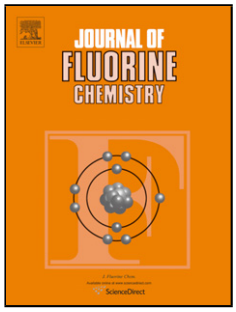


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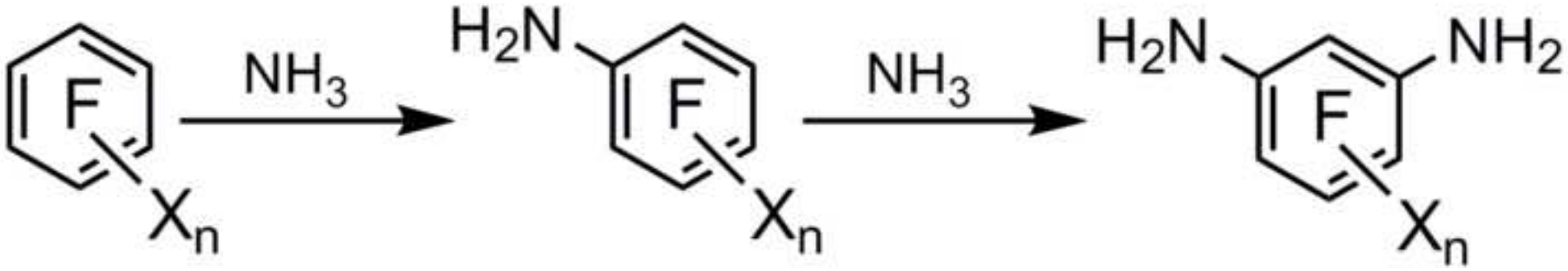
*Graphical Abstract - Pictogram




X = Cl, n = 1,2,3; H, n = 1,2; $CF_3$, n = 1

The number of $NH_2$ groups is controlled by the reaction temperature

# Selective mono- and diamination of some polyhalogenbenzenes in anhydrous ammonia

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Highlights

Aminodefluorination of polyhalogenbenzenes in anhydrous ammonia was investigated.

The optimal conditions for selective introducing one and two amino groups were elucidated.

Purification of the crude products is feasible by using simple experimental procedures.

Potentially scalable method to prepare valuable polyfluoroarylenediamines was developed.

# Selective mono- and diamination of some polyhalogenbenzenes in anhydrous ammonia

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Aminodefluorination of polyhalogenbenzenes (chloropentafluoro-, 1,3-dichlorotetrafluoro-, *sym*-trichlorotrifluoro-, 1,2,3,5-tetrafluoro- and 1,2,4,5-tetrafluoro-3-trifluoromethylbezenes) in anhydrous ammonia was investigated. The optimal conditions for selective preparation of mono- and diamino derivatives, which are ensured by the reaction temperature, were elucidated. In some examples of diamine synthesis, in order to improve the selectivity of second aminodefluorination, it is advisable to separate the isomeric monoamino derivatives produced in the first step of the synthesis.

*Keywords*: polychlorofluorobenzenes; anhydrous ammonia; aminodefluorination; nucleophilic substitution; polyhalogenaromatic amines

## 1. Introduction

Various mono- and diamino derivatives of polyhalogenarenes are demanded for high-tech processes and materials. In particular, diaminopolyfluoroarenes serve as structural blocks in the synthesis of materials used in optical communication devices, nanofilters and membranes, laser media, nonlinear optics and molecular electronics [1-5]. Exhaustively halogenated arylenediamines were shown [1, 6] to be the valuable monomers for polymers applicable as transmission medium in optoelectronics, since replacing all aromatic hydrogen atoms by halogenes (fluorine, chlorine) improves the key property of material, i.e. transparency at the wavelengths of 1.3 and 1.5 μm, called telecommunications "transparency windows". Partially fluorinated amines are widely used for the synthesis of polyimides with improved characteristics [7-9], pharmaceutical preparations [10-12] and chemical remedies of plant protection [13]. For example, to construct polyfluorobenzoazaheterocycles exhibiting a variety of biological activity [10, 12], polyfluorinated aromatic amines with a nonsubstituted position *ortho* to the amino group were employed as the universal building blocks [14, 15].

The most convenient method for preparing such compounds appears to be aminodefluorination of electrophilic polyfluoroarenes. This process efficiently occurs in anhydrous ammonia applied as a reagent and a solvent simultaneously. In the works [16-18] by example of aminodefluorination of perfluoro(het)arenes (benzene, naphthalene, pyridine), we have shown that the anhydrous ammonia has several advantages over the other aminating systems, i.e. aqueous and aqueous-alcohol ammonia. These advantages consist in *i*) selectivity of synthesis of arenes containing one or two amino groups due to a significant differences in the reaction conditions; *ii*) a high purity of products owing to the absence of hydrodeflurination realized in aqueous ammonia medium [19]; *iii*) processability and scalability of the method as a general route to synthetically important polyluorinated anilines and aromatic diamines.

The purpose of the present work is to extend the reported aminodefluorination protocol [16-18] to polychlorofluorobenzenes and partially fluorinated benzenes with the aim of preparing valuable polyhalogenaromatic mono- and diamines.

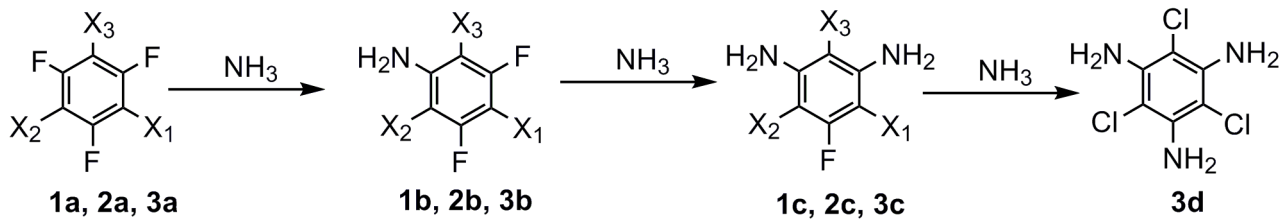
## 2. Results and discussion

Polychlorofluorobenzenes containing one, two or three chlorine atoms are formed as by-products in the synthesis of hexafluorobenzene from hexachlorobenzene (Halex process) [20-22], which makes them potential starting materials for preparing functionalized polyhalogenarenes. Reactions of chloropentafluorobenzene (**1a**), 1,3-dichlorotetrafluorobenzene (**2a**) and *sym*-trichlorotrifluorobenzene (**3a**) with ammonia in aqueous and aqueous-alcoholic media were described in the works [23-26] and used to synthesize their amino derivatives. However, these processes are not sufficiently site-selective and accompanied by the formation of

