ISSN 1070-4280, Russian Journal of Organic Chemistry, 2015, Vol. 51, No. 11, pp. 1551–1559. © Pleiades Publishing, Ltd., 2015.
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Reactions of Polyfluorobenzenethiols with Polyhalomethanes and Their Derivatives in An Alkaline Medium

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Received June 29, 2015

Abstract—New process direction was found in the reaction of polyfluoroarenethiols with fluorodichloromethane, chloroform, and bromoform in an alkaline medium consisting in the replacement of the thiol group by a hydrogen atom. This process competes with the formation of expected products, dihalomethyl polyfluoro-aryl sulfides and tris(arylsulfanyl)methanes. In reaction of 2,3,5,6-tetrafluorobenzenethiol with dichloro-methane bis(2,3,5,6-tetrafluorophenylsulfanyl)methane was obtained. Reactions of polyfluoroarenethiols with pentafluorobenzyl chloride occur mainly with the substitution of the chlorine atom, with pentafluorobenzal chloride and with pentafluorobenzotrichloride a substitution of a fluorine atom in the *para*-position takes place.

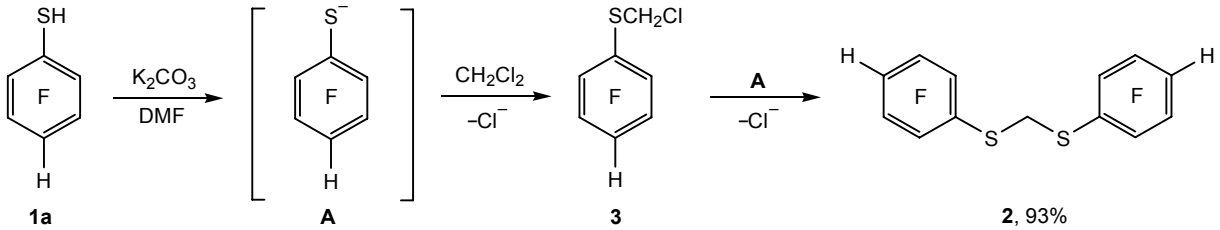
DOI: 10.1134/S1070428015110068

Among the biologically active compounds substances are widely spread where the structure contains a fluorine atom bound to an aromatic fragment [1]. Recently papers were published on the proteins modification by reaction of free thiol groups of cysteine with polyfluoroaromatic compounds with the formation of macrocycles [2, 3]. Another well-known pharmacophoric fragment is the difluoromethyl group, in particular that linked to a sulfur atom [1]. It was shown formerly that the difluoromethyl polyfluorophenyl sulfides were obtained by reacting polyfluorobenzenethiols with difluorochloromethane that acted as a source of difluorocarbene [4].

In this connection the target of this research was the examination of alkylation reactions of polyfluorobenzenethiols with polyhalomethanes in basic conditions as an approach to the preparation of haloalkyl polyfluoroaryl sulfides.

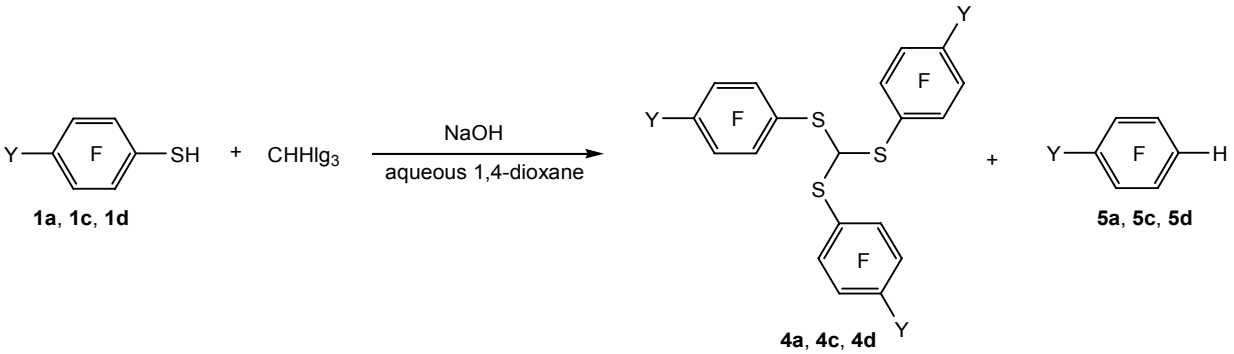
Potassium carbonate is extensively used as a base in polar aprotic solvents, and its reactions with phenols and arenethiols were a subject of special studies [5]. Reaction of 2,3,5,6-tetrafluorobenzenethiol **1a** with dichloromethane in DMF in the presence of K_2CO_3 at room temperature led to the successive substitution of chlorine atoms with the formation of bis(2,3,5,6-tetrafluorophenylsulfanyl)methane **2** (Scheme 1). The formation of the product of one chlorine substitution, chloromethyl 2,3,5,6-tetrafluorophenyl sulfide **3** [6], was detected by the methods of GC-MS and ^1H, ^{19}F NMR spectroscopy.

Scheme 1.



1a **A** **3** **2**, 93%

Scheme 2.



Y = H (**a**), F (**b**), Cl (**c**), CF_3 (**d**).

Compound no.	Hlg	Content in the mixture, % (yield)	
		4	**5**
1a	Cl	97 (79%)	3
1a	Br	95 (70%)	5
1c	Cl	9 (14%)	91 (48%)
1d	Cl	–	(66%)
1d	Br	–	(54%)

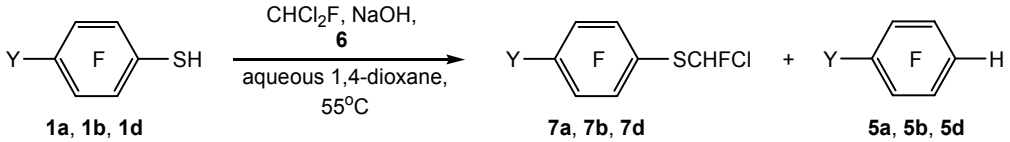
It was expectable that in the reaction of thiol **1a** with chloroform in similar conditions three chlorine atoms might be replaced by tetrafluorobenzenethiol groups. For instance, in the reaction of pentafluorobenzenethiol **1b** with iodoform in DMF tris(pentafluorophenylsulfanyl)methane was obtained in a low yield [7]. We established that no tris(2,3,5,6-tetrafluorophenylsulfanyl)methane **4a** formation occurs thiol **1a**, chloroform, and K_2CO_3 in DMF (14 days, 20–25°C): in the reaction mixture initial thiol **1a** and 1,2,4,5-tetrafluorobenzene **5a** were found in a ratio 92 : 8 (^{19}F NMR). The formation of arene **5a** was formally the result of the reduction of thiol **1a**; we considered this reaction direction as unexpected thus calling for more detailed study.

