JOC The Journal of Organic Chemistry

NOTE

pubs.acs.org/joc

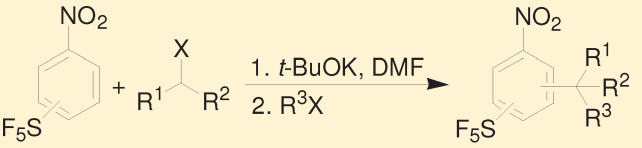
Preparation of SF_5 Aromatics by Vicarious Nucleophilic Substitution Reactions of Nitro(pentafluorosulfanyl)benzenes with Carbanions

Petr Beier, Tereza Pastýříková, and George Iakobson

Institute of Organic Chemistry and Biochemistry, Academy of Sciences of the Czech Republic, Flemingovo nám. 2, 166 10 Prague, Czech Republic

Supporting Information

ABSTRACT: Vicarious nucleophilic substitutions (VNS) of hydrogen in 1-nitro-4-(pentafluorosulfanyl)benzene with carbanions provide 2-substituted 1-nitro-4-(pentafluorosulfanyl)-benzenes in good to high yields. VNS of 1-nitro-3-(pentafluorosulfanyl)benzene gives a mixture of 6- and 4-substituted 1-nitro-3-(pentafluorosulfanyl)benzenes in 85:15 to >98:2 ratio and good to high yields. In basic media, the VNS reactions lead to the formation of carbanions that can be alkylated by alkyl halides affording the corresponding alkylated products in moderate yields. Transformation of primary products to substituted (pentafluorosulfanyl)anilines and 3- or 4-substituted (pentafluorosulfanyl)benzenes is also described.



X = Cl, Br, OPh
R^1 = H, Me, Cl, Br
R^2 = Cl, Br, SO_2Ph, CN, CO_2R, $P(O)(OEt)_2$
R^3 = H, Me, $PhCH_2$, $CH_2{=}CHCH_2$

The introduction of a strongly electron-withdrawing and highly lipophilic pentafluorosulfanyl (SF_5) group into organic molecules can dramatically alter their properties. The SF_5 group is highly hydrolytically stable, and in recent years, increasing numbers of publications (mostly patents) have appeared describing a variety of applications for this class of compounds, including liquid crystals, energetic materials, advanced polymer materials, agrochemicals, and even pharmaceuticals.[1,2] However, a general lack of synthetic methodologies and inaccessibility of basic building blocks for the synthesis of SF_5-containing compounds are the main constraints to broader utilization of these compounds. For SF_5 benzenes, there are two main synthetic procedures available. The first is based on direct fluorination of bis(nitrophenyl)disulfides and provides economical access to 1-nitro-4-(pentafluorosulfanyl)benzene (**1**) and 1-nitro-3-(pentafluorosulfanyl)benzene (**2**).[3] Another route is the recently disclosed two-step procedure for the conversion of diaryl disulfides to (pentafluorosulfanyl)arenes.[4] Compounds **1** and **2** are strongly deactivated toward electrophilic aromatic substitution, and their functionalization using S_EAr chemistry has not been achieved. Nucleophilic aromatic substitutions of halogen of halonitro(pentafluorosulfanyl)benzenes are known;[5] however, no publications have reported that **1** or **2** are reactive toward nucleophiles by nucleophilic aromatic substitution, despite the electronic suitability of the system for such reactions. The only reported synthetic transformation starting from **1** or **2** and yielding SF_5-benzenes is the reduction of the nitro group to a corresponding (pentafluorosulfanyl)aniline, which was further acylated, halogenated (using electrophilic halogenation), or diazotized (with follow up reactions).[2a,b,3b,6] We have recently reported efficient S_NAr of the nitro group in compounds **1** and **2** with alkoxides and thiolates.[7] This method provides straightforward access to substituted 4- and 3-(pentafluorosulfanyl)benzenes.

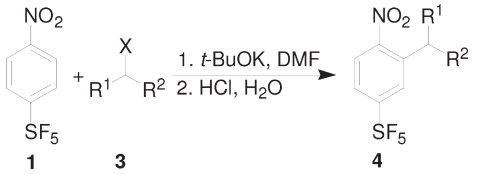
Vicarious nucleophilic substitution of hydrogen (VNS) is a process that has been known for more than 30 years.[8] It is a reaction of electron-deficient aromatic or heteroaromatic systems with a nucleophile, having a leaving group at the nucleophilic center. In VNS reactions, the aromatic hydrogen is substituted for the nucleophile, with concomitant departure of the leaving group. The VNS reaction has been studied mainly on nitrobenzene derivatives and represents a good method for introducing carbon, oxygen, and nitrogen functional groups into aromatic systems. With the aim of providing a new route to obtain functionalized aromatic intermediates containing the SF_5 group, we began to investigate nucleophilic aromatic substitution for hydrogen (rather than the nitro group), starting from nitro-(pentafluorosulfanyl)benzenes. Here, we report our findings concerning VNS reactions starting from **1** and **2** using carbon nucleophiles.

At first, we explored the reaction of **1** with chloromethyl phenyl sulfone (**3a**) in the presence of excess base, KOH, in DMSO or *t*-BuOK in DMF, according to Makosza and coworkers.[9] We found *t*-BuOK/DMF to be a better base system in terms of reaction yield and ease of product isolation. The reaction was finished in less than 30 min at −40 °C, providing 1-nitro-2-((phenylsulfonyl)methyl)-4-(pentafluorosufanyl)benzene (**4a**) in 84% yield (Table 1, entry 1). Typically, dropwise addition of a solution of **1** and **3a** (1 equiv) in DMF to a cooled solution of *t*-BuOK (3−4 equiv) in DMF resulted in the formation of a deep

Received: March 29, 2011
Published: May 05, 2011

violet mixture, and the reaction was terminated by the addition of aqueous hydrochloric acid. The substitution took place exclusively at the *ortho*-position relative to the nitro group. Excellent reactivities were also observed with esters of chloroacetic or dichloroacetic[10] acids (Table 1, entries 2−4), while for the case of methyl 2-chloropropionate (**3e**)[11] the yield was low (Table 1, entry 5) and could not be improved by changing the reaction temperature or time. With diethyl chloromethylphosphonate (**3f**), the VNS reaction took place in less than 10 min at −60 °C, with a respectable 84% yield (Table 1, entry 6). Because chloroacetonitrile is unstable in basic media, phenyoxyacetonitrile was used for installation of the cyanomethyl group. In this case, the leaving group was phenolate rather than chloride, and the reaction required ambient temperature (Table 1, entry 7). Chloroform and bromoform could also be used as pronucleophiles; however, the generated trihalomethyl carbanions are unstable, and good product yields required a combination of very short reaction times (1−2 min) and low temperature in a THF/DMF solvent mixture (Table 1, entries 8 and 9).[12]

Table 1. VNS Reactions of 1[a]



