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Determination of pK_a values of fluoroalkanesulfonamides and investigation of their nucleophilicity

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ABSTRACT

The pK_a values of a series of fluoroalkanesulfonylamides were measured by potentiometric titration. Different kinds of alkyl halides and tosylates were employed to investigate the nucleophilicity of fluoroalkanesulfonylamides. Fluoroalkanesulfonylamides with longer fluoroalkyl chain have weaker nucleophilicity.

1. Introduction

Since the discovery of Prontosil in 1932, a great deal of benzenesulfonylamides have been synthesized and found effective for the treatment of bacterial infections [1]. Common alkanesulfonylamides, however, found little application in the pharmaceutical or agrochemical area at that time [1]. When fluorine was introduced into these common alkanesulfonylamides, their biological activity was satisfactorily improved [1–4]. For example, Trepka and Moore found that fluorinated *N*-phenylalkanesulfonylamides showed potent herbicidal and anti-inflammatory activities in 1970s [2–4]. Lu recently reported that *N*-alkylfluoroalkanesulfonylamides were environment-friendly insecticides [5]. The introduction of fluorine atoms conferred them high acidity and lipophilicity, resulting in their unique bioactivity. Fluoroalkanesulfonylamides also have special physical and chemical properties. Addition of fluorine atoms to aryl-substituted fluoroalkanesulfonylamides gave a linear acidity increase of 1.47 pK_a units per fluorine and an excellent correlation of partition coefficient in a second-order equation [6]. In the reaction between perfluoroalkanesulfonylamides and perfluoroalkanesulfonyl fluorides or perfluoroalkanesulfonyl chlorides, bis(perfluoroalkanesulfonyl)imides was successfully synthesized [7]. Perfluoroalkanesulfonylamides reacting with sulfonyl chloride could generate *N*-sulfinylperfluoroalkanesulfonylamides which were very important intermediates [8,9]. *N*,*N*-Dichlorofluoroalkanesulfonylamides, another kind of reactive species, could be conveniently synthesized by the reaction of fluoroalkanesulfonylamides with aqueous KOH and chlorine gas [10]. Transformation of perfluoroalkanesulfonylamides to the corresponding R_fSO_2NHK by solid potassium hydroxide in 1,2-dimethoxyethane, the nucleophilicity was increased strongly enough to react with CS_2 and RX forming (*S*,*S*)-dialkyl *N*-(perfluoroalkylsulfonyl)carbodithioimidates [11]. *N*,*N*-Dialkylfluoroalkanesulfonylamides were obtained as undesired products with aqueous KOH using DMF as the solvent in the same reaction [11]. However, nature of the reaction was still unknown. To the best of our knowledge, efforts to investigate the details of the nucleophilicity and acidity of fluoroalkanesulfonylamides as well as the compatibility of fluoroalkanesulfonylamides with different kinds of electrophiles have not already been made till now. Therefore, it is important and meaningful to gain more insight into the acidity and nucleophilicity of fluoroalkanesulfonamides, even though some nucleophilic reactions of perfluoroalkanesulfonylamides have been reported [12]. Herein, we report the results.

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2. Results and discussion

Fluoroalkanesulfonylamides could be conveniently synthesized by using fluoroalkanesulfonyl fluorides as starting materials [5,13]. **1a–c** and **1e–g** were favorably obtained in high yield when fluoroalkanesulfonyl fluorides reacted with liquid ammonia at a temperature below −60 °C (entries 1–3 and 5–7, Table 1). Treatment of **1c** with NaOH in methanol, **1d** was satisfactorily formed according to our previous work [14]. $FO_2S(CF_2)_2O(CF_2)_2SO_2F$ reacted with liquid ammonia, giving **1h** in 97% yield (entry 8). Meanwhile, **1i** was generated from $FO_2S(CF_2)_2O(CF_2)_4O(CF_2)_2SO_2F$ in the same reaction condition (entry 9).

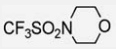
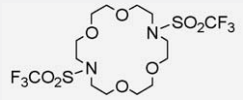
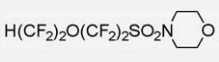
There are several methods for the determination of pK_a value [15]. Among them, potentiometric titration has been the standard method for pK_a measurement due to its accuracy and reproducibility [16]. Furthermore, most fluorinated compounds are often water-insoluble and have unfavorable molar absorption coeffi-

Table 1
Preparation of fluoroalkylsulfonamides and their pK_a values.
$RfSO_2 + NH_3$ (liquid) $\xrightarrow{<-60\,^\circ C}$ $\xrightarrow{acid}$ $RfSO_2NH_{2\,1a-i}$.

Entry	$RfSO_2NH_2$	Yield[a] (%)	pK_{a1}[b]	pK_{a2}[b]
1[c]	$CF_3SO_2NH_2$	80 (**1a**)	6.28	9.37
2	$Cl(CF_2)_2SO_2NH_2$	88 (**1b**)	6.17	7.82
3	$I(CF_2)_2O(CF_2)_2SO_2NH_2$	92 (**1c**)	6.22	7.80
4[d]	$H(CF_2)_2O(CF_2)_2SO_2NH_2$	87 (**1d**)	5.83	7.75
5	$I(CF_2)_4O(CF_2)_2SO_2NH_2$	94 (**1e**)	5.70	7.66
6	$I(CF_2)_6O(CF_2)_2SO_2NH_2$	93 (**1f**)	4.22	7.57
7	$Cl(CF_2)_6O(CF_2)_2SO_2NH_2$	98 (**1g**)	5.74	7.56
8[c]	$H_2NO_2S(CF_2)_2O(CF_2)_2SO_2NH_2$	97 (**1h**)	5.67	7.92
9	$H_2NO_2S(CF_2)_2O(CF_2)_4O(CF_2)_2SO_2NH_2$	94 (**1i**)	5.90	7.80

[a] Isolated yield.
[b] The pK_a values were determined in MeOH using KOH as the base and METTLER TOLEDO T70 3.0.0 as potentiometric titrator.
[c] **1a** and **1h** are water soluble.
[d] **1d** was prepared from the hydrodehalogenation of **1c** [14].

Table 2
Nucleophilicity of the fluoroalkanesulfonylamides.
$RfSO_2 + RX \xrightarrow[THF,Temperature]{K_2CO_3} RfSO_2NR_2$.