hydrodefluorinated by-products that make difficult and tricky the purification of the crude reaction mixture. Carrying out of the reaction in anhydrous ammonia significantly improves the synthetic result. Thus, in the relatively mild conditions (Entry 1, Table 1; Scheme 1) **1a** can be converted into 4-chlorotetrafluoroaniline (**1b**) mixed with a small amount of *ortho*-isomer 2-chlorotetrafluoroaniline (85:15). Recrystallization of the crude product in Entry 1 results in the pure amine **1b**. According to [23], in aqueous ammonia the isomeric chlorotetrafluoroanilines are formed in the ratio 70:22 in 48 h at 120 °C (the molar ratio **1a**:$NH_3$ is 1:23). Thus, aminodefluorination of **1a** in anhydrous ammonia occurs at the lower temperature and is characterized by the higher regioselectivity.

Both these facts appear to be provided by effects of the medium. Anhydrous liquid ammonia as a medium for $S_NAr$-processes behaves like a dipolar aprotic solvent [27-29] due to weak solvation of nucleophiles by means of hydrogen bonds. Consequently, reactivity of nucleophiles in anhydrous ammonia is higher [27] than that in polar protic solvents [30, 31]. Therefore, a transition state of the nucleophile addition stage is more reagent-like in anhydrous ammonia as compared to that in aqueous and aqueous-alcoholic media, and regioselectivity is more dependent on the polyhalogenarene structure [18]. In the considered aminodefluorination process, the total activating inductive effect (-*I*) of two *ortho*-fluorines, being a factor that acts in the early transition state [32, 33], increases the preference of the nucleophile addition to the position 4 in compound **1a**.

Use of monoamine **1b** as a substrate for the introduction of a second amino group is more expedient than one-pot bis-aminodefluorination of **1a**, because this enables to exclude the formation of 2-chloro-4,5,6-trifluoro-1,3-phenylenediamine and to get 4-chloro-2,5,6-trifluoro-1,3-phenylenediamine (**1c**) selectively (Entry 2, Table 1; Scheme 1). The yield and purity of **1c** thus obtained are significantly higher than after reaction of **1a** in aqueous ammonia [23], wherein a sample of **1c** with 91 % purity was isolated in yield 56 % and its purification from isomeric diamine to 97 % purity led to a decrease in the yield to 30 %.




$X_1$ = Cl, $X_2$ = $X_3$ = F (**1a, 1b, 1c**)
$X_1$ = $X_2$ = Cl, $X_3$ = F (**2a, 2b, 2c**)
$X_1$ = $X_2$ = $X_3$ = Cl (**3a, 3b, 3c, 3d**)

**Scheme 1**. Aminodefluorination of polychlorofluorobenzenes **1a**-**3a**

The synthesis of 2,4-dichloro-3,5,6-trifluoroaniline (**2b**) was described both starting from 1,3-dichlorotetrafluorobenzene **2a** [24] and from the mixture of isomeric

dichlorotetrafluorobenzenes containing 65-70 % of **2a** [25]. The use of this accessible mixture as a starting material is a real advantage of the method; however, to isolate the desired product **2b** a laborious procedure, i.e. preparative chromatography, was applied in [25]. We carry out the reaction in anhydrous $NH_3$ at 15 °C (cf. 80 °C in [25] and 180 °C in [24]) on the mixture of isomeric dichlorotetrafluorobenzenes. In these conditions, **2a** predominantly undergoes aminodefluorination over the other isomers and the formed amines can be separated from unreacted halogenebenzenes as hydrochloric salts (Entry 3, Table 1; Scheme 1). Crystallization of the crude product obtained by decomposing the salts, affords amine **2b**, purity 95%. Reaction of this compound with anhydrous ammonia (Entry 4, Table 1), as well as in the case of monochloro derivatives **1a**,**b**, is more selective than one-pot bis-aminodefluorination of **2a**. 4,6-Dichloro-2,5-difluoro-1,3-phenylenediamine (**2c**) can be isolated from the crude product in a preparative scale with purity >98% using the technique based on the different capacity of diamines to form complexes with 18-crown-6 [16-18]. A method for producing a diamine **2c** described previously [25] involves the chromatographic separation of a compounds mixture formed at ammonolysis of isomeric dichlorotetrafluorobenzenes in aqueous ammonia.

**Table 1**
Experimental conditions and product yields for reactions of polyhalogenearenes with anhydrous $NH_3$.

| Entry | Polyhalo-genarene | Reactant amounts[a] | | Reaction conditions | | Reaction products | | |
|---|---|---|---|---|---|---|---|---|
| | | Substrate (g) | $NH_3$ (ml) | Temperature (°C, ±5) | Time (h) | Amines | Crude product yields (g) | Isolated product yields (g/%) |
| 1 | **1a** | 10 | 30 | 70 | 24 | **1b** | 9[b] | 6.5/65 |
| 2 | **1b** | 6.5 | 20 | 155 | 200 | **1c** | 5.3 | 4.5/70 |
| 3 | **2a**[c] | 16.7 | 30 | 15 | 30 | **2b** | 12 | 8.3/51 |
| 4 | **2b** | 3.0 | 20 | 135 | 20 | **2c** | 2.8 | 2.5/80 |
| 5 | **3a** | 3.0 | 20 | 60 | 5 | **3c** | 2.7 | 2.3/77 |
| 6 | **3a** | 3.0 | 20 | 150 | 80 | **3d** | 2.5 | 1.8/62 |
| 7 | **4a** | 10 | 30 | 115 | 36 | **4b** | 9.1 | 7.4/75 |
| 8 | **4b** | 10 | 15[d] | 210 | 36 | **4c** | 9.2[e] | 4.6/72[e] |
| 9 | **4a** | 10 | 15[f] | 220 | 68 | **4c** | 7.5 | 6.7/68 |
| 10 | **5b** | 3.0 | 15[d] | 200 | 280 | **5c** | 2.7[g] | 1.8/70[g] |
| 11[h] | **6a** | 5.0 | 50 | 60 | 15 | **6b** | 4.3 | 3.8/76 |
| 12 | **6a** | 3.0 | 50 | 130 | 20 | **6c** | 2.6 | 2.3/77 |

