Notes

Formation of Fluorinated Heterocycles from Aromatic Silyl Enol Ethers

Yan-Song Liu,† Suzanne T. Purrington,*,† and Wei-Yuan Huang‡

Department of Chemistry, Box 8204, North Carolina State University, Raleigh North Carolina 27695-8204, and Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences, 354 Fenglin Rd., Shanghai 200032, China

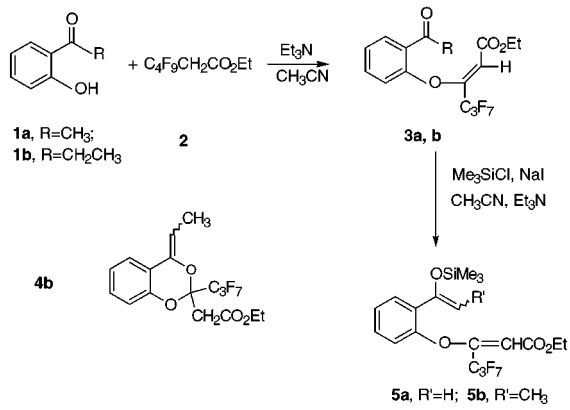
Received October 29, 1997

Because of the interesting characteristics bestowed on many organic compounds that contain fluorine, there has been considerable effort to broaden synthetic methods for the incorporation of fluorine.[1] Fluorinated acrylates have been used as building blocks for formation of heterocyclic compounds containing polyfluoroalkyl side chains.[2] In an effort to extend this methodology, we have investigated the reaction of 2′-hydroxyphenones with a polyfluoroacrylate ester. Although more than one product was formed in these reactions and low yields were obtained, the reactions show a rich mechanistic diversity. It is interesting that two such similar compounds react by such different pathways.

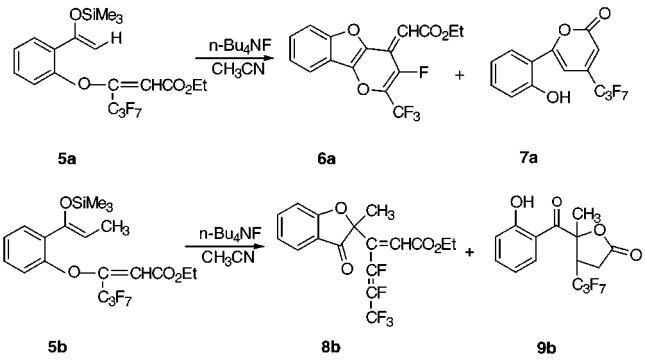
In the presence of triethylamine, reaction of 2′-hydroxyacetophenone **1a** or 2′-hydroxypropiophenone **1b** with ethyl 2,2-dihydrononafluorohexanoate **2**[3] gave rise to the aryloxy esters **3** as shown in Scheme 1. The fluorinated ester first loses HF to form an intermediate acrylate which adds Michael fashion with loss of fluoride ion to give the product. Only the Z isomer was formed as determined from the ^3J (CF) coupling constant of 5.3 Hz.[4] In the case of ketone **1b**, byproduct **4b** was formed in 9% yield.

The trimethylsilylenol ethers of the ketones **5** were prepared in good yield from esters **3a**/**3b** and chlorotrimethylsilane[5] as shown in Scheme 1. The silyl compounds, upon treatment with tetrabutylammonium fluoride in acetonitrile, each gave two major products (Scheme 2). One of the resulting compounds suffered extensive dehydrofluorination while the other lost the ethoxy moiety. Loss of fluorine from polyfluoroalkyl chains has been reported previously.[6] The acetophenone derivative **5a** gives rise to **6a** with the loss of fluorine and lactone

Scheme 1



Scheme 2



7a with the loss of the ethoxy group. The tricyclic system **6a** was formed as a mixture of E and Z isomers separable by column chromatography. Compounds with this ring system have found use as antiasthma agents;[7] to our knowledge, no fluorine-containing analogues have been reported. On the other hand the propiophenone derivative **5b** undergoes less extensive dehydrofluorination to form the 3(2*H*)-benzofuranone **8b** and with the loss of the ethoxy group, lactone **9b**. The steric effect of the methyl group in **5b** alters the pathway for formation of the lactone. The proposed mechanisms for the formation of compounds **6a**, **7a**, **8b**, and **9b** from **5a** and **5b** are illustrated in Scheme 3.