Entry	$RfSO_2NH_2$	RX[a]	$RfSO_2NR_2$	Conditions (temperature, time)	Yield[b] (%)
1[c]	**1a**	CH_3I	$CF_3SO_2N(CH_3)_2$	Reflux, 14 h	100 (**2aa**)
2	**1a**	C_2H_5I	$CF_3SO_2N(C_2H_5)_2$	Reflux, 22 h	90 (**2ab**)
3[c]	**1a**	n-C_3H_7Br	CF_3SO_2NH(n-C_3H_7) CF_3SO_2N(n-$C_3H_7)_2$	90 °C, 2 d	33 (**2ac**) 57 (**2ad**)
4[c]	**1a**	n-C_4H_9I	CF_3SO_2NH(n-C_4H_9) CF_3SO_2N(n-$C_4H_9)_2$	90 °C, 2 d	15 (**2ae**) 85 (**2af**)
5[c]	**1a**	n-C_4H_9Br	CF_3SO_2NH(n-C_4H_9) CF_3SO_2N(n-$C_4H_9)_2$	90 °C, 2 d	28 (**2ae**) 66 (**2af**)
6[c]	**1a**	n-C_4H_9Cl	–	90 °C, 2 d	–
7[d]	**1a**	$PhCH_2Br$	$CF_3SO_2NHCH_2C_6H_5$ $CF_3SO_2N(CH_2C_6H_5)_2$	Reflux, 22 h	6 (**2ag**) 29 (**2ah**)
8	**1a**	$PhCH_2Br$	$CF_3SO_2N(CH_2C_6H_5)_2$	Reflux, 22 h	86 (**2ah**)
9	**1a**	$Ts(OCH_2CH_2)_2OH$	$CF_3SO_2N[(CH_2CH_2O)_2H]_2$	Reflux, 2 d	71 (**2ai**)
10	**1a**	$Ts(OCH_2CH_2)_3OH$	$CF_3SO_2N[(CH_2CH_2O)_3H]_2$	Reflux, 2 d	68 (**2aj**)
11[c]	**1a**	$Ts(OCH_2CH_2)_2OTs$		Reflux, 21 h	75 (**2ak**)
12	**1a**	$Ts(OCH_2CH_2)_3OTs$		90 °C, 6d	9 (**2al**)
13	**1d**	CH_3I	$H(CF_2)_2O(CF_2)_2SO_2N(CH_3)_2$	Reflux, 19 h	88 (**2da**)
14	**1d**	C_2H_5I	$H(CF_2)_2O(CF_2)_2SO_2N(C_2H_5)_2$	Reflux, 2 d	89 (**2db**)
15	**1d**	n-C_3H_7Br	$H(CF_2)_2O(CF_2)_2SO_2NH$(n-C_3H_7) $H(CF_2)_2O(CF_2)_2SO_2N$(n-$C_3H_7)_2$	90 °C, 3 d	37 (**2dc**) 41 (**2dd**)
16	**1d**	n-C_4H_9I	$H(CF_2)_2O(CF_2)_2SO_2NH$(n-C_4H_9) $H(CF_2)_2O(CF_2)_2SO_2N$(n-$C_4H_9)_2$	90 °C, 2 d	43 (**2de**) 45 (**2df**)
17	**1d**	$PhCH_2Br$	$H(CF_2)_2O(CF_2)_2SO_2N(CH_2C_6H_5)_2$	Reflux, 17 h	88 (**2dg**)
18	**1d**	CH_2=$CHCH_2Br$	$H(CF_2)_2O(CF_2)_2SO_2N(CH_2CH$=$CH_2)_2$	Reflux, 31 h	75 (**2dh**)
19[c]	**1d**	$Ts(OCH_2CH_2)_2OTs$		Reflux, 2 d	87 (**2di**)
20	**1h**	CH_3I	$(CH_3)_2NO_2S(CF_2)_2O(CF_2)_2SO_2N(CH_3)_2$	Reflux, 18 h	35 (**2ha**)
21	**1h**	C_2H_5I	$(C_2H_5)_2NO_2S(CF_2)_2O(CF_2)_2SO_2N(C_2H_5)_2$	90 °C, 31 h	26 (**2hb**)
22	**1h**	CH_2=$CHCH_2Br$	$(CH_2$=$CHCH_2)_2NO_2S(CF_2)_2O(CF_2)_2SO_2N(CH_2CH$=$CH_2)_2$	90 °C, 31 h	31 (**2hc**)
23	**1h**	$PhCH_2Br$	$(C_6H_5CH_2)_2NO_2S(CF_2)_2O(CF_2)_2SO_2N(CH_2C_6H_5)_2$	Reflux, 3 d	28 (**2hd**)
24	**1i**	CH_3I	$(CH_3)_2NO_2S[(CF_2)_2O(CF_2)_2]_2SO_2N(CH_3)_2$	Reflux, 18 h	30 (**2ia**)
25	**1i**	C_2H_5I	$(C_2H_5)_2NO_2S[(CF_2)_2O(CF_2)_2]_2SO_2N(C_2H_5)_2$	90 °C, 33 h	27 (**2ib**)
26	**1i**	CH_2=$CHCH_2Br$	$(CH_2$=$CHCH_2)_2NO_2S[(CF_2)_2O(CF_2)_2]_2SO_2N(CH_2CH$=$CH_2)_2$	90 °C, 31 h	31 (**2ic**)
27	**1i**	$PhCH_2Br$	$(C_6H_5CH_2)_2NO_2S[(CF_2)_2O(CF_2)_2]_2SO_2N(CH_2C_6H_5)_2$	Reflux, 2 d	86 (**2id**)

[a] The molar ratio of $RfSO_2NH_2$ to RX was about 1:2.2.
[b] Isolated yield.
[c] The yields of the products were determined by ^{19}F NMR.
[d] The molar ratio of **1a** to $PhCH_2Br$ was 1:1.1.

cients [17]. Therefore, potentiometric titration was employed for the pK_a determination of **1a**–**1i**. The results are shown in Table 1. In the cases of **1c**, **1e** and **1f**, the titration must be conducted in darkness to avoid the hydrodehalogenation [14]. Elongation of the fluoroalkyl chain led to a gentle decrease of pK_{a1} and pK_{a2} (entries 1 and 2, entries 3, 5 and 6). The pK_{a1} difference (1.48) between **1e** and **1f** was larger than that (0.52) between **1c** and **1e** (entries 3, 5 and 6). It seems that the halogen bonding interaction between iodine and negative ion of nitrogen in RfNHK (**1f**) played important role in stabilizing the anion, which apparently decreased the pK_a value [18]. Replacement of iodine with hydrogen in **1c** resulted in increase of the acidity (**1d**), which was very close to **1e** (entries 4 and 5). This was indicated that the hydrogen bonding interaction between the hydrogen atom and the negative ion greatly stabilized the anion, which further decreased the pK_a value of product. Substitution of the terminal iodine (**1f**) with chlorine (**1g**) increased the pK_{a1} value by 1.52. But little difference was found in their pK_{a2} values (entries 6 and 7). Comparing the pK_a value of **1h** and **1i** with **1d** and **1e**, no significant difference was observed in either their pK_{a1} or pK_{a2} values (entries 8 and 9), indicating that the introduction of another sulfonylamide group into fluoroalkanesulfonylamides had little influence on their acidity.

Generally, the pK_a values of fluoroalkanesulfonamides are lower than the non-fluorinated analogues, thus leading to their weaker nucleophilicity. Although the *N*-substituted fluoroalkanesulfonylamides could be synthesized from the reaction of fluoroalkanesulfonyl fluorides and the corresponding substituted amines, most of the amines are not commercially available, thus making the procedure not much versatile. Therefore, it is interesting to investigate the nucleophilic substitution of fluoroalkanesulfonylamides.

