Substitutive Bromination of Perfluorotoluene with Aluminium Bromide

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Abstract: It is shown that along with the formation of 4-bromoperfluorotoluene and 2,4-dibromoperfluorotoluene as the main products of the reaction of perfluorotoluene with aluminium bromide the isomeric tribromodifluorobenzotrifluorides and 4,4'-dibromo-ortho, para-dibromostilbene are also formed as minor components of the reaction mixture. Aluminium bromofluoride formed in situ is presumably a catalyst of isomerization of intermediate pentafluorobenzotribromide into corresponding brominated derivatives of benzotrifluoride.

Keywords: 4-bromoperfluorotoluene; 2,4-dibromoperfluorotoluene; aluminium bromofluoride.

Earlier it has been found that gradual addition of AlBr₃ to boiling perfluorotoluene (1) led to the formation of p-bromotoluene (2) as the only reaction product [1]. Detailed study of this reaction demonstrated that under more mild conditions (pot temperature <45°C) pentafluorobenzotribromide (3) was the initial product, which transformed into a mixture of 2 and p-bromotetrafluorobenzotribromide (4) in the ratio 2:4 = 5:1 under prolonged refluxing of the reaction mixture (8h) [2].

In order to obtain di- and tribromotoluenes containing bromine atoms in aromatic moiety - as potential starting materials for preparing the corresponding di- and trihydrofluorotoluenes (the reduction of perfluoroarylhalogenides to the corresponding perfluoroarylhydrides was described in [3,4]) - we have attempted to achieve deep bromination of perfluorotoluene under the action of AlBr₃ without affecting CF₃-group.

It’s obvious that the migration of bromine atom from benzyl to aromatic position proceeds with the participation of benzyl carbocations A, generated under the action of aluminium halogenides (cf. [2]), but unlike perfluorobenzyl carbocation in which positive charge is located in o- and p-positions of the aromatic ring, charge localization in bromo- and dibromoperfluorobenzyl cations is not so evident due to +M-effect of bromine atoms in aromatic moiety.

Indeed the quantum-chemical calculation of a number of dibromopentafluorobenzyl cations and subsequent analysis of integral atomic characteristics obtained within the frame of R. Bader’s theory gives any preference in favor of any definite brominated products from the point of view of atomic charges distribution. Thus the absolute values of aromatic C-atoms charges are almost totally determined by the nature of the nearest substituent: the average charge value for C(F) is +0.68μ and for C(Br) -0.03μ.

From the other hand the insignificant variation of the charge values of C(F)-atoms should be formally determined by mesomeric effects. Indeed the most electron-deficient centre in 2,4-dibromopentafluorobenzyl cation is located at C(F)-atom in the fifth position of aromatic ring, though its charge is higher than average value for C(F)-atoms on 0.01e only; among all C(F)-atoms in this cation the lowest positive charge is observed at C-atom in the third position (+0.67Pμ). The charge distribution obtained for 2,4-dibromocation is in a good agreement with total energy values (thermodynamic stability) of tribromotoluenes 6-8 (see below).
We have established that the reaction of 1 with AlBr\textsubscript{3} under the conditions of preparing p-bromoperfluorotoluene [1], but provided that the relative content of AlBr\textsubscript{3} was increased from 13 up to 52.5% resulted in the formation of p-bromotoluene 2 and o,p-dibromotoluene 5 as the main reaction products (the yields 39 and 16.3% respectively based on 1 taken in the reaction) along with a complex mixture of minor components 5a-10. The following compounds were identified according to CMS-data: m,p-dibromotoluene 5a, isomeric tribromobenzotrifluorides 6-8 in a ratio 6:7:8 = 3:1:0.1, o,p-dibromoperfluorobenzylbromide (9) and a mixture of E,Z-isomers of 4,4′-bis-dibromoocatafluoro- O±,O- -dibromostilbene (10).

The bromination of perfluorotoluene gives p-bromoperfluorotoluene 2 as the only reaction product whereas the bromination of toluene 2 leads to the formation of dibromotoluene 5 and its isomer 5a as well in a ratio 5:5a = 20:1, that is rather connected with competitive localization of electron-deficient centre in m-position of p-bromoperfluorobenzyl cation as a result of electron-donating influence of bromine atom. The formation of isomeric tribromides 6-8 evidences the products of further bromination of dibromotoluenes 5-5a evidently indicates at the absence of clear-cut distribution of positive charge in o,p-dibromoperfluorobenzyl cation that is determined by competitive influence of electronic and steric factors: on the one hand the electron withdrawing influence of CF\textsubscript{2}-group and +M-effect of two bromine atoms and on the other hand steric hindrances created by such bulky substituents as difluoromethylene and two bromine atoms.

In fact, according to quantum-chemical calculations the relative thermodynamic stability of tribromobenzotrifluorides 6-8 decreases in the row 6>7>8, being irrespective of the calculation method type and a choice of the basis set. Herein the difference in total energies of isomers is sufficiently small and changes slightly upon transition from the pair 6-7 (1.9 kcal/mol) to the pair 7-8 (0.9 kcal/mol), that most likely indicates at the competitive influence of steric and electronic effects of the substituents and at the qualitative level confirms CMS-data (6:7:8 = 3:1:0.1). Here it is worth noting the seeming quantitative disagreement between the ratio of the compounds 6-8 according to CMS-data and the ratio of calculated total energies of these isomers. Obviously, such difference can be explained by a number of complicated factors of real medium, especially the effects of specific and nonspecific solvation leaving from account in our calculations.

