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One-pot syntheses of 1,2,3-triazoles containing a pentafluorosulfanylalkyl group via click chemistry

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ABSTRACT

1,4-Disubstituted 1,2,3-triazoles containing a pentafluorosulfanylalkyl group were synthesized in good to excellent yields (57–91%) by the click cycloadditions of in situ generated SF_5-alkyl azides with aromatic and aliphatic alkynes. Nucleophilic substitution of the SF_5 group was observed for the first time in a bench-top reaction.

Fluorine-containing compounds have attracted extensive attention due to the unique properties of fluorine (high electronegativity, low polarizability, relative small size) which induce modifications of physical properties for these compounds and make them suitable for use in life and material sciences.[1] Profiting from various methods for introduction of fluorine atoms onto carbon, fluorine-containing compounds with C–F bonds have dominated fluorine chemistry. However, the pentafluorosulfanyl group (SF_5) has a higher dielectric constant and electron-withdrawing ability than the trifluoromethyl (CF_3) group which may introduce unique properties into organic compounds that include low surface energy, high chemical resistance, high thermal stability, high electronegativity, and hydrophobicity.[2] As an attractive analog of the CF_3 group, SF_5-containing compounds are of value in the fields of pharmaceutical chemistry,[3] polymer sciences,[4] explosive studies,[5] and electronic applications.[6] The synthetic methodologies for the introduction of pentafluorosulfanyl groups into organic compounds have been extensively developed by Gard,[4,7] but there are still only a limited number of key SF_5-containing building blocks available. Recently, the commercial availability of arylpentafluorosulfanyl compounds such as 4-nitro-pentafluorosulfanylbenzene[8] which are prepared by direct fluorination methods facilitated the exploration of utilities of SF_5-containing compounds in medicinal and material sciences.[3,9]

Heterocycles, where the SF_5 group is directly attached to the ring, are a class of more intriguing compounds that would have potential bioactivity and could be used as intermediates to construct more complex molecules of interest.[10] Based on this opportunity, syntheses of heterocyclic compounds bearing the SF_5 group such as pyrrole[11] and furans[12] have been reported. As part of our wider interest in development of high dense nitrogen-containing compounds as potential energetic materials, we have reported new thermally stable pentafluorosulfanyl propanyl-substituted quaternary salts,[5c] SF_5-substituted pyrazoles,[5b] and 1,2,3-triazoles[5b] where the presence of the pentafluorosulfanyl group increased density remarkably and as a result enhanced the detonation performance of the energetic materials relative to most of their perfluoroalkyl or alkyl analogs. In continuation, we now report the syntheses of 1,4-disubstituted 1,2,3-triazole derivatives which are connected to a pentafluorosulfanyl group through a short alkyl spacer (C_2, C_3) by using click chemistry of 1-azido-2(3)-pentafluorosulfanylethane (propane) with alkynes. In contrast to the heterocyclic compounds bearing a SF_5 group on the ring directly, the short spacer would properly insulate the strong electron-withdrawing effect of SF_5 group and retain the inherent properties of the heterocycle to a greater extent.

The advent of the Cu(I)-catalyzed ligation of organic azides and alkynes has improved selectivity and has enjoyed many applications of so-called 'click chemistry' in synthesis, medicinal chemistry, molecular biology, and material science.[13] Exclusive regioselectivity, wide substrate scope, mild reaction conditions, and high yields have made it the method of choice for selective preparation of 1,4-disubstituted-1,2,3-triazoles.[14] Practically, we chose the Cu(I)-catalyzed cycloaddition reaction for the preparation of SF_5-ethyl and SF_5-propanyl triazoles and the catalyst was

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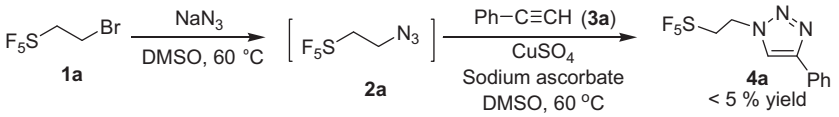
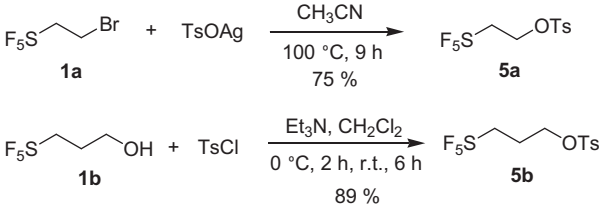