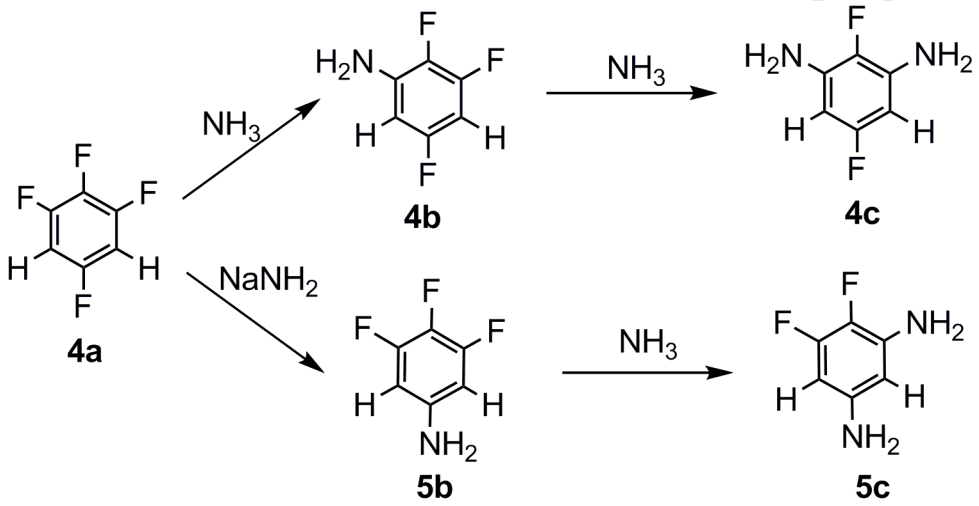
[a] An autoclave volume is 100 ml in Entries 11 and 12, and 50 ml in other Entries. The molar ratio substrate:$NH_3$ is varied from 1:10 to 1:20.
[b] In the mixture with 2-chlorotetrafluoroaniline (15% according to $^{19}$F NMR).
[c] 67 % in the mixture with isomeric dichlorotetrafluorobenzenes.
[d] Dioxane (20 ml) was used as co-solvent.
[e] The crude product contains 28% of **4b** (according to $^{19}$F NMR), yield of pure **4c** is given considering the conversion.
[f] *t*-BuOMe (20 ml) was used as co-solvent.
[g] The crude product contains 15% of **5b** (according to $^{19}$F NMR), yield of pure **5c** is given considering the conversion.
[h] Preparation of compound **6b** was reported in [17].

Symmetrical trichlorotrifluorobenzene (**3a**) undergoes sufficiently selective mono-aminodefluorination in aqueous-alcohol ammonia at 160 °C to form 2,4,6-trichloro-3,5-difluoroaniline (**3b**) [26]. At 180 °C in this system, a mixture of approximately equal amounts of **3b** and 2,4,6-trichloro-5-fluoro-1,3-phenylenediamine (**3c**) is formed [26]. We have shown that in anhydrous ammonia at 60 °C diamine **3c** can be obtained in high yield and purity and no amount of **3b** has been detected in the crude product (Entry 5, Table 1; Scheme 1).

The data obtained indicate that the replacement of fluorine atoms by chlorine atoms moving from the substrate **1a** to **2a** and **3a** considerably facilitates their aminodefluorination (cf. the time-temperature modes in Entries 1-5, Table 1). This is due to the relative activating influences of chlorine *vs.* fluorine on the rate constants of $S_NAr$ reactions ($k_{Cl/F}$ ~3−4 for *ortho*-substituents; $k_{Cl/F}$ ~30−35 for *para*- substituents) [32, 34]. Compound **3a**, owing to the presence of three chlorine atoms, at 150 °C in anhydrous ammonia is completely converted into 1,3,5-triamino-2,4,6-trichlorobenzene (**3d**) (Entry 6, Table 1; Scheme 1). Introduction of three amino groups into mono- and dichlorinated compounds **1a** and **2a** in anhydrous ammonia is possible in principle, but it occurs under more hard conditions. Thus, compound **1a** in 200 h at 180 ° C gives a mixture containing 90% of diamine **1c** and 10% of 1,3,5-triamino-2-chloro-4,6-difluorobenzene; compound **2a** in 10 h at 180 ° C turns into a mixture of diamine **2c** and 1,3,5-triamino-2,4-dichloro-6-fluorobenzene in the ratio 77:23. These triamines were not isolated from the product mixtures and the assumptions on their structures were based on the data of GC-MS and $^{19}$F NMR. 1,3,5-Triamino-2-chloro-4,6-difluorobenzene has a molecular ion with *m/z* 193 and singlet at $\delta$ -166.4 ppm, 1,3,5-triamino-2,4-dichloro-6-fluorobenzene – a molecular ion with *m/z* 209 and singlet at $\delta$ -162.2 ppm. The $^{19}$F NMR chemical shifts of these compounds are comparable with those calculated by the additive scheme using substituent shielding parameters [35].

