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Synthesis of fluorine containing glycolurils and oxazolines from oxides of internal perfluoroolefins

Lyudmila V. Saloutina *, Aleksandr Ya. Zapevalov, Victor I. Saloutin, Pavel A. Slepukhin, Mikhail I. Kodess, Oleg N. Chupakhin

I. Ya. Postovsky Institute of Organic Synthesis, Urals Branch of the Russian Academy of Sciences, 22/20 S. Kovalevskoy/Academicheskaya, GSP-147, 620041 Ekaterinburg, Russia

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2-Amino-5-fluoro-4,5-bis(perfluoroalkyl)-4,5-dihydrooxazol-4-ols
4,5-Dihydroxy-4,5-bis(perfluoroalkyl)imidazolidine-2-ones

ABSTRACT

The reaction of oxides of internal perfluoroolefins **1**–**3** with urea gave two kinds of novel fluorine containing N-heterocyclic compounds depending on the solvent nature: 1,5-bis(perfluoroalkyl)tetraazabicyclo[3.3.0]octane-3,7-diones **4a**–**c** and 2-amino-5-fluoro-4,5-bis(perfluoroalkyl)-4,5-dihydrooxazol-4-ols **7a**–**d**. Use of polar dimethylsulfoxide, N,N-dimethylacetamide and acetonitrile afforded glycolurils **4a**–**c** in moderate yields. In dioxane, unexpected cyclization occurred resulting in oxazolines **7a**–**d** in high yields. A similar reaction of oxiranes **2**, **3** with urea in aqueous dioxane gave mixtures of 4,5-dihydroxy-4,5-bis(perfluoroalkyl)imidazolidine-2-ones **9b**, **c**, glycolurils **4b**, **c** and oxazolines **7b**–**d**. The molecular structure of *trans*-isomers of oxazoline **7b** and imidazolidine **9b** has been established by X-ray crystallography.

1. Introduction

The development of the chemistry of N-heterocycles based on urea, such as bicyclic bisureas or glycolurils and their precursors – imidazolidine-2-ones – is of great interest due to high physiological activity of the former [1–3]. It has been shown earlier that glycolurils of octane series are perspective class of neurotropic compounds. One of representatives of this class, 2,4,6,8-tetramethylglycoluril (mebicar) is used in medical practice as a day tranquillizer [1]. Among imidazolidine-2-ones diphenin is known as antiepileptic drug [1]. Moreover, glycoluril derivatives can be used as molecular capsules [4], stabilizers for polymers [5,6] and fluorescent chemosensors [7]. In the last years glycolurils are widely used in supramolecular chemistry as building blocks for preparation of nanoporous materials, synthetic receptors and liquid crystals [8].

The methods known for preparation of glycolurils are based on reaction of ureas with α-dicarbonyl compounds or 4,5-dihydroxyimidazolidine-2-ones [9], but there are no data in the literature on synthesis of fluorine containing glycolurils. On the other hand, we have shown previously that oxides of internal perfluoroolefins can be used for synthesis of fluorine containing N,O,S-heterocycles such as pyrazines, quinaxolines, oxazines, benzoxazines and thiazolines [10–13].

The aim of this work was to describe an approach towards the synthesis of novel perfluoroalkyl containing N-heterocycles: bis(perfluoroalkyl)glycolurils and bis(perfluoroalkyl)oxazolines using oxides of internal perfluoroolefins. We report in the present paper on conversion of octafluoro-2,3-epoxybutane **1** (*cis:trans* ~ 10:90), dodecafluoro-3,4-epoxyhexane **2** (*cis:trans* ~ 10:90) and dodecafluoro-2,3-epoxyhexane **3** (*cis:trans* ~ 10:90) [14] into glycolurils **4a**–**c** and oxazolines **7a**–**d** through the reaction with urea. To investigate the effect of a solvent on a direction of the reaction aprotic solvents possessing different polarity, such as acetonitrile, N,N-dimethylacetamide (DMAA), dimethylsulfoxide (DMSO) and dioxane, have been tested.

* Corresponding author. Tel.: +7 343 374 59 54; fax: +7 343 374 59 54.
E-mail address: fc403@ios.uran.ru (L.V. Saloutina).

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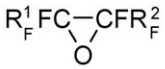


1-3

	R^1_F	R^2_F
1	CF_3	CF_3
2	CF_2CF_3	CF_2CF_3
3	CF_3	$CF_2CF_2CF_3$

2. Results and discussion

We have found that the reaction of oxiranes **1**–**3** with urea in polar DMSO, DMAA and acetonitrile leads to formation of glycolurils, 1,5-bis(perfluoroalkyl)-2,4,6,8-tetraazabicyclo[3.3.0]octane-3,7-diones **4a**–**c** in yields ~20–42% (Table 1, runs 1–3, 5, 8).

The scheme of the reactions can be rationalized as shown in Scheme 1.

Probably, the first step of the reaction involves the initial attack of urea NH_2 group on one of epoxide carbon atoms, followed by ring opening and formation of intermediates **A**. Then the latter are transformed into glycolurils **4a**–**c** by adding a molecule of urea and eliminating H_2O. Heterocyclic products formed by the oxiranes and urea in a ratio 1:1 were not isolated in this case in contrast to reactions of internal perfluoroepoxides with other diamines (ethylenediamine, o-phenylenediamine) which afford exclusively monocyclic compounds—2,3-bis(perfluoroalkyl)-1,2,5,6-tetrahydro-1,4-pyrazine-2-ols [10] and quinoxalines [12].

The structure of compounds **4a**–**c** obtained in pure form was determined by ^{19}F, ^{1}H, ^{13}C NMR, IR spectroscopy, EIMS (**4a**, **c**) and elemental analyses.

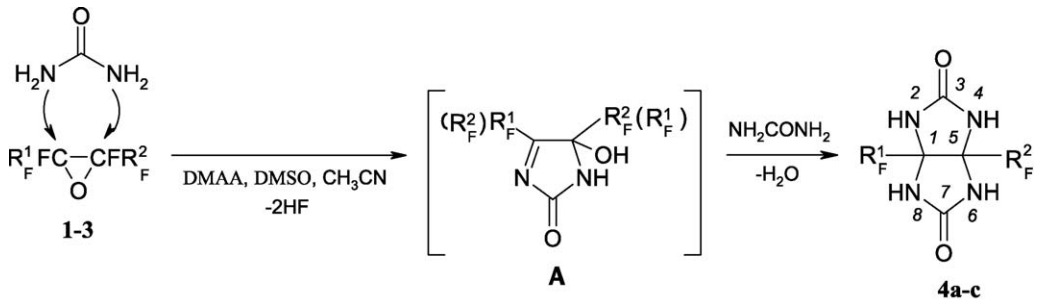
Examination of ^{19}F NMR spectra of the reaction mass obtained by reaction of oxiranes **1**–**3** with urea in the above solvents showed the presence of hem-diols **6a**–**c** [12] (~30–46%) (along with glycolurils **4a**–**c**), which probably formed from isomeric ketones **5a**–**c**. The latter seems to be the result of anionic isomerization of the oxiranes **1**–**3** under the action of F^-(Scheme 2, Table 1) [10,12,15]. Note, when submular amount of urea was used the isomeric ketones were obtained as major reaction products, and heterocycles **4a**–**c** were formed in low yields.

We have found that a similar reaction of oxiranes **1**, **2** with urea in dioxane possessing low polarity [16] yields unexpected heterocyclic products, 2-amino-4,5-bis(perfluoroalkyl)-5-fluoro-4,5-dihydrooxazol-4-ols **7a**, **b** (mainly in *trans*-form) (Scheme 3; Table 1, runs 4, 6). Probably, in this case the first reaction step is the attack of the carbonyl oxygen atom of urea on the epoxide carbon atoms resulting in ring opening and formation of adducts **B**. Eliminating HF the latter give intermediates **C** which undergo intramolecular cyclization to afford heterocycles **7a**, **b**. This surprising reactivity can be explained by higher nucleophilicity of the carbonyl oxygen atom of urea in dioxane since this solvent forming H-bonds with NH_2 groups of the nucleophile does not promote ionization of N–H-bonds, in contrast to polar DMSO, DMAA and acetonitrile [16].