Scheme 1.

generated in situ by reduction of $CuSO_4{\cdot}5H_2O$, since this method was less costly and was reported to give more pure material than some Cu(I) salts that were commercially available. The isolation of SF_5-ethyl azide **2** could be hazardous due to its low boiling point and high nitrogen content. Therefore, the commercially available SF_5-ethylbromide **1a** was treated in DMSO with sodium azide at 60 °C for 12 h to generate SF_5-ethyl azide **2** in situ and then phenylacetylene, copper sulfate, and sodium ascorbate were added. The mixture was stirred for 18 h at 60 °C (Scheme 1), but only a trace of the desired product **4a** was isolated which presumably was caused by the low conversion of the first step. Considering that tosylate is a better substrate for nucleophilic substitution reaction, SF_5-ethyl tosylate **5a** was then synthesized by treatment of silver tosylate with **1a** based on the literature method (Scheme 2).[15] SF_5-propyl tosylate **5b** was also prepared from SF_5-propanol **1b** and *p*-$CH_3C_6H_4SO_2Cl$ (*p*-TsCl) by using triethylamine as a base in 89% yield (Scheme 2).[16]

With tosylates in hand, the one-pot preparation of 1,4-disubstituted 1,2,3-triazole was carried out again by treating tosylate **5a** with sodium azide (1.2 equiv) in DMSO at 60 °C for 12 h followed by the addition of phenylacetylene (1.2 equiv) and catalyst (10 mmol %). After stirring for 18 h at 60 °C, 1-(2'-pentafluorosulfanylethyl)-4-phenyl-1*H*-[1,2,3]-triazole **4a** was isolated in 80% yield as an exclusive product in two-steps (Table 1, entry 1).[17] Under the same reaction conditions, tosylate **5b** also gave the desired triazole



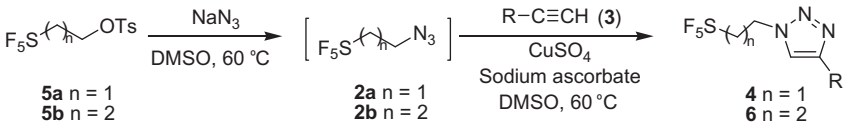
Scheme 2.

6a in 81% yield (Table 1, entry 2). When the method was extended to a series of aromatic and aliphatic alkynes, regioselective triazoles were obtained exclusively in good to excellent yields (57–91%) (Table 1).[18] Normally, slightly higher yields were achieved for the reaction starting from **5b** rather than that of **5a** with the same alkyne. It is noteworthy that the reaction gave rise to 1-(2'-pentafluorosulfanylethyl)-1*H*-[1,2,3]-triazole **4e** with concomitant desilylation when trimethylsilylacetylene was involved (Table 1, entry 9). In an attempt to reduce the reaction time, reaction temperature was increased from 60 °C to 80 °C for the substitution reaction of tosylate **5b** with sodium azide followed by the addition of 3,3,3-trifluoropropyne **3f** and catalyst.

Surprisingly, the bistriazole product **8a** was obtained in 10% yield in addition to the desired product **6f**. It is likely that displacement of the SF_5 group by the azido group occurred to form the diazide intermediate **7** via nucleophilic attack at the carbon atom under the higher reaction temperature conditions. Usually, the leaving ability of a group in a nucleophilic substitution reaction is related to its basicity. The SF_5 group would be considered a weak base due to its highly polarized S–F bonds which make it a good leaving group.[19] Bistriazole **8b** was isolated in 60% yield in two-steps when the reaction was carried out by using three equivalents of sodium azide at 80 °C which indicated that the SF_5 group was completely substituted by an azido group (Scheme 3).[20] This first observation of nucleophilic substitution of the SF_5 group in a bench-top reaction may not be as practical as an application in synthetic chemistry due to the inconvenient incorporation of SF_5 group into an organic compound, but it leads to better understanding of the functional characteristics of this group.