It is known that under the action of hydroxide ions dichlorocarbene forms from chloroform [8]. At heating thiol **1a** with chloroform in the presence of sodium hydroxide in aqueous 1,4-dioxane the main product was compound **4a**, and the admixture of arene **5a** was insignificant. On the contrary, from 4-chloro-2,3,5,6-tetrafluorobenzenethiol **1c** mainly 3-chloro-1,2,4,5-tetrafluorobenzene **5c** was obtained, and 2,3,5,6-tetrafluoro-4-trifluoromethylbenzenethiol **1d** gave 1,2,4,5-tetrafluoro-3-trifluoromethylbenzene **5d**. Analogous results were obtained in reactions of thiols **1a**, and **1d** with bromoform: the main product of thiol **1a** conversion was compound **4a**, and of thiol **1d**, arene **5d** (Scheme 2). At heating compound **4a** at 75°C in aqueous dioxane in the presence of sodium hydroxide the formation of arene **5a** occurred in a negligible degree (3%), and thiol **1a** was not found in the reaction mixture. The ratios of products **4** and **5** are reported according to the data of ^{19}F NMR spectroscopy.

In the reaction of polyfluoroarenethiols with fluorodichloromethane **6** the formation was expectable both of fluorochloromethyl polyfluoroaryl sulfides **7** and of arenes **5**. The published data indicated the occurrence of the first route: in the reaction of thiophenol with compound **6** fluorochloromethyl phenyl sulfide was obtained in 70% yield [9].

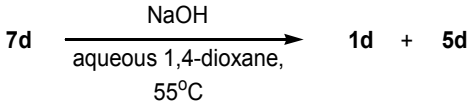
In reaction of thiols **1a** and **1b** with compound **6** we obtained fluorochloromethyl 2,3,5,6-tetrafluorophenyl sulfide **7a** and fluorochloromethyl pentafluorophenyl sulfide **7b** respectively along with a small amounts of arenes **5a** and **5b**. From thiol **1d** arene **5d** formed in a larger amount than sulfide **7d**. At heating with sodium hydroxide in aqueous 1,4-dioxane sulfide **7d** was completely converted in arene **5d** and benzenethiol **1d** (Scheme 3). The ratio of reaction products **5** and **7** are given according to GLC data corrected for thiol consumption.

Scheme 3.



1a, **1b**, **1d** **7a**, **7b**, **7d** **5a**, **5b**, **5d**

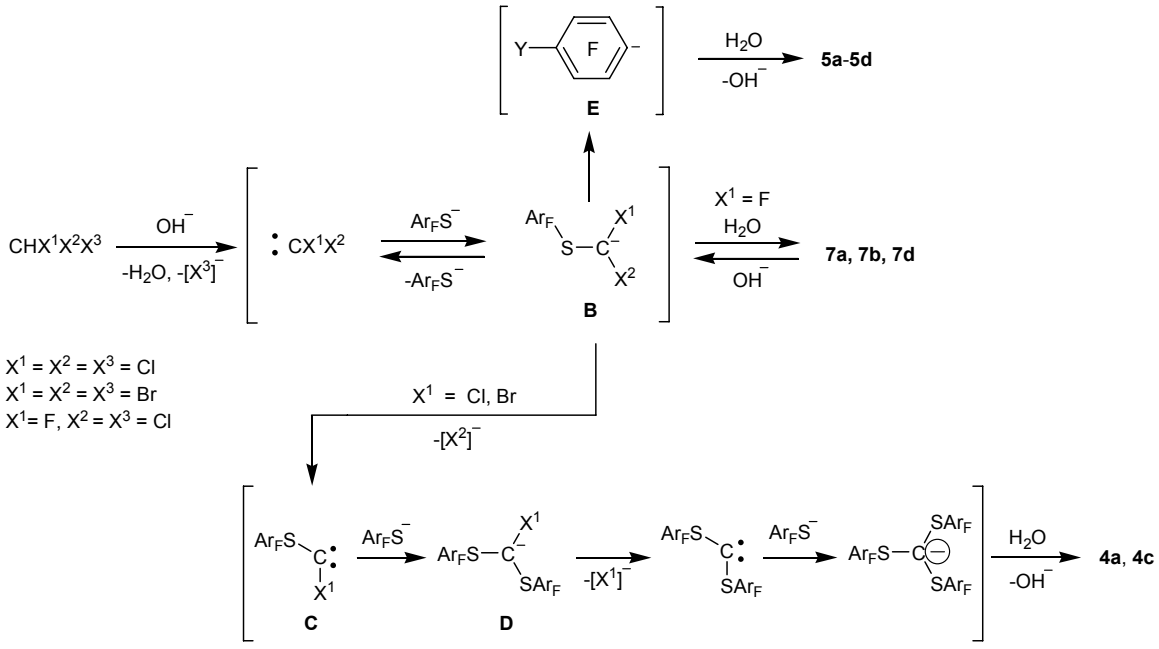
Compound no.	Y	Content in the mixture, % (yield)	
		7	**5**
1a	H	96 (65%)	4
1b	F	97 (54%)	3
1d	CF_3	37 (15%)	63 (36%)



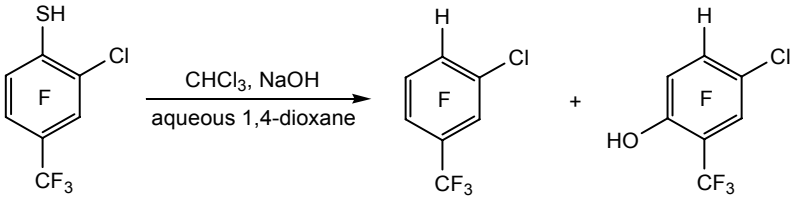
The latter fact suggests that the reaction of polyfluoroarenethiols **1** with compound **6** with the formation of sulfides **7** is reversible. On the other hand, this result may also mean that arenes **5** might form under the reaction conditions from sulfides **7**, and the ratio of compounds **5** and **7** is affected by the nature of the substituent in the *para*-position of polyfluoroarenethiol **1**.