It has been found by ^{19}F NMR spectroscopy that nucleophilic ring opening of unsymmetrical oxirane **3** under similar conditions occurs in both possible directions (paths *a* and *b*; Scheme 3) to give regioisomeric oxazolines **7c**, **d** (mainly in *trans*-form). Approximately equal yields of these compounds (Table 1, run 9) point out

Table 1
Solvent effect on the product composition and yields of heterocyclic reaction products.

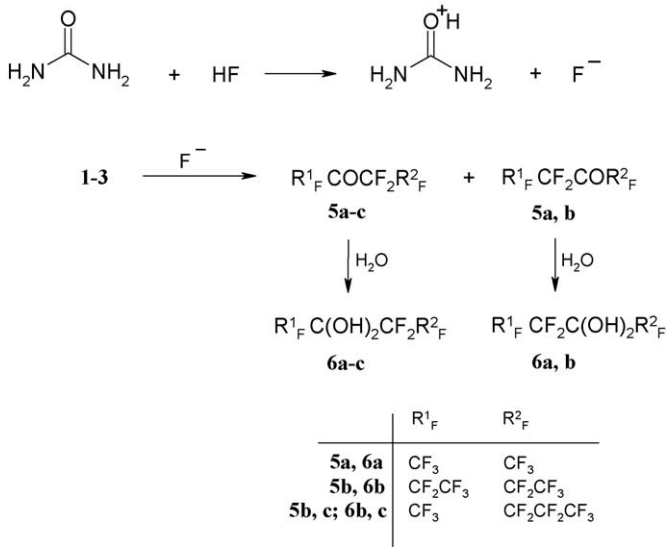
Run no.	Oxirane	Solvent	Product ratio (mol.%, from ^{19}F NMR)	Yield (%)
1.	**1**	Dimethylsulfoxide	**4a**, **6a** (~54:46)	**4a** (21)
2.	**1**	N,N-Dimethylacetamide	**4a**, **6a** (~62:38)	**4a** (31)
3.	**1**	Acetonitrile	**4a**, **6a** (~70:30)	**4a** (42)
4.	**1**	Dioxane	*trans*-**7a**	62
5.	**2**	Dimethylsulfoxide	**4b**, **6b** (~60:40)	**4b** (29)
6.	**2**	Dioxane	*trans*-**7b**	60
7	**2**	Dioxane–H_2O	**4b**, *trans*-**9b**, *trans*-**7b** (~16.3:53.2:30.5)	**4b** (9.8), *trans*-**9b** (21); *trans*-**7b** (9.0)
8.	**3**	Dimethylsulfoxide	**4c**, **6b**, **6c** (~56:22:22)	**4c** (23)
9.	**3**	Dioxane	*trans*-**7c**, *trans*-**7d** (~53:47)	*trans*-**7c**, *trans*-**7d** ~ 48:18 (66)
10.	**3**	Dioxane–H_2O	*trans*-**9c**, *cis*-**9c**, *trans*-**7c**, *trans*-**7d** (~69.9:9.6:15.4:5.1)	**4c** (5.3); *trans*-**9c**: *cis*-**9c** ~ 5:1 (32.7)



1-3 **A** **4a-c**

	R^1_F	R^2_F
4a	CF_3	CF_3
4b	CF_2CF_3	CF_2CF_3
4c	$C^1F_2C^2F_2C^3F_3$	C^1F_3

Scheme 1.



Scheme 2.

nearly the same probability for nucleophilic attack at both epoxide carbon atoms of compound **3**. That is in accordance with our data on interacting 2,3-epoxyperfluoroalkanes with 2-aminophenol and NH_3 [12,17].

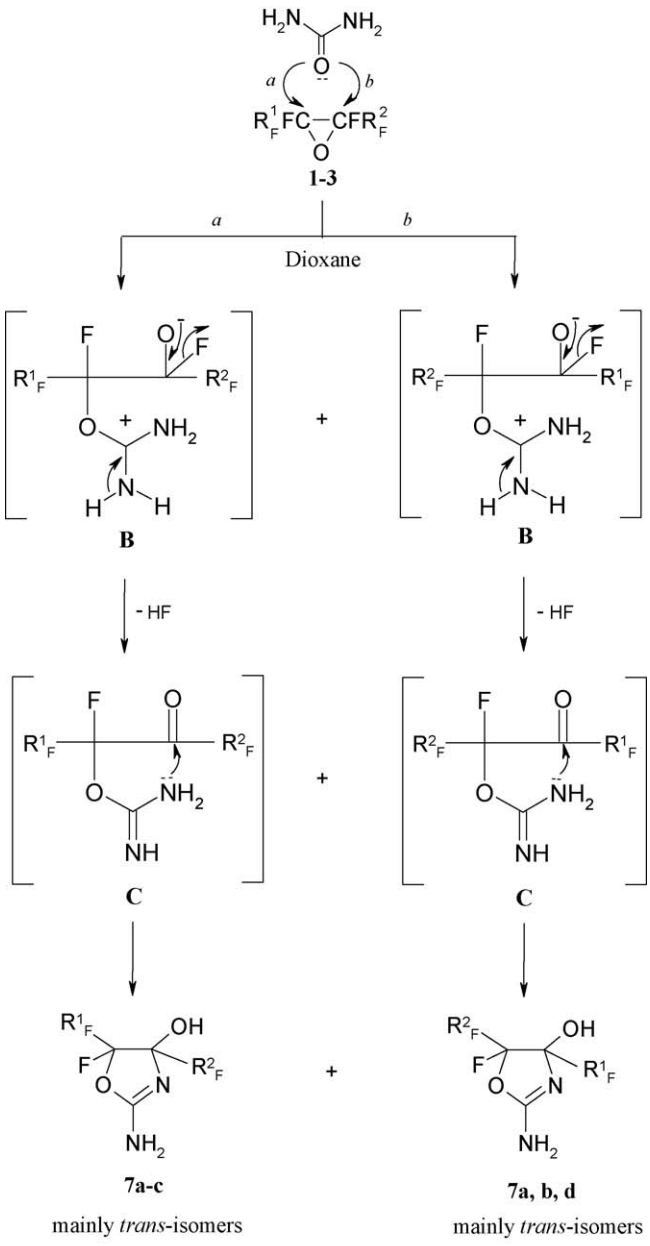
The structure of *trans*-isomers of compounds **7a–c** obtained in individual form was determined by ^{19}F, ^{1}H, ^{13}C NMR, IR spectroscopy and elemental analysis.

In the ^{19}F NMR spectrum of *trans*-isomer of **7a** in Me_2SO-d_6 we observed two doublets of quartets at −77.96 ppm ($^{3}J_{FF}$ 2.9, $^{5}J_{FF}$ 1.7 Hz) and −78.87 ppm ($^{4}J_{FF}$ 19.5, $^{5}J_{FF}$ 1.7 Hz) which were assigned to CF_3–C^5 and CF_3–C^4 groups, respectively. Small value of $^{5}J_{FF}$ coupling constant evidences *anti*-position of CF_3 groups in molecule **7a**. Rather large value for the constant between F atoms at C^5 and C^4 ($^{4}J_{FF}$ = 19.5 Hz) is due substantially to a contribution of through-space spin–spin coupling which occurs at geometrical vicinity of the coupling nuclei [11].

Spectra of *trans*-isomers of oxazolines **7b–d** were more complex because fluorine atoms of all difluoromethylene groups were nonequivalent. The assignment of ^{19}F signals for these compounds was made using 2D ^{19}F–^{19}F COSY homonuclear experiments. The conclusion about configuration of cycles was made on the basis of the analysis of coupling constants $^{4}J_{FF}$. In oxazoline **7d**, the coupling constant between atom F at C^5 and CF_3 group at C^4 was equal to 19.5 Hz as in the case of compound **7a**. More larger $^{4}J_{FF}$ constants between atom F at C^5 and nonequivalent atoms F of difluoromethylene group at C^4 were observed for compounds **7b**, **c**: $^{4}J(F^5–F^A) \approx 40$ and $^{4}J(F^5–F^B) \approx 25$ Hz. These values testify to *cis*-arrangement of the coupling nuclei and thus to *trans*-configuration of oxazolines **7b–d**.

