Synthesis of Polychlorofluoroarenes from Polyfluoroarenethiols, SOCl₂ and SO₂Cl₂

P. V. Nikul’shin, A. M. Maksimov, R.A. Bredikhin, and V. E. Platonov

e-mail: platonov@nioch.nsc.ru

Received December, 2017

Abstract. The thiol group in polyfluoroarenethiols was replaced by the chlorine atom, using SOCl₂ and SO₂Cl₂ as chlorinating reagents. By heating in ampules at 200–220°C polyfluoro-and polychlorofluoroarenethiols with SO₂Cl₂ monochloro- and dichloropolyfluoroarenes and also 1,2,4-trichlorotrifluorobenzene were synthesized. Dichloropolyfluoroarenes contain chlorine atoms in ortho- and para-positions.

Keywords: Thionyl chloride, sulfuryl chloride, thiol group, polyfluoroarenethiols, polychlorofluoroarenes

Polychlorofluoroarenes are important products for the synthesis of a large number of polyfluoroaromatic compounds with various functional groups. Selective participation of the C_Ar-Cl bond in the metallation reactions is one of the directions of transformation of chloropolyfluoroarenes. The Grignard reagents [1], polyfluoroaryl lithiums [1] and polyfluoroarylzinc compounds [2] formed from chloropolyfluoroarenes are versatile and convenient to use for the synthesis of a large number of functional derivatives of polyfluoroaromatic compounds. In this connection, in recent years, we have been developing a method of synthesis of chloropolyfluoroarenes consisting in substitution of the thiol group in polyfluoroarenethiols by chlorine atom. By this method a series of chloropolyfluoroaromatic compounds was synthesized in high yields [3, 4]. The process was realized at high temperature (~400°C) in a flow reactor as join pyrolysis of polyfluoroarenethiols with Cl₂ as well as with SOCl₂ and SO₂Cl₂ as chlorine sources [3]. In addition to the reactions in the flow system, we studied the conversion of polyfluoroarenethiols with PCl₅ in ampoules at ~ 200°C, which also led to the preparation of chloropolyfluoroarenes [4]. On the example of the reaction of pentafluorobenzenethiol 1 with Cl₂ and PCl₅, carried out under different conditions, the scheme for the replacement of the thiol group by the chlorine atom was suggested. This scheme includes the
intermediate formation of pentafluorobenzenesulfenyl chloride 2 and its conversion under the action of Cl₂ and PCl₅ to chloropentafluorobenzene 3 with the participation of an intermediate radical σ-complex [3, 4].

Use in the gas phase process, along with Cl₂, thionyl chloride and sulfuryl chloride as chlorine sources, characterizes the reaction of substitution of the thiol group in polyfluoroarenethiols by the chlorine atom in the methodical and practical sense as a rather general way of synthesis of chloropolyfluoroarenes. The reactions of polyfluoroarenethiols with PCl₅, carried out in ampoules at a lower temperature (~200°C) [4], are additional evidence in favor of such conclusion. We have also studied the conversion of polyfluoroarenethiols with SOCl₂ and SO₂Cl₂ in ampoules under similar conditions to increase the possibilities of this type of reactions.

We have shown that when thiol 1 was heated with SOCl₂ or SO₂Cl₂ in ampoules at ~200°C, arene 3 was obtained with high yields. It was found that the reaction of thiol 1 with SOCl₂ requires a longer time to achieve a good yield of arene 3 than in the case of using SO₂Cl₂ at the same temperature of process (Scheme 1).

![Scheme 1](image)

When the reaction time of thiol 1 with SOCl₂ was reduced from 24 h to 5 h at ~200°C, the reaction mixture contained arene 3, the supposed decafluorodiphenylpolysulfanes and sulfenyl chloride 2 in a ratio of ~ 55: 34: 11, respectively (according to NMR ²⁹F).

In the reaction of thiol 1 with SO₂Cl₂ at ~200 °C for 2.5 h, the reaction mixture contained arene 3 in a larger amount than in the case of the reaction of thiol 1 with SOCl₂ for 5 h. In addition to arene 3, the supposed decafluorodiphenylpolysulfanes and sulfenyl chloride 2 were also present in the mixture. The ratio of these products was ~ 79: 18: 3, respectively (according to NMR ²⁹F). However, a comparison of the results of the reactions of thiol 1 with SOCl₂ (5 h) and SO₂Cl₂ (2.5 h) is relative, since the mass yields of the reaction mixtures have not been evaluated.