The set of processes in reaction of polyfluoroarenethiols with trihalomethanes and a base is presented in Scheme 4. First under the action of the base the trihalomethane is converted into dihalocarbene [8]. The latter reacts evidently reversibly with the anion of polyfluoroarenethiol [4] forming a carbanion of dihalomethyl polyfluoroaryl sulfide **B** that is apparently stabilized by the sulfur atom [10]. At the protonation of anion **B** with, e.g., water dihalomethyl polyfluoroaryl sulfide **7a**, **7b**, and **7d** is obtained that under the action of a hydroxide anion may be converted into anion **B**. On the other hand, from the anion **B** chloride or bromide ions may eliminate giving carbene **C** and further by the reaction with the thiolate anion carbanion **D** may form. The latter as a result of analogous transformations and protonation affords compound **4**. Finally, a decomposition of carbanion **B** may be presumed with the formation of polyfluoroaryl anion **E** and further of arene **5** under the action of water [11].

Scheme 4.

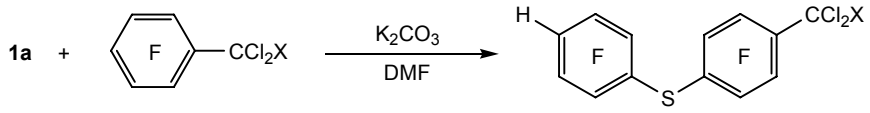


Scheme 5.

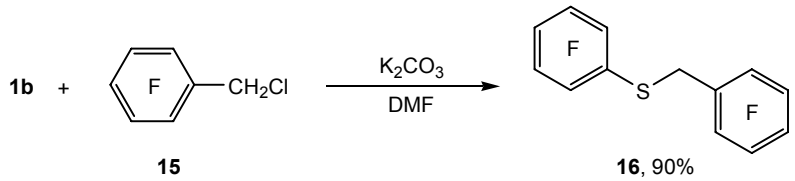


8 **9**, 21% **10**, 5%

Scheme 6.



11, **12** **13** (78%), **14** (81%)



15 **16**, 90%

X = H (**11**, **13**), Cl (**12**, **14**).

The examples of similar transformations are known, and the process may be either successive with carbanion formation or synchronous. For instance, the decarbonylation of 2,6-dichlorobenzaldehyde under the treatment with hot concentrated solution of sodium hydroxide proceeded through an intermediate formation of a carbanion [12]. On the contrary, basing on kinetic measurements of the decarboxylation of pentafluorobenzoic acid under the action of strong bases, for instance, of, 1,8-bis(dimethylamino)naphthalene ("protone sponge"), the limiting stage is regarded as synchronous process of hydrogen cation transfer from the protonated base to the carbon atom linked to the ionized carboxy group with the rupture of this carbon-carbon bond [13].

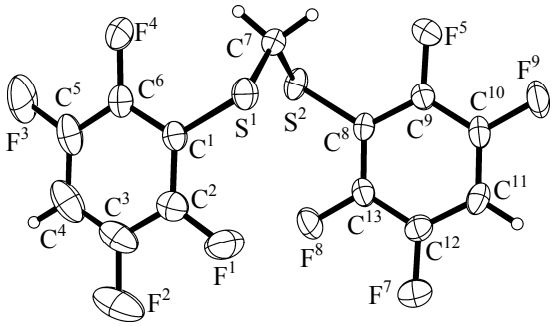
The increase in the content of arene **5d** in the products of reaction of polyfluoroarenethiols with fluorodichloromethane and chloroform as compared with arenes **5a**–**5c** is evidently due to the considerable electron-acceptor effect of the trifluoromethyl group compared to atoms of hydrogen, fluorine, and chlorine as shows the comparison of kinetic and equilibrium acidity of *para*-substituted deuterobenzenes. For instance, the rate constant of hydrogen/deuterium exchange in 4-deuterobenzotrifluoride in the presence of potassium amide in liquid ammonia essentially exceeds this rate for *para*-deuterofluorobenzene [14]. Apparently due to this effect the formation of arene **5d** occurs easier than that of arenes **5a**–**5c**.

By an example of the reaction of 2-chloro-3,5,6-trifluoro-4-trifluoromethylbenzenethiol **8** with chloroform in the presence of sodium hydroxide we demonstrated the possibility of hydrodesulfurization of chloropolyfluoroarenethiol with the retention of the chlorine atom. The reduction of thiols under the action of Raney nickel [15] may be accompanied with the replacement of the chlorine atom by a hydrogen. Along with the conversion of thiol **8** into 1-chloro-2,4,5-trifluoro-3-trifluoromethylbenzene **9** we observed 4-chloro-3,6-difluoro-2-trifluoromethylphenol **10** which may be ascribed to the reaction of aromatic nucleophilic substitution of the fluorine atom in position *4* of the arising arene **9** under the action of the hydroxide anion (Scheme 5).

