Electronic supplementary materials *Mendeleev Commun.*, 2018, **28**, 511–512

3,4-Epoxyperfluorooxolane in the synthesis of new fluorine-containing furo[3,4-*b*]quinoxaline derivatives

Tatjana I. Filyakova, Vera I. Filyakova, Alexander Ya. Zapevalov, Mikhail I. Kodess, Pavel A. Slepukhin, Victor I. Saloutin and Valery N. Charushin

Materials and methods.

3,4-Epoxyperfluorooxolane **5** was prepared according to the known method [S1] by hypohalogenic epoxidation of perfluoro-3-oxolene. The purity of the starting and prepared compounds was monitored by TLC on Sorbfil plates (UV-254, eluent $CHCl_3$). Spots on the plates were detected by UV light and by treatment with $Cu(OAc)_2$ aqueous solution.

^1H, ^{13}C, and ^{19}F NMR spectra were recorded on Bruker DRX-400 and Bruker AVANCE-500 spectrometers using TMS and C_6F_6 as the internal standards. IR spectra were recorded on a Perkin-Elmer Spectrum One FT-IR instrument equipped with attenuated total reflection (ATR) or the diffusion reflection accessory (DRA) units for the 400–4000 cm^{-1} range in solid form. Elemental analysis was carried out using a Perkin Elmer PE 2400 element analyzer.

*Reaction of perfluoro-3,4-epoxyoxolane **5** with SbF_5.*

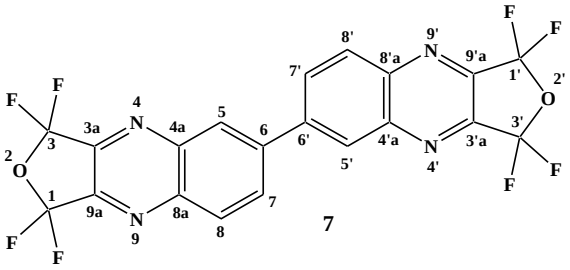
Antimony pentafluoride (1.4 g, 6.5 mmol) was placed in a glass ampoule and cooled with dry ice; and epoxyoxolane **5** (3.0 g, 15.5 mmol) was added. The ampoule was sealed; the reaction mixture was kept at room temperature for 2 h, cooled with dry ice, carefully opened, and poured into H_2SO_4 (conc.), and rectified. The product, pentafluoroacetoacetic acid fluoride $CF_3C(O)CF_2C(O)F$, was obtained in the yield of 1.7 g (57%), b.p. 14–16 °C. IR, ν/cm^{-1}: 1895 (COF), 1810 (C=O). ^{19}F NMR (376 MHz, acetone-d_6), δ: 90.15 (t, 3F, CF_3), 52.74 (dq., 2F, CF_2), 186.03 (t, 1F, COF).

*Reaction of perfluoro-3,4-epoxyoxolane **5** with c 3,3',4,4'-tetraaminobiphenyl **2**.*

3,3',4,4'-Tetraaminobiphenyl **2** (3.0 g, 14 mmol), $NaHCO_3$ (2.36 g, 28 mmol), and dioxane (20 ml) were placed in a glass ampoule and cooled with dry ice; and epoxyoxolane **5** (2.8 g, 14 mmol) was added. The ampoule was sealed; the reaction mixture was warmed up to ~ 20 °C and heated for 6 h in a boiling water bath, while the ampoule was periodically and carefully taken out from the bath and shaken. Then the ampoule was cooled to room temperature and carefully

opened; the precipitate was filtered off; the filtrate was poured into a Petri dish; and the solvent was evaporated. A brown solid (5.45 g) was obtained, which was purified by column chromatography on silica gel (initial eluent was CH_2Cl_2 : hexane of 6 : 1; then $CHCl_3$: MeOH : hexane of 20 : 1 : 1). The following compounds were isolated (listed according to the elution order):

1,1,1',1',3,3,3',3'-Octafluoro-1,1',3,3'-tetrahydro-6,6'-bifuro[3,4-b]quinoxaline **7**