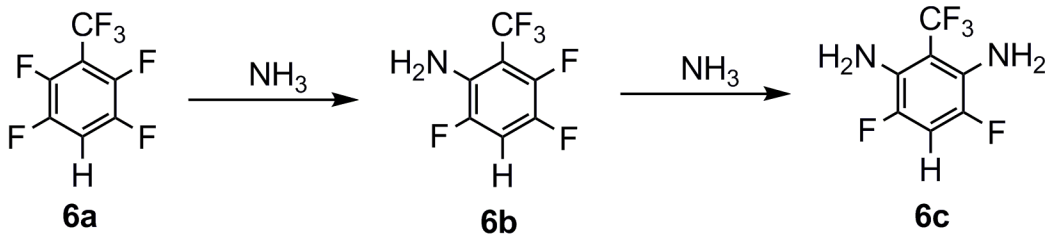
1,2,3,5-Tetrafluorobenzene (**4a**) is less reactive relative to nucleophiles in comparison with completely halogenated benzenes **1a**-**3a**. It was shown [36] that in aqueous ammonia at 250 °C **4a** affords the mixture of 2,3,5-trifluoroaniline (**4b**) and 2,5-difluoro-1,3-phenylenediamine (**4c**), which were separated by chromatography in low yield. Preparative-scale synthesis of **4b** was

carried out starting from octafluorotoluene [14, 15] in four steps including hydrolysis of $CF_3$ group and decarboxylation. Diamine **4c** was prepared from **2a** via its reaction with hydrazine hydrate [37] followed by the reduction of hydrazino to amino group and hydrodechlorination [38]. In anhydrous ammonia at 115 °C **4a** undergoes monoaminodefluorination at position 1 to form **4b** (Entry 7, Table 1; Scheme 2). The high selectivity of the process is provided by the fact that the position 2 in substrate is deactivated by the electron donor effect of a *para*-fluorine atom, and the position 5 − also by the lack of *ortho*-fluorine atoms contributing to nucleophilic attack [32, 33]. Diamine **4c** can be prepared in comparable yields both from aniline **4b** (Entry 8, Table 1) and via one-pot bis-aminodefluorination of benzene **4a** (Entry 9, Table 1) at 200-220 °C. Under incomplete conversion (Entry 7, Table 1), diamine **4c** is easily separated from unreacted **4b** by crystallization.




**Scheme 2**. Aminodefluorination of tetrafluorobenzene **4a**

Orientation of **4a** aminodefluorination changes drastically upon the action of a charged nucleophile $NaNH_2$ in liquid ammonia at -60 °C [36]. Under these conditions, formed is a product of the replacement of fluorine atom at the position 5, i.e. 3,4,5-trifluoroaniline (**5b**) (Scheme 2). This change of orientation was suggested [36] to be due to the fact that the amide ion exhibits protophilic activity and a mechanism which involves a benzine intermediate is implemented. Aniline **5b** thus obtained undergoes in anhydrous ammonia replacement of fluorine atom at a *para*-position to hydrogen atom, to form previously unknown 4,5-difluoro-1,3-phenylenediamine (**5c**) (Entry 10, Table 1; Scheme 2). At 200 °C the reaction proceeds slowly, but an increase of the temperature to 220 °C intensifies hydrodefluorinaton at the *para*-position to the amino group to form 5-fluoro-1,3-phenylenediamine. This compound was identified in the mixture according to $^{19}F$ NMR ($\delta$ -114.9 ppm, cf. [39]) and GC-MS data (*m*/*z* 126, [*M*]+). Separation of diamine **5c** from unreacted aniline **5b** and from minor amount of hydrodefluorinated product (≤3%) was carried out by means of complexation with 18-crown-6 similarly to [16-18].




**Scheme 3**. Aminodefluorination of heptafluorotoluene **6a**

In α,α,α-2,3,5,6-heptafluorotoluene (**6a**) an electron withdrawing effect of trifluoromethyl group activates positions 2 and 6 to a nucleophilic attack. As we have shown previously [17], arene **6a** undergoes aminodefluorination in anhydrous $NH_3$ at 60 °C to give 3,4,6-trifluoro-2-trifluoromethylaniline (**6b**) (Entry 11, Table 1; Scheme 3). Bis-aminodefluorination of **6a** occurs at 130 °C (Entry 12, Table 1). 4,6-Difluoro-2-trifluoromethyl-1,3-phenylenediamine (**6c**) thus obtained contains no impurities in appreciable amount, so the crude product can be purified by sublimation.

## 3. Conclusions

Thus, polychlorofluorobebzenes **1a**-**3a** and partially fluorinated benzenes **4a** and **6a** undergo aminodefluorination by the action of anhydrous ammonia to form mono- and diamino derivatives. Bis-aminodefluorination occurs at significantly higher temperatures than monoaminodefluorination (temperature differences is 60-160 °C), whereby conditions were found for selective introduction of one or two amino groups. In the case of non-selective reactions of **1a** and **2a**, an intermediate isolation of monoamines can enhance selectivity and yield of diamine, as well as simplify its purification. Varying the nucleophile nature at the step of tetrafluorobenzene **4a** amination ($NH_3$ vs. $^-NH_2$), resulting in a change of the replacement orientation [36], enables the synthesis of two different diamines **4c** and **5c** from **4a**. The results obtained confirm aminodefluorination of electrophilic polyfluoroarenes with use of anhydrous ammonia as a reagent and a solvent simultaneously to be a convenient and general route to polyfluoroaromatic mono- and diamines. The mentioned advantages open up prospects for a large-scale use of these compounds in modern materials and fine organic synthesis.

## 4. Experimental

### *4.1. Materials*

The following commercial products were used: anhydrous $NH_3$, 18-crown-6, *tert*-butyl methyl ether (*t*-BuOMe), acetone, $CH_2Cl_2$, hexane, decane, $H_2$, Pd/C (0.5%). $K_2CO_3$ and $MgSO_4$ were calcined prior to use.

Chloropentafluorobenzene (**1a**), mixture of dichlorotetrafluorobenzenes (the content of 1,3-dichlorotetrafluorobenzene (**2a**) was 67%), *sym*-trichlorotrifluorobenzene (**3a**) were prepared as described in [21], 1,2,3,5-tetrafluorobenzene (**4a**), 3,4,5-trifluoroaniline (**5b**), and octafluorotoluene

– as described in [40, 36, 41] respectively; their physical properties were identical to those reported in the literature.