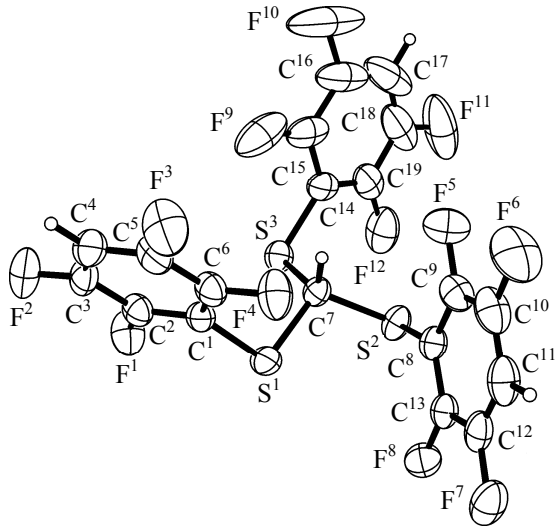
In the reaction of benzenethiol **1a** with pentafluorobenzal chloride **11** and pentafluorobenzotrichloride **12** in DMF in the presence of potassium carbonate we obtained respectively 1-(dichloromethyl)-2,3,5,6-tetrafluoro-4-[(2,3,5,6-tetrafluorophenyl)sulfanyl]benzene **13** and 1,2,4,5-tetrafluoro-3-[(2,3,5,6-tetrafluorophenyl)sulfanyl]-6-(trichloromethyl)benzene **14** resulting from the nucleophilic substitution of a fluorine atom in the *para*-position of compounds **11** and **12** for a tetrafluorobenzenethiol group. At the same time the reaction of pentafluorobenzenethiol **1b** with pentafluorobenzyl chloride **15** under similar conditions led to the formation in a large yield of 2,3,4,5,6-penta-

fluorobenzyl pentafluorophenyl sulfide **16** resulting from the nucleophilic substitution of a chlorine atom in the benzyl position for a pentafluorobenzenethiol group (Scheme 6), whereas the substitution of the fluorine atom in the *para*-position of compound **15** occurred to an insignificant extent.

The structure of compounds **2** and **4a** was proved by the data of X-ray diffraction analysis (see the figure). The symmetry of molecules in the crystal is close to C_2 and C_3 respectively. The bond distances S–C in the studied compounds are close to analogous bond lengths in, for example, bis(phenylsulfanyl)methane [16], bis-(4-bromophenylsulfanyl)methane [17], and bis{*o*-[(dibenzo[*d*,*g*][1,3,6]trithiosin-6-yl)thio]phenyl}sulfide [18]. Torsion angles HCSC of the latter compound lie in the range 15–92°, whereas in compound **4a** they are equal 42, 46, and 49°. According to gas phase DFT/B3LYP/L1 calculations this cisoid conformation of compound **4a** is the most stable. In the crystal molecular packing the C–F···π interactions frequently appear with the distances F-centroid 3.480(2)–3.869(3) (**2**) and 3.221(5)–3.396(3) Å (**4a**). Also weak C–H···F interactions should be mentioned [H···F 2.44 Å, CH···F 123° (**2**), 2.49 Å, 150° (**4a**)].



2



4a

Structures of bis(2,3,5,6-tetrafluorophenylsulfanyl)methane **2** and tris(2,3,5,6-tetrafluorophenylsulfanyl)methane **4a** according to XRD analysis data.

EXPERIMENTAL

Analytic measurements were carried out in the Multi-Access Chemical Service Center of the Siberian Branch of the Russian Academy of Sciences. The NMR spectra of reaction mixtures or solutions of individual compounds in CCl_4 and acetone-d_6 or $CDCl_3$ (10 vol %) were registered on spectrometers Bruker AV-300 [282.4 (^{19}F), and 300.1 (^{1}H) MHz] and Bruker Avance-400 [282.4 (^{19}F), and 400.1 (^{1}H) MHz], internal references were C_6F_6 (–162.9 ppm from $CFCl_3$) and HMDS (0.04 ppm from TMS). Chemical shifts are reported with respect to C_6F_6 and TMS. IR spectra were recorded on a spectrophotometer Bruker Vector 22 from pellets with KBr for solid and from films for liquid samples. UV spectra were obtained on a spec-trophotometer Hewlett Packard 8453 from solutions in hexane. The molecular mass and elemental compo-sition was determined from the high resolution mass spectra taken on instruments Finnigan MAT 8200 of DFS (ionizing electrons energy 70 eV). GC-MS spectra were measured on an instrument Hewlett-Packard G1081A equipped with a gas chromatograph HP 5890 Series II and a mass-selective detector HP 5971 (EI, 70 eV), capillary column HP-5 (5% of diphenyl-, 95% dimethylsiloxane) 30 m × 0.25 mm × 0.25 μm, carrier gas helium, flow rate 1 mL/min. Injector temperature 280°C, ion source temperature 173°C. Scanning rate 1.2 scan/s in mass region 30–650 a.u.m.

Analytic GLC was carried out on a chromatograph Hewlett Packard 5980, equipped with a quartz capillary column HP-5 (stationary phase dimethyldiphenylpoly-silixane block copolymer), 30 m × 0.52 mm × 2.6 μm, and a thermal conductivity detector (TCD). The melting points were measured on a Koeffler heating block.

X-ray diffraction analysis of compounds **2** and **4a** was performed using a diffractometer Bruker Kappa Apex (MoK_α-radiation, graphite monochromator, 296 K). The absorption corrections were made by the empirical using SADABS software. The structures were solved by the direct method and refined in the anisotropic approximation for nonhydrogen atoms applying the program package SHELX97. Hydrogen atoms were

refined in the *riding* model. The crystallographic data were deposited in the Cambridge Crystallographic Data Center.

Commercial reagents and solvents were used without special purification. Fluorodichloromethane **6** was a technical product from a gas cylinder. Initial polyfluoroarenethiols of 97–99% purity (GLC data) were obtained by procedure [19], thiol **8** of 91% purity contained an impurities of 1-chloro-2,3,5,6-tetrafluoro-4-trifluoromethylbenzene (6%) and 1-chloro-2,3,4,5-tetrafluoro-6-trifluoromethylbenzene (2%).

^{19}F NMR spectra of obtained 1,2,4,5-tetrafluorobenzene **5a** [20], pentafluorobenzene **5b** [21], 3-chloro-1,2,4,5-tetrafluorobenzene **5c** [22], 1,2,4,5-tetrafluoro-3-trifluoromethylbenzene **5d** [23] are consistent with the published data.