As shown in Table 2, the nucleophilic reactions of fluoroalkanesulfonylamides were much influenced by the electrophilicity of the electrophiles. Strong electrophilic alkyl halides favored the alkylation reaction. For example, treatment of **1a** with methyl iodide and K_2CO_3 in refluxing THF for 14 h gave the dimethylated product, **2aa**, in 100% yield (entry 1). Replacing methyl iodide with ethyl iodide under the same condition, however, longer reaction time was necessary for complete conversion (entry 2). Taking n-C_3H_7Br or n-C_4H_9I instead of ethyl iodide as the electrophile, the reaction became more difficult and time consuming (entries 3 and 4). Higher temperature was needed for completion of the reaction. Mono- and di-substitution occurred simultaneously while increasing the temperature to 90 °C. Similar results were obtained in the reaction between **1a** and n-C_4H_9Br (entry 5). No reaction happened in the case of n-C_4H_9Cl (entry 6). The electrophilicity of the alkyl halides also has influence on the ratio of the products. Lower yield of di-substituted product **2af** was formed when n-C_4H_9Br was used as compared with n-C_4H_9I (entries 4 and 5). Nevertheless, the formation of the di-substituted fluoroalkanesulfonylamides was still dominant. The di-substitution was accelerated by the first alkylation. It was proposed that the electron donating effect of the first alkyl group on the N atom improved its nucleophilicity, thus resulting in the favorable formation of di-substituted ones. In addition, the yield was obviously affected by the reactant ratio. The dibenzylated product **2ah** was obtained in 86% yield when 2.2 equivalent of $PhCH_2Br$ was used. However, only 6% yield of monobenzylated product **2ag** and 29% yield of **2ah** were formed when 1.1 equivalent of $PhCH_2Br$ was employed under the same condition (entries 7 and 8). Di-substituted fluoroalkanesulfonylamide was also the main product even in the presence of insufficient of benzyl bromide (entry 8).

Similar results were obtained when tosylates were used as electrophiles (entries 9 and 10). It is worth noting that intramolecular cyclization happened preferentially in the reaction of **1a** with di(ethylene glycol) di-*p*-tosylate, even 2.2 equivalent of tosylate $Ts(OCH_2CH_2)_2OTs$ was used (entry 11). While in the case of tri(ethylene glycol) di-*p*-tosylate, $Ts(OCH_2CH_2)_3OTs$, only 9% yield of intermolecular cyclization product **2al** was formed (entry 12). It seems that the chelating interaction between potassium cations and azacrown ether was inhibited by the strong electron withdrawing effect of trifluoromethanesulfonyl group on N atoms, thus leading to no template effects of potassium cation on the ring closing procedure [19].

The length of fluoroalkyl chain not only affects the pK_a value of the fluoroalkanesulfonamides as aforementioned but also influences their nucleophilicity. As compared with trifluoromethanesulfonamide **1a**, longer reaction time was required for 1,1,2,2-tetrafluoro-2-(1,1,2,2-tetrafluoroethoxy)ethanesulfonamide **1d** to achieve the similar results (entries 13–16). Elongation of the fluoroalkyl chain increased the electron withdrawing effect of the fluoroalkylsulfonyl group, leading to the lower nucleophilicity of **1d**.

In the case of di-sulfonamides **1h** and **1i**, tetraalkylated products were readily obtained (entries 20–27). But the yields were slightly low. Increasing the reaction temperature or prolonging the reaction time had little improvement of the transformation.

3. Conclusion

In summary, the pK_{a1} and pK_{a2} values of a series of fluoroalkanesulfonylamides were measured by potentiometric titration. The sulfonylamides with longer fluoroalkyl chain showed stronger acidity. The terminal substituents also have influences on their pK_a values. Different alkyl halides and tosylates were employed to investigate the nucleophilicity of fluoroalkanesulfonylamides. It was demonstrated that elongation of the fluoroalkyl chain reduced the nucleophilicity of the sulfonamides, which is, to some extent, in accordance with the decrease of their pK_a values. Further investigation on the applications of these fluoroalkanesulfonylamides is going on.

4. Experimental

4.1. General

Unless otherwise stated, NMR spectra were recorded in deuterated chloroform at 300 MHz (^{1}H NMR) and 282 MHz (^{19}F NMR). ^{13}C NMR spectra were recorded at 75 or 100 MHz in $CDCl_3$. All chemical shifts were reported in ppm relative to TMS and $CFCl_3$ (positive for downfield shifts) as external standards. Melting points were measured and uncorrected. MeOH was distilled from 4A molecular sieves before use. Analytical pure THF was used without further purification. All fluoroalkanesulfonyl fluorides except $Cl(CF_2)_2SO_2F$, $FO_2S(CF_2)_2O(CF_2)_2SO_2F$ and $FO_2S(CF_2)_2O(CF_2)_4O(CF_2)_2SO_2F$ were obtained from commercial source. $Cl(CF_2)_2SO_2F$, $FO_2S(CF_2)_2O(CF_2)_2SO_2F$ and $FO_2S(CF_2)_2O(CF_2)_4O(CF_2)_2SO_2F$ were prepared according to the literature [13c,20]. **1d** was prepared according to our previous work [14]. The pK_{a1} and pK_{a2} values of fluoroalkanesulfonylamides were measured in MeOH. Samples in the range from 5×10^{-5} M to 1×10^{-2} M were dissolved in methanol and titrated with KOH (0.02 M in the same solvent). Potentiometric titrator (METTLER TOLEDO T70 3.0.0) was employed to monitor the whole titration process.

4.2. Typical procedure for the preparation of 1a

In a 500 mL three-neck flask equipped with katathermometer and magnetic stirrer, CF_3SO_2F (170 g, 1.12 mol) was bubbled into liquid NH_3 (300 mL) within 1.5 h (during this procedure,

temperature of the reaction system inevitably rose up to about −60 °C. But it returned to −78 °C quickly when bubbling stopped. It was the same case for **1b** and **c** and **1e** and **i**). The reaction was stirred at −78 °C for 2 h under nitrogen atmosphere. Then the excess of ammonia was removed by evaporation. The residue was added in dioxane (500 mL), acidified with anhydrous HCl till the PH value is below 2 and filtered. The filtrate was then distilled to give a light yellow powder. Sublimation of the crude powder under vacuum gave a white crystal **1a** (134 g, 80%). ^{1}H NMR (CD_3COCD_3): δ 7.60 (s, 2H). ^{19}F NMR (CD_3COCD_3): δ 80.4 (s, 3F).