7

Yield 1.26 g (37.0 %)**.** Colorless crystals, m.p. 164–166 °C (subl.). Found, %: C, 49.03; H, 1.41; N, 11.58, F 31.08. For $C_{20}H_6F_8N_4O_2$, calculated, %: C, 49.40; H, 1.24; N, 11.52, F 31.26. FW 486.28. IR, ν/cm^{-1}: 1624, 1582, 1497 (C=C, C=N), 1274, 1255, 1215, 1183, 1151, 1122, 1054 (C-F). ^{1}H NMR (500 MHz, DMSO-d$_6$), δ: 8.64 (d, 2H, H$^{8,8'}$, J = 8.9 Hz), 8.92 (dd, 2H, H$^{7,7'}$, J = 8.9 and 2.1 Hz), 9.15 (d, 2H, H$^{5,5'}$, J = 2.1 Hz). ^{19}F NMR (470.5 MHz, DMSO-d$_6$), δ: 89.4 (m, 4F, CF_2), 89.5 (m, 2F, CF_2). ^{13}C NMR (126 MHz, DMSO-d$_6$), δ: 122.08 (t, $^1J_{CF}$ = 264.4 Hz, 4*CF_2), 128.9 (C$^{5,5'}$), 131.1 (C$^{8,8'}$), 133.5 (C$^{7,7'}$), 142.4 (C$^{4a,4'a}$), 142.7, and 143.0 (both t, $^2J_{CF}$ = 28.5 Hz, C$^{3a,3'a}$ and C$^{9a,9'a}$), 144.1 (C$^{6,6'}$), 144.3 (C$^{8a,8'a}$).

The molecule of compound **7** in the crystal is located at a special position (in the center of inversion). The general view of the molecule is shown in Figure S1.

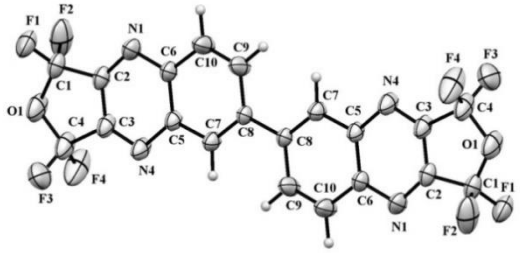
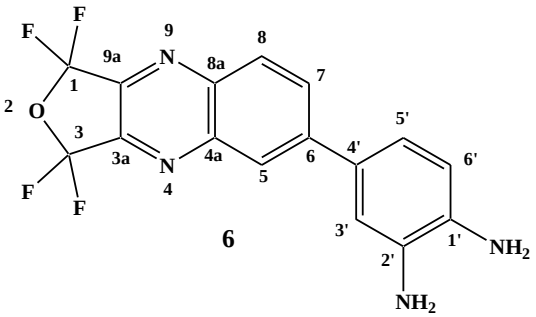


Figure S1 Molecular structure of **7** showing thermal ellipsoids at the 50% probability level.

Excepting for the fluorine atoms, the molecule is flat within 0.1 Å. The anisotropic thermal parameters of C(9) and C(10) atoms indicate either strong oscillations or a possible unresolved disorder of these atoms perpendicular to the heterocycle plane. This may be related with torsion stresses caused by the spatial convergence of hydrogens at C(7) and C(9) atoms. The C–C bond length between heterocyclic moieties is 1.494 Å, which indicates the absence of significant

conjugation and the relative isolation of π-systems of quinoxaline fragments. There are some shortened intermolecular contacts in the crystal, predominantly of C...F type, wherein the contact between C(8) and F(2) [*x*–1, *y*, *z*] of 3.014 Å is noticeable and smaller by 0.156 Å than the sum of the Van der Waals radii.

6-(3,4-Diaminophenyl)-1,1,3,3-tetrafluoro-1,3-dihydrofuro[3,4-b]qinoxaline ***6***



6

Yield 1.91 g (39.0 %). Burgundy colored crystals, m.p., 158–160 °C. Found, %:. C 54.52; H 2.71; F 21.36; N 15.78. For $C_{16}H_{10}F_4N_4O$, calculated, %: C 54.86; H 2.88; F 21.70; N 16.00. FW 350.28. IR, *ν*/cm^{-1}: 3462, 3428, 3381, 3356 (N-H), 1626, 1577, 1502 (C=C, C=N) 1305, 1205, 1187, 1135, 1059 (C-F). ^{1}H NMR (500 MHz, DMSO-d$_6$), *δ*: 4.74 (br.s, 2H, NH_2), 5.13 (br.s, 2H, NH_2), 6.68 (d, 1H, *J* = 8.1 Hz, H$^{6'}$), 7.17 (dd, 1H, *J* = 8.1, and 2.2 Hz, H$^{5'}$), 7.22 (d, 1H, *J* = 2.2 Hz, H$^{3'}$), 8.35 (d, 1H, *J* = 9.1 Hz, H^8), 8.37 (d, 1H, *J* = 2.0 Hz, H^5), 8.47 (dd, 1H, *J* = 9.1 and 2.0 Hz, H^7). ^{19}F NMR (470.5 MHz, DMSO-d$_6$), *δ*: 89.25 (m, 2F, CF_2), 89.72 (m, 2F, CF_2). ^{13}C NMR (126 MHz, DMSO-d$_6$), *δ*: 112.7 (C$^{3'}$), 114.4 (C$^{6'}$), 117.6 (C^5), 122.2 and 122.4 (both t, $^1J_{CF}$ = 263.4 Hz, 2*CF_2), 122.6 (C$^{5'}$), 124.9 (C$^{4'}$), 130.1 (C^7), 132.9 (C^8), 135.4 and 137.8 (C$^{1'}$ and C$^{2'}$), 140.1 and 142.3 (both t, $^2J_{CF}$ = 28.6 Hz, C^{3a} and C^{9a}), 143.0, 145.1 and 146.6 (C^{4a}, C^6, C^{8a}).