It should be noted that in ^{1}H NMR spectra of oxazolines **7a–d** in Me_2SO-d_6 signals of OH-protons were appeared as doublets ($J \sim 2$ Hz). So, we proposed the doublet splitting to be caused by spin–spin coupling of the OH-proton with F atom at C^5 through four bonds. To solve that question we used $^{19}F\{^{1}H\}$ and $^{1}H\{^{19}F\}$ double resonance techniques. These experiments have shown that in the case of compounds **7a**, **d** when the substituent at C^4 is CF_3 group, splitting is caused by coupling of OH-proton with atom F^5. However, in oxazolines **7b**, **c** suppression of F^5 signal resulted in only insignificant narrowing of the doublet of OH-proton, and disappearance of the doublet splitting was observed at suppression of the low-field signal F^A of difluoromethylene groups at C^4.

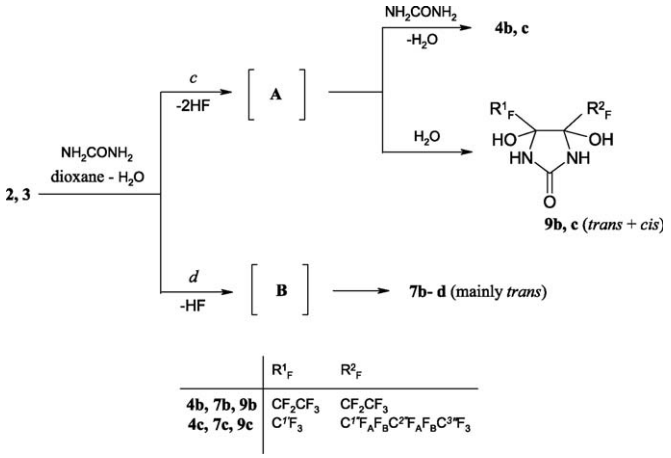
The interaction of oxiranes **2**, **3** with urea in aqueous dioxane under the same conditions was found to give mixtures of reaction



	R^1_F	R^2_F
1, 7a	CF_3	CF_3
2, 7b	CF_2CF_3	CF_2CF_3
3, 7c	$C^{1'}F_3$	$C^{1''}F_AF_BC^{2''}F_AF_BC^{3''}F_3$
3, 7d	$C^{1''}F_3$	$C^{3'}F_3C^{2'}F_AF_BC^{1'}F_AF_B$

Scheme 3.

products. So, at interaction of oxirane **2** with urea in system dioxane–H_2O (~9:1) glycoluril **4b**, dihydroxyimidazolidine **9b** (preferably in *trans*-form) (Scheme 4, path *c*) and oxazoline **7b** (preferably in *trans*-form) (Scheme 4, path *d*) were obtained (Table 1, run 7). A similar reaction of compound **3** gave glycoluril **4c**, dihydroxyimidazolidine **9c** (*trans*:*cis* ~ 88:12) and oxazolines **7c**, **d** (preferably in *trans*-form) (Scheme 4; Table 1, run 10). As can be seen from Table 1 (runs 7 and 10), use of aqueous dioxane results in low yields of oxazolines **7b–d** (Scheme 4, path *d*). The main direction of the reaction becomes formation of dihydroxyimidazolidines **9b**, **c** and glycolurils **4b**, **c** (Scheme 4, path *c*).



Scheme 4.

Proceeding the reaction by the pathway *c* and formation of the intermediate **A** can be explained by participation of polar water along with dioxane in solvation process which promotes activation of N–H urea bond through its ionization [16]. The further addition of a molecule of urea to intermediate **A** with elimination of H_2O leads to glycolurils **4b**, **c**. The other way for stabilization of the intermediate **A** is the addition of H_2O molecule which affords dihydroxyimidazolidinones **9b**, **c** (Scheme 4).

Compounds (**4b**, **c**; *trans*-**7b** and *trans*-**9b**) were isolated in pure form, and their structure was proved by IR, ^{1}H, ^{19}F, ^{13}C NMR spectroscopy and elemental analyses.

The molecular structure of oxazoline **7b** and dihydroxyimidazolidinone **9b** has been established by X-ray diffraction experiments (Figs. 1 and 2, Table 2). Monocrystal samples of compounds **7b**, **9b** suitable for X-ray establishments have been obtained by recrystallization from benzene–dioxane mixture.

According to X-ray data, the structure of compound **7b** has *ac*-conformation of F(11) and O(2)-atoms with (*SS*/*RR*)-configuration of C(3) and C(4) atoms of heterocycle. Imidazolidinone **9b** has *ac*-conformation of OH-groups and (*SS*/*RR*)-configuration of C(3) and C(4) atoms. Thus, molecules of compounds **7b** and **9b** have *trans*-arrangement of pentafluoroethyl groups. Bond lengths and angles of oxazoline **7b** and dihydroxyimidazolidinone **9b** are typical for these classes of compounds (Table 3).

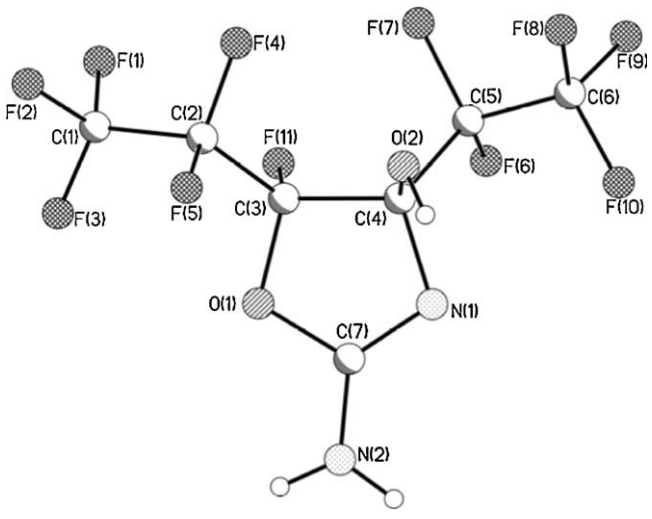


Fig. 1. Molecular structure of *trans*-isomer of 2-amino-5-fluoro-4,5-bis(pentafluoroethyl)-4,5-dihydrooxazol-4-ol (**7b**).

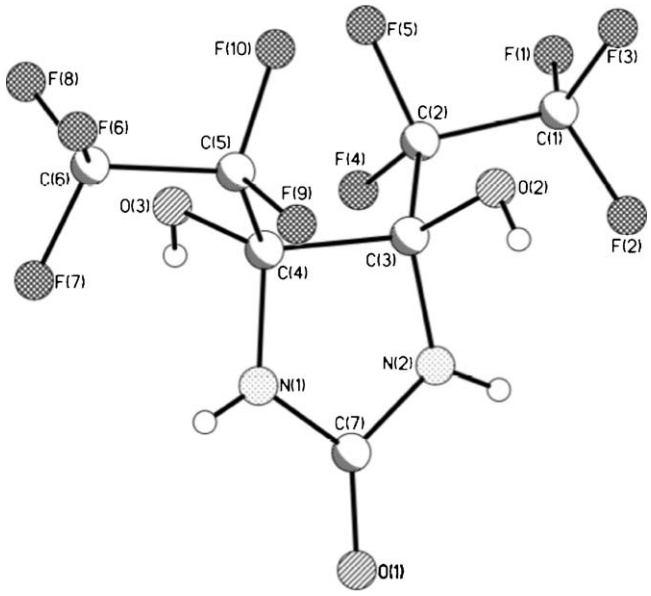


Fig. 2. Molecular structure of *trans*-isomer of 4,5-dihydroxy-4,5-bis(pentafluoroethyl)imidazolidine-2-one (**9b**).

Table 2
Crystal data and structure refinement for compounds **7b**, **9b**.

Compound	**7b**	**9b**
Empirical formula	$C_{11}H_{11}F_{11}N_2O_4$	$C_{13}H_{16}F_{10}N_2O_6$
Formula weight	444.22	486.28
Crystal system	Triclinic	Triclinic
Space group	$P\bar{1}$	$P\bar{1}$
Unit cell dimensions		
a (Å)	8.7925(4)	8.7560(6)
b (Å)	10.0968(11)	9.3803(10)
c (Å)	10.5752(9)	11.8906(17)
α (°)	84.140(8)	77.236(10)
β (°)	79.361(6)	89.116(9)
γ (°)	66.398(8)	88.370(8)
Volume (Å^3), Z	845.09(12), 2	952.06(18), 2
Density (calculated) (g cm^{-3})	1.746	1.696
μ (mm^{-1})	0.206	0.191
F(0 0 0)	4 4 4	4 9 2
Crystal size (mm)	0.55 × 0.50 × 0.45	0.5 × 0.4 × 0.3
θ range for data collection	2.99–31.46°	2.90–31.51°
Reflections collected	9526	11717
Independent reflections	4700 (R_{int} = 0.0215)	5466 (R_{int} = 0.0148)
Reflections with $I > 2\sigma(I)$	1651	3290
Completeness (to θ)	96.1% (27.00°)	97.8% (26.00°)
Parameters	257	296
Goodness-of-fit on F^2	1.001	1.001
R_1 [$I > 2\sigma(I)$]	0.0700	0.0408
wR_2[$I > 2\sigma(I)$]	0.2016	0.1166
R_1 (all data)	0.1601	0.0700
wR_2 (all data)	0.2292	0.1261
Largest diff. peak and hole (eÅ^{-3})	0.421 and −0.312	0.329 and −0.241

Table 3
Selected bond lengths [Å] for compounds **7b** and **9b**.