1 **3** **4**

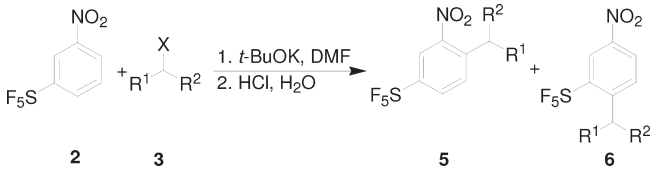
entry		X	R^1	R^2	temp (°C)	time (min)	yield [b] (%)
1	**3a**	Cl	H	$PhSO_2$	−40	30	**4a**, 84
2	**3b**	Cl	H	CO_2Et	−30	10	**4b**, 76
3	**3c**	Cl	H	CO_2Bu-*t*	−30	10	**4c**, 91
4	**3d**	Cl	Cl	CO_2Me	−30	10	**4d**, 83
5	**3e**	Cl	Me	CO_2Me	−5	6	**4e**, 9
6	**3f**	Cl	H	$P(O)(OEt)_2$	−60	10	**4f**, 84
7	**3g**	PhO	H	CN	rt	10	**4g**, 74
8	**3h**	Cl	Cl	Cl	−70	2[c]	**4h**, 74
9	**3i**	Br	Br	Br	−70	2[c]	**4i**, 74

[a] Reactions were carried out using **1** (1.0 mmol), **3** (1.0 mmol), and *t*-BuOK (3.0−4.0 mmol) in DMF (3.5 mL). [b] Isolated yields. [c] Reactions were conducted in THF/DMF (1:1) solvent mixture.

Compound **2** was found to be much less reactive for nucleophilic aromatic substitution of the nitro group in reactions with alcoholates or thiolates than compound **1** because the nitro group in **2** is located in a position that is not conjugated with the SF_5 group.[7] However, in VNS reactions the situation is different. Compound **2** should be more reactive that **1** in VNS reactions because in the former case the reaction proceeds via addition in positions conjugated with both of the activating groups. Indeed, VNS reactions with **2** took place with efficiencies similar to those observed with **1** (Table 2). The product mixture contained two compounds: the major product **5**, with the substituent in the ortho position relative to the nitro group (para to SF_5), and the minor product **6**, with the substituent in the para position relative to the nitro group. The octahedral coordination geometry of the SF_5 group exerts higher steric effect than the nitro group planar to the benzene ring. This is evident, for example, from the crystal structure of compound **2**.[13] Products were obtained either as pure major isomers **5a**, **5d**, **5h**, or **5i** or a mixture of isomers in 73−94% yields. The product ratio ranged from 85:15 for phenoxyacetonitrile to more than 98:2 for the case of bromoform (Table 2). More sterically demanding carbanions, derived from methyl dichloroacetate (**3d**), chloroform (**3h**), or bromoform (**3i**), appear to have provided the highest **5**:**6** product ratio.

Considering a reaction mechanism analogous to the one reported for VNS reactions with nitrobenzene derivatives,[8] the first step is attack of the carbanion generated from **3** to the aromatic ring of **1** or **2** in the ortho position relative to the nitro group and the formation of σ^H-adduct **A**. In compound **2**, the attack also takes place to a small extent in the para position. Adduct **A** undergoes base-induced β-elimination of HX[1] to form anion **B**. Anion **B** can be protonated to give products **4** and **5** or alkylated with primary alkyl halides to give **7** and **8** (Scheme 1). This reaction sequence was demonstrated on nitrobenzene and its derivatives.[14] Our results from a one-pot VNS/alkylation sequence are shown in Table 3.

Table 2. VNS Reactions of 2[a]



2 **3** **5** **6**

entry		X	R^1	R^2	temp (°C)	time (min)	product, yield [b] (%)	**5**:**6**[c]
1	**3a**	Cl	H	$PhSO_2$	−40	30	**5a**, 90; **6a**, 4	96:4
2	**3c**	Cl	H	CO_2Bu-*t*	−30	10	**5c** + **6c**, 94	94:6
3	**3d**	Cl	Cl	CO_2Me	−30	10	**5d**, 79	98:2
4	**3f**	Cl	H	$P(O)(OEt)_2$	−60	10	**5f** + **6f**, 73	95:5
5	**3g**	PhO	H	CN	rt	10	**5 g** + **6 g**, 73	85:15
6[d]	**3h**	Cl	Cl	Cl	−70	2	**5h**, 91	96:4
7[d]	**3i**	Br	Br	Br	−70	2	**5i**, 84	>98:2

[a] Reactions were carried out using **2** (1.0 mmol), **3** (1.0 mmol), and *t*-BuOK (3.0−4.0 mmol) in DMF (3.5 mL). [b] Isolated yields. [c] Determined by ^{19}F NMR of the crude product mixture. [d] Reactions were conducted in a THF/DMF (1:1) solvent mixture.

dx.doi.org/10.1021/jo200618p |*J. Org. Chem.* 2011, 76, 4781–4786

Scheme 1. Proposed Mechanism of the VNS Reactions of 1 and 2

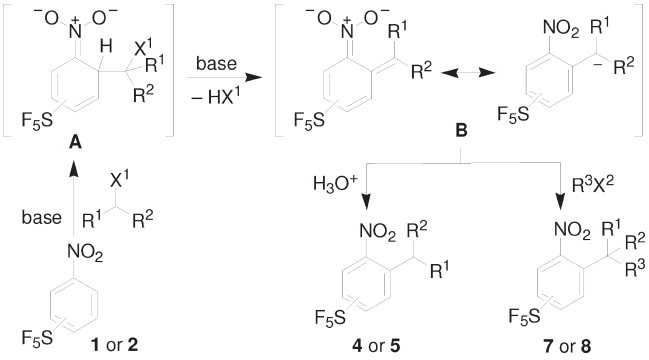
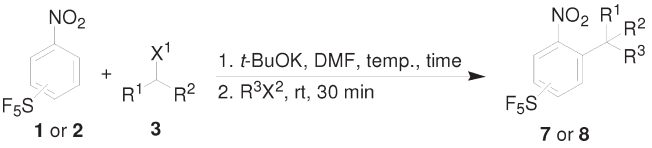


Table 3. VNS/Alkylation Sequence of 1 and 2[a]



entry		X^1	R^1	R^2	X^2	R^3	temp (°C)	time (min)	yield[b] (%)
1	**1**	Cl	H	CO_2Et	Br	$PhCH_2$	−30	10	**7b**, 59
2	**1**	OPh	H	CN	I	CH_3	rt	10	**7g**, 57
3	**2**	Cl	H	$PhSO_2$	Br	$CH_2{=}CHCH_2$	−40	30	**8a**, 84
4	**2**	Cl	Cl	CO_2Me	I	*n*-Bu	−30	10	**8d**, 0

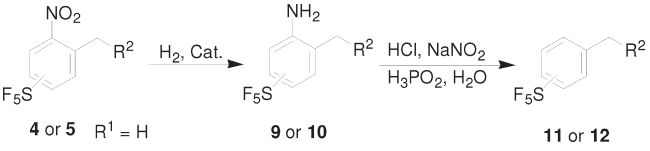
[a] Reactions were carried out using **1** or **2** (1.0 mmol), **3** (1.0 mmol), and *t*-BuOK (3.0 mmol) in DMF (3.5 mL) followed by addition of R^3X^2 (2.0 mmol), rt, 30 min. [b] Isolated yields.