The above results of the reactions of thiol 1 with SOCl₂ and SO₂Cl₂ may indicate that the process involving SO₂Cl₂ takes less time than using SOCl₂. Therefore, we further carried out the reactions of polyfluoroarenethiols with SO₂Cl₂.

Sulfenyl chloride 2 and decafluorodiphenylpolysulfanes formed in the reaction of thiol 1 with SO₂Cl₂ at ~ 200°C for 2.5 hours can be of interest to obtain arene 3 from them under the action of SO₂Cl₂. In this connection, the reaction of sulfenyl chloride 2 with SO₂Cl₂ (~ 200 °C, 5 h) was carried out. As a representative of these polysulfanes, it seemed reasonable to carry out the
reaction of decafluorodiphenyldisulfane 4 with SO₂Cl₂ in the reaction conditions of thiol 1 with SO₂Cl₂ (~200°C, 5 h).

As it turned out, when sulfenyl chloride 2 and disulfane 4 were heated with SO₂Cl₂, compound 3 was also obtained in high yields (Scheme 2).

**Scheme 2**

A similar process occurs in the case of para-substituted derivatives of thiol 1. Thus, when 2,3,5,6-tetrafluorobenzenethiol 5 was heated with SO₂Cl₂, 1-chloro-2,3,5,6-tetrafluorobenzene 6 was obtained. The reaction of 4-chloro-2,3,5,6-tetrafluorobenzenethiol 7 with SO₂Cl₂ gave 1,4-dichloro-2,3,5,6-tetrafluorobenzene 8. When 4-tifluoromethyl-2,3,5,6-tetrafluorobenzenethiol 9 was reacted with SO₂Cl₂, 4-chloroheptafluorotoluene 10 was obtained in a high yield (Scheme 3).

**Scheme 3**

At the same time, the attempt to obtain 1-bromo-4-chloro-2,3,5,6-tetrafluorobenzene 11 by chlorination of 4-bromo-2,3,5,6-tetrafluorobenzenethiol 12 at ~ 180°C showed that in this reaction the replacement of the bromine atom by chlorine occurs also to a large extent. With an increase in the reaction temperature to ~ 240°C, compound 8 was obtained with a small admixture of arene 11 (Scheme 4). We have previously shown that a similar process occurred in the reaction of thiol 12 with PCl₃ under similar conditions [4].

**Scheme 4**
5-Chlorononafluoroindan 15 and 5,6-dichloroctafluoroindan 16 were obtained from 5-nonafluorindanthiol 13 and 6-chloroctafluoroindan-5-thiol 14, respectively (Scheme 5).

Scheme 5

Heating of a mixture of dichlorotrifluorobenzenethiols with SO$_2$Cl$_2$ in an ampoule was used to synthesize practically individual 1,2,4-trichlorotrifluorobenzene 17 (Scheme 6).

Scheme 6

The isomeric mixture of dichlorotrifluorobenzenethiols was prepared from a technical mixture of $o$-, $m$-, $p$-C$_6$Cl$_2$F$_4$ and KSH (90% yield) [5]. When thiol 1 is mixed with SO$_2$Cl$_2$ at room temperature, mainly sulfenyl chloride 2 is formed, along with a small amount of disulfane 4 (according to NMR $^{19}$F, Scheme 7).

Scheme 7

It is possible that compound 4 in the reaction with SO$_2$Cl$_2$ is converted to sulfenyl chloride 2 [6]. The latter, under the action of the chlorine atom formed from SO$_2$Cl$_2$ [7-9] (Equations 3 and 4, Scheme 8), is converted to arene 3, including the intermediate formation of the radical $\sigma$-complex A.
[4]. Probably, the reaction of thiol 1 with SO₂Cl₂ in the flow system at ~ 400°C, described by us earlier [3], proceeds in a similar manner.

**Scheme 8**

![Scheme 8](image)

**EXPERIMENTAL**

Authors would like to acknowledge the Multi-Access Chemical Service Center SB RAS for spectral and analytical measurements.