7b		**9b**	
Bond	Å	Bond	Å
O(1)–C(7)	1.368(3)	O(1)–C(7)	1.2229(16)
O(1)–C(3)	1.388(3)	O(2)–C(3)	1.3936(16)
O(2)–C(4)	1.408(3)	O(3)–C(4)	1.3888(17)
N(1)–C(7)	1.296(4)	N(1)–C(7)	1.3538(18)
N(1)–C(4)	1.433(4)	N(1)–C(4)	1.4309(17)
C(7)–N(2)	1.303(4)	N(2)–C(7)	1.3634(18)
F(11)–C(3)	1.365(3)	N(2)–C(3)	1.4298(17)
C(3)–C(4)	1.569(5)	C(4)–C(3)	1.6020(18)

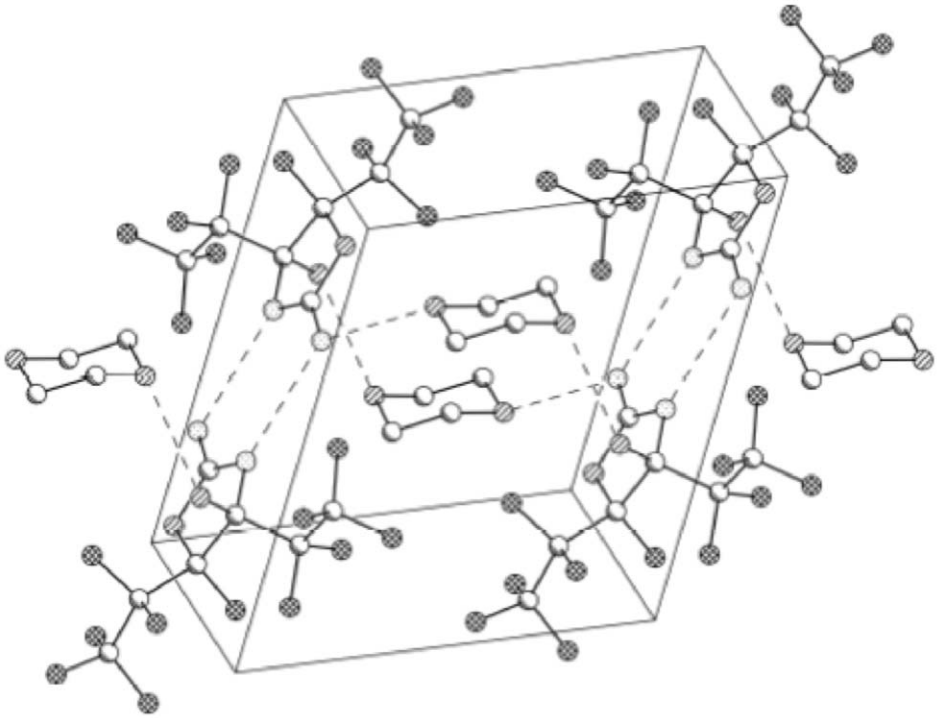


Fig. 3. H-bonds in crystals of *trans*-oxazoline **7b** according to X-ray structural data (H-atoms were omitted for clarity).

Note, both *trans*-oxazoline **7b** and *trans*-imidazolidinone **9b** are crystallized from benzene–1,4-dioxane mixture (~1:1) as solvates with 1,4-dioxane. Thus, crystals of *trans*-isomers of compounds **7b** and **9b** were formed by solvated molecules **7b** (**7b**:1,4-dioxane = 1:1) and **9b** (**9b**:1,4-dioxane = 2:3, one molecule of 1,4-dioxane in private position on centre of inversion). Molecular packing of solvated structures **7b** and **9b** is stabilized by systems of H-bonds (Figs. 3 and 4). There are two types of H-bonds in systems of molecular packing for these compounds. First, there are "dimerous" NH···X bonds between fluorinated heterocycles, such as N(2)–H(2A)···O(1) [$-x+1, -y, -z+2$] in **9b**. Second, there are "bridged" bonds between NH- and OH-groups of fluorinated heterocycles and O-atoms of 1,4-dioxane, for example, O(2)–H(1)···O(2S) in structure **7b**. Parameters of H-bonds are presented in Table 4.

Crystallographic data for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data

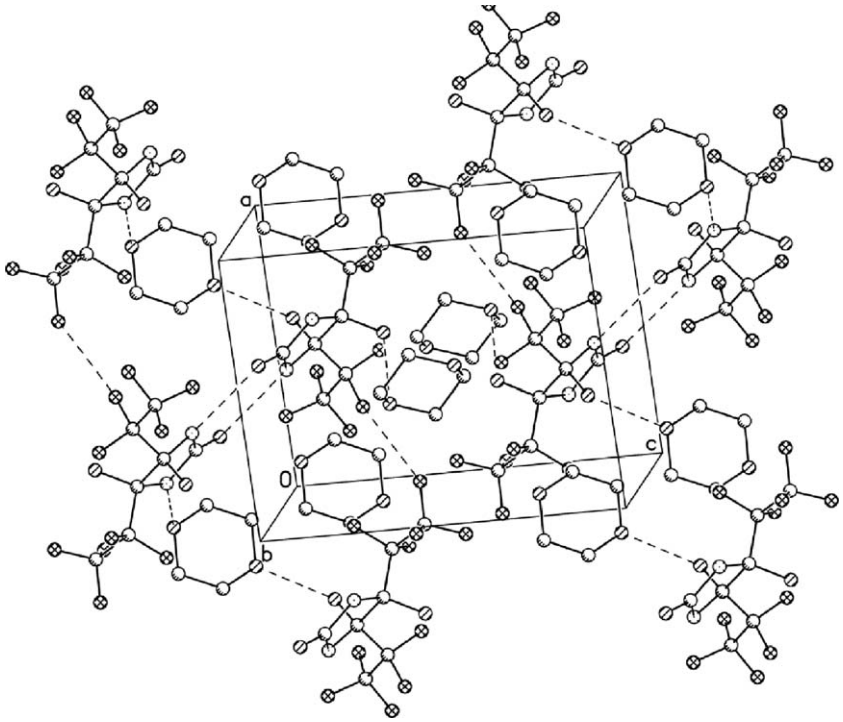


Fig. 4. H-bonds in crystals of *trans*-imidazolidine **9b** according to X-ray structural data (H-atoms were omitted for clarity).

Table 4
Hydrogen bonds with H.A < r(A) + 2.000 Å and <DHA> 110°.

D–H	d(D–H)	d(H.A)	<DHA	d(D.A)	A
7b					
N2–H2A	0.860	2.136	167.74	2.982	N1 [−x, −y + 1, −z + 1]
N2–H2A	0.860	2.466	115.36	2.939	F10 [−x, −y + 1, −z + 1]
N2–H2B	0.860	2.130	160.25	2.954	O1S [−x + 1, −y + 1, −z + 1]
O2–H1	0.848	1.953	163.85	2.778	O2S
9b					
N2–H2A	0.799	2.085	163.21	2.859	O1 [−x + 1, −y, −z + 2]
N2–H2A	0.799	2.439	113.67	2.855	F2
N1–H1	0.726	2.248	166.61	2.959	O3S
N1–H1	0.726	2.497	112.48	2.854	F7
O3–H3	0.825	1.930	156.54	2.707	O1S [−x + 1, −y + 1, −z + 1]
O2–H2	0.740	1.957	173.25	2.694	O2S [−x, −y, −z + 2]

Centre as supplementary no. CCDC 732294 (**7b**) and 732295 (**9b**). Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 !EZ, UK (fax: +44 1223/336 033 e mail: deposit@ccdc cam ac uk).