Upon treatment with tetrabutylammonium fluoride, the oxygen−silicon bond of compound **5** is cleaved with the formation of an enolate ion, which undergoes an intramolecular Michael addition reaction to the α,β-unsaturated ester. The result is intermediate **I** (Scheme 3), which then ring opens with the aryloxy anion as a leaving group, and the formation of intermediate **II**, which can either isomerize to **III** or enolize to **IV**. In intermediate **III**, the aryloxy anion acts as a nucleophile to attack the double bond to give rise to **V**, which dehydrofluorinates further and gives **8**. Starting with propiophenone derivative **5b**, where R′ is a methyl group,

† North Carolina State University.
‡ Shanghai Institute of Organic Chemistry.

(1) (a) Banks, R. E.; Smart, B. E.; Tatlow, J. C. *Organofluorine Chemistry, Principles and Commercial Applications*; Plenum Press: New York, 1994. (b) Hu, C.-M.; Qing, F.- L.; Huang, W.-Y. *J. Org. Chem.* **1991**, *56*, 2801.

(2) (a) Huang, W.-Y.; Liu, Y.-S.; Lu, L. *J. Fluorine Chem.* **1994**, *66*, 263. (b) Liu, Y.-S.; Huang, W.-Y. *J. Chem. Soc., Perkin Trans I*, **1997**, 981.

(3) Huang, W.-Y.; Lu, L.; Zhang, Y.-F. *Chin. J. Chem.* **1990**, 281.

(4) Bégué, J.-P.; Bonnet-Delpon, D.; Mesureur, D.; Ourevitch, M. *Magn. Reson. Chem.* **1991**, *29*, 675.

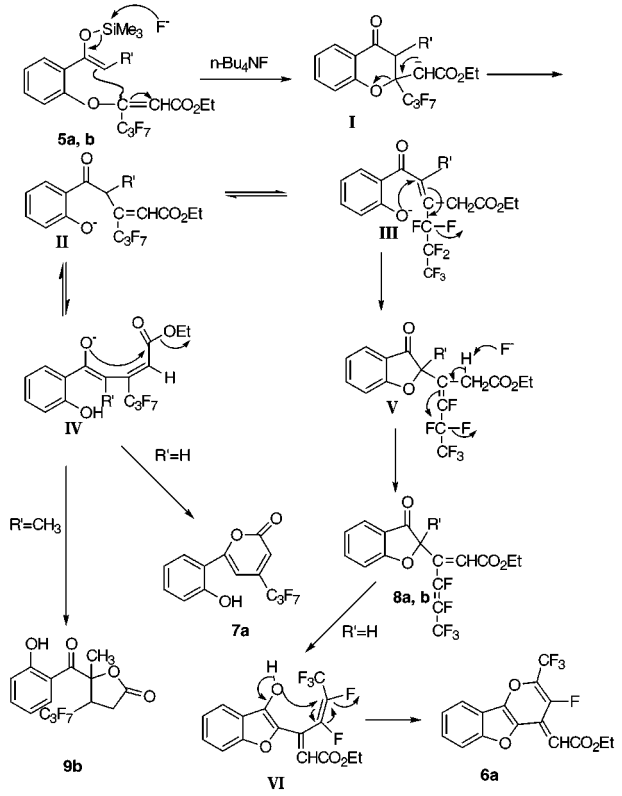
(5) Cazeau, P.; Duboudin, F.; Moulines, F.; Babot, O.; Dunogues J. *Tetrahedron* **1987**, *43*, 2075.