4.3. Typical procedure for the preparation of 1b and c, 1e–g and 1i

1,1,2,2-Tetrafluoro-2-(1,1,2,2-tetrafluoro-2-iodoethoxy)ethanesulfonyl fluoride (9.80 g, 23.0 mmol) was added dropwise into liquid NH_3 (45 mL) which was cooled by acetone/dry ice bath. After being stirred at −78 °C for 2 h, the excess of ammonia was removed by evaporation. The resulting white slurry was acidified to a pH of 2 with diluted H_2SO_4 and extracted with diethyl ether (80 mL), washed with water (3 × 20 mL), dried over anhydrous Na_2SO_4, concentrated under reduced pressure and dried in vacuum to give the crude product. 8.95 g of pure **1c** (21.2 mmol, 92%) was obtained as a white solid by column chromatography on silica gel using dichloromethane as the eluent. ^{1}H NMR: δ 5.36 (s, 2H). ^{19}F NMR: δ −115.8 (s, 2F), −84.8 (m, 2F), −81.0 (t, J = 12.4 Hz, 2F), −64.3 (t, J = 12.4 Hz, 2F).

1b: white solid; mp 76–77 °C. Yield: 88%. ^{1}H NMR: δ 5.50 (s, 2H). ^{19}F NMR: δ −110.7 (s, 2F), −65.6 (s, 2F). MS (ESI, m/z, %): 214.0 $[M]^-$ (100). IR (KBr): 3377, 3284, 1539, 1361, 1198, 1180, 1162, 1131, 1085, 833, 698, 614, 588, 540, 493, 428 cm^{-1}. Anal. Calcd. for $C_2H_2ClF_4NO_2S$: C, 11.14; H, 0.94; N, 6.50. Found: C, 11.15; H, 0.93; N, 6.54.

1e: white solid. Yield: 94%. ^{1}H NMR: δ 5.32 (s, 2H). ^{19}F NMR: δ −124.8 (m, 2F), −116.7 (d, J = 7.9 Hz, 2F), −113.8 (m, 2F), −83.5 (m, 2F), −81.5 (t, J = 12.9 Hz, 2F), −59.8 (t, J = 13.9 Hz, 2F).

1f: white solid; mp 90–92 °C. Yield: 93%. ^{1}H NMR: δ 5.40 (s, 2H). ^{19}F NMR: δ −124.6 (s, 2F), −121.5 (s, 2F), −120.5 (s, 2F), −115.8 (s, 2F), −112.5 (s, 2F), −82.2 (m, 2F), −80.6 (t, J = 13.4 Hz, 2F), −58.6 (t, J = 14.5 Hz, 2F). MS (ESI, m/z, %): 621.8 $[M]^-$ (100). IR (KBr): 3607, 3374, 3189, 1563, 1388, 1369, 1328, 1209, 1144, 1090, 1038, 999, 942, 842, 692, 647, 622, 543, 491 cm^{-1}. Anal. Calcd. for $C_8H_2F_{16}INO_3S$: C, 15.42; H, 0.32; N, 2.25. Found: C, 15.51; H, <0.3; N, 2.43.

1g: white solid; mp 71–72 °C. Yield: 98%. ^{1}H NMR: δ 5.36 (s, 2H). ^{19}F NMR: δ −124.6 (m, 2F), −121.5 (s, 2F), −120.7 (s, 2F), −119.5 (s, 2F), −115.7 (s, 2F), −82.1 (m, 2F), −80.5 (t, J = 12.4 Hz, 2F), −67.4 (t, J = 12.3 Hz, 2F). MS (ESI, m/z, %): 530.0 $[M]^-$ (100). IR (KBr): 3384, 3275, 1374, 1329, 1209, 1145, 1100, 1052, 998, 940, 882, 707, 698, 685, 656, 627, 547, 491 cm^{-1}. Anal. Calcd. for $C_8H_2ClF_{16}NO_3S$: C, 18.07; H, 0.38; N, 2.63. Found: C, 17.93; H, <0.3; N, 2.80.

1i: white solid. Yield: 94%. ^{1}H NMR (CD_3COCD_3): δ 8.12 (s, 4H). ^{19}F NMR (CD_3COCD_3): δ −125.9 (m, 4F), −117.9 (s, 4F), −83.5 (m, 4F), −81.8 (m, 4F).

4.4. Typical procedure for the preparation of 1h

In a 100-mL three-neck flask equipped with katathermometer and magnetic stirrer, $FO_2SCF_2CF_2OCF_2CF_2SO_2F$ (5.02 g, 13.1 mmol) was added dropwise into liquid NH_3 (30 mL) within 40 min. The reaction mixture was stirred at −78 °C for 2 h. After removing excessive ammonia, the residue was acidified with diluted H_2SO_4 till pH value below 2. Then water was evaporated. The crude product was extracted with acetone and purified by column chromatography on silica gel using dichloromethane/acetonitrile (4:1) as the eluent. 4.82 g of pure **1h** (12.8 mmol, 97%) was obtained as a white solid. mp 125–126 °C. ^{1}H NMR (CD_3COCD_3): δ 8.03 (s, 4H). ^{19}F NMR (CD_3COCD_3): δ −117.2 (s, 4F), −81.2 (s, 4F). MS (ESI, m/z, %): 375.0 $[M]^-$ (100). IR (KBr): 3406, 3307, 1532, 1376, 1347, 1305, 1232, 1183, 1156, 1114, 916, 771, 655, 637, 609, 565, 503, 481, 419 cm^{-1}. Anal. Calcd. for $C_4H_4F_8N_2O_5S_2$: C, 12.77; H, 1.07; N, 7.45. Found: C, 12.94; H, 0.79; N, 7.31.

4.5. Typical procedure for the preparation of 2aa–ah, 2ak, 2da–di, 2ha–hd and 2ia–id

In a 15 mL round bottom sealed tube equipped with a magnetic stirrer, **1d** (0.220 g, 0.740 mmol) and 1-iodobutane (0.278 g, 1.51 mmol) were dissolved in THF (7 mL). K_2CO_3 (0.196 g, 1.42 mmol) was then added. After being heated at 90 °C for 2 days, the reaction mixture was cooled, concentrated and acidified with diluted H_2SO_4 till pH < 2. The resulting emulsion was extracted with ethyl ether (30 mL), washed by water (3 × 15 mL) and dried over anhydrous Na_2SO_4. The crude product was purified by column chromatography to give pure **2de** (0.112 g, 0.317 mmol, 43%) and **2df** (0.137 g, 0.335 mmol, 45%) using petroleum ether/ethyl acetate (20:1) as the eluent.

2de: colorless liquid. Yield: 43%. ^{1}H NMR: δ 5.87 (tt, J = 52.6 Hz, J = 3.2 Hz, 1H), 4.82 (s, 1H), 3.33 (q, J = 6.8 Hz, 2H), 1.58 (m, 2H), 1.39 (m, 2H), 0.95 (t, J = 7.1 Hz, 3H). ^{19}F NMR: δ −137.2 (dt, J = 52.6 Hz, J = 5.2 Hz, 2F), −116.1 (s, 2F), −88.3 (m, 2F), −81.5 (m, 2F). ^{13}C NMR: δ 44.6, 32.3, 19.4, 13.4. MS (EI, m/z, %): 310 (100), 136 (36.0), 128 (29.8), 119 (44.3), 101 (42.7), 78 (19.9), 57 (38.3), 56 (30.5). IR (KBr): 3313, 3133, 2968, 2881, 1430, 1398, 1330, 1285, 1200, 1143, 1078, 857, 749, 612, 583 cm^{-1}. Anal. Calcd. for $C_8H_{11}F_8NO_3S$: C, 27.20; H, 3.14; N, 3.97. Found: C, 27.46; H, 3.19; N, 3.88.