3. Conclusion

In conclusion, we have reported the synthetic approach to novel perfluoroalkyl containing N-heterocyclic compounds, glycolurils **4a–c** and oxazolines **7a–d**, through the reaction of oxides of internal perfluoroolefins **1–3** with urea.

Use of polar aprotic solvents, such as dimethylsulfoxide, N,N-dimethylacetamide and acetonitrile, gives glycolurils **4a–c** as a result of the initial attack of NH_2 function of urea at one of epoxide carbon atoms, in moderate yields.

A similar reaction in dioxane affords unexpected heterocyclic products, oxazolines **7a–d**, likely due to the initial attack of the carbonyl oxygen atom of urea, in high yields.

Use of aqueous dioxane as a solvent in the reaction between oxiranes **2**, **3** and urea results in low yields of oxazolines **7b–d** and glycolurils **4b**, **c**; 4,5-dihydroxy-4,5-bis(perfluoroalkyl)imidazilidine-2-ones **9b**, **c** are major reaction products in this case.

The compounds obtained are of interest as biologically active substances and new convenient precursors for synthesis of complex heterocyclic systems.

4. Experimental

^1H, ^{13}C and ^{19}F NMR spectra were recorded on a Bruker DRX-400 spectrometer operating at 400, 100 and 376 MHz, respectively. Chemical shifts are reported in ppm (δ) from internal $(CH_3)_4Si$ for hydrogen and carbon and external CCl_3F for fluorine (Me_2SO-d_6). Mass spectra were obtained on a GV 7070 E instrument, ionization energy 70 eV. Infrared spectra were obtained on a Perkin Elmer Spectrum One FT-IR spectrometer in Nujol. The ν_{max} are reported in cm^{-1}. Elemental analyses were carried out on a Perkin Elmer PE 2400 elemental analyzer. Melting points were measured in open capillaries and are reported uncorrected. Oxiranes **1–3** were prepared according to a reported procedure [14]. Solvents were dried according to standard procedures [18].

X-ray structural analyses of compounds **7b** and **9b** were accomplished by using "Xcalibur 3" diffractometer with CCD (λ(Mo Kα) = 0.71073 Å, T = 295(2) K, ω-scans with 1.0° steps in ω and 20 s per frame exposure). The structures were solved by direct methods and refined by full-matrix least-squares technique against on F^2 in anisotropic–isotropic approximation. Hydrogen atoms were located from Fourier synthesis and refined in riding model. All calculations were performed using SHELX [19]. The crystal data and structure refinement for **7b** and **9b** are presented in Table 2.

4.1. The reaction of oxirane (1) with urea

4.1.1. Procedure 1

A mixture of oxirane **1** (8.0 g, 37.04 mmol) and urea (7.1 g, 118.33 mmol) in Me_2SO (20 mL) was heated for 6 h in a sealed tube in a boiling water bath, with intermittent shaking. After cooling (−70 °C), the tube was opened and ^{19}F NMR spectrum of the reaction mixture was recorded (Table 1, run 1). The content of the tube was poured into ice water (200 mL). The resultant precipitate was collected by filtration, washed with water and acetone, and then dried (~60–70 °C) to give 2.2 g, 21% yield of glycoluril **4a** as a white powder. A sample of compound **4a** for analyses was obtained by recrystallization from dry acetone. The ether extract of filtrate contained hem-diol **6a** and traces of glycoluril **4a** and unidentified products (from ^{19}F NMR).

*4.1.1.1. 1,5-Bis(trifluoromethyl)-2,4,6,8-tetraazabicyclo[3.3.0]octane-3,7-dione (**4a**), mp 328–330 °C (decomp.).* IR: ν 1690, 1704, 1742 (C=O), 2500–3500 (NH). ^1H NMR: δ 8.83 (s, NH). ^{13}C NMR (DMSO-d_6): δ 77.11 (q, $^2J_{CF}$ = 35.3 Hz, C-1, C-5), 121.89 (q, $^1J_{CF}$ = 285.3 Hz, CF_3), 158.27 (s, C-3, C-7). ^{19}F NMR: δ −76.27 (3F, s, CF_3). EIMS, m/z (rel. int.): 279 (2.2) $[M+1]^+$, 278 (10.3) $[M]^+$, 235 (29.1) $[M-NHCO]^+$, 209 (100) $[M-CF_3]^+$, 196 (30.2) $[M-C_2F_3H]^+$, 166 (36.2) $[M-CF_3-CONH]^+$, 140 (9.6) $[M-2CF_3]^+$, 139 (46.4) $[M-H-2CF_3]^+$, 138 (11.0) $[M-2CF_3H]^+$, 123 (46.5) $[CF_3C(NH)C(NH)]^+$, 113 (25.8), 112 (25.7) $[M-2CF_3-CO]^+$, 97 (14.5) $[M-2CF_3-CONH]^+$, 96 (55.3) $[M-2CF_3-CON]^+$, 92 (6.6), 77 (12.9), 76 (6.9), 70 (7.3) $[CF_3H]^+$, 69 (79.8) $[CF_3]^+$. Anal. Calcd for $C_6H_4F_6N_4O_2$: C, 25.9; H, 1.4; F, 41.0; N, 20.1. Found: C, 26.0; H, 1.3; F, 41.0; N, 20.1.

4.1.2. Procedure 2

Similarly, a mixture of oxirane **1** (1.5 g, 6.94 mmol) and urea (1.3 g, 21.67 mmol) in DMAA (20 mL) was heated for 5 h. The reaction mixture (Table 1, run 2) was worked up as described above in Section 4.1.1 to yield 0.6 g, 31% yield of glycoluril **4a**. The ether extract of the filtrate contained hem-diol **6a** and traces of glycoluril **4a** and unidentified products (from ^{19}F NMR).

4.1.3. Procedure 3

Similarly, a mixture of oxirane **1** (1.5 g, 6.94 mmol) and urea (1.7 g, 28.33 mmol) in CH_3CN (40 mL) was heated for 17 h. The reaction mixture (Table 1, run 3) was worked up as described above in Section 4.1.1 to yield 0.8 g, 42% yield of glycoluril **4a**. The ether extract of the filtrate contained hem-diol **6a** and traces of unidentified products (from ^{19}F NMR).

4.1.4. Procedure 4

A mixture of oxirane **1** (3.0 g, 13.89 mmol), urea (1.7 g, 28.33 mmol) and dioxane (50 mL) was heated for 20 h in a

sealed tube in a boiling water bath, with intermittent shaking. After cooling (−70 °C), the tube was opened and ^{19}F NMR spectrum of the reaction mixture was recorded (Table 1, run 4). Then the content of the tube was poured into ice water (300 mL). The resultant precipitate was collected by filtration, and the filtrate was extracted with ether. The extract was dried under $MgSO_4$ and evaporated. The united solid (4.0 g) was dried (∼40–50 °C) and recrystallized from benzene–hexane mixture to give 2.2 g, 62% yield of *trans*-isomer of oxazoline **7a** as a white powder.

*4.1.4.1. Trans-isomer of 2-amino-5-fluoro-4,5-bis(trifluoromethyl)-4,5-dihydroxyoxazol-4-ol (**7a**), mp 111–111.5 °C.* IR: ν 1595 (NH), 1680, 1700 (C=N), 3030 br. (OH), 3185, 3260, 3330, 3380, 3400, 3520 (OH, NH). ^{1}H NMR: δ 7.80 (s, 2H, NH_2), 8.03 (d, 1H, OH, J_{HF} 2.2 Hz). ^{13}C NMR (Me_2CO-d_6): δ 99.16 (qd, $^2J_{CF}$ 32.2, 24.5 Hz, C-4), 112.68 (dq, $^1J_{CF}$ 251.5, $^2J_{CF}$ 35.9 Hz, C-5), 120.40 (qd, $^1J_{CF}$ 283.3, $^2J_{CF}$ 39.4 Hz, CF_3–C-5), 123.28 (q, $^1J_{CF}$ 285.2 Hz, CF_3–C-4), 162.78 (s, C-2). ^{19}F NMR: δ −132.32 (qqd, 1F, $^4J_{FF}$ 19.5, $^3J_{FF}$ 2.9, $^4J_{FH}$ 2.2 Hz, C^5F), −78.87 (dq, 3F, $^4J_{FF}$ 19.5, $^5J_{FF}$ 1.7 Hz, CF_3–C^4), −77.96 (dq, 3F, $^3J_{FF}$ 2.9, $^5J_{FF}$ 1.7 Hz, CF_3–C^5). Anal. Calcd for $C_5H_3F_7N_2O_2$: C, 23.4; H, 1.2; F, 52.0; N, 10.9. Found: C, 23.5; H, 1.0; F, 52.1; N, 11.2.