α,α,α-2,3,5,6-Heptafluorotoluene (**6a**). A 200 ml autoclave was charged with octafluorotoluene (30 g), $K_2CO_3$ (6 g), Pd/C (0.5%) (4.5 g) and decane (100 ml). The autoclave was sealed, purged twice and charged with $H_2$ to the pressure of 100 atm. The reaction mixture was heated up to the 220 °C upon stirring by rotation of the autoclave and kept under these conditions for 30 h, $H_2$ being added up to 100 atm as expenditure. On completion, the autoclave was cooled and the reaction mixture was filtered. Heptafluorotoluene **6a** was distilled off from the solution (23 g, 83%), purity 97%, b.p. 110-113 °C, spectral data are identical to those reported in [42].

*4.2. Methods*

$^1H$, $^{19}F$ and $^{13}C$ NMR spectra were recorded on NMR spectrometers Bruker AV-300 (300.13, 282.36 and 75.48 MHz for $^1H$, $^{19}F$ and $^{13}C$ correspondingly) using signals of solvents and $C_6F_6$ (δ = -163.0 ppm from $CCl_3F$) as internal standards; δ are given in ppm relative to TMS and $CCl_3F$. IR spectra were recorded on Bruker Vector-22 instrument in ATR mode. The precise molecular weights of ions were determined by high-resolution mass spectrometry on Thermo Scientific DFS instrument, ionizing energy 70 eV. GC-MS analyses of component mixtures were performed using Hewlett Packard G1081A equipment comprising an HP 5890 Series II gas chromatograph and an HP5971 mass-selective detector in the conditions described in [16].

*4.3. Synthetic procedures*

*4.3.1. Typical procedure for the reaction of polyhalogenarenes with anhydrous $NH_3$*

Polyhalogenarene was placed into a steel autoclave equipped with two inlet/outlet valves. The required amount of anhydrous liquid $NH_3$ was added into the autoclave by self-flowing through a measuring funnel with back pressure cooled to -33 °C and the autoclave was sealed. The reaction mixture was heated up to the given temperature upon stirring by rotation of the autoclave and kept under these conditions for the necessary time. On completion, the autoclave was cooled, $NH_3$ was slowly vented through an outlet valve, products were extracted with acetone and extract was filtered. Solvent was evaporated to give a crude product, which was then purified. The reactant amounts, reaction conditions, and product yields are listed in Table 1. Methods of isolation of compounds and their characteristics are given below.

*4.3.2. 4-Chloro-2,3,5,6-tetrafluoroaniline (**1b**)*

The crude product (Entry 1, Table 1) was purified by crystallization from hexane, purity 99%, mp 54-56 °C (*cf.* [43] mp 54-55 °C). IR: ν 3483, 3392, 3254, 3191 ($NH_2$), 1657, 1612, 1504, 1175, 1111, 930, 881 $cm^{-1}$. NMR spectral data are identical to those reported in [43].

*4.3.3. 4-Chloro-2,5,6-trifluoro-1,3-phenylenediamine (**1c**)*

The crude product (Entry 2, Table 1) was purified by crystallization from hexane, purity 99%, mp 133-134 °C (*cf.* [23] mp 133.5-134.5 °C). IR: ν 3446, 3331, 3196 ($NH_2$), 1660, 1626, 1602, 1504, 1434, 1307, 1270, 1178, 1112, 922, 849 $cm^{-1}$. NMR spectral data are identical to those reported in [23].

*4.3.4. 2,4-Dichloro-3,5,6-trifluoroaniline (**2b**)*

The crude product was synthesized from the mixture of isomeric dichlorotetrafluorobenzenes (25 g) containing ~67 % of 1,3-isomer **2a** (Entry 3, Table 1). After cooling and removing $NH_3$ the reaction mixture was dissolved in $CH_2Cl_2$ and filtered. Gaseous HCl was passed through the solution up to the end of precipitation. The precipitate was filtered off and mixed with water, agueous NaOH was added up to alkalescent pH. Anilines were extracted with $CH_2Cl_2$, the extract was dried over $MgSO_4$, and the extractant was distilled off. The crude product was purified by crystallization from hexane, purity 95%. IR: ν 3502, 3403 ($NH_2$), 1641, 1599, 1497, 1468, 1244, 1142, 899, 793 $cm^{-1}$. NMR spectral data are identical to those reported in [25].

*4.3.5. 4,6-Dichloro-2,5-difluoro-1,3-phenylenediamine (**2c**)*

The crude product (Entry 4, Table 1) was purified by complexation with 18-crown-6 (3.1 g) as described in [17], purity 99%, mp 137.5-138.7 °C (*cf.* [25] mp 136-136 °C). IR: ν 3448, 3340, 3190 ($NH_2$), 1649, 1626, 1498, 1466, 1416, 1325, 1234, 1130, 862, 783 $cm^{-1}$. NMR spectral data are identical to those reported in [25].

*4.3.6. 2,4,6-Trichloro-5-fluoro-1,3-phenylenediamine (**3c**)*

The crude product (Entry 5, Table 1) was purified by crystallization from hexane, purity 99%, mp 155.2-155.5 °C (*cf.* [26] mp 152-153 °C). IR and NMR spectral data are identical to those reported in [26].

*4.3.7. 1,3,5-Triamino-2,4,6-trichlorobenzene (**3d**)*

The crude product (Entry 6, Table 1) was purified by crystallization from hexane, purity 97%, mp 209-211 °C. IR: ν 3437, 3350, 3323 ($NH_2$), 1616, 1454, 1137, 1057, 740, 719 $cm^{-1}$. $^1H$ NMR (acetone-$d_6$+DMSO-$d_6$): $\delta$ 5.00 (br.s, $NH_2$). $^{13}C$ NMR (DMSO-$d_6$): $\delta$ 93.2 (C-2, C-4, C-6), 140.8 (C-1, C-3, C-5). HRMS calcd. for $C_6H_6N_3Cl_3$: 224.9627, found: 224.9634.

*4.3.8. 2,3,5-Trifluoroaniline (**4b**)*

The crude product (Entry 7, Table 1) was purified by distillation to collect the fraction with bp 175-177 °C. Purity of aniline **4b** is >97%. IR: ν 3498, 3410, 3219 ($NH_2$), 3095 ($C_{ar}$-H), 1657, 1606, 1523, 1464, 1236, 1203, 1126, 1047, 991, 829, 771 $cm^{-1}$. NMR spectral data are identical to those reported in [36].