Reactions of thiol (1a) with dichloromethane, compounds (11 and 12), and of thiol (1b) with compound (15). To a solution of the reagent in DMF in the presence of potassium carbonate thiol **1a** or **1b** was added. The reaction mixture that turned yellow-green [7] was stirred with a magnetic stirrer at 20°C, observing a gradual disappearance of the coloration. On the completion of the reaction the mixture was poured into a 5-fold greater volume of 5% HCl solution. The organic product was separated and purified by crystallization from EtOH (**2**, **13**, and **16**) or by sublimation in a vacuum (**14**).

Bis(2,3,5,6-tetrafluorophenylsulfanyl)methane (2). From 1.97 g (10.82 mmol) of thiol **1a**, 0.46 g (5.41 mmol) of dichloromethane, and 1.53 g (11.09 mmol) of K_2CO_3 in 10.0 mL of DMF after 7 days 1.90 g (5.05 mmol) of compound **2** was obtained. Yield 93%. Colorless crystals. Purity 99.8% (GLC), mp 62–64°C (EtOH). IR spectrum, ν, cm^{-1}: 3109, 3082, 1630, 1616, 1493, 1435, 1379, 1232, 1176, 918, 847, 710. UV spectrum, λ_{max}, nm (log ε): 209 (4.20), 277 (4.02). ^{1}H NMR spectrum, δ,ppm: 4.42 s (2H), 7.16 t.t (2H$_{arom}$, $J_{H\text{-}F^{3,5}}$ 9.5, $J_{H–F^{2,6}}$ 7.2 Hz). ^{19}F NMR spectrum, δ, ppm: 24.2 m (4F$^{3,3',5,5'}$), 28.5 m (4F$^{2,2',6,6'}$). Mass spectrum, *m/z* (I_{rel}, %): 376 (8) $[M]^+$, 195 (100) $[M – HC_6F_4S]^+$, 181 (4) $[M – HC_6F_4SCH_2]^+$, 163 (4) $[M – C_6HF_4S_2]^+$, 137 (6) $[M – C_8H_3F_4S_2]^+$. Found, %: C 41.45; H 1.06; F 40.60; S 16.90. $[M]^+$ 375.9621. $C_{13}H_4F_8S_2$. Calculated, %: C 41.49; H 1.07; F 40.39; S 17.04. $[M]^+$ 375.9621.

XRD analysis. Monoclinic system, space group $P2_1/c$. $C_{13}H_4F_8S_2$, *M* 376.28, *a* 14.8264(9), *b* 5.2109(3), *c* 18.032(1) Å, β 90.736(2)°, *V* 1393.0(2) Å^3, *Z* 4, d_{calc} 1.794 g/cm^3. 3595 indepen-dent reflections (θ_{max} 28.7°), among them 2786 observed reflections. Final refinement parameters *R* 0.0394, *S* 0.984 (CCDC 1405717).

Chloromethyl 2,3,5,6-tetrafluorophenyl sulfide (3) [6] was identified in the reaction mixture. ^{1}H NMR spectrum, δ, ppm: 4.90 s (2H), 7.27 m (1H$_{arom}$). ^{19}F NMR spectrum, δ, ppm: 24.6 m (2F^{3,5}), 28.9 m (2F^{2,6}). GC-MS: *M* 230.

1-(Dichloromethyl)-2,3,5,6-tetrafluoro-4-[(2,3,5,6-tetrafluorophenyl)sulfanyl]benzene (13). The reaction mixture obtained from 0.21 g (1.15 mmol) of thiol **1a**, 0.29 g (1.16 mmol) of benzyl chloride **11**, and 0.17 g (1.23 mmol) of K_2CO_3 in 2.0 mL of DMF was stirred for 5 h at 22°C and treated as described above. Yield 0.37 g (0.90 mmol) (78%). Colorless crystals, mp 40–42°C (EtOH). Purity 97% (GC-MS). IR spectrum, ν, cm^{-1}: 3087, 1631, 1495, 1481, 1441, 1398, 1381, 1311, 1281, 1236, 1219, 1178, 1128, 1055, 968, 920, 893, 849, 775, 712, 602. UV spectrum, λ_{max}, nm (log ε): 203 (4.19), 287 (3.79). ^{1}H NMR spectrum, δ, ppm: 6.92 s (1H, $CHCl_2$), 7.14m (1H, H$_{arom}$). ^{19}F NMR spectrum, δ, ppm: 22.4 m (2F^{3,5}), 25.2 m (2F$^{3',5'}$), 29.3–29.5 m (4F$^{2,2',6,6'}$). Mass spectrum, *m/z* (I_{rel}, %): 414 (14) $[M + 2]^+$, 412 (19) $[M]^+$, 379 (35) $[M + 2 – Cl]^+$, 378 (14) $[M + 1 – Cl]^+$, 377 (100) $[M – Cl]^+$, 228 (10), 188 (8), 161 (8). Found, %: C 37.58; H 0.41; Cl 16.96; F 37.08; S 7.75. $[M]^+$ 411.9117. $C_{13}H_2Cl_2F_8S$. Calculated, %: C 37.80; H 0.49; Cl 17.16; F 36.79; S 7.76. $[M]^+$ 411.9121.

1,2,4,5-Tetrafluoro-3-[(2,3,5,6-tetrafluorophenyl)sulfanyl]-6-(trichloromethyl)benzene (14). A mixture of 0.24 g (1.29 mmol) of thiol **1a**, 0.38 g (1.30 mmol) of compound **12**, and 0.18 g (1.30 mmol) of K_2CO_3 in 2.0 mL of DMF was stirred for 5 h at 22°C and treated as described above. Yield 0.47 g (1.05 mmol) (81%). Light yellow liquid. IR spectrum, ν, cm^{-1}: 3082, 1632, 1495, 1470, 1441, 1383, 1281, 1236, 1178, 1132, 1045, 985, 922, 825, 783, 727, 714, 702. ^{1}H NMR spectrum, δ, ppm: 7.16 t.t ($J_{H\text{-}F^{3',5'}}$ 9, $J_{H\text{-}F^{2',6'}}$ 7 Hz). ^{19}F NMR spectrum, δ, ppm: 25.3 m (2F$^{3',5'}$), 29.0 m (2F), 29.1 m (2F), 29.6 m (2F). Found $[M]^+$ 445.8735. $C_{13}HCl_3F_8S$. Calculated $[M]^+$ 445.8731.