According to the X-ray diffraction data, the crystals of compound **6** have a centrosymmetric space group. The general view of the molecule is shown in Figure S2.

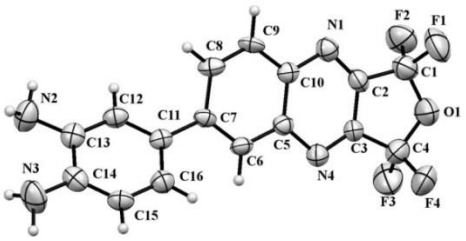


Figure S2 Molecular structure of **6** showing thermal ellipsoids at the 50% probability level.

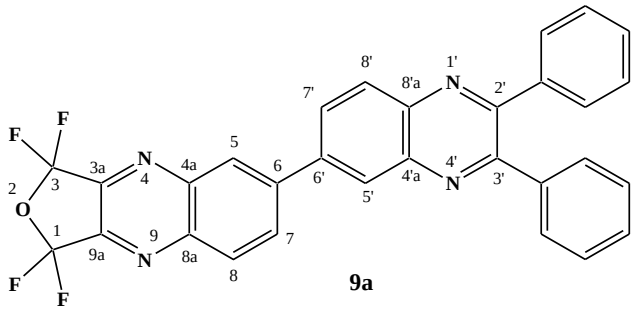
The diaminophenyl substituent is displaced at an angle of 39° with respect to the heterocycle plane. The heterocyclic moiety is flat within 0.03 Å. The nitrogen atoms in the amino groups have a trigonal configuration, which indicating the absence of a significant conjugation with the

phenyl substituent. The protons of amino groups form some shortened intermolecular contacts with fluorine atoms. In particular, the contacts between N(2)H(2A) and F(3) [0.5–*x*, *y*–0.5, 0.5–*z*] of 2.251 Å (for 0.419 Å smaller than the sum of Van der Waals radii), and between N(3)H(3A) and F(1) [–*x* + 1/2, *y* + 1/2, –*z* + 1/2] of 2.476 Å can be considered as weak hydrogen bonds between these molecules. There are no other essentially shortened intermolecular contacts in the crystal.

The analytically pure samples of compounds **6** and **7** were obtained by recrystallization from benzene: hexane mixture of 1: 1.

*6-(2,3-Diphenylqinoxalin-6-yl)-1,1,3,3-tetrafluoro-1,3-dihydrofuro[3,4-b]qinoxaline **9a**.*

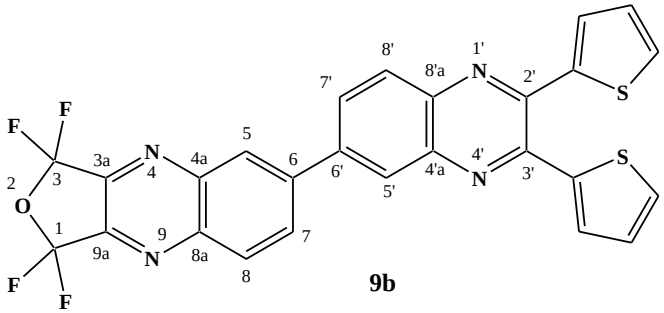
Diamine **6** (0.23 g, 0.66 mmol) and EtOH (4 ml) were placed in a flask equipped with a reflux condenser, dropping funnel, and magnetic stirring bar; then a solution of benzil **8a** (0.14 g, 0.66 mmol) in EtOH (4 ml) was added dropwise. The reaction mixture was refluxed under stirring for 2 h and cooled to room temperature; the precipitate was filtered off and air-dried. The light brown colored solid residue was purified by column chromatography on silica gel (eluent CH_2Cl_2 : hexane of 10 : 1). Compound **9a** was isolated as greenish-yellow crystals in the yield of 0.27 g (78%), m.p. 229–230 °C.