(6) (a) Dondy, B.; Portella, C. *J. Org. Chem.* **1993**, *58*, 6671. (b) Haas, A.; Hardt, T. P.; Wallmichrath, T. *15th Int. Symp. on Fluorine Chem.* Vancouver, Canada, August 1997.

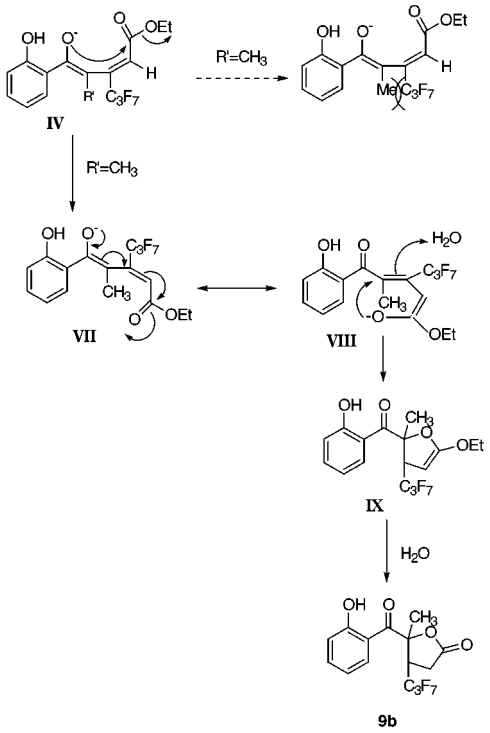
(7) Wright, J. B.; Johnson, H. G. *J. Med. Chem.* **1973**, *16*, 861.

S0022-3263(97)01989-0 CCC: $15.00
Published on Web 07/18/1998

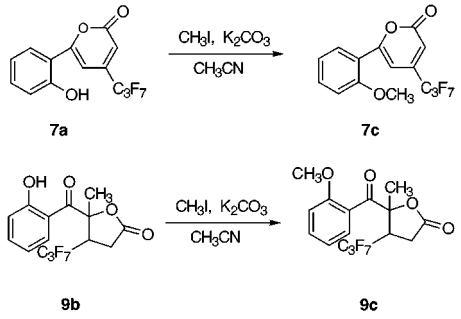
Scheme 3



Scheme 4



Scheme 5



8b is the final product. With the acetophenone derivative **5a** where R′ is H, **8a** tautomerizes to **VI**. In **VI**, the enol acts as a nucleophile and adds intramolecularly in a 1,6-conjugate manner followed by elimination of fluoride to give **6a** as the final product.

From the other intermediate, enolate **IV**, the products also depend on the R′ groups. When R′ is H, the oxygen of the enolate attacks the carbonyl group of the ester to give compound **7a**. This compound is formed from the s-cis conformer of the enolate. When R′ is a methyl group, because of the steric hindrance between the methyl and the heptafluoropropyl groups, the enolate favors conformer **VII**, which can form enol ether **IX**. Subsequent hydrolysis by water present in the tetrabutylammonium fluoride solution leads to **9b** (Scheme 4).

It was found that the reaction product ratio (**6a** vs **7a**, **8b** vs **9b**) depends on the reaction conditions. K_2CO_3 was used in order to increase the amounts of defluorination products **6a** and **8b**. However, to our surprise, **7a** (62%) and **9b** (64%) were found to be the major products with only trace amounts of **6a** (5%) and **8b** (6%). It is possible that the presence of base accelerates the rate of conversion from **II** to enolate **IV**, leading to the increasing yields of **7a** and **9b**.

The structures of compounds **7a** and **9b** were further confirmed by an etherification reaction. When **7a** (or **9b**) was treated with methyl iodide in acetonitrile in the presence of potassium carbonate, **7c** (or **9c**) was obtained in high yield (Scheme 5).