2,3,4,5,6-Pentafluorobenzyl pentafluorophenyl sulfide (16). A mixture of 1.01 g (5.05 mmol) of thiol **1b**, 1.10 g (5.08 mmol) of compound **15**, and 0.70 g (5.07 mmol) of K_2CO_3 in 10 mL of DMF was stirred for 4.5 h at 22°C and treated as described above. We obtained 1.85 g of white precipitate containing according to GC-MS data 94% of compound **16**. Yield 90%.

Colorless crystals, mp 69–70°C (EtOH). IR spectrum, ν, cm^{-1}: 1659, 1641, 1524, 1506, 1485, 1433, 1310, 1126, 1097, 993, 978, 883, 864. ^1H NMR spectrum, δ, ppm: 4.05 br.s (CH_2). ^{19}F NMR spectrum, δ, ppm: 0.9 m (2F), 1.7 m (2F), 8.5 t (1F, *J* 20 Hz), 12.0 t.t (1F, *J* 20.3 Hz), 18.1 m (2F), 29.9 m (2F). Found, %: C 41.24; H 0.64; F 49.91; S 8.28. $[M]^+$ 379.9715. $C_{12}H_2F_{10}S$. Calculated, %: C 41.07; H 0.53; F 49.97; S 8.43. $[M]^+$ 379.9712.

Reaction of polyfluoroarenethiols with trihalomethanes. To a solution of sodium hydroxide in aqueous 1,4-dioxane polyfluoroarenethiol **1** was added, then $CHCl_3$ or $CHBr_3$ was added, or a flow of compound **6** was passed (input ~3L/h). The reaction mixture was heated with stirring at a desired temperature in a flask equipped with a reflux condenser. On completion of the reaction the reaction mixture was cooled, treated with conc. HCl till pH < 1. The organic product was separated, dried with $CaCl_2$, and analyzed by the methods GC-MS, GLC, ^{19}F and ^1H NMR spectroscopy.

Reaction of thiol (1a) with $CHCl_3$. In DMF. The reaction mixture obtained from 1.02 g (5.60 mmol) of thiol **1a**, 0.23 g (1.93 mmol) of $CHCl_3$ in 2.0 mL of DMF, and 0.76 g (5.51 mmol) of K_2CO_3 after 14 days at room temperature contained thiol **1a** and 1,2,4,5-tetrafluorobenzene **5a** [20] in the ratio 92 : 8 (^{19}F NMR spectrum).

In 1,4-dioxane. From 3.05 g (16.76 mmol) of thiol **1a**, 2.97 g (24.87 mmol) of $CHCl_3$, 6.95 g (173.75 mmol) of NaOH in solution of 17 mL of 1,4-dioxane and 10 mL of water (14 h, 48–53°C) a mixture was obtained containing according data thiol **1a**, tris-(2,3,5,6-tetrafluorophenylsulfanyl)methane **4a**, and arene **5a** in a ratio 8 : 89 : 3 (^{19}F, ^1H NMR). To the reaction mixture conc. HCl was added, the products were extracted with $CHCl_3$, the organic layer was separated, washed with water and 10% solution of Na_2CO_3. The solvent and arene **5a** were distilled off on a rotary evaporator. Yield of **tris(2,3,5,6_tetrafluorophenylsulfanyl)methane (4a)** 2.45 g (4.40 mmol) (79%). Colorless crystals, mp 92–94°C (EtOH). IR spectrum, ν, cm^{-1}: 3083, 1633, 1608, 1493, 1436, 1377, 1235, 1179, 1128, 917, 893, 862, 850, 760, 734, 712. UV spectrum, λ_{max}, nm (log ε): 215 (4.45), 275 (4.18). ^1H NMR spectrum, δ, ppm: 6.89 s (1H, $C_{sp^3}H$), 7.21 m ($3H_{arom}$). ^{19}F NMR spectrum, δ, ppm: 25.1 m ($2F^{3,5}$), 29.6 m ($2F^{2,6}$). Mass spectrum, *m/z* (I_{rel}, %): 556 (0.1) $[M]^+$, 377 (12) $[M + 2 - C_6HF_4S]^+$, 376 (20) $[M + 1 - C_6HF_4S]^+$, 375 (100) $[M - C_6HF_4S]^+$, 194 (26) $[M - C_{12}H_2F_8S_2]^+$, 193 (35) $[M - C_{12}H_3F_8S_2]^+$, 181 (11) $[M - C_{13}H_3F_8S_2]$. Found, %: C 40.94; H 0.80; F 41.06; S 17.45. $[M - C_6HF_4S]^+$ 374.9541. $C_{13}H_3F_8S_2$. Calculated, %: C 41.01; H 0.72; F 40.97; S 17.29. $[M - C_6HF_4S]^+$ 374.9520.

XRD analysis. Orthorhombic system, space group $Pna2_1$. $C_{19}H_4F_{12}S_3$, *M* 556.40, *a* 9.9472(4), *b* 12.7033(5), *c* 16.4762(6) Å, *V* 2082.0(1) $Å^3$, *Z* 4, d_{calc} 1.775 g/cm^3. 4600 independent reflections (θ_{max} 27.1°), among them 3706 observed reflections. Final refinement parameters *R* 0.0383, *S* 1.064. The ellip-soids of one tetrafluorophenyl group are strongly elongated. An attempt was done of disordering this group by two positions. This led to a small decrease (0.0018) in the *R*-factor, but the ellipsoids remained strongly extended. (CCDC 1405718).