4.2. The reaction of oxirane (2) with urea

4.2.1. Procedure 1

Similarly to procedure in Section 4.1.1, a mixture of oxirane **2** (7.2 g, 22.78 mmol) and urea (4.1 g, 68.33 mmol) in Me_2SO (20 mL) was heated for 6 h. The reaction mixture (Table 1, run 5) was worked up as described in Section 4.1.1 to afford 2.5 g, 29% yield of 1,5-bis(pentafluoroethyl)-2,4,6,8-tetraazabicyclo[3.3.0]octane-3,7-dione **4b** as a white powder. The ether extract of filtrate contained hem-diol **6b** and traces of glycoluril **4b** and unidentified products (from ^{19}F NMR).

*4.2.1.1. 1,5-Bis(pentafluoroethyl)-2,4,6,8-tetraazabicyclo[3.3.0]octane-3,7-dione (**4b**), mp 324–326 °C (decomp.).* IR: ν 1700, 1745 (C=O), 3240 br., 3110, 3440 br. (NH). ^{1}H NMR: δ 8.49 (s, NH). ^{13}C NMR (Me_2CO-d_6): δ 79.33 (tt, $^2J_{CF}$ 27.8, $^3J_{CF}$ 13.1 Hz, C-1, C-5), 111.72 (tq, $^1J_{CF}$ 267.8, $^2J_{CF}$ 35.9 Hz, $2CF_2$), 118.33 (qt, $^1J_{CF}$ 289.2, $^2J_{CF}$ 36.6 Hz, $2CF_3$), 158.63 (s, C-3, C-7). ^{19}F NMR: δ −78.28 (s, 3F, CF_3), −119.35 (s, 2F, CF_2). Anal. Calcd for $C_8H_4F_{10}N_4O_2$: C, 25.4; H, 1.1; F, 50.3; N, 14.8. Found: C, 25.4; H, 1.2; F, 50.0; N, 14.8.

4.2.2. Procedure 2

Similarly to procedure in Section 4.1.4, a mixture of oxirane **2** (3.1 g, 9.81 mmol) and urea (1.2 g, 20 mmol) in dioxane (50 mL) was heated for 22 h. The reaction mixture (Table 1, run 6) was worked up as described above in Section 4.1.4 to give 2.1 g, 60% yield of *trans*-isomer of oxazoline **7b** as a white powder.

*4.2.2.1. Trans-isomer of 2-amino-5-fluoro-4,5-bis(pentafluoroethyl)-4,5-dihydroxyoxazol-4-ol (**7b**), mp 129 °C.* IR: ν 1589, 1605 (NH), 1706, 1733 (C=N), 3118 br., 3360, 3510, 3521 (OH, NH). ^{1}H NMR: δ 7.89 (br.s, 2H, NH_2), 7.99 (d, 1H, J_{HF} 1.9 Hz, OH). ^{13}C NMR: δ 100.53 (q, $^2J_{CF}$ 24.4 Hz, C-4), 109.46 (tdq, $^1J_{CF}$ 264.9, $^2J_{CF}$ 43.3, 37.3 Hz, CF_2–C-5), 112.31 (tq, $^1J_{CF}$ 264.6, $^2J_{CF}$ 34.5 Hz, CF_2–C-4), 112.62 (ddd, $^1J_{CF}$ 252.6, $^2J_{CF}$ 36.4, 25.8 Hz, C-5), 117.90 (qt, $^1J_{CF}$ 288.8, $^2J_{CF}$ 34.8 Гц, CF_3), 118.60 (qt, $^1J_{CF}$ 288.6, $^2J_{CF}$ 35.7 Hz, CF_3), 160.79 (s, C-2). ^{19}F NMR: δ −129.02 (m, 1F, C^5F), CF_AF_B–C^5: −126.81 (ddd, 1F, $^2J_{FF}$ 291.4, J_{FF} 24.5, 7.4 Hz, CF_B,), −121.08 (dd, 1F, $^2J_{FF}$ 291.4, $^3J_{FF}$ 10.3 Hz, CF_A), CF_AF_B–C^4: −125.38 (dt, 1F, $^2J_{FF}$ 275.6, J_{FF} 24.5 Hz, CF_B), −118.90 (ddd, 1F, $^2J_{FF}$ 275.6, $^4J_{FF}$ 39.8, $^4J_{FH}$ 1.9 Hz, CF_A), −80.16 (dd, 3F, J_{FF} 13.2, 1.3 Hz, CF_3–CF_2–C^5), −78.25 (dd, 3F, J_{FF} 2.6, 1.6 Hz, CF_3–CF_2–C^4). Anal. Calcd for $C_7H_3F_{11}N_2O_2$: C, 23.6; H, 0.8; F, 58.7; N, 7.9. Found: C, 23.8; H, 0.6; F, 59.0; N, 8.1.

4.2.3. Procedure 3

Similarly to procedure in Section 4.1.4, a mixture of oxirane **2** (5.1 g, 16.1 mmol) and urea (2.9 g, 48.4 mmol) in aqueous dioxane (50 mL, dioxane–water ∼ 9:1) was heated for 25 h. After cooling (−70 °C), the tube was opened and ^{19}F NMR spectrum of the reaction mixture was recorded (Table 1, run 7). Then the content of the tube was poured into ice water (200 mL) and the resultant precipitate was collected by filtration. The filtrate and the precipitate were worked up as following.

4.2.3.1. Treatment of the precipitate. After drying (∼40–50 °C), the precipitate (1.5 g) containing *trans*-isomer of oxazoline **7b** and glycoluryl **4b** (**7b**:**4b** ∼ 3:2, from NMR ^{19}F) was extracted with $CHCl_3$ and Et_2O. The insoluble residue was washed with water and with acetone and dried (∼50–60 °C) to yield 0.6 g, 9.8% yield of glycoluril **4b**. The extracts were evaporated and the solid obtained (0.8 g) was recrystallized from benzene–hexane mixture (2:1) and from benzene to give 0.5 g, 9.0% yield of *trans*-isomer of oxazoline **7b**.

4.2.3.2. Treatment of the water–dioxane filtrate. The water–dioxane filtrate was extracted with Et_2O. The extract was dried under $MgSO_4$ and evaporated. The solid obtained (2.8 g) containing *trans*-isomer of imidazolidine **9b** and *trans*-isomer of oxazoline **7b** (**9b**:**7b** ∼ 92:8) was washed with $CHCl_3$ and recrystallized from benzene–MeOH mixture (∼10:2) to yield 1.2 g, 21% yield of *trans*-isomer of imidazolidine **9b**.

*4.2.3.3. Trans-isomer of 4,5-dihydroxy-4,5-bis(pentafluoroethyl)imidazolidine-2-one (**9b**), mp 152–153 °C.* IR (DRA): ν 1748 (C=O), 2473, 2865–2997, 3130 br., 3218, 3360 (NH, OH). ^{1}H NMR: δ 7.70 (d, 1H, J_{HF} 2.5 Hz, OH), 8.14 (s, 1H, NH). ^{13}C NMR: δ 89.01 (t, $^2J_{CF}$ 23.2 Hz, C–OH), 112.53 (ddq, $^1J_{CF}$ 267.9, 263.1; $^2J_{CF}$ 34.8 Hz, CF_2), 118.73 (qt, $^1J_{CF}$ 288.3, $^2J_{CF}$ 36.0 Hz, CF_3), 157.95 (s, C=O). ^{19}F NMR: δ −123.49 (dm, 1F, $^2J_{FF}$ 277.9 Hz, CF_B), −115.56 (ddd, 1F, $^2J_{FF}$ 277.5, J_{FF} 14.4, 12.8 Hz, CF_A), −78.06 (d, 3F, J_{FF} 3.2 Hz, CF_3). Anal. Calcd for $C_7H_4F_{10}N_2O_3$: C, 23.7; H, 1.1; F, 53.7; N, 7.9. Found: C, 23.5; H, 0.9; F, 53.5; N, 7.7.