Experimental Section

Melting points are uncorrected. Analytical thin-layer chromatography (TLC) was performed on Baker-flex silica gel IB2-F plates. Flash chromatography was performed on Aldrich silica gel (70−230 mesh). ^{1}H NMR, ^{19}F NMR, and ^{13}C NMR spectra were recorded at 300, 282, and 75 MHz, respectively. All chemical shifts are reported in parts per million downfield (positive) of the standard: $CFCl_3$ for ^{19}F and tetramethylsilane for ^{1}H and ^{13}C NMR spectra. Elemental analyses were performed by Atlantic Microlab, Inc., Norcross, GA, and the HRMS were performed by the mass spectrometry facility at NCSU.

Preparation of 2.[3] With magnetic stirring, a mixture of $Na_2S_2O_4$ (17.4 g, 100 mmol) and $NaHCO_3$ (8.7 g, 104 mmol) was added to a solution of C_4F_9I (34.6 g, 100 mmol), ethyl vinyl ether (9.36 g, 130 mmol), 130 mL of CH_3CN, and 80 mL of H_2O at 5−10 °C. After 10 min the solution was diluted with 300 mL of water. The organic layer was separated, the aqueous layer was extracted with Et_2O (30 mL × 3), and 80 mL of acetone was added to the combined organic layer. Then a mixture of chromium trioxide (20 g, 200 mmol), concentrated sulfuric acid (20 mL), and H_2O (100 mL) was added dropwise to the solution, maintaining the temperature of the reaction mixture below 10 °C. After stirring at room temperature overnight, the mixture was extracted with ether (100 mL x 3). After removal of solvent, EtOH (30 mL), benzene (50 mL), and *p*-toluenesulfonic acid (1 g) were added to the residue. The mixture was refluxed for 16 h, and the water formed during the reaction was removed using a Dean−Stark trap. The reaction mixture was diluted with 50 mL of H_2O and extracted with ether (60 mL × 3). The combined organic layer was washed with 5% $NaHCO_3$ (40 mL) and saturated NaCl solution (50 mL) and dried over $MgSO_4$. Distillation gave **2** (20.13 g, 66%) as a colorless liquid: bp, 146−149 °C. ^{1}H NMR ($CDCl_3$): δ 1.27 (t, 3H, J = 7.2 Hz), 3.10 (t, 2H, J = 17.5 Hz), 4.21 (q, 2H, J = 7.2 Hz). ^{19}F NMR ($CDCl_3$): δ −81.6 (t, 3F, J = 10.5 Hz), −112.4 (m, 2F), −124.4 (m, 2F), −126.4 (m, 2F).

Preparation of Aryloxy Esters 3. Ethyl 2,2-dihydrononafluorohexanoate **2** (0.61 g, 2.0 mmol), 2′-hydroxyacetophenone, **1a** (0.27 g, 2.0 mmol) or 2′-hydroxypropiophenone **1b** (0.30 g, 2.0 mmol), and 6 mmol of triethylamine in 5 mL of acetonitrile were stirred under reflux until ^{19}F NMR indicated the complete consumption of **2** (2−4 h). The solvent was then evaporated, and the residue was purified by column chromatography using petroleum ether/ethyl acetate (30:1) as eluant to afford **3a** (or **3b**) as a light yellow oil.