2df: colorless liquid. Yield: 45%. ^{1}H NMR: δ 5.86 (tt, J = 52.5 Hz, J = 3.2 Hz, 1H), 3.37 (d, J = 37.0 Hz, 4H), 1.61 (s, 4H), 1.34 (m, 4H), 0.95 (t, J = 6.8 Hz, 6H). ^{19}F NMR: δ −137.3 (dt, J = 52.5 Hz, J = 5.1 Hz, 2F), −115.9 (s, 2F), −88.5 (m, 2F), −81.7 (m, 2F). ^{13}C NMR: δ 48.3, 30.5, 19.7, 13.6. MS (EI, m/z, %): 366 (17.8), 324 (100), 310 (26.8), 192 (16.1), 119 (20.1), 101 (17.5), 57 (38.6), 43 (14.6). IR (KBr): 2964, 2939, 2879, 1469, 1390, 1326, 1283, 1143, 1034, 925, 857, 748, 582 cm^{-1}. Anal. Calcd. for $C_{12}H_{19}F_8NO_3S$: C, 35.21; H, 4.68; N, 3.42. Found: C, 35.18; H, 4.80; N, 3.50.

2aa: colorless liquid. Yield: 89%. ^{1}H NMR: δ 3.07 (s, 6H). ^{19}F NMR: δ −75.1 (s, 3F).

2ab: colorless liquid. Yield: 90%. ^{1}H NMR: δ 3.46 (q, J = 6.8 Hz, 4H), 1.26 (t, J = 6.8 Hz, 6H). ^{19}F NMR: δ −77.0 (s, 3F).

2ac: white solid. Yield: 16%. ^{1}H NMR: δ 4.79 (s, 1H), 3.28 (q, J = 6.4 Hz, 2H), 1.65 (m, 2H), 0.99 (t, J = 6.4 Hz, 3H). ^{19}F NMR: δ −78.0 (s, 3F).

2ad: colorless liquid. Yield: 46%. ^{1}H NMR: δ 3.31 (t, J = 7.3 Hz, 4H), 1.67 (m, 4H), 0.94 (t, J = 7.3 Hz, 6H). ^{19}F NMR: δ −76.4 (s, 3F). ^{13}C NMR: δ 120.1 (q, J = 323.7 Hz, CF_3), 50.0, 21.7, 10.9. MS (EI, m/z, %): 233 (12.3), 204 (100), 164 (12.8), 162 (38.2), 69 (8.4), 43 (66.8), 42 (11.4), 41 (13.4). IR (KBr): 2973, 2942, 2882, 1715, 1506, 1471, 1390, 1226, 1200, 1133, 1005, 874, 801, 741, 599, 511 cm^{-1}. Anal. Calcd. for $C_7H_{14}F_3NO_2S$: C, 36.04; H, 6.05; N, 6.00. Found: C, 35.99; H, 5.97; N, 5.75.

2ae: colorless liquid. ^{1}H NMR: δ 4.77 (s, 1H), 3.31 (q, J = 6.8 Hz, 2H), 1.60 (m, 2H), 1.39 (m, 2H), 0.95 (t, J = 7.3 Hz, 3H). ^{19}F NMR: δ −78.0 (s, 3F).

2af: colorless liquid. Yield: 77%. ^{1}H NMR: δ 3.34 (t, J = 6.8 Hz, 4H), 1.61 (m, 4H), 1.34 (m, 4H), 0.95 (t, J = 7.3 Hz, 6H). ^{19}F NMR: δ −76.4 (s, 3F). ^{13}C NMR: δ 120.1 (q, J = 323.7 Hz, CF_3), 48.1, 30.4, 19.7, 13.6. MS (EI, m/z, %): 218 (13.6), 178 (5.3), 176 (100), 69 (2.9), 57 (21.8), 56 (6.3), 42 (4.6), 41 (9.1). IR (KBr): 2964, 2938, 2878, 1469, 1389, 1225, 1189, 1133, 1030, 926, 597, 510 cm^{-1}. Anal. Calcd. for $C_9H_{18}F_3NO_2S$: C, 41.37; H, 6.94; N, 5.36. Found: C, 41.45; H, 6.87; N, 5.20.

2ag: white solid. Yield: 6%. ^{1}H NMR: δ 7.42–7.32 (m, 5H), 5.03 (s, 1H), 4.45 (d, J = 5.9 Hz, 2H). ^{19}F NMR: δ −77.8 (s, 3F).

2ah: white solid. Yield: 29%. ^{1}H NMR: δ 7.37–7.33 (m, 6H), 7.20–7.17 (m, 4H), 4.43 (s, 4H). ^{19}F NMR: δ −76.1 (s, 3F).

2ak: colorless liquid. Yield: 41%. ^{1}H NMR: δ 3.77 (t, J = 3.2 Hz, 4H), 3.51 (s, 4H). ^{19}F NMR: δ −75.6 (s, 3F).

2da: colorless liquid. Yield: 88%. ^{1}H NMR: δ 5.87 (tt, J = 52.5 Hz, J = 3.2 Hz, 1H), 3.09 (s, 6H). ^{19}F NMR: δ −138.0 (dt, J = 52.6 Hz, J = 5.2 Hz, 2F), −115.9 (s, 2F), −89.1 (m, 2F), −82.7 (m, 2F). ^{13}C NMR: δ 38.2. MS (EI, m/z, %): 119 (10.5), 110 (5.4), 108 (100), 101 (14.5), 92 (12.3), 51 (6.4), 44 (10.0), 42 (11.1). IR (KBr): 2962, 1424, 1386, 1329, 1286, 1200, 1135, 1001, 967, 857, 719, 581, 489 cm^{-1}. Anal. Calcd. for $C_6H_7F_8NO_3S$: C, 22.16; H, 2.17; N, 4.31. Found: C, 22.15; H, 2.22; N, 4.24.

2db: colorless liquid. Yield: 89%. ^{1}H NMR: δ 5.86 (tt, J = 52.6 Hz, J = 3.2 Hz, 1H), 3.48 (d, J = 27.0 Hz, 4H), 1.26 (t, J = 7.3 Hz, 6H). ^{19}F NMR: δ −138.0 (dt, J = 52.6 Hz, J = 5.2 Hz, 2F), −117.0 (s, 2F), −89.2 (m, 2F), −82.3 (m, 2F).