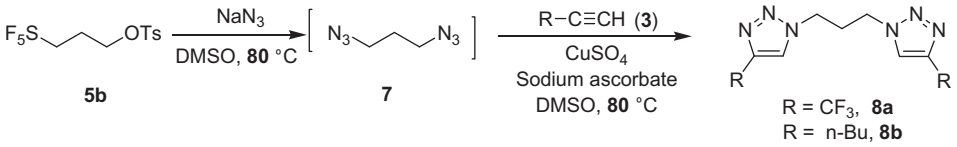
In summary, the click chemistry of in situ generated 1-azido-2(3)-pentafluorosulfanylethane (propane) with aliphatic or aromatic alkynes gave rise to 1,4-disubstituted 1,2,3-triazoles in good yields. The result that the SF_5 group is active for nucleophilic substitution suggests that compounds containing the SF_5 group may be able to degrade by nucleophilic attack in the environment which makes them more environmentally benign.

Table 1
One-pot preparation of 1,4-disubstituted 1,2,3-triazole via click chemistry



Entry	R	1,2,3-Triazole (**4**)	Yield[a] (%)
1	Ph	**4a**	80
2	Ph	**6a**	81
3	4-F–C_6H_4	**4b**	78
4	4-F–C_6H_4	**6b**	91
5	4-^{t}Bu–C_6H_4	**4c**	57
6	4-^{t}Bu–C_6H_4	**6c**	61
7	^{n}Bu	**4d**	73
8	^{n}Bu	**6d**	76
9	Me_3Si	**4e**	72
10	Me_3Si	**6e**	68
11	CF_3	**4f**	65
12	CF_3	**6f**	86

[a] Isolated yields in two-steps.



Scheme 3.