4.3. The reaction of oxirane (3) with urea

4.3.1. Procedure 1

Similarly to procedure in Section 4.1.1, a mixture of oxirane **3** (7.5 g, 23.73 mmol) and urea (4.3 g, 71.67 mmol) in Me_2SO (17 mL) was heated for 8 h. The reaction mixture (Table 1, run 8) was worked up as described in Section 4.1.1 to afford 2.1 g (23%) of 1-heptafluoropropyl-5-trifluoromethyl-2,4,6,8-tetraazabicyclo[3.3.0]octane-3,7-dione **4c** as a white powder. The ether extract of filtrate contained hem-diols **6b**, **c** and traces of glycoluril **4c** and unidentified products (from ^{19}F NMR).

*4.3.1.1. 1-Heptafluoropropyl-5-trifluoromethyl-2,4,6,8-tetraazabicyclo[3.3.0]octane-3,7-dione (**4c**), mp 326–328 °C (decomp.).* IR: ν 1705, 1735 (C=O), 3095 br., 3220 br. (NH).^{1}H NMR: δ 8.64 (s, 2H, 2NH), 8.93 (s, 2H, 2NH). ^{13}C NMR: δ 78.22 (t, $^2J_{CF}$ 29.0 Hz, C-5), 79.03 (q, $^2J_{CF}$ 34.7 Hz, C-1), 108.76–116.12 (m, $C^{1'}F_2$, $C^{2'}F_2$), 114.65 (q, $^1J_{CF}$ 294.5 Hz, $C^{3'}F_3$), 121.97 (q, $^1J_{CF}$ 284.3 Hz, $C^{1''}F_3$), 158.32 (s, C-3, C-7). ^{19}F NMR: δ −121.91 (m, 2F, $C^{2'}F_2$), −116.93 (m, 2F, $C^{1'}F_2$), −81.06 (t, 3F, J_{FF} 10.9 Hz, $C^{3'}F_3$), −74.71 (tt, 3F, J_{FF} 21.5, 4.9 Hz, $C^{1''}F_3$). EIMS, *m/z* (rel. int.): 379 (2.2) $[M+1]^+$, 378 (6.7) $[M]^+$, 336 (7.2) $[M-NCO]^+$, 335 (82.3) $[M-NHCO]^+$, 296 (34.7) $[M-C_2F_3H]^+$, 281 (5.9) $[M-C_2F_3H-NH]^+$, 276 (8.6) $[M-C_2F_3]^+$, 273 (17.2), 266 (7.3) $[M-CF_3-CONH]^+$, 239 (35.9) $[M-2CF_3-H]^+$, 223 (9.1) $[C_3F_7C(NH)C(NH)]^+$, 216 (23.7), 213 (21.4), 210 (6.1), 209 (85.0) $[M-C_3F_7]^+$, 201 (8.5), 196 (18.5) $[M-2CF_3H-CON]^+$, 181 (5.6) $[M-C_3F_7-CN]^+$, 173 (6.1), 169 (20.4) $[C_3F_7]^+$, 166 (47.8), 146 (5.7),

140 (9.5) $[M-CF_3-C_3F_7]^+$, 139 (61.3) $[M-CF_3H-C_3F_7]^+$, 138 (9.2) $[M-C_3F_7H-CF_3H]^+$, 131 (8.6), 123 (55.3) $[CF_3CNCO]^+$, 121 (6.4), 120 (5.7), 119 (15.3) $[C_2F_5]^+$, 113 (44.2), 112 (21.7), 108 (6.1) $[CF_3C(NH)C]^+$, 78 (5.7), 77 (8.7), 76 (5.1), 70 (8.9) $[CF_3H]^+$, 69 (100) $[CF_3]^+$. Anal. Calcd for $C_8H_4F_{10}N_4O_2$: C, 25.4; H, 1.1; F, 50.3; N, 14.8. Found: C, 25.6; H, 0.9; F, 50.0; N, 14.7.

4.3.2. Procedure 2

Similarly to procedure in Section 4.1.4, a mixture of oxirane **3** (3.2 g, 10.13 mmol) and urea (2.1 g, 35 mmol) in dioxane (50 mL) was heated for 18 h. The reaction mixture (Table 1, run 9) was poured into ice water (200 mL), and the resultant precipitate was collected by filtration, washed with water and dried at room temperature. After recrystallization from a mixture hexane–benzene, *trans*-isomer of 2-amino-4-heptafluoropropyl-5-fluoro-5-trifluoromethyl-4,5-dihydrooxazol-4-ol **7c** was obtained as a white powder, 0.7 g, 19% yield. The water–dioxane filtrate was extracted with Et_2O, the extract was dried under $MgSO_4$ and evaporated. The solid residue (a mixture of *trans*-isomers of compounds **7c**, **d**) was dried (~40–50 °C) and recrystallized from benzene–hexane to result in 1.7 g, 47% yield of a mixture of *trans*-isomers of oxazolines **7c**, **d** (**7c**:**7d** ~ 2:1) as a white powder.

*4.3.2.1. Trans-isomer of 2-amino-4-heptafluoropropyl-5-fluoro-5-trifluoromethyl-4,5-dihydrooxazol-4-ol (**7c**), mp 112–113 °C.* IR: ν 1596 (NH), 1702, 1732 (C=N), 3100 br., 3380, 3500 (OH, NH). ^{1}H NMR: δ 7.90 (br.s, 2H, NH_2), 8.07 (d, 1H, OH, J_{HF} 2.0 Hz). ^{19}F NMR: δ −131.83 (ddm, 1F, $^4J_{FF}$ 38.9, 24.6 Hz, C^5F), −124.75 (ddm, 1F, $^2J_{FF}$ 287.1, J_{FF} 9.9 Hz, $C^{2''}F_B$), −121.20 (dm, 1F, $^2J_{FF}$ 282.4 Hz, $C^{1''}F_B$), −121.09 (dm, 1F, $^2J_{FF}$ 287.1 Hz, $C^{2''}F_A$), −116.59 (ddqd, 1F, $^2J_{FF}$ 282.4, $^4J_{FF}$ 38.7, J_{FF} 11.3, 9.6 Hz, $C^{1''}F_A$), −80.58 (dd, 3F, $^4J_{FF}$ 11.3, 8.1 Hz, $C^{3''}F_3$), −77.76 (d, 3F, J_{FF} 7.3 Hz, $C^{1'}F_3$). EIMS, *m*/*z* (rel. int.): 339 (10.9) $[M-OH]^+$, 337 (10.9) $[M-F]^+$, 289 (6.0), 240 (38.2) $[M-CF_3CFO]^+$, 220 (6.7) $[M-CF_3CFO-HF]^+$, 197 (11.5), 188 (5.5) $[M+1-C_3F_7]^+$, 187 (100) $[M-C_3F_7]^+$, 169 (32.2) $[C_3F_7]^+$, 121 (38.0), 119 (8.2) $[C_2F_5]^+$, 111 (7.1), 109 (8.5), 100 (9.4) $[C_2F_4]^+$, 97 (17.1), 78 (8.6), 71 (21.9), 70 (15.2) $[CF_3H]^+$, 69 (100) $[CF_3]^+$. Anal. Calcd for $C_7H_3F_{11}N_2O_2$: C, 23.6; H, 0.8; F, 58.7; N, 7.9. Found: C, 23.8; H, 0.6; F, 58.7; N, 7.9.

*4.3.2.2. Trans-isomer of 2-amino-5-heptafluoropropyl-5-fluoro-4-trifluoromethyl-4,5-dihydrooxazol-4-ol (**7d**).* IR: ν 1596 (NH), 1702, 1732 (C=N), 3100 br., 3380, 3500 (OH, NH). ^{1}H NMR: δ 7.83 (br.s, 2H, NH_2), 8.02 (d, 1H, J_{HF} 2.2 Hz, OH). ^{19}F NMR: δ −129.95 (m, 1F, C^5F), −125.64 (ddd, 1F, $^2J_{FF}$ 288.3, J_{FF} 11.4, 10.1 Hz, $C^{2'}F_B$), −123.20 (dddd, 1F, $^2J_{FF}$ 288.3, J_{FF} 24.1, 11.0, 5.1 Hz, $C^{2'}F_A$), −122.44 (dm, 1F, $^2J_{FF}$ 298.6 Hz, $C^{1'}F_B$), −118.53 (ddq, 1F, $^2J_{FF}$ 298.6, J_{FF} 22.6, 11.4 Hz, $C^{1'}F_A$), −80.73 (ddd, 3F, J_{FF} 11.4, 8.5, 3.0 Hz, $C^{3'}F_3$), −78.53 (dd, 3F, J_{FF} 20.2, 7.0 Hz, $C^{1''}F_3$).