Reactions with alkyl halides, such as methyl iodide, allyl bromide, or benzyl bromide, gave moderate to good yields of the desired alkylated products (Table 3, entries 1−3); however, an attempt to create a quaternary carbon center was not successful, and **5d**, **6d**, and other unidentified products were formed instead of the expected **8d** (Table 3, entry 4).

To demonstrate the versatility of this methodology for the synthesis of functionalized SF_5-benzenes, several transformations of primary products **4** and **5** were performed. Catalytic hydrogenation provided substituted (pentafluorosulfanyl)anilines **9** and **10** (Table 4). The choice of catalyst was crucial for the outcome of these reactions. While employment of 10% Pd/C in the reaction with **4f** gave good yields of the aniline derivative **9f**, the formation of *N*-hydroxylamine derivatives was observed with compounds **4c** and **5a**. On the other hand, with Raney nickel, good to high yields of aniline derivatives **9c** and **10a** were obtained (Table 4, entries 1 and 3). Finally, the amino groups in **9f** and **10a** were substituted for hydrogen atoms under standard diazotation conditions in the presence of H_3PO_2, providing meta- or para-substituted SF_5-benzenes **11f** and **12a**, respectively, in good yields (Table 4, entries 2 and 3).

In summary, in the present work, vicarious nucleophilic substitutions of hydrogen of *p*- and *m*-nitro(pentafluorosulfanyl)benzenes (**1** and **2**) with a range of carbanions have been shown to provide novel substituted nitro(pentafluorosulfanyl)benzenes **4**−**6** in good yields. High regioselectivities were obtained for VNS reactions of **2**. These reactions were performed under kinetic conditions (low reaction temperatures, short reaction times, and equimolar amounts of **3**), unlike the nucleophilic aromatic substitutions for the nitro group of **1** and **2**.[7] The VNS/alkylation sequence enabled synthesis of alkylated derivatives **7** and **8** in one-pot reaction from **1** and **2**, respectively. Follow-up transformation of the primary products **4** and **5** expanded the scope of the synthetic method and provided substituted (pentafluorosulfanyl)anilines **9** and **10** and substituted (pentafluorosulfanyl)benzenes **11f** and **12a**.

Table 4. Synthesis of (Pentafluorosulfanyl)anilines 9 or 10[a] and Substituted (Pentafluorosulfanyl)benzenes 11f or 12a[b]



entry		R^2	cat.	yield[c] (%)	yield[c] (%)
1	**4c**	CO_2Bu-*t*	Ra-Ni	**9c**, 97	
2	**4f**	$P(O)(OEt)_2$	Pd/C	**9f**, 77	**11f**, 72
3	**5a**	SO_2Ph	Ra-Ni	**10a**, 79	**12a**, 65

[a] Reactions were carried out using **4** or **5** with 10% Pd/C (cat.) in THF or with Ra-Ni (cat.) in EtOH at rt for 4−15 h. [b] Reactions were carried out using **9f** or **10a** (0.18 mmol), HCl (excess), $NaNO_2$ (3−5 equiv), H_3PO_2 (excess) in water, −10 °C to rt, 1−1.5 h. [c] Isolated yields.

EXPERIMENTAL SECTION

General Procedure for the Synthesis of Compounds 4−6.

A solution of **1** or **2** (1.0 mmol) and **3** (1.0 mmol) in DMF (1.0 mL) was added dropwise to a solution of *t*-BuOK (3.0−4.0 mmol) in DMF (2.5 mL) or a mixture of DMF (0.8 mL) and THF (1.7 mL) at an appropriate temperature. The reaction was terminated after a given time by addition of aq HCl (10 mL, 1 M), followed by extraction into *t*-BuOMe or CH_2Cl_2 (3 × 15 mL). The combined organic phase was washed with brine (15 mL), dried ($MgSO_4$), and concentrated under reduced pressure. Purification by column chromatography (silica gel, PE−EtOAc) gave the desired products **4**−**6**.

4a: white solid (84%); mp 124−125 °C; R_f 0.45 (PE−EtOAc, 3:1); IR (KBr) ν_{max} 3117, 3097, 3073, 3045, 3020, 2957, 2884, 1613, 1585, 1539, 1357, 1325, 1155, 1085, 835; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.96 (s, 2H), 7.50−7.54 (m, 2H), 7.61−7.62 (m, 1H), 7.66−7.69 (m, 3H), 7.91−7.93 (m, 1H), 8.08−8.11 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 58.2, 124.4, 126.0, 127.8 (quin, J = 4.6 Hz), 128.2, 129.4, 131.7 (quin, J = 4.7 Hz), 134.5, 137.3, 150.6, 156.6 (quin, J = 19.6 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.2 (dm, J = 151.0 Hz, 4F), 79.3−80.9 (m, 1F); MS (EI) m/z 264 (6), 263 (9), 262 (100), 245 (24), 141 (51), 77 (88). Anal. Calcd for $C_{13}H_{10}F_5NO_4S_2$: C, 38.71; H, 2.50; N, 3.47. Found: C, 38.90; H, 2.58; N, 3.29.

4b: pale yellow oil (76%); R_f 0.40 (PE−EtOAc, 9:1); FTIR (film) ν_{max} 3120, 3100, 3076, 3047, 2987, 2942, 2878, 1738, 1618, 1584, 1537, 1355, 1223, 1183, 1028, 836; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.27 (t, 3H, J = 7.1 Hz), 4.09 (s, 2H), 4.20 (q, 2H, J = 7.3 Hz), 7.77−7.79 (m, 1H), 7.86−7.90 (m, 1H), 8.15−8.20 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.0, 38.6, 61.7, 125.6−125.8 (m), 126.4−126.7 (m), 130.8−131.1 (m), 130.9, 150.1−150.3 (m), 155.8−156.5 (m), 168.8; ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.2 (dm, 4F, J = 150.3 Hz), 79.9−81.5 (m, 1F); MS (EI) m/z 316 (7), 290 (42), 289 (47), 262 (87), 261 (58), 246 (100), 119 (49), 107 (23), 89 (29), 77 (24); HRMS (ESI^-) m/z calcd for $C_{10}H_9F_5NO_4S$ $[M - H]^-$ 334.01724, found 334.01779.

dx.doi.org/10.1021/jo200618p | J. Org. Chem. 2011, 76, 4781–4786

4c: pale yellow solid (91%); mp 85−87 °C; R_f 0.47 (PE−EtOAc, 9:1); FTIR (film) ν_{max} 3119, 3100, 3075, 3045, 2983, 2935, 1732, 1617, 1584, 1537, 1481, 1395, 1370, 1354, 1232, 1153, 851; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.45 (s, 9H), 4.01 (s, 2H), 7.75−7.76 (m, 1H), 7.84−7.87 (m, 1H), 8.14−8.17 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 27.9, 40.8, 82.6, 125.5, 126.3 (quin, J = 4.7 Hz), 130.9 (quin, J = 4.7 Hz), 131.5, 150.2, 155.9−156.5 (m), 167.9; ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.2 (dm, 4F, J = 150.8 Hz), 80.0−81.6 (m, 1F); MS (EI) m/z 290 (22), 262 (22), 241 (7), 89 (11), 57 (100), 56 (18), 41 (47). Anal. Calcd for $C_{12}H_{14}F_5NO_4S$: C, 39.67; H, 3.88; N, 3.86. Found: C, 39.91; H, 3.90; N, 3.65.

