}$ = 33.1 Hz, $^{2}J_{C-F}$ = 25.9 Hz, $^{2}J_{C-F}$ = 23.0 Hz, $^{3}J_{C-F}$ = 1.9 Hz), 112.2 (ddddd, $^{1}J_{C-F}$ = 281.0 Hz, $^{1}J_{C-F}$ = 261.6 Hz, $^{2}J_{C-F}$ = 37.4 Hz, $^{2}J_{C-F}$ = 25.4 Hz, $^{2}J_{C-F}$ = 22.3 Hz), 117.2 (dtdt, $^{1}J_{C-F}$ = 270.0 Hz, $^{2}J_{C-F}$ = 27.1 Hz, $^{3}J_{C-F}$ = 6.0 Hz, $^{3}J_{C-F}$ = 1.2 Hz), 126.6 (dd, $^{3}J_{C-F}$ = 5.7 Hz, $^{4}J_{C-F}$ = 1.2 Hz, 2C), 128.7, 128.9 (d, $^{2}J_{C-F}$ = 26.1 Hz), 131.4 (d, 2C, $^{4}J_{C-F}$ = 1.9 Hz), HRMS (EI); calcd for $C_{12}H_{10}F_6O_2$ 300.0585, found 300.0585.

Ethyl 2,2,3,3-Tetrafluoro-4-oxo-4-phenylbutanoate (7ca). To a CH_2Cl_2 solution (2 mL) of a crude mixture of **1ca**, **6ca**, and **6ca′** prepared above was added BF_3 etherate (63 mg, 0.45 mmol) at room temperature, and the reaction mixture was stirred at room temperature for 24 h. The complete consumption of **6ca** and **6ca′** was confirmed by GC, and the mixture was poured into water (10 mL), neutralized by aq $NaHCO_3$, and extracted with Et_2O (20 mL × 3). The combined organic layer was dried over $MgSO_4$ and concentrated under reduced pressure. From ^{19}F NMR analysis, **1ca** was found to remain unchanged under the conditions, and **7ca** was formed in 89% yield from **6ca** and **6ca′**. It can be isolated by column chromatography (silica gel/hexane−AcOEt = 20:1). **7ca**: IR (neat) 2989, 1780 (C=O), 1701 (C=O), 1317, 1104 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.37 (t, J = 7.3 Hz, 3H), 4.42 (q, J = 7.2 Hz, 2H), 7.53−7.57 (m, 2H), 7.69−7.73 (m, 1H), 8.09−8.11 (m, 2H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −113.68 (t, $^{3}J_{F-F}$ = 5.0 Hz, 2F), −121.05 (t, $^{3}J_{F-F}$ = 4.7 Hz, 2F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.6, 63.8, 108.1 (tt, $^{1}J_{C-F}$ = 264.4 Hz, $^{2}J_{C-F}$ = 28.8 Hz), 115.6 (tt, $^{1}J_{C-F}$ = 271.9 Hz, $^{2}J_{C-F}$ = 28.3 Hz), 129.0 (2C), 130.1 (t, $^{4}J_{C-F}$ = 3.4 Hz, 2C), 130.9 (t, $^{3}J_{C-F}$ = 2.9 Hz), 135.5, 159.7 (t, $^{2}J_{C-F}$ = 29.7 Hz), 185.4 (t, $^{2}J_{C-F}$ = 27.8 Hz); HRMS (ESI) calcd for $C_{12}H_{10}F_4O_3Na$ 301.0458, found 301.0460.

A mixture of DAST (490 mg, 3.04 mmol) and SbF_3 (110 mg, 0.62 mmol) in a Teflon reactor with a tight screw cap was stirred at 0 °C for 10 min. Then, a CH_2Cl_2 solution (2 mL) of **7ca** (107 mg, 0.39 mmol) was added, and the mixture was stirred at room temperature for 48 h. The mixture was poured into water (10 mL), neutralized with aq $NaHCO_3$, and extracted with Et_2O (20 mL × 3). The yields of **1ca** (42%), **6ca** (21%), and **6ca′** (31%) were determined by ^{19}F NMR using fluorobenzene as an internal standard.

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Supporting Information Available: General experimental methods and ^{1}H and ^{13}C NMR spectra of all new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.