Acknowledgments

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References and notes

1. (a) Hiyama, T.; Kanie, K.; Kusumoto, T.; Morizawa, Y.; Shimizu, M. *Organofluorine Compounds*; Springer: Berlin-Heidelberg, 2000; (b)*Organofluorine Chemistry*; Chambers, R. D., Ed.; Springer: Berlin, 1997; (c) Dolbier, W. R., Jr. *J. Fluorine Chem.* **2005**, *126*, 157–163; (d) Thayer, A. M. *Chem. Eng. News* **2006**, *84*, 15–24.
2. (a) Dolbier, W. R., Jr. *Chim. Oggi* **2003**, *21*, 66–69; (b) Verma, R. D.; Kirchmeier, R. L.; Shreeve, J. M. *Adv. Inorg. Chem.* **1994**, *41*, 125–169.
3. (a) Lim, D. S.; Choi, J. S.; Pak, C. S.; Welch, J. T. *J. Pestic. Sci.* **2007**, *32*, 255–259; (b) Mo, T.; Mi, X.; Milner, E. E.; Dowc, G. S.; Wipf, P. *Tetrahedron Lett.* **2010**, *51*, 5137–5140; (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.
4. (a) Winter, R.; Nixon, P. G.; Terjeson, R. J.; Mohtasham, J.; Holcomb, N. R.; Grainger, D. W.; Granham, D.; Castner, D. G.; Gard, G. L. *J. Fluorine Chem.* **2002**, *115*, 107–113; (b) Nixon, P. G.; Winter, R.; Castner, D. G.; Holcomb, R.; Grainger, D. W.; Gard, G. L. *Chem. Mater.* **2000**, *12*, 3108–3112; (c) Winter, R.; Nixon, P. G.; Gard, G. L.; Castner, D. G.; Holcomb, R.; Hu, Y.-H.; Grainger, D. W. *Chem. Mater.* **1999**, *11*, 3044–3049.
5. (a) Sitzmann, M. E.; Gilardi, R.; Butcher, R. J.; Koppes, W. M.; Stern, A. G.; Thrasher, J. S.; Trivedi, N. J.; Yang, Z.-Y. *Inorg. Chem.* **2000**, *39*, 843–850; (b) Ye, C.; Gard, G. L.; Winter, R. W.; Syvret, R. G.; Twamley, B.; Shreeve, J. M. *Org. Lett.* **2007**, *9*, 3841–3844; (c) Gao, H.; Ye, C.; Winter, R. W.; Gard, G. L.; Sitzmann, M. E.; Shreeve, J. M. *Eur. J. Inorg. Chem.* **2006**, 3221–3226.
6. (a) Geiser, U.; Schlueter, J. A.; Wang, H. H.; Kini, A. M.; Sche, P. P.; Zakowicz, H. I.; Van Zile, M. L.; Dudek, J. D.; Williams, J. M.; Renn, J.; Whangbo, M. H.; Nixon, P. G.; Winter, R. W.; Gard, G. L. *J. Am. Chem. Soc.* **1996**, *118*, 9996–9997; (b) Schlueter, J. A.; Ward, B. H.; Geiser, U.; Wang, H. H.; Kini, A. M.; Parakka, J. P.; Morales, E.; Koo, H. J.; Whangbo, M. H.; Winter, R. W.; Mohtasham, J.; Gard, G. L. *J. Mater. Chem.* **2001**, *11*, 2008–2013; (c) Clair, T. L.; Clair, A. K.; Thrasher, J. S. US 5220070, 1993; *Chem. Abstr*. **1993**, *117*, 470558.
7. (a) Gard, G. L. *Chim. Oggi* **2009**, *27*, 10–13; (b) Winter, R.; Gard, G. L. *J. Fluorine Chem.* **2007**, *128*, 896–901.
8. (a) Bowden, R. D.; Greenhall, M. P.; Moilliet, J. S.; Thomson, J. WO 9705106, 1997; *Chem. Abstr*. **1997**, *126*, 205251.; (b) Bowden, R. D.; Comina, P. J.; Greenhall, M. P.; Kariuki, B. M.; Loveday, A.; Philp, D. *Tetrahedron* **2000**, *56*, 3399–3408; (c) Umemoto, T. US 7592491, 2008; *Chem. Abstr*. **2008**, *149*, 1155217.
9. Welch, J. T.; Lim, D. S. *Bioorg. Med. Chem.* **2007**, *15*, 6659–6666.
10. (a) Billen, D.; Boyle, J.; Critcher, D. J.; Gethin, D. M.; Hall, K. T.; Kyne, G. M. (Pfizer Ltd) US 20070149464, 2007; *Chem. Abstr*. **2007**, *147*, 703939.; (b) Billen, D.; Boyle, J.; Critcher, D. J.; Gethin, D. M.; Hall, K. T.; Kyne, G. M. (Pfizer Ltd) US 20080146643, 2008; *Chem. Abstr*. **2008**, *149*, 79598.
11. Dolbier, W. R., Jr.; Zheng, Z. *J. Org. Chem.* **2009**, *74*, 5626–5628.
12. Dolbier, W. R., Jr.; Mitani, A.; Xu, W.; Ghiviriga, I. *Org. Lett.* **2006**, *8*, 5573–5575.
13. Wu, P.; Fokin, V. V. *Aldrichim. Acta* **2007**, *40*, 7–17. and references cited therein.
14. (a) Hein, J. E.; Fokin, V. V. *Chem. Soc. Rev.* **2010**, *39*, 1302–1315; (b) Spiteri, C.; Moses, J. E. *Angew. Chem., Int. Ed.* **2010**, *49*, 31–33; (c) Nandivada, H.; Jiang, X.; Lahann, J. *Adv. Mater.* **2007**, *19*, 2197–2208.