4d: pale yellow solid (83%); mp 75−77 °C; R_f 0.10 (PE−EtOAc, 49:1); FTIR (film) ν_{max} 3121, 3073, 3044, 3012, 2960, 1751, 1614, 1584, 1540, 1354, 1169, 840; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.85 (s, 3H), 6.10 (s, 1H), 7.97−8.00 (m, 1H), 8.17−8.21 (m, 1H), 8.37−8.39 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 53.8, 54.1, 125.6, 127.9 (quin, J = 4.7 Hz), 129.3 (quin, J = 4.9 Hz), 131.9, 148.7, 156.7 (quin, J = 19.6 Hz), 167.0; ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.1 (dm, 4F, J = 150.8 Hz), 79.2−80.8 (m, 1F); MS (EI) m/z 309 (14), 296 (23), 261 (37), 246 (35), 230 (16), 217 (16), 140 (14), 123 (22), 107 (17), 89 (27), 75 (34), 59 (100). Anal. Calcd for $C_9H_7ClF_5NO_4S$: C, 30.39; H, 1.98; N, 3.94. Found: C, 30.62; H, 2.15; N, 3.69.

4e: pale yellow oil (9%); R_f 0.15 (PE−EtOAc, 49:1); FTIR (film) ν_{max} 3119, 3042, 2956, 2925, 2854, 1742, 1614, 1582, 1537, 1359, 1176, 835; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.66 (d, 3H, J = 7.2 Hz), 3.70 (s, 3H), 4.33 (q, 1H, J = 7.2 Hz), 7.82−7.85 (m, 1H), 7.90 (m, 1H), 7.99−8.01 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 17.7, 41.3, 52.6, 125.2, 126.1 (quin, J = 4.7 Hz), 128.0 (quin, J = 4.7 Hz), 136.1, 150.3, 155.8−157.0 (m), 172.5; ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.0 (dm, 4F, J = 150.7 Hz), 80.0−81.6 (m, 1F); MS (EI) m/z 316 (5), 304 (13), 290 (12), 289 (100), 276 (63), 260 (18), 259 (17), 246 (11), 231 (20), 230 (16), 133 (27), 102 (27), 93 (20), 89 (23), 77 (27); HRMS (ESI$^-$) m/z calcd for $C_{10}H_9F_5NO_4S$ $[M - H]^-$ 334.01724, found 334.01738.

4f: pale yellow oil (84%); R_f 0.47 (PE−EtOAc, 1:1); FTIR (film) ν_{max} 3115, 3070, 3039, 2988, 2935, 2912, 1614,1583,1482, 1539, 1358, 1253, 1052,1027, 851; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.27 (dt, 6H, J = 7.1, 0.5 Hz), 3.76 (d, 2H, J = 23.0 Hz), 4.03−4.12 (m, 4H), 7.59−7.65 (m, 1H), 7.91−7.96 (m, 1H), 8.36−8.38 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.2 (d, J = 5.9 Hz), 30.6 (d, J = 136.9 Hz), 62.7 (d, J = 6.6 Hz), 125.6 (d, J = 2.9 Hz), 125.7−126.0 (m), 129.0 (d, J_{CP} = 10.3 Hz), 130.8−131.1 (m), 150.3−150.5 (m), 155.4−156.0 (m); ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.5 (dm, 4F, J = 151.4 Hz), 79.9−81.5 (m, 1F); ^{31}P NMR (162 MHz, $CDCl_3$) δ 22.0 (s); MS (EI) m/z 354 (19), 353 (54), 326 (16), 325 (15), 313 (18), 297 (100), 233 (17), 233 (17), 218 (14), 119 (11), 109 (55), 91 (20), 81 (36); HRMS (ESI) m/z calcd for $C_{11}H_{16}F_5NO_5PS$ $[M + H]^+$ 400.04015, found 400.03968.

4g: pale yellow oil (74%); R_f 0.15 (PE−EtOAc, 9:1); FTIR (film) ν_{max} 3121, 3078, 3049, 2255, 1618, 1587, 1538, 1353, 1122, 911, 835; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.25 (s, 2H), 7.98−8.00 (m, 1H), 8.10−8.11 (m, 1H), 8.27−8.30 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 22.6, 115.3, 126.4, 127.0, 127.7 (quin, J = 4.7 Hz), 129.2 (quin, J = 4.8 Hz), 148.7, 156.8 (quin, J = 20.0 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.2 (dm, 4F, J = 150.9 Hz), 78.9−80.5 (m, 1F); MS (EI) m/z 269 (14), 261 (100), 144 (20), 134 (26), 114 (36), 107 (50), 89 (39); HRMS (EI) m/z calcd for $C_8H_5F_5N_2O_2S$ $[M]^+$ 287.9992, found 288.0005.

4h: pale yellow oil (74%); R_f 0.50 (PE−EtOAc, 9:1); FTIR (film) ν_{max} 3116, 3070, 1613, 1585, 1542, 1351, 1315, 1210, 1191, 1070, 923, 841; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 (s, 1H), 7.95−7.98 (m, 1H), 8.09−8.11 (m, 1H), 8.57−8.58 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 64.7, 125.4, 128.2 (quin, J = 4.9 Hz), 128.6 (quin, J = 4.6 Hz), 135.9, 146.5, 157.0 (quin, J = 20.5 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.0 (dm, 4F, J = 151.2 Hz), 78.8−80.4 (m, 1F); MS (EI) m/z 314 (3), 312 (4), 298 (7), 296 (16), 261 (15), 260 (100), 230 (26), 123 (18), 75 (16); HRMS (EI) m/z calcd for $C_7H_4Cl_2F_4NO_2S$ $[M - F]^+$ 311.9276, found 311.9268.