2dc: colorless liquid. Yield: 37%. ^{1}H NMR: δ 5.87 (tt, J = 52.5 Hz, J = 3.2 Hz, 1H), 3.41 (s, 1H), 3.30 (t, J = 6.8 Hz, 2H), 1.64 (m, 2H), 0.98 (t, J = 7.8 Hz, 3H). ^{19}F NMR: δ −137.9 (dt, J = 52.6 Hz, J = 5.2 Hz, 2F), −116.8 (s, 2F), −89.0 (m, 2F), −82.2 (m, 2F). ^{13}C NMR: δ 46.5, 23.6, 10.7. MS (EI, m/z, %): 310 (100), 128 (27.4), 122 (76.4), 119 (47.0), 106 (18.5), 101 (47.5), 78 (21.6), 43 (43.9). IR (KBr): 3317, 2976, 2886, 1432, 1372, 1330, 1285, 1200, 1143, 1075, 986, 857, 750, 612, 584 cm^{-1}. HRMS for $C_7H_9F_8NO_3S$: 339.0175. Found: 339.0171.

2dd: colorless liquid. Yield: 41%. ^{1}H NMR: δ 5.86 (tt, J = 52.5 Hz, J = 3.2 Hz, 1H), 3.33 (d, J = 32.0 Hz, 4H), 1.66 (m, 4H), 0.94 (t, J = 7.3 Hz, 6H). ^{19}F NMR: δ −137.9 (dt, J = 52.5 Hz, J = 5.1 Hz, 2F), −116.6 (s, 2F), −89.1 (m, 2F), −82.3 (m, 2F). ^{13}C NMR: δ 50.2, 21.8, 10.8. MS (EI, m/z, %): 352 (100), 310 (25.7), 164 (44.2), 119 (24.0), 101 (15.6), 70 (15.4), 43 (59.9), 42 (15.3). IR (KBr): 2974, 2943, 2884, 1472, 1390, 1327, 1284, 1203, 1139, 1015, 976, 873, 857, 744, 583, 524 cm^{-1}. Anal. Calcd. for $C_{10}H_{15}F_8NO_3S$: C, 31.50; H, 3.97; N, 3.67. Found: C, 31.80; H, 4.22; N, 3.62.

2dg: colorless liquid. Yield: 88%. ^{1}H NMR: δ 7.32 (m, 6H), 7.18 (m, 4H), 5.87 (tt, J = 52.5 Hz, J = 3.2 Hz, 1H), 4.45 (s, 4H). ^{19}F NMR: δ −137.9 (dt, J = 52.6 Hz, J = 5.1 Hz, 2F), −115.8 (s, 2F), −89.1 (m, 2F), −82.0 (m, 2F). ^{13}C NMR: δ 133.7, 128.8, 128.4, 51.4. MS (EI, m/z, %): 386 (5.0), 196 (6.0), 195 (7.6), 194 (11.7), 93 (5.0), 92 (67.9), 91 (100), 65 (8.4). IR (KBr): 3035, 2360, 1508, 1458, 1389, 1326, 1200, 1144, 1059, 932, 895, 748, 698, 610, 505 cm^{-1}. Anal. Calcd. for $C_{18}H_{15}F_8NO_3S$: C, 45.29; H, 3.17; N, 2.93. Found: C, 45.07; H, 3.37; N, 2.96.

2dh: colorless liquid. Yield: 75%. ^{1}H NMR: δ 5.87 (tt, J = 52.6 Hz, J = 3.2 Hz, 1H), 5.82–5.68 (m, 2H), 5.35–5.25 (m, 4H), 3.98 (d, J = 5.0 Hz, 4H). ^{19}F NMR: δ −138.0 (dt, J = 52.6 Hz, J = 5.2 Hz, 2F), −116.9 (s, 2F), −89.1 (m, 2F), −82.1 (m, 2F). ^{13}C NMR: δ 131.4, 120.8, 50.0. MS (EI, m/z, %): 348 (14.5), 160 (25.6), 119 (15.4), 101 (15.6), 96 (17.7), 69 (20.4), 68 (14.4), 41 (100). IR (KBr): 3091, 2993, 2939, 1646, 1447, 1423, 1390, 1328, 1284, 1200, 1144, 1059, 992, 936, 910, 857, 778, 749, 615, 578, 504 cm^{-1}. Anal. Calcd. for $C_{10}H_{11}F_8NO_3S$: C, 31.84; H, 2.94; N, 3.71. Found: C, 32.04; H, 3.09; N, 3.67.

2di: colorless liquid. Yield: 71%. ^{1}H NMR: δ 5.87 (tt, J = 52.6 Hz, J = 3.2 Hz, 1H), 3.77 (s, 4H), 3.56 (s, 4H). ^{19}F NMR: δ −137.8 (dt, J = 52.6 Hz, J = 5.2 Hz, 2F), −116.2 (s, 2F), −88.8 (m, 2F), −82.2 (m, 2F). ^{13}C NMR: δ 66.5, 46.9. MS (EI, m/z, %): 119 (100), 107 (38.8), 106 (59.4), 66 (65.7), 54 (74.6), 52 (26.4), 43 (49.7), 41 (37.3). IR (KBr): 2980, 2936, 2871, 1456, 1394, 1330, 1286, 1266, 1200, 1118, 1078, 991, 958, 857, 751, 711, 699, 610, 578, 495 cm^{-1}. Anal. Calcd. for $C_8H_9F_8NO_4S$: C, 26.17; H, 2.47; N, 3.81. Found: C, 26.32; H, 2.46; N, 3.77.

2ha: white solid; mp 72–73 °C. Yield: 35%. ^{1}H NMR: δ 3.09 (s, 12H). ^{19}F NMR: δ −115.3 (s, 4F), −82.3 (s, 4F). ^{13}C NMR: δ 38.2. MS (EI, m/z, %): 110 (4.9), 109 (3.5), 108 (100), 100 (5.1), 92 (18.6), 44 (18.9), 43 (5.8), 42 (12.2). IR (KBr): 2920, 2851, 1491, 1459, 1394, 1382, 1293, 1224, 1164, 1130, 1115, 1066, 975, 751, 705, 641, 599, 539, 482 cm^{-1}. Anal. Calcd. for $C_8H_{12}F_8N_2O_5S_2$: C, 22.23; H, 2.80; N, 6.48. Found: C, 22.68; H, 2.90; N, 6.38.

2hb: colorless liquid. Yield: 26%. ^{1}H NMR: δ 3.49 (d, J = 30.1 Hz, 8H), 1.26 (t, J = 7.3 Hz, 12H). ^{19}F NMR: δ −116.3 (s, 4F), −82.0 (s, 4F). ^{13}C NMR: δ 42.9, 14.1. MS (EI, m/z, %): 473 (9.5), 136 (100), 120 (44.5), 72 (7.9), 71 (15.2), 56 (13.7), 44 (21.7), 42 (12.5). IR (KBr): 2988, 2947, 2887, 1509, 1459, 1389, 1334, 1299, 1214, 1138, 1023, 945, 792, 695, 585, 504 cm^{-1}. Anal. Calcd. for $C_{12}H_{20}F_8N_2O_5S_2$: C, 29.51; H, 4.13; N, 5.74. Found: C, 29.93; H, 4.20; N, 5.72.