15. Winter, R. W.; Gard, G. L. *J. Fluorine Chem.* **2006**, *127*, 1188–1194.
16. Wessel, J.; Kleemann, G.; Seppelt, K. *Chem. Ber.* **1983**, *116*, 2399–2407.
17. General procedure for the preparation of triazoles. A solution of tosylate **5** (1.0 mmol) and sodium azide (1.2 mmol) in DMSO (5 mL) was stirred at 60 °C for 8 h in a sealed Schlenk tube. After cooling to room temperature, the tube was immersed in liquid nitrogen, and $CuSO_4{\cdot}5H_2O$ (10 mmol%, 25 mg), sodium ascorbic acid (10 mmol%, 19 mg), and the corresponding alkyne **3** (1.2 mmol) were added successively. The mixture was allowed to warm to room temperature and stirred at 60 °C for 18 h in a sealed Schlenk tube. The reaction mixture was diluted with water (30 mL), extracted with diethyl ether (20 mL × 3). The combined organic layer was dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The residue was purified by flash chromatography (silica gel, hexane/ether/2:1–1:1) or by recrystallization from chloroform/hexane.
18. Selected data: **4a**, ^{1}H NMR δ 7.81–7.84 (m, 3H), 7.39–7.43 (m, 3H), 4.92 (t, J = 7.0 Hz, 2H), 4.28–4.33 (m, 2H) ppm. ^{13}C NMR δ 149.0, 130.9, 129.8, 129.4, 126.7, 121.0, 69.9, 46.7 ppm. ^{19}F NMR δ 82.2 (quin, J = 146.5 Hz, 1F), 66.3 (d, J = 145.7 Hz, 4F) ppm. IR (KBr) ν 3084, 3047, 1479, 1460, 1439, 1386, 1233, 1080, 1049, 1024, 869, 825, 764, 696, 615 cm^{-1}. MS (EI) m/z 299 (7, [M]$^+$), 271 (5), 144 (27), 145 (25), 116 (100), 102 (6), 89 (39), 77 (7), 40 (38). Anal. Calcd for $C_{10}H_{10}F_5N_3S$ (MW 299.26): C, 40.13; H, 3.37; N, 14.04. Found: C, 40.34; H, 3.30; N, 13.85. Compound **6a**, ^{1}H NMR δ 7.83–7.87 (m, 2H), 7.79 (s, 1H), 7.37–7.41 (m, 3H), 4.54 (t, J = 6.4 Hz, 2H), 3.78–3.83 (m, 2H), 2.60–2.64 (m, 2H) ppm. ^{13}C NMR δ 149.1, 131.1, 129.8, 129.3, 126.6, 120.6, 69.3, 49.0, 28.0 ppm. ^{19}F NMR δ 84.1 (quin, J = 145.2 Hz, 1F), 65.2 (d, J = 145,0 Hz, 4F) ppm. IR (KBr) ν 3119, 3093, 3038, 2976, 1467, 1438, 1225, 1198, 1080, 877, 810, 768, 692 cm^{-1}. MS (EI) m/z 314 (23, [M+1]$^+$), 313 (21, [M]$^+$), 285 (12), 186 (11), 144 (27), 130 (63), 116 (100), 103 (31), 89 (51), 41 (74). Anal. Calcd for $C_{11}H_{12}F_5N_3S$ (MW 313.29) C, 42.17; H, 3.86; N, 13.41; Found: C, 42.34; H, 3.79; N, 13.05. **4b**, ^{1}H NMR δ 7.80–7.84 (m, 3H), 7.13–7.18 (m, 2H), 4.91 (t, J = 7.0 Hz, 2H), 4.29–4.32 (m, 2H) ppm. ^{13}C NMR δ 165.4, 162.1, 148.1, 128.5, 127.1, 120.8, 116.9, 116.7, 69.9, 46.8 ppm. ^{19}F NMR δ 82.2 (quin, J = 146.1 Hz, 1F), 66.1 (d, J = 144,0 Hz, 4F), −112.9 (s, 1F) ppm. IR (KBr) ν 3093, 2970,1613, 1562, 1499, 1458, 1229, 1081, 886, 833, 628, 565 cm^{-1}. MS (EI) m/z 317 (6, [M]$^+$), 289 (2), 162 (30), 134 (100), 107 (27), 89 (5), 57 (10), 40 (42). Anal. Calcd for $C_{10}H_9F_6N_3S$ (MW 317.25) C, 37.86; H, 2.86; N, 13.24; Found: C, 38.15; H, 2.74; N, 13.00. **6b**, ^{1}H NMR δ 7.80–7.84 (m, 2H), 7.75 (s, 1H), 7.12–7.16 (m, 2H), 4.54 (t, J = 6.6 Hz, 2H), 3.73–3.81 (m, 2H), 2.62–2.67 (m, 2H) ppm. ^{13}C NMR δ 165.3, 128.4, 120.4, 116.9, 116.6, 69.2, 49.0, 27.9 ppm. ^{19}F NMR δ 84.0 (quin, J = 148.3 Hz, 1F), 65.2 (d, J = 144,0 Hz, 4F), −113.1 (s, 1F) ppm. IR (KBr) ν 3101, 2978,1610, 1561, 1499, 1461, 1225, 1089, 902, 828, 631, 524 cm^{-1}. MS (EI) m/z 331 (21, [M]$^+$), 303 (15), 204 (11), 174 (7), 148 (57), 134 (100), 121 (34), 107 (43), 41 (68). Anal. Calcd for $C_{11}H_{11}F_6N_3S$ (MW 331.28) C, 39.88; H, 3.35; N, 12.68; Found: C, 40.16; H, 3.37; N, 12.72. **4c**, ^{1}H NMR δ 7.81 (s, 1H), 7.77 (d, J = 7.5 Hz, 2H), 7.49 (d, J = 7.5 Hz, 2H), 4.91 (t, J = 7.0 Hz, 2H), 4.27–4.32 (m, 2H), 1.37 (s, 9H) ppm. ^{13}C NMR δ 152.6, 149.0, 128.1, 126.7, 126.4, 120.7, 70.0, 46.7, 35.6, 