The ¹⁹F and ¹H NMR spectra were recorded on a Bruker AV-300 [282.4 (¹⁹F) and 300 (¹H) MHz] spectrometer in CCl₄ with added (CD₃)₂CO, internal reference C₆F₆ and HMDS (0.04 ppm from TMS). Positive values of chemical shifts correspond to the signal downfield shift.

GC analysis was carried out on gas chromatograph LKhM-72 with a detector of thermal conductivity (TDC) and packed (stuffed) columns 2 m long and 4 mm inside diameter, which were filled with a solid inert carrier of Chromosorb W-AW-DMCS, impregnated with a liquid stationary phase (dimethyl polysiloxane BC-1 or dimethyltrifluoropropyl polysiloxane SCTF-50) in an amount of 15% of the mass of the carrier. The flow rate of helium through each of the columns is 60 ml/min. The temperature of the evaporator is 280°C, the initial temperature of the column is 50°C - 1 min, 10 deg/min to 280°C, the isotherm at 280°C before the exit of all components of the sample, the temperature of TDC 280°C.

Initial polyfluoroarenethiols were obtained by the method [10].

The formation of compounds 2 and 4 and the final products by reactions of the polyfluoroarenethiols chlorination was confirmed by comparing the chemical shifts and spin-spin coupling constants of the ¹⁹F and ¹H NMR spectra of these compounds with the literature data [3, 5, 11].

**Method 1.** Polyfluoroarenethiol was placed in an ampoule and SOCl₂ or SO₂Cl₂ was added by portions. After the end of the visible gas evolution, the ampoule was sealed, placed into a metal case, and heated. After the reaction completed, the ampoule was cooled, opened, its content was placed into a flask under a layer of water with ice (80–100 g), and subjected to steam distillation.
The reaction product was separated, dried with CaCl\(_2\), and analyzed by GC, \(^{19}\)F and \(^1\)H NMR methods.

Similarly, the reactions of sulphenyl chloride 2 and disulfane 4 with SO\(_2\)Cl\(_2\) were carried out. In this case, the ampoule was sealed immediately after the reagents were placed in it.

**Reactions of pentafluorobenzenethiol 1 with SOCl\(_2\).** From 2.77 g (13.84 mmol) of compound 1 and 3.30 g (27.74 mmol) of SOCl\(_2\) (200–202°C, 24 h), 2.52 g of compound 3 were obtained (GC content: 97.3%), yield: 88%.

The results of the reactions of polyfluoroarenethiolos (1, 5, 7, 9, 13, 14, a mixture of C\(_6\)Cl\(_2\)F\(_3\)SH, and also compounds 2 and 4) with SO\(_2\)Cl\(_2\) are given in Table 1.