Reaction of compound (4a) with NaOH. To a solution of 0.29 g (7.25 mmol) of NaOH in a mixture of 2.0 mL of 1,4-dioxane and 1.3 mL of water 0.57 g (1.02 mmol) of compound **4a** was added, and the reaction mixture was heated for 5 h at 75°C, cooled, poured into 5% HCl solution (6 mL), extracted with CCl_4 (3 mL), the organic layer was separated, dried with $CaCl_2$ to obtain a mixture of compounds **4a** and **5a**, 97 : 3 (^{19}F NMR spectrum).

Reaction of 4-chloro-2,3,5,6-tetrafluorobenzenethiol (1c) with $CHCl_3$. A mixture of 2.05 g (9.47 mmol) of thiol **1c**, 2.02 g (16.92 mmol) of $CHCl_3$, and 4.69 g (117.25 mmol) of NaOH in a mixture of 20 mL of 1,4-dioxane and 10 mL of water after heating (argon atmosphere, 37 h, 74–77°C) was treated with 3% HCl solution (11 mL), the separated precipitate of compound **4c** (0.19 g) was filtered off, the filtrate was extracted with $CHCl_3$ (10 and 5 mL), the organic layer was separated, washed with 10% solution of Na_2CO_3 and with water. To the extract 0.2042 g (1.098 mmol) of hexafluorobenzene was added as internal quantitative reference and the solution was analyzed by ^{19}F NMR spectroscopy and GC-MS method. The extract contained compound **4c**, 3-chloro-1,2,4,5-tetrafluorobenzene **5c** [22], and hexafluorobenzene in a ratio 3 : 78 : 19 (^{19}F NMR spectrum). Yield in the mixture of arene **5c** 48%, overall yield of compound **4c** 14%.

Tris(4-chloro-2,3,5,6-tetrafluorophenylsulfanyl)-methane (4c), mp 105–107°C (EtOH). IR spectrum, ν, cm^{-1}: 3082, 1631, 1497, 1375, 1215, 1179, 1043, 963, 893, 819, 668, 567. ^1H NMR spectrum, δ, ppm: 6.91 s (1H). ^{19}F NMR spectrum, δ, ppm: 23.4 m ($6F^{3,5}$), 31.0 m ($6F^{2,6}$). GC-MS: *M* 661.

Reaction of thiol (1d) with $CHCl_3$. A mixture of 1.50 g (6.00 mmol) of thiol **1d**, 2.47 g (20.69 mmol) of $CHCl_3$, and 2.83 g (70.75 mmol) of NaOH in 10 mL of 1,4-dioxane and 8 mL of water after heating (9 h, 88°C) was subjected to steam distillation to obtain 1.17 g of a mixture containing (GLC) 15% of initial thiol **1d** and 65% of arene **5d**. Yield of arene **5d** in the mixture 58%, 66% calculated on reacted thiol **1d**.

Reaction of thiol (1a) with $CHBr_3$. The reaction mixture obtained from 1.60 g (8.79 mmol) of thiol **1a**, 4.53 g (17.93 mmol) of $CHBr_3$, and 3.64 g (91.00 mmol) of NaOH in 12 mL of 1,4-dioxane and 9 mL of water (60–70°C, 8 h) contained compounds **4a** and **5a** in a ratio 95 : 5 (^{19}F NMR). After adding 5% HCl solution till pH < 1 the separated precipitate of compound **4a** was filtered off and dried in air. We obtained 1.15 g (2.07 mmol) of compound **4a**, yield 70%.

Reaction of thiol (1d) with $CHBr_3$. A mixture of 1.24 g (4.96 mmol) of thiol **1d**, 1.88 g (7.44 mmol) of $CHBr_3$, 2.17 g (54.25 mmol) of NaOH in 10 mL of 1,4-dioxane and 8 mL of water after heating (40 h, 88°C) was subjected to steam distillation; we obtained 0.81 g of a mixture containing (GLC) 29% of thiol **1d** and 59% of arene **5d**. Yield of arene **5d** in the mixture 44%, 54% calculated on reacted thiol **1d**.

Reaction of thiol (1a) with fluorodichloromethane (6). The flow of compound **6** was passed for 6 h at 55°C through a mixture of 22.05 g (121.15 mmol) of thiol **1a** and 23.05 g (576.25 mmol) of NaOH in 160 mL of 1,4-dioxane and 132 mL of water. Then conc. HCl was added till pH < 1, and the mixture was subjected to steam distillation. We obtained 24.40 g of a mixture containing (GLC) 17% of initial thiol **1a**, 65% of sulfide **7a**, and 3% of arene **5a**. Yield of sulfide **7a** in the mixture 53%, 65% calculated on reacted thiol **1a**, 65%. Sulfide **7a** was isolated by vacuum distillation.

Fluorochloromethyl (2,3,5,6-tetrafluorophenyl) sulfide (7a). Colorless liquid, bp 85°C (12–14 mmHg). ^{1}H NMR spectrum, δ, ppm: 7.1 d (1H, $J_{H\text{-}F\alpha}$ 55 Hz), 7.2 m ($1H_{arom}$). ^{19}F NMR spectrum, δ, ppm: 25.2 m ($2F^{3,5}$), 31.0 m ($2F^{2,6}$), 59.2 d ($1F^{\alpha}$, $J_{F\alpha\text{-}H}$ 55 Hz). Found,%: C 33.76; H 0.84; Cl 14.07; F 37.88; S 12.75. $[M]^+$ 247.9488. $C_7H_2ClF_5S$. Calculated, %: C 33.82; H 0.81; Cl 14.26; F 38.21; S 12.90. $[M]^+$ 247.9486.

Reaction of thiol (1b) with fluorodichloromethane (6). The flow of compound **6** was passed for 5 h at 45°C through a mixture of 11.81 g (59.05 mmol) of thiol **1b**, 12.42 g (310.50 mmol) of NaOH in 80 mL of 1,4-dioxane and 66 mL of water. Then conc. HCl was added till pH < 1, and the mixture was subjected to steam distillation. We obtained 13.58 g of a mixture containing (GLC) 6% of initial thiol **1b**, 63% of sulfide **7b**, and 2% of arene **5b**. Yield of sulfide **7b** in the mixture 54%. Sulfide **7b** was isolated by vacuum distillation.