32.1 ppm. ^{19}F NMR δ 82.3 (quin, J = 149.2 Hz, 1F), 66.4 (d, J = 147.2 Hz, 4F) ppm. IR (KBr) ν 3101, 2967, 2872, 1495, 1459, 1366, 1228, 1200, 1079, 869, 823, 623, 559 cm^{-1}. MS (EI) m/z 355 (18, [M]$^+$), 356 (6, [M+1]$^+$), 312 (41), 172 (23), 157 (46), 144 (83), 129 (25), 57 (100). Anal. Calcd for $C_{14}H_{18}F_5N_3S$ (MW 355.37) C, 47.32; H, 5.11; N, 11.82; Found: C, 47.35; H, 5.11; N, 11.79. **6c**, ^{1}H NMR δ 7.77–7.81 (m, 3H), 7.45–7.50 (m, 2H), 4.52 (t, J = 6.6 Hz, 2H), 3.72–3.77 (m, 2H), 2.61 (quint, J = 7.1 Hz, 2H), 1.37 (s, 9H) ppm. ^{13}C NMR δ 151.1, 147.7, 127.0, 125.3, 125.0, 119.1, 68.0, 47.6, 34.2, 30.8, 26.6 ppm. ^{19}F NMR δ 84.2 (quin, J = 145.2 Hz, 1F), 65.2 (d, J = 145.0 Hz, 4F) ppm. IR (KBr) ν 3112, 2973, 2876, 1497, 1464, 1439, 1359, 1223, 1196, 1067, 1046, 873, 849, 815, 620 cm^{-1}. MS (EI) m/z 370 (4, [M+1]$^+$), 369 (21, [M]$^+$), 341 (10), 326 (92), 284 (10), 242 (13), 198 (16), 158 (54), 115 (43), 57 (71), 41 (100). Anal. Calcd for $C_{15}H_{20}F_5N_3S$ (MW 369.40) C, 48.77; H, 5.46; N, 11.38; Found: C, 48.38; H, 5.36; N, 11.56. **4d**, ^{1}H NMR δ 7.34 (s, 1H), 4.82 (t, J = 7.0 Hz, 2H), 4.20–4.23 (m, 2H), 2.73 (t, J = 7.7 Hz, 2H), 1.65–1.67 (m, 2H), 1.39–1.42 (m, 2H), 0.95 (t, J = 7.3 Hz, 3H) ppm. ^{13}C NMR δ 149.7, 122.0, 70.0, 46.3, 32.3, 26.1, 23.1, 14.6 ppm. ^{19}F NMR δ 82.3 (quin, J = 146.3 Hz, 1F), 66.3 (d, J = 145.7 Hz, 4F) ppm. IR (KBr) ν 3119, 3065, 2958, 2930, 2857, 1557, 1454, 1421, 1312, 1222, 1140, 1059, 932, 883, 833, 808, 553 cm^{-1}. MS (EI) m/z 280 (10, [M+1]$^+$), 236 (19), 237 (16), 222 (7), 208 (25), 108 (13), 96 (21), 54 (100), 41 (70). Anal. Calcd for $C_8H_{14}F_5N_3S$ (MW 279.27) C, 34.41; H, 5.05; N, 15.05; Found: C, 34.23; H, 4.92; N, 14.80. **6d**, ^{1}H NMR δ 7.29 (s, 1H), 4.45 (t, J = 6.6 Hz, 2H), 3.68–3.72 (m, 2H), 2.74 (t, J = 7.7 Hz, 2H), 2.53–2.58 (m, 2H), 1.65–1.69 (m, 2H), 1.38–1.41 (m, 2H), 0.96 (t, J = 7.3 Hz, 2H) ppm. ^{13}C NMR δ 148.5, 120.3, 68.0, 47.3, 31.0, 26.7, 24.8, 21.8, 13.3 ppm. ^{19}F NMR δ 84.2 (quin, J = 145.1 Hz, 1F), 65.0 (d, J = 145.0 Hz, 4F) ppm. IR (KBr) ν 3117, 3063, 2962, 2928, 2860, 1557, 1459, 1368, 1219, 1179, 1137, 1055, 903, 844, 821, 633 cm^{-1}. MS (EI) m/z 294 (1, [M+1]$^+$), 293 (2, [M]$^+$), 251 (8), 222 (7), 166 (9), 110 (23), 96 (19), 80 (16), 61 (29), 54 (73), 41 (100). Anal. Calcd for $C_4H_6F_5N_3S$ (MW 293.30) C, 36.86; H, 5.50; N, 14.33; Found: C, 36.87; H, 5.47; N, 14.80. **4e**, ^{1}H NMR δ 7.75 (s, 1H), 7.65 (s, 1H), 4.91 (t, J = 7.0 Hz, 2H), 4.26–4.31 (m, 2H) ppm. ^{13}C NMR δ 134.9, 125.0, 69.9, 46.5 ppm. ^{19}F NMR δ 82.2 (quin, J = 146.4 Hz, 1F), 66.2 (d, J = 147.1 Hz, 4F) ppm. IR (KBr) ν 3130, 3019, 2972, 1468, 1390, 1299, 1263, 1224, 1121, 1087, 1032, 825, 642, 596 cm^{-1}. MS (EI) m/z 224 (5, [M+1]$^+$), 223 (16, [M]$^+$), 195 (10), 135 (4), 127 (13), 89 (16), 72 (6), 59 (8), 47 (39), 41 (100), 40 (97). Anal. Calcd for $C_4H_6F_5N_3S$ (MW 223.17) C, 21.53; H, 2.71; N, 18.83; Found: C, 21.65; H, 2.63; N, 18.66. **4f**, ^{1}H NMR δ 7.95 (s, 1H), 4.94 (t, J = 6.7 Hz, 2H), 4.30–4.34 (m, 2H) ppm. ^{13}C NMR δ 124.8, 122.8, 119.2, 69.4, 47.3 ppm. ^{19}F NMR δ 81.6 (quin, J = 146.4 Hz, 1F), 66.3 (d, J = 146.0 Hz, 4F), −61.3 (s, 3F) ppm. IR (KBr) ν 3081, 1577, 1386, 1227, 1167, 1055, 997, 866, 833, 744, 621 cm^{-1}. MS (EI) m/z 291 (17, [M]$^+$), 272 (3), 182 (2), 140 (10), 127 (43), 108 (39), 89 (42), 75 (16), 69 (28), 47 (100). Anal. Calcd for $C_5H_5F_8N_3S$ (MW 291.17): C, 20.63; H, 1.73; N, 14.43. Found: C, 20.63; H, 1.58; N, 14.26. Compound **6f**, ^{1}H NMR δ 7.93 (s, 1H), 4.58 (t, J = 6.8 Hz, 2H), 3.74–3.79 (m, 2H), 2.62–2.65 (m, 2H) ppm. ^{13}C NMR δ 124.3, 122.9, 119.3, 68.9,