2hc: light yellow liquid. Yield: 31%. ^{1}H NMR: δ 5.83–5.69 (m, 4H), 5.34–5.24 (m, 8H), 3.98 (d, J = 5.0 Hz, 8H). ^{19}F NMR: δ −116.2 (s, 4F), −81.8 (s, 4F). ^{13}C NMR: δ 131.5, 120.7, 50.0. MS (EI, m/z, %): 160 (28.3), 96 (83.4), 94 (23.1), 81 (15.3), 69 (36.7), 68 (15.8), 56 (15.1), 41 (100). IR (KBr): 3091, 2997, 2943, 2875, 1647, 1448, 1423, 1388, 1338, 1299, 1226, 1200, 1144, 992, 934, 910, 782, 737, 668, 603, 501 cm^{-1}. HRMS for $C_{16}H_{20}F_8N_2O_5S_2$: 536.0686. Found: 536.0682.

2hd: white solid; mp 112–113 °C. Yield: 28%. ^{1}H NMR: δ 7.32–7.29 (m, 12H), 7.17 (m, 8H), 4.46 (s, 8H). ^{19}F NMR: δ −115.0 (s, 4F), −81.6 (s, 4F). ^{13}C NMR: δ 133.8, 128.8, 128.7, 128.4, 51.4. MS (MALDI, m/z, %): 759.4 [M+Na], 775.3 [M+K]. IR (KBr): 3036, 1498, 1459, 1376, 1339, 1303, 1201, 1144, 1092, 1062, 938, 925, 906, 889, 796, 767, 742, 726, 693, 603, 509 cm^{-1}. Anal. Calcd. for $C_{32}H_{28}F_8N_2O_5S_2$: C, 52.17; H, 3.83; N, 3.80. Found: C, 52.36; H, 4.03; N, 3.57.

2ia: white solid; mp 81–83 °C. Yield: 30%. ^{1}H NMR: δ 3.10 (s, 12H). ^{19}F NMR: δ −126.2 (m, 4F), −115.8 (s, 4F), −83.6 (m, 4F), −82.5 (s, 4F). ^{13}C NMR: δ 38.2. MS (EI, m/z, %): 119 (3.7), 110 (4.9), 109 (3.6), 108 (100), 100 (3.4), 92 (13.9), 44 (8.7), 42 (5.3). IR (KBr): 1379, 1336, 1287, 1213, 1150, 1129, 1001, 969, 881, 701, 658, 573, 485 cm^{-1}. Anal. Calcd. for $C_{12}H_{12}F_{16}N_2O_6S_2$: C, 22.23; H, 1.87; N, 4.32. Found: C, 22.34; H, 1.92; N, 4.33.

2ib: colorless liquid. Yield: 27%. ^{1}H NMR: δ 3.48 (d, J = 25.1 Hz, 8H), 1.26 (t, J = 7.3 Hz, 12H). ^{19}F NMR: δ −126.2 (m, 4F), −116.7 (s, 4F), −83.6 (m, 4F), −82.2 (s, 4F). ^{13}C NMR: δ 42.8, 14.1. MS (EI, m/z, %): 689 (7.7), 137 (5.9), 136 (100), 120 (19.0), 119 (8.1), 71 (8.3), 56 (7.1), 44 (10.0). IR (KBr): 2987, 1471, 1390, 1314, 1288, 1214, 1148, 1024, 945, 791, 696, 590, 506 cm^{-1}. HRMS for $C_{16}H_{20}F_{16}N_2O_6S_2$: 704.0507. Found: 704.0503.

2ic: colorless liquid. Yield: 31%. ^{1}H NMR: δ 5.82–5.69 (m, 4H), 5.35–5.25 (m, 8H), 3.98 (d, J = 5.9 Hz, 8H). ^{19}F NMR: δ −126.1 (m, 4F), −116.6 (s, 4F), −83.5 (m, 4F), −82.0 (s, 4F). ^{13}C NMR: δ 131.4, 120.8, 50.0. MS (EI, m/z, %): 160 (60.6), 144 (19.3), 96 (75.3), 94 (21.7), 81 (16.0), 69 (33.6), 68 (17.4), 41 (100). IR (KBr): 3091, 2992, 2937, 1645, 1446, 1423, 1395, 1333, 1288, 1217, 1148, 1058, 991, 935, 910, 892, 766, 720, 614, 573, 504 cm^{-1}. HRMS for $C_{20}H_{20}F_{16}N_2O_6S_2$: 752.0507. Found: 752.0511.

2id: white solid; mp 135–136 °C. Yield: 86%. ^{1}H NMR: δ 7.32–7.30 (m, 12H), 7.17 (m, 8H), 4.45 (s, 8H). ^{19}F NMR: δ −126.1 (m, 4F), −115.7 (s, 4F), −83.6 (m, 4F), −81.9 (s, 4F). ^{13}C NMR: δ 133.7, 128.8, 128.7, 128.4, 51.4. MS (EI, m/z, %): 260 (5.0), 196 (24.0), 195 (19.9), 194 (14.7), 93 (4.8), 92 (63.4), 91 (100), 65 (4.5). IR (KBr): 3034, 1497, 1458, 1379, 1363, 1327, 1289, 1217, 1172, 1141, 1062, 1007, 936, 923, 906, 889, 744, 708, 693, 606, 690, 533, 499 cm^{-1}. Anal. Calcd. for $C_{36}H_{28}F_{16}N_2O_6S_2$: C, 45.38; H, 2.96; N, 2.94. Found: C, 45.39; H, 3.28; N, 2.74.

4.6. Typical procedure for the preparation of 2ai, 2aj and 2al

1a (0.152 g, 1.02 mmol) and 2-(2-hydroxyethoxy)ethyl 4-methylbenzenesulfonate (0.580 g, 2.23 mmol) were dissolved in THF (10 mL) and placed in a 25 mL round bottom flask which was equipped with a magnetic stirrer. K_2CO_3 (0.286 g, 2.10 mmol) was then added. After being refluxed for 2 days, the reaction mixture was diluted by Et_2O (30 mL) and filtered. The solvent was

evaporated and the crude product was purified by column chromatography to give 0.232 g of pure **2ai** (colorless liquid, 0.714 mmol, 71%) using dichloromethane/methanol (20:1) as the eluent. ^{1}H NMR: δ 3.75–3.59 (m, 16H), 2.89 (s, 2H). ^{19}F NMR: δ −75.7 (s, 3F). ^{13}C NMR: δ 120.0 (q, J = 323.8 Hz, CF_3), 72.6, 69.7, 61.6, 49.6. MS (EI, m/z, %): 190 (15.8), 176 (16.2), 118 (31.4), 88 (28.5), 75 (17.9), 56 (25.5), 45 (100), 44 (17.7). IR (KBr): 3400, 2938, 2877, 1385, 1226, 1191, 1127, 1066, 1004, 701, 594 cm^{-1}. Anal. Calcd. for $C_9H_{18}F_3NO_6S$: C, 33.23; H, 5.58; N, 4.31. Found: C, 32.95; H, 5.46; N, 4.00.