3a. Yield: 0.68 g (85%). IR (neat): 1730, 1682, 1599, 1576, 1237 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 1.00 (t, 3H, J = 7.1 Hz), 2.64 (s, 3H), 3.91 (q, 2H, J = 7.1 Hz), 6.30 (s, 1H), 6.94 (d, 1H, J = 8.2 Hz), 7.17 (m, 1H), 7.43 (m, 1H), 7.86 (d, 1H, J = 7.2 Hz). ^{19}F NMR ($CDCl_3$): δ −80.72 (t, 3F, J = 10.6 Hz), −117.34 (m, 2F), −126.08 (s, 2F). ^{13}C NMR ($CDCl_3$): δ 13.7, 31.4, 61.6, 107.8, 111.3, 112.5 (t, J = 5.3 Hz), 113.9, 115.7 (m), 119.5 (m), 124.0, 128.6, 130.9, 133.5, 148.8 (t, J = 26.5 Hz), 155.7, 161.6, 197.9. MS m/z: 402 (M^+), 359 (5), 315 (80), 267 (10), 187 (60), 137 (80), 121 (100). Anal. calcd for $C_{16}H_{13}F_7O_4$: C, 47.77; H, 3.26. Found: C, 48.00; H, 3.40.

3b. Yield: 0.57 g (69%). IR (neat): 1729, 1686, 1600, 1210 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 0.99 (t, 3H, J = 7.1 Hz), 1.18 (t, 3H, J = 7.2 Hz), 3.00 (q, 2H, J = 7.2 Hz), 3.90 (q, 2H, J = 7.1 Hz), 6.29 (s, 1H), 6.94 (d, 1H, J = 8.2 Hz), 7.16 (m, 1H), 7.41 (m, 1H), 7.82 (d, 1H, J = 7.7 Hz). ^{19}F NMR ($CDCl_3$) δ: −80.77 (t, 3F, J = 10.3 Hz), −117.33 (m, 2F), −126.15 (s, 2F). MS m/z: 416 (M^+), 387 (1), 343 (7), 315 (100), 247 (6), 196 (24), 167 (11), 121 (21). Anal. calcd for $C_{17}H_{15}F_7O_4$: C, 49.05; H, 3.63. Found: C, 49.25; H, 3.56.

4b. Colorless oil eluted off the column after **3b**, 0.075 g (9%). IR (neat): 2985, 1745, 1675, 1584, 1232, 1125, 1029 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 1.20 (t, 3H, J = 7.2 Hz), 1.81 (d, 3H, J = 7.0 Hz), 3.05 (m, 2H), 4.10 (m, 2H), 5.59 (q, 1H, J = 7.0 Hz), 7.06 (m, 2H), 7.22 (t, 1H, J = 7.7 Hz), 7.42 (d, 1H, J = 7.7 Hz). ^{19}F NMR ($CDCl_3$): δ −81.11 (m, 3F), −121.71 (m, 2F), −124.55 (m, 2F). ^{13}C NMR ($CDCl_3$): δ 9.67, 13.90, 37.75, 61.14, 98.44 (t, J = 27.6 Hz), 102.92, 116.93, 117.48, 122.45, 122.87, 129.48, 140.63, 146.83, 166.15. MS m/z: 416 (M^+), 387 (1), 369 (5), 329 (18), 315 (11), 247 (12), 205 (11), 159 (13), 131 (100). HRMS: calcd for $C_{16}H_{13}F_7O_4$, 416.0859, found, 416.0842.

Preparation of Silyl Enol Ethers 5. Under N_2, 2 mmol of compound **3a** (0.80 g) or **3b** (0.83 g), 3 mmol (0.33 g) of freshly distilled chlorotrimethylsilane, 5 mmol (0.30 g) of anhydrous triethylamine, 0.01 g of anhydrous NaI, and 5 mL of anhydrous acetonitrile were placed in a three-necked flask.[5] The reaction mixture was stirred at room temperature for 1 h, then was heated to reflux for about 3 h. After the complete consumption of **3**, the reaction mixture was cooled to room temperature and poured onto crushed ice, extracted with Et_2O (30 mL × 3), washed with saturated NaCl solution (20 mL × 2), and dried over anhydrous $MgSO_4$. After removal of solvent, the residue was purified by column chromatography, using petroleum ether/ethyl acetate (50:1) as eluant to give impure **5** as yellow oil.