49.5, 27.8 ppm. ^{19}F NMR δ 83.7 (quin, J = 145.1 Hz, 1F), 65.2 (d, J = 145.2 Hz, 4F), −61.1 (s, 3F) ppm. IR (KBr) ν 3146, 3111, 2982, 1571, 1467, 1389, 1265, 1224, 1145, 1052, 996, 861, 777, 617 cm^{-1}. MS (EI) m/z 305 (3, [M]$^+$), 286 (3), 196 (2), 178 (11), 150 (43), 127 (4), 122 (13), 89(9), 41 (100). Anal. Calcd for $C_6H_7F_8N_3S$ (MW 305.19): C, 23.61; H, 2.31; N, 13.77. Found: C, 23.70; H, 2.25; N, 13.66.

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20. Compound **8b**, ^{1}H NMR δ 7.36 (s, 2H), 4.34 (t, J = 6.4 Hz, 4H), 2.74 (t, J = 7.7 Hz, 4H), 2.52–2.57 (m, 2H), 1.66–1.79 (m, 4H), 1.39–1.42 (m, 4H), 0.96 (t, J = 7.3 Hz, 6H) ppm. ^{13}C NMR δ 148.7, 121.3, 46.5, 31.5, 30.7, 25.3, 22.3, 13.8 ppm. IR (KBr) ν 3131, 3080, 2955, 2926, 2861, 1691, 1555, 1460, 1217, 1147, 1055, 830 cm^{-1}. MS (EI) m/z 291(3, [M+1]$^+$), 290 (2, [M]$^+$), 234 (12), 166 (96), 139 (21), 124 (21), 68 (32), 41 (100). Anal. Calcd for $C_{15}H_{26}N_6$ (MW 290.41): C, 62.04; H, 9.02; N, 28.94. Found: C, 61.90; H, 9.00; N, 27.99.