4i: pale yellow oil (74%); R_f 0.72 (PE−EtOAc, 9:1); FTIR (film) ν_{max} 3113, 3068, 2927, 2874, 1611, 1584, 1538, 1477, 1350, 1312, 1144, 1120, 1068, 922, 855; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 (s, 1H), 7.89−7.92 (m, 1H), 8.01−8.04 (m, 1H), 8.62−8.63 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 32.1, 125.1, 128.2 (quin, J = 4.7 Hz), 130.8 (quin, J = 4.9 Hz), 137.3, 145.2, 157.0 (quin, J = 20.0 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.0 (dm, 4F, J = 151.1 Hz), 78.9−80.5 (m, 1F); MS (EI) m/z 342 (47), 340 (46), 262 (10), 261 (100), 245 (7), 230 (11), 215 (9), 205 (11), 186 (8), 174 (7), 169 (8), 109 (26), 107 (32), 103 (13), 95 (18), 89 (27), 88 (21), 87 (22), 86 (16), 78 (34), 76 (19), 75 (40); HRMS (CI) m/z calcd for $C_7H_5Br_2F_5NO_2S$ $[M + H]^+$ 419.8328, found 419.8320.

5a and **6a**. **5a**: pale yellow solid (90%); mp 173−175 °C; R_f 0.15 (PE−EtOAc, 4:1); FTIR (film) ν_{max} 3107, 3062, 3042, 2958, 2924, 1615, 1576, 1538, 1348, 1324, 1151, 839; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.98 (s, 2H), 7.53−7.57 (m, 2H), 7.63−7.66 (m, 1H), 7.68−7.72 (m, 1H), 7.75−7.77 (m, 2H), 7.99−8.01 (m, 1H), 8.39−8.40 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 58.1, 123.6 (quin, J = 4.9 Hz), 126.8, 128.3, 129.5, 130.3 (quin, J = 4.6 Hz), 134.6, 134.9, 137.9, 148.9, 154.0 (quin, J = 20.6 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.3 (dm, 4F, J = 151.2 Hz), 79.1−80.7 (m, 1F); MS (EI) m/z 263 (10), 262 (97), 245 (17), 244 (5), 141 (60), 89 (11), 78 (11), 77 (100); HRMS (CI) m/z calcd for $C_{13}H_{11}F_5NO_4S_2$ $[M + H]^+$ 404.0050, found 404.0059. **6a**: pale yellow solid (4%); mp 157−160 °C; R_f 0.23 (PE−EtOAc, 4:1); FTIR (film) ν_{max} 3107, 2970, 1605, 1586, 1525, 1353, 1320, 1305, 1151, 1085, 856, 837, 821, 805; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.78 (s, 2H), 7.53−7.58 (m, 2H), 7.68−7.76 (m, 3H), 8.16−8.18 (m, 1H), 8.42−8.44 (m, 1H), 8.68−8.69 (m, 1H); ^{13}C NMR (150.9 MHz, $CDCl_3$) δ 59.9 (quin, J = 3.0 Hz), 124.1 (quin, J = 5.4 Hz), 125.8, 128.3, 129.5, 131.6, 134.6, 135.0, 138.6, 147.4, 154.2 (quin, J = 18.4 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ 67.8 (dm, 4F, J = 150.6 Hz), 81.3−82.9 (m, 1F); MS (EI) m/z 403 $[M]^+$ (4), 281 (14), 207 (50), 141 (100), 108 (17), 107 (19), 96 (17), 89 (28), 77 (89); HRMS (EI) m/z calcd for $C_{13}H_{10}F_5NO_4S_2$ $[M]^+$ 402.9971, found 402.9977.

5c and **6c**: pale yellow solid (94%, **5c**:**6c** = 94:6); R_f 0.29 (PE−EtOAc, 9:1); FTIR (film) ν_{max} 3122, 3107, 2983, 2936, 1733, 1617, 1575, 1539, 1395, 1370, 1352, 1153, 851. Anal. Calcd for $C_{12}H_{14}F_5NO_4S$: C, 39.67; H, 3.88; N, 3.86. Found: C, 39.98; H, 3.93; N, 3.61. **5c**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.45 (s, 9H), 4.02 (s, 2H), 7.48−7.51 (m, 1H), 7.95−7.97 (m, 1H), 8.50−8.51 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 27.9, 40.6, 82.6, 123.3 (quin, J = 4.8 Hz), 130.3 (quin, J = 4.6 Hz), 133.8, 134.1, 148.5, 152.4−153.2 (m), 168.0; ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.4 (dm, 4F, J = 151.0 Hz), 80.0−81.6 (m, 1F); MS (EI) m/z 290 (25), 262 (21), 261 (24), 246 (12), 89 (14), 63 (13), 57 (100). **6c**: ^{19}F NMR (376 MHz, $CDCl_3$) δ 66.1 (dm, 4F, J = 149.4 Hz), 81.9−83.4 (m, 1F).

5d: pale yellow oil (79%); R_f 0.06 (PE−EtOAc, 46:1); FTIR (film) ν_{max} 3122, 3049, 3011, 2960, 1751, 1615, 1575, 1542, 1439, 1351, 1168, 835; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.85 (s, 3H), 6.14 (s, 1H), 8.11−8.17 (m, 2H), 8.49−8.50 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 53.8, 54.2, 123.1 (quin, J = 4.9 Hz), 130.9 (quin, J = 4.6 Hz), 132.1, 134.2, 147.1, 153.7 (quin, J = 20.8 Hz), 167.1; ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.3 (dm, 4F, J = 151.0 Hz), 79.1−80.7 (m, 1F); MS (EI) m/z 336 (10), 324 (9), 309 (18), 296 (21), 261 (34), 260 (20), 246 (29), 230 (16), 217 (16), 204 (13), 123 (25), 108 (16), 107 (17), 89 (28), 75 (34), 59 (100); HRMS (CI) m/z calcd for $C_9H_8ClF_5NO_4S$ $[M + H]^+$: 355.9783, found 355.9789.

5f and **6f**: pale yellow solid (73%, **5f**:**6f** = 95:5); R_f 0.26 (PE−EtOAc, 1:1); FTIR (film) ν_{max} 3120, 3102, 3045, 2988, 2935, 2911, 1613, 1574, 1541, 1488, 1355, 1254, 1053, 1027, 850; MS (EI) m/z 380 (6), 354 (19), 353 (54), 326 (16), 325 (15), 297 (100), 245 (11), 109 (46), 91 (18), 89 (14), 81 (35); HRMS (ESI) m/z calcd for $C_{11}H_{15}F_5NNaO_5PS$ $[M + Na]^+$ 422.02209, found 422.02185. **5f**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.26 (dt, 6H, J = 7.1, 0.5 Hz), 3.74 (d, 2H, J = 23.0 Hz),

dx.doi.org/10.1021/jo200618p | J. Org. Chem. 2011, 76, 4781–4786

4.03−4.15 (m, 4H), 7.81−7.84 (m, 1H), 7.91−7.96 (m, 1H), 8.36−8.38 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.2 (d, J = 5.9 Hz), 30.6 (d, J = 136.9 Hz), 62.7 (d, J = 6.6 Hz), 123.2−123.4 (m), 129.7−130.0 (m), 131.6−131.7 (m), 133.6−133.7 (m), 148.6−148.7 (m), 152.1−152.6 (m); ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.5 (dm, 4F, J = 151.4 Hz), 79.9−81.7 (m, 1F); ^{31}P NMR ($CDCl_3$) δ 22.2 (s). **6f**: ^{19}F NMR (376 MHz, $CDCl_3$) δ 67.2 (dm, 4F, J = 149.1 Hz), 82.0−83.7 (m, 1F); ^{31}P NMR ($CDCl_3$) δ 22.6 (s).