9a

Found, %: C, 68.55; H, 3.04; N, 10.60; F 14.28. For $C_{30}H_{16}F_4N_4O$, calculated, %: C, 68.70; H, 3.08; N, 10.68; F 14.49. FW 524.48. IR, ν/cm^{-1}: 1580, 1514, 1487, 1439, 1392, 1345 (C=C, C=N), 1292, 1209, 1185, 1121, 1062, (C-F). ^{1}H NMR (500 MHz, DMSO-d$_6$), δ: 7.37–7.45 (m, 6H, 4*H*m*, 2*H*p*), 7.51–7.54 (m, 4H, 4*H*o*), 8.32 (d, J = 8.7 Hz, 1H, H$^{8'}$), 8.54 (dd, J = 8.7 and 2.1 Hz, 1H, H$^{7'}$), 8.59 (d, J = 8.9 Hz, 1H, H^8), 8.80 (d, J = 2.1 Hz, 1H, H$^{5'}$), 8.86 (dd, J = 8.9 and 2.0 Hz, 1H, H^7), 9.00 (d, J = 2.0 Hz, 1H, H^5). ^{19}F NMR (470.5 MHz, DMSO-d$_6$), δ: 89.4 (m, 2F, CF_2), 89.6 (m, 2F, CF_2). ^{13}C NMR (126 MHz, DMSO-d$_6$), δ: 122.13 (t, $^1J_{CF}$ = 264.6 Hz, 2*CF_2), 127.80, 128.01 (4*C), 128.88, 128.92, 129.56, 129.61 (2*C), 129.67 (2*C), 129.77, 130.84, 133.62, 138.49, 138.54, 138.78, 140.58, 142.17 (t, $^2J_{CF}$ = 30.1 Hz, C^{3a} or C^{9a}), 142.77 (t, $^2J_{CF}$ = 28.8 Hz, C^{3a} or C^{9a}), 144.44 (C^{8a}), 153.72 and 153.89 (C$^{2'}$ and C$^{3'}$).

6-[2,3-Di(thiophen-2-yl)quinoxalin-6-yl]-1,1,3,3-tetrafluoro-1,3-dihydrofuro[3,4-b]quinoxaline ***9b.*** Diamine **6** (0.08 g, 0.23 mmol), 1,2-di(2-thenyl)ethane-1,2-dione **8b** (0.05 g, 0.23 mmol) and EtOH (4 ml) were placed in a flask equipped with a reflux condenser, dropping funnel, and magnetic stirring bar. The reaction mixture was refluxed under stirring for 3 h and cooled to room temperature; the precipitate was filtered off and air-dried. The light brown colored solid residue was purified by column chromatography on silica gel (eluent CH_2Cl_2 : hexane of 10 : 1). Compound **9b** was isolated as greenish-yellow crystals in the yield of 0.10 g (83%), m.p. 257–258 °C.



9b

Found, %: C, 58.41; H, 2.11; N, 10.33; F 13.98; S 11.51. For $C_{26}H_{12}F_4N_4S_2O$, calculated, %: C, 58.21; H, 2.25; N, 10.44; F 14.16; S 11.95. FW 536.52. IR, ν/cm^{-1}: 1583, 1520, 1487, 1438, 1393, 1340, 1379 (C=C, C=N), 1279, 1189, 1123, 106, (C-F). ^{1}H NMR (500 MHz, $CDCl_3$), δ: 7.07 (dd, J = 3.7 and 1.5 Hz, 1H, H_{thi}), 7.08 (dd, J = 3.7 and 1.5 Hz, 1H, H_{thi}), 7.33 (m, 2H, H_{thi}), 7.56 (m, 2H, H_{thi}), 8.15 (dd, J = 8.7 and 2.0 Hz, 1H, H^7), 8.25 (d, J = 8.7 Hz, 1H, H^8), 8.50 (m, 3H), 8.72 (m, 1H). ^{19}F NMR (470.5 MHz, $CDCl_3$), δ: 87.4 (m, 2F, CF_2), 87.6 (m, 2F, CF_2). ^{13}C NMR (126 MHz, $CDCl_3$), δ: 122.08 (t, $^1J_{CF}$ = 265.3 Hz, 2*CF_2), 127.70, 127.71, 127.95, 128.26, 129.08, 129.43, 129.75, 129.82, 130.13, 131.24, 133.22 (12*CH), 139.41, 140.68, 140.78, 141.20, 141.28, 143.27 (tt, $^2J_{CF}$ = 29.7, $^3J_{CF}$ = 2.0 Hz, C^{3a} or C^{9a}), 144.00 (tt, $^2J_{CF}$ = 29.5, $^3J_{CF}$ = 2.2 Hz, C^{3a} or C^{9a}), 144.22, 144.97, 145.01, 147.60 and 147.74 ($C^{2'}$ and $C^{3'}$).

[S1] T.I. Filyakova, A.Ya. Zapevalov and I.P. Kolenko, *Patent USSR 666176*, 1979 (*Byull. Izobret.*, 1979, no. 21).