4.3.3. Procedure 3

Similarly, a mixture of oxirane **3** (1.9 g, 6.01 mmol) and urea (1.2 g, 20 mmol) in aqueous dioxane (20 mL, dioxane:water ~ 9:1) was heated for 23 h. After the reaction was completed, ^{19}F NMR spectrum of the reaction mixture was recorded (Table 1, run 10). Then the content of the tube was poured into ice water (200 mL). The resultant precipitate was collected by filtration, washed with water and dried (~50–60 °C) to give 0.12 g, 5.3% yield of glycoluril **4c**. The filtrate was extracted with ether, and the extract was dried ($MgSO_4$) and evaporated. The solid residue (1.1 g) consisting of imidazolidine **9c** (*trans*:*cis* ~ 88:12) and oxazolines **7c**, **d** (**7c**:**7d** ~ 75:25) in the ratio **9c**:**7c** + **7d** ~ 80:20 (from ^{19}F NMR), was dried (~40–50 °C) and washed with $CHCl_3$. The solid residue was recrystallized from benzene to yield 0.7 g, 32.7% yield of 4,5-dihydroxy-4-heptafluoropropyl-5-trifluoromethyl-imidazolidine-2-one **9c** (*trans*:*cis* ~ 5:1), mp 110–115 °C. IR (DRA): ν 1713 (C=O), 2640 br., 3285 br. (NH, OH). Anal. Calcd for: $C_7H_4F_{10}N_2O_3$: C 23.7; H 1.1; F 53.7; N 7.9. Found: C 23.9; H 1.0; F 53.7; N 7.9.

*4.3.3.1. Trans-isomer of 4,5-dihydroxy-4-heptafluoropropyl-5-trifluoromethyl-imidazolidine-2-one (**9c**).* ^{1}H NMR: δ 7.57 (br.s, 1H, NH), 7.73 (br.s, 1H, NH), 8.19 (s, 1H, OH), 8.42 (s, 1H, OH). ^{19}F NMR: δ −122.94 (dm, 1F, $^2J_{FF}$ 287.5 Hz, $C^{2''}F_B$), −119.69 (dm, 1F, $^2J_{FF}$ 287.5 Hz, $C^{2''}F_A$), −116.98 (dm, 1F, $^2J_{FF}$ 281.8 Hz, $C^{1''}F_B$), −114.43 (dqw, 1F, $^2J_{FF}$ 281.9, J_{FF} 12.5 Hz, $C^{1''}F_A$), −80.95 (dd, 3F, J_{FF} 12.5, 8.8 Hz, $C^{3''}F_3$), −76.96 (m, 3F, $C^{1'}F_3$).

*4.3.3.2. Cis-isomer of 4,5-dihydroxy-4-heptafluoropropyl-5-trifluoromethyl-imidazolidine-2-one (**9c**).* ^{1}H NMR: δ 7.65 (s, 1H, NH), 7.94 (s, 1H, OH), 7.96 (s, 1H, NH), 8.35 (s, 1H, OH). ^{19}F NMR: δ −123.77 (ddm, 1F, $^2J_{FF}$ 289.2, J_{FF} 13.5 Hz, $C^{2''}F_B$), −120.75 (dm, 1F, $^2J_{FF}$ 289.2 Hz, $C^{2''}F_A$), −119.87 (dqdq, 1F, $^2J_{FF}$ 280.0, J = 23.9, 13.0, 11.4 Hz, $C^{1''}F_B$), −117.56 (dqm, 1F, $^2J_{FF}$ 278.0, J_{FF} 17.2 Hz, $C^{1''}F_A$), −80.82 (dd, 3F, J_{FF} 11.4, 9.9 Hz, $C^{1''}F_3$), −77.34 (ddd, 3F, J_{FF} 23.9, 17.2, 4.3 Hz, $C^{1'}F_3$).

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References

[1] M.D. Mashkovskii, Lekarstvennye sredstva (Drugs), vol. 1, Novaya Volna, Moscow, 2002, pp. 39, 86.
[2] S.S. Novikov, Izv. Akad. Nauk SSSR, Ser. Khim. (1979) 2261–2278 (Bull. Acad. Sci. USSR, Div. Chem. Sci. (Engl. Transl.) 28 (1979) 2083–2099).
[3] O.V. Lebedev, L.I. Khmel'nitskii, L.V. Epishina, L.I. Suvorova, I.V. Zaikonnikova, I.E. Zimakova, S.V. Kirshin, A.M. Karpov, V.S. Chudnovskii, M.V. Povstyanoi, V.A. Eres'ko, Tselenapravlennyi poisk novykh neirotropnykh preparatov (Purposeful Search for New Neurotropic Agents), Zinatne, Riga, 1983, p. 81.
[4] D. Ajami, J. Rebek Jr., J. Am. Chem. Soc. 128 (2006) 5314–5315.
[5] R. Helwig, A. Aumueller, P. Neumann, H. Trauth, DE Patent 3,530,666 (1987) (C.A. 107 (1987) 41059x).
[6] A. Krause, A. Aumueller, E. Korola, H. Trauth, DE Patent 4,303,522 (1994) (C.A. 121 (1994) 205400n).
[7] N. She, M. Gao, L. Cao, G. Yin, A. Wu, Synlett 18 (2007) 2533–2536.
[8] M. Kölbel, F.M. Menger, Adv. Mater. 13 (2001) 1115–1119.
[9] A.N. Kravchenko, A.S. Sigachev, E.Yu. Maksareva, G.A. Gazieva, N.S. Trunova, B.V. Lozhkin, T.S. Pivina, M.M. Ilin, K.A. Lissenko, Yu.V. Nelyubina, V.A. Davankov, O.V. Lebedev, N.N. Makhova, V.A. Tartakovskii, Izv. Akad. Nauk SSSR, Ser. Khim. (2005) 680–692 (Russian Chem. Bull. Int. Ed., 54 (2005) 691–704).
[10] L.V. Saloutina, A.Ya. Zapevalov, M.I. Kodess, V.I. Saloutin, J. Fluorine Chem. 87 (1998) 49–55.
[11] L.V. Saloutina, A.Ya. Zapevalov, M.I. Kodess, V.I. Saloutin, G.G. Aleksandrov, O.N. Chupakhin, J. Fluorine Chem. 104 (2000) 155–165.
[12] L.V. Saloutina, A.Ya. Zapevalov, V.I. Saloutin, M.I. Kodess, V.E. Kirichenko, M.G. Pervova, O.N. Chupakhin, J. Fluorine Chem. 126 (2005) 976–983.
[13] L.V. Saloutina, A.Ya. Zapevalov, V.I. Saloutin, P.A. Slepukhin, M.I. Kodess, V.E. Kirichenko, M.G. Pervova, O.N. Chupakhin, J. Fluorine Chem. 128 (2007) 769–778.
[14] I.P. Kolenko, T.I. Filyakova, A.Ya. Zapevalov, E.P. Lurye, Izv. Akad. Nauk SSSR, Ser. Khim. (1979) 2509–2512 (Bull. Acad. Sci. USSR, Div. Chem. Sci. (Engl. Transl.) 28 (1979) 2323–2326).
[15] A.Ya. Zapevalov, T.I. Filyakova, I.P. Kolenko, M.I. Kodess, Zh. Org. Khim. 22 (1986) 93–99 (J. Org. Chem. USSR (Engl. Transl.) 22 (1986) 80–85).
[16] C. Reichardt, Rastvoriteli i effekti sredi v organicheskoi khimii (Solvents and Solvent Effects in Organic Chemistry), Mir, Moscow, 1991, pp. 24–124.
[17] L.V. Saloutina, A.Y. Zapevalov, M.I. Kodess, I.P. Kolenko, Zh. Org. Khim. 26 (1990) 731–739 (C.A. 113 (1990) 151794q).
[18] Organicum, Practicum po organicheskoi khimii (Organicum. Organisch-chemisches grundpraktikum), vol. 2, Mir, Moscow, 1992, pp. 402–427.
[19] G.M. Sheldrick, SHELX97 Program for the Refinement of Crystal Structure, University of Göttingen, Germany, 1997.