5g and **6g**: pale yellow oil (73%, **5g**:**6g** = 85:15); R_f 0.13 (PE−EtOAc, 93:7); FTIR (film) ν_{max} 3124, 3106, 3052, 2255, 1618, 1574, 1540, 1353, 903, 849; HRMS (EI) m/z calcd for $C_8H_5F_5N_2O_2S$ $[M]^+$ 287.9992, found 287.9979. **5g**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.30 (s, 2H), 7.93−7.96 (m, 1H), 8.11−8.14 (m, 1H), 8.59−8.60 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 22.6, 115.3, 123.9 (quin, J = 4.9 Hz), 129.5, 131.4 (quin, J = 4.6 Hz), 131.9, 147.1, 153.7 (quin, J = 20.4 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.4 (dm, 4F, J = 151.2 Hz), 79.0−80.6 (m, 1F); MS (EI) m/z 269 (16), 261 (100), 205 (19), 134 (49), 114 (38), 107 (42), 89 (35), 88 (26). **6g**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.24 (s, 2H), 8.00−8.02 (m, 1H), 8.45−8.47 (m, 1H), 8.75−8.76 (m, 1H); ^{19}F NMR (376 MHz, $CDCl_3$) δ 65.8 (dm, 4F, J = 149.1 Hz), 80.7−82.3 (m, 1F).

5h: colorless oil (91%); R_f 0.30 (PE); FTIR (film) ν_{max} 3120, 3062, 1613, 1574, 1544, 1350, 1201, 1123, 910, 854, 820; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.57 (s, 1H), 8.13−8.16 (m, 1H), 8.34−8.36 (m, 1H), 8.41−8.42 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 64.6, 123.0 (quin, J = 5.0 Hz), 130.9, 131.3 (quin, J = 4.6 Hz), 138.0, 144.9, 154.3 (quin, J = 20.0 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.3 (dm, 4F, J = 151.4 Hz), 78.7−80.3 (m, 1F); MS (EI) m/z 314 (3), 312 (4), 298 (5), 296 (13), 261 (14), 260 (100), 230 (25), 123 (17), 75 (14); HRMS (EI) m/z calcd for $C_7H_4Cl_2F_4NO_2S$ $[M - F]^+$ 311.9276, found 311.9265.

5i: pale yellow solid (84%); mp 39−41 °C; R_f 0.11 (PE); FTIR (film) ν_{max} 3116, 3085, 3065, 2926, 2876, 1610, 1573, 1539, 1485, 1349, 1121, 853; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (s, 1H), 8.09−8.12 (m, 1H), 8.34−8.35 (m, 1H), 8.38−8.41 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 32.1, 122.7 (quin, J = 5.0 Hz), 131.3 (quin, J = 4.6 Hz), 135.5, 139.3, 143.7, 153.9 (quin, J = 20.4 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.3 (dm, 4F, J = 151.4 Hz), 78.8−80.4 (m, 1F); MS (EI) m/z 342 (43), 340 (42), 314 (38), 312 (52), 262 (12), 261 (100), 205 (26), 109 (21), 107 (34), 103 (14), 95 (19), 89 (26), 88 (29), 87 (24), 86 (19), 78 (26), 76 (23), 75 (37); HRMS (CI) m/z calcd for $C_7H_5Br_2F_5NO_2S$ $[M + H]^+$ 419.8328, found 419.8318.

General Procedure for the Synthesis of Compounds 7 and 8.

To a solution of **1** or **2** (1.0 mmol) and **3** (1.0 mmol) in DMF (1.5 mL) was added dropwise a solution of *t*-BuOK (3.0 mmol) in DMF (3.0 mL) at an appropriate temperature. Alkyl halide (2.0 mmol) was added after a given time; the reaction mixture was warmed to rt during 10 min and stirred for 30 min followed by workup similar to that for compounds **4**−**6**.

7b: colorless liquid (59%); R_f 0.25 (PE−EtOAc, 9:1); FTIR (film) ν_{max} 3116, 3091, 3067, 3032, 2985, 2939, 1733, 1613, 1584, 1537, 1497, 1356, 1164, 855; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.15 (t, 3H, J = 7.1 Hz), 3.20 (dd, 1H, J = 13.7, 7.6 Hz), 3.51 (dd, 1H, J = 13.7, 7.6 Hz), 4.12 (q, 2H, J = 7.1 Hz), 4.47 (t, 1H, J = 7.6 Hz), 7.08−7.10 (m, 2H), 7.19−7.25 (m, 3H), 7.58−7.79 (m, 1H), 7.86−7.87 (m, 1H), 7.89−7.91 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.8, 39.0, 48.8, 61.7, 125.0, 126.0 (quin, J = 4.6 Hz), 126.9, 128.6, 128.8 (quin, J = 4.7 Hz), 128.9, 134.1, 137.3, 150.5, 155.6−156.1 (m), 170.9; ^{19}F NMR (470.4 MHz, $CDCl_3$) δ 62.0 (dm, 4F, J = 150.8 Hz), 80.1−81.4 (m, 1F); MS (EI) m/z 380 (4), 361 (7), 334 (21), 318 (7), 306 (7), 246 (52), 178 (9), 107 (12), 105 (14), 91 (100); HRMS (CI) m/z calcd for $C_{17}H_{17}F_5NO_4S$ $[M + H]^+$ 426.0798, found 426.0783.

7g: pale yellow liquid (57%); R_f 0.48 (PE−EtOAc, 9:1); FTIR (film) ν_{max} 3117, 3100, 3076, 3046, 2994, 2947, 2248, 1615, 1600, 1586, 1539, 1356, 835; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.77 (d, 3H, J = 7.1 Hz), 4.75 (q, 1H, J = 7.1 Hz), 7.93−7.96 (m, 1H), 8.13−8.17 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.9, 28.2, 119.5, 126.2, 127,5 (quin, J = 4.7 Hz), 127.6 (quin, J = 4.8 Hz), 133.4, 148.7, 156.7−157.3; ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.1 (dm, 4F, J = 151.0 Hz), 78.9−80.5 (m, 1F); MS (EI) m/z 275 (100), 260 (27), 230 (20), 158 (17), 129 (30), 118 (42), 109 (26), 102 (39), 101 (35), 89 (45), 75 (37); HRMS (CI) m/z calcd for $C_9H_7F_5N_2O_2S$ $[M + H]^+$ 303.0227, found 303.0224.