It was mentioned above that benzotribromide 3 is an intermediate of the reaction of 1 with AlBr\textsubscript{3} that leads to the formation of toluene 2. The compound 3 can be readily obtained in 56% yield from equimolecular mixture of 1 and AlBr\textsubscript{3} at 20°С (the yield of compound 3 can be increased up to 80% if the excess of perfluorotoluene is used (see experimental)) [2]. Nevertheless we failed to obtain toluene
GLC; the yields of afforded 22 g of a fraction (42-105°C/10 Torr) that contained reaction products and compounds temperature ~135°C).

CH reflux 3h (pot temperature 160-165°C, evolution of Br perfluorotoluene [11]. During the integration and consequent energy second derivatives. The topological ground state: a type of each stationary convergence criteria for forces and 311++G** calculation are recorded. Quantum-chemical calculations were recorded on Finnigan Polaris Q (Trace GC ultra) Mass spectrometer.

The reaction of perfluorotoluene with AlBr₃ was confirmed experimentally by easy isomerization of 1,2-dibromohexafluoropropane into 2,2-dibromohexafluoropropane [8].

The experimental data obtained allow coming to the conclusion, that isomerization of primarily formed pentafluorobenzotribromide 3 into bromobenzotrifluorides is achieved under the action of ABF but not AlBr₃. The absence of stirring and usage of relatively large quantities of AlBr₃ favours the formation of ABF in the form of relatively big aggregated particles, conserving its activity during several hours. If these conditions are not kept sufficiently fast formation of polymeric AlF₃ occurs in the presence of such active source of fluoride anion as perfluorotoluene. Taking into consideration that this compound is a weak Lewis acid it can be hardly a catalyst of the reactions under the question.

**Experimental**

¹H, ¹⁹F NMR spectra were recorded on Bruker AVANCE-300 spectrometer at 300 and 282 MHz, accordingly; the external standard was CDCl₃ or D₂O. Chemical shifts for ¹H spectra are presented vs. the residual signal of the solvent (δf 7.25; 4.79) and are given in ppm vs. tetramethylsilane. Chemical shifts in ¹⁹F spectra are given in ppm vs. CF₃CO₂H. Downfield shifts are positive. The mass spectra were recorded on Finnigan Polaris Q (Trace GC ultra) Mass spectrometer.

**Quantum-chemical calculations**

Quantum-chemical modeling of tribromosubstituted perfluorotoluenes and corresponding dibromosubstituted benzyl cations was carried out in GAUSSIAN 03 program package [11] using different DFT functionals and standard triple split basis sets (results obtained by m06-2x [12] / 6-311++G** calculation are discussed). During optimization of molecule parameters standard convergence criteria for forces and atomic shifts were used. All models obtained correspond to the ground state: a type of each stationary point was determined by calculations of matrix of potential energy second derivatives. The topological analysis of the charge density distribution function (Ф(𝐫)) and consequent Ф̂(𝐫) integration over atomic basins were performed using AIMAll program package [13]. During the integration the absolute value of 1/4πɛ₀²Φ̂(𝐫) was not more than 6Г—10⁻³ for the whole molecule.

**The reaction of perfluorotoluene with AlBr₃**

Aluminium bromide (15.6 g, 58 mmol) was added portion wise during 1 h to the boiling perfluorotoluene 1 (26 g, 110 mmol) (mol. ratio 1:AlBr₃ = 1.89:1), the reaction mixture was kept under reflux 3h (pot temperature 160-165°C, evolution of Br₂), cooled to ~25°C, extracted with boiled CH₂Cl₂, extract was filtered, the solvent and 1 that didn’t enter the reaction were distilled off (pot temperature ~135°C). According to CMS-data the residue contained compounds 2 and 5 as the main reaction products and compounds 5a (5a:5 = 1:20), 6-10 as minor components. Further rectification afforded 22 g of a fraction (42-105°C/10 Torr) that contained 88% of compounds 2 and 5 (2:5 = 2:1) (GLC); the yields of 2 and 5 39,5 Pë 16,3% respectively. The bromide 2 was identified by comparison...
precipitate was washed with F113 (2×35 ml), the solvent was evaporated, the residue was combined and the stirring was continued for 1.5 h more, the liquid part of the reaction mixture was decanted, and 2Br-F. The mass-spectra of 2,4,6-Br and 3,4-Br were suggested according to CMA-data. Herein it has been taken into consideration that ionization of bromine containing derivatives of benzotrifluoride affords molecular ions, whereas the compounds containing bromine atoms in Ω±-position form ions [M-Br]+.


The preparation of pentafluorobenzotribromide 3

Aluminium bromide (25 g, 93.6 mmol) was added in 1-1.2 g portions to perfluorotoluene (105 g, 445 mmol) under vigorous stirring for 1.5 h, sustaining the temperature of the reaction mixture at 38-40°C, the stirring was continued for 1.5 h more, the liquid part of the reaction mixture was decanted, the precipitate was washed with F113 (2x35 ml), the solvent was evaporated, the residue was combined with the liquid part of the reaction mixture and distilled to give 31.2 g (79%) of tribromide 3, b.p. 92-93,5°C/2-3 Torr; lit.data: b.p. 110B°C/5 Torr [2]. Mass-spectrum 3 (m/z, reference, %): 337 [M-Br]+ (100%); 258 [M-2Br]+; 178 [C7F8]+; 160 [C7F4]+; 141 [C7F3]+; 129 [C6F3]+; 93 [C5F3]+.

References

Recommended for publication by Prof. S. Sterlin