2aj: colorless liquid. Yield: 68%. ^{1}H NMR: δ 3.72–3.65 (m, 20H), 3.58 (m, 4H), 3.16 (s, 2H). ^{19}F NMR: δ −75.9 (s, 3F). ^{13}C NMR: δ 119.9 (q, J = 323.1 Hz, CF_3), 72.7, 70.3, 70.1, 69.9, 61.5, 49.1. MS (EI, m/z, %): 220 (15.1), 176 (17.4), 174 (28.2), 162 (17.7), 89 (58.4), 87 (25.6), 56 (20.1), 45 (100). IR (KBr): 3414, 2877, 1456, 1386, 1355, 1225, 1193, 1126, 1070, 1004, 701, 595 cm^{-1}. Anal. Calcd. for $C_{13}H_{26}F_3NO_8S$: C, 37.77; H, 6.34; N, 3.39. Found: C, 37.41; H, 6.60; N, 3.24.

2al: light yellow liquid. Yield: 9%. ^{1}H NMR: δ 3.70 (m, 16H), 3.62 (s, 8H). ^{19}F NMR: δ −76.0 (s, 6F). ^{13}C NMR: δ 119.9 (q, J = 323.9 Hz, CF_3), 70.5, 70.1, 49.3. MS (EI, m/z, %): 393 (82.3), 220 (17.6), 100 (39.1), 70 (20.3), 69 (28.1), 56 (100), 45 (18.6), 42 (24.2). IR (KBr): 2876, 1456, 1386, 1359, 1226, 1190, 1125, 1002, 769, 730, 701, 595 cm^{-1}. HRMS for $C_{14}H_{24}F_6N_2O_8S_2$: 526.0878. Found: 526.0871.

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References

[1] R.D. Trepka, J.K. Harrington, J.W. McConville, K.T. McGurran, A. Mendel, D.R. Pauly, J.E. Robertson, J.T. Waddington, J. Agric. Food Chem. 22 (1974) 1111–1119.
[2] R.D. Trepka, J.K. Harrinqton, J.E. Robertson, J.T. Waddington, J. Agric. Food Chem. 18 (1970) 1176–1177.
[3] J.K. Harrington, J.E. Robertson, D.C. Kvam, R.R. Hamilton, K.T. McGurran, R.J. Trancik, K.F. Swinale, G.G.I. Moore, J.F. Gerster, J. Med. Chem. 13 (1970) 137.
[4] G.G.I. Moore, J.K. Harrington, J. Med. Chem. 18 (1975) 386–391.
[5] L. Lu, Q.-H. Tang, Q. Lu, X.-Y. Wang, Q.-M. Fu, X. Feng, J. Liu, CN1858038A, 2006.
[6] R.D. Trepka, J.K. Harrington, J.W. Belisle, J. Org. Chem. 39 (1974) 1094–1098.
[7] (a) J.J.R. Foropoulos, D.D. DesMarteau, Inorg. Chem. 23 (1984) 3720–3723;
(b) S. Singh, D.D. DesMarteau, Inorg. Chem. 29 (1990) 2982–2985;
(c) L.-Q. Hu, D.D. DesMarteau, Inorg. Chem. 32 (1993) 5007–5010;
(d) K. Sogabe, Y. Hasegawa, Y. Wada, T. Kitamura, S. Yanagida, Chem. Lett. (2000) 944–945.
[8] H.W. Roesky, G. Holtschneider, H.H. Giere, Z. Naturforsch. Teil B 25 (1970) 252.
[9] (a) S.-Z. Zhu, Q.-Y. Chen, J. Chem. Soc., Chem. Commun. (1991) 732–733;
(b) S.-Z. Zhu, A.-W. Li, K. Wu, Chin. Chem. Lett. 3 (1992) 703–706.
[10] S.-Z. Zhu, C.-M. Zhou, A.-W. Li, B. Xu, J. Fluorine Chem. 67 (1994) 7–8.
[11] A.-W. Li, X. Bin, S.-Z. Zhu, J. Fluorine Chem. 69 (1994) 257–259.
[12] (a) H.-J. Lehmler, V.V.V.N.S. Rama Rao, D. Nauduri, J.D. Vargo, S. Parkin, J. Fluorine Chem. 128 (2007) 595–607;
(b) K.E. Bell, D.W. Knight, M.B. Gravestock, Tetrahedron Lett. 36 (1995) 8681–8684.
[13] (a) R.N. Haszeldine, T. Gramstad, J. Chem. Soc. (1956) 173–180;
(b) X. Hao, A. Yoshida, J. Nishikido, J. Fluorine Chem. 127 (2006) 193–199;
(c) J.-C. Xiao, C.-P. Zhang, C. Yan, Z.-W. Qiang, CN101503382A, 2009.
(d) W.-Y. Huang, C.-M. Hu, H.-Y. Lu, Huaxue Xuebao 41 (1983) 448–456.
[14] C.-P. Zhang, Q.-Y. Chen, J.-C. Xiao, Y.-C. Gu, J. Fluorine Chem. 130 (2009) 671–673.
[15] S. Babić, A.J.M. Horvat, D. Mutavdžić Pavlović, M. Kaštelan-Macan, Trends Anal. Chem. 26 (2007) 1043–1061.
[16] (a) Z. Qiang, C. Adams, Water Res. 38 (2004) 2874–2890;
(b) R. Wróbel, L. Chmurzynski, Anal. Chim. Acta 405 (2000) 303–308.
[17] (a) O. Hakli, K. Ertekin, M. Sabih Ozer, S. Aycan, J. Anal. Chem. 63 (2008) 1051–1056;
(b) G. Garrido, V. Nogales, C. Rafols, E. Bosch, Talanta 73 (2007) 115–120.
[18] (a) V. Amico, S.V. Meille, E. Corradi, M.T. Messina, G. Resnati, J. Am. Chem. Soc. 120 (1998) 8261–8262;
(b) P. Metrangolo, G. Resnati, Chem. Eur. J. 7 (2001) 2511–2519;
(c) E. Corradi, S.V. Meille, M.T. Messina, P. Metrangolo, G. Resnati, Tetrahedron Lett. 40 (1999) 7519–7523.
[19] (a) N.G. Lukyanenko, S.S. Basok, L.K. Filonova, J. Chem. Soc., Perkin Trans. 1 (1988) 3141–3147;
(b) R.N. Greene, Tetrahedron Lett. 16 (1972) 1793–1796;
(c) A.V. Bogatsky, N.G. Lukyanenko, S.S. Basok, L.K. Ostrovskaya, Synthesis (1984) 138.
[20] (a) W.-M. Qiu, D.J. Burton, J. Fluorine Chem. 60 (1993) 93–100;
(b) J. Zhang, D.D. DesMarteau, S. Zuberi, J.-J. Ma, L.-X. Xue, S.M. Gillette, H. Blau, R. Gerhardt, J. Fluorine Chem. 116 (2002) 45–48;
(c) C.Y. Guo, R.L. Kirchmeier, J.M. Shreeve, J. Am. Chem. Soc. 113 (1991) 9000–9001.