8a: pale yellow oil (84%); R_f 0.26 (PE−EtOAc, 9:1); FTIR (film) ν_{max} 3120, 3095, 3070, 2987, 1643, 1610, 1573, 1540, 1448, 1353, 1324, 1310, 1151, 1085, 899, 851; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.92−3.00 (m, 1H), 3.10−3.17 (m, 1H), 5.00−5.08 (m, 2H), 5.45−5.58 (m, 2H), 7.48−7.53 (m, 2H), 7.65−7.69 (m, 3H), 7.95−7.97 (m, 1H), 8.02−8.05 (m, 1H), 8.17−8.18 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 32.5, 62.5, 119.8, 122.9 (quin, J = 4.9 Hz), 128.7, 129.4, 129.8 (quin, J = 4.6 Hz), 130.6, 131.1, 131.4, 134.5, 136.8, 150.3, 153.4 (quin, J = 20.2 Hz); ^{19}F NMR (470.4 MHz, $CDCl_3$) δ 62.3 (dm, 4F, J = 151.2 Hz), 79.4−80.6 (m, 1F); MS (EI) m/z 302 (100), 272 (68), 256 (23), 245 (13), 175 (12), 128 (26), 77 (40); HRMS (CI) m/z calcd for $C_{16}H_{15}F_5NO_4S_2$ $[M + H]^+$ 444.0363, found 444.0373.

9c. A suspension of Raney nickel (100 mg) was washed with ethanol (3 × 10 mL). Ethanol (10 mL) and **4c** (130 mg, 0.36 mmol) were added, a balloon filled with hydrogen was attached, and the mixture was stirred at rt for 4 h, followed by filtration, washing with hot THF (3 × 5 mL), and concentration of filtrate under reduced pressure. The resulting residue contained pure **9c** (116 mg, 97%) as a white solid: R_f 0.36 (PE−EtOAc, 4:1); mp 83 °C; FTIR (film) ν_{max} 3479, 3381, 3255, 2993, 2920, 2851, 1710, 1640, 1603, 1502, 1394, 1372, 1336, 1325, 1137, 920, 852, 832; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.43 (s, 9H), 3.47 (s, 2H), 4.47 (br s, 2H), 6.62−6.67 (m, 1H), 7.41−7.44 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 27.9, 39.9, 82.0, 114.8, 118.8, 126.2 (quin, J = 4.6 Hz), 128.2 (quin, J = 4.6 Hz), 144.2−144.8 (m), 148.3, 170.3; ^{19}F NMR (376 MHz, $CDCl_3$) δ 64.2 (dm, 4F, J = 150.3 Hz), 86.2−87.9 (m, 1F); MS (EI) m/z 333 $[M]^+$ (14), 278 (10), 277 (100), 260 (44), 259 (68), 233 (19), 231 (15), 230 (22), 104 (26), 77 (12), 57 (74). Anal. Calcd for $C_{12}H_{16}F_5NO_2S$: C, 43.22; H, 4.84; N, 4.20. Found: C, 43.09; H, 4.77; N, 4.07.

9f. Pd/C (10%, 70 mg) was added to a solution of **4f** (570 mg, 1.43 mmol) in THF (20 mL). A balloon filled with hydrogen was attached, and the mixture was stirred at rt for 15 h, followed by filtration, washing with hot THF (3 × 5 mL), and concentration of filtrate under reduced pressure. Chromatography purification (silica gel, EtOAc) gave **9f** (406 mg, 77%) as a pale yellow liquid: R_f 0.36 (EtOAc); FTIR (film) ν_{max} 3355, 3245, 2988, 2934, 2911, 1647, 1602, 1580, 1503, 1230, 1053, 1029, 838, 806; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.25 (t, 6H, J = 7.1 Hz), 3.11 (d, 2H, J = 21.0 Hz), 3.99−4.09 (m, 4H), 4.72 (br s, 2H), 6.65−6.69 (m, 1H), 7.40−7.47 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.2 (d, J = 5.9 Hz), 30.8 (d, J = 139.8 Hz), 62.8 (d, J = 7.3 Hz), 115.5−115.6 (m), 116.3−116.6 (m), 125.9−126.2 (m), 129.1−129.4 (m), 148.8−148.9 (m), 164.6−164.7 (m); ^{19}F NMR (376 MHz, $CDCl_3$) δ 64.1 (dm, 4F, J = 150.3 Hz), 88.0−87.8 (m, 1F); ^{31}P NMR (162 MHz, $CDCl_3$) δ 26.7 (s); MS (EI) m/z 370 (10), 369 (76), 341 (11), 295 (31), 246 (16), 241 (19), 233 (20), 232 (100), 185 (23), 168 (19), 104 (25); HRMS (ESI) m/z calcd for $C_{11}H_{17}F_5NNaO_3PS$ $[M + Na]^+$ 392.04791, found 392.04773.

10a. Prepared according to **9c** from **5a** in 15 h giving **10a** (79%) as a white solid: R_f 0.30 (PE−EtOAc, 3:2); mp (subl) 250 °C; FTIR (KBr) ν_{max} 3468, 3386, 3235, 3100, 3068, 2988, 2934, 1635, 1606, 1580, 1499, 1288, 1151, 1083, 937, 835; ^{1}H NMR (400 MHz, DMSO-d_6) δ 4.68 (s, 2H), 5.71 (s, 2H), 6.88−6.91 (m, 1H), 7.01−7.04 (m, 1H), 7.10−7.11 (m, 1H), 7.59−7.63 (m, 2H), 7.72−7.76 (m, 1H), 7.82−7.84 (m, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 56.0, 111.6, 111.9, 114.7, 128.0, 129.0, 133.2, 133.8, 138.7, 148.7, 153.6−154.0 (m); ^{19}F NMR (470.4 MHz, DMSO-d_6) δ 63.9 (dm, 4F, J = 150.1 Hz), 88.1−89.7 (m, 1F); MS (EI) m/z 373 $[M]^+$ (7), 232 (100), 124 (21), 104 (8), 77 (11); HRMS (EI) m/z calcd for $C_{13}H_{12}F_5NO_2S_2$ $[M]^+$ 273.0230, found 373.0225.