Fluorochloromethyl pentafluorophenyl sulfide (7b). Colorless liquid, bp 76°C (12–14 mmHg). ^{1}H NMR spectrum, δ, ppm: 7.0 d (1H, $J_{H\text{–}F\alpha}$ 55 Hz). ^{19}F NMR spectrum, δ, ppm: 2.3 m ($2F^{3,5}$), 14.5 t.t ($1F^4$, $J_{F4\text{–}F3,5}$ 21, $J_{F4\text{–}F2,6}$ 5 Hz), 32.3 m ($2F^{2,6}$), 59.4 d (1F, $J_{F\alpha\text{-}H}$ 55 Hz). Found, %: C 31.62; H 0.47; Cl 13.53; F 42.49; S 11.87. $[M]^+$ 265.9386. C_7HClF_6S. Calculated, %: C 31.54; H 0.38; Cl 13.30; F 42.76; S 12.03. $[M]^+$ 265.9392.

Reaction of thiol (1d) with fluorodichloromethane (6). The flow of compound **6** was passed for 6 h at 55°C through a mixture of 20.13 g (80.52 mmol) of thiol **1d**, 21.04 g (526.0 mmol) of NaOH in 160 mL of 1,4-dioxane and 132 mL of water. Then conc. HCl was added till pH < 1, and the mixture was subjected to steam distillation. We obtained 30.64 g of a mixture containing (GLC) 9% of initial thiol **1d**, 11% of sulfide **7d**, 19% of arene **5d**, and 1,4-dioxane. Yields of sulfide **7d** and arene **5d** in the mixture were 15% and 36% respectively, calculated on reacted thiol **1d**. Sulfide **7d** was isolated by vacuum distillation of reaction mixtures obtained in several runs.

Fluorochloromethyl 2,3,5,6-tetrafluoro-4-trifluoromethylphenyl sulfide (7d). Colorless liquid, bp 84°C (12–13 mmHg). ^{1}H NMR spectrum, δ, ppm: 7.2 d ($1H_{H\text{-}F\alpha}$, $J_{H\text{-}F\alpha}$ 55 Hz). ^{19}F NMR spectrum, δ, ppm: 23.6 m ($2F^{3,5}$), 32.9 m ($2F^{2,6}$), 59.6 d ($1F^{\alpha}$, $J_{F\alpha\text{-}H}$ 55 Hz), 105.2 t (3F, $J_{CF\text{-}F3,5}$ 22 Hz). Found, %: C 30.21; H 0.44; Cl 10.93; F 48.42; S 10.30. $[M]^+$ 315.9369. C_8HClF_8S. Calculated, %: C 30.35; H 0.32; Cl 11.20; F 48.01; S 10.13. $[M]^+$ 315.9360.

Reaction of sulfide (7d) with NaOH. To a solution of 1.73 g (43.25 mmol) of NaOH in 13 mL of 1,4-dioxane and 11 mL of water was added 2.07 g (98%, 6.41 mmol) of sulfide **7d**, and the reaction mixture was heated for 6 h at 55°C while stirring. On cooling 20 mL of 5% HCl solution was added till pH < 1. The organic layer was separated. We obtained a mixture of arene **5d** and thiol **1d** in a ratio 90 : 10 (^{19}F NMR spectrum) without impurity of initial sulfide **7d**. The steam distillation provided 0.92 g (4.22 mmol) of arene **5d**. Yield 66%.

Reaction of 2,3,5-trifluoro-4-trifluoromethyl-6-chlorobenzenethiol (8) with $CHCl_3$. A mixture of 2.96 g (11.10mmol) of thiol **8**, 2.02 g (16.92 mmol) of $CHCl_3$, 4.82 g (120.5mmol) of NaOH in 20 mL of 1,4-dioxane and 13mL of water after heating (21 h, 48–54°C) was subjected to steam distillation, and we obtained 1.21 g of a mixture containing (GLC) 2% of initial thiol **8**, 45% of arene **9**, and 9% of phenol **10** along with 1,4-dioxane. Yield in the mixture of arene **9** 21%. Arene **9** was isolated by distillation of reaction mixtures obtained in several runs.

1-Chloro-2,4,5-trifluoro-3-trifluoromethylbenzene (9). Colorlesss liquid. Purity 96% (GLC), bp 111–113°C. ^{1}H NMR spectrum, δ, ppm: 7.5 d.t (1H, $J_{H–F^1}$ 9, $J_{H–F^{2,4}}$ 7 Hz). ^{19}F NMR spectrum, δ, ppm: 24.4 d.d.d (1F, F^1, $J_{F1–H}$ 9 Hz), 27.0 q.d.d (1F, F^2, J_{F1-F2} 22, $J_{F2–H}$ 7 Hz), 46.0 q.d.d (1F, F^4, $J_{F1–F4}$ 14, $J_{F4–H}$ 7 Hz), 105.1 t (3F, CF_3, $J_{CF3–F^{2,4}}$ 22 Hz). Found, %: C 35.27; H 0.55; Cl 14.87; F 48.83. $[M]^+$ 233.9672. C_7HClF_6. Calculated, %: C 35.85; H 0.43; Cl 15.12; F 48.60. $[M]^+$ 233.9671.

4-Chloro-3,6-difluoro-2-trifluoromethylphenol (10) was identified in the mixture. ^{1}H NMR spectrum, δ, ppm: 7.3 d.d (1H, H_{arom}, J_{H-F6} 11, J_{H-F3} 7 Hz), 8.0 br.s (1H, OH). ^{19}F NMR spectrum, δ, ppm: 20.5 d.d (1F, F^6, $J_{F6–H}$ 11 Hz), 44.2 q.d.d (1F, F^3, $J_{F3–F6}$ 14, $J_{F3–H}$ 7 Hz), 105.1 d (3F, CF_3, $J_{CF3–F3}$ 26 Hz). GC-MS: *M* 231.

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