5a. Yield: 0.80 g (84%). ^{1}H NMR ($CDCl_3$): δ 0.23 (s, 9H), 0.97 (t, 3H, J = 7.2 Hz), 3.87 (q, 2H, J = 7.1 Hz), 4.70 (s, 1H), 4.96 (s, 1H), 6.19 (s, 1H), 6.87−7.60 (m, 4H). ^{19}F NMR ($CDCl_3$): δ −80.8 (t, 3F, J = 10.3 Hz), −117.1 (m, 2F), −126.1 (m, 2F).

5b. Yield: 0.69 g (71%). ^{1}H NMR ($CDCl_3$): δ 0.07 (s, 9H), 0.98 (t, 3H, J = 7.1 Hz), 1.73 (d, 3H, J = 6.9 Hz), 3.88 (q, 2H, J = 7.1 Hz), 5.36 (q, 1H, J = 6.9 Hz), 6.16 (s, 1H), 6.87 (d, 1H, J = 8.0 Hz), 7.09 (m, 2H), 7.48 (d, 1H, J = 7.5 Hz). ^{19}F NMR ($CDCl_3$): δ −80.9 (t, 3F, J = 9.9 Hz), −117.3 (m, 2F), −126.4 (m, 2F).

Preparation of Compounds 6−9 without K_2CO_3. To a solution of 1 mmol of **5a** (0.47 g) or **5b** (0.49 g) in 5 mL of anhydrous acetonitrile under N_2 was added 1 mL of tetrabutylammonium fluoride (1 M solution in THF). The reaction mixture was heated to reflux for about 2 h. The reaction was monitored by TLC (petroleum ether/$CHCl_3$ 3:1) until the complete consumption of **5**. Then, the reaction mixture was cooled to room temperature and 10 mL of water was added. The resulting solution was extracted with Et_2O (30 mL × 3), washed with saturated NaCl solution (20 mL × 2), and dried over $MgSO_4$. After removal of solvent, the crude product was subject to column chromatography, using petroleum ether/ethyl acetate (50:1) as eluant to give **6a** (or **8b**). Afterward, the eluant was changed to petroleum ether/ethyl acetate (3:1) to give **7a** (or **9b**).

6a1. Yellow solid, mp 101−103 °C, 0.09 g (25%). IR ($CHCl_3$): 1723, 1643, 1595, 1258, 1237 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 1.33 (t, 3H, J = 7.1 Hz), 4.26 (q, 2H, J = 7.1 Hz), 5.97 (s, 1H), 7.37 (m, 1H), 7.49 (m, 2H), 7.69 (d, 1H, J = 7.6 Hz). ^{19}F NMR ($CDCl_3$): δ −65.53 (d, 3F, J = 21.2 Hz), −137.37 (q, 1F, J = 21.2 Hz). ^{13}C NMR ($CDCl_3$): δ 14.43, 60.95, 101.66 (d, J = 5.5 Hz), 112.70, 118.15, 119.08, 119.51 (q, J = 266.0 Hz), 123.42, 123.72, 124.64, 128.46, 137.94, 138.68 (d, J = 14.5 Hz), 148.82 (d, J = 269.1 Hz), 154.59, 165.17. MS m/z: 342 (M^+), 297 (70), 270 (100), 187 (12), 160 (9). UV: λ_{abs}($CHCl_3$) 342.0 nm.

6a2. Yellow solid, mp 89−91 °C, 0.054 g (16%). IR ($CHCl_3$): 1718, 1609, 1405, 1243, 1215 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 1.39 (t, 3H, J = 7.1 Hz), 4.33 (q, 2H, J = 7.1 Hz), 5.80 (s, 1H), 7.38 (m, 1H), 7.51 (m, 1H), 7.64 (d, 1H, J = 8.4 Hz), 7.74 (d, 1H, J = 7.8 Hz). ^{19}F NMR ($CDCl_3$): δ −65.72 (d, 3F, J = 20.8 Hz), −147.43 (q, 1F, J = 20.8 Hz). ^{13}C NMR ($CDCl_3$): δ 14.36, 60.59, 99.76 (d, J = 6.0 Hz), 112.94, 117.12, 118.99, 124.27, 124.57, 128.78, 137.05 (d, J = 8.9 Hz), 139.75, 149.06 (d, J = 259.7 Hz), 154.48, 165.23. MS m/z: 342 (M^+), 297 (66), 270 (100), 257 (1), 241 (7), 148 (8), 123 (6). UV: λ_{abs}($CHCl_3$) 341.0 nm. HRMS: calcd for $C_{16}H_{10}F_4O_4$, 342.0515; found, 342.0508.