*4.3.9. 2,5-Difluoro-1,3-phenylenediamine (**4c**)*

The crude product was purified by crystallization from hexane (Entry 8, Table 1) or sublimed (Entry 9, Table 1), purity 99%, mp 47-48 °C (*cf*. [36] mp 40-41 °C). IR and NMR spectral data are identical to those reported in [38].

*4.3.10. 4,5-Difluoro-1,3-phenylenediamine (**5c**)*

The crude product (Entry 10, Table 1) was purified by complexation with 18-crown-6 as described in [17], purity 98%. IR: ν 3437, 3334, 3213 ($NH_2$), 3073 ($C_{ar}$-H), 1625, 1605, 1528, 1474, 1257, 1217, 1168, 1035, 989, 829, 780 $cm^{-1}$. $^1$H NMR (acetone-$d_6$) (Fig. S1a): $\delta$ 4.42, 4.62 (both br.s of equal intensity, 2H each, $NH_2$), 5.78 (ddd, 1H, $J_{HH}$= 2 Hz, $J_{HF}$= 6 Hz, 13 Hz, H-6), 5.91 (ddd, 1H, $J_{HH}$= 2 Hz, $J_{HF}$= 1.8 Hz, 7 Hz, H-2). $^{19}$F NMR (acetone-$d_6$) (Fig. S1b): $\delta$ -176.7 (ddd, 1F, $J_{FF}$=20 Hz, $J_{HF}$=6 Hz, 7 Hz, F-4), -141.5 (ddd, 1F, $J_{FF}$=20 Hz, $J_{HF}$=1.8 Hz, 13 Hz, F-5). HRMS calcd. for $C_6H_6N_2F_2$: 144.0494, found: 144.0491.

*4.3.11. 3,4,6-Trifluoro-2-trifluoromethylaniline (**6b**)*

The crude product (Entry 11, Table 1) was purified by fractional distillation, purity 98%, bp 128-132 °C [17]. IR and NMR spectral data are identical to those reported in [17].

*4.3.12. 4,6-Difluoro-2-trifluoromethyl-1,3-phenylenediamine (**6c**)*

The crude product (Entry 12, Table 1) was extracted from the reaction mass using $CH_2Cl_2$ and purified by sublimation, purity 99%, mp 46-47 °C. IR: ν 3494, 3400, 3350, 3236 ($NH_2$), 3109, 3078 ($C_{ar}$-H), 1639, 1502, 1323, 1111, 1092, 908, 872 $cm^{-1}$. $^1$H NMR (acetone-$d_6$) (Fig. S2a): $\delta$ 4.80 (br.s, 4H, $NH_2$), 7.11 (t, 1H, $J_{HF}$= 11 Hz, H-5). $^{19}$F NMR (acetone-$d_6$) (Fig. S2b): $\delta$ -146.3 (d, 2F, $J_{HF}$=11 Hz, F-4,6), -55.3 (s, 3F, $CF_3$). HRMS calcd. for $C_7H_5N_2F_5$: 212.0367, found: 212.0363.

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**Supplementary data**

**References**

[1] S. Ando, T. Matsuura, S. Sasaki, in Fluoropolymers 2: Properties, Ed. G. Hougham, Kluwer Academic-Plenum Publishers, New York, 1999, 277–303.

[2] Yu.N. Sazanov, Russ. J. Appl. Chem. (Engl. Transl.) 74 (2001) 1253–1269.

[3] M.G. Dhara, S. Banerjee, Prog. Polym. Sci. 35 (2010) 1022–1077.

[4] M. Rubal, C.W. Wilkins Jr, P.E. Cassidy, C. Lansford, Y. Yamada, Polym. Adv. Technol. 19 (2008) 1033–1039.

[5] Y. Shirota, H. Kageyama, Chem. Rev. 107 (2007) 953–1010.

[6] K. Tajiri, T. Makino, Y. Yamagishi, F. Yamamoto, N. Kawakami, K. Kawada, WO patent 2006109812 (2006).

[7] C.Wang, X. Zhao, G. Li, J. Jiang, Colloid Polym. Sci. 289 (2011) 1617–1624.

[8] C. Wang, X. Zhao, G. Li, J. Jiang, Polym. Degrad. Stab. 94 (2009) 1746–1753.

[9] I.K. Shundrina, T.A. Vaganova, S.Z. Kusov, V.I. Rodionov, E.V. Karpova, E.V. Malykhin, J. Fluorine Chem. 132 (2011) 207–215.

[10] Organofluorine Compounds in Medicinal Chemistry and Biomedical Applications, Eds R. Filler, Y. Kobayashi, and L. M. Yagupolskii, Elsevier, Amsterdam, 1993.

[11] L. Revesz, F.E. Di Padova, T. Buhl, R. Feifel, H. Gram, P. Hiestand, U. Manning, R. Wolf, A. G. Zimmerlin, Bioorg. Med. Chem. Lett. 12 (2002) 2109–2112.

[12] Antibiotics and Antiviral Compounds. Chemical Synthesis and Modification, Eds R. Krohn, H.A. Kirst, H. Maag, VCH: Weinheim: New York, 1993.

[13] M.N. Gandy, M.G. Corral, J.S. Mylne, K.A. Stubbs, Org. Biomol. Chem. 13 (2015) 5586-5590.

[14] L.Yu. Safina, G.A. Selivanova, K.Yu. Koltunov, V.D. Shteingarts, Tetrahedron Lett. 50 (2009) 5245–5247.

[15] S.S. Laev, L.Yu. Gurskaya, G.A. Selivanova, I.V. Beregovaya, L.N. Shchegoleva, N.V. Vasil'eva, M.M. Shakirov, V.D. Shteingarts, Eur. J. Org. Chem. (2007) 306–316.

[16] S.Z. Kusov, V.I. Rodionov, T.A. Vaganova, I.K. Shundrina, E.V. Malykhin, J. Fluorine Chem. 130 (2009) 461–465.