**Table 1**

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Substrate, g (mmol)</th>
<th>SO(_2)Cl(_2), g (mmol)</th>
<th>The molar ratio of the substrate to SO(_2)Cl(_2)</th>
<th>Temp. (°C)</th>
<th>Time (h)</th>
<th>Yield of mixture (g)</th>
<th>The content (yield) of the product by GC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1, 2.76 (13.79)</td>
<td>4.01 (29.95)</td>
<td>2.17</td>
<td>203-205</td>
<td>5</td>
<td>2.55</td>
<td>3, 98.3 (90)</td>
</tr>
<tr>
<td>2</td>
<td>2, 3.01 (12.83)</td>
<td>3.76 (21.21)</td>
<td>2.19</td>
<td>200-202</td>
<td>5</td>
<td>2.37</td>
<td>3, 98.0 (89)</td>
</tr>
<tr>
<td>3</td>
<td>4, 3.05 (7.66)</td>
<td>2.08 (15.53)</td>
<td>2.03</td>
<td>203-205</td>
<td>5</td>
<td>2.67</td>
<td>3, 91.2 (85)</td>
</tr>
<tr>
<td>4</td>
<td>5, 2.24 (12.30)</td>
<td>3.40 (25.39)</td>
<td>2.06</td>
<td>200-202</td>
<td>5</td>
<td>2.07</td>
<td>6, 99.0 (90)</td>
</tr>
<tr>
<td>5</td>
<td>7, 3.29 (15.19)</td>
<td>4.21 (31.41)</td>
<td>2.07</td>
<td>203-205</td>
<td>5</td>
<td>2.91</td>
<td>8, 99.1 (87)</td>
</tr>
<tr>
<td>6</td>
<td>9, 2.39 (9.55)</td>
<td>2.88 (21.51)</td>
<td>2.25</td>
<td>218-220</td>
<td>5</td>
<td>2.17</td>
<td>10, ~100 (90)</td>
</tr>
<tr>
<td>7</td>
<td>13, 1.98 (6.34)</td>
<td>1.79 (13.37)</td>
<td>2.11</td>
<td>220-222</td>
<td>5</td>
<td>1.89</td>
<td>15, 99.4 (94)</td>
</tr>
<tr>
<td>8</td>
<td>14, 3.00 (9.13)</td>
<td>2.54 (18.97)</td>
<td>2.08</td>
<td>218-220</td>
<td>5</td>
<td>2.80</td>
<td>16, 99.3 (92)</td>
</tr>
<tr>
<td>9</td>
<td>a mixture of C(_6)Cl(_2)F(_3)SH, 3.04 (13.37)</td>
<td>3.87 (28.90)</td>
<td>2.22</td>
<td>203-205</td>
<td>5</td>
<td>2.82</td>
<td>17, 99.4 (91)</td>
</tr>
</tbody>
</table>

0.15 g (0.75 mmol) of compound 1 was mixed in a flask with 0.21 g (1.57 mmol) of SO\(_2\)Cl\(_2\) at room temperature. At the end of the gas evolution, the resulting mixture was compounds 2 and 4 in a ratio of ~ 95: 5, respectively (\(^{19}\)F NMR data).

**Method 2.** Compound 1 was placed in an ampoule and SOCl\(_2\) or SO\(_2\)Cl\(_2\) was added by portions. After the end of the visible gas evolution, the ampoule was sealed, placed into a metal case, and heated. After the reaction completed, the ampoule was cooled, opened, its content was dissolved in ~ 2 ml of methylene chloride and analyzed by \(^{19}\)F NMR.

Heating of 0.12 g (0.60 mmol) of compound 1 with 0.16 g (1.35 mmol) of SOCl\(_2\) at 202-204°C for 5 h gave a mixture of compounds 2, 3, 4 (NMR \(^{19}\)F) and also probably decafluorodiphenyltrisulfane (\(\delta\) ppm: 13.5 (F-4 and F-4’ ) [12]) and decafluorodiphenyltetrasulfane.
(δ ppm: 13.4 (F-4 and F-4') ( [12]) contained in the methylene chloride solution. In these two polysulfanes, chemical shifts of meta-atoms of fluorine are in the region of 2.1±2.6 ppm [12], ortho- atoms of fluorine are in the region of 31±32 ppm [12]. The ratio of compounds 2, 3, 4 and a mixture of decafluorodiphenyltrithiocyanuric chloride and -tetrastannane was ~ 11: 55: 10: 24, respectively (19F NMR data).

Similarly, heating of 0.20 g (1.00 mmol) of thiol 1 with 0.27 g (2.02 mmol) of SO2Cl2 at 200-202°C for 2.5 h gave compounds 2, 3, 4 and a mixture of decafluorodiphenyltrithiocyanuric chloride and -tetrastannane in a ratio of ~ 3: 79: 3: 15, respectively (19F NMR data).

Reactions of 4-bromo-2,3,5,6-tetrafluorobenzenethiol (12) with SO2Cl2. From 0.32 g (1.23 mmol) of compound 12 and 0.34 g (2.54 mmol) of SO2Cl2 (180-182°C, 5 h), a mixture containing compounds 8 and 11 in a ratio of 69: 31, respectively.) was obtained (NMR 19F data). When the reaction temperature was increased to 238-240°C (5 h), heating of 0.27 g (1.03 mmol) of compound 12 and 0.30 g (2.24 mmol) of SO2Cl2 gave a mixture containing compounds 8 and 11 in a ratio of 97: 3, respectively (19F NMR data).

The work was supported by the Russian Foundation for Basic Research (Project No. 15-03-08869a).

References