7a. Yellow solid, mp 174−176 °C, 0.078 g (22%). IR ($CHCl_3$): 3338 (br), 1723, 1600, 1536, 1349, 1237, 1215 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 6.48 (s, 1H), 6.81 (br, 1H), 6.95 (m, 2H), 7.16 (s, 1H), 7.31 (t, 1H, J = 7.7 Hz), 7.77 (d, 1H, J = 7.9 Hz). ^{1}H NMR ($CDCl_3$-D_2O): δ 6.52 (s, 1H), 6.94 (d, 1H, J = 8.2 Hz), 7.04 (t, 1H, J = 7.7 Hz), 7.13 (s, 1H), 7.37 (m, 1H), 7.80 (m, 1H). ^{19}F NMR ($CDCl_3$): δ −80.32 (t, 3F, J = 10.3 Hz), −116.57 (m, 2F), −126.48 (s, 2F). ^{13}C NMR ($CDCl_3$): δ 100.81, 112.93 (t, J = 7.3 Hz), 116.91, 117.74, 121.43, 128.50, 133.14, 145.11, 154.69, 159.71, 160.61. MS m/z: 356 (M^+), 328 (100), 299 (21), 209 (33), 187 (50), 121 (92), 92 (44). HRMS: calcd for $C_{14}H_7F_7O_3$, 356.0283; found, 356.0271. UV: λ_{abs}($CHCl_3$) 366.0 nm.

8b. Yellow oil, 0.103 g (28%). IR (neat): 1729, 1611, 1381, 1344, 1296, 1173, cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 1.27 (t, 3H, J = 7.1 Hz), 1.72 (s, 3H), 4.21 (q, 2H, J = 7.1 Hz), 6.59 (s, 1H), 7.15 (m, 2H), 7.68 (m, 2H). ^{19}F NMR ($CDCl_3$): δ −68.64 (dd, 3F, J = 21.7, 11.6 Hz), −132.96 (dq, 1F, J = 141.0, 11.6 Hz), −165.13 (dq, 1F, J = 141.0, 21.7 Hz). ^{13}C NMR ($CDCl_3$): δ 14.01, 23.00, 61.82, 87.81, 113.71, 119.08, 123.21, 125.53, 128.10, 138.05 (d, J = 18.8 Hz), 139.11, 163.12, 170.94, 197.92. MS m/z: 376 (M^+), 348 (4), 331 (9), 303 (8), 275 (32), 256 (37), 228 (100), 121 (69). HRMS: calcd for $C_{17}H_{13}F_5O_4$, 376.0734, found, 376.0738. UV: λ_{abs}($CHCl_3$) 252.0, 329.0 nm.

9b. Yellow solid, mp 143−145 °C, 0.167 g (43%). IR (neat): 3092 (br), 1745, 1691, 1617, 1467, 1211 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 1.45 (s, 3H), 2.75 (m, 2H), 3.75 (m, 1H), 7.15 (m, 2H), 7.70 (m, 2H). ^{19}F NMR ($CDCl_3$): δ −80.92 (t, 3F, J = 12.1 Hz), −110.05 (m, 2F), −124.85 (dd, 2F, J = 43.2, 9.9 Hz). ^{13}C NMR ($CDCl_3$): δ 22.06, 29.80, 43.58 (t, J = 20.6 Hz), 87.47, 113.90, 119.71, 122.86, 125.29, 138.99, 171.32, 175.96, 201.38. MS m/z: 388 (M^+), 371 (1), 329 (1), 267 (7), 201 (8), 173 (18), 148 (50), 121 (100). HRMS: calcd for $C_{15}H_{11}F_7O_4$, 388.0546, found, 388.0538. UV: λ_{abs}($CHCl_3$) 250.0, 327.0 nm.