[17] T.A. Vaganova, S.Z. Kusov, V.I. Rodionov, I.K. Shundrina, E.V. Malykhin, Russ. Chem. Bull., Int. Ed. 56 (2007) 2239–2246.

[18] T.A. Vaganova, S.Z. Kusov, V.I. Rodionov, I.K. Shundrina, G.E. Sal'nikov, V.I. Mamatyuk, E.V. Malykhin, J. Fluorine Chem. 129 (2008) 253–260.

[19] S.Z. Kusov, V.I. Rodionov, T.A. Vaganova, I.K. Shundrina, E.V. Malykhin, Russ. Chem. Bull., Int. Ed. 58 (2009) 823–827.

[20] N.N. Vorozhtsov Jr., V.E. Platonov, G.G. Yakobson, Izv. Akad. Nauk SSSR, Ser Khim. (1963) 1524–1531.

[21] G.G. Yakobson, V.E. Platonov, N.N. Vorozhtsov Jr., J. Gen. Chem. USSR (Engl. Transl.) 35 (1965) 1158–1161.

[22] G.M. Brooke, J. Fluorine Chem. 86 (1997) 1–76.

[23] G.A. Selivanova, L.M. Pokrovskii, V.D. Shteingarts, Russ. J. Org. Chem. (Engl. Transl.) 37 (2001) 404–409.

[24] FR patent 1408502 (1965); Chem.Abstr. 63 (1965) 17968f.

[25] G.A. Selivanova, L.M. Pokrovskii, V.D. Shteingarts, Russ. J. Org. Chem. (Engl. Transl.) 38 (2002) 1023–1029.

[26] N. Ishikawa, I. Fujii, Nippon Kagaku Zasshi 87 (1966) 1089-1092 DOI: 10.1246/nikkashi1948.87.10_1089

[27] T.A. Kizner, V.D. Shteingarts, J. Org. Chem. USSR (Engl. Transl.) 20 (1984) 991–997.

[28] E.V. Malykhin, V.D. Shteingarts, Rossiiskii Khimicheskii Zhurnal (1999), 43(1), 49-56; Chem. Abstr. 131 (1999) 44438.

[29] P. Ji, J.H. Atherton, M.I. Page, J. Org. Chem. 76 (2011) 3286–3295.

[30] T.O. Bamkole, J. Hirst, I. Udoessien, J. Chem. Soc. Perkin Trans. 2 (1973) 110–114

[31] T.O. Bamkole, J. Hirst, I. Udoessien, J. Chem. Soc. Perkin Trans. 2 (1973) 2114–2119.

[32] R.D. Chambers, D. Close, D. Lyn, H. Williams, J. Chem. Soc., Perkin Trans. 2 (1980) 778–780.

[33] R.D. Chambers, M.J. Seabury, D.L.H. Williams, N. Hughes, J. Chem. Soc., Perkin Trans. 1 (1988) 255–257.

[34] R. Bolton, J.P.B. Sandall, J. Chem. Soc., Perkin Trans. 2 (1976) 1541–1545.

[35] S. Ando, T. Matsuura, Magn. Res. Chem. 33 (1995) 639–645.

[36] A.A. Shtark, T.V. Chuikova, G.A. Selivanova, V.D. Shteingarts, Russ. J. Org. Chem. (Engl. Transl.) 23 (1987) 2271–2277.

[37] N. Ishikawa, S. Hayashi, Nippon Kagaku Zasshi 89 (1968) 321–324; Chem. Abstr. 69 (1968) 67021.

[38] S. Sugawara, N. Ishikawa, Kogyo Kagaku Zasshi 72 (1969) 2425–2427; Chem. Abstr. 72 (1970) 66514.

[39] J. Hirst, S.J. Una, J. Chem. Soc. B (1969) 646–648.

[40] V.I. Sokolenko, A.Ya. L'vova, V.S. Tyurin, V.E. Platonov, G.G. Yakobson, Zhurn. Org. Khim. 6 (1970) 2496–2498.

[41] Sintezy Ftororganicheskikh soedinenii [Syntheses of Organofluorine Compounds], Eds I.L. Knunyants, G.G. Yakobson, Khimiya, Moscow, 1973, 143-144.

[42] V.I. Krasnov, V.E. Platonov. Russ. J. Org. Chem. (Engl. Transl.) 36 (2000) 1488–1499.

[43] H. Kobayashi, T. Sonoda, J. Fluorine Chem. 27 (1985) 1–22.

**Scheme captions**

**Scheme 1**. Aminodefluorination of polychlorofluorobenzenes **1a-3a**

**Scheme 2**. Aminodefluorination of tetrafluorobenzene **4a**

**Scheme 3**. Aminodefluorination of heptafluorotoluene **6a**

**Figure(s)**

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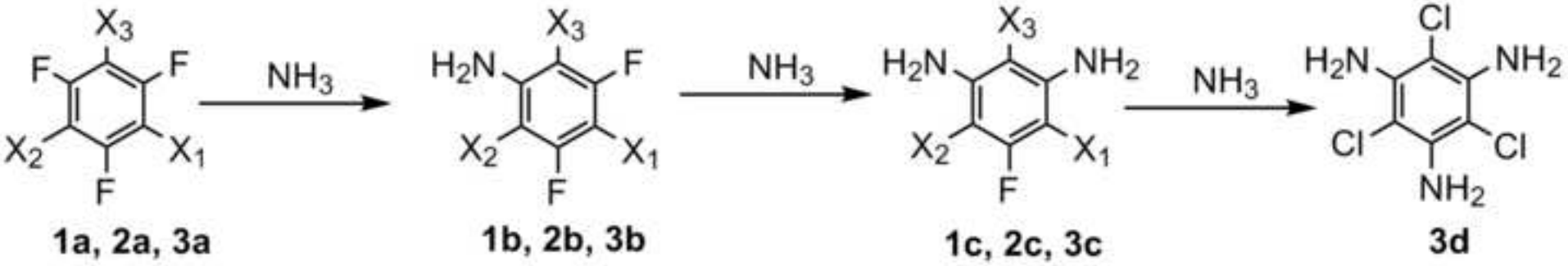