dx.doi.org/10.1021/jo200618p |*J. Org. Chem.* 2011, 76, 4781–4786

11f. Aqueous HCl (35%, 1.9 mL) was added to **9f** (68 mg, 0.17 mmol), and the mixture was stirred for 10 min at rt before it was cooled to −10 °C. Aqueous H_3PO_2 (50%, 1.8 mL) was added followed by the addition of $NaNO_2$ (64 mg, 0.92 mmol) in water (0.6 mL). The mixture was warmed to rt during 1.5 h, water (10 mL) was added, and the product was extracted into Et_2O (4 × 10 mL), dried, and concentrated under reduced pressure. The resulting residue was purified by flash column chromatograpy to give **11f** (43 mg, 72%) as a pale yellow liquid: R_f 0.30 (EtOAc); FTIR (film) ν_{max} 3073, 2987, 2914, 1606, 1541, 1486, 1441, 1393, 1249, 1055, 1030, 845; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.26 (t, 6H, J = 7.1 Hz), 3.21 (d, 2H, J = 21.7 Hz), 4.01−4.10 (m, 4H), 7.38−7.50 (m, 2H), 7.62−7.71 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.2 (d, J = 5.9 Hz), 33.7 (d, J = 139.0 Hz), 62.4 (d, J = 6.6 Hz), 124.3−124.6 (m), 127.0−127.3 (m), 128.7−128.9 (m), 132.8−133.0 (m), 132.8−133.0 (m), 153.7−154.2 (m); ^{19}F NMR (376 MHz, $CDCl_3$) δ 62.2 (dm, 4F, J = 149.2 Hz), 83.0−84.7 (m, 1F); ^{31}P NMR (162 MHz, $CDCl_3$) δ 24.7 (s); MS (EI) m/z 333 (14), 278 (10), 277 (100), 260 (44), 259 (72), 233 (78), 231 (15), 230 (25), 104 (27), 77 (13), 57 (71); HRMS (ESI) m/z calcd for $C_{11}H_{16}F_5NaO_3PS$ $[M + Na]^+$ 377.03701, found 377.03697.

12a. Prepared according to **11f** from **10a** (66 mg, 0.18 mmol) and $NaNO_2$ (37 mg, 0.53 mmol) giving **12a** (65%) as a white solid: R_f 0.26 (PE−EtOAc, 4:1); mp (subl) 207 °C; FTIR (film) ν_{max} 3058, 1599, 1583, 1494, 1309, 1153, 834; ^{1}H NMR (400 MHz, DMSO-d_6) δ 4.83 (s, 2H), 7.40−7.42 (m, 2H), 7.59−7.63 (m, 2H), 7.71−7.78 (m, 3H), 7.82−7.84 (m, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 59.5, 125.6 (quin, J = 4.6 Hz), 127.8, 129.0, 131.7, 133.2, 133.8, 138.1, 152.2−152.8; ^{19}F NMR (376 MHz, DMSO-d_6) δ 64.3 (dm, 4F, J = 150.6 Hz), 86.3−87.9 (m, 1F); MS (EI) m/z 217 (100), 109 (29), 89 (11), 77 (13); HRMS (ESI^-) m/z calcd for $C_{13}H_{10}F_5O_2S_2$ $[M - H]^-$ 357.00462, found 357.00479.

■ ASSOCIATED CONTENT

Supporting Information. copies of ^{1}H, ^{13}C, ^{19}F, and ^{31}P NMR spectra of newly synthesized products. This material is available free of charge via the Internet at http://pubs.acs.org.

■ AUTHOR INFORMATION

Corresponding Author
beier@uochb.cas.cz

■ ACKNOWLEDGMENT

Support for this work from the Academy of Sciences of the Czech Republic (Research Plan AVZ40550506) is gratefully acknowledged.

■ REFERENCES

(1) For reviews, see: (a) Kirsch, P. *Modern Fluoroorganic Chemistry*; Wiley-VCH: Weinheim, 2004; pp 146−156. (b) Winter, R. W.; Dodean, R. A.; Gard, G. L. In *ACS Symposium Series, 911: Fluorine-Containing Synthons*; Soloshonok, V. A., Ed.; American Chemical Society: Washington, DC, 2005; pp 87−118. (c) Kirsch, P.; Röschenthaler, G. V. In *ACS Symposium Series, 949: Current Fluoroorganic Chemistry*; Soloshonok, V. A., Mikami, K., Yamazaki, T., Welch, J. T., Honek, J. F., Eds.; American Chemical Society: Washington, DC, 2007; pp 221−243.

(2) (a) Crowley, P. J.; Mitchell, G.; Salmon, R.; Worthington, P. A. *Chimia* **2004**, *58*, 138–142. (b) Kirsch, P.; Bremer, M.; Heckmeier, M.; Tarumi, K. *Angew. Chem., Int. Ed.* **1999**, *38*, 1989–1992. (c) Stump, B.; Eberle, C.; Schweizer, W. B.; Kaiser, M.; Brun, R.; Krauth-Siegel, R. L.; Lentz, D.; Diederich, F. *ChemBioChem* **2009**, *10*, 79–83.

(3) (a) Bowden, R. D.; Greenhall, M. P.; Moilliet, J. S.; Thomson, J. US 5741935, 1997, and WO 9705106, 1997. (b) Bowden, R. D.; Comina, P. J.; Greenhall, M. P.; Kariuki, B. M.; Loveday, A.; Philp, D. *Tetrahedron* **2000**, *56*, 3399–3408. (c) Chambers, R. D.; Spink, R. C. H. *Chem. Commun.* **1999**, 883–884.

(4) Umemoto, T. WO 2008/118787, 2008.

(5) (a) Sipyagin, A. M.; Bateman, C. P.; Tan, Y.-T.; Thrasher, J. S. *J. Fluorine Chem.* **2001**, *112*, 287–295. (b) Sipyagin, A. M.; Enshov, V. S.; Kashtanov, S. A.; Bateman, C. P.; Mullen, B. D.; Tan, Y.-T.; Thrasher, J. S. *J. Fluorine Chem.* **2004**, *125*, 1305–1316.

(6) Sheppard, W. A. *J. Am. Chem. Soc.* **1962**, *84*, 3064–3072.

(7) Beier, P.; Pastýříková, T.; Vida, N.; Iakobson, G. *Org. Lett.* **2011**, *13*, 1466–1469.

(8) For reviews, see: (a) Makosza, M.; Winiarski, J. *Acc. Chem. Res.* **1987**, *20*, 282–289. (b) Makosza, M.; Wojciechowski, K. *Liebig Ann. Chem.* **1997**, 1805–1816. (c) Makosza, M. *Chem. Soc. Rev.* **2010**, *39*, 2855–2868.

(9) (a) Blazej, S.; Makosza, M. *Chem.—Eur. J.* **2008**, *14*, 11113–11122. (b) Makosza, M.; Golinski, J.; Baran, J. *J. Org. Chem.* **1984**, *49*, 1488–1494.

(10) Makosza, M.; Sienkiewicz, K.; Wojciechowski, K. *Synthesis* **1990**, 850–852.

(11) Mudryk, B.; Makosza, M. *Synthesis* **1988**, 1007–1009.

(12) Makosza, M.; Owczarczyk, Z. *J. Org. Chem.* **1989**, *54*, 5094–5100.

(13) Zarantonello, C.; Guerrato, A.; Ugel, E.; Bertani, R.; Benerollo, F.; Milani, R.; Venzo, A.; Zaggia, A. *J. Fluorine Chem.* **2007**, *128*, 1449–1453.

(14) Lawrence, N. J.; Liddle, J.; Jackson, D. A. *Synlett* **1996**, 55–56.