Preparation of Compounds 6−9 using K_2CO_3. In the presence of 4 mmol (0.55 g) of K_2CO_3, the reaction was carried out in a similar manner with 1 mmol of **5a** (0.47 g) or **5b** (0.49 g) and gave **6a** (0.02 g, 5%), **7a** (0.22 g, 62%) or **8b** (0.024 g, 6%), and **9b** (0.25 g, 64%).

Preparation of Methyl Ethers 7c, and 9c. Compound **7a** (0.018 g, 0.5 mmol) or compound **9b** (0.019 g) was dissolved in 2 mL of THF, and methyl iodide (21 mg, 1.5 mmol) and K_2CO_3 (14 mg, 1 mmol) were added. The solution was heated to reflux for about 5 h until consumption of **7a** (or **9b**) was complete. After the solution was cooled to room temperature, 2 mL of water was added, and the mixture was extracted with Et_2O (10 mL × 3), washed with saturated NaCl solution, and dried over $MgSO_4$. After removal of solvent, the residue was subjected to column chromatography, using petroleum ether/ethyl acetate as eluant to give **7c** (or **9c**).

7c. Yellow solid, mp 73−75 °C, 0.018 g (83%). IR (neat): 1745, 1632, 1542, 1594, 1349, 1258 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 3.86 (s, 3H), 6.42 (s, 1H), 6.97 (m, 2H), 7.17 (s, 1H), 7.38 (m, 1H), 7.87 (dd, 1H, J = 7.9, 1.6 Hz). ^{19}F NMR ($CDCl_3$): δ −80.32 (t, 3F, J = 10.5 Hz), −116.65 (q, 2F, J = 10.5 Hz), −126.65 (s, 2F). MS: 370 (M^+, 100), 342 (95), 327 (8), 299 (21), 180 (73), 135 (90). HRMS: calcd for $C_{15}H_9F_7O_3$, 370.0440, found, 370.0428.

9c. Light yellow oil, 0.016 g (87%). IR (neat): 1745, 1725, 1611, 1462, 1227 cm^{-1}. ^1H NMR ($CDCl_3$): δ 1.54 (s, 3H), 2.57 (dd, 1H, J = 17.8, 4.0 Hz), 2.75 (dd, 1H, J = 18.0, 5.7 Hz), 3.67 (s, 3H), 3.71 (m, 1H), 7.11 (m, 2H), 7.65 (m, 2H). ^{19}F NMR ($CDCl_3$): δ −80.8 (m, 3F), −109.9 (m, 2F), −124.8 (m, 2F). ^{13}C NMR ($CDCl_3$): δ 22.10, 29.71, 43.87 (t, J = 20.5 Hz), 52.52, 87.49, 113.88, 119.81, 122.72, 125.17, 138.82, 170.89, 171.29, 201.30. MS m/z: 402 (M^+), 371 (9), 342 (2), 315 (3), 223 (30), 173 (15), 148 (100).

Acknowledgment. Mass spectra were obtained at the Mass Spectrometry Laboratory for Biotechnology the NCSU. Partial funding for the facility was obtained from the North Carolina Biotechnology Center and the National Science Foundation (Grant 9111391). We thank Prof. Carl Bumgardner for stimulating discussion of these results and Dr. Yangzhen Ciringh and Dr. Ferenc Gyenes for the technical assistance.

Supporting Information Available: ^1H, ^{13}C, and ^{19}F NMR spectra of compounds **3a,b**−**9c** (32 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

JO971989J