$X_1$ = Cl, $X_2$ = $X_3$ = F (**1a, 1b, 1c**)

$X_1$ = $X_2$ = Cl, $X_3$ = F (**2a, 2b, 2c**)

$X_1$ = $X_2$ = $X_3$ = Cl (**3a, 3b, 3c, 3d**)

**Figure(s)**

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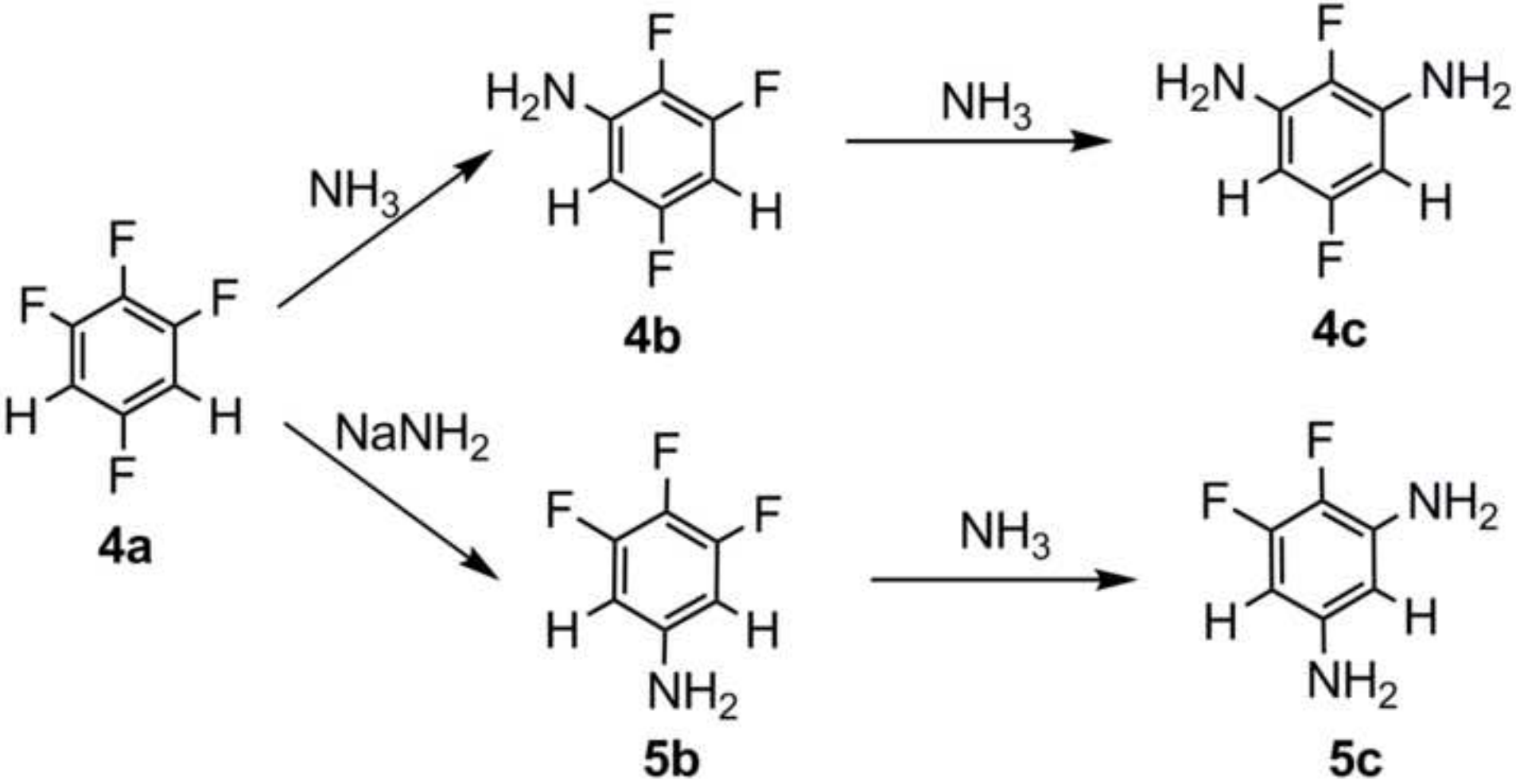

**Figure(s)**

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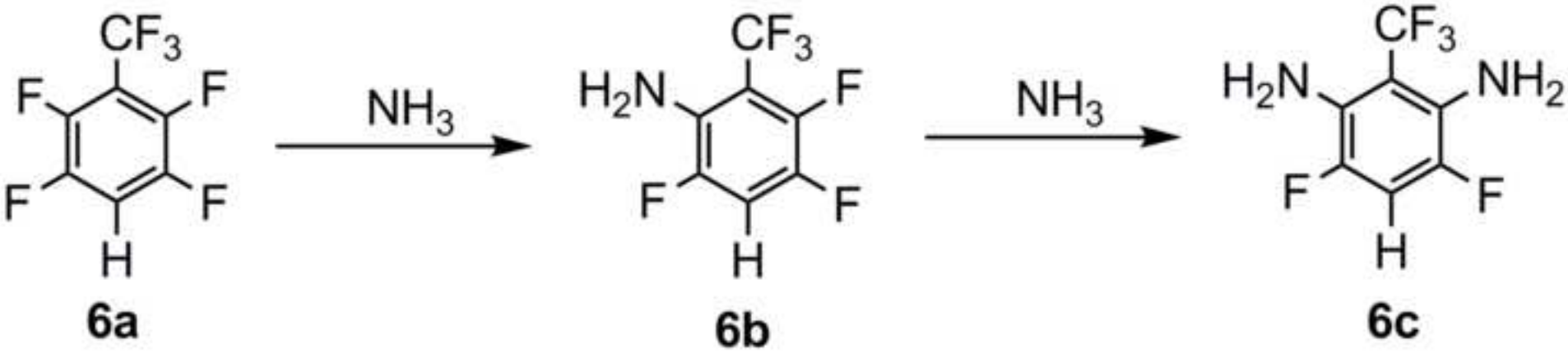


**6